NCAR Annual Report | ASP report | CISL report | EOL report | ESSL report | RAL report

The National Center for Atmospheric Research

2008 Annual Report

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The National Center for Atmospheric Research
2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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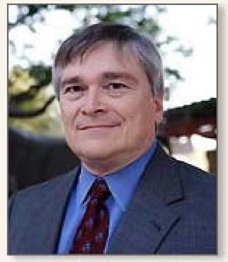
Empowering Society



The National Center for Atmospheric Research (NCAR) is a true community partner in fostering research and in building human capacity in the atmospheric and related sciences. My first experience at NCAR was as a supercomputing fellow in 1976, which led to three years of dissertation work in collaboration with NCAR scientists and then a post-doctoral fellowship in the Advanced Study Program. Since that first experience, nearly 400 post-doctoral fellows have been hosted by NCAR. In my case, a graduate student fellowship and a post-doctoral experience have resulted in a life-long connection to NCAR. I worked as a ladder scientist from 1981 to 1985, then served as a member of community committees while at Penn State, and then I was elected as a trustee for the University Corporation for Atmospheric Research (UCAR), NCAR's managing body, and I became Chairman of the UCAR Board in 2007. In spite of a long-standing admiration, and recognition that NCAR has played a transformative role in my career, my appreciation of NCAR has increased in the few months that I've had the privilege of working here.

With National Science Foundation funding, NCAR provides an extraordinary level of service, support and research that is of critical importance to society. Whether offering assistance to the research community or pursuing answers to scientific questions, NCAR is marked by the high caliber of its staff and capabilities. The variety of NCAR Annual Report (NAR) highlights underscores this reality.

This year's annual report features only a few of the many scientific efforts engaged in by NCAR and our community's scientists. By focusing on five themes— Regional Climate Change, Science at the Terascale and Beyond, Empowering Society to Cope with Weather and Climate, Technology: Bringing Innovation to the Fore, and Energizing Science with the Community Climate System Model —we provide a snapshot of NCAR competencies, facilities, and the community-wide

NCAR's Laboratory & Program Reports

LABORATORIES

The Computational and Information Systems Laboratory (CISL)

The Earth Observing Laboratory (EOL)

The Earth and Sun Systems Laboratory (ESSL)

The Research Applications Laboratory (RAL)

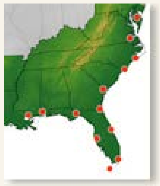
PROGRAMS

The Advanced Study Program (ASP)

accomplishments achieved in Fiscal Year 2008. Additional details on the support, tools, and research efforts being pursued within NCAR's four Laboratories can be found in the Laboratory Annual Reports.

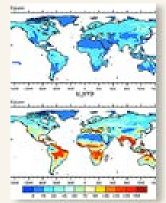
These five themes were selected for their prominence in terms of scientific and societal relevance and interest. For example, with climate change a recognized reality, society is increasingly demanding information and understanding of how these changes will affect individuals, cities, states and nations. Changes to regional climate will vary—some areas will receive more precipitation, some less, temperatures will be higher in some places than in others, some coastal areas will be affected by sea level rise, etc. Decision makers and ecosystem managers need regional-scale information to address potential challenges, making regional climate research a priority for atmospheric and Earth system scientists both at NCAR and in the community we serve.

Models can help answer questions about regional—and global—climate and weather. However, as understanding of Earth system dynamics and interactions grows, models grow increasingly complex, requiring greater processing power to generate climate scenarios in a timely fashion. Scientific needs are demanding petascale (the ability to generate arithmetic calculations at a sustained rate in excess of 1,000-trillion operations per second) computing resources, technology, and problem-solving environments. NSF, NCAR and the community are working together to supply such capabilities by providing the required infrastructure, expertise, and educational opportunities needed to meet the demands of the coming petascale era.



Apparatus capable of supporting weather- and climate-related decisions span beyond models. Many of the tools and technology developed at NCAR are created for our community, agencies, and society to minimize or provide notice of the adverse effects of weather and climate. Whether improving short-term weather forecasts, delivering early warning of hurricane landfall location, or supporting remote sensing of upper atmospheric disturbances that could affect satellite communications, NCAR tools, software and services are designed to address these issues.

As part of our mandate from NSF to support community research activities, many of the tools and technology mentioned above are created in-house, in collaboration with community members. Whether designing and fabricating scientific instrumentation, augmenting existing algorithms to meet new research needs, or consulting with public and private organizations on questions related to weather, climate, and other geoscience issues, NCAR has shown itself capable of rising to the challenge over the years and throughout FY2008.



The last section of the NCAR Annual Report covers the Community Climate System Model (CCSM), a climate model created by our science community's best and brightest researchers. The first such model to be developed in a collaborative fashion, CCSM is energizing science by producing exciting new results in areas such as ice sheet and carbon cycle modeling, and regional hurricane simulation. The latest version, CCSM4, will soon be frozen in time for model runs to be generated for the Fifth Assessment Report of the Intergovermental Panel on Climate Change. Also, the Whole Atmosphere Community Climate Model, the latest addition to the CCSM suite, allows modeling of Earth system interactions from the surface up to the upper atmosphere and into space. It's an exciting time for CCSM, as its capabilities continue to expand and grow more robust.

I invite you to delve further into the NCAR Annual Report, as well as the Laboratory Annual Reports, to learn more about these and our many other FY2008 efforts.

Best wishes,

Eric Barron

Next TOPIC HIGHLIGHT: Regional Climate

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The National Center for Atmospheric Research
2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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FY2008 NAR Metrics – Highlights

Table of Contents

These metrics are qualitative and quantitative measurements and assessments of the productivity, quality, and impacts of NCAR programs and activities.

Field Campaigns (top) - Collecting field data has always been a scientist's stock in trade. Direct observations shed insights on weather, climate, and related Earth-system phenomena. Ranging from a few weeks to several months, field campaigns (field-based observing missions or experiments) ensure successful data collection.

NCAR led or participated in 38 field campaigns in 15 countries and the United States. Locations ranged from the Amazon to the Arctic, and included more than 1,100 participants.

Editorships (top) – NCAR staff also serve as editors of publications. These positions recognize the appointee's leadership in the field and serve a critical role in developing a given field's future focus.

Sixty-one NCAR staff served in 86 different editorial roles in 57 journals. Publications included top tier journals such as Journal of Geophysical Research - Atmospheres and Atmospheric Environment, to targeted journals such as Radio Science.

External Committee Service (top) – NCAR staff are called upon to participate in and often lead external scientific, technical, policy, and educational committees. These committees are instrumental to advancing and promoting the work of the scientific and technical community.

More than 145 NCAR staff served in a multitude of roles on 403 external committees for national and international scientific, education, and governmental organizations, including organizations such as the Intergovernmental Panel on Climate Change, the American Geophysical Union, and the American Meteorological Society (AMS). Positions ranged from Chair of the Board of Directors to Committee Advisor.

Presentations (top) – NCAR Staff give formal scientific and technical presentations about data, models, theories, hypotheses, reviews, and results.

Two-hundred-sixty-five NCAR staff made 1,740 scientific and technical presentations to audiences in the tens of thousands across the country and around world, from Fairbanks, Alaska to Beijing, China. Examples range from Tim Scheitlin's Visualization Lab demo to U.S. Representative John Hall (D-NY), to a presentation on Large Eddy Simulation of an Idealized tropical cyclone at the AMS Conference on Hurricanes and Tropical Meteorology by Yongsheng Chen (see: http://ams.confex.com/ams/28Hurricanes/techprogram/paper_138272.htm).

Colloquia & Symposia (top) – Smaller, often unilateral events, colloquia, symposia and tutorials focus primarily on education or training. This metric measures entire events that NCAR hosted alone, or co-hosted with other institutions or agencies.

NCAR sponsored 75 colloquia in Boulder and abroad, in countries including Turkey, Bulgaria, Taiwan, and Korea. Participants per session averaged out to 35, for a total audience of more than 2,745 peers and students. Some of the co-hosts include the University of Washington, NOAA, NASA, and the Seoul National University.

Workshops (top) – NCAR-hosted or -co-hosted workshops and conferences are generally larger, bilateral events convened for the purpose of discussion, consultation and exchange of views and information.

NCAR sponsored 109 workshops and conferences in seven countries and 10 U.S. states. We partnered with sponsors from the university community, such as Arizona State University and Cornell University, government agencies including NOAA and NASA, as well as with non-profit partners like the Sloan Foundation and the American Statistical Association. In total, these workshops and conferences reached close to 5,000 participants.

Teaching Appointments (top) – NCAR staff make important contributions through teaching appointments at institutions of higher education in positions ranging from Faculty Affiliate to Professor.

Teaching appointments at institutions of higher education currently number 59. Twenty-two percent of these appointments occur in nine countries around the world; 78% took place in 13 U.S. states including NCAR's Super Computing partner, the University of Wyoming. Four years is the average tenure for current appointments, totaling more than 225 years of service.

Graduate Advisors (top) – NCAR staff serve as research advisors for graduate students around the world.

Of the 90 graduate students that have NCAR staff serving as graduate advisors, 26% hail from Colorado State University and the University of Colorado; 31% attend schools in 19 other states. The remaining 43% study at schools around the world, including four students from the University of Warsaw who are advised by Wojciech Grabowski.

Thesis committee

(top) – NCAR staff serve as dissertation or thesis committee members for internal and external graduate students.

Twelve Master students and 90 PhD candidates work with 55 NCAR staff as they pursue their degrees from universities in 21 U.S. states; this includes 37 students from Colorado institutions. Twenty-nine students come from 17 countries, with German students leading the international count at eight.

NCAR Student Appointments

(top) – Students also enjoy NCAR-based appointments.

In FY08, there were 56 student appointments: Eight were Graduate Students, nine Post-doctoral Fellows, 12 Graduate Research Assistants and 27 undergraduate Student Assistants appointments. These students hail from home institutions ranging from Denver's Metro State College, to Whitman College in Walla Walla, WA.

K-12 Outreach

(top) –

Twenty-five NCAR Staff worked with K-12 students from more than 50 schools. Activities ranged from public lectures, to tours and field trips. Under-served and international students also benefitted from this volunteer effort, including schools in the Navajo Reservation school system and Julio, Argentina's Escuela Provincial No. 38.

Informal science education and presentations

(top) - NCAR scientists participate in educational activities in many other ways, including efforts such as student mentoring and contributing to provision of informal science education resources. Examples range from serving on an exhibit advisory committee, to providing and vetting science content in Web sites and modules, to supporting community outreach at local community events, including judging at a science fair and supporting Super Science Saturday.

This year's count totaled more than 40 events. Among the highlights: Cory Wolff served as a Science Fair Judge in the Boulder schools, and Tim Lin presented on Education Soundings in West Lafayette, IN schools.

Awards

(top) – Each year a number of NCAR Staff are honored for their work and contributions to the Atmospheric and related sciences. Fiscal year 2008 was an extraordinary year. In October of 2007, 59 NCAR staff received the 2007 Nobel Peace Prize for their work with the Intergovernmental Panel on Climate Change. The IPCC shared the award with Al Gore, Jr. for "efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change." Download the list of NCAR IPCC participants in the document, Saluting NCAR's participants on the Nobel Prize-winning Intergovernmental Panel on Climate Change.

Jeff Kiehl of CGD was also selected as a Fellow of the American Geophysical Union (AGU). It is a special tribute for members who have made exceptional scientific contributions and attained acknowledged eminence in the Earth and space sciences. This honor may be bestowed on only 0.1% of the membership in any given year. Jeff received this award for his "major and lasting contributions to our understanding of the radiative forcing and feedback processes that govern climate change." To learn more about the AGU go to http://www.agu.org/.

Fellowships

(top) – a fellowship is typically a special appointment granting support for a term in order to support advanced research or study.

John Michalakes received a NVIDIA Graduate Internship from the NVIDIA Corporation. NVIDIA is the world leader in visual computing technologies and the inventor of the GPU, which generates interactive graphics on workstations. NVIDIA offers internships and co-op terms year-round for undergraduate and graduate students who thrive on innovation and are passionate about developing cutting-edge technology. http://www.nvidia.com/page/fellowship_programs.html

Aaron Andersen was honored as a fellow by the Uptime Institute. Using benchmarking, abnormal incident data, and industry Best Practices collected from members of its knowledge communities, The Uptime Institute, Inc. (the Institute) has distilled uptime management into scientific disciplines and practices which can be confidently applied. The synergy of a knowledge community encourages more to be shared so that more is known, and then there is even more to be shared. This exponential increase in knowledge is facilitated by the Institute and its faculty of Distinguished Fellows. http://www.upsite.com/TUIpages/tuihome.html

Of particular note is the Leopold Leadership Fellowship, awarded to Patricia Romero-Lankao and Joan Kleypas. Each year, the Stanford University's Woods Institute for the Environment awards this Fellowship to up to 20 academic environmental scientists working in the United States and Canada. Through the program, Fellows learn to effectively communicate about science associated with complex environmental issues to a variety of audiences, including the media, policy makers, business leaders and other non-scientists. Leopold Fellows receive intensive experiential training, expert consultation, and peer networking to hone these skills. Today, more than 100 Leopold Leadership Fellows – Paty and Joanie included – are actively engaged in scientific outreach on a range of issues, from marine conservation science and river restoration ecology to the impacts of global climate change on human health. http://leopoldleadership.org/content/

Visitor Appointments

(top) – Each year students, scientists, engineers, weather forecasters, and other professionals from around the country and world receive special visitor appointments from labs and programs across NCAR to collaborate with scientific, educational, or technical staff; conduct independent research; or participate in and/or oversee a professional project. Many receive financial support for their visits and some visitors temporarily join the NCAR staff.

Total Visits	756		Visits by visitors on payroll	39
1 - 7 days	246		1 - 7 days	0
8 - 30 days	203		8 - 30	2
31 - 90 days	152		31 - 90 days	18
91 - 180 days	62		91 - 180 days	3
180+ days	93		180+ days	16

NCAR Visitors hailed from 371 institutions, located in 47 different U.S. states and 37 different countries.

Publications

(top) – A publication is an academic or technical work of writing containing original research results, reviews of existing results, or scholarship. “Refereed” publications undergo an editorial “blind” or anonymous process of peer review by one or more referees (who are experts in the same field) in order to check that the content of the paper is suitable for publication in the journal. A paper may undergo a series of reviews, edits and re-submissions before finally being accepted or rejected for publication. "Non-refereed" articles have been reviewed by editors or boards before being accepted for publication but have not gone through a formal blind review. Attached are NCAR’s referred and non-referred publications lists for the period October 1, 2007 to September 30, 2008. Search for recent NCAR publications by author, date, keyword or status please go to the NCAR Publications database at: http://www.essl.ucar.edu/publications/index.php

For excellent library resources please go the NCAR Library Web site at: http://www.ucar.edu/library/

NCAR Refereed Publications: 521 (download PDF Bibliography)

Author Collaborations Summary	
UCAR Only	85
UCAR & University	116
UCAR & Other	93
UCAR, University, & Other	226

NCAR Non-Refereed Publications: 253 (download PDF Bibliography)

Author Collaborations Summary	
UCAR Only	97
UCAR & University	44
UCAR & Other	44
UCAR, University, & Other	55

UCAR Outstanding Publication Award

> B. Stephens, K. Gurney, Pieter P. Tans, Colm Sweeney, Wouter Peters, Lori Bruhwiler, Philippe Ciais, Michel Ramonet, Philippe Bousquet, Takakiyo Nakazawa, Shuji Aoki, Toshinobu Machida, Gen Inoue, Nikolay Vinnichenko, Jon Lloyd, Armin Jordan, Martin Heimann, Olga Shibistova, Ray L. Langenfelds, L. Paul Steele, Roger J. Francey, and A. Scott Denning, 2007: Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO2. Science, 316, 1732-1735.

Past research has recognized that only half of the CO2 emitted into the atmosphere from fossil fuel combustion stays there and called it the "missing carbon sink." This paper is the first to answer what happens to that CO2 – a longstanding mystery of the global carbon cycle – and concludes that the missing carbon sink does not exist. The finding has energized the carbon cycle community to test these conclusions.

Collaborators (top) – NCAR defines collaborators using the National Science Foundation's definition of partner organizations as being "academic institutions, other nonprofits, industrial or commercial firms, state or local governments, and schools or school systems that have been involved with NSF base-funded projects." Partner Organizations may provide financial or in-kind support, supply facilities or equipment, collaborate in research exchange personnel or otherwise contribute project support.

NCAR Collaborators come from 714 institutions, which are located in all 50 states, and 62 countries including 260 universities and local and national organizations. These range from the Denver Botanic Gardens to the India Meteorological Department.

For a full list of each metrics topic, download NCAR 2007-2008 Metrics Details.xls

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2008 Annual Report
NCAR

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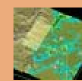
Regional Climate Change

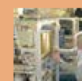
With broad public acceptance of climate change, the primary question being asked of NCAR by society has evolved from "Is climate change really occurring?" to "How will climate change affect different regions?" NCAR and our science community are responding to these questions through collaborative research in a number of critical areas such as vulnerability and resilience, impacts of climate change on human health, water, fisheries and natural ecosystems, as well as using integrated assessment models to examine possible technology and energy trajectories. In addition to this work, NCAR and the science community continue to address critical physical science issues, such as the rapid retreat of sea ice, and understanding the effects of clouds and airborne particles on climate.

Next Climatographies...

Highlighted Projects


Climatographies: Helping Users Grasp Local Weather, Day by Day and Season to Season


Minutes that Save Lives: New Warning System Boosts Flash-Flood Prediction


At the Top of the Troposphere: Starting up START08


BEACHON Shines a Light on Plant-Atmosphere Interactions

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2008 Annual Report
NCAR

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Science at the Terascale and Beyond

Terascale and petascale computing capabilities are essential for tackling larger and ever-more challenging research questions. Improving current understanding of Earth system dynamics requires more data, higher resolution models, and trained experts capable of creating and running increasingly complex models. Both on behalf of and with help from the community, NCAR is successfully addressing many of these challenges, with solutions ranging from provision of new, faster, better computing technology, software and tools, to fostering collaboration across disciplines, and tackling complex scientific questions.

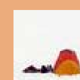
Next The Bluefire Supercomputer...

Highlighted Projects


Cool Technology, Blazing Speed: Bluefire Pushes NCAR Computing to the Next Level


Theme of the Year: Making Sense of Chaos


Will Hurricanes Thrive in Tomorrow's Climate? Nested Model Sets Sights on Decadal Trends


CADIS Provides a Home for Polar Data—and an Open Door to Researchers

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The National Center for Atmospheric Research
2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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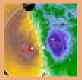
Empowering Society to Cope with Weather and Climate

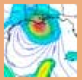
Weather is an everyday occurrence, but when trying to anticipate the effects of changing climate, or extreme weather events, society benefits from research and technological assistance. This can come in the form of better weather forecasts, or earlier prediction of solar storms, heavy snowfall or hurricanes. NCAR research, technology transfer solutions, and collaborative work with national and international weather and climate agencies are helping effectively tackle these challenges.

Next Hurricane Nowcasting...

Highlighted Projects


VORTRAC Puts Hurricane Landfall Nowcasting on Track


How Soon the Monsoon? Scientists Study the Onset of Taiwan's Dangerous Rains


Global Data Archives Pave Way for Progress in Weather Forecasting Research


Decision-Support System a Wintertime Win for State Transportation Departments


CSAC: Ordering Solar Data To Go

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The National Center for Atmospheric Research
2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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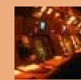
Innovative Technology

NCAR is a go-to source for innovative technology expertise and solutions. From timely weather warnings, to facilitating trouble-free air travel, to understanding how carbon affects regional and global environments, NCAR provides the staff, tools and technology that researchers and society want and need.

Next Safer Flying...

Highlighted Projects


The Forecast for 2025: Safer and Smoother Flying, with Help from New Weather Tools


Building an Integrated Weather Radar Facility


CILAS: Fast, Accurate Analysis of Carbon's Isotopic Fingerprints


NCAR Design and Fabrication Services: Handcrafted Hardware for Atmospheric Sampling


ASPEN Makes Dropsonde Analysis a Slam Dunk

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The National Center for Atmospheric Research
2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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Energizing Science with CCSM

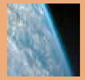
With technology innovations trumping geographic boundaries, a base model from which to move forward, and willing participation of the climate modeling community, the vision of a community climate model became reality in the late 1990s with the Community Climate System Model (CCSM). Today's CCSM is far more complex than the original, and includes much more Earth system detail.

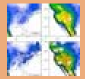
In 2009, CCSM version 4 (CCSM4) is expected to be released to the public. CCSM4 will be among the models included in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, and will be used to make future projections of the Earth's climate. Among its new capabilities, CCSM4 be able to run a complete carbon cycle, and two new components will allow assessment of future air quality of mega-cities and improve predictions of future atmospheric ozone levels.

From inception, the CCSM project was novel in its approach of involving the U.S. climate science community in creating a true community model and approach to climate research. Today, it is through ongoing development of the CCSM and similar, community-driven models and projects that researchers are finding answers to critical questions related to the climate and Earth system dynamics.

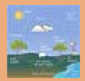
Next Modeling Chemistry & Climate...

Highlighted Projects


Higher and Higher: WACCM Tracks Chemistry and Climate from Ground to Thermosphere


Merging Models to Simulate Effects of Global Warming on the Western U.S.


Modeling the Slips and Stresses of Polar Ice on the Move


From Plants to People, Carbon Cycle Modeling Takes on New Realism

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2008 Annual Report

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Saluting NCAR's participants on the Nobel Prize–winning Intergovernmental Panel on Climate Change

Fourth Assessment Report (2007)

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FY 2008 NCAR Refereed Publications

521 Publication(s) for the time period 2007-10-01 to 2008-09-30
Group(s): CISL, SERE, RAL, EOL, ESSL
Class: Refereed; Status: Published; (most recent first, AMS format)

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The National Center for Atmospheric Research
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NCAR

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Climatographies: Helping Users Grasp Local Weather, Day by Day and Season to Season

Typical weather behavior—prevailing wind patterns, wind strength, annual precipitation, and more—is critical information for planners in government and industry. Whether identifying the perfect location for wind turbines, assessing the effect of coal plant emissions on downwind communities, or creating a disaster preparedness plan in case of terrorist threat, planners benefit from knowledge of long-term weather conditions. Climatographies—thorough, quantitative descriptions of climate—provide exactly this information.

Planners can identify or eliminate potential airport locations if they know when and how wind shear might affect proposed airport sites

Merging the power of weather forecasting models with observations gathered from weather gauging stations, satellite and airborne instruments, and other means, scientists in NCAR's Research Applications Lab (RAL) have generated regional climatographies with horizontal grid increments as small as 3 kilometers (1.86 miles) and global climatographies with grid spacings of 40 km (24 miles). These descriptions of diurnal and seasonal atmospheric processes and events help planners better understand how weather conditions at a given time—for example, a summer afternoon at 4 p.m. —might affect the direction that a plume from a chemical plant is likely to travel.

In addition to their use in calculating possible transport direction of particulatesat different times of day, these mesoscale analyses of current climates can be used in other ways. For example, planners can identify or eliminate potential airport locations if they know when and how wind shear might affect proposed airport sites. Additionally, climatographies benefit those desiring to select the ideal time and season for an event, such as a sailing regatta on the Great Lakes or a fall marathon.

An additional benefit of RAL's climatographies is that they can be constructed for

Click to enlarge image. Wind farm.

areas with sparse observational data. By using, for example, NCAR's Weather Research and Forecasting (WRF) model, which has a built-in data assimilation capability, meteorological conditions in the model can be "nudged" toward available observational data until model output closely matches observed regional conditions. If the model accurately replicates weather conditions defined by the sparse observations, planners can then use the "tuned" model to interpolate climatic conditions in nearby areas that have only sparse data. The result is a 4-dimensional (the three spatial dimensions and time), gridded realization of the current climate that is consistent with model dynamics and available observations.

Virtually any location can benefit from climatographies, but one domain where this information will soon be used to a greater degree is for the development of alternative energy farms and facilities. For example, climatographies are helping industry experts find favorable locations for potential solar and wind farms. Both solar and wind power depend on very specific meteorological conditions; before placement, companies need to identify locales that have enough sun or wind to make creating the required infrastructure cost effective. Using climatographies increases the chances of identifying these ideal locations, says RAL scientist Tom Warner. With few companies equipped to handle this sort of task efficiently, many utility companies are turning to NCAR to find viable solutions.

Next Flood Prediction...

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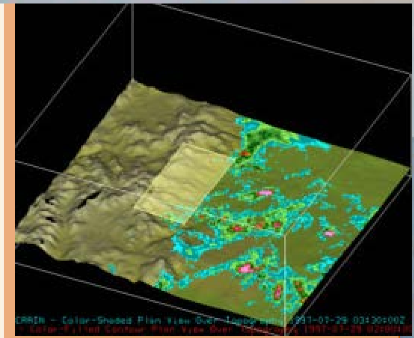
Minutes that Save Lives: New Warning System Boosts Flash-Flood Prediction



Click to enlarge image. Radar estimated rainfall mosaic overlain onto a digital elevation model of the Front Range Flash Flood forecasting domain.

With a 30-minute head start, emergency managers can dramatically reduce flash-flood risk along Colorado's Front Range. The Front Range, with its steep topography and intense summer storms, is unusually vulnerable to summertime flash floods. A new forecasting system that underwent testing and development during summer 2008 may soon provide emergency managers with information on the likelihood of a flash flood minutes or even hours before waters start rising.

Flash floods are difficult to predict because they happen suddenly, often the result of heavy cloudbursts stalling over a particular watershed.

Flash floods are difficult to predict because they happen suddenly, often the result of heavy cloudbursts stalling over a particular watershed. Today's weather forecasting systems provide relatively accurate information on 6-hour to 1-day timescales; however, flash floods typically occur in minutes to hours. Radar systems provide real-time information on storm direction, but typically don't provide forecast information on how a storm will grow or dissipate. Merging these systems' capabilities with watershed-specific information—soil type, topography, hydrologic conditions, etc.—could substantially advance flash flood prediction.

In an effort to give emergency managers more notice about weather conditions that could lead to flooding, David Gochis and David Yates, both scientists at the National Center for Atmospheric Research (NCAR), created and are testing a prototype system that fuses weather forecasting capabilities and radar data with hydrologic data sets.

NCAR's flash flood system uses National Weather Service radar observations of current conditions and short-term computerized weather forecasts. The weather forecasts are generated by the NCAR-based Weather Research and Forecasting model (WRF), which produces highly detailed simulations of the local atmosphere. The system integrates weather information with data sets that describe watershed hydrology and terrain. These data incorporate information about land surface conditions, such as terrain slope, soil composition, and surface vegetation. They also include information on streamflow and channel conditions. By combining information about the land and the atmosphere, the system projects whether an intense storm is likely to stall over a specific area of the Front Range and how it could affect the flow of water on the ground. "This new system is unique in that it provides a detailed forecast of the location and duration of a severe storm, as well as the watershed's likely response to the heavy rain," says Yates. "Since flash floods are complex and fast-moving events, we need to know about both weather and ground conditions in order to predict them."

During the summer 2008 testing season, the system generated five daily weather forecasts. Each began at a different time of day and ran for 24 hours. When severe weather was imminent, countless short-term (30- to 60-minute), radar-based precipitation and streamflow forecasts were generated for specific watersheds to identify the potential for flash floods.

Currently, Gochis and Yates are evaluating the forecasts to assess model accuracy. They will keep flood and emergency managers along the Colorado Front Range—Denver, Boulder, Fort Collins—aware of the model’s progress. Once model performance is deemed adequate, the model will be shared with the flood management community in Colorado and beyond.

Next Top of the Troposphere...

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At the Top of the Troposphere: Starting up START08

The region of the atmosphere near the tropopause where the upper troposphere meets the lower stratosphere, known as the UTLS, can have a significant impact on climate and climate change. It is in the troposphere where clouds form and most of Earth's weather happens. The stratosphere is where Earth's protective ozone layer resides, shielding the planet from much of the Sun's incoming ultraviolet radiation. The boundary between these parts of the atmosphere is characterized by large variations in chemical concentrations and atmospheric dynamics. Because the UTLS boundary region is at very high altitudes approximately eleven miles at lower latitudes, six miles at the poles few instruments are capable of capturing first-hand views of the UTLS. Limited observational data hampers the ability of computer models to accurately portray the chemical and physical dynamics of the UTLS, or to capture the influence of this region's dynamics on the broader atmosphere.

Limited observational data hampers the ability of computer models to accurately portray the dynamics of the Upper Troposphere/Lower Stratosphere region. With the debut of the NSF/NCAR Gulfstream-V (GV) research aircraft, scientists have exciting opportunities to pursue photochemistry, cloud, aerosol, radiation, and transport research in the UTLS.

With the 2007 debut of the NSF/NCAR Gulfstream-V (GV) research aircraft, with its high altitude and long-range capabilities, scientists have new and exciting opportunities to pursue photochemistry, cloud, aerosol, radiation, and transport research in the UTLS.

With improved new technology and more detailed observations directly focused on the UTLS region, scientists will gain increased insight into the processes that regulate the composition of the UTLS. Their enhanced observations provide key diagnostics to test the next generation of climate computer models and their ability to accurately predict the feedbacks among climate, chemistry and dynamics in the UTLS region.

Click to enlarge image. NCAR and CIRES scientists aboard the NSF/NCAR Gulfstream-V prepare instruments for measuring carbon monoxide and ozone during the START08 field project. In situ measurements of meteorological parameters, trace species, and microphysical properties were used, in combination with model simulations of regional dynamics, to trace the history of the air found in this region and to better understand the transport boundary between the UT and LS.

With the GV in mind, the scientific community has developed a UTLS Initiative that is investigating the coupled dynamic, chemical, and microphysical processes in the UTLS. The initiative will take advantage of in situ observations collected by instruments mounted on the aircraft. Used in combination with an array of available satellite measurements and computer models of varying scale and complexity, the resulting data set is expected to greatly enhance current scientific understanding of the UTLS. As part of the initiative, scientists will study the interactions between atmospheric chemicals and clouds and look at perturbations and feedbacks of radiative processes that can affect compounds (such as ozone) that are sensitive to changes in short- and long-wave radiation.

Transport processes dominate the chemical distributions and microphysical conditions in the UTLS. As a result, one of the early UTLS field programs, the Stratosphere-Troposphere Analyses of Regional Transport (START08) experiment, studied the chemical and transport characteristics of the UTLS region, looking at specific major transport pathways over the Northern Hemisphere's mid-latitudes. Led by Elliot Atlas of the University of Miami, NCAR's Laura Pan, and Kenneth Bowman of Texas A&M, a total of 18 START08 missions flew between April and June 2008. Flights extended in range from the Gulf of Mexico to Northern Canada, and in altitude from sea level to 47,000 feet. During flight, GV instruments measured meteorological parameters, atmospheric structure, trace gas species, and microphysical properties that will be used in combination with model simulations of regional dynamics to trace the history of the air found in this region and to better understand the transport boundary between the UT and LS. START08 will improve understanding of the chemistry and microphysics of this region by developing effective observational and modeling tools for characterizing major transport influences.

Next Plant-Atmosphere Interactions...

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2008 Annual Report
NCAR

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BEACHON Shines a Light on Plant-Atmosphere Interactions

Mountain pine beetles are eating their way through huge swaths of forest in western North America. These pests are doing more than ruining the natural scenery—they're also altering local weather patterns.

In the Rocky Mountains, NCAR scientists are exploring how trees and other vegetation influence clouds, rainfall, and temperatures as one part of an international field project, BEACHON (Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, H2O, Organics, and Nitrogen).

By studying interactions between the planet's surface and the atmosphere, BEACHON (pronounced "beacon") will allow scientists to glean insights into local air quality and long-term climate change, as well as weather patterns. Plants emit water vapor and other gases, in addition to microscopic particles that influence the atmosphere in subtle and complex ways. When portions of a forest die, the local atmosphere can change.

By studying interactions between the planet's surface and the atmosphere, BEACHON (pronounced "beacon") will allow scientists to glean insights into local air quality and long-term climate change, as well as weather patterns.

"In terms of impacts on the atmosphere, there's a big difference between a living forest and a dead forest," says Alex Guenther, a scientist in NCAR's Atmospheric Chemistry Division who's a principal investigator on the project. "With a dead forest, we may get different rainfall patterns, for example."

When large areas of trees are killed by pine beetles or other causes, interactions between Earth's surface and the atmosphere are disrupted. Scientists believe that this can change cloud and precipitation patterns at least for the short term, which can, in turn, further alter the land cover. Temperatures could rise because there are fewer particles in the air to block incoming sunshine, fall because there are fewer gases to trap solar radiation and prevent it from escaping into space, or change in more subtle ways because of new cloud cover patterns. Forest changes

Click to enlarge image. NCAR scientist Alex Guenther examines an instrument at a field site in a Colorado forest.

This BEACHON field project is scheduled to continue for four years over a region extending from southern Wyoming to northern New Mexico, which will allow researchers to examine the impacts of emissions in different seasons and measure year-to-year changes. For more information on BEACHON, and the variety of research projects that fall under this program, see the BEACHON website.

also influence local temperatures, in part because plants, soil, and other types of land cover absorb varying amounts of incoming heat from the Sun.

BEACHON researchers will use specially equipped aircraft as well as towers that reach above the forest canopy to measure emissions at up to about 100 feet above the ground. Additional observations will come from a variety of soil and moisture sensors, sensors for gases and tiny particles, plus radars and lidars (laser-based radar).

“BEACHON will give us a very comprehensive picture of a forest’s impact on the atmosphere,” Guenther says. “But at this point, we don’t know what the project will reveal. We may end up with more questions than answers.”

Next TOPIC HIGHLIGHT: Terascale Computing

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Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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Cool Technology, Blazing Speed: Bluefire Pushes NCAR Computing to the Next Level

Supercomputers are a powerful tool scientists use for answering complex scientific questions of importance to society, such as where and when dangerous storms may strike. Funded by the National Science Foundation (NSF), NCAR's computing capabilities were significantly enhanced by the addition of a powerful IBM supercomputer named bluefire to NCAR's supercomputer center. Bluefire is the latest system in NCAR's 30-year tradition of providing high performance computing to the atmospheric sciences community, and it began its service ranked as the 30th most powerful computer in the world.

More than three times more powerful and energy efficient than the supercomputers it replaces, bluefire is a million times more powerful than the first recognized supercomputer, the Cray 1-A that NCAR used from 1977 to 1986.

More than three times more powerful and three times more energy efficient than the supercomputers it replaces, bluefire is a million times more powerful than the first recognized supercomputer, the Cray 1-A that NCAR used from 1977 to 1986. Bluefire is composed of IBM's latest generation of processors: the POWER 6 is the world's fastest microprocessor with a clock speed of 4.7 GHz. With 4,064 processors and a peak speed of more than 76 teraflops (76 trillion floating-point operations per second), bluefire will support the simulation needs of geosciences researchers for years.

Bluefire will play a central role in supporting and accelerating climate change research, studying changes in future patterns of precipitation and drought around the world, changes to agriculture and growing seasons, and the complex influence of global warming on hurricanes, among many other research questions. "Bluefire is on the leading edge of high-performance computing technology," said Tom Bettge, Director of Operations and Services in NCAR's Computational and Information Systems Laboratory (CISL). "Scientists will be able to conduct breakthrough calculations, study vital problems at much higher resolution and

Click to enlarge image. The IBM Power 575 supercomputer ("Bluefire") at NCAR.

Among the Climate Simulation Laboratory projects to be run on bluefire:

- Significant development of the carbon cycle and atmospheric chemistry component for release with Community Climate System Model Version 4, and coupled runs to support this release
- Seasonal and interannual prediction and predictability with coupled ocean-atmosphere-land models
- Experiments examining the influence of chemistry using the

complexity, and get results more quickly than before."

Among the climate simulations run on bluefire are those that NCAR and community scientists will provide to the Intergovernmental Panel on Climate Change (IPCC). In addition, 12 million processor hours have been allotted by the NSF-appointed Climate Simulation Laboratory Allocation Panel to 13 projects that will take place between 2008 and 2010 in support of the multi-agency Climate Change Science Program.

Next Theme-of-the-Year Workshop...

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The National Center for Atmospheric Research
2008 Annual Report

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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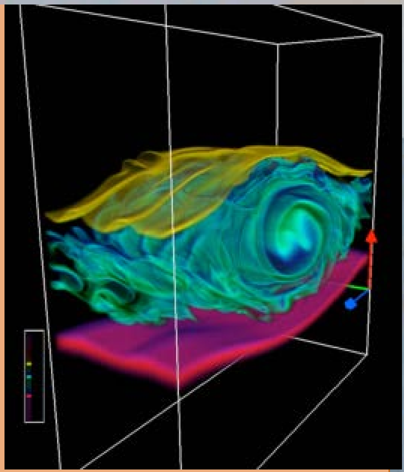
Theme of the Year: Making Sense of Chaos

Turbulence—random, chaotic flow—is a property that characterizes movement within much of the natural world. From the microscale level—a summertime breeze across a field—to the macroscale—solar-terrestrial interactions—turbulent flows affect everything on Earth. The scientific leaders of NCAR recognized early on that understanding turbulent dynamics at a fundamental level would be essential. They also realized that, because of the difficulty of solving classical problems in turbulence through direct mathematical analysis, a multidisciplinary approach would be more effective. NCAR's Theme of the Year (TOY) does exactly this, by combining mathematical and physical models, computational science, observations, and experiments to try and make sense out of chaos.

Each TOY workshop series includes a summer school session that accommodates the schedules of graduates, post-graduates, and other new researchers working on mathematical and geophysical questions, helping them view issues from a multidisciplinary perspective, learn from current experts, and meet future colleagues.



Click for full image.Renderings of a 3D Kelvin-Helmholtz instability using the VAPOR visualization and analysis platform. This image was created by students participating in the IMAGe Theme-of-the-Year 2008 Summer School on Geophysical Turbulence. Students of the summer school received hands-on experience performing the end-to-end processes of numerical simulation, visualization, and analysis using state-of-the-art resources.

Run by the Institute for Mathematics Applied to Geosciences (IMAGe) in the Computational and Information Systems Laboratory (CISL), the TOY workshop series have been run over multiple weeks at NCAR for each of the past four years. The workshops typically bring in 20 to 30 people, and are a blend of research presentations, discussion, and opportunities for less formal interaction. Each TOY series includes a summer school session that accommodates the schedules of graduates, post-graduates, and other new researchers working on mathematical and geophysical questions, helping them view issues from a multidisciplinary perspective, learn from current experts, and meet future colleagues. Typically, the TOY summer school draws on material generated during the three preceding workshops and features prominent researchers in the field.

The 2008 TOY was designed to support geophysical and mathematical community members exploring turbulence from their particular perspective, as well as to increase interconnections between the two disciplines through theory, computation, and experiment. Led by Keith Julien (Applied Mathematics, University of Colorado at Boulder) and Annick Pouquet (Geophysical Turbulence Program, NCAR) the three workshops included “Turbulent Theory and Modeling,” “Petascale Computing: Its Impact on Geophysical Modeling and Simulation,” and “Observing the Turbulent Atmosphere: Sampling Strategies, Technology, and Applications.”

In the 2008 “Summer School: Geophysical Turbulence,” 30 Ph.D. students from around the world took part in the three-week session that combined lectures on practical issues in numerical modeling and data analysis with hands-on experience in end-to-end computational science, from numerical simulation to presentation of results. In week three, students were divided into small groups and tasked with exploring a problem in atmospheric turbulence modeling, relying on knowledge gained during the previous two weeks of the school. Students ran their experiments on NCAR’s Blue Gene/L supercomputer, examined the resulting data using visualization and analysis tools developed in CISL, and presented their results to summer school peers, instructors, and organizers.

The 2008 TOY, like its predecessors, not only builds cross-community collaborations in areas of vital research importance, it provides newer scientists with valuable education and networking opportunities that many will turn to again throughout their careers.

Next Predicting Hurricanes...

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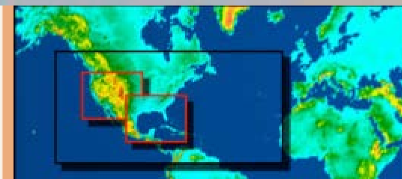
Will Hurricanes Thrive in Tomorrow’s Climate? Nested Model Sets Sights on Decadal Trends

Because of their coarse resolution, global climate models (GCMs) do a poor job of accurately simulating climate in regions with highly variable topography, such as the mountainous areas of the western U.S. A typical GCM computational grid-cell—a snapshot of conditions within a computer model at a specific location on Earth—is about as big as Belgium or the state of Maryland, so despite impressive gains in knowledge of global climate change, GCM information from regions with rugged, varied topography is smeared out over this grid-cell and is therefore of only limited use in expanding scientists’ ability to understand and predict regional Earth system dynamics. This characteristic in turn inhibits producing accurate, reliable predictions of regional climate change, which are required for developing adaptation and mitigation strategies. For example, extreme weather events like heavy rainfall or heat waves are projected to become more frequent as climate changes. Warming means that precipitation now occurs as rain more often than snow, that snow melts earlier, that runoff and risk of flooding increase in early spring, and risks of drought and wildfire in summer increase as warmer air dries the land. Such events have enormous implications for agriculture, hydrology, water resources, and urban planning, particularly over the intermountain West.

Once complete, this information will be of critical importance to insurance and energy industries, which, along with the National Science Foundation, are funding this research.

To plan for the impacts of climate change, western U.S. states require improved models and more powerful computers dedicated to climate modeling and prediction. NCAR has a record of world leadership and achievement in advancing knowledge of weather and climate variability and change. In keeping with its core mission, NCAR develops and supports advanced observing facilities, increasingly powerful supercomputing capabilities and related software, valuable research data sets, and widely used state-of-the-science community weather and climate models.



Click to enlarge image. NCAR scientists are using a combination of weather and climate computer models to simulate the atmosphere in three dimensions at resolutions ranging from about 20 miles across a large part of the Northern Hemisphere (full box), down to 7.5 miles on the area bounded by the inner black box, and even as fine as 2.5 miles in targeted areas of North America (red boxes). This strategy enables scientists to forecast future climate in detail for specific regions without overloading existing supercomputing resources.

A project of this magnitude and complexity requires a very powerful supercomputer to produce results within a reasonable amount of time. NCAR’s computing capability increased threefold with the installation of the new IBM system bluefire. During the time before the normal workload grew to fill the new computer, seven projects were chosen to make optimal use of this resource—NRCM was among these. From July to October 2008, generating NRCM past and future climate simulations made use of 25 percent of bluefire’s total processing power—an unusually large fraction of the system for a single project. Like the other six Accelerated Scientific Discovery projects, the NRCM effort may not have been feasible under normal circumstances because of its intensive computing needs. This marks the third program in which the National Science Foundation and NCAR’s Computational and Information Systems Laboratory (CISL) have made special accommodations for very large computational experiments; as new supercomputing systems come online, CISL and NSF will solicit applications and allocate resources to support large-scale, scientifically important projects.

To create a viable model that can handle varied regional topography in global simulations, scientists merged NCAR's Weather Research and Forecasting (WRF) model with the Community Climate System Model (CCSM). This Nested Regional Climate Model (NRCM) will allow fundamental progress in understanding and predicting regional climate variability and change. In particular, the multiscale capability of the NRCM allows researchers to better understand how regional-scale processes influence global climate.

The increased fidelity of NRCM simulations will also improve decision makers' local and regional planning efforts. NCAR scientists performed a series of simulations using the NRCM to examine likely changes in future climate and regional weather statistics over the intermountain West. These unique data sets will be of immense interest and utility to many stakeholders, both in the U.S. and internationally.

Next Home for Polar Data...

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The National Center for Atmospheric Research
2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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CADIS Provides a Home for Polar Data—and an Open Door to Researchers

Click to enlarge image. Campsite on polar expedition (Photo: Rob Bauer, National Snow and Ice Data Center).

Researchers who study rapidly changing polar regions need data on climate, weather, land and sea ice, snow cover, and other environmental factors. But data are only as good as the management structure that serves them up. In the As part of the International Polar Year (IPY), the National Science Foundation (NSF) has provided funding to ensure that polar researchers have easy access to data that help them study Earth system processes in the Arctic. As a result, NSF's Arctic Observing Network (AON) now has its own data archive system where scientists can easily submit or access data. The Arctic Observing Network, a major NSF IPY initiative, was created to improve observational capabilities in the Arctic and leave a long-term legacy for the benefit of science and society. Scientists will use AON data to increase their understanding of the regional and global causes and consequences of present-day environmental Arctic change, to predict the course of future Arctic change and its regional and global consequences, and to foster the development of adaptive responses to Arctic change.

CADIS will facilitate the discovery and use of data by encouraging metadata standardization and exchange of Arctic Observing Network datasets via a user-friendly Web site and applications.

NCAR's Earth Observing Laboratory (EOL) and the Computational and Information Systems Laboratory (CISL) have worked closely with UCAR's Unidata program and external groups, including the National Snow and Ice Data Center, to develop the Cooperative Arctic Data and Information Service (CADIS). CADIS will facilitate the discovery and use of data by encouraging metadata standardization and exchange of AON datasets via a user-friendly Web site and applications.

The NCAR-UCAR-NSIDC partnership will build CADIS by integrating NCAR/UCAR strength in computer technology with the long-term archiving capabilities provided by NSIDC's experience in managing crysopheric data. Through its involvement and collaboration on this effort, the CADIS team has devised a standardized method for metadata and data collection, tracking, management, and dissemination that will benefit researchers who turn to AON for atmospheric, meteorological, and other geophysical data.

Through these efforts, for the first time, researchers can access a coordinated, streamlined data management system that allows them to add, store, retrieve, subset, visualize, and analyze valuable information collected as part of AON. Reducing the amount of time scientists spend searching for data increases the time they can spend doing research and analysis with the data to better understand the rapidly changing dynamics of the Arctic environment.

Next TOPIC HIGHLIGHT: Empowering Society

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The National Center for Atmospheric Research
2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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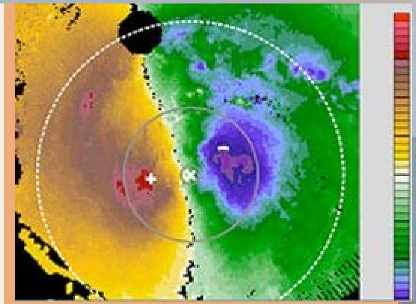
VORTRAC Puts Hurricane Landfall Nowcasting on Track



Click to enlarge image. VORTRAC will provide forecasters at the National Hurricane Center with frequent, detailed updates on hurricanes as they approach land. The VORTRAC interface (above) includes a display of winds derived from Doppler radar data (right, with the hurricane center marked with an X), an estimate of the hurricane's central pressure (top), and a warning message that displays if the pressure is dropping rapidly (left). (Illustration courtesy Michael Bell, NCAR.)

Rapidly intensifying storms can catch vulnerable coastal areas by surprise. In 2007, Hurricane Humberto struck near Port Arthur, Texas, unexpectedly strengthening from a tropical depression to a hurricane in less than 19 hours. And in 2004, Hurricane Charley's top winds increased from 110 to 145 miles per hour in just six hours as the storm neared Florida's southwest coast.

Researchers at NCAR and the Naval Research Laboratory (NRL) have developed a means to continually monitor storms approaching U.S. coasts. The system, which relies on existing coastal Doppler radars, provides details on hurricane winds and central pressure every six minutes, indicating whether a hurricane is gathering strength before reaching shore.

Researchers at NCAR and the Naval Research Laboratory (NRL) have developed a means to continually monitor storms approaching U.S. coasts. The system, known as VORTRAC (Vortex Objective Radar Tracking and Circulation), enables hurricane specialists to continually monitor central pressure as a dangerous storm nears land.

Successfully tested by the National Hurricane Center last year, the system known as VORTRAC (Vortex Objective Radar Tracking and Circulation) enables hurricane specialists, for the first time, to continually monitor the trend in central pressure as a dangerous storm nears land. One of VORTRAC's strengths is that it can use radar data to estimate the barometric pressure at the center of a hurricane a key measure of its intensity. This capability could prove invaluable to vulnerable communities, says NCAR scientist Wen-Chau Lee.

VORTRAC relies on the National Oceanic and Atmospheric Administration’s Doppler radar network. The VORTRAC team developed a series of mathematical formulas that combine data from a single radar near the center of a landfalling storm with general knowledge of Atlantic hurricane structure in order to map the approaching system's rotational winds. VORTRAC also infers the barometric pressure in the eye of the hurricane, a very reliable index of its strength. About 20 Doppler radars are scattered along the U.S. Gulf and Atlantic coastlines from Texas to Maine. Each radar can measure winds blowing toward or away from it.

“However, until now, no single radar could provide an estimate of a hurricane's rotational winds and central pressure,” says Michael Bell, NCAR scientist.

After years of refinement and testing, supported mainly by NSF and NOAA, VORTRAC is now ready for prime time. “It’s a dream come true. By merging several techniques, we can now provide a missing link in short-term hurricane prediction,” says Paul Harasti, who is a project scientist at NRL as part of NCAR’s Visiting Scientist Program.

Next How Soon the Monsoon...

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How Soon the Monsoon? Scientists Study the Onset of Taiwan's Dangerous Rains

From May 15–June 30, 2008, scientists from around the globe worked together on an intensive field campaign designed to improve understanding of extreme rain events in southern Taiwan. The Southwest Monsoon Experiment/Terrain-influenced Monsoon Rainfall Experiment (SoWMEX/TiMREX) took place in the western plain/mountain slope region of southern Taiwan during onset of the Asian summer monsoon season.

Southern Taiwan's complex regional geography—a mixture of sea coast, plains, and steep, high mountains—in combination with highly variable weather patterns (summertime monsoons and the springtime Mei-Yu, a persistent east-west zone of disturbed weather) affect how much and how fast rain falls. Heavy rainfall events are common, particularly in monsoon season, often triggering flood events and landslides that cause human casualties and significant property damage.

Heavy rainfall events are common, often triggering flood events that cause human casualties. TiMREX enhances scientists' understanding of the physics related to Taiwan's flood-producing convective systems.

SoWMEX/TiMREX will enhance scientists' understanding of the physics related to Taiwan's heavy rain and flood-producing convective systems. Their goal is to better forecast and quantitatively estimate rainfall in mountainous regions prone to intense orographic precipitation events, both in Taiwan and elsewhere globally. Policymakers, government officials, and regional residents will also benefit since better weather nowcasts will provide more advanced warning of floods and landslides.

As part of TiMREX, the U.S. team, led by NCAR's Wen-Chau Lee, deployed advanced radar systems (including NCAR's S-Pol polarimetric, Doppler radar system). In addition to these systems, Taiwan provided upstream soundings by operating dropsondes and ship soundings over the northern boundary of the South China Sea. Data collected during this experiment will provide better information on prevailing flows over the ocean during the onset of Asian summer monsoon, which

Click to enlarge image. TiMREX team in Tawain, with S-Pol radar in the background.

NCAR's S-Pol radar provided the first-ever S-band (10-cm wavelength) polarametric measurements taken in Taiwan, providing Taiwanese meteorologists with detailed information on surface moisture distribution and size of precipitation particles for example, large versus small raindrops, ice versus water. Also, NCAR's Clutter Mitigation Decision algorithm, implemented in Nexrad systems throughout the United States, was used for the first time in Taiwan, giving scientists a clear picture of low-level winds decontaminated from heavy ground clutter, which is essential for nowcasting convection initiation, maintenance, and regeneration.

can be used for weather forecasting and quantitative rainfall forecasts.

Wind regimes, which greatly influence rainfall location and amount, were thought to always come in from the southwest during Taiwan's Mei-Yu season; meteorological models were initialized based on this expectation. However, in 2008, southerly winds predominated, blowing over the flatter coastal plain and parallel to the steep terrain, which dramatically shifted the location and timing of heavy rain events. This seemingly simple, but critical piece of knowledge will inform future modeling efforts. In addition, the variety of instruments brought in from global research centers and Taiwan's existing dense network of weather stations detected mesoscale weather patterns within the larger-scale monsoon events. This "weather within weather" discovery, though in its early stages, will prove useful in improving nowcasting models.

TiMREX wrapped up in June, but SoWMEX will continue for the next five years. SoWMEX's smaller meteorological efforts will build on this year's global effort. Several NCAR scientists, including Lee, will be involved in these ongoing studies.

Next Global Data Archives...

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2008 Annual Report
NCAR

[Director's Message](#)
[Metrics](#)
[Back to homepage](#)
. . . .
TOPICS

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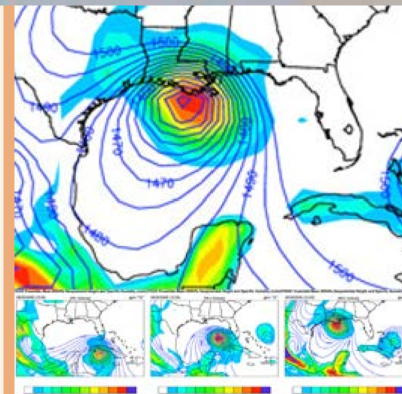
Global Data Archives Pave Way for Progress in Weather Forecasting Research

The adage “forewarned is forearmed” is especially critical when it comes to severe weather such as tropical storms, hurricanes, and tornadoes. The World Weather Research Programme strives to ensure that society is better prepared for weather-related phenomena by working to accelerate improvement of one- to 14-day forecast reliability. Toward this end, program leaders established the Interactive Grand Global Ensemble (TIGGE), a component of The Observing System Research and Predictability Experiment (THORPEX). TIGGE efforts include support of international collaboration related to weather prediction, identifying new methods for combining weather model ensembles, improving understanding of forecast errors, and developing a prototype Global Interactive Forecasting System.

The TIGGE mission is daunting. TIGGE data providers generate more than 240 gigabytes of data in the form of 1.6 million global gridded meteorological data fields every day—this adds up to more than 88 terabytes annually. Data generation is only half of the story, for to fully use this large volume of data, research scientists must be able to easily access it. NCAR is one of three TIGGE data archive and distribution centers, along with the China Meteorological Administration (CMA) and the European Center for Medium-Range Weather Forecasts (ECMWF). The center’s Computational and Information Systems Laboratory has developed a system to facilitate this process that dynamically handles the constant flow of information from 10 international weather prediction data providers and serves the data via the [NCAR TIGGE portal](#).

TIGGE data providers generate more than 240 gigabytes of data in the form of 1.6 million global gridded meteorological data fields every day

The TIGGE portal provides several interfaces to ensure that user needs and data flow are efficiently achieved. Through one interface, a user can browse the archive and select forecast files for download; through another, users can select individual parameters, spatial subsets from the global domain, and user-specified grid



Click to view movie (Quicktime), or view the AVI version, here. This data output from TIGGE shows tropical storm Gustav.

resolution across multiple centers. To complement this access, the TIGGE portal also directs users to various tools for analyzing the data, a Web forum to share ideas and questions with fellow users, and the option to select an output data format (either GRIB2 or netCDF) for subsets prepared by the system.

TIGGE supports research efforts that cut across organizational and geographical boundaries. This process is vital to improving our understanding of environmental processes and regional linkages, which, in turn, improves overall forecasting capabilities. NCAR, CMA, and ECMWF streamline the process of finding, integrating, and assimilating observational and modeled data by providing robust data services, tools, and cyberinfrastructure. These capabilities are essential to achieving the goal of accurate one- to 14-day predictions of severe weather events.

Next Decision-Support System...

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2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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Decision-Support System a Wintertime Win for State Transportation Departments

Click to enlarge image. This map shows highways (in color) involved in the MDSS project around Des Moines, Iowa. (Illustrations courtesy UCAR/NCAR/NSF.).

For most motorists, driving through inclement weather is challenging at best, terrifying at worst. When such trips occur without incident, it is thanks in no small part to surface transportation managers working behind the scenes to ensure smooth, safe traffic flow. However, despite the best efforts of U.S. highway managers and their staff, extreme weather causes more than 7,000 highway fatalities annually and 500 million hours of driver delay.

Of the four seasons, winter weather by far causes the greatest number of accidents and slowdowns. In a Federal Highway Administration (FHWA) poll asking highway managers how traffic flow and safety might be improved, the universal response was that better short-term prediction related to wintertime road conditions would be an asset. Arming managers with advance knowledge of when roads might hit freezing temperatures, better information on pavement conditions will roadways be snowy, icy, slushy, or clear? and guidance on the type and amount of materials (sand, salt, chemicals) to apply would all contribute to safer roadways.

The FHWA asked experts in NCAR's Research Applications Laboratory (RAL), who have experience with helping the aviation industry mitigate winter weather conditions, to work with state Departments of Transportation (DOT) and their stakeholders to provide better short-term prediction.

The FHWA asked experts in NCAR's Research Applications Laboratory (RAL), who have experience with helping the aviation industry mitigate winter weather conditions, to work with state Departments of Transportation (DOT) and their stakeholders to provide better short-term prediction. Also on the development team were researchers from NOAA, the Massachusetts Institute of Technology's Lincoln Laboratory, and the Army's Cold Regions Research and Engineering Laboratory.

The result is the Maintenance Decision Support System (MDSS). This software, which is provided to the weather and transportation communities through an open technology transfer process, facilitates decision making by providing a Web-based interface and set of tools that road maintenance experts can work with directly. MDSS prototype systems were tested and refined on roads in Minnesota and Iowa over several winters. After the initial trial, NCAR scientists continued working with teams of plow drivers and DOT maintenance managers to further improve the system. Today, the system provides road maintenance managers with 48-hour forecasts of air and pavement conditions and precipitation events, including precipitation type and its impact on the roadway surface.

MDSS provides diagnostics related to how to best apply available DOT road treatment materials, including quantities and timing. To ensure best use of resident expertise and accurately capture availability of manpower and equipment, the system's automated suggestions can be overridden. Incorporating both modeled weather and roadway data and user inputs, MDSS can map out a variety of scenario options or, if the user prefers, automatically update the system.

In addition to its value in aiding winter drivers, the MDSS offers DOTs financial and environmental advantages. Lacking information, road maintenance staff often err on the side of safety, applying more chemicals, salt, or sand than necessary. Better guidance on quantities and timing reduces excess use of these materials. Moreover, less sand, salt, and chemicals washing into nearby waterways and vegetation also benefits the local environment.

Each successive winter, MDSS continues to prove itself a success with road maintenance crews. The spring 2009 MDSS software release will incorporate video camera imagery, vehicle location and activity data, and pavement-condition model improvements.

Next Solar Data To Go...

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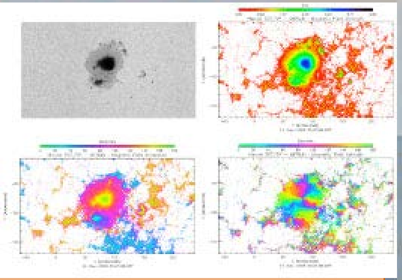
CSAC: Ordering Solar Data To Go



Click to enlarge image. Typical results of a magnetic inversion of a sunspot region, launched through the CSAC/MERLIN web client.

The Sun, because of its distance from Earth and its very nature, challenges scientific understanding. Its basic functions are enigmatic at best, and impenetrably complex at worst. However, without the Sun, Earth would be just another rock suspended in space. And if that's not incentive enough to study humankind's local star, then improving prediction capabilities related to space weather and changes in the Sun's magnetic fields, radiative output, and solar wind should be. Even slight changes in these solar manifestations can wreak havoc on Earth-bound and satellite-based communications, and can make life uncomfortable if not hazardous to astronauts' health.

CSAC streamlines the solar data acquisition process, and spares the data user the hard work of inferring solar magnetic fields from spectro-polarimetric analysis. Acquiring solar data becomes almost as easy as ordering books from Amazon

The solar science community depends largely on data collected from telescopes and satellites to gain insights on solar phenomena. Data acquisition, however, is only the first step. Making data useful to the widest possible community requires processing to eliminate noise and non-essential information. And feeding the refined data into a common analysis package adds additional value. Access to processed, pre-packaged data helps scientists who require data for practical applications (such as shutting down GPS satellites just prior to the occurrence of a predicted magnetic storm) and lets physicists modeling Earth-Sun interactions better understand core science questions.

The Community Spectro-Polarimetric Analysis Center (CSAC), recently made available to the astrophysics community, provides this data service. CSAC offers pre-processed (calibrated and reduced) spectro-polarimetric data that provide key information about vector magnetic fields. Using spectro-polarimetry solar data, scientists can look at the properties of the Sun's electro-magnetic radiation to capture views of solar magnetism and dynamics over time.

Using the CSAC website, researchers can select a solar region and a timeframe they want to study and specify what type of data they're interested in (for example, a spectral range). Within a few hours the data are processed and made available, allowing the researchers to study the solar atmosphere's magnetic fields and associated thermodynamic properties. This is the first time ever that such analysis tools have been made available to the community at large.

Currently, CSAC is only providing data processed from HINODE's Solar Optical Telescope, but additional data sources—including the National Solar Observatory's SPINOR (Spectro-Polarimeter for INfrared and Optical Regions), DLSP (Diffraction-Limited Spectro-Polarimeter), and SOLIS (Synoptic Optical Long-term Investigations of the Sun)—are expected to come online soon. For HINODE's data, CSAC is already providing preliminary results for the vector magnetic field and atmospheric parameters that meet standard model criteria and assumptions; these parameters can then be refined by the user as needed.

"CSAC streamlines the solar data acquisition process, and spares the data user the hard work of inferring solar magnetic fields from spectro-polarimetric analysis. Acquiring solar data becomes almost as easy as ordering books from Amazon," says NCAR scientist Roberto Casini. By making data acquisition easier and providing pre-processed information, NCAR is helping the community in its drive to develop a better understanding of what's going on in the solar system and beyond.

Next TOPIC HIGHLIGHT: Innovative Technnology

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The Forecast for 2025: Safer and Smoother Flying, with Help from New Weather Tools

Click to enlarge image. Flight traffic control room.

Air travel is becoming more crowded and complex. More than 600 million people fly within the United States annually, and up to 1 billion people are expected to travel to and from U.S. air hubs in the near future. Experts say that, lacking an overhaul, U.S. aviation infrastructure will lose its leading-edge stature during this century. Looking to ensure a safe, robust aviation system, Congress created the Joint Planning Development Office (JPDO) to design a Next Generation Air Transportation System (NextGen) for the United States by 2025.

NextGen, which will be implemented in stages, will address aviation concerns ranging from observing and forecasting critical aviation weather parameters, including seasonal storms and turbulence and visibility, to ensuring seamless, automated communication and navigation capabilities and dealing with new issues such as space weather and upper-atmosphere radiation events. A variety of agencies and organizations came together to create an initial Integrated Work Plan (IWP), a blueprint for creating NextGen operation improvements and development and research milestones. NextGen is designed to streamline a passenger's experience from the moment she steps onto the curb of an airport for flight departure to the point when she begins the trip home from the airport.

NextGen will address aviation concerns ranging from observing and forecasting critical aviation weather parameters, including seasonal storms and turbulence and visibility, to ensuring seamless, automated communication and navigation capabilities and dealing with new issues such as space weather and upper-atmosphere radiation events.

Weather is the one constant at each point of a passenger's journey. The NextGen concept for weather hinges on the ability to develop a common weather "picture," and to integrate that picture into decision-making processes. Tens of thousands of global weather observations and sensor reports from ground-, airborne-, and space-based sources will be fused into a single national (and eventually global), constantly updatable weather information system. Experts from NCAR's Research Applications Laboratory (RAL) will play a leading research and design role in this area. In 2008, NCAR's team of aviation and weather experts received funding to address some of the issues described above. Among other tasks, RAL was asked to help design NextGen Network-Enabled Weather (NNEW), a system that will automate the gathering and integration of weather data, ensuring rapid dissemination of aviation information in real time.

NextGen Network-Enabled Weather: The key to the NextGen weather system

NCAR scientists are working closely with the Federal Aviation Administration, the National Oceanic and Atmospheric Administration, the U.S. Department of Defense, and NASA to develop the lynchpin of the NextGen weather system—NextGen Network-Enabled Weather (NNEW). NNEW is a virtual tool that seamlessly fuses 4-dimensional (length, breadth, height, and time) weather data into a single picture. NNEW will be the authoritative source of weather information for NextGen. With NNEW, for the first time, forecasters asking the same question about weather over a given area, for a given period of time, will receive the same answer.

In today's aviation world, users can get information from any number of sources, but the information varies, depending on the system queried. The Air Force may have a different answer to a question about the likelihood of 10 a.m. rainstorms and wind shear over Swansea, KY, than WSI Corporation, a business focused on providing real-time weather data. The Naval Air Systems Command is likely to provide yet a third answer.

The NNEW algorithm is able to sift through the thousands of real-time global weather observations and sensor reports from ground-, airborne-, and space-based sources. It weights each piece of data based on history of performance, selecting the "best of the best" answer.

NextGen is designed to move away from today's human-intensive infrastructure. Currently, everything from communications to piloting, dispatch, and airline control is performed manually. Technicians have done a very capable job in past years, but with the expected increases in flights and related congestion on the ground, information overload is becoming an issue. Not to mention that ground-based communications infrastructure radio transmitters, navigation sites, and radars are less reliable and less accurate than satellite-based versions, and they cost more to maintain.

RAL and the other NNEW partners are teaming with the Open Geospatial Consortium and various other standards bodies to motivate the development of open standards and technology that will make NNEW possible. A first NNEW prototype is complete, and a second version, with expanded capabilities, is expected in 2009.

NextGen is a national priority to meet the air transportation needs of the United States in the 21st century. As part of the team that will provide the necessary scientific underpinning and technology to support the weather- and climate-related needs of this system, NCAR scientists will work collaboratively with operational stakeholders to determine the role of weather in aviation operations, build and test the NNEW weather component, and build and test fully integrated NextGen components. These efforts are expected to generate tailored solutions that will address aviation's current and future safety, capacity, and efficiency issues.

Next Integrated Weather Radar Facility...

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Building an Integrated Weather Radar Facility

Radars provide scientists with up-to-the-minute information on atmospheric conditions—information that can be used to answer real-time weather questions or be fed into weather and climate models. To assure that such tools are available to the research community, the National Science Foundation (NSF) provides, on a competitive basis, direct access to radar and other instrumentation through the Earth Observing Laboratory (EOL) at the National Center for Atmospheric Research's, Colorado State University (CSU), University of Wyoming, and Colorado-based Center for Severe Weather Research (CSWR).

In 2008, NCAR launched a strategic partnership with CSU to develop an Integrated Weather Radar Facility that will expand the capabilities of both organizations. In addition to smaller radars, both institutions support transportable 10-cm, multiparameter Doppler radars that will be jointly operated in this new partnership. (NCAR operates S-Pol, an S-band Dual Polarization Doppler Radar; CSU operates CHILL, which is also a polarized S-band weather radar system). A key objective of this collaboration is to create a national test bed facility that other institutes, agencies, and scientists can use to assess new ideas and theories about summer and winter precipitation.

As well as providing continuous radar operation, NCAR and CSU staff will quality check incoming and archived radar data. Virtual CHILL (V-CHILL) software will be used for remote operation and display of data from the Integrated Weather Radar Facility. A critical aspect of this integrated facility will be the establishment of a culture of shared enterprise between NCAR and CSU with the theme of "... accelerated process, from engineering development to field deployment." NCAR and CSU will also benefit from user feedback obtained during S-Pol field deployments that use technology developed jointly by the two institutions. In addition to these benefits, NCAR and CSU will support small (less than 20-hour) research projects for university students and scientists who require targeted weather research data.

Click to enlarge image. Colorado State University's CHILL and the National Center for Atmospheric Research's S-Pol radars. Both are dual-polarized S-band radar and will be included as part of the Integrated Weather Radar Facility.

NSF radars available to the community include S-POL (NCAR), airborne Doppler Radar (ELDORA) (NCAR), and mobile Doppler radars (CSWR) and CHILL (CSU).

Shared engineering and scientific activities between CHILL and NCAR/EOL S-band research radars will provide the scientific community with a number of opportunities, ranging from provision of a long-term mesoscale test bed to assess radar and other instruments, to improving data quality procedures, derived products, numerical models, and networking capabilities. Additionally, this partnership will act as a magnet to, and provide a framework for, local field campaigns, as well as offering continuous hands-on educational opportunities to new, junior scientists. Sidebar: NSF radars available to the community include S-POL (NCAR), airborne Doppler Radar (ELDORA) (NCAR), and mobile Doppler radars (CSWR) and CHILL (CSU).

Next Measuring Carbon...

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CILAS: Fast, Accurate Analysis of Carbon’s Isotopic Fingerprints

Click to enlarge image. The Carbon Isotope Laser Absorption Spectrometer (CILAS) will provide in situ measurement capability to study ‘fast’ carbon exchange processes involving 13C/12C CO^2 isotopes, and may be operated in the field continuously for long time periods (hours to days).

Vast quantities of carbon dioxide (CO_2) cycle between Earth’s atmosphere, oceans, and soils. By knowing the location of CO_2 sources (regions where more carbon is released than taken up) and sinks (where more carbon is absorbed than released), scientists can refine theories about how carbon gets processed and distributed, and how it evolves in a particular location or region. This in turn feeds understanding of regional and global climate change trends.

Funded by an NSF biocomplexity grant, CILAS exploits the latest optical fiber and photonics technologies, providing a laser-based gas sensor system that can take continuous, in situ measurements of $13CO^2$ /$12CO^2$ ratios.

One method of answering the source-sink question is to compare ratios of CO^2 isotope--$13CO^2$ and $12CO^2$. These isotopes provide clues as to where and how carbon was generated--for example, what percentage of the carbon originated from fossil fuel burning, what percentage was generated by plant respiration, and what percentage resulted from ocean uptake or release of CO^2. Lest it sound like an obvious or easy solution for understanding carbon dynamics, distinguishing between the processes involving these two isotopes requires extreme measurement precision.

To obtain the full story from carbon isotopes using traditional techniques, samples of air are collected in glass flasks at different heights and locations in the atmosphere. Once collected, the flasks are taken to a laboratory and the constituents are measured using an isotope ratio mass spectrometer (IRMS)--an instrument capable of providing very precise measurements of the sample’s chemical constituents. Despite their accuracy, using mass spectrometers as a research tools poses some problems. Often it takes weeks to months to obtain results, and because these large instruments are difficult to move, making field measurements is not possible. Additionally, transporting flask samples back to the lab limits the number of measurements that can be taken.

Scientists have long seen the need for a field instrument that can provide real-time readings that approach the precision of an IRMS. Collaborating with scientists at the University of Colorado, Rice University, and NOAA, NCAR scientists and research engineers have created just such an instrument--the high-precision carbon isotope laser absorption spectrometer (CILAS).

Funded by an NSF biocomplexity grant, CILAS exploits the latest optical fiber and photonics technologies, providing a laser-based gas sensor system that can take continuous, in situ measurements of $13CO^2$ /$12CO^2$ ratios. The high quality of the custom-developed laser source combined with advanced spectroscopic techniques and data processing enables precision and accuracy that approaches the performance of laboratory-bound IRMS. A recent performance analysis of CILAS indicated that an accuracy of 0.005% or better can be obtained.

A critical component in CILAS's creation was the support by NCAR's Design and Fabrication Services Facility in the Earth Observing Laboratory, which helped to create an infrastructure--metal instrument casing, compact design, external frame--that ensured CILAS would be both portable and rugged enough to withstand harsh field conditions. Researchers will put CILAS through additional calibration verification in the laboratory by simulating a host of field conditions and comparing the instrument's performance with an IRMS before it enters an intensive field testing period. CILAS, developed from the ground up and vetted through an extensive performance verification protocol, is well on its way to becoming an invaluable state-of-the-art tool for carbon cycle research for NCAR and the university community.

Next Design and Fabrication...

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Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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NCAR Design and Fabrication Services: Handcrafted Hardware for Atmospheric Sampling

Since 1960, NCAR has provided the science community with tools and services that it might not otherwise have. Though it grabs fewer headlines than the advanced research aircraft or powerful new supercomputers, instrumentation creation is one of NCAR's most important services as it is essential for answering research questions. Scientists studying Earth, the atmosphere, oceans, and space have come to depend on these instruments and the team that delivers them.

Whether creating something from scratch based on conversations with a principal investigator, or rendering into physical form a researcher's hand-drawn interpretation of an instrument, the skilled team of design and fabrication services staff can design it, build it, and provide seasoned counsel on use, based on years of experience.

An instrument's purpose, the materials used to create it, where and how long it will be used, and other factors all need to be considered both prior to and during instrumentation manufacture. Consequently, the design and fabrication process requires a combination of ingenuity, craftsmanship, patience, and a solid understanding of science and engineering. Part of the Earth Observing Laboratory (EOL), Design and Fabrication Service (DFS) designers, engineers, and highly skilled fabrication specialists work closely together, having invented and constructed innumerable scientific devices throughout NCAR's history.

Like any workshop, DFS is stocked with everything from manual to power tools although in this case, many of the power tools are precision and computer-aided versions. Together, this equipment is used to roll, turn, spin, cut, and otherwise shape a variety of metals aluminum, copper, brass and plastics, transforming them into just about anything a scientist needs. Machine shop products range from heavy parts for radar pedestals to tapered aircraft inlets to light-weight, precise optical mountings for aircraft or satellite instruments.

Click to enlarge image. Steve Rauenbuehler designer/engineer (right) and Dave Allen, Instrument Maker II (left) in front of an instrument pod to be installed on the Gulf Stream V research aircraft.

Click to enlarge image. Early morning launch of Sunrise Gondola.

But more than the tools and machinery, it's the team of skilled technicians that is responsible for this instrumental magic. Whether creating something from scratch based on conversations with a principal investigator, or rendering into physical form a researcher's hand-drawn interpretation of an instrument, the design and fabrication services staff can design it, build it, and provide seasoned counsel based on years of experience.

Within NCAR's scientific community, DFS has a reputation of being able to build just about anything a given experiment requires. Among its many recent projects, last fall the team created a gondola and pointing system for the Sunrise telescope. The gondola design team, which included NCAR's High Altitude Observatory staff, had to ensure that, once the gondola launched, the telescope's pointing system remained stable enough to capture highly resolved images of the Sun.

The DFS team is also in the process of creating pods that will be attached beneath the wings of the NSF/NCAR Gulfstream-V (GV). Based on an idea originated and patented by DFS manager Jack Fox, DFS engineer Steve Rauenbuehler, and EOL Research Application Facility's Mark Lord, the pods can carry up to an additional 800 pounds of scientific instruments. These innovative, tear-drop-shaped pods are designed with a detachable middle portion that is easily accessible from beneath the wing. When pod-mounted instruments are employed, more room is available on board for additional personnel or instruments a critical function in a plane where space is at a premium. Alternatively, instrumentation can be attached directly to the pod to gather data during flights.

Whether a project requires creating housings or towers for field instruments, making inlets that don't contaminate the sample, or designing and manufacturing the GV's pods, the DFS crew of designers, engineers and instrument makers has proved time and again that they're up for any task.

Next Adding Value to Weather Data...

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ASPEN Makes Dropsonde Analysis a Slam Dunk

Dropsondes go where humans don't dare—into the eye of a hurricane. For scientists to understand extreme events like storms, as well as more routine weather, it's critical that they can observe such phenomena. But in the case of tornadoes or hurricanes, sending a plane into the eye of the storm to collect in situ measurements of temperature, pressure, relative humidity, and wind speed is, at best, foolhardy. Moreover, should a plane ever venture into that eye, the airborne instrumentation would capture only part of the information required. Researchers need to know what's happening throughout the storm's vertical column of air—from the top of the column to the surface—to understand a weather event's idiosyncrasies.

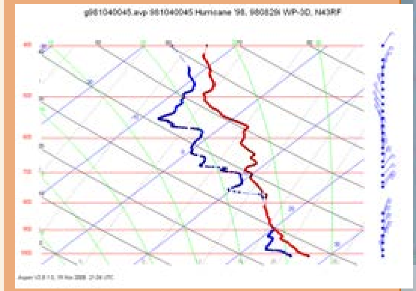
The Atmospheric Sounding Processing Environment (ASPEN) software developed in NCAR's Earth Observing System Laboratory (EOL), makes data processing operations as automatic as possible, and also gives users influence over quality control methods.

Dropsondes solve this problem. Light, tough, relatively inexpensive, and deployable in large numbers, sondes can be dropped from a plane into a hurricane's eye. As the device falls, it transmits relevant weather data back to an on-plane receiver or a nearby ground-based site. On average, a dropsonde descent takes 10 minutes, during which the sonde collects detailed pressure, temperature, wind, and humidity data about once per second.

After a dropsonde reaches the ground, data collection is complete. The next step in the research process is data clean-up and analysis. Atmospheric Sounding Processing Environment (ASPEN), software, developed in NCAR's Earth Observing System Laboratory (EOL), makes this process easy. Not only is ASPEN designed to make data processing operations as automatic as possible, it also gives users some level of influence over quality control (QC) methods.

Once a scientist selects the desired sounding file—which includes all information collected during the sonde's descent—the data are uploaded into ASPEN for processing and analysis. If desired, the user can change the QC parameters and

Click to enlarge image. The navigator reviews the ingress checklist before descending down to 1000 feet for a low level investigation mission.



Click to enlarge image. Typical output from ASPEN includes atmospheric state parameter displays, as well as Skew-T Log-P graphs (above). The latter provide a particularly useful meteorological depiction of the atmosphere. This graph is from a hurricane sounding measured by a NOAA P3 Orion research aircraft.

ASPEN was derived from software developed by NOAA's Hurricane Research Division (HRD). Occasionally the two programs produce subtly different results. ASPEN was extensively modified in 2008 to more closely match the near-surface results produced by HRD's program. HRD scientists, who frequently use ASPEN, also requested that ASPEN be modified to produce additional diagnostic parameters that will be used for research on improved hurricane forecasting. Added to the standard data product, these parameters are relayed in real time during hurricane reconnaissance flights and are integrated in current HRD research analyses. Their inclusion in ASPEN is critical to this research.

reprocess the data as often as desired. An added bonus: users can save their modifications, so when opening a new sounding, analysis will use the customized QC parameters.

Researchers have used ASPEN operationally for more than 10 years, most notably as the real-time dropsonde QC application for Hurricane Hunter aircraft. The software provides the standard QC processing for EOL radiosonde and dropsonde observations, and is employed by numerous organizations in the science community. ASPEN's analysis capabilities can, for example, provide details about surface-level wind speeds. This is particularly important because these low level winds, found in extreme environments such as a hurricane eyewall, can inflict tremendous damage. With near-surface data in hand, forecasters and decision makers are better able to predict storm damage in populated areas.

Next TOPIC HIGHLIGHT: Science and CCSM

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2008 Annual Report
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[Director's Message](#)
[Metrics](#)
[Back to homepage](#)
. . . .
TOPICS

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Higher and Higher: WACCM Tracks Chemistry and Climate from Ground to Thermosphere

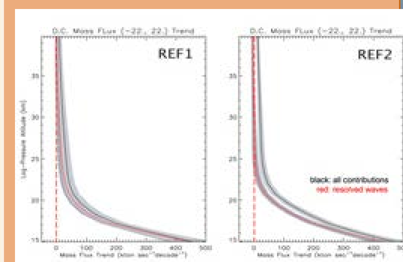
Historically, climate models have been relatively simple, tackling important physical and radiative processes in the troposphere rather than attempting to replicate the Earth system as a whole. This was due in part to the inherent complexity of the Earth system and its feedbacks, and also to the fact that the computing power needed to run more extensive models was not available. With petascale computing (1,000 trillion floating point operations processed per second) a near reality, processing times are less of an obstacle today. Likewise, modeling capabilities and scientific understanding have advanced. These evolutionary steps have led to the development of more complex models, which have a greater number of system components and can simulate a larger range of phenomena in the natural system. WACCM the Whole Atmosphere Community Climate Model is one such a model.

Historically, climate models have been relatively simple, tackling important physical and radiative processes in the troposphere rather than attempting to replicate the Earth system as a whole. WACCM's capabilities represent a major advance in climate models.

[WACCM](#) simulates Earth-atmosphere interactions from the troposphere (the lowest portion of the atmosphere, starting at Earth's surface) up to the lower thermosphere at 140 kilometers. In addition to its ability to represent interactions between the major physical elements of the natural system atmosphere, oceans, land WACCM has an atmospheric chemistry component that can simulate the transport and photochemistry of trace species throughout the atmosphere.

WACCM's capabilities represent a major advance in climate models. WACCM is one of only a few models able to simulate atmospheric physics, the transport of chemical species (for example, ozone, methane, water vapor, etc.), and the combined effect[of atmospheric chemistry and physics on climate variability between the troposphere and upper atmosphere. Scientists have gained a greater appreciation of the importance of the physical and chemical interactions between

Click to enlarge image. This highly oblique image of northwestern African captures the curvature of the Earth and shows its atmosphere (Photo: NASA/JPL/UCSD/JSC).



Click to enlarge image. Trends in vertical mass flux integrated between 22°S and 22°N in two WACCM simulations where greenhouse gases (GHG) increase with time. The Reference-1 simulation (REF1) covers the years 1950-2003, while the Reference-2 run (REF2) covers 1990-2050. REF1 specifies GHG concentrations from observations, while REF2 uses estimates from the A1B scenario of the Intergovernmental Panel on Climate Change (IPCC). The results show that the mass flux in the Tropics increases with increasing GHG concentrations. This reflects an acceleration of the Brewer-Dobson circulation, which is brought about by changes in wave forcing that are a response to the effects of GHG. See Garcia and Randel (JAS, 65, 2731, 2008).

different atmospheric regions, and learned that changes in the propagation of planetary waves into the stratosphere (due to natural or anthropogenic factors) likely play a role in tropospheric climate variability.

As of 2008, WACCM has become the latest addition to the Community Climate System Model suite. In addition to ongoing use by community members and in work being done for the World Meteorological Organization Ozone Assessment program, future WACCM modeling runs will be included in the Fifth Assessment Report for the Intergovernmental Panel on Climate Change. Projected applications of the model for scientific studies include the following:

- Investigate interactions between stratospheric dynamics and chemistry to clarify the role of natural and anthropogenic variability in ozone depletion during the last 20 years and into the 21st century.
- Investigate the effects of solar variability on the middle and upper atmosphere on time scales ranging from the solar rotation period (about 25 days) to the 11-year solar cycle.
- Study processes controlling the stratosphere/troposphere exchange of mass and minor constituents.
- Interpret observations from NASA and NSF programs: Upper Atmosphere Research Satellite (UARS), Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED), Earth Observing System (EOS) (High Resolution Dynamics Limb Sounder (HIRDLS)), and the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR).
- Investigate the effects of coupling between the stratosphere and the troposphere on climate variability.
- Understand whether stratospheric ozone and temperature changes induced by the 11-year solar cycle play a role in observed correlations between the solar cycle and tropospheric and lower stratospheric temperature and geopotential patterns.
- Study physical and chemical processes in the vicinity of the mesopause, in particular changes associated with increasing CO^2 concentrations.

Next Merging Models...

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2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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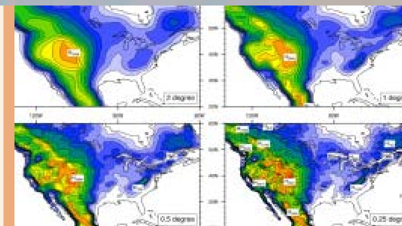
Merging Models to Simulate Effects of Global Warming on the Western U.S.

Because of their coarse resolution, global climate models (GCMs) do a poor job of accurately simulating climate in regions with highly variable topography, such as the mountainous western U.S. A typical GCM grid point—a snapshot of conditions at a location on Earth—is about as big as Belgium or the state of Maryland, so it comes as little surprise that despite impressive gains in knowledge of global climate change, GCM information from regions with rugged, varied topography is of limited use in expanding scientists' ability to understand and predict regional Earth system dynamics.

In turn, this inhibits producing accurate, reliable predictions of regional climate change, which are required for adaptation and mitigation strategies. For example, extreme weather events like heavy rainfall or heat waves are projected to become more frequent as climate changes. Warming means that precipitation now occurs more often as rain instead of snow, that snow melts earlier, that runoff and risk of flooding increase in early spring, and risk of drought and wildfire in summer increases as warmer air dries the land. Such events have enormous implications for agriculture, hydrology, water resources, and urban planning, particularly over the intermountain West.

Because of their coarse resolution, global climate models (GCMs) do a poor job of accurately simulating climate in regions with highly variable topography, such as the mountainous western U.S. The Nested Regional Climate Model will allow fundamental progress in understanding and predicting regional climate variability and change.

To plan for the impacts of climate change, western U.S. states require improved models and more powerful computers dedicated to climate modeling and prediction. NCAR has a record of world leadership and achievement in advancing knowledge of weather and climate variability and change. In keeping with its core mission, NCAR develops and supports advanced observing facilities, increasingly powerful supercomputing capabilities and related software, valuable research data



Click to enlarge image. The orography of the U.S. at climate model (CCSM) resolutions of approximately 125 miles (upper left), 62 miles (upper right), 31 miles (lower left) and 15 miles (lower right). Most climate models are run with resolutions no finer than the upper right panel for climate change experiments. With NRCM, typical simulations will be run at resolutions of 2.5 miles or less over the intermountain West.

Accelerated Scientific Discovery: A project of this magnitude and complexity requires a very powerful supercomputer to produce results within a reasonable amount of time. NCAR's computing capability increased threefold with the installation of the new IBM system bluefire. During the time before the normal workload grew to fill the new computer, seven projects were chosen to make optimal use of this resource—NRCM was among these. From July to October 2008, generating NRCM past and future climate simulations made use of 25 percent of bluefire's total processing power. Like the other six accelerated scientific discovery projects, the NRCM effort may not have been feasible because of its intensive computing needs. This marks the third program in which the National Science Foundation and NCAR's Computational and Information Systems Laboratory (CISL) have made special accommodations for very large computational experiments; as new supercomputing systems come online, CISL and NSF will solicit applications and allocate resources to support large-scale, scientifically important projects.

sets, and widely used state-of-the-science community weather and climate models.

To create a viable model that can handle varied regional topography in global simulations, scientists merged NCAR's Weather Research and Forecasting (WRF) model with the Community Climate System Model (CCSM). This Nested Regional Climate Model (NRCM) will allow fundamental progress in understanding and predicting regional climate variability and change. In particular, the multiscale capability of the NRCM allows researchers to better understand how regional-scale processes influence global climate.

The increased fidelity of NRCM simulations will also improve decision makers' local and regional planning efforts. NCAR scientists performed a series of simulations using the NRCM to examine likely changes in future climate and regional weather statistics over the intermountain West. These unique data sets will be of immense interest and utility to many stakeholders, both in the U.S. and internationally.

Next Community Ice Sheet Model...

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Modeling the Slips and Stresses of Polar Ice on the Move

Click to enlarge image. Surface lakes of meltwater (called supraglacial lakes) on the Greenland Ice Sheet. Courtesy National Science Foundation and Ian Johgin/University of Washington Polar Science Center.

If melted, all of the ice on the Earth's surface could raise global sea level by more than 200 feet. Because most of this ice resides in the ice sheets of Greenland and Antarctica, interest in understanding ice sheet dynamics is growing, particularly among scientists responsible for designing the Community Climate System Model (CCSM).

Recently, scientists modified the Community Land Model (CLM), a component of CCSM, to compute ice sheet surface mass balance—the net accumulation of snow minus melting or evaporation. But to obtain a full picture on ice sheet behavior, they must pair information on surface mass balance with estimates of dynamic changes in ice flow. To achieve this end, William Lipscomb and Steve Price, scientists at Los Alamos National Laboratory, are in the process of adapting GLIMMER, an ice sheet model created at the University of Bristol, for inclusion in CCSM4, the latest version of the community model.

If melted, all of the ice on the Earth's surface could raise global sea level by more than 200 feet.

"In retooling GLIMMER, it is important to be able to represent both ice sheet dynamics—vertical shear stress, lateral shear stress, and longitudinal normal stress—and surface mass balance, at scales of 10 kilometers or less," says Lipscomb.

Surface mass balance is hard to model with precision because, over small distances, ice sheets tend to have steep edges and undulating topography. Also, the rate of ice sheet melt is sensitive to temperature and elevation changes, with temperatures decreasing as elevation increases. Accounting for surface processes, such as percolation and refreezing of water within the ice and snow, can further complicate mass balance modeling. Despite this, Lipscomb says, CLM's excellent surface energy and snow scheme is capable of generating accurate surface mass balance estimates.

GLIMMER is expected to become part of CCSM4 by the end of 2008. It will not have all of the desired ice sheet dynamics capabilities, but the team is working on additional improvements that will be included in future CCSM versions. Currently, Lipscomb, Price, and other CCSM contributors are testing the model to make sure all of the pieces work together as anticipated. These efforts will mean that, for the first time, CCSM will include a dynamic Greenland ice sheet component. This represents a significant improvement; to date, the thickness and extent of the Greenland and Antarctic ice sheets in CCSM have remained static.

Further out, the team plans to create a Community Ice Sheet Model (CISM) that will allow dynamic simulations of the Antarctic and paleo ice sheets, in addition to Greenlandic ice sheets. CISM will help scientists predict and hindcast regional and global ice sheet retreat and the resulting sea level rise. Also, researchers expect that CCSM's ocean and ice sheet models will be fully coupled. This will let the model replicate intrusions of warm water beneath ice shelves, shedding insights on how this phenomenon may feed back on itself and cause ice margins to destabilize. Scientists think that this mechanism might trigger the rapid retreat of the West Antarctic Ice Sheet—which could raise sea level by a meter or more within a century or less.

Next Modeling the Carbon Cycle...

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The National Center for Atmospheric Research
2008 Annual Report
NCAR

Director's Message
Metrics
Back to homepage
. . . .
TOPICS

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From Plants to People, Carbon Cycle Modeling Takes on New Realism

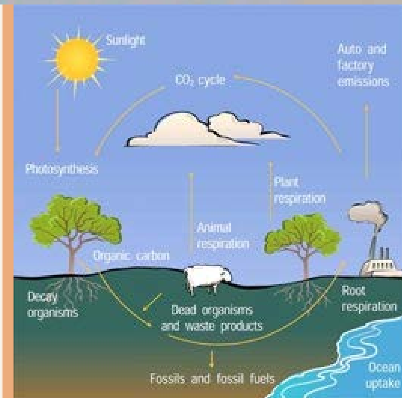
Carbon in all its various forms—carbon dioxide, methane, organic matter, calcium carbonate—cycles through the atmosphere, biosphere, and hydrosphere. Understanding the lifecycle of carbon and its fluxes between Earth's various "spheres" is important to comprehending, planning for, and modeling current and future global climate. This is particularly true because carbon's lifecycle is long—methane and carbon dioxide, for example, remain in the atmosphere for one or more decades—which means that carbon dynamics significantly influence environmental change.

This long lifetime also means that ecosystem and policy planners need to develop climate and carbon-related adaptation and mitigation strategies decades in advance. To do this, tools are needed that can assess how climate will be affected, for example, in the event that large swathes of tropical rain forest disappear. Lacking the right information, policies will fail.

Understanding the lifecycle of carbon and its fluxes between Earth's various "spheres" is important to comprehending, planning for, and modeling current and future global climate.

Biogeochemical models help scientists refine their understanding of the carbon cycle, and climate models shed light on the effects of global climate change. Until recently, however, carbon cycle modeling and climate system modeling were generally considered to be separate efforts. The Community Climate System Model (CCSM), one of the few climate models that has incorporated a carbon cycle component for quite a while, is designed to address exactly these questions. And, in the model's newest version, CCSM4, the carbon cycle component will be even more robust.

For CCSM4, scientists in the CCSM Biogeochemistry Working Group wanted to create a model that considers human carbon emissions in its scenarios, as opposed to atmospheric trajectory of carbon dioxide, the way most climate models have done in the past. This model output, says Scott Doney, a senior scientist at



Click to enlarge image. This diagram shows the carbon cycle. All life is based on the carbon atom. It can exist in a solid, a liquid, or a gas. Carbon constantly moves through all living things, as well as through the oceans, atmosphere, and Earth's crust. Carbon dioxide in the atmosphere plays a vital role in regulating air temperature on Earth.

Woods Hole Oceanographic Institution and part of the Biogeochemistry Working Group, will help guide economic and environmental policies, as well as technology decisions related to release of anthropogenic carbon. The information will answer questions such as how climate will change in future, how much carbon will be removed from or added to the atmosphere, and whether there any potential surprises that planners should take into consideration critical questions for ensuring a healthy global society.

In 2005, prior to the current CCSM4 effort, scientists ran a preliminary set of experiments coupling simple carbon models with CCSM's land and ocean components. Based on the lessons learned, the carbon cycle team wanted to add more sophisticated biogeochemical components as a standard part of CCSM.

The team plans to wrap up work on the development of CCSM4 soon, so that its model runs can be generated in time for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). It's currently unclear what carbon cycle components will be included in the frozen model version, Doney says. The carbon cycle group wants to add the updated carbon cycle component, but it needs to ensure that any new functionality doesn't impede how well the model currently works.

In the realm of CCSM4 and carbon cycle capabilities, what is guaranteed so far is that the new CCSM ocean model will have fully dynamic plankton capabilities, and the new CCSM land model will have a better treatment of plants, trees, soils, and other components, ensuring that carbon cycle dynamics pertaining to ecosystem function are accurate. By spring 2009, the team will have decided what to include. Regardless, it is guaranteed to set a new benchmark for the carbon cycle work to come.

Next TOPIC: NCAR Metrics

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DIRECTOR'S MESSAGE

ASP Director Maura Hagan

The Advanced Study Program (ASP) helps NCAR and the scientific communities that it serves to prepare for the future by promoting cutting-edge research activities, engaging in human and institutional capacity building, and developing partnerships between NCAR scientists and their colleagues in universities and other institutions.

Through its component Postdoctoral Fellowship, Graduate Visitor, and Faculty Fellowship programs, ASP primarily addresses the NCAR strategic goal: cultivating a scientifically literate and engaged citizenry and a diverse and creative workforce. But, the ASP postdoctoral fellows' research contributions also play a notable role in pursuing the NCAR strategic goal: improving understanding of the atmosphere, the Earth system, and the Sun. The two-year ASP postdoctoral fellowship appointments encourage the development of young scientists in the field of atmospheric science, direct attention to timely scientific areas needing special emphasis, and help NCAR and the community prepare for the future through the professional development of early career researchers. Approximately 10 new appointments are made annually for positions in all of the NCAR Labs. Fellows' research advances are reported separately in the NCAR Laboratory Annual Reports.

Accomplishments

In FY2008, the ASP made eight new postdoctoral fellowship appointments and continued its collaboration with the Inter-American Institute for Global Change Research (IAI) with special NSF support by hosting two IAI-ASP postdoctoral fellows. ASP hosted 11 faculty fellows with eight accompanying student visitors and two NCAR scientists received support for their long-term visits to two U.S. universities through the Faculty Fellowship Program. The Graduate Visitor Program provided support for nine graduate students to spend time in residence at NCAR in support of their thesis research. Most of these awards also included support for at least one two-week visit for their thesis advisor. ASP successfully engaged student and faculty from two Historically Black Colleges and Universities (HBCUs) in our programs in FY2008, and made numerous fellowship and visitor awards to deserving candidates from historically underrepresented groups in the geosciences. More on all of these programs can be found in this report.

FY2009 Plans

ASP will continue to engage and develop the scientific workforce of the future through its core visitor and fellowship program elements that engage all graduate students and postdoctoral fellows in residence at NCAR, including monthly seminars, monthly informational socials, the annual ASP retreat and ongoing mentoring opportunities. Through the highly successful Thompson Lecture Series, ASP will bring two prominent scientists to NCAR for extended interactions with this cohort in fall 2008 and spring 2009.

The annual ASP Colloquium series will be expanded to include two events in summer 2009 on the topics of "Exploring the Atmosphere Using Observational Instruments and Techniques" and "Ecosystems and Climate: Modeling and Analysis of Observed Variability in Marine Ecosystems".

ASP will also provide organizational support for the NCAR Software Engineering Assembly and the activities of the Early Career Scientists Assembly (ECSA), including the Junior Faculty Forum on Future Scientific Directions. Additional details along with other ASP plans are included in this report.

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TABLE OF CONTENTS

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Director's Message

Table of Contents

ASP Postdoctoral Fellowships

Strategic Goals: Science, Facilities & Technology

Research Catalog

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ASP POSTDOCTORAL FELLOWSHIPS: CROSS-LABORATORY, MULTI-DISCIPLINARY RESEARCH AT NCAR

ASP is unlike most other NCAR divisions or institutes, because it contributes to all NCAR goals and strategic priorities. It serves as a catalyst for burgeoning research activities that span the boundaries of NCAR laboratories and divisions. As such, the ASP contributes to all five NCAR strategic goals and to multiple priorities within these goal areas.

Luciana Rizzo in Brazil.

The most important ASP component is the Postdoctoral Fellowship Program, which has been a part of NCAR for forty-three years and has brought over 425 postdoctoral scientists to NCAR. The ASP appoints approximately 7-10 new postdoctoral scientists each year. During their two-year NCAR appointments, the fellows conduct research in collaboration with NCAR scientists throughout the Center. Many fellows hold joint appointments across divisions or laboratories. All fellows benefit from the opportunity to work with NCAR scientists, from exposure to the breadth of science at NCAR, and from the independence they are encouraged to develop. Many former fellows now occupy prominent positions at UCAR universities or at NCAR, and many of the present collaborations between NCAR and university scientists derive from associations that developed in the postdoctoral program. The institution benefits from these appointments through the research and investigation of new topics and directions in areas that that might not otherwise be addressed.

Amit Teller in Turkey

In FY08, the ASP appointed 8 fellows (from over 110 applications) in a diversity of disciplines spanning the various labs and divisions within the organization. In addition to the diversity of disciplines, the new fellows represent a diversity of population including gender and ethnicity. Also in FY2008, the ASP held monthly 'socials' that often included an education or career development aspect. Socials during the past year included a panel discussion with IPCC members, a discussion entitled the International Coordination of Global Climate Research Programs and Setting Priorities for Future Funding Opportunities, and an opportunity to interact with journalists. These socials not only brought members of ASP together, but also included any postdoctoral fellow or graduate student within the organization who wished to attend. In 2006 ASP helped form a new NCAR Fellows Association. The Association generally meets on a monthly basis in a social setting in order to provide friendship and support to other postdocs and graduate students at NCAR. The ASP continued to support the Association in FY2008 and will do so in FY2009. The ASP aims to create a meaningful experience not only for ASP fellows, but for all fellows at NCAR. As part of this plan, NCAR/ASP is a sustaining member of the National Postdoctoral Association.

In FY2009, ASP plans to continue the core elements of the program, including monthly seminars, bi-weekly research reviews, monthly socials, and the Thompson Lecture Series along with the annual research planning sessions and on-going mentoring that postdoctoral fellows receive. The postdoctoral program receives its funding from the National Science Foundation.

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NCAR'S STRATEGIC GOAL'S

NCAR's Strategic Plan, ***NCAR as an Integrator, Innovator and Community Builder***, outlines five Strategic Goals, and the priorities for achieving each. In the following sections we report on progress made in FY 2008 toward each scientific goal and priority.

NCAR's has 5 Strategic Goals. Follow the links below to learn about ASP's contribution to these goals.

1. Improve understanding of the atmosphere, the Earth system, and the Sun,
2. Increase societal resilience to weather, climate, and other atmospheric hazards,
3. Cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce,
4. Provide robust, accessible, and innovative information services and tools, and
5. Provide world-class ground, airborne, and space-borne observational facilities and services.

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RESEARCH CATALOG

- Kelley Barsanti
- Ramit Bhattacharyya
- Mercy Borbor-Cordova
- Simona Bordoni
- Rebecca Centeno-Elliott
- Wiebke Deierling
- Mark Flanner
- Jacob Fugal
- Mary Hayden
- Åse-Marit Janse
- Song-Lak Kang
- Saewung Kim
- Cecile Piret
- Andrea Sealy
- Xiaoli Luan
- Sean Swenson
- Amit Teller
- Simone Tilmes
- Knut Waagan
- Nedjeljka Zagar

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ABOUT THIS GOAL: CULTIVATE A SCIENTIFICALLY LITERATE AND ENGAGED CITIZENRY AND A DIVERSE AND CREATIVE WORKFORCE

Through ASP, a diverse workforce will be prepared to address the questions that span the intellectual boundaries of NCAR laboratories and divisions, and that contribute to all NCAR strategic goals. Further, ASP enhances the intellectual development of young scientists, directs attention to emerging scientific issues, and supports interactions with universities through its component programs.

Priority 2: Enhancing science education

- Faculty Fellowship Program
- Graduate Visitor Program
- Junior Faculty Forum on Future Scientific Directions
- Summer Colloquium

Priority 3: Improving public awareness and understanding

- Girl Scouts

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KELLEY BARSANTI - ATMOSPHERIC CHEMISTRY DIVISION

Kelley Barsanti’s research activities in FY 2008 focused on process-level investigations of the formation of secondary organic aerosols (SOA) in the atmosphere. Building on her PhD work, Kelley continues to use process-level models to explore the contribution of individual compounds/classes of compounds to SOA. In collaboration with Jim Smith from NCAR and Peter McMurry from the University of Minnesota, she has been developing a model to investigate the role of organic salts in the earliest stages of particle growth. The contribution of organic salts to SOA has been proposed previously, but has not been investigated thoroughly. Kelley and her co-authors recently submitted a paper proposing that organic salt formation may be important to SOA formation, particularly to the growth of newly formed particles. That hypothesis is supported by field data and process-level modeling results. Also proposed was the importance of amines as a base in forming such salts. Laboratory, field, and modeling studies are planned to further investigate the role of organic salts in the growth of newly formed particles and existing SOA.

In addition to developing process-level models, Kelley uses the Biosphere-Atmosphere Interactions (BAI) chamber at NCAR to conduct experiments that compliment the modeling studies described above. In FY 2007, Kelley constructed the BAI chamber to further explore SOA generated from biogenic precursors. The BAI chamber consists of a 10 m3 Teflon chamber suspended in a light-tight enclosure, in which SOA generated from single compounds, as well as from live tree emissions, can be investigated. In FY 2008, Kelley conducted chamber experiments as part of a collaborative study designed to compare properties of SOA formed from Ponderosa pine emissions in laboratory, with SOA formed in a forested region dominated by Ponderosa pine. The collaborators involved were Jim Greenberg, Alex Guenther, Peter Harley, Thomas Karl, Saewung Kim (ASP postdoc), and Jim Smith from NCAR; and Rob Griffin from Rice University (ASP faculty fellow), and his student Meredith Cleveland from the University of New Hampshire. The ultimate goal of Kelley’s work is to use the knowledge gained from models and laboratory experiments to better represent organic aerosols (including SOA) in regional and global air quality and climate models.

Relevant Recent Publications

Barsanti, K., McMurry, P., Smith, J. (2008) The Potential Contribution of Organic Salts to New Particle Growth. Atmos. Chem. Phys. Discuss., submitted

Boy, M., Karl, T., Turnipseed, A., Mauldin, L., Kosciuch, E., Greenberg, J., Rathbone, J., Smith, J., Held, A., Barsanti, K., Wehner, B., Bauer, S., Widensohler, A., Bonn, B., Kulmala, M., Guenther, A. (2008) New Particle Formation at the Front Range of the Colorado Rocky Mountains. Atmos. Chem. Phys., 8, 1577-1590.

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Director's Message

Table of Contents

ASP Postdoctoral Fellowships

Strategic Goals: Science, Facilities & Technology

Research Catalog

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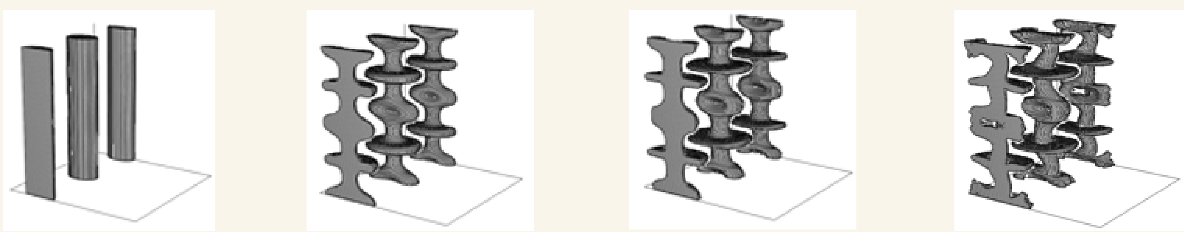
RAMIT BHATTACHARYYA - HIGH ALTITUDE OBSERVATORY

Spontaneous current sheet formation and break-up of magnetic flux surfaces

Spontaneous current sheet formation is an ubiquitous plasma phenomenon with both theoretical and observational implications. Theoretically it takes our understanding well beyond the standard concept of continuous magnetic fields. Observationally, resistive dissipation of these current sheets into thermal energy may play an important role in solar coronal heating. There are two aspects of the current sheet problem. The inevitability of their formation is the subject of Parker's theory [1, 2] according to which, in a perfectly conducting plasma it is impossible to simultaneously satisfy the local equilibrium condition and to preserve the global magnetic topology with magnetic fields that are continuous everywhere. The equally important second aspect is to understand the dynamics of the system as the current sheets are formed and is the motivation for this work. The time evolution of the system towards the current sheet formation is explored through numerical simulations specifically designed for this purpose.

The plasma is considered to be infinitely conductive, incompressible, viscous and described by the single-fluid magnetohydrodynamic equations. As the magnetic flux surfaces are the potential sites for the current sheet formation, the magnetic field is expressed in terms of intersecting magnetic flux surfaces. This gives us a direct visualization and hence a better insight into the dynamics of the process. As the current sheets form, the local gradients are steepened more and more till it reaches some threshold value. At this point the numerical dissipation sets in and the flux surfaces break. We use this very breakage to identify the sites at which the current sheets are forming.

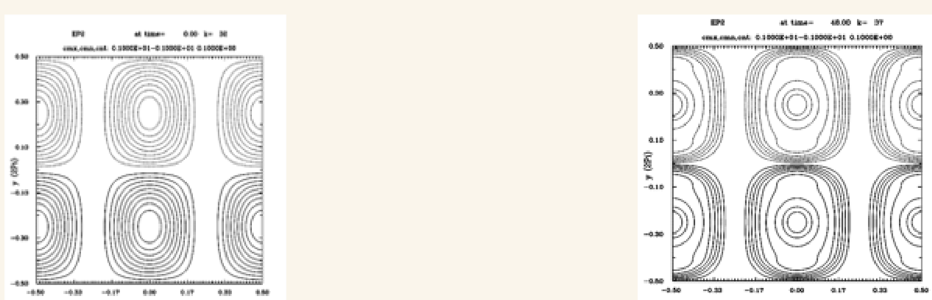
The numerical simulations are performed with a customized version of the EULAG modeling system [3]. Simulation runs with 128^3 and 180^3 grid resolutions have been performed and analyzed. In the following, a brief excerpt of the obtained results is presented to convey the general idea. This specific set belongs to a 128^3 run with a static flow and prescribed cylindrical flux surfaces as the initial condition. With time, as the flow builds up, different sections of these surfaces interact with each other and undulate (Figure 1). From 96 time units (seconds) onward numerical dissipation sets in and the flux surfaces start to break.



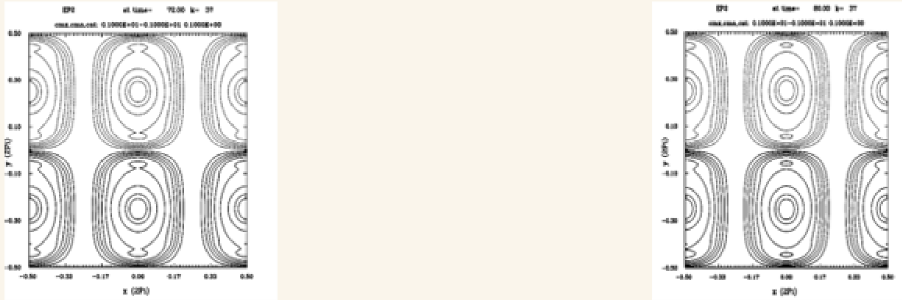
t = 0 s | t = 32 s | t = 96 s | t = 192 s

Figure 1. Temporal evolution of a given set of flux surfaces

Figure 2 represent the time evolution of a section of the above flux surfaces on a Cartesian plane (in this case xy plane).



t = 0 s | t = 48 s



t = 72 s   t = 80 s

Figure 2. Time evolution of a given cross section of the flux surfaces on a Cartesian plane

The observed necking and breaking of the flux surfaces in presence of numerical dissipation are the omnipresent signs for current sheet formation.

These initial results along with the numerical probes designed to analyze them are a stepping stone to understand the dynamics of current sheet formation in more realistic and complex magnetofluid systems. An immediate goal in this direction is to address the issue of formation of current sheets in finite time as described in the works of Grauer and Marliani [4].

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[1] E. N. Parker 1994, Spontaneous current sheets in magnetic fields, Oxford U Press.
[2] E. N. Parker 2007, Conversations on electric and magnetic fields in the cosmos, Princeton U press.
[3] Prusa, Smolarkiewicz and Wyszogrodzki 2008, Computers & Fluids 37, 1193–1207.
[4] R. Grauer & C. Marliani 2000, PRL 84, 4850

Collaborators

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2. Piotr Smolarkiewicz, MMM/NCAR, Boulder, Colorado

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MERCY BORBOR-CORDOVA - INSTUTUTE FOR THE STUDY OF SOCIETY AND ENVIRONMENT

An Investigation of Socio-Ecological Parameters Contributing to Dengue Transmission during the Dry Season in Guayaquil, Ecuador.

Scenarios from climate models predict substantial changes in North Andes atmospheric conditions over the next decades. The tropical Andes are located in a particularly vulnerable region regarding the impact of climate variability and change. The potential changes will have fundamental consequences for the local population, exacerbating directly and indirectly the degradation of ecosystems which will, in turn, potentially alter food systems and/or lead to the (re-)emergence of infectious disease pathogens. Climate change, coupled with existing cultural and socio-economic factors, would increase the vulnerability of the North Andes region.

In order to better assess current and future impacts of climate change Mercy J. Borbor and Mary Hayden, developed a pilot project during summer 2008 in Guayaquil-Ecuador applying a socio-ecological approach to address the following research questions:

- What are the inter-urban areas of Guayaquil with high risk of dengue transmission?
- What types of containers are associated with Aedes aegypti pupae presence and density at each study household?
- Do differing socio-ecological characteristics of low income neighborhoods have an impact on mosquito populations and dengue transmission?

Figure 1. Mercy J. Borbor and Mary Hayden surveying neighborhoods with high indicence of dengue in Guayaquil. Ecuador.

We selected two neighborhoods with contrasting dengue scenarios. The one with high dengue incidence C1: 1 de Mayo in the year 2008; whereas, the neighborhood with lower dengue incidence C2: Union de Bananeros per number total of households . These two neighborhoods are less than 1km apart and share similar residential characteristics in terms of housing density and construction. A summary of the main characteristics and findings of the surveys is in the following table.

Cooperativa 1: 1ero de Mayo	**Cooperativa 2: Union de Bananeros**
The size of your population : 460 households Random Sample size : 162 households	The size of your population : 340 households Random Sample size : 151 households
Total lower containers: 38 Number Pupae : 18 Rate of # container/household: 0.24 Rate of # pupae/household: 0.11	Total lower containers: 139 Number pupae: 11 Rate of # container/household: 1.04 Rate of # pupae/household: 0.08
Total Cases dengue: 28 Number Dengue cases/household sample: 0.18	Total Cases dengue : 35 Number Dengue cases/household sample : 0.23

The structured interview revealed that about 98 % of the household storage water in different type of container such as: 55 gal tanks, cisterns, 500 lt reservoir (high tank), and a variety of low containers (empty little pots, pans, etc.). Water is storage in 55 gal and small containers even tough 98% of the houses have piping water. Our statistical analysis suggests that lower containers are highly associated to the presence of pupae which was mostly identified as Aedes Aegypti. The rate of dengue was higher in neighborhood with more number of lower containers and pupae as well.

Preliminary Coastal nutrient and water budget assessments for Academy Bay, Santa Cruz in the Galapagos Islands-Ecuador.

The Galapagos Islands, a unique and fragile ecosystem considered "a living laboratory of evolution" that still possesses 95% of their original biodiversity. The coastal zones of these islands are susceptible to changes from land-ocean interactions, climate shifts and human activities. Human activities from tourism, urbanization, and wastewater are altering nitrogen and phosphorus nutrient levels in groundwater and along this coastline. . The ecosystem metabolism of the coastal waters is sensitive to these human activities; however, there is limited information and research of these complex interactions in the Galapagos Islands.

During the summer 2008 Mercy J. Borbor-Cordova and Alisha Fernandez, Ph.D. student at Penn State and SOARS student, traveled to Galapagos to develop a preliminary assessment of the water and nutrient fluxes in the Academy Bay identifying the what are the most important drivers leading to changes in the nutrient. The Pressure-State-Impact-Response (PSIR) assessment was used to identify socio-ecological stresses; through which it was determined that tourism and urbanization highly affect nutrient concentrations. An increase in these stresses may induce state changes and result in impacts such as eutrophication and algal blooms. The PSIR and budget analyses used are a framework for assessment on coastal management and policy.

The Land Ocean Interaction Coastal Zone (LOICZ) methodology was used to quantify the water-salt and nutrient budgets for Academy Bay. The hydrographic budget described inputs and outputs within this system, and was used to determine the salinity and residence time. Dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) nutrient budgets were used to determine the net ecosystem metabolism (NEM) equation, which defines a system as a source or a sink. DIN and DIP concentrations revealed that the NEM is autotrophic dominated by primary producers. The targeted area is also a sink for DIN and DIP.

This work would serve to develop a full proposal to investigate socio-ecological changes of the Galapagos Islands due to human influences on the complex interactions between land and the coastal zone and subsequently develop strategies for integrated coastal management and monitoring in this unique ecosystem.

	Indicators	Stressor	Description	Present pressure status	Trend Expectation
PRESSURE	NO_3, NO_2, PO_4, fecal coliform levels	Urbanization	Sewage production from humans, i.e. human discharge	Minor/ medium	Increase
	Salinity levels	Water demand	Demand for permanent population *	Major	Increase
	Fenols, Hydrocarbons	Fuel stations	Contamination of water from fuel extraction and transport	Major	Increase
	Annual visitors, hotel bed #, total venue	Tourism	Visitors and impacts from increased human population.	Major	Increase
	# sold in local market, # exported	Fisheries, Fishing	Annual extracted from ocean (fish, sea cucumbers), hatcheries	Medium	Increase
	Taxis driven, emission records***	Vehicle traffic	Emissions from rising vehicle use affects water and air quality	Medium	Increase
	Commercial and domestic boat #	Boat traffic	Boat traffic Academy Bay for tourist and domestic use	Medium/Major	Increase
	Precipitation, SSTs, upwelling, microalgae, runoff	Climate change	Environmental conditions past and present	Medium	Unknown
STATE		Urbanization	Growing local population, x 10 increase in 30 years may have serious impacts on coastal environment; Nutrient concentrations already altered by current population		
		Water demand	Demand looks to increase greatly with populations growth from locals and tourists; Potentially hazardous as freshwater supply seemed very low to withstand current and future water demands; Current water use 7 m^3 per person		
		Fuel stations	High use of oil from commercial ships in Santa Cruz and within other Galapagos Islands		
		Tourism	14% per year increase during last 15 years; Limitation at 120,000 tourists and currently at 100,000		
		Fisheries, Fishing	Past threat to local ecosystem; Currently represents < 4% of total income in Galapagos		
		Vehicle traffic	Over 350 taxis in use currently; 1970 approx. 3 taxis in use		
		Boat traffic	Busy and main transport system within Academy and other Galapagos Islands; no data yet to quantify gasoline byproduct, waste pollutants and overall disruption to marine life		
		Climate change	Average to low precipitation, no major river/streams system and no local watershed for Santa Cruz; Potential mixing of freshwater with ocean waters, warm SSTs		
		Urbanization	Eutrophication, harmful and/or natural algal bloom, microbiological pollution along the coast		

I M P A C T		Water demand	Salinization aquifers, steep costs for building and maintaining
		Fuel stations	Fenols and oil leaking
		Tourism	Eutrophication, microbiological and air pollution, introduction of exotic species
		Fisheries, Fishing	Loss of diversity
		Vehicle traffic	Emissions contamination of shore waters; oil leaks into freshwater supply
		Boat traffic	Introduce waste pollutants, alter nutrient levels and disrupt marine life
		Climate change	Loss of cold, nutrient rich coastal upwelling, potential decrease in plankton growth, potential increase in fish mortality, economic upset to coastal fisheries and marine-dependent communities
R E S P O N S E		Permanent monitoring of water quality (biochemical parameters) in Academy Bay; Treatment of used waters; regulations on waste disposal; enforce tourist limitations; model to project population growth, contaminants in fresh and salt water and tourism	

**Population and stressors that implement population count includes only permanent residents (10,000 people) and not tourist populations (100,000 annually) that interact with local ecosystem*

*** No current data with current fuel consumption and emissions into waterways*

**** No current data for annual emissions in Academy Bay, Santa Cruz*

Adaptation to the health impacts of Air Pollution and climaTe Extremes in Latin American cities (ADAPTE).

Collaborators: Patricia Romero-Lankao, Alejandro Leon, Olga Wihelmi, Eduardo Behrentz, Daniela Parra, Griselda Gunther, Angelica Rosas, Laura Dawidoski, Rosana Abrutzky.

This is a project funded by the Inter American Institute for Global Change Research (IAI) aiming to investigate the independent and combined effects of exposure to weather related stresses and air pollution and human vulnerability to urban health in four Latin American cities (Buenos Aires, Bogotá, Mexico City, and Santiago Chile). The project will explore how patterns in human mortality/morbidity and vulnerability vary spatially, and the human and natural factors accounting for this differential distribution within the cities.
Mercy collaboration is the following activities and components of the project: a) participation in the Project Workshop that it will take place in November 17-19, 2008, at NCAR Boulder. CO b) Help in the preparation and development of training sessions for GIS application for Air pollution risk mapping and Vulnerability Assessment (Lead by Paty Romero-Lankao). Finally, she will collaborate in the Development of Integrated Databases for the 4 cities, selection and application of methods of analysis (statistical and geostatistical) for intercomparison among cities.

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Director's Message

Table of Contents

ASP Postdoctoral Fellowships

Strategic Goals: Science, Facilities & Technology

Research Catalog

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SIMONA BORDONI - MESOSCALE AND MICROSCALE METEOROLOGY & RESEARCH APPLICATIONS LABORATORY

Simona Bordoni's main research area is in the field of tropical circulations, with a specific interest on the dynamics of monsoon systems. Building on research conducted during her PhD, she has used idealized numerical experiments to explore dynamical mechanisms, which are implicated in the existence of large-scale monsoons such as the Asian Monsoon. One of the most notable features that all monsoons have in common and that, despite its importance, remains to date poorly understood, is the rapid onset of the summertime precipitation and the rapid associated circulation changes. Traditionally, monsoons have been interpreted as planetary-scale sea breeze circulations, driven by the differences in heat capacities between land masses and surrounding oceans that, when heated by sunlight, lead to strong thermal contrasts between warm land and cooler ocean surfaces. While still widely accepted, the land-sea breeze paradigm cannot account for the rapid onset and end of monsoons. Using numerical experiments with a General Circulation Model (GCM) in aquaplanet (water covered earth) configuration, Bordoni has been able to simulate transitions in the tropical overturning circulation that in all essential aspects resemble the onset and end of observed monsoons. The results from the numerical experiments suggest that the reorganization of the tropical circulation leading to the rapid onset of monsoons is mainly driven, rather than by the contrast in thermal properties between land and ocean, by the interaction of the large-scale energy-containing midlatitude waves with the mean tropical flow. Ongoing analysis of observational data confirms that similar mechanisms are also acting in Earth's large-scale monsoons, such as the Asian Monsoon.

Bordoni has also started using output from nested regional climate simulations with the Weather and Forecasting (WRF) model to better understand the dynamics of the low-level jet along the Gulf of California during the North American Monsoon season. High-resolution satellite-derived data show that the onset of the North American monsoon is accompanied by a seasonal reversal of the flow along the Gulf of California, from northerly during winter to southerly during summer. The summertime southerly jet is modulated on the synoptic time-scale by distinct transients, which shape important features of the monsoon such as the distribution and the northward extent of the monsoonal precipitation. Despite the importance of these mesoscale circulations for the North American monsoon, many questions on their dynamics remain open. The output from the nested regional climate simulations provide an ideal tool to answer such questions, because they do not only capture reasonably well the larger-scale forcing, but also provide high enough resolution to resolve the complex topography and the scales of interests in the core North American monsoon region.

Publications:

Bordoni S. and T. Schneider, 2008: "Monsoons as eddy-mediated regime transitions of the tropical overturning circulation" *Nature Geoscience*, **1**, doi:10.1038/ngeo248.

T. Schneider and **S. Bordoni**, 2008: "Eddy-mediated regime transitions in the seasonal cycle of Hadley circulations and implications for monsoon dynamics" *J. Atmos. Sci.*, **65**, 915 – 934

Conference presentations and seminars:

"Monsoons as eddy-mediated regime transitions of the tropical overturning circulation". Invited Seminar at the Max Planck Institute for Meteorology, Hamburg, Germany, September 2008.

"Monsoons as eddy-mediated regime transitions of the tropical overturning circulation: I. Simulations with an aquaplanet GCM". Oral presentation at the ASM 28th Conference on Hurricanes and Tropical Meteorology, Orlando Fl, April 2008.

"Monsoons as eddy-mediated regime transitions of the tropical overturning circulation: II. The zonal momentum budget in the Asian Monsoon system". Poster presentation at the ASM 28th Conference on Hurricanes and Tropical Meteorology, Orlando Fl, April 2008.

Non-research activities:

Bordoni is part of the ASP committee for the Thompson Lecture series to host Prof. Ray Pierrehumbert in Fall 2008. She also served in the Max Eaton Award Committee during the 28th Conference on Hurricanes and Tropical Meteorology of the American Meteorological Society in May 2008, to select the best presentation by a PhD student.

This research is supported by the National Science Foundation.

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REBECCA CENTENO-ELLIOTT - HIGH ALTITUDE OBSERVATORY

The Solar Oxygen Abundance

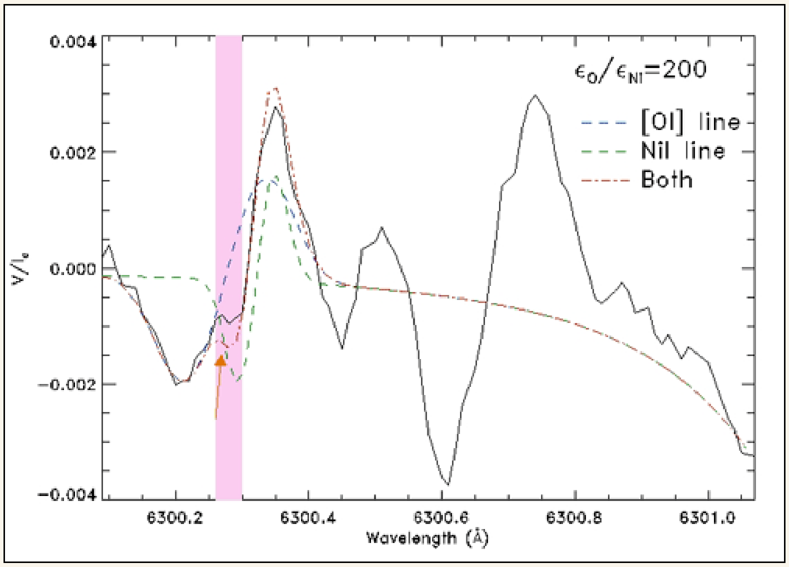

Figure 1
Averaged Stokes V spectrum observed in a sunspot umbra. Black, solid: Observation. Red, dash-dotted: Synthesis of the OI , NiI and FeI lines combined. Blue, dashed: Synthesis of [OI] and FeI lines only. Green, dashed: Synthesis of NiI and FeI lines only. All profiles are normalized to the average disk-center quiet-Sun continuum. Notice how the [OI] and NiI lines have similar amplitudes. However, the differences in their rest wavelengths and effective Lande factors give rise to a peculiar and strongly asymmetric shape of the blend when they are combined together. Particularly interesting is the feature marked by the arrow in the figure, exactly at the switchover point between the [OI] and the NiI blue lobes. This feature constrains the ratio of the relative abundance of O and Ni.

Oxygen is the third most abundant chemical element in the Universe, after Hydrogen and Helium, and the one that is most frequently produced by nuclear fusion in stellar interiors. Its abundance in the Sun was thought to be well established since the 1980s (850±80 parts per million particles, ppm; Anders & Grevesse 1989; more recently 680±100 Grevesse & Sauval 1998). However, a recent work (Asplund et al. 2004) using a new 3D hydrodynamical model of the solar atmosphere (as well as updated atomic and molecular data) recommends a revision of the O abundance to a lower value of 460±50 ppm. The revised solar composition fits better within its galactic environment but it also creates a serious problem, namely it ruins the exceptionally good agreement between the sound speed predicted by solar interior models and that inferred from helioseismology. Since chemical abundances are not directly measurable and imply a model-dependent inference, the observations are not conclusive and arguments exist both in favor and against the revision. The controversy on whether the proposed revision should be adopted and the doubts that it would cast on stellar structure and evolution models is serious enough that it is often referred to as the solar oxygen crisis (Ayres et al. 2006).

In this work we present new data that sets strong constraints on the solar Oxygen abundance. Our approach, based on the analysis of spectro-polarimetric observations, is almost model-independent and therefore extremely robust. The asymmetry of the Stokes V profile of the 6300 A [OI] and NiI blend measured in the umbra of a sunspot is used as an indicator of the relative abundances of these two elements. The peculiar shape of the profile requires a value of 710 ± 100 ppm. The uncertainty range includes the model dependence as well as uncertainties in the oscillator strengths of the lines. We emphasize that the very low degree of model dependence in our analysis makes it very reliable compared to traditional determinations.

References:

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WIEBKE DEIERLING - EARTH OBSERVING LABORATORY & MICROSCALE AND MESOSCALE METEOROLOGY DIVISION

Wiebke Deierling's research activities in FY 2008 continued from FY 2007, focused on utilizing physical relationships between total lightning activity and storm dynamical and microphysical parameters. An aim of her research is the utilization of these relationships for meteorological applications such as predicting lightning or alternatively making use of lightning information to improve thunderstorm forecasts.

Concerning nowcasting storms, her work aims to develop a lightning prediction system for short (e.g. < 30 minutes) and longer (up to several hours) lead times. To predict lightning on very short time scales the National Center for Atmospheric Research (NCAR) Auto-Nowcaster (ANC) system is used. For prediction of lightning on longer time scales, the skill of a combination of model forecasts and climatological parameters is tested. From the model forecast, microphysical and dynamical cloud parameters are used to compute areas of lightning potential threat based on previously observed physical relationships. This work is in collaboration with Cathy Kessinger (NCAR/RAL).

In collaboration with David Dowell (NCAR/MMM) she also works on assimilating radar data into WRF using the Kalman ensemble filter technique and validate model output with the radar derived microphysics, 3D wind-field and total lightning data.

Wiebke also collaborates with Christelle Barthe (CNRS/France) and Mary Barth (NCAR/ACD) investigating the use of microphysical and dynamical storm parameters to estimate total lightning in cloud-resolving models. The aim of this study is to determine if total lightning can be parameterized via the ice mass fluxes in WRF-CHEM. Three different storms have been simulated to show that this relationship can be used in cloud resolving models to diagnose the total lightning flash rate. The model results are compared to radar and lightning data. Sensitivity tests of the microphysics scheme and the horizontal resolution of the domain have also been performed.

Furthermore, Wiebke Deierling is investigating the relationship between precipitation ice mass, rainfall and total lightning in collaboration with Walt Petersen (MSFC). Total lightning activity has been shown to be closely related to graupel and ice crystal mass in convection. Therefore it may be possible to use radar data in conjunction with total lightning data to estimate the fractions of liquid water content or convective rainfall that originate from cold rain and warm rain processes. This would be useful for climatological and microphysical studies that need information about warm and cold rain processes in order to determine their role in the water cycle. Preliminary investigations show encouraging results.

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Director's Message

Table of Contents

ASP Postdoctoral Fellowships

Strategic Goals: Science, Facilities & Technology

Research Catalog

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MARK FLANNER - CLIMATE AND GLOBAL DYNAMICS DIVISION & THE INSTITUTE FOR INTEGRATIVE AND MULTIDISCIPLINARY EARTH SCIENCE

During the last fiscal year (October 1, 2007 - September 30, 2008) I have continued research on the climate forcing of atmospheric particles deposited to snowpack, conducted new research on the coupling of anthropogenic heat flux with climate models, and begun research on climate and biogeochemical effects of smoke emissions from fires in the Amazon.

The snow research recently culminated in a paper (submitted to ACP) describing the coupled atmosphere-snow influence of carbonaceous particles on springtime climate. This study considers the radiative effects of "surface dimming" (the reduction in surface insolation caused by extinction from particles in the atmosphere), "surface darkening" (reduced snow albedo from particle deposition, resulting in increased absorption), and atmospheric warming caused by solar absorption from soot in the atmosphere. We find that springtime climate is uniquely susceptible to solar warming mechanisms because of expansive snow cover and relatively intense insolation. Likely related, we also find that climate models contributing to the IPCC 4th Assessment Report almost universally underpredict rates of springtime warming and snow cover decline over Eurasia during the last 30 years. Another highlight of the snow-related research has been incorporation of the Snow, Ice, and Aerosol Radiative (SNICAR) model into the NCAR Community Land Model. SNICAR will thus likely provide the physical representation for prognosing snow reflectance and aging in the next release of the NCAR Community Earth System Model.

Another component of my research has been to develop a global dataset of anthropogenic heat flux, and integrate this energy term into the NCAR Community Atmosphere Model. A description of this project, including a map of present-day heat flux, can be found here: http://www.cgd.ucar.edu/tss/ahf/

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JACOB FUGAL - EARTH OBSERVING LABORATORY

Jacob Fugal's research is currently centered on designing, building, and testing the new HOLODEC 2 (Holographic Detector for Clouds 2) instrument. The design process began with determining instrument parameters that best suit technology capabilities to the science goals for HOLODEC 2. These science goals include 1) measuring small ice crystals size distributions after excluding shattered ice particles, 2) examining the extent to which cloud particles cluster on sub-cm spatial scales in response to turbulence and mixing processes, and 3) examining the sub-cm structure of mixed-phase regions of clouds. After determining the optimum desired instrument parameters, Fugal presented an instrument development proposal to funding committees inside NCAR's Earth Observing Laboratory and won internal funding to build the instrument.

The instrument is currently being designed and machined using engineers and fabricating resources inside the Earth Observing Laboratory. Scott Spuler has designed the optical systems that are able to withstand the rigors of an airborne environment. Jack Fox has begun the mechanical design. Mark Lord and others have helped in making sure the instrument design will pass the aircraft certification requirements to allow the instrument to fly aboard the NSF HIAPER (High-performance Instrumented Airborne Platform for Environmental Research) Gulfstream V.

Fugal is also working on implementing his hologram processing algorithm for use on the Lincoln supercomputer that is part of the NSF sponsored TeraGrid project. Lincoln is a hybrid supercomputer that combines nVidia Graphics Processing Units (GPUs) and Intel Xeon CPUs. Since much of the computationally intensive hologram reconstruction computations can be parallelized and offloaded to the nVidia GPU using nVidia's CUDA technology, hologram reconstruction can run at about 10 times the speed of doing it on CPUs alone. This is an important step in lowering the difficulty in making measurements of cloud particles using holography.

The instrument is on schedule to be ready for test flights in June 2009 with the reconstruction and results of the flights available within a few months after that.

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Director's Message

Table of Contents

ASP Postdoctoral Fellowships

Strategic Goals: Science, Facilities & Technology

Research Catalog

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MARY HAYDEN - INSTUTUTE FOR THE STUDY OF SOCIETY AND ENVIRONMENT

Hurricane Ike Impact. South Texas 2008

Mary Hayden began her field with as project director and co-PI on a NOAA funded study investigating the roles of climate variability and human-environmental interactions on the potential for dengue fever to emerge along the US/Mexico border in Arizona and Sonora, MX. In collaboration with the University of Colorado at Denver, ISSE, the Centers for Disease Control and Prevention (CDC), Arizona Department of Health Services, Arizona Office of Border Health, and the Oficina de la Salud Publica in Nogales, Sonora, she evaluated both environmental and human factors in the distribution of the tropical mosquito vector for dengue fever virus, *Aedes aegypti*, into a desert climate.

In collaboration with the CDC's Border Infectious Disease Surveillance program, she was part of an investigation of an outbreak of dengue fever that was undertaken in December 2005 in Brownsville, Texas and Matamoros, Tamaulipas, Mexico documenting the first case of locally acquired dengue hemorrhagic fever in the United States.

As an outgrowth of the initial investigation in 2005, she has worked with the Pan American Health Organization on a project investigating the role of waste tires as oviposition sites for disease vectors in Brownsville, TX and Matamoros, MX. Funding is being sought to expand the study to better understand the human-environmental interactions that contribute to dynamics of disease transmission in the TX-MX border region. She has also collaborated with CDC's Dengue Branch in San Juan, Puerto Rico on a study examining dry season transmission of dengue fever.

Mary has collaborated with the Border Infectious Disease Surveillance program, CDC, and US/Mexico Border Health Commission in developing West Nile Virus (WNV) prevention materials for use with more vulnerable populations such as migrant workers in CA and AZ. These materials, including a fotonovela and radio spots, are being widely disseminated in response to WNV outbreaks in both of these states. She and colleagues recently were recognized by the American Public Health Association for these materials.

A new project which has just received funding from Google.org is the development of a prototype Earth-gauging system integrating weather and health data to manage meningitis. This project aims to build and implement a prototype decision-support system that integrates two- to 14-day weather forecasts and epidemiological data to provide actionable information that can be used to contain the spread of meningitis epidemics. In 2009 we intend to establish local partnerships in Ghana, demonstrate weather-meningitis links, and develop and verify ensemble derived forecasts for meningitis management. Mary is part of a multi-institutional, multi-national research team led by Rajul Pandya (UCAR/NCAR) and Frederick Semazzi (North Carolina State University) which includes researchers from Ghana and IRI.

Mary and colleague Rebecca Morss recently undertook a research project investigating decision-making with Hurricane Ike in Galveston, TX. Semi-structured intercept interviews (N=49) were conducted in Galveston, TX and Kemah, TX five weeks after Hurricane Ike made landfall. These interviews were designed to elicit residents' responses to forecast information in order to better understand evacuation decision-making and sources of information, perception of risk, and barriers to evacuation. Analysis will be forthcoming in early 2009.

In keeping with her interests in integrating physical and social science, she has presented seminars on qualitative methods at NCAR's Weather and Society Integrated Study (WAS*IS) workshops in Boulder, CO, Norman, OK and Mt. Macedon, Australia as well as the Gordon Research Conference in April 2008.

Mary has also collaborated with NCAR on recent projects including the ASP Summer Climate and Health Colloquia in 2004 and 2006 and has served as a mentor for students in the SOARS summer program in 2005, 2007, and 2008 on climate and health related topics.

Publications

Spiegel J, Bennett S, Hattersley L, **Hayden MH**, Kittayapong P, Nalim S, Wang D, Zielinski-Gutierrez E, and Gubler D. (2005). Barriers and bridges to prevention and control of dengue: the need for a social-ecological approach. *EcoHealth* 2 (4): 273-290

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Ramos M, Mohammad H, Zielinski-Gutierrez E, Hayden M, Robles Lopez JL, Fournier M, Rodríguez Trujillo A, Burton R, Brunkard J, Anaya-Lopez L, Abell A, Kuri-Morales P, Smith B, Munoz J, Waterman S, and the Dengue Serosurvey Working Group. (2008) Epidemic Dengue and Dengue Hemorrhagic Fever at the Texas-Mexico Border: Results of a household-based seroepidemiological survey, December 2005. *American Journal of Tropical Medicine and Hygiene.* 78(3): 364-369

Hayden MH, Uejio C, Walker K, Ramberg, F, Moreno R, Mearns LO, Rosales C, Gameros M, Zielinski-Gutierrez E and Janes CR. (under review) Environmental and Human Factors in the Distribution of *Aedes aegypti* along the Arizona/Sonora Border. *EcoHealth*

Recent Selected Presentations

Hayden M and Zielinski-Gutierrez E. **Disasters and Behavioral Health Conference.** July 8-10, 2008. Colorado Springs, CO. "An Ecological Model for Examining Population/Community Resilience".

Hayden M and Pulwarty R. **Gordon Research Conference. Oceans and Human Health.** June 29-July 4, 2008. Tilton, NH."Climate Change and Health: Linking Qualitative and Quantitative Approaches to Inform Adaptation".

Hayden M. Tulane University School of Public Health. January 23, 2008. New Orleans, LA. "Weather, Climate and Health".

Hayden M. American Meteorological Society Annual Meeting. January 20-24, 2008. New Orleans, LA. Symposium chair. "Connecting Research and Applications for the Benefit of Society".

Hayden M, Zielinski-Gutierrez E, Fonseca-Ford M, and Waterman S. **Conference of Latin American Geographers.** May 31-June 2, 2007. Colorado Springs, CO. "WNV Educational Materials for Low Literacy Audiences".

Hayden M. and Robles, JL. **US-MX Border Health Association Annual Meeting.** May 20-22, 2007. South Padre Island, TX. "Dengue Fever Outbreak in Brownsville, TX and Matamoros, Tamaulipas".

Hayden M and Uejio C. **Arizona Vector-borne and Zoonotic Diseases Conference.** May 1-2, 2007. Mesa, AZ. " The Re-Invasion of Aedes aegypti in southern Arizona /northern Mexico".

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Director's Message
Table of Contents
ASP Postdoctoral Fellowships
Strategic Goals: Science, Facilities & Technology
Research Catalog

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ÅSE-MARIT JANSE - HIGH ALTITUDE OBSERVATORY

Spontaneous Current Sheets: Radically different in 3D fields vs in 2D fields!

Under conditions of very high electrical conductivity, such as in the fully ionized, million-degree solar corona, the magnetic field is essentially frozen into the plasma and, therefore, the magnetic field topology cannot change. The topology is described by where each thin flux tube enters and leaves the volume, and the twist and linkages of the magnetic flux tubes. The freezing of magnetic flux prevents the mixing of local fluid volumes that trap different flux systems. This can induce thin sheets of intense electric- current density to flow tangentially on the magnetic flux surfaces. The non linear thinning of these current sheets can reach the point where resistive dissipation becomes significant, producing heating and changes in field topology, as described by the Parker theory. If small-scale current sheet production pervades the corona, the dissipated energy is a means to heat the quiescent corona. Macroscopic size current sheets have been suggested to be the origin of solar flares.

Together with B. C. Low (HAO, NCAR), I have studied current-sheet formation in a special class of magnetic fields: Topologically untwisted magnetic fields. (Basically a field is untwisted if: (i) each of its flux tubes is internally untwisted, that is, there is no net twist along its entire length from a tube footpoint to the other footpoint, and, (ii) these flux tubes do not twist among themselves.) Our model starts with a topologically untwisted field inside a cylinder of perfectly conducting fluid. The field is anchored by its magnetic footpoints fixed at the cylinder ends, so that its topology is invariant to a continuous change in the length of the cylinder. Whereas this field of a fixed topology may have a continuous equilibrium state, as a potential field, for a particular length of the cylinder, no continuous equilibrium state is available to the field when the cylinder is given other lengths. In the latter case, magnetic discontinuities or current sheets must form, whose dissipation can then change the field topology to one compatible with a continuous state.

While magnetic neutral points or separatrix flux surfaces are necessary for current sheet formation in two-dimensional fields, in fully three-dimensional fields current sheets form readily even in the complete absence of neutral points and separatrix surfaces, and, these sheets can form densely throughout the field in response to changes in the magnetic volume.

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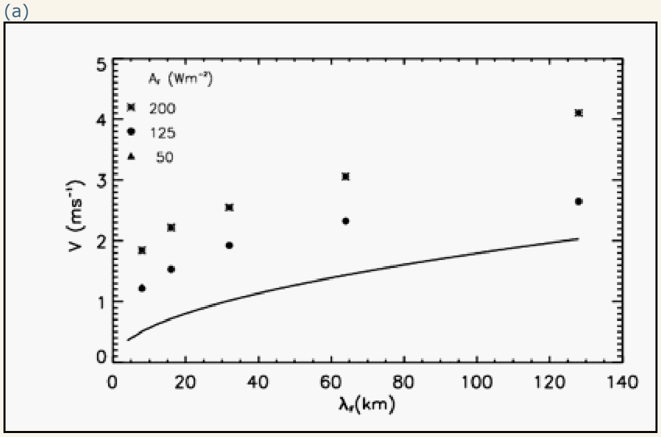
SONG-LAK KANG - RESEARCH APPLICATIONS LABORATORY

Convective Boundary Layer (CBL) forced by surface heterogeneity and its influence on moist convection initiation

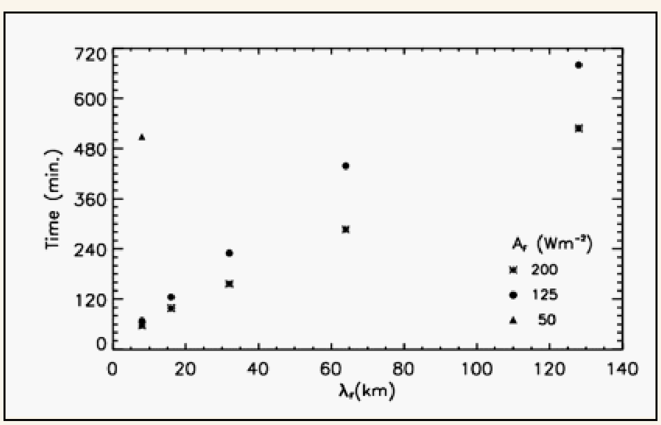
My research aims at contributing improvement of the atmospheric processes associated with land surface heterogeneity in a mesoscale model. This aims include the effect of the surface heterogeneity on moist convection initiation (CI). Given many recent studies suggesting significant effects of land use change on the weather and climate system, the interaction processes between land surface and the atmosphere should be fully understood. In addition, in a numerical model for predicting weather and/or climate, the interaction processes should be dealt with realistically and appropriately. However, still the interaction mechanisms are not fully explained and the parameterizations dealing with the interaction processes remain to be improved.

Given the multi-scale feature of land surface heterogeneity, the processes could be understood as a function of heterogeneity scale. I explained that in the convective boundary layer (CBL) the land-heterogeneity-induced horizontal flows could be temporally oscillatory using low-pass filtered equations of horizontal velocity and potential temperature. The oscillation onset is the transition of the CBL from in a quasi-stationary state to in a nonquasi-stationary state. The oscillation onset would occur when horizontal advection by surface-heterogeneity-induced mesoscale motions is strong enough to decrease the potential temperature gradient on the heterogeneity scale. I theoretically estimate the critical velocity magnitude for the oscillation onset. For the details, one can refer to Kang (2008). The critical velocity is a function of the surface heterogeneity scale. Using a compressible nonhydrostatic numerical model of Bryan and Fritsch (2002), I investigated the responses of the convective boundary layer (CBL) to surface heterogeneity on scales between a few tens of kilometers and a few hundreds of kilometers. The simulation results demonstrate that the CBL forced by surface heat flux variation that is sinusoidal with a amplitude of 100 Wm^{-2} or higher and a wavelength of the order of 10 km becomes in a nonquasi-stationary state.

(a)



In Fig. 1a, the horizontal wind speed at the oscillation onset of the generated horizontal flows at 95 m above the ground level (agl) is presented. We use the critical velocity scale that is theoretically derived to provide guidance for the oscillation onset. The values of $z_i = 736$ m (z_i is the CBL height) and $w_* = 0.77$ m s^{-1} (w_* is the convective velocity scale) at 30 min. from the horizontally homogeneous CBL case are used for computing the critical velocity scales. For all the cases that initiate the temporal oscillation within the 12 hr period, the generated horizontal wind speeds at their oscillation onsets are larger than the critical velocity scales. Also, the horizontal wind speed at the oscillation onset increases as the surface heterogeneity scale (λ_f) increases.



(b)

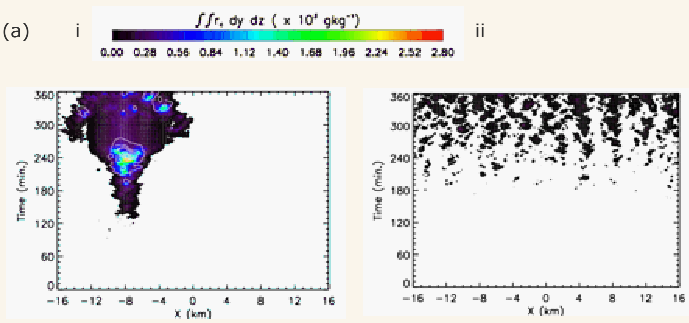
Fig. 1b presents the time it takes for the generated horizontal flows at 95 m agl to initiate the temporal oscillation. The horizontal flows generated by shorter-wavelength and higher-amplitude surface heat flux variation initiate the temporal oscillation at an earlier time. Given the time scale of the Coriolis parameter, the assumption of no Coriolis force used in this study could be valid for 4 hr at middle latitudes. The LES results presented in Fig. 1b suggest that within the time limit of 4 hr, for the horizontal flows to be oscillatory, the wavelength of surface heat flux variation should be shorter than 50 km at a variation amplitude higher than 100 Wm^{-2}. However, if the variation amplitude is lower than 50 Wm^{-2} or the variation wavelength is longer than 50 km, the generated horizontal flows seem to be in a quasi-stationary state within the time period of 4 hr.

Fig. 1. (a) The magnitude of the generated horizontal velocity at 95 m agl at the oscillation onset and (b) the time when the onset of the temporal oscillation occurs (b) for every case. The solid line in represents the critical velocity scale as a function of the wavelength of the surface heat flux variation.

Most boundary layer parameterizations in current mesoscale models are based on the horizontally homogeneous CBL that is also assumed in a quasi-stationary state. Given the heterogeneous CBLs that may be in a nonquasi-stationary state, one raises a question about the applicability of mesoscale models to investigate the effect of surface heterogeneity on the atmosphere. In particular, the land surface is extremely heterogeneous on a scale of the order of 10 km, the CBL turbulence cannot be described with the mixed-layer similarity (Kang and Davis, 2008). The different turbulence properties, along with the mesoscale structure, create a CI environment that can develop a deep moist convection in a shorter time in a more focused area than in a horizontally homogeneous CBL. In other words, significant change of land surface from its neighboring area by human modification such as urbanization may result in more occurrences of more locally and rapidly developing thunderstorms.

Fig. 2a shows the time evolutions of cloud water and rain water mixing ratios. The surface heterogeneity is prescribed only in the x direction. Thus, in order to present the mixing ratio distribution along the x direction, the value is summed over the y and z directions. For the strongly heterogeneous case with the sinusoidal surface flux variation of amplitude of 200 Wm^{-2} and wavelength of 32 km, clouds start to form at about 130 min locally over the center of the warm patch (Fig. 2ai). Here, the warm patch is defined as the region where the surface heat flux is above the domain average and the surface moisture flux is below the domain average. For the homogeneous surface case, clouds start to form randomly at about 230 min, which is 100 min late to the heterogeneous case (Fig. 2aii). Also Fig. 2b demonstrates that for the strongly heterogeneous case clouds grow to reach the height of 6 km, which is the model top of my numerical experiment, in 230 min (Fig. 2bi). However, for the homogeneous case, clouds grow much below the model top in the integration period of 360 min (Fig. 2bii). For the details of this numerical experiment and result, one can refer to Kang et al. (2008).

(a) i ii



(b)

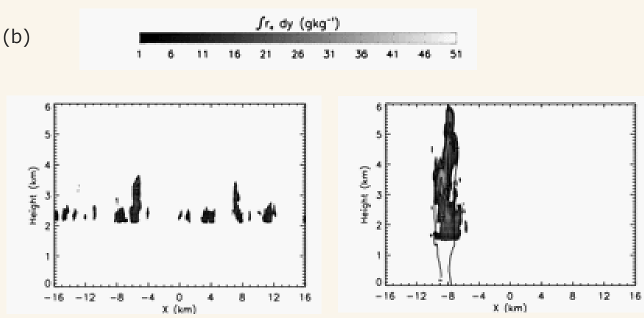


Fig. 2. (a) Time evolutions of cloudwater and rainwater mixing ratios for (i) the heterogeneous case and (ii) the homogeneous case. The values of the mixing ratios are summed over the y and z directions. The contour interval for rainwater mixing ratio is 1.0 x 10^3 gkg^{-1} . (b) Distance-height cross sections of cloudwater and rainwater mixing ratios (i) at 230 min for the heterogeneous and (ii) at 360 min for the homogeneous case.

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SAEWUNG KIM - ATMOSPHERIC CHEMISTRY DIVISION

IPCC (2007) summarized six anthropogenic radiative-forcing terms affecting global climate change. Among them, photochemical ozone and aerosols in the troposphere are directly related to chemistry of Volatile Organic Compounds (VOC) and their oxidation products. The global budget of VOC emission indicates that ~90% of global VOC emissions are composed of Biogenic VOC (BVOC; Goldstein and Galbally, 2007). Therefore, the series of direct and indirect evidence, indicating significances of unidentified BVOC in the forest canopy (Goldstein and Galbally, 2007) has urged research on identifications of the missing BVOC and their oxidation products due to their roles of contributing oxidation capacity and aerosol formation in the atmosphere.

Despite the significant implications of photochemistry and secondary organic aerosol (SOA) formation in the troposphere, the measurement of semi-volatile organic compounds (SVOC), a subsection of BVOC, in the atmosphere has been particularly limited due to technical challenges of high reactivity and vulnerability to wall loss during the sampling stage. These technical difficulties can be overcome by using in-situ techniques such as proton-transfer-reaction mass spectrometry (PTR-MS), which has been established as a standard CIMS technique for VOC measurement (de Gouw and Warneke, 2007).

In this context, we have examined analytical characteristics of PTR-MS to measure ambient sesquiterpene, which represents a class of terpenoid compounds (e.g. isoprene; C_5H_8, monoterpene; $C_{10}H_{16}$, and sesquitepréne) that have received increasing attention in atmospheric chemistry and plant biology due to their biologically active role and the SOA forming potential of their oxidation products from reactions with ozone (Kesselmeier and Staudt, 1999; Duhl et al., 2008). Laboratory studies in collaboration with Dr. Detlev Helmig (CU) and Dr. Thomas Karl (NCAR) indicated that quantitative SQT measurements within 20 % accuracy can be achieved with PTR-MS if two major product ions (m/z 149^+ and 205^+) out of seven major product ions (m/z 81^+, 95^+, 109^+, 123^+, 135^+, 149^+ and 205^+) are accounted for. The estimated detection limit (less than 20 pptv for ten-minute integration time) suggests that PTR-MS can be a viable tool for ambient measurements of SQT when sufficiently long integration times are chosen. The findings are submitted to Atmospheric Measurement Technology.

The findings of the lab experiments were applied in a field campaign, which was conducted in the South Rocky Mountain Ponderosa Pine forest canopy near Colorado Springs. We deployed two PTR-MS systems in the forest canopy-one is for ambient measurements and the other is for branch enclosure measurements. As described in Figure 1, the purpose of the study is to investigate photochemistry and secondary organic aerosol formation using top-down and bottom up approaches. In addition, unidentified BVOC were explored using mass scan measurements. A mass spectrum from enclosure measurement is presented in Figure 2a. As expected, 232-MBO and monoterpene are major emissions from Ponderosa Pine. However, number of minor species was also identified such as acetone, sesquiterpene, and oxygenated monoterpene as shown in Figure 2a. In addition, we have two unidentified emission compounds at m/z 169^+ and 183^+. We are currently conducting research for identifying those compounds and possible roles in photochemistry and SOA formation of those indentified and unidentified compounds. Figure 2b presents the ambient mass spectrum, taken around noontime in the forest canopy. The ambient mass spectrum shows many peaks, were not found in the emission spectrum as indicated in Figure 2a. The most pronounced peak in the ambient spectrum is from acetone (m/z = 59^+), which is an oxidation product of both MBO and monoterpene. This suggests that photochemical oxidation in the forest canopy is undergoing very fast. We can indentify around half of peaks in the spectrum. However, the other half of peaks cannot be identified with our current knowledge on oxidation of BVOC. Studies to identify those unknown peaks will be conducted in collaborations with other NCAR chemists such as a reaction chamber study.

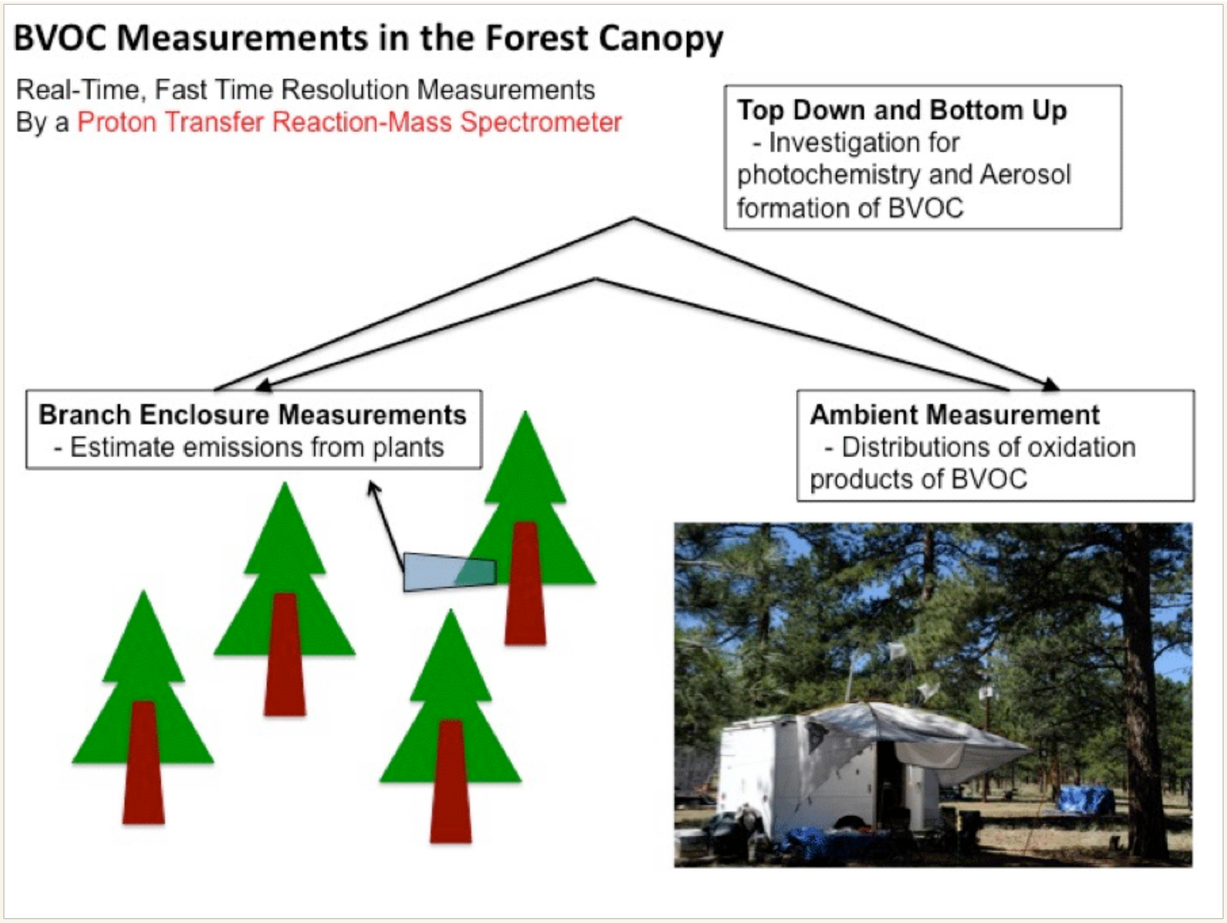

Figure 1. The concept of the field campaign to study photochemistry and secondary aerosol formation in the forest canopy

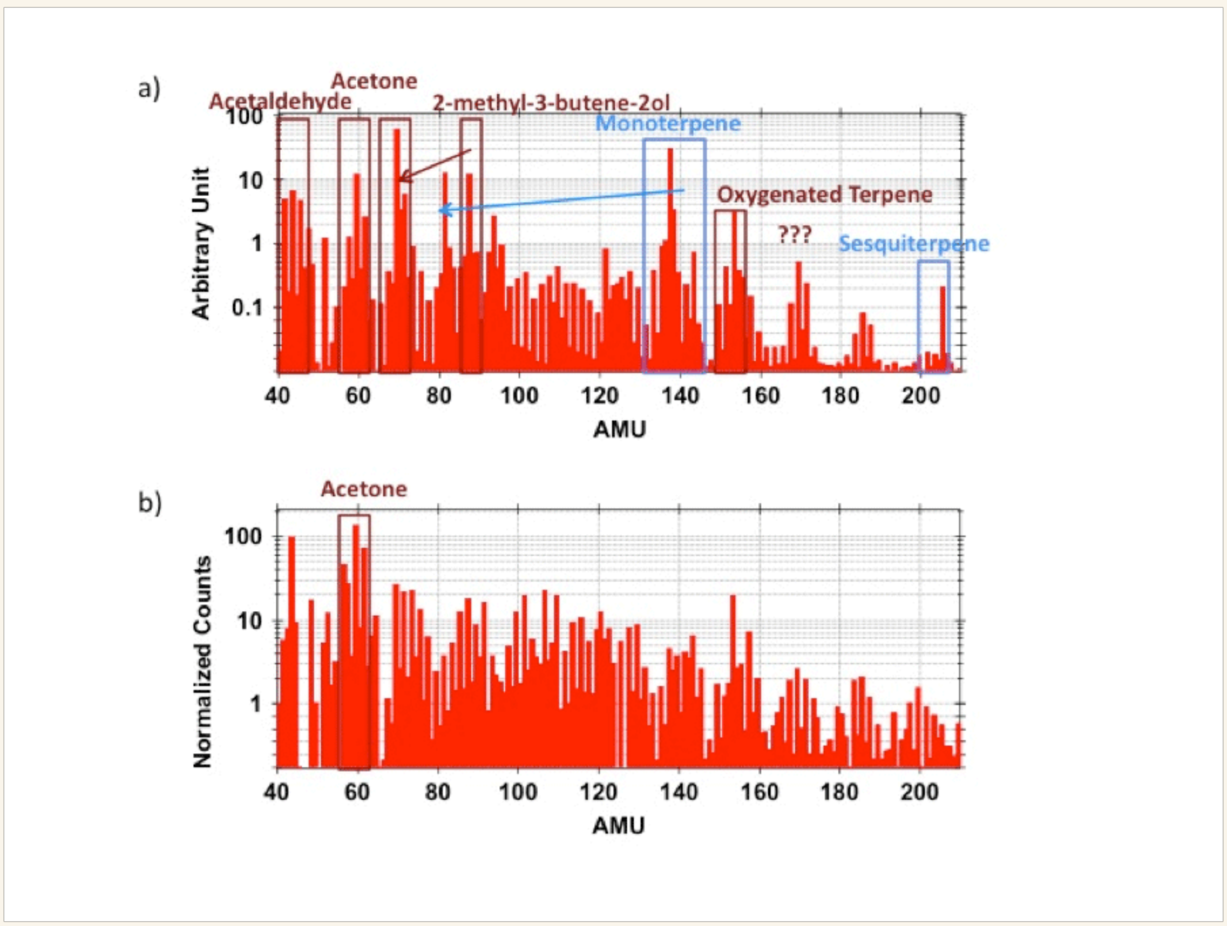

Figure 2. The proton-transfer-reaction mass spectrometry spectrum of a) branch enclosure measurement of Ponderosa Pine and b) ambient measurement

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Director's Message
Table of Contents
ASP Postdoctoral Fellowships
Strategic Goals: Science, Facilities & Technology
Research Catalog

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CECILE PIRET - INSTITUTE FOR MATHEMATICS APPLIED TO GEOSCIENCES

Cecile Piret joined NCAR as an ASP postdoctoral fellow in IMAGe in June 2008. Her research interests include numerical methods to solve partial differential equations (PDEs). In particular, she studies the radial basis functions (RBF) method. Since its introduction in the 1970s, the RBF method has proved to be a powerful tool for interpolating and more recently, has been used to solving PDEs. Its strengths lie not only in its inherent ability to handle scattered nodes, but also in its spectral accuracy, the unconditional non-singularity of the system to which it leads and in the remarkable simplicity of its algorithm in any number of dimensions. Cecile focuses her research in two very different facets of the RBF methodology. The first one, a continuation of her thesis work, is the research on the method itself, as a numerical technique. It is a young method about which many more aspects still need to be explored. The second is the application of the RBF method to geophysical problems, in particular, to the modeling of Tsunamis.

Publications since June 2008

J. Schmidt, C. Piret, N. Zhang, B. Kadlec, Y. Liu, D. Yuen, G. B. Wright, and E. Sevre, Modeling of Tsunami Equations and Atmospheric Swirling Flows with Graphics Accelerated Hardware (GPU) and Radial Basis Functions (RBF), to be submitted to Concurrency and Computation: Practice and Experience.

Conference papers and presentations since June 2008

J. Schmidt, C. Piret, B. Kadlec, D. Yuen, E. Sevre, N. Zhang, Y. Liu, Simulating tsunami Shallow-Water Equations with Graphics Accelerated Hardware (GPU) and Radial Basis Functions (RBF), in proceedings of the South China Sea Tsunami Workshop 2008, SCSTW 2008. Shanghai, China, December 2008.

C. Piret, "The Radial Basis Functions (RBF) Method applied to solving partial differential equations (PDEs) on the surface of the sphere." Earthquake Research Institute. Tokyo, Japan, October 2008

Collaborators

Natasha Flyer (IMAGe, NCAR, Boulder, CO)

Bengt Fornberg (University of Colorado, Boulder, CO)

David Yuen (University of Minnesota, MN)

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Director's Message

Table of Contents

ASP Postdoctoral Fellowships

Strategic Goals: Science, Facilities & Technology

Research Catalog

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ANDREA SEALY - CLIMATE AND GLOBAL DYNAMICS DIVISION

During the past year I have collaborated with Natalie Mahowald (formerly CGD/TIIMES, now faculty at Cornell University) to examine the interaction of vegetation dynamics with desert dust and Sahel precipitation using an atmospheric general circulation model. Our simulations were conducted with the National Center for Atmospheric Research (NCAR) Community Atmosphere Model (CAM3) with various configurations of model simulations to isolate factors such as dust radiative forcing, vegetation and sea surface temperature (SST). Our results suggest that for both observed and interactive SST, dust radiative forcing acts to reduce precipitation. However when dynamic vegetation is introduced, for interactive SST, the result is an increase in Sahel precipitation. Conversely, for observed SST cases, introducing dynamic vegetation results in an even further decrease in Sahel precipitation than using the model's default vegetation.

Natalie Mahowald and I have also collaborated in providing CAM3 simulations for the West African Monsoon Modeling and Evaluation (WAMME) initiative which uses general circulation models and regional climate models to address issues regarding the role of land-ocean-atmosphere interaction, land-use and water-use change, vegetation dynamics, as well as aerosol, particularly dust, on West African monsoon development.

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Director's Message

Table of Contents

ASP Postdoctoral Fellowships

Strategic Goals: Science, Facilities & Technology

Research Catalog

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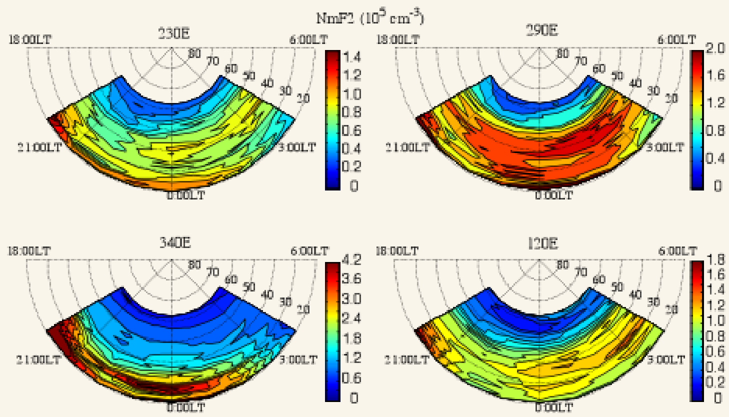
XIAOLI LUAN - HIGH ALTITUDE OBSERVATORY

Mid-latitude nighttime enhancement in F-region electron density from global COSMIC measurements under solar minimum winter condition

In collaboration with colleagues in HAO (Wenbin Wang, Alan Burns, Stanley C. Solomon and Jiuhou Lei), Xiaoli Luan carried out an analysis on the global geographic morphology of the ionospheric electron density enhancement during the night-time and was aimed to discussion the mechanisms that involved. The global observation of electron density profiles from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) provide a good opportunity to do this analysis over the whole globe as well as over wide altitudinal band. The Figure presents the peak electron density (NmF_2) of the ionospheric F2-layer during the night-time at different longitudinal regions. From the COSMIC observation, both the peak electron density of the F2-layer and the way of its enhancements during the night-time are found to be distinctly different among the majority of the longitudes (~45-245°E), the Atlantic Ocean sector, the eastern part of the North American sectors. Several mechanisms can cause these longitudinal variations, including the separation between the geographic and geomagnetic axes, the difference of the magnetic field intensity at different longitudes and also the longitudinal variation of the magnetic meridional winds.



F_2-layer peak density (NmF_2) during night at different longitudinal sectors: North America (230°E and 290°E), North Atlantic Ocean (340°E) and East Asia (120°E). Note different contour scales in each longitudinal sector.

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SEAN SWENSON - CLIMATE AND GLOBAL DYNAMICS DIVISION

My research in the past year has focused mainly on two subjects: model assessment and the application of remote sensing data to quantify the water balance of Lake Victoria. Soil moisture simulations from the latest version of the Community Land Model (CLM) were compared against a network of in situ observations from Illinois. The model mean state was too set and showed little depth dependence in variability relative to the observations; both of these factors are important in determining the partitioning of energy and moisture fluxes. In collaboration with Keith Oleson and Dave Lawrence, I performed numerous simulations to examine the interplay between forcing data, soil hydraulic properties, and model parameters. As a result of this work, we were able to gain an understanding of the causes of the model bias, and to adjust model parameterizations to give realistic simulations of soil moisture variability in this region. I presented these results to the Land Model Working Group at the June CCSM meeting in Breckenridge, and some of this research has been included in the current version of the Community Land Model that will be used to generate climate projections for the upcoming fifth IPCC.

The second research topic that I examined was the water balance of Lake Victoria. The relative roles of climate variability and human management in the decline of Lake Victoria's water levels in the mid-2000's has been the subject of considerable interest recently. I used satellite data to compare the response of Lake Victoria's groundwater and lake levels to other lakes in East Africa. These data indicated that human control of the lake level via dam operations was responsible for roughly half of the observed lake level decline. I also applied remote sensing data to the quantification of the fluxes and stores of the lake water budget, and used observations of downstream lake levels to infer discharge from Lake Victoria. The goal of this research was to provide publically available observations of the lake water balance based entirely on satellite data products for comparison to past estimates, as well as for future comparisons to examine the role of possible climate change. A manuscript describing this work was recently submitted to peer review.

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AMIT TELLER - RESEARCH APPLICATIONS LABORATORY

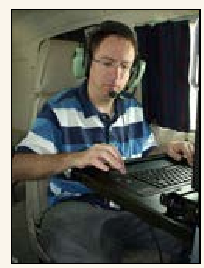
Amit Teller's research focuses on the interactions between clouds, aerosols and precipitation with special emphasis on the contribution of different types of aerosols from anthropogenic and natural sources to the development of precipitation. The research in this field is composed of in-situ airborne measurements to characterize the aerosol and the cloud particles' properties and the use of the data in detailed models that simulate the cloud dynamic and microphysical processes. During FY2008 Amit Teller was involved in cloud measurements and characterization projects as well as in cloud model studies aimed at interpreting the measurements. The following activities were the main portion of Amit Teller's work:

I. Improvements of the NCAR/RAL WRF bin microphysics scheme.

The WRF NCAR/RAL bin microphysics scheme is a powerful tool to simulate cloud microphysical processes using the bin approach. This means that the simulation accurately calculates the size and mass distributions for each of the different cloud species (water droplets, ice crystals, graupel particles and snow particles) for each grid point and time step. In previous versions of this scheme aerosols were transferred into droplets using simple parameterization in which the activation depends only on the supersaturation. In this project we applied a more sophisticated algorithm for converting aerosol to droplets by using Köhler theory so that aerosol size distributions and chemical compositions are considered. This tool can now be used to investigate the sensitivity of the cloud processes to different aerosol size distribution profiles and chemical compositions in mixed phase clouds.

This research has been carried out with collaboration of Lulin Xue and Zaitao Pan from St. Louis University and Istvan Geresdi from University of Pécs, Hungary. Other collaborators from NCAR are Roy Rasmussen and Greg Thompson from RAL.

II. Cloud and aerosol observations in Istanbul, Turkey and their analysis



An intensive field campaign aimed at characterization of cloud and aerosols in the area of Istanbul, Turkey has been carried out under the scientific support of NCAR between December 2007 and June 2008. A major component in this campaign has been a research aircraft that was equipped with different instruments for measuring aerosol and cloud droplets. Amit Teller was responsible for the preparation of the Operational Plan. He also served as flight scientist in 7 research flights and he is one of the lead authors of the project final report. A major contribution of Amit Teller to the report is a full characterization of 16 clouds. This work analyzes the aerosol measurements in the area of the cloud base and cloud penetrations that were carried out at different altitudes. In another chapter we used the observed data to initialize the WRF bin microphysics detailed cloud model in order to study what physical processes have the largest role in precipitation formation.

This research has been carried out with collaboration of Don Collins from Texas A&M University, and Peter Buseck from Arizona State University. Other NCAR collaborators are Roelof Bruintjes, Matt Pocernic, Sarah Tessendorf and Duncan Axisa from RAL.

III. Numerical modeling study on factors affecting precipitation from orographic clouds

Participants in the recent WMO Cloud Modeling Workshop (Cozumel, 2008) were asked to simulate different case studies and to present the results in the workshop. One of the suggested case studies was an Orographic Mixed-phase Stratiform Cloud. We run the case in our WRF bin microphysics scheme and presented the results in the workshop. Following the workshop it has been agreed to publish the results in a scientific paper that will include the contributions of the different research groups that worked on this particular case. This paper is planned to be submitted in the near future.

This research has been carried out with collaboration of Lulin Xue and Zaitao Pan from St. Louis University, Istvan Geresdi from University of Pécs, Hungary and Andreas Muhlbauer and Ulrike Lohmann from ETH, Zurich, Switzerland. Collaborators from NCAR are Roy Rasmussen and Greg Thompson from RAL

Conference proceedings and posters

Teller A., D. Axisa, R. Bruintjes, D. Collins, A. Mutlu, C. Kluzek, M. Pocernich, P. R. Buseck, E. Freney, S. Tessendorf, S. Hunter, O. Şen, K. Kocak, H. Toros, A. Köse, M. Tunc, Cloud and Aerosol Research in Istanbul Final Report 2007-2008, NCAR/RAL, 2008 (in review).

Teller A., and Z. Levin, On the relative effects of modifying aerosol loadings and thermodynamic conditions to precipitation from mixed-phase convective clouds, 15th International Conference on Clouds and Precipitation, Cancun, Mexico, July 2008.

Xue, L., **A. Teller**, C. Liu, R. Rasmussen, and Z. Pan, Development and sensitivity test of a new WRF microphysics scheme, 9th WRF Users' Workshop, Boulder, CO, June 2008.

Teller, A., D. Axisa, D. Breed, and R. Bruintjes, The effects of giant CCN and Ice Nuclei on clouds and precipitation: A case study from the Saudi Arabia program for the assessment of rainfall augmentation, 17th AMS/WMA Symposium on Planned & Inadvertent Weather Modification, Westminster, CO, April 2008.

Axisa, D., **A. Teller**, D. Breed, and D. R. Collins, Aerosol-cloud interactions over central Saudi Arabia, 17th AMS/WMA Symposium on Planned & Inadvertent Weather Modification, Westminster, CO, April 2008.

Axisa, D., V. Salazar, **A. Teller**, S. Hunter, M. Pocernich, A. Mutlu, C. Kluzek, D. Collins, R. Bruintjes, O. Sen, G. Antonietti, G. Walker, Aerosol and cloud microphysical measurements during PAPRICA (Precipitation augmentation program and research in Istanbul clouds and aerosols), International fourth symposium on atmospheric sciences (ATMOS 2008), Istanbul, Turkey, March 2008.

Presentations and seminars

The 7th World Meteorological Organization (WMO) International Cloud Modeling Workshop, Cozumel, Mexico, The use of detailed cloud models in cloud seeding research - A review, July 2008.

Technical University of Istanbul, Istanbul, Turkey, Department of Meteorological Engineering seminar, The effects of aerosols on mixed phase convective cloud processes and precipitation, 10 June 2008.

University of Wyoming, Laramie, WY, USA, Department of Atmospheric Science seminar, The effects of aerosols on mixed phase convective cloud processes and precipitation, 29 April 2008.

National Center for Atmospheric Research, Boulder, CO, USA, RAL seminar, The Effects of Aerosols on Clouds and Precipitation, 27 February 2008.

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Director's Message

Table of Contents

ASP Postdoctoral Fellowships

Strategic Goals: Science, Facilities & Technology

Research Catalog

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KNUT WAAGAN - HIGH ALTITUDE OBSERVATORY

Waagan (ASP postdoc at HAO) has worked on the numerical solution of ideal magnetohydrodynamics (MHD) equations, with special attention to solar and heliospheric applications. He has developed a highly robust second order numerical scheme, based on the use of an entropic Riemann solver and ensuring positive density and pressure. It is currently being implemented in the FLASH code. It is aimed to be part of a heliosphere model under development at HAO by M. Miesch, Y. Fan, S. Gibson and others. With colleagues at the University of Oslo (N.H. Risebro, S. Mishra, A. McMurry, F. Fuchs), he has studied the numerical modeling of stratified magnetoatmospheres. He is also working on compressible MHD turbulence simulations with FLASH in collaboration with C. Klingenberg and W. Schmidt at Würzburg University, and C. Federrath at Heidelberg University.

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NEDJELJKA ZAGAR - CLIMATE AND GLOBAL DYNAMICS DIVISION

Two main focuses of Nedjeljka's research in FY2008 were large-scale dynamics and data assimilation.

Together with her collaborators at CGD and IMAGE divisions she addressed the question about how large part of the atmospheric energy is associated with the inertio-gravity motions which are important part of the global circulation primarily because of their role in the tropical system. Four analysis systems have been employed: operational analyses of ECMWF and NCEP, the NCEP/NCAR reanalyses and the DART/CAM, an ensemble analysis system developed at NCAR (http://www.image.ucar.edu/DAReS). Such analysis fields are the main information source for understanding the atmospheric variability on time scales from days to decades. Furthermore, the reanalysis datasets are used to tune and validate climate models for their ability to reproduce the present day climate, and thus to provide some confidence about their simulated circulations into the future.

The methodology Nedjeljka developed to analyze the large-scale circulation is based on the three-dimensional normal-mode function (NMF) expansion. This enables both quantification of energy in each mode (defined by the zonal wave number k, meridional mode n and vertical eigenstructure m) and the representation of motions in terms of the balanced (ROT) and the inertio-gravity (IG) motions. Figure 1 presents the energy distribution among various motion types in DART/CAM analyses for July 2007. It shows that about 88% of the wave energy is in the balanced (ROT) motion and about 12% in the eastward- and westward-propagating (EIG and WIG, respectively) IG motions. About 1% of the wave energy in this system in July 2007 was associated with the mixed Rossby-gravity (MRG) waves and about 2.7% with the Kelvin wave (KW) motion, which is the most energetic among all IG waves.

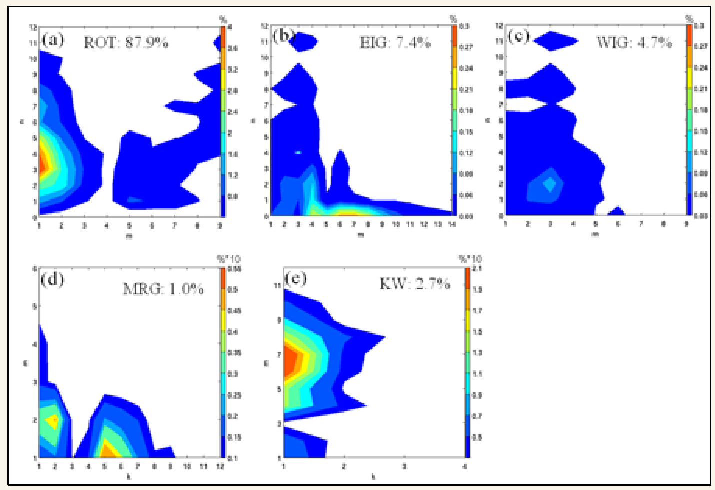

Figure 1
click for full size image

The time evolution of the Kelvin wave at two model levels in the operational anayses of ECMWF during July 2007 can be observed here.

The normal-mode expansion has also been employed by Nedjeljka to study the dynamics of the short-range forecast errors, an important issue for the data assimilation modeling. Questions asked are about the characteristic structures of the forecast errors in time and space. By comparing the error structures in the NMF space a relative contributions of the balanced and unbalanced modes to the error fields can be quantified. Another application of the NMFs is the diagnosis of the systematic tendencies of the analysis systems to place the observations into specific motions, usually identified as the analysis system bias.

During FY2008, Nedjeljka has given about 10 presentations, mainly invited, about her research.

Per-reviewed papers:

Zagar, N., A. Stoffelen, G.-J. Marseille, C. Accadia and P. Schluessel, 2008: Impact assessment of simulated Doppler wind lidars with a multivariate variational assimilation in the tropics. *Mon. Wea. Rev.*, 136, 2443-2460.

Vilibic, I., G. Beg Paklar, **N. Zagar** , H. Mihanovic, N. Supic, M. Zagar, N. Domijan, M. Pasaric, 2008: Summer breakout of trapped bottom dense water from the northern Adriatic. *JGR Oceans*, 113, doi:10.1029/2007JC004535.

Other publications:

Beg Paklar, G., **N. Zagar**, M. Zagar, R. Vellore, D. Koracin, P.-M. Poulain, M. Orlic, I. Vilibic, V. Dadic, 2008: Modeling the trajectories of satellite-tracked drifters in the Adriatic Sea during a summertime bora event. *JGR Oceans*, in print.

Zagar, N., J. Tribbia, J. Anderson and K. Raeder: Quantification of inertio-gravity energy in atmospheric analyses by using normal modes. Part I: Intercomparison of four analysis systems. Submitted to *Mon. Wea. Rev.*

Zagar, N., J. Tribbia, J. Anderson and K. Raeder: Quantification of inertio-gravity energy in atmospheric analyses by using normal modes. Part II: Large-scale equatorial waves. Submitted to *Mon. Wea. Rev.*

Stoffelen, A., J. de Kloe, G.-J. Marseille, K. Houchi, H. Koernich and **N. Zagar**, 2008: Scientific preparations for Aeolus and Aeolus follow-on. Proceedings of the 9th Annual Winds workshop. Annapolis, Maryland, 14-18 April 2008, 7 pages.

Zagar, N., J. Tribbia, J. L. Anderson and K. Raeder: Diagnosis of model biases by using DART. Poster presentation on the 13th Annual CCSM Workshop, Breckenridge, 17-19 June 2008.

Research Catalog

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RESEARCH CATALOG

- Kelley Barsanti
- Ramit Bhattacharyya
- Mercy Borbor-Cordova
- Simona Bordoni
- Rebecca Centeno-Elliott
- Wiebke Deierling
- Mark Flanner
- Jacob Fugal
- Mary Hayden
- Åse-Marit Janse
- Song-Lak Kang
- Saewung Kim
- Cecile Piret
- Andrea Sealy
- Xiaoli Luan
- Sean Swenson
- Amit Teller
- Simone Tilmes
- Knut Waagan
- Nedjeljka Zagar

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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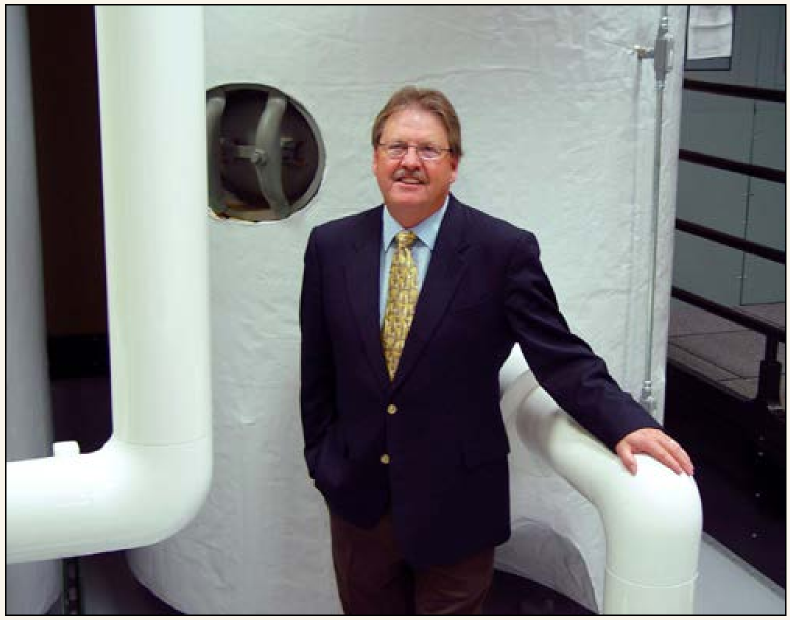
Message from CISL Director Al Kellie


Al Kellie by the liquid coolant reservoir for the 650-KW supercomputer bluefire.

Welcome to CISL's FY2008 Annual Report. CISL integrates world-class high performance computing with research and development and applied mathematics to extend the reach of the atmospheric and related sciences community. CISL aligns itself with the overarching priorities of the NSF Strategic Plan and Cyberinfrastructure (CI) Vision and with the NCAR Strategic Plan. Each section of this report describes a CISL project, specifies the strategic goals and priorities it supports, then lists all of its funding sources.

FY2008 has been a year of growth and achievement for CISL, but it also marks a turning point in our approach to our upcoming challenges. Scientific needs are demanding petascale computing resources, and the technology to provide them is arriving now. Large additional investments and developments in facilities, tools, problem-solving environments, education, applied math and statistics, numerical methods, and computer science are all required to produce new discoveries and fulfill the promise of science at the petascale. In FY2008, CISL began refocusing its efforts to facilitate and speed this transition.

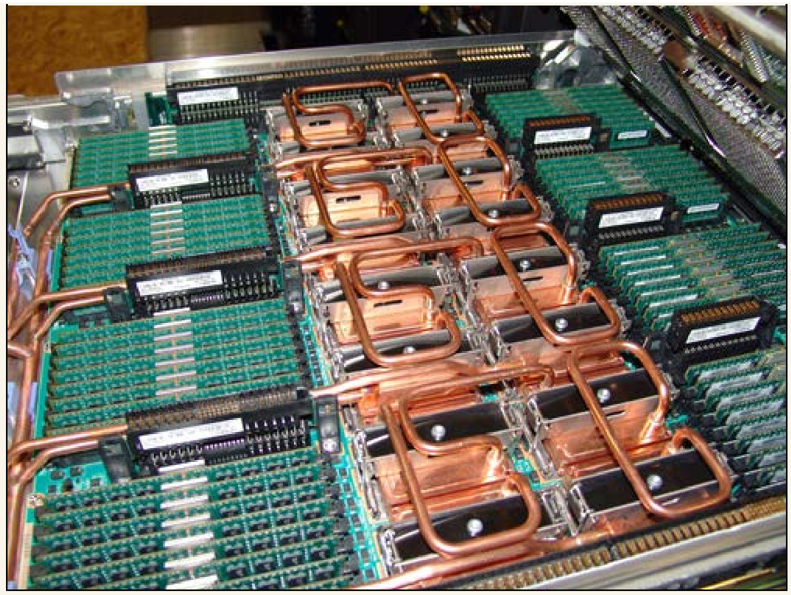
In alignment with NCAR's strategic plan, CISL is advancing into the petascale era on three fronts: facilities, science, and education.

- Facility designs and infrastructure deployments need to provide the computation, storage, and connectivity necessary for a secure, Grid-enabled center that will grow to meet rapidly increasing demands.
- Research throughout CISL, especially in its math institute and computational science efforts, aims to provide the geosciences and related communities with mathematical and statistical tools and the numerical methods necessary to solve petascale science challenges.
- Education for the next generation of U.S. scientists and engineers who will use and develop petascale systems continues to be a high priority for CISL.

Our work to advance the goals of 21st-century computational geoscience research is supported by our diverse and talented staff, and is continually informed by fresh input from our collaborators, users, and panels of community advisors.

Developments in facilities and cyberinfrastructure

This annual report describes our top achievements and near-term plans for facilities and cyberinfrastructure in three sections: increasing the capability and capacity of NCAR's supercomputing facilities; procuring, deploying, and operating NCAR's hardware cyberinfrastructure; and developing software cyberinfrastructure to create problem-solving environments. Highlights for FY2008 include developing the NCAR Supercomputing Center with Wyoming partners, deploying the bluefire supercomputer, serving our first full year as



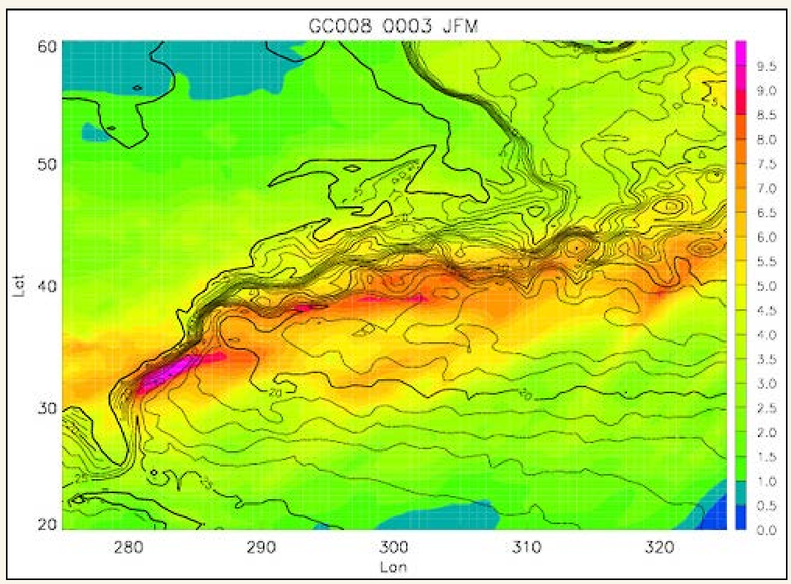
Each node in bluefire contains thirty-two 4.7-GHz processors that require liquid coolant carried by copper tubes to heat sinks mounted over the processors.

a TeraGrid resource provider, and partnering with NCAR's Advanced Study Program for training graduate students, model developers, and scientists to analyze atmospheric dynamical cores being considered for next-generation models.

Our top accomplishments also include procuring a next-generation mass storage archive, strengthening NCAR's data stewardship role, using ESMF for the TeraGrid Build Test Environment, producing a new Science Gateway Framework, deploying a new TIGGE portal for international data archive and access, and continuing to update the VAPOR and NCL visualization tools.

I invite you to read about all of our work in these areas in the supercomputing facilities, hardware cyberinfrastructure, and software cyberinfrastructure sections of this report.

CISL progress in science and research



The CCSM simulation that produced this image proves that current supercomputers can simulate the Earth System at resolutions 100 times as computationally demanding as the production CCSM. This work shows that upcoming petascale systems will be able to resolve important physical processes that have to be parameterized now.

Descriptions of our primary research accomplishments and plans appear in the section "Research in computational science and math for geophysics: TDD and IMAGe" and in the CISL research catalog. Directed by CISL's Technology Development Division (TDD) and its Institute for Mathematics Applied to Geosciences (IMAGe), our contributions support scientific computation, numerical methods, geophysical modeling, and the analysis of geophysical data and model experiments. The top highlight for FY2008 was the successful integration of HOMME's spectral element dynamical core with almost every physics algorithm in the Community Atmosphere Model. When it ran on a 57,600-processor computer, this prototype model simulated a little-understood feature of the atmosphere's kinetic energy spectrum with unprecedented fidelity.

Our top science and research advances also include continuous improvements in data assimilation and statistical methods for summarizing and interpreting complex model output. Ongoing work in numerical methods for improving geophysical models is progressing in GASPAR, GHOST, CAM-HOMME, RBFs, and adaptive mesh refinement. The evolution of our ability to simulate multiscale processes continues in the areas of magnetohydrodynamics, helical flows, planetary boundary layer processes, and multiresolution statistical models. And of extreme value to the future of geophysical modeling, we continue advancing the computational science technologies needed for simulation at the petascale.

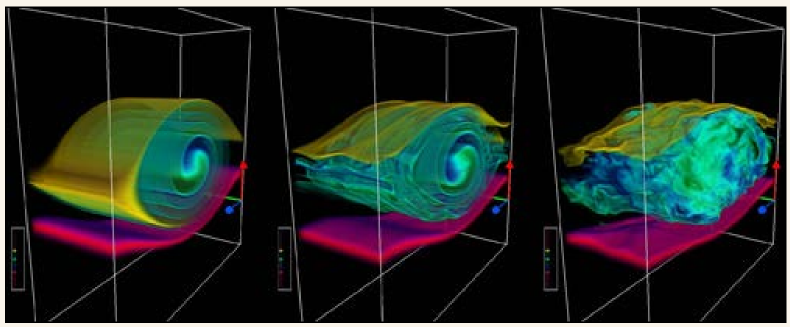
Please read about all of our FY2008 work in these areas in the research and Research catalog sections of this report.

Education initiatives

A high priority for CISL is our work to prepare the next generation of U.S. scientists and engineers for the challenges of scientific computing in the 21st century. We operate several recurring programs, conduct summer schools, support NCAR and UCAR education efforts, and collaborate with other institutions to help satisfy this critical need. CISL's FY2008 education highlight was co-hosting the NCAR Advanced Study Program (ASP) colloquium entitled Numerical Techniques for Global Atmospheric Models. Jointly supported by NSF, NASA, and DOE, this event immersed 38 students, 13 modeling mentors, 18 lecturers, and 4 organizers in weeks of intensive work that produced significant benefits for both the attendees and the atmospheric research community.

Some of the participants in NCAR's 1-13 June 2008 ASP Colloquium. Participants performed hundreds of test runs to analyze 13 dynamical cores for atmospheric models, yielding insights into the advantages and disadvantages of each core. The results from the workshop are available to the research community via a new science gateway developed collaboratively by the Earth System Curator and Earth System Grid projects in CISL. This work was supported by NCAR's Cyberinfrastructure Strategic Initiative, which is developing a Science Gateway Framework that can be used to build a variety of custom portals.

CISL initiated and operates several education and outreach programs. SIParCS offers 10-12-week internships for exceptional students to gain practical experience with a wide variety of parallel computational science problems by working with the HPC systems and applications related to NCAR's Earth System science mission. The IMAGe Theme of the Year (TOY) assembles multidisciplinary teams of young geoscientists and applied mathematicians to immerse them in the challenges of the geosciences' large computational problems. Each year, CISL provides multiple trainings in NCL data analysis and visualization both here in Boulder and internationally. And weekly, CISL's Visualization Laboratory uses collaborative technologies and stereo 3D scientific visualizations to demonstrate NCAR science to visitors and colleagues.



Renderings of a 3D Kelvin-Helmholtz instability using the VAPOR visualization and analysis platform. This image was created by students participating in the IMAGe Theme-of-the-Year 2008 Summer School on Geophysical Turbulence. Students of the summer school received hands-on experience performing the end-to-end processes of numerical simulation, visualization, and analysis using state-of-the-art resources.

I invite you to read more about CISL's educational programs in the education and outreach section of this report.

CISL's priorities for FY2009

Our plans for the future are organized by our three paths into the era of petascale science: facilities and infrastructure, science and research, and education of the future workforce. Specifically, we will:

- Establish new ways to exploit massively parallel computing systems
- Provide robust, reliable, secure supercomputers for the geosciences
- Develop NCAR's Grid cyberinfrastructure capabilities
- Develop NCAR's software cyberinfrastructure
- Continue developing the NCAR Supercomputing Center in Wyoming
- Strengthen NCAR's research data stewardship role
- Continue to expand the TIGGE international data archive and access system
- Expand numerical methods for improving geophysical models
- Enhance data assimilation methods
- Improve techniques for simulating multiscale processes
- Continue upgrading the VAPOR and NCL visualization tools
- Enhance the SIParCS and TOY internship programs
- Modernize the Visualization Lab to help NCAR tell its story
- Continue training users in scientific data analysis and visualization

CISL provides levels of support for science that are without peer anywhere in the country. Our ongoing goal is to provide a balanced computing environment that supports our traditional base of atmospheric sciences researchers and integrates with the larger geosciences community via distributed facilities such as the TeraGrid.

As we look to the future, we continually adapt ourselves and our organization to maximize our contribution to understanding the complexities of the Earth System. As you read this report, I hope you share our sense of expectation for significant progress in the future.

I invite you to review our accomplishments and plans in the FY2008 CISL Annual Report.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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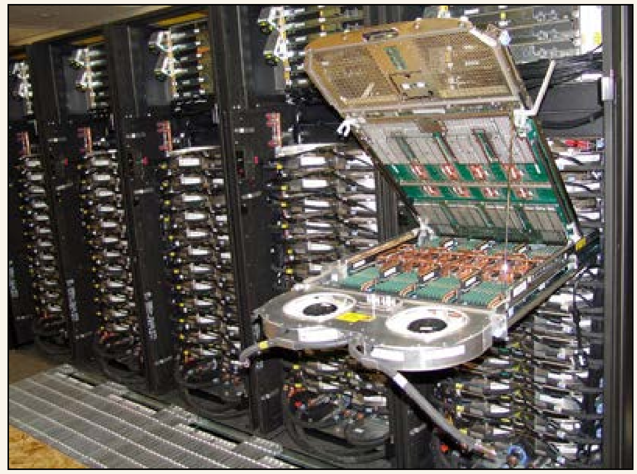
Reintroduction of liquid cooling for high performance computing



A closed loop carries liquid coolant from a heat exchanger in the bottom of each cabinet to heat sinks over the processors. The heat exchanger regulates the fluid temperature, keeping it low enough to cool the chips yet warm enough to avoid condensation inside the system. A separate chilled-water loop connects the heat exchangers in each cabinet with a large reservoir that is cooled by the computer facility's chilled-water system.

With the installation of the IBM Power 575 computer bluefire in FY2008, CISL re-embraced the technology of liquid-cooled supercomputer processors. One decade ago, the last liquid-cooled Cray system was decommissioned and removed from the Mesa Lab computing facility. During FY2008, CISL staff and members of UCAR Physical Plant Services planned and installed water cooling infrastructure to cool bluefire, the second phase of the ICESS procurement.

Liquid cooling was reintroduced because increases in the density and speed of supercomputing processors produce too much heat for air cooling to remove from the cabinets. The IBM POWER systems (Power Optimization With Enhanced RISC) began with air cooling and are now actively using liquid (in our case, water) cooling both at the surface of the processors and for heat capture at the back of each cabinet. The POWER3, POWER4, and POWER5 systems blackforest, bluesky, and bluevista were completely air cooled. In 1999, IBM's POWER3 processors in blackforest operated at 0.375 GHz; in 2002, POWER4 processors at NCAR ran at 1.3 GHz; and in 2005, bluevista's POWER5 processors ran at 1.9 GHz. In 2008, the POWER6 processors in the water-cooled system bluefire are running at 4.7 GHz. At full load, the bluefire system draws 65 KW of electricity.

Water cooling is significantly more efficient than air cooling, and it is identified as a state-of-the-art practice by EPA guidelines for data centers. In addition to air cooling, the bluefire system uses two liquid-cooling technologies. One system directs hot air expelled from the back of the computer across a large coolant coil built into the rear door of each computer cabinet; this captures nearly 60% of the waste heat before it enters the air in the computer room.

The second system uses a liquid-to-liquid heat exchanger in the bottom of each cabinet to regulate the temperature at the surface of each of the 384 processors using a 3,000-gallon chilled-water reservoir nearby. One closed loop carries chilled water between the reservoir and the heat exchangers, and another closed loop distributes coolant from the heat exchangers to the processors.

While liquid cooling is much more efficient than air cooling, water inside the supercomputer room -- and inside the supercomputer itself -- presents challenges. Clearly, top-quality installations must be followed because the risk of leaks must be rigorously controlled. NCAR's in-house mechanical and electrical facilities staff distinguished themselves during their expert installation of these complex new systems.

One additional risk is introduced with this technology specifically because it is so efficient. If one of the two water chillers fails, the coolant temperature can rise so rapidly that the computers may overheat in the three minutes required for the redundant chiller to come on line. The thermal mass of the water in the 3,000-gallon reservoir slows the rise of the coolant temperature, giving the backup chiller and CISL staff time to react before the computers are compromised. The concept of thermal storage is analogous to Uninterruptible Power Supplies (UPS) for electrical systems. For mechanical systems, a reservoir of water, ice, or other liquid is stored in the system and works just like the batteries in a UPS system.

In FY2009, the liquid cooling facility will be maintained to continue serving the production computing needs of bluefire. No additional liquid-cooling requirements will be added to NCAR's computing facility during the next fiscal year.

In this installation photo, two 1,500-gallon chilled-water tanks (background) are located near bluefire (to the left of the open floor panels). To mitigate condensation, a worker insulates the incoming chilled-water pipes from the reservoir and the outgoing warm-water pipes from bluefire. This chilled-water system terminates at heat exchangers in the bottom of each cabinet. A separate liquid cooling loop regulates the internal temperature inside each of bluefire's 11 cabinets.

This advancement in computing facility technology fulfills NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools," and the related strategic priority of "Enhancing capability and capacity of NCAR supercomputing." This work is supported by NSF Core funding.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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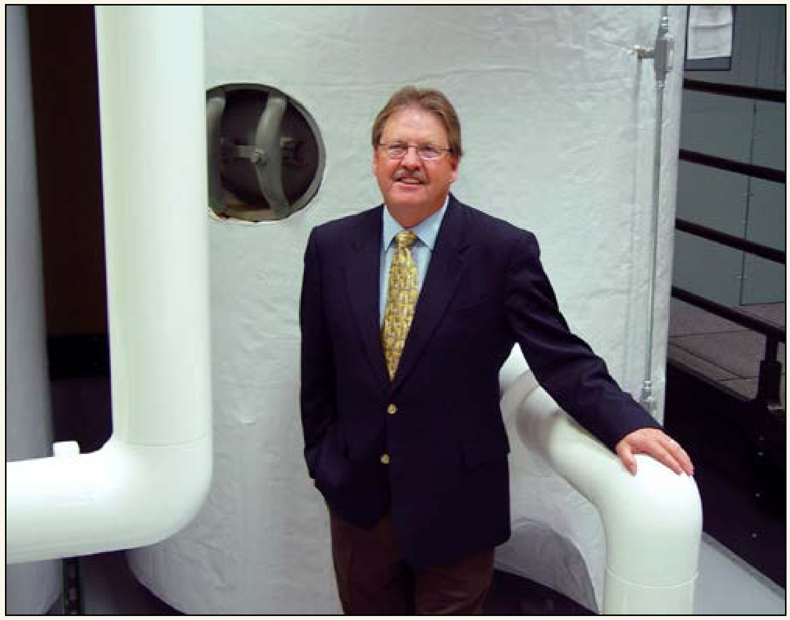

Al Kellie by the liquid coolant reservoir for the 650-KW supercomputer bluefire.

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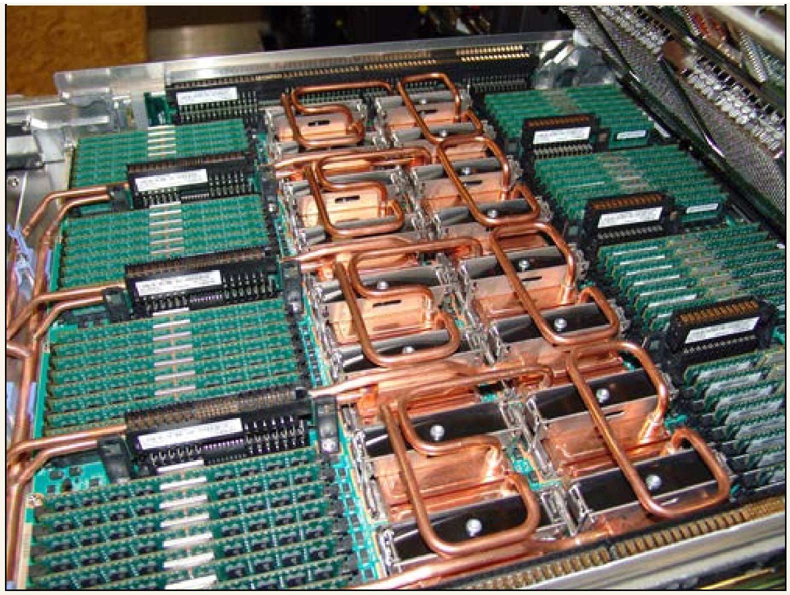


Each node in bluefire contains thirty-two 4.7-GHz processors that require liquid coolant carried by copper tubes to heat sinks mounted over the processors.

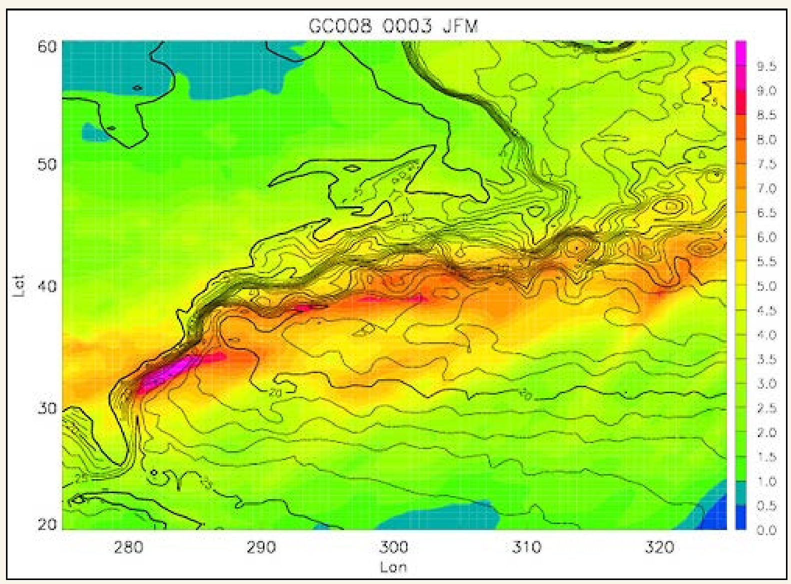
a TeraGrid resource provider, and partnering with NCAR's Advanced Study Program for training graduate students, model developers, and scientists to analyze atmospheric dynamical cores being considered for next-generation models.

Our top accomplishments also include procuring a next-generation mass storage archive, strengthening NCAR's data stewardship role, using ESMF for the TeraGrid Build Test Environment, producing a new Science Gateway Framework, deploying a new TIGGE portal for international data archive and access, and continuing to update the VAPOR and NCL visualization tools.

I invite you to read about all of our work in these areas in the supercomputing facilities, hardware cyberinfrastructure, and software cyberinfrastructure sections of this report.

CISL progress in science and research

Descriptions of our primary research accomplishments and plans appear in the section "Research in computational science and math for geophysics: TDD and IMAGe" and in the CISL research catalog. Directed by CISL's Technology Development Division (TDD) and its Institute for Mathematics Applied to Geosciences (IMAGe), our contributions support scientific computation, numerical methods, geophysical modeling, and the analysis of geophysical data and model experiments. The top highlight for FY2008 was the successful integration of HOMME's spectral element dynamical core with almost every physics algorithm in the Community Atmosphere Model. When it ran on a 57,600-processor computer, this prototype model simulated a little-understood feature of the atmosphere's kinetic energy spectrum with unprecedented fidelity.



The CCSM simulation that produced this image proves that current supercomputers can simulate the Earth System at resolutions 100 times as computationally demanding as the production CCSM. This work shows that upcoming petascale systems will be able to resolve important physical processes that have to be parameterized now.

Our top science and research advances also include continuous improvements in data assimilation and statistical methods for summarizing and interpreting complex model output. Ongoing work in numerical methods for improving geophysical models is progressing in GASPAR, GHOST, CAM-HOMME, RBFs, and adaptive mesh refinement. The evolution of our ability to simulate multiscale processes continues in the areas of magnetohydrodynamics, helical flows, planetary boundary layer processes, and multiresolution statistical models. And of extreme value to the future of geophysical modeling, we continue advancing the computational science technologies needed for simulation at the petascale.

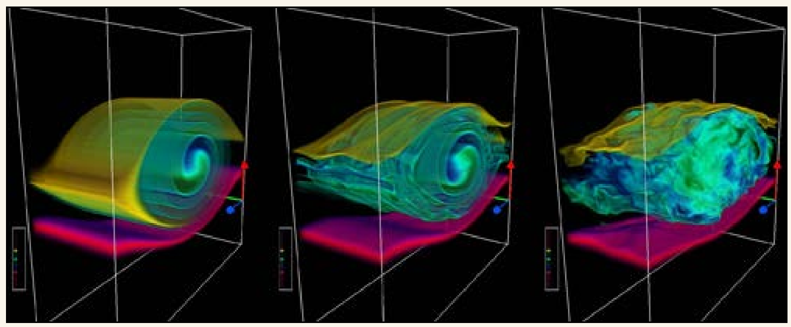
Please read about all of our FY2008 work in these areas in the research and Research catalog sections of this report.

Education initiatives

A high priority for CISL is our work to prepare the next generation of U.S. scientists and engineers for the challenges of scientific computing in the 21st century. We operate several recurring programs, conduct summer schools, support NCAR and UCAR education efforts, and collaborate with other institutions to help satisfy this critical need. CISL's FY2008 education highlight was co-hosting the NCAR Advanced Study Program (ASP) colloquium entitled Numerical Techniques for Global Atmospheric Models. Jointly supported by NSF, NASA, and DOE, this event immersed 38 students, 13 modeling mentors, 18 lecturers, and 4 organizers in weeks of intensive work that produced significant benefits for both the attendees and the atmospheric research community.

Some of the participants in NCAR's 1-13 June 2008 ASP Colloquium. Participants performed hundreds of test runs to analyze 13 dynamical cores for atmospheric models, yielding insights into the advantages and disadvantages of each core. The results from the workshop are available to the research community via a new science gateway developed collaboratively by the Earth System Curator and Earth System Grid projects in CISL. This work was supported by NCAR's Cyberinfrastructure Strategic Initiative, which is developing a Science Gateway Framework that can be used to build a variety of custom portals.

CISL initiated and operates several education and outreach programs. SIParCS offers 10-12-week internships for exceptional students to gain practical experience with a wide variety of parallel computational science problems by working with the HPC systems and applications related to NCAR's Earth System science mission. The IMAGe Theme of the Year (TOY) assembles multidisciplinary teams of young geoscientists and applied mathematicians to immerse them in the challenges of the geosciences' large computational problems. Each year, CISL provides multiple trainings in NCL data analysis and visualization both here in Boulder and internationally. And weekly, CISL's Visualization Laboratory uses collaborative technologies and stereo 3D scientific visualizations to demonstrate NCAR science to visitors and colleagues.



Renderings of a 3D Kelvin-Helmholtz instability using the VAPOR visualization and analysis platform. This image was created by students participating in the IMAGe Theme-of-the-Year 2008 Summer School on Geophysical Turbulence. Students of the summer school received hands-on experience performing the end-to-end processes of numerical simulation, visualization, and analysis using state-of-the-art resources.

I invite you to read more about CISL's educational programs in the education and outreach section of this report.

CISL's priorities for FY2009

Our plans for the future are organized by our three paths into the era of petascale science: facilities and infrastructure, science and research, and education of the future workforce. Specifically, we will:

- Establish new ways to exploit massively parallel computing systems
- Provide robust, reliable, secure supercomputers for the geosciences
- Develop NCAR's Grid cyberinfrastructure capabilities
- Develop NCAR's software cyberinfrastructure
- Continue developing the NCAR Supercomputing Center in Wyoming
- Strengthen NCAR's research data stewardship role
- Continue to expand the TIGGE international data archive and access system
- Expand numerical methods for improving geophysical models
- Enhance data assimilation methods
- Improve techniques for simulating multiscale processes
- Continue upgrading the VAPOR and NCL visualization tools
- Enhance the SIParCS and TOY internship programs
- Modernize the Visualization Lab to help NCAR tell its story
- Continue training users in scientific data analysis and visualization

CISL provides levels of support for science that are without peer anywhere in the country. Our ongoing goal is to provide a balanced computing environment that supports our traditional base of atmospheric sciences researchers and integrates with the larger geosciences community via distributed facilities such as the TeraGrid.

As we look to the future, we continually adapt ourselves and our organization to maximize our contribution to understanding the complexities of the Earth System. As you read this report, I hope you share our sense of expectation for significant progress in the future.

I invite you to review our accomplishments and plans in the FY2008 CISL Annual Report.

Director's Message

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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Table of Contents

The Earth System Curator

Research Data Archive

Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Research (VAPOR)

The North American Regional Climate Change Assessment Program

Bringing new functionality to data visualization using Google Earth

Chronopolis: Federated digital preservation across space and time

Community tools and frameworks for geoscientific analysis and visualization

Followup reports on FY2007 Earth System Knowledge Environment plans that are not featured this year:

CISL Portal (was SCD portal)

Grid-BGC

Strategic priority: Cultivating a scientifically engaged citizenry: Education and outreach

Supporting projects:

Summer Internships in Parallel Computational Science program

IMAGe Theme of the Year education and outreach

Vislab outreach program

Training in geoscientific tools

Conference outreach

Security administrators training

Research catalog

Fournier, Aimé. Analyses and applications of three spatial discretization methods

Mininni, Pablo. GHOST Development

Pouquet, Annick. Exploiting the symmetries of the Taylor-Green (TG) flow in the case of coupling to a magnetic field

Pouquet, Annick. MHD turbulence at high Reynolds number

Pouquet, Annick. Modeling of turbulent flows with magnetic fields

Pouquet, Annick. Rotating flows, waves, eddies and helicity

Pouquet, Annick. IMAGe Theme-of-the-Year 2008

Rosenberg, Duane. GASpAR Development

Rosenberg, Duane. Symposium on Turbulence and Dynamos at Petaspeed

St.Cyr, Amik. Multiscale techniques

St.Cyr, Amik. Scalable preconditioning techniques

Visiting collaborator reports:

Brachet, Marc

Cossette, Jean-Francois

Finnigan, John

Jarecka, Dorota

Jonker, H.

Ortiz, Pablo

Piotrowski, Zbigniew

Wang, Lian-Ping

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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Advancing NCAR's strategic goals

NCAR's January 2006 Strategic Plan, *NCAR as an Integrator, Innovator and Community Builder*, outlines five strategic goals and the priorities for achieving each. CISL supports NCAR's mission, vision, values, goals, and priorities by:

- Provisioning hardware, software, and grid cyberinfrastructure in a robust supercomputing facility
- Conducting research in mathematics, statistics, and computational science that targets significant improvements in geosciences simulation
- Developing, funding, and conducting education initiatives to prepare the next generation of U.S. scientists and engineers for the era of petascale supercomputing

Individual projects in CISL's FY2008 Annual Report support many of the goals and priorities in NCAR's strategic plan. CISL's overall efforts focus primarily on NCAR's strategic goals to 1) Provide robust, accessible, and innovative information services and tools and 2) Cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce.

Each section of this report specifies which of the NCAR strategic goals and priorities are supported by the work described in that section. For example, the multi-year project of integrating the Community Atmosphere Model (CAM) with a dynamical core in CISL's High-Order Method Modeling Environment (HOMME), HOMME-CAM integration using HOMME's spectral-element dynamical core, supports NCAR's strategic plan on multiple levels:

- Efforts to accurately simulate observed processes in Earth's atmosphere support NCAR's mission "To understand the behavior of the atmospheric and related systems and the global environment."
- The HOMME project supports NCAR's strategic goal of "Developing community models for weather, climate, atmospheric chemistry, and solar-terrestrial research."
- HOMME also advances NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment."

In general, our FY2008 Annual Report is organized to demonstrate how CISL projects support NCAR's strategic plan:

NCAR Strategic Goal 4: Provide robust, accessible, and innovative information services and tools

> NCAR Strategic Priority: Enhancing capability and capacity of NCAR supercomputing
>
> NCAR Strategic Priority: Developing and providing advanced services and tools
>
> NCAR Strategic Priority: Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D
>
> NCAR Strategic Priority: Creating an Earth system knowledge environment

NCAR Strategic Goal 3: Cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce

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Production deployment of bluefire supercomputer

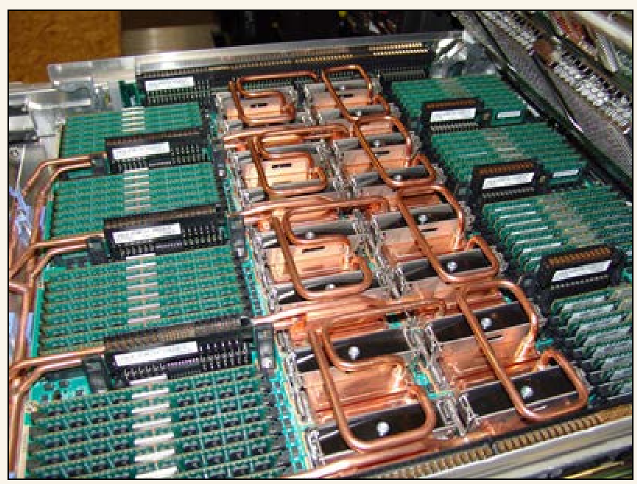
On April 24, 2008, NCAR took delivery of an IBM Power 575 Hydro-Cluster supercomputer, the first in a highly energy-efficient class of machines to be shipped anywhere in the world. The system, named bluefire, has 4,064 POWER6 processors, a peak computation rate of over 76 teraflops, and consists of 11 cabinets each weighing 3,200 pounds. Bluefire is over three times more powerful, and based on floating-point-operations per Watt, is three times more energy efficient than the supercomputers it replaced, bluevista and blueice. For historical reference, it is over a million times more powerful than the first recognized supercomputer, the Cray 1-A, that NCAR used from 1977-1986.

During FY2008 NCAR took delivery of the first IBM Power 575 Hydro-Cluster supercomputer ever installed, continuing a 30-year tradition of providing a sustainable high performance computing environment to the atmospheric sciences community. The bluefire system is based on the world's fastest microprocessor, the IBM POWER6 dual-core chip with a 4.7 GHz clock speed. In June 2008 bluefire was ranked as the 30th most powerful computer in the world by the Top500 project.

Impact on science

Scientists at NCAR and across the country will use bluefire to accelerate research into climate change, including future patterns of precipitation and drought around the world, changes to agriculture and growing seasons, and the complex influence of global warming on hurricanes. Researchers also will use it to improve weather forecasting models so society can better anticipate where and when dangerous storms may develop or hurricanes may strike. The system will also allow scientists to study in unprecedented detail the relationship between solar processes and weather on Earth, gain a deeper understanding of turbulence, and develop and refine models that simulate many of the processes responsible for elements of the Earth climate system.

During the first quarter of FY2009, several projects have the opportunity to study challenging problems by participating in the Accelerated Scientific Discovery program on bluefire, where large amounts of capability computing resources will be dedicated to a few users. Specifically, projects include nested regional climate modeling, the effect of anthropogenically forced radiative forcing on convective storms, the role of eddies in ocean circulation variability, the effect of the corona on the Earth's magnetosphere and ionosphere, and a study of the winter precipitation, snowpack, and runoff from Colorado's headwater basins using a high-resolution model.



Chilled-water heat sinks cover the 16 POWER6 chips in one node of the bluefire cluster. Within 11 cabinets, each weighing 3,600 pounds, bluefire contains 128 such nodes. The unique liquid cooling system, where chilled water is carried by copper tubes directly to the chips, is 33% more energy efficient than air cooling.

Researchers will rely on bluefire to generate the climate simulations necessary for the next report on global warming by the Intergovernmental Panel on Climate Change (IPCC), which conducts detailed assessments under the auspices of the United Nations. The IPCC was a recipient of the 2007 Nobel Peace Prize.

The most powerful microprocessor available

Bluefire houses the new POWER6 processor, the world's fastest microprocessor with a clock speed of 4.7 GHz. The system consists of 4,064 processors, 12 terabytes of memory, and 150 terabytes of FAStT DS4800 disk storage.

Within the landscape of high-performance computing technology, bluefire is on the leading edge. Bluefire is the

This installation photo of the chilled-water reservoir shows two 1,500-gallon storage tanks connected in series by copper pipes (before the pipes were insulated to prevent condensation in the computer room). Chilled water from the tanks is used to prevent bluefire from overheating in the event of a power outage that could momentarily disrupt the supply of chilled water.

second phase of a system called the Integrated Computing Environment for Scientific Simulation (ICESS) at NCAR. After undergoing acceptance testing during June 2008, it began full-scale operations in August 2008, and will provide supercomputing support for researchers at NCAR and other organizations through 2011.

Return to liquid-cooled hardware

Bluefire relies on a unique, water-based cooling system that is 33 percent more energy efficient than traditional air-cooled systems. Heat is removed from the electronics by water-chilled copper plates mounted in direct contact with each POWER6 microprocessor chip. As a result of this water-cooled system and POWER6 efficiencies, bluefire is three times more energy efficient per rack than its predecessor.

It was a significant challenge to the NCAR facilities engineering staff to prepare the Mesa Laboratory computer room for bluefire. Because bluefire was the first IBM Hydro-Cluster installed in the field, nearly everything about its installation is innovative. The chilled water required to provide cooling for bluefire had to be obtained (tapped) from the existing, dual 450-ton water chillers. In addition, to mitigate the impact of a power outage where NCAR's water chillers would fail over to the twin backup system, two 1,500-gallon chilled water storage tanks were installed in the NCAR machine room. The first technical specifications from IBM were obtained in August 2007, and the work was completed by April 2008. Numerous technical challenges were overcome on this project including dynamic scope changes from IBM, discovery of insufficient facility capabilities, and new fabrication techniques. All challenges were overcome and the project was completed on time and within budget.

Supporting NCAR's strategic plan

The ICESS project in general and bluefire in particular advance NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools" and NCAR's strategic priority of "Enhancing capability and capacity of NCAR supercomputing." Notably, bluefire expands and extends the CISL-developed on-demand capability computing model that enables the entire cluster or portions of it to support dedicated or shared special computing campaigns, such as the Accelerated Scientific Discovery campaign or this year's High Resolution Hurricane Simulation Special Computing Campaign.

This project is made possible through NSF Core funds, including CSL funding.

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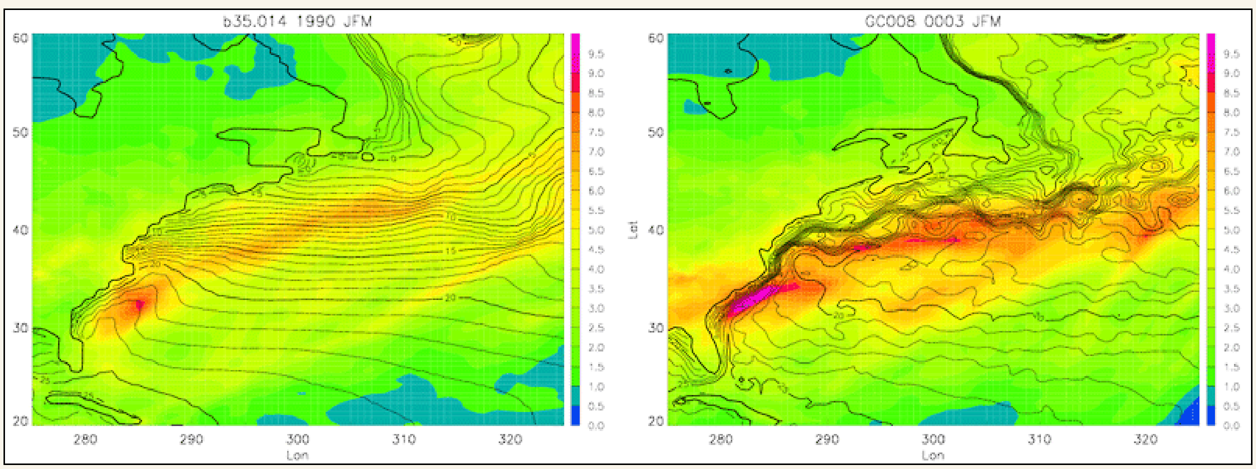
Ultra-high-resolution CCSM

Over the last several years we have made concerted efforts to significantly improve the scalability of the various components of the upcoming Community Climate System Model (CCSM4). We initially modified the Parallel Ocean Program (POP) to improve its efficiency at 0.1° resolution on large processor counts. We next improved the simulation rate of the Community Ice CodE (CICE) at 0.1° on large processor counts. In collaboration with the Climate and Global Dynamics (CGD) division, the CCSM coupler was significantly redesigned to increase the flexibility of the coupling architecture. These improvements to the coupler, along with scalability enhancements to component models, enable CCSM4 to execute efficiently at high resolution on systems with large numbers of processors.

Our attention to the scalability of the entire CCSM system has enabled the first-ever coupling within the U.S. of an eddy-resolving ocean and sea ice model at 0.1° to an ultra-high resolution atmospheric model and land model at both 0.5° and 0.25°. Using a grant through the Lawrence Livermore National Laboratory Institutional Grand Challenge program, we have competed 2.5 years of a fully coupled simulation using 0.5° atmosphere, and 2 years of a fully coupled simulation using a 0.25° atmosphere.



The winter season precipitation rate (mm/day) in the North Atlantic from CCSM using 0.5° atmosphere and land models coupled to a 1° (left panel) and a 0.1° (right panel) ocean and sea ice model. The more realistic representation of the Gulf Stream in the 0.1° Parallel Ocean Program (POP) causes the atmospheric winter storms to become stronger and track along the Gulf Stream well offshore versus the lower-resolution model where the maximum precipitation area is confined closer to the coast.

Our discovery is significant because it demonstrates that it is possible to simulate the Earth System on currently available supercomputer resources at resolutions that are 100 times as computationally demanding as the current production CCSM simulation. Our work demonstrates that it will be possible to utilize the upcoming NSF petascale system to finally resolve many of the important physical processes with the Earth System that have been previously only been parameterized.

Future plans include continuing to improve the scalability of each component model and the entire coupled system through improvements in partitioning and decomposing the computational grid across processors. We also plan to complete the addition of the Parallel I/O (PIO) library into all component models.

This work advances NCAR's strategic priority of "Conducting research in computer science, applied mathematics, statistics, and numerical methods." Our work is supported through the NSF cooperative Grant NSF01, and through the Department of Energy CCPP program grant #DE-FC03-97ER62402.

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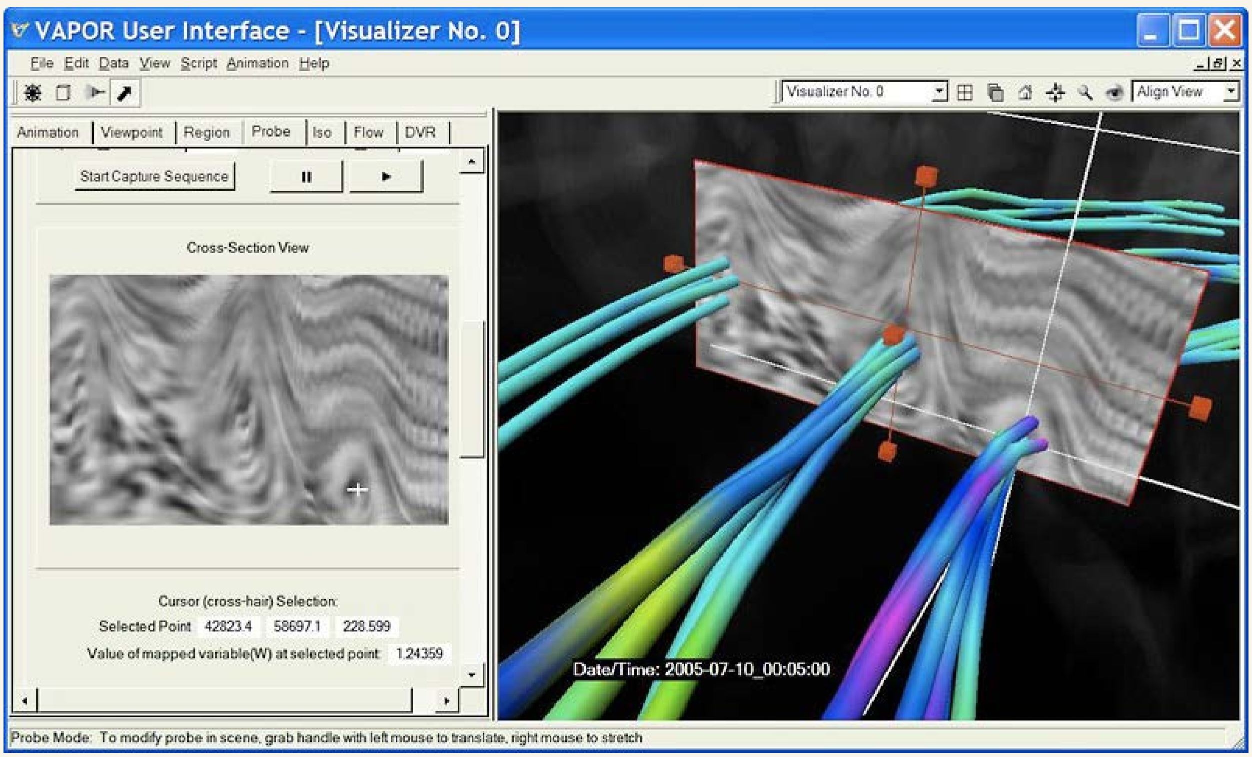
Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Research (VAPOR)

The VAPOR project is an Open Source software development effort aimed at improving the ability of researchers in the Earth sciences to analyze and interpret results from some of the largest numerical simulation outputs. The genesis of this work was an NSF-ITR research grant that supported CISL as well as collaborators at the University of California, Davis and the Ohio State University. VAPOR has transitioned from a research project to a maturing product, and with the expiration of our ITR grant late in FY2008, VAPOR is presently supported entirely through NSF Core funding.

Though VAPOR's origins are strongly rooted in geophysical turbulence, recent work on VAPOR has focused on expanding its capabilities to support the needs of the broader Earth sciences community. Development of VAPOR is closely guided by a steering committee comprised of geoscientists from around the world that sets development priorities, dictates software requirements, and serves as friendly users for testing and evaluating new software features.



This figure shows vortices in the eye wall of a WRF hurricane simulation, produced by Yongsheng Chen, NCAR. Illustrated are two new capabilities added to VAPOR this year: 2D dense texture flow visualization and support for WRF data. Though still in its infancy, VAPOR's WRF model support is fulfilling a critical unmet need in numerical weather research: providing tools for interactive, 3D visual data analysis.

Decades of continual advancements in microprocessor technologies have led to numerical simulations of Earth sciences phenomena computed at unprecedented scales. These simulations generate extraordinary amounts of data. But our ability to manage, analyze, and gain insights from these data has not kept pace with our ability to generate them. For many numerical modelers, the greatest challenge in the discovery process begins after the simulation has completed when the analysis process begins. The VAPOR project focuses on the problem of large-data exploration with an intelligent approach: by exploiting multiresolution data representation coupled with advanced interactive visualization and quantitative analysis capabilities, VAPOR provides a comprehensive desktop environment suitable for exploring terascale-size -- and soon petascale-size -- data sets.

Thus VAPOR supports two of NCAR's strategic priorities: "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment."

Work in FY2008 focused on broadening VAPOR's capabilities to better meet the needs of a more general Earth and space sciences computational fluid dynamics community. In particular, much of the past year's development has been aimed at users of the Weather Research Forecast (WRF) model. Interest from WRF researchers is strong: following an initial release of the software offering rudimentary WRF support, over 500 copies of the package were downloaded in a single week.

Noteworthy events in FY2008 include:

- Two new major versions of the software were completed and released. Major new capabilities include: 2D dense texture flow visualization, mapped isosurfaces, user preferences support, and support for importing and visualizing WRF data sets.
- Over 6,000 copies of VAPOR have been download by the scientific community (~1,000 of the most current version, released in June 2008).
- VAPOR was cited by 10 refereed, scholarly scientific publications in 2008, and imagery produced by VAPOR was featured on two journal covers.
- The VAPOR team continued its education efforts, hosting Ph.D. interns from UCLA and the Colorado School of Mines.
- A second invited paper on VAPOR was accepted for publication by the *New Journal of Physics*.
- VAPOR was the cornerstone the TOY geophysical turbulence summer school, attended by ~30 PhD students from around the globe.

Work in FY2009 will continue to focus on expanding VAPOR's feature set to attract a wider geosciences user base. A survey of current and potential future users was conducted in January 2008; the results will guide much of the year's development. Significant areas of planned development include:

- Integration with CISL's NCL package to further VAPOR's geo-referenced data capabilities
- Improving the VAPOR data model and tools to better prepare for petascale simulations
- Improving our support structure to better handle the growing VAPOR user base

This project was originally made possible through support from NSF's Information Technology Research for National Priorities (ITR) program, and is now entirely supported by NSF Core funds.

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IMAGe Theme of the Year education and outreach

An acknowledged hallmark of mathematical science is that the same mathematical and statistical methods and models can be used to solve problems in very different contexts. The success of mathematics in the geosciences, however, must be based on geoscientists and applied mathematicians working in multidisciplinary teams and being knowledgeable in complementary scientific fields. Moreover, long-term investments in multidisciplinary applications must include training new researchers within this collaboration model.

TOY 2008 posited that advances on difficult multiscale problems in the Earth-Sun system are more likely to come from integrating knowledge in mathematical modeling, computational science, observation, and experiments. The series of TOY workshops on turbulence theory, computation, and observations was based on this idea. Accordingly, the TOY 2008 summer school also surveyed these three themes with the intent to train the coming generation of mathematical and physical scientists to think broadly when attacking turbulence problems.

The 2008 summer school was run for three weeks with each week devoted to one of the themes from the workshops earlier in the year. An internationally recognized group of researchers worked with 30 Ph.D. students during the school. The third week was particularly beneficial because it gave the students hands-on experience running large simulation models and analyzing the output (see the Pouquet paper IMAGe Theme-of-the-Year 2008 in the CISL Research Catalog for more details). This format effectively reinforced the course material with practical experience in numerical modeling and simulation.

The TOY 2008 summer school participants gathered in front of the Mesa Lab on July 18, 2008. Keith Julien (left), Professor of Applied Mathematics at CU-Boulder and Annick Pouquet (not pictured), Director of IMAGe's Geophysical Turbulence Program at NCAR, co-directed the 2008 TOY. TOY establishes collaborations around potentially rewarding research activities and encourages contributions from talented young investigators in a variety of disciplines.

TOY 2009 will operate at a smaller scale and will involve student training within the workshops rather than at a separate summer school. This will include tutorial segments within the workshops, student presentations with peer feedback, and fielding several SIParCS projects. TOY 2009 may also include visits to several graduate programs in applied mathematics, offering a minisyposium to the students as insight into the numerical challenges specific to simulating geophysical processes.

By enhancing collaborations with the university community and by performing valuable education and outreach activities at the highest level, this work supports the NCAR strategic priorities "Engaging a broader and more diverse community in the atmospheric and geosciences" and "Supporting and enhancing formal science education at all levels." TOY workshops and schools are sponsored by the NSF cooperative agreement through UCAR and by NSF funding through the division of mathematical sciences.

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The Earth System Curator

The Earth System Curator project is creating a software environment for assembling, running, and archiving information about climate models. The intent is to make it easier for scientists to search, browse, and compare models, model components, and datasets in a distributed collaborative environment. Curator partners include NCAR (the Earth System Grid and Earth System Modeling Framework projects), the Geophysical Fluid Dynamics Laboratory, MIT, and the Georgia Institute of Technology.

This is the user interface of a prototype portal that supports the description, search, browse, distribution, and comparison of models and datasets. It was developed jointly by the Curator project, the Earth System Grid, and the NCAR Cyberinfrastructure Strategic Initiative. The screen shown enables modelers to browse across models, model sub-components, datasets, and specific model simulations using a faceted search approach that enables users to successively narrow and refine their target. The portal is part of an effort to create comprehensive new computational environments for climate modeling and analysis, and it was deployed initially to support a 2008 NCAR Advanced Study Program summer colloquium focused on intercomparing the dynamical cores of atmospheric models.

The Curator project was motivated by the increasing globalization of climate modeling and analysis activities. It began in 2005 during preparations for the Fourth Intergovernmental Panel on Climate Change assessment and report. Many factors contributed to the desire to create an Earth System Curator portal: the increasing complexity of climate models, the emergence of data standards that enhanced the ability to compare model outputs, the new social, scientific, and technical interactions stimulated by the assessment and other model intercomparison projects, and the need for a distributed collaborative environment capable of supporting international collaborations. The portal was intended to extend and enhance projects such as the Earth System Grid data distribution portal by helping it evolve into a more comprehensive computational environment.

By creating a collaborative modeling environment that serves the climate domain, the Earth System Curator supports the NCAR strategic priority of "Developing community models for weather, climate, atmospheric chemistry, and solar-terrestrial research." It also fulfills NCAR's strategic priority of "Creating an Earth System Knowledge Environment" by serving as a key element of this effort to integrate the suite of infrastructure and scientific software at NCAR and improve support of modeling and analysis workflows. This effort has leveraged the Science Gateway Framework developed as part of the Cyberinfrastructure Strategic Initiative. The Science Gateway Framework enables developers to reuse a foundation of common infrastructure to create custom portals.

During FY2008 the Curator team worked with the Earth System Grid project and the NCAR Cyberinfratructure Strategic

Initiative to create a prototype portal. The portal included a faceted search and browse function developed by ESG with detailed scientific properties collected by the Curator group, a trackback page that retrieved specific configuration of models used to generate datasets, and a table for dynamically comparing the properties of selected components. The portal was used to support the 2008 NCAR ASP colloquium entitled Numerical Techniques for Global Atmospheric Models, which compared 13 atmospheric dynamical cores from different groups.

During FY2008 the Curator group also advanced the ability to automatically document the configurations and properties of models. Working with the Earth System Modeling Framework (ESMF) group, SIParCS student Rocky Dunlap from the Georgia Institute of Technology prototyped the capability to generate descriptive XML files from models using ESMF and upload them into the prototype portal. Information about the models is automatically propagated throughout the portal internals and interface. This enables modelers to capture information about specific models and model versions with much greater ease and detail than previously possible.

In FY2009 the Curator team will help transition the portal from its prototype status into production in the Earth System Grid. The team will also work with technical leads, both U.S. and international, of the next IPCC assessment to develop new portal capabilities related to metadata.

Earth System Curator is supported by a grant from the National Science Foundation Science Engineering Information Integration and Informatics program, and by a NASA grant from the Science Mission Directorate.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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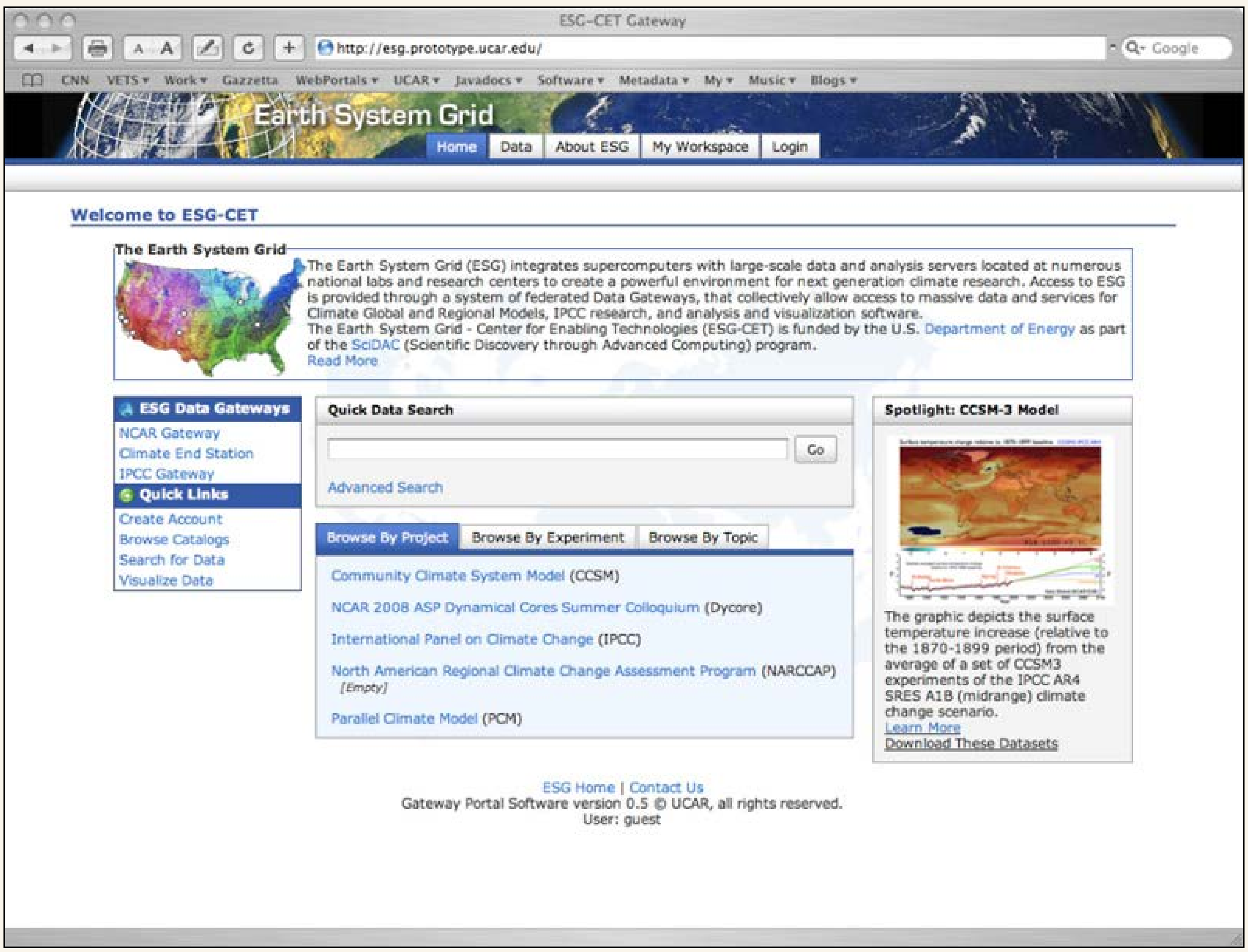
The Earth System Grid Center for Enabling Technologies (ESG-CET)

The Earth System Grid Center for Enabling Technologies (ESG-CET) is a five-year project funded by the U.S. Department of Energy (DOE) SciDAC-2 program to develop and deploy an international virtual facility for climate and related impacts research. A follow-on to our earlier ESG project, the effort has grown into a large-scale collaboration among NCAR (SCD, CGD, and HAO), Argonne National Labs (ANL), Oak Ridge National Labs (ORNL), Lawrence Livermore National Labs Program for Climate Model Diagnosis and Interpretation (LLNL/PCMDI), NOAA's Pacific Marine Environmental Laboratory (NOAA/PMEL), the University of Southern California Information Sciences Institute (USC/ISI), Lawrence Berkeley National Laboratory (LBNL), and Los Alamos National Laboratory (LANL).



This is a snapshot of an early release of a new ESG web portal that provides access to climate change simulation datasets, climate models, regional climate data, and analysis and visualization tools. It is built on the ESKE Science Gateway Framework (SGF), which is new cyberinfrastructure that can be deployed for multiple distributed Gateways. ESG now provides services to over 12,000 people worldwide and has delivered close to half a petabyte of data. The new infrastructure will be used to support the next IPCC Assessment Report, among other things.

ESG currently provides a production service for most of the joint NSF/DOE climate change simulations conducted over the last seven years as well as the IPCC 4th Assessment Report data holdings. Access is provided through a combination of web portal access as well as desktop applications that mediate large-scale transfers to the user. ESG currently has over 12,000 registered users worldwide, manages over 225 TB of data in archives distributed around the nation, and has delivered close to 500 TB of data to its constituents. Over the past two years, more than 400 scientific journal articles have been published from analyses of data delivered by the ESG. ESG thus plays an important role in advancing NCAR's strategic plan, including "Developing and providing advanced tools and services," "Engaging a broader and more diverse community in the atmospheric and geosciences," "Creating an Earth System Knowledge Environment," and "Advancing a global community's ability to advance climate research." It is also an excellent example of cross-agency collaboration to advance science.

During FY2008 we have continued to operate our production systems and grow our data offerings as new climate data products have become available. Our primary focus has been the continued development of ESG-CET requirements as a primary driver for the ESKE SGF development effort in support of the general distribution of climate model data, and the upcoming IPCC AR5 requirements. We developed a comprehensive metadata/domain model, including relational tables and object-oriented mappings, along with an RDF-based framework for semantically based search and discovery of scientific data.

As we move toward a globally distributed federated system, security considerations have become a primary concern, and we have invested a lot of effort in working with partners in the U.K. and Europe to develop a security design that will enable cross-virtual-organization interoperability. We have worked with PCMDI to enable remote publishing of datasets from a rich client application into the gateway data holdings, in support of upcoming IPCC AR5 publishing activities. Metadata and ontologies are very important relative to enabling the required level of scientific query, and to that end we have worked extensively with the Earth System Curator project over the past year, and have also recently begun a collaboration with the EU METAFOR project on the shared development of climate model metadata ontologies.

ESG-CET continues to be highly visible in the global community, and we have presented posters and papers at a pair of DOE SciDAC meetings as well as at the European Geophysical Union conference in Vienna, Austria. We have several papers in progress that will be published in FY2009.

In FY2009 we will transition the existing operational ESG system onto the new ESKE SGF infrastructure, migrating on order of 14,000 users to the new system. In parallel with that, we will begin deploying a new ESG-CET distributed federated testbed that will connect IPCC/CMIP5 data provisioning sites in the U.S., the U.K., the EU, and later, Asia.

Primary support for this project is from DOE's Scientific Discovery Through Advanced Computing program contract DE-FC02-06ER25772 with additional support from NSF via NCAR's Cyberinfrastructure Strategic Initiative and NSF Core funding.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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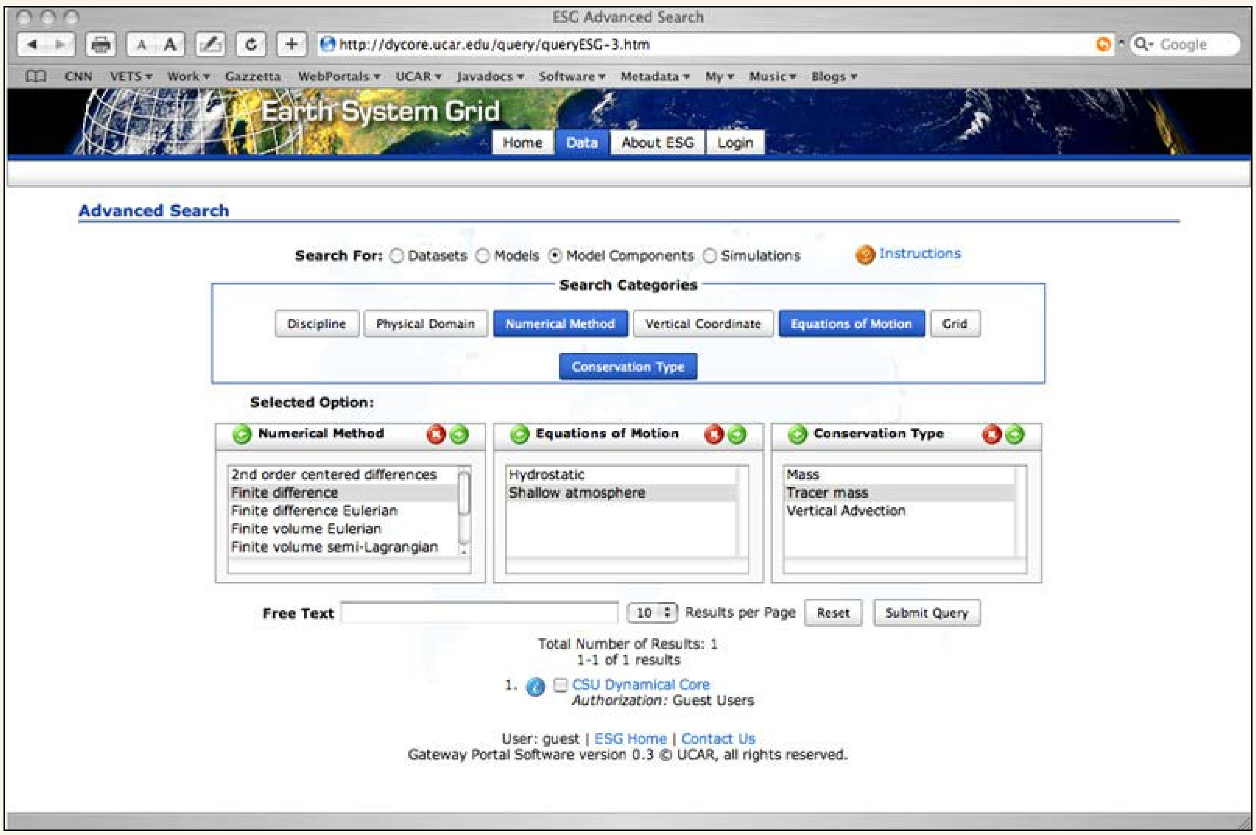
The Cyberinfrastructure Strategic Initiative: Realizing an Earth System Knowledge Environment, Building a science gateway framework, and the Community Data Portal

The NCAR Cyberinfrastructure Strategic Initiative (CSI) was originally proposed as a collection of strategic activities that spanned data and knowledge management, collaboration environments, and advancing our web presence. Having accomplished our goals and realizing production capabilities in the latter two, our primary focus is now on *advancing data and knowledge environments* and aggressively developing our opportunity space in this and related areas. The CSI effort currently funds a collection of strategic and opportunity-development activities, along with core foundational thrusts including the development of the ESKE Science Gateway Framework and the Community Data Portal (CDP). Our overarching goals are to build the cyberinfrastructure, integrate and extend the Information Technology, develop the critical relationships and projects with scientific and educational projects, and foster the development of human resources and culture such that we can effectively develop our Earth System Knowledge Environment (ESKE).



This image is a snapshot of a prototype interface that bridges across models and data. Developed on the emerging ESKE Science Gateway Framework (SGF), it reflects collaboration across multiple projects, including the Cyberinfrastructure Strategic Initiative, the Earth System Curator (ESC), and the Earth System Grid. The SGF provides a powerful new capability: semantic organization of digital objects. Once digital collections are classified as part of an ontology, Semantic Web technologies may be employed to provide a "faceted search" capability such as the one depicted above. While this is useful in its own right, it paves the way to deliver systems with semantically mediated workflows, where data integration happens behind the scenes, allowing scientists to acquire the resources they need without necessarily having to know about all of the complexity and heterogeneity that lies underneath.

The Community Data Portal (CDP) is aimed at developing and delivering innovative cyberinfrastructure that provides a shared technology base and facility for data and knowledge management for a broad set of digital holdings across UCAR, NCAR, and UOP. The basic idea is to develop and deliver the foundations for building "science gateways" and knowledge environments, including a broad spectrum of functionality spanning data search and discovery, semantic organization, catalogs and metadata browsing, support for virtual organizations, data download and upload, publishing, digital preservation, and analysis and visualization services. The CSI thus plays an important role in supporting NCAR's strategic plan including "engaging a broader and more diverse community in the atmospheric and geosciences," "developing and providing advanced tools and services," and "creating an Earth System Knowledge Environment."

Developing the ESKE Science Gateway Framework (SGF): We made significant progress developing the next-generation ESKE Science Gateway Framework (SGF) in FY2008. The new SGF will include support for virtual organization branding/skinning; federated identity, authorization, and security; search and browse functions; publishing workflows; data management, analysis, and visualization; access to MSS/HPSS holdings; data preservation; metadata, ontology, and semantic support; support for community annotation and tagging; metrics; workflows; federation with ESG, THREDDS, WMO, GCMD, CADIS, Google Earth, etc.; GIS capabilities; and support for a wide variety of digital object types. The result will be an Open Source software product, and our first production release will occur in early FY2009. We also interfaced the SGF with the LAS (Live Access Server) and TDS (Thredds Data Server) to enable data subsetting, post-processing, and visualization. We leveraged emerging OpenID technology to enable federated authentication and attributes exchange and also developed and implemented a model for federated group membership management.

Supported numerous data, modeling, and technology projects: In FY2008, we continued to support the spectrum of existing projects and also worked with a number of new ones. This included IPCC, the THORPEX Interactive Grand Global Ensemble (TIGGE), the NCAR GIS Strategic Initiative, HAO's TGCM project, the Whole Atmosphere Community Climate Model (WACCM), ACME-07, the Cooperative Arctic Data and Information Service (CADIS), the Earth System Modeling Framework (ESMF), the NSF Earth System Curator (ESC) project, the IHOPE/ARCHEOMEDES project, and the Google Earth Opportunity Fund effort.

The World Meteorological Organization Information System (WMO-WIS): In FY2008 the CSI also supported collaborative efforts to develop the World Meteorological Organization (WMO) Information System (WIS), with CISL staff serving on several WMO committees and expert teams, including the WIS metadata group (IPET-MI), the WIS data and codes group (ET-CTS), the WIS global federation group (ET-WISC), and the WMO Intercommission Coordination Group (ICG-WIS). The CSI also supported contributions relative to the organization and development of the Global Earth Observing System of Systems (GEOSS) effort.

THORPEX Interactive Grand Global Ensemble (TIGGE): CSI-supported staff continued to engage in the design, software engineering, and deployment of core TIGGE systems that are based in large part on underlying CDP technology. We completed and released a new version of the TIGGE portal that fulfilled the data access requirements of the project Phase I including file-based access, data subsetting, and geographic-based data selection and regridding.

2008 NCAR DyCore workshop: As depicted in the image above and described in the highlight Cyberinfrastructure for next-generation atmospheric models, the CSI supported a collaboration that spanned this initiative, the Earth System Curator project, and the Earth System Grid to support the 2008 DyCore workshop on model inter-comparison, including semantic-based search, data distribution, comparison of model configuration, and track-back functionality.

Opportunity development: The CSI successfully developed a funding stream for the Chronopolis digital preservation effort (funded by the U.S. Library of Congress), continued to work with EOL and other partners to develop support for the Virtual Operations Center (VOC), and contributed to NSF DataNet and TeraGrid proposals.

Overall, the CSI has impact ranging from local to global, with a solid track record of building important new collaborations.

In FY2009 we will continue to pursue opportunity development in the areas of science gateway and portal development, semantic and knowledge systems, integrated data management, analysis, and visualization environments, and digital preservation initiatives. The initiative now has a large operational responsibility, and we will continue to work with a large number of projects and customers to continue good service, learn from it, and evolve our capabilities accordingly. From a technology standpoint, we will migrate all of our existing science portals to the new Science Gateway Framework during FY2009. We will continue our contributions to the IPCC, WMO-WIS, and GEOSS efforts, working with international partners to realize our vision of globally federated data and knowledge environments. We also intend to develop a thrust on environmental/climate Science Gateways for the TeraGrid in FY2009. Overall, an overarching theme in the upcoming year is one of cross-project integration in the ESKE context -- with an emphasis on establishing ESKE support foundations.

This project is supported through NCAR Strategic Initiative funding and NSF Core funding, augmented by specific project support as described throughout this report.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

NCAR is sponsored by the National Science Foundation.

Cyberinfrastructure for next-generation atmospheric models


Morning lectures in the Main Seminar Room of NCAR's Mesa Lab.

CISL's people, technology, and facilities played a key role in the 2008 NCAR Advanced Study Program (ASP) colloquium entitled Numerical Techniques for Global Atmospheric Models. The colloquium, which was jointly supported by NSF, NASA, and the Department of Energy, was held at NCAR on 1-13 June in Boulder, Colorado. This working group of graduate students, model developers, and scientists analyzed 13 atmospheric dynamical cores that are being considered for next-generation models.

Dynamical cores solve the equations that describe the properties of the atmosphere over time, including its motion. Their development and selection is a critical part of the process of creating new atmospheric models. They are especially important now, because increased computer power is making new types of atmospheric models possible. The limitations of past supercomputers required separate development paths for regional-scale weather models and global-scale climate models. Current supercomputers that operate at tens of teraflops -- and the coming petascale systems running at thousands of teraflops -- will allow a single model to simulate atmospheric phenomena on multiple scales, from local to global. However, spanning these scales requires high computational efficiency and numerical accuracy of the dynamical cores. ASP colloquium participants performed hundreds of test runs to analyze these 13 cores, yielding insights into the advantages and disadvantages of each.

The workshop demonstrated the relevance of the emerging Earth System Knowledge Environment, a strategic priority within CISL that seeks to integrate and expand modeling and data services. The results from the workshop are available to the research community via a new science gateway developed collaboratively by the Earth System Curator and Earth System Grid (ESG) projects in CISL. The effort was also supported by NCAR's Cyberinfrastructure Strategic Initiative, which is developing a Science Gateway Framework that can be used to build a variety of custom portals. The teams jointly extended the Earth System Grid portal by adding structured information, or metadata, about the scientific and technical properties of the dynamical cores and by building new tools, such as comparison tables, that utilize that metadata. Modelers who examine the portal will find not just datasets for download, but a rich store of semantic information that enables them to better understand how and why results were obtained.

FY2008 accomplishments

Key accomplishments of FY2008 include:

- Development of a prototype web portal that links output datasets with model descriptions, experiment specifications, and other semantic information
- Deployment of the portal for the 2008 ASP colloquium entitled Numerical Techniques for Global Atmospheric Models
- Consulting and facilities support for this colloquium, including computing time, data storage, and new user training

FY2009 plans

During FY2009, the collaborators who developed the prototype portal will turn to a larger project: the next Intergovernmental Panel on Climate Change (IPCC) assessment. There is a need for collaborative metadata development and for further evolution of portal capabilities that were introduced for the ASP colloquium. One of the major challenges is coordination with a broad international community. Collaborators anticipate working closely with the European project Metafor (Common Metadata for Climate Modelling Digital Repositories), using international bodies such as the World Climate Research Programme and the Global Organization for Earth System Science Portals (GO-ESSP) to help facilitate the interactions.

Sponsors

The ASP colloquium was sponsored by the National Science Foundation, NASA, and the Department of Energy. The first phase of the Curator project was sponsored by the National Science Foundation. Ongoing Curator work has been funded by NASA. NCAR's Cyberinfrastructure Strategic Initiative is funded through NCAR base funds provided by the National Science Foundation.

Project description

This ASP colloquium attracted graduate students with backgrounds in atmospheric science, applied mathematics, and/or computer science, and it introduced them to the latest developments in weather and climate modeling. An elite group of lecturers, model developers, and mentors provided input and guidance for the two weeks of intensive analysis. A total of 38 students, 13 modeling mentors, 18 lecturers, and 4 organizers participated in this event that produced significant benefits for both the attendees and the atmospheric research community. The graduate students received training and experience in atmospheric science, modeling, and computer architectures, and they performed and archived more than 350 simulations from models that incorporated the 13 dynamical cores. The organizers now have a large archive of data for their research. The modeling community has a rich and timely intercomparison dataset -- described in detail using metadata and available through a science gateway -- that may be used to compare and improve the dynamical cores.

During all afternoon tutorial sessions, the students, mentors, and researchers ran models using the dynamical cores, then archived data and metadata on the NCAR Mass Storage System.

The NSF-funded Curator project provided front-line support for the colloquium. The goal of Curator is to contribute to comprehensive science portals in which model source code, simulations, datasets, and individual model components are linked through metadata. This benefits model intercomparison projects, which require that modelers have information about the algorithms and codes they are analyzing. A specific benefit to modelers is the effort to standardize how datasets are linked to models: how they were generated, what flags were set, which input datasets were used, what initial conditions were used, and so on. Collaborators working on other aspects of the Curator project include the Georgia Institute of Technology, the Massachusetts Institute of Technology, Princeton University, and the European Metafor project.

Rather than trying to build a computing environment from scratch, the Curator project enhanced the Earth System Grid portal, which had an initial ontology -- a structured collection of metadata -- in place. Sylvia Murphy of Earth System Curator coordinated the joint effort, organized the development of new metadata with Luca Cinquini of ESG, and was the primary point of contact for the colloquium organizers. CISL software engineer Julien Chastang created several specialized tools for use with the enhanced metadata. One is a "trackback" page that details the model configuration associated with a particular dataset. It shows the scientific and technical properties for a model as a whole, and for each constituent component in the model. A second tool enables modelers to dynamically create comparison tables for a select set of models or components and a select set of properties. For the ASP colloquium, these tools helped participants track and understand the characteristics of each core, including information about the resolution, time step, spatial filtering, and input datasets that were used for each simulation.

Since ESG will be a primary portal for hosting IPCC Fifth Assessment data, and the enhancements from Curator will be folded into the main ESG portal, the improvements in metadata and tools arising from this ASP colloquium will benefit the next IPCC assessment.

Timeframe for the project

The ASP Colloquium was a one-time event. The portal developed to support it was the culmination of the Curator project, a three year, NSF-funded effort whose first phase ended during FY2008. The project will continue for another two years with NASA funding for the NCAR participants.

Accomplishments overview

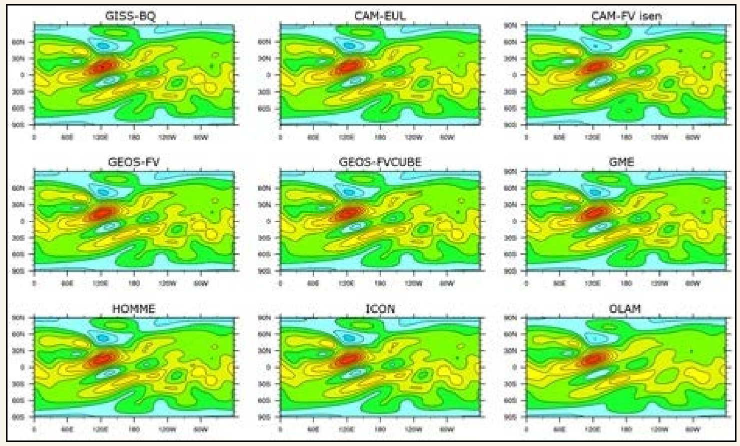
CISL deployed a new science portal for archiving data and metadata for the colloquium. Building on CISL's strategic effort to develop a flexible Science Gateway Framework, the new portal was developed jointly by CISL staff working on the Earth System Curator and Earth System Grid projects. CISL also provided facilities support: for this colloquium alone, the NCAR Mass Storage System (MSS) received a 1.1 TB archive of model output. CISL staff wrote software to automatically load the data from the MSS onto the new portal, publish it on the web, and upload the metadata for each test case.

Supporting 38 new users and providing the appropriate cyberinfrastructure for the project required a significant commitment from CISL:

- Allocated dedicated time on NCAR's 624-processor 4.7-TFLOPS supercomputer bluevista for colloquium participants
- Oriented the new users to the NCAR computing facility
- Provided training tailored to the project
- Presented a lecture on the challenges of employing massively parallel processing technology
- Implemented a new job queue for the project
- Issued user names and one-time password devices to new users
- Produced daily usage reports for the project
- Provided laptops for some of the participants

Evaluation measures and outcomes

The four primary colloquium organizers will prepare a research paper for publication describing how this approach to testing dynamical cores can benefit the field (the full test case formulation used in the colloquium will be available as an NCAR technical report shortly). Christiane Jablonowski (University of Michigan) and Peter H. Lauritzen (NCAR, ESSL, CGD) created a specific set of idealized test cases designed to highlight strengths and find weaknesses in the cores. Christiane and Peter are now analyzing the data generated during the colloquium to understand how both the test suite and the cores performed. The testing approach used for the colloquium has the potential to become a community standard for testing dynamical cores. The ongoing analysis and their paper will further develop this idea. The organizers are editing a book based on contributions from the colloquium lecturers that is going to be published in the Springer series Lecture Notes in Computational Science and Engineering. Curator collaborators have also prepared a paper on their methodology and findings, submitted to the Earth Science Informatics Journal.



Output of nine models running test case 5-0-0 (Mountain-induced Rossby wave): 700 hPa zonal wind at day 15. The test starts with balanced and isothermal initial conditions. A 2-km-high Gaussian-hill-shaped mountain is placed at [90°E, 30°N] (not shown) to trigger Rossby waves. The test evaluates the treatment of the orography and reveals numerical noise (especially at later days).

About NCAR's Advanced Study Program

NCAR's Advanced Study Program encourages the development of young scientists in the fields of atmospheric and related science, and it directs attention to timely scientific areas needing special emphasis. The ASP also helps to organize new science initiatives, supports interactions with universities, and promotes continuing education at NCAR. Sponsored by the National Science Foundation and NASA, the 2008 ASP summer colloquium's primary organizers were Peter H. Lauritzen (NCAR, ESSL, CGD), Christiane Jablonowski (University of Michigan), Mark Taylor (Sandia National Laboratories), and Ramachandran D. Nair (NCAR, CISL, IMAGe). Four distinguished lecturers presented the four keynotes: Professor John Thuburn, Professor of Applied Mathematics in the School of Engineering, Computer Science, and Mathematics at the University of Exeter, U.K.; Professor Dale Durran, Professor and Chair of Atmospheric Sciences, Adjunct Professor of Applied Mathematics, Atmospheric Sciences at the University of Washington; Dr. Todd Ringler, Climate, Ocean, and Sea Ice Modeling Group, Theoretical Division at the Los Alamos National Laboratory; and Professor David A. Randall, Department of Atmospheric Science at Colorado State University.


Some of the participants in NCAR's 1-13 June 2008 ASP Colloquium on Numerical Techniques for Global Atmospheric Models.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

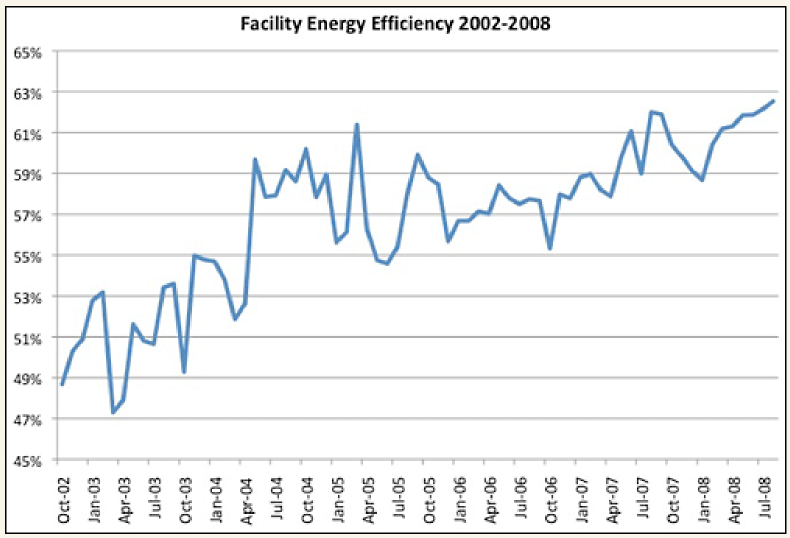
NCAR is sponsored by the National Science Foundation.

Expand the capability and capacity of NCAR supercomputing facilities

The trend of dramatic increases in power and cooling requirements for replacement computing systems was identified by CISL staff six years ago. In 2007, Congress directed the EPA to study data center efficiency. The study recommends three sets of guidelines for computing facilities to implement: "improved," "best practice," and "state of the art." CISL continues to be actively engaged with the management of high-end facilities and has implemented many of the recommendations from all three categories in the Mesa Lab computer room. CISL is planning a new supercomputing facility that will fully meet "state of the art" specifications.

Providing computing facilities to meet NCAR's needs is fundamental to NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools," and to the related strategic priority of "Enhancing capability and capacity of NCAR supercomputing." We continue a two-pronged approach to meeting this challenge.

First, we have solidified and prepared the NCAR Mesa Lab computing facility infrastructure to operate at capacity for the next two years. With the installation of the POWER6 system bluefire, the Mesa Lab computing facility is now successfully operating at nearly 100% capacity. Bluefire uses liquid-based cooling on the processors and for air passing through the cabinet; this is an EPA "state of the art" recommendation. These incremental improvements have greatly enhanced the energy efficiency of the Mesa Lab computing facility. The chart shows how efficiency has improved over the last six years. The facility energy efficiency is calculated by dividing the computer systems' power consumption by the total power consumed.



This chart shows how efficiency has improved at the Mesa Lab computing facility over the last six years.

Having implemented many of the EPA recommendations, we still experience significant constraints on both electrical and cooling capacity. CISL's second initiative is to continue planning the construction of a new facility. In August 2008, NSF, UCAR, and NCAR agreed on a multi-step process to pursue the initiation and approval of this construction project. NCAR, UCAR, and the University of Wyoming are proceeding with the release of a request for information (RFI) for architecture and engineering services.

In FY2009, NSF will establish a formal process for review and approval of the development during its major phases. NSF, NCAR, UCAR, and the Wyoming partners will work together to finalize business plans, milestones, and timelines within the framework NSF establishes.

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Plans for developing the NCAR Supercomputing Center (NSC) with Wyoming partners

NCAR is partnering with the University of Wyoming and other entities within the State of Wyoming to develop a supercomputing center dedicated to meeting the fast-growing, specialized high-performance computing needs of Earth System scientists.

In partnership with the University of Wyoming (UW), the State of Wyoming, Cheyenne LEADS, the Wyoming Business Council, and NSF, NCAR continues making plans to develop the NCAR Supercomputing Center (NSC) in Cheyenne, Wyoming. The vision for this collaborative project is summarized by:

- The primary purpose of the NSC should be to enable Earth System science discoveries.
- The facility should be dedicated to Earth System science problems.
- Because environmental problems know no boundaries, the NSC should serve to broaden participation in this geoscientific enterprise.
- The facility should be world class and built to last.
- The NSC should be energy efficient and as green to build and operate as practicable.
- Time is of the essence: many Earth System science questions have huge societal impacts and require dedicated computational resources to be made available as soon as possible.

This stated vision is well aligned with the NSF Strategic Plan and the NSF vision for cyberinfrastructure (CI). The project is motivated by the scientific needs of the Earth System sciences community and is being proposed in direct response to the exploding demand for both capability and capacity high-performance computing (HPC) resources from geosciences researchers. Whether because of a need for greater model resolution, increased model complexity, better statistics, more predictive power, longer simulation times, or a combination of these factors, Earth System investigators are clamoring for petascale computing, data analysis, and visualization resources and exascale data management capabilities.

The provisioning of such capabilities requires the availability of a large-scale computing center capable of handling the multi-megawatt heat loads of future systems. The basic size and infrastructure requirements for the NSC have been determined with these power demands in mind, and a preliminary conceptual design for the facility has been developed that will support the supercomputing needs of Earth System science researchers for the next two to three decades.

Plans for development of the NSC are fully aligned with NSF's larger CI vision and will directly contribute to the creation of a national petascale cyberinfrastructure. As proposed, the NSC will be a peer with other NSF Track-2 facilities and will serve as a "stepping stone" for Earth System science investigators to fully utilize NSF's multi-disciplinary, one-petaflop-sustained Track-1 facility.

Detailed FY2008 accomplishments

During FY2008, NCAR personnel continued their efforts to work with NSF and partners in Wyoming to develop a path forward for the NSC project. As part of an internal project review process, NSF commissioned a subcommittee of the NSF Geosciences Advisory Committee (GEO-AC) in fall 2007 to examine and make recommendations regarding the supercomputing needs of the atmospheric sciences community. This panel of community experts completed their work in winter 2008 and delivered their final report to the GEO-AC in April. Among the panel's findings were:

- "The National Center for Atmospheric Research (NCAR) plays a critical role in providing high-end computing facilities, leadership in developing community models, and data curation for the ATM research community, and will continue to do so in the future."
- "The computing needs of the ATM research community are rapidly outstripping the ability to provide them within the NCAR Mesa Lab."
- "Any additional computing facilities aimed at supporting ATM science must be tightly integrated with the existing facilities provided by NCAR, e.g. by means of high-speed networks and shared file systems."

Key recommendations made by the panel included that NSF should "continue to support the work that NCAR is doing for the community in providing computing facilities ... community model development, and data curation" and "provide a new Track-2-class facility, dedicated to ATM researchers, through an open competition with a highly specific set of ATM requirements."

In response to the subcommittee findings and recommendations, NSF made the decision in early summer 2008 to support plans developed by NCAR, UCAR, and Wyoming for construction of the NSC. In late August, NSF, UCAR, and NCAR personnel agreed on a multi-step process to pursue project initiation and approval. NCAR, UCAR, and the UW are proceeding with the release of a request for information (RFI) for architecture and engineering (A&E) services. The RFI release will precede the preparation and release of a formal request for proposals (RFP) as part of the A&E firm selection process. In parallel with this selection process, NSF will utilize external and internal guidance to define a formal project process. In late FY2009 following completion of the initial facility design effort, NCAR will prepare and submit a project proposal to NSF. This proposal will be reviewed as part of the multi-step project review and approval process to be put in place by NSF.

Impacts

As envisioned, the NSC will play a key role in providing HPC resources to the Earth System sciences community for many years to come. Planning and development of this large, complex project has required six years of effort on the part of NCAR personnel, and roughly four more years of work will be required before NSC supercomputing resources will be available for use by the scientific community. NCAR intends to fully integrate the NSC into the NSF TeraGrid follow-on, and the NSC development effort will be conducted within the guidelines of the NSF Strategic Plan and the NSF cyberinfrastructure vision. Earth System science researchers are faced with immense challenges to effectively utilize petascale systems, and the availability of large-scale parallel systems via the NSC -- in combination with access to software engineering and parallel algorithm research expertise -- is needed to ensure that investigators can prepare their codes and simulations to run effectively on NSF Track-1 computing resources.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

NCAR is sponsored by the National Science Foundation.

Geoscience Application Requirements for Petascale Architectures II (GARPA-2) Workshop

The GARPA-2 workshop was held at San Diego Supercomputing Center (SDSC) on February 21-22, 2007. In August 2007, the NSF funding for this workshop series was extended into FY2008. During the GARPA-2 workshop, participants identified a broad set of geoscience application areas as being suitable to go to the petascale, as well as having profound science impact. One of these was climate simulation. In FY2008, the GARPA workshops engendered collaborations in this area that have borne fruit.

In particular, a collaboration between NCAR, SDSC, and Lawrence Livermore National Laboratory resulted in a Gordon Bell finalist paper at SuperComputing 2007, entitled "WRF Nature Run." This research used up to 15,360 processors of the New York Blue IBM BG/L machine at Stony Brook University and Brookhaven National Laboratory, and it achieved 3.4 TFLOPS sustained. Further, a high-resolution coupled climate modeling collaboration emerged from GARPA-2 that included NCAR, the Center for Ocean, Land, Atmosphere Studies (COLA), the University of Miami, and the University of California, Berkeley. This collaboration began the development of an interactive ensemble (IE) version of CCSM based on CCSM coupler 7, as well as Grand Challenge simulations using 0.5-degree atmospheric and land models coupled to 10-km ocean and sea-ice components. In 2009, the funding left at NCSA for GARPA will be spent to support understanding the challenges faced by petascale geoscience applications that are candidates to use the NSF Track-1 system at the University of Illinois in 2011.

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Data center expansion advanced conceptual design

In FY2008, NSF granted approval to proceed with the initial design phase of the NCAR Supercomputing Center to be located near Cheyenne, Wyoming. A Request for Information for architecture and engineering services was issued and will be followed by the release of a Request for Proposals for these services early in the next fiscal year. In FY2009, NSF will establish a formal process for review and approval of the development during its major phases. NSF, NCAR, UCAR, and the Wyoming partners will work together to finalize business plans, milestones, and timelines within the framework NSF establishes.

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Chilled water system upgrade

The chilled water system that was completed in FY2007 now serves the new 3,000-gallon water reservoir for the bluefire supercomputer in production usage. The new chilled water system at NCAR's Mesa Lab facility is performing nominally.

This facility upgrade was made possible through NSF Core funds, including CSL funding.

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Cyberinfrastructure procurement, deployment, and operations

NCAR maintains a comprehensive computational environment to satisfy the center's strategic goal to "Provide robust, accessible, and innovative information services and tools" to universities and the broader scientific community. This facility supports the NCAR strategic priority of "Enhancing capability and capacity of NCAR supercomputing." Within the context of the NCAR Strategic Plan, CISL fulfills these responsibilities and provides robust computational and scientific data services including:

- High performance production computing
- Data analysis and visualization
- Data storage and archival
- Network connectivity
- Cultivation of the research data archive
- Data distribution

Delivered to NCAR in April 2008, bluefire was the first IBM Power 575 supercomputer to be shipped anywhere in the world. It is over three times more powerful and three times more energy efficient than the supercomputers it replaces. Entering full production in early FY2009, bluefire will be used to improve climate and weather simulations, study solar processes, gain a deeper understanding of turbulence, and refine oceanic and atmospheric circulation models. CISL continues to provide the numerical simulation community with resources that offer the best combination of computational capability and capacity that can be used effectively.

CISL also actively participates in projects designed to provide advanced services and tools to enable Earth System science for a diverse community of users:

- TeraGrid integration
- Experimental computing systems
- Earth System Knowledge Environment

During FY2008 NCAR took delivery of the first IBM Power 575 supercomputer with the POWER6 compute processor to be installed worldwide. Named bluefire, the deployment represented the second phase of the Integrated Computing Environment for Scientific Simulation (ICESS) contract with IBM. It nearly tripled the compute capacity, over FY2007 levels, available to scientists.

During the first quarter of FY2009 several projects will be afforded the opportunity to study challenging problems by participating in the Accelerated Scientific Discovery Program (ASD) on bluefire, where large amounts of capability computing resources will be dedicated to a few users. CISL is committed to deploying and maintaining an end-to-end computational environment, and during FY2009 will enhance the data analysis and visualization environment by significantly increasing the amount of online disk storage available to scientists.

NCAR's supercomputers are managed by CISL under the UCAR/NSF Cooperative Agreement and are supported by NSF Core funds including CSL funding.

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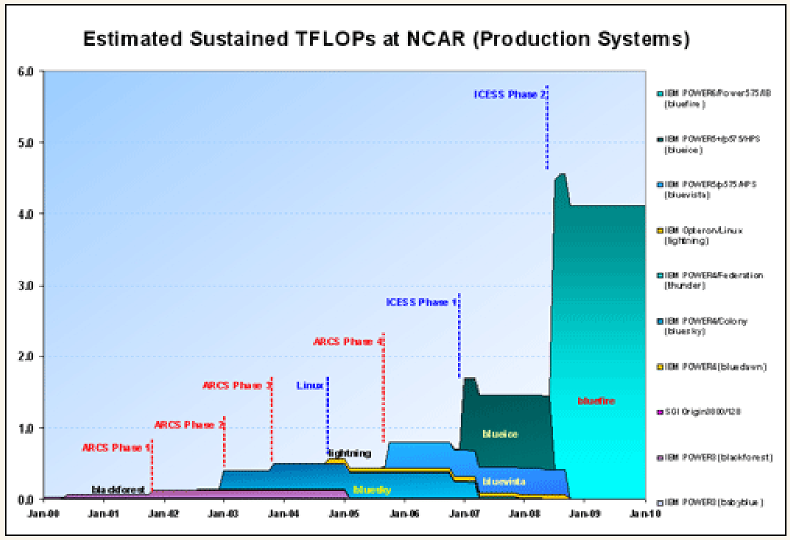
Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

NCAR is sponsored by the National Science Foundation.

Production supercomputing

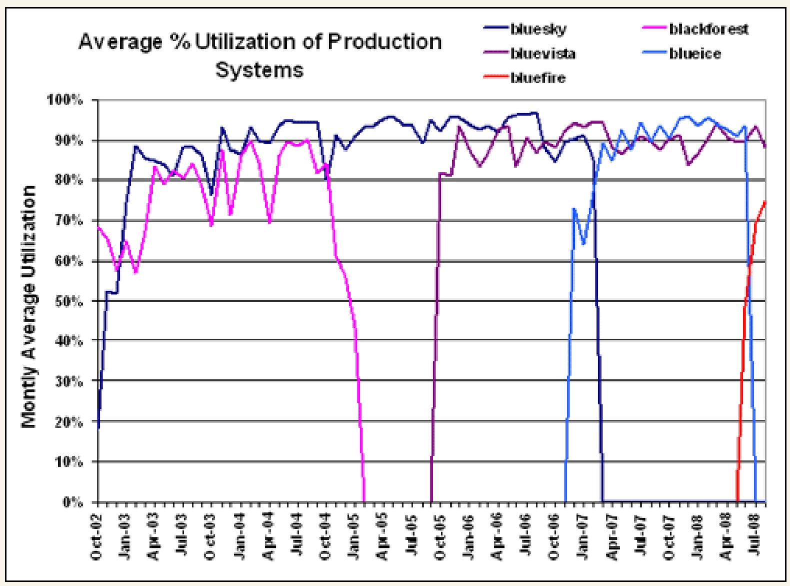
To fulfill its mission, CISL strives to provide a balanced computational environment to facilitate scientific research. This includes robust, reliable, effective, and efficient production supercomputing, state-of-the-art storage, data analysis, and data visualization services, and numerous other computational tools for its community of users.



Estimated sustained computing capacity (in teraflops) available to the NCAR community over the past 10 years. On average, CISL provides substantial capacity increases every 16 months to meet the scientific research demands of the community.

Within the realm of production supercomputing, CISL's goals are to provide equitable access to reliable computing resources with minimal user wait times, while maximizing resource utilization. These goals are achieved by maintaining and monitoring a proper balance of resource allocation, prioritized job scheduling, a well-tuned queue structure, and single-job resource limits.

CISL works to increase the computational capacity available to the community on a regular basis. Deployment of the IBM Power 575 system bluefire during FY2008 provided nearly a three-fold increase in computing capacity over the amount delivered during FY2007. Upgrades and enhancements to peripheral resources, which complement and supplement the high-end computing environment, are applied to appropriately match the growth in compute capacity.



Average utilization (defined as the percent of compute nodes assigned to users at any one time) of the production computing platforms provided by CISL. During the time period shown, the major IBM systems (blackforest, bluesky, bluevista, blueice, and bluefire) were deployed on schedule and reached nearly 90% utilization within a few months. Keeping scientific production at a high level meets NCAR's goal of providing reliable and robust computational services to the community.

The compute capacity available for scientific research will remain level during FY2009. Enhancements are planned that will significantly increase the amount of online, readily accessible data storage for analysis and visualization to meet the demands of the community.

This work fulfills NCAR's strategic priority of "Enhancing capability and capacity of NCAR supercomputing" and is supported by NSF Core funds, including CSL funding.

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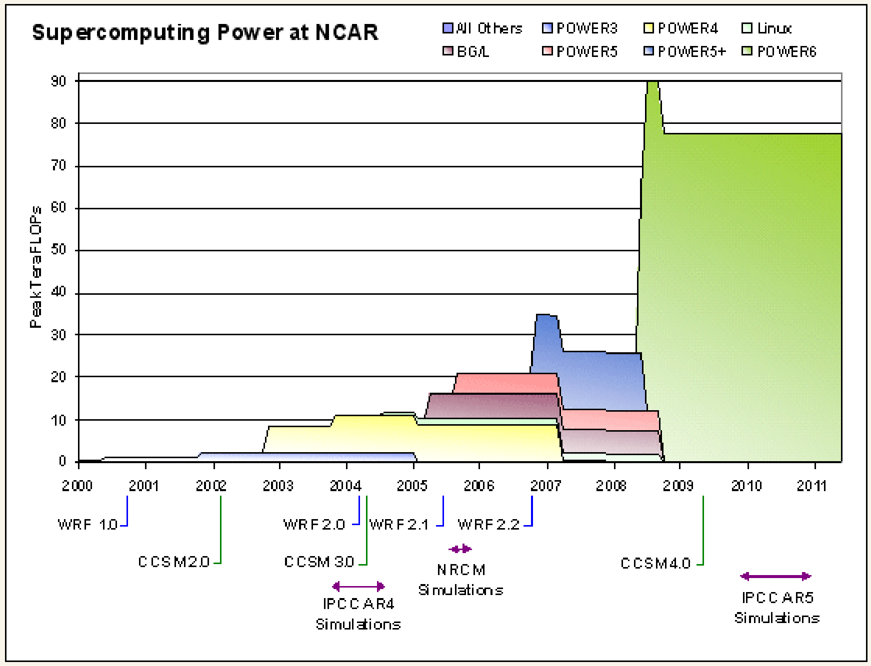
Supercomputer status

During the third quarter of FY2008, CISL deployed the second phase of hardware of the Integrated Computing Environment for Scientific Simulation (ICESS) contract with IBM. The new supercomputer bluefire is based on the IBM POWER6 dual-core processor and the commodity Infiniband Switch communication technology.



The computing capacity at NCAR, as shown by recent increases in the center's peak capacity (in teraflops), allows NCAR scientists to develop, test, and release updated versions of the WRF and CCSM models. CCSM version 3 was used to provide climate simulations to the IPCC AR4, which was awarded the Nobel Peace Prize in October 2007. With anticipated increases in computational capability at NCAR, activities are underway to build and test CCSM version 4 for participation in the 2010-2011 IPCC AR5.

The deployment of bluefire nearly tripled the high-end computing capacity available at NCAR. The IBM POWER5+ system blueice, which was the first phase of ICESS hardware installed and in operation since mid-FY2007, was decommissioned in July 2008. The availability of bluefire is consistent with CISL's strategic plan to significantly enhance the high-end computational environment at NCAR during FY2008, and it upgraded the production cyberinfrastructure available to the university, NCAR, and Climate Systems Laboratory (CSL) communities served by CISL.

During the first quarter of FY2009, priority access to bluefire will be given to seven Accelerated Scientific Discovery projects that require large numbers of processors and long periods of computational residency time to satisfy ambitious scientific goals. Nearly 40% of bluefire -- 1,600 processors -- will be devoted to these ASD projects selected from the NSF GEO/ATM community. Results from using this amount of computing capability and capacity devoted to several grand challenge problems were demonstrated during the Breakthrough Science program in FY2007. This allows scientists to simulate and analyze problems requiring computing resources not usually available within NCAR's production environment.

During FY2008, the power constraints within the NCAR computing facility required CISL to decommission the IBM POWER5 system bluevista and the IBM POWER5+ system blueice to supply sufficient electrical capacity for bluefire. The deployment of bluefire allows CISL to meet the continuing needs and requirements of the scientific community for computationally expensive endeavors, such as preparation for the IPCC AR-5 climate simulations with the Community Climate System Model Version 4 (CCSM4), which is currently under development. The computing capacity available for scientific research will remain level during FY2009.

This work aligns with the NCAR strategic priority of "Enhancing capability and capacity of NCAR supercomputing" and is supported by NSF Core funds, including CSL funding."

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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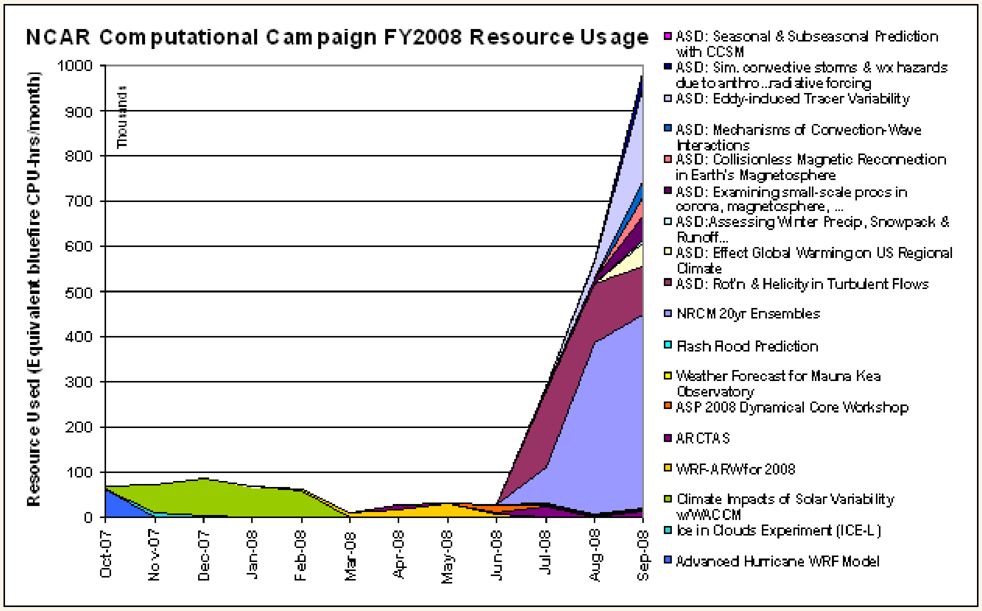
Supercomputer special campaigns

This year, CISL supported seven computing campaigns on the production supercomputer clusters, in addition to the Accelerated Scientific Discovery projects that began using the new IBM POWER6 system, bluefire, in August and September. The provision of large portions of new supercomputers, special queues, pre-emptive scheduling, consulting services, and operational workload monitoring to support breakthrough, on-demand and real-time computing, further enhances the production computing services provided by CISL to the NCAR, university, and Climate Simulation Laboratory (CSL) scientific user communities. Some computational campaigns recur annually, such as the hurricane real-time forecasts, while others are either a one-time event or are accommodated on an as-needed basis.



This chart tracks the usage of NCAR computational resources by special computing campaigns (On-Demand and early Accelerated Scientific Discovery usage) during FY2008. CISL's provision of significant computational resource to special campaigns is accelerating the pace of scientific discovery through numerical simulation.

While the NCAR production supercomputing environment provides capacity computing to NCAR, university, and CSL scientists, the special campaign mechanism supports ongoing and special computational projects and campaigns and on-demand capability computing.

The following table lists the special computational campaigns supported by CISL during FY2008. The Advanced Hurricane WRF Model campaign conducted real-time hurricane forecasting with an enhanced version of WRF during the 2007 hurricane season. The ICE-L was a joint project among NCAR's Earth & Sun Systems Laboratory's MMM, RAL, and ATD divisions in support of aircraft field experiments to measure ice particles in clouds. The ARCTAS computational campaign supported real-time daily chemical forecasts for the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites project. Near real-time NWP with WRF-ARW was provided during the spring to support MMM's collaborations with the National Severe Storms Lab (NSSL) and the Storm Prediction Center (SPC) through their springtime Hazardous Weather Testbed (HWT) Experiment.

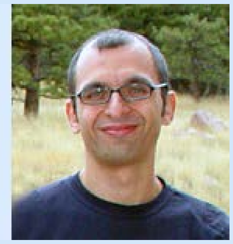
FY2008 special campaign	Principal investigator	Period	System
Advanced Hurricane WRF Model	Chris Davis, et al.	May 07 - Nov 07	blueice
ICE-L, Ice in Clouds Experiment, Layer Clouds	Greg Thompson	Nov 07 - Dec 07	bluevista
Climate Impacts of Solar Variability using WACCM within the CCSM	Fabrizio Sassi	Nov 07 - Feb 08	blueice
Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)	Louisa Emmons, et al.	Mar 08 - Apr 08	blueice
Real-time explicit convective forecasting with WRF-ARW for 2008	Morris Weisman, et al.	Mar 08 - Jun 08	blueice
Advanced Study Program 2008 Workshop	Peter Hjort Lauritzen	Jun 08 - Jun 08	bluevista

Weather Forecast for Mauna Kea Observatory	Tiziana Cherubini	Jun 08 - Sep 08	lightning
Flash Flood Predictions	David Gochis	Jul 08 - Aug 08	bluevista
Accelerated Scientific Discovery	many (see ASD report)	Sep 08 - Nov 08	bluefire

On-demand computing and consulting support was provided for the 2008 Advanced Studies Program Workshop on Numerical Techniques for Global Atmospheric Models. CISL provided access to the production Linux cluster to support real-time weather forecasting for the Mauna Kea Observatory (see sidebar). Additionally, CISL supported the NCAR Front Range Flash Flood Prediction System via provision of real-time computing resources.

During FY2009, approximately one-half of the new IBM POWER6 system bluefire will be dedicated to Accelerated Scientific Discovery projects during the first two months of the year. Additionally, CISL operations, consulting, and systems staff will continue to provide full 24x7 support for the special campaigns and on-demand, real-time computing throughout the year.

The special computing campaigns and provision of on-demand and real-time computing support the NCAR strategic priority of "Developing and providing advanced services and tools." This work is made possible through NSF Core funds, including CSL funding.

CISL provided remote access to the production Linux cluster (lightning) for Tiziana Cherubini (University of Hawaii) to continue operational, real-time weather forecasting for the Mauna Kea Observatory while a new computer system was being installed at her center. Davide Del Vento of CISL's Consulting Services Group helped her install model procedures and scripts on lightning. She reported that "The working environment seems to be the ideal one to run WRF [the Weather Research and Forecasting modeling system]. WRF has been running quite regularly since then, thanks particularly to CISL support."

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

NCAR is sponsored by the National Science Foundation.

Supporting supercomputer users

NCAR's strategic commitment is to provide robust, accessible, and innovative information services and tools to our customers. CISL provides end-to-end service for its supercomputing users using the full capability of the laboratory staff. For increased efficiency, consulting service has been expanded to include other groups within CISL who provide frontline assistance as well as in-depth expertise. Contacts are tracked using an ExtraView HelpDesk trouble ticket system.

Computer Production Group (CPG) staff, represented by Raisa Leifer, Scott Baker, and Susan Albertson (left to right), provide 24x7x365 frontline customer support and computer room operations and monitoring. CPG staff, always available to handle any contingency, are critical for the business continuity of the computing facility and the institution.

In FY 2008, frontline support resolved 1,582 tickets in the time interval from September 2007 through August 2008. In the same interval, advanced support resolved an additional 1,061 contacts, for a total of 2,643. The average number of log entries per ticket was 4.5, with communication highest with users on complex cases. Average response time for frontline support for ticket resolution was about 1.3 days, while a longer average response time of about 4.2 days was required for more complex issues. The average number of staff who worked on tickets was 1.31, demonstrating cross-team cooperation in resolving issues.

A benefit of tiered customer support has been to free CISL staff to supply customized, one-on-one service for special campaigns such as the Accelerated Scientific Discovery program, which is providing opportunities for capability computing projects requiring hundreds of thousands of processor hours on the new IBM POWER6 platform, bluefire. As the system was brought online, the consulting group provided input on making the system easier to access, documentation and training on the new features of the system, and help to users in porting and scaling their parallel codes to run well on the new platform.

In FY2009, we anticipate further growth in this type of scientific support, as well as to continue support for new versions of NCAR "flagship" models such as CCSM and WRF. We also expect to increase support for TeraGrid-allocated projects.

This work supports NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools" to our customers. This ongoing service is supported by NSF Core funds including CSL funding.

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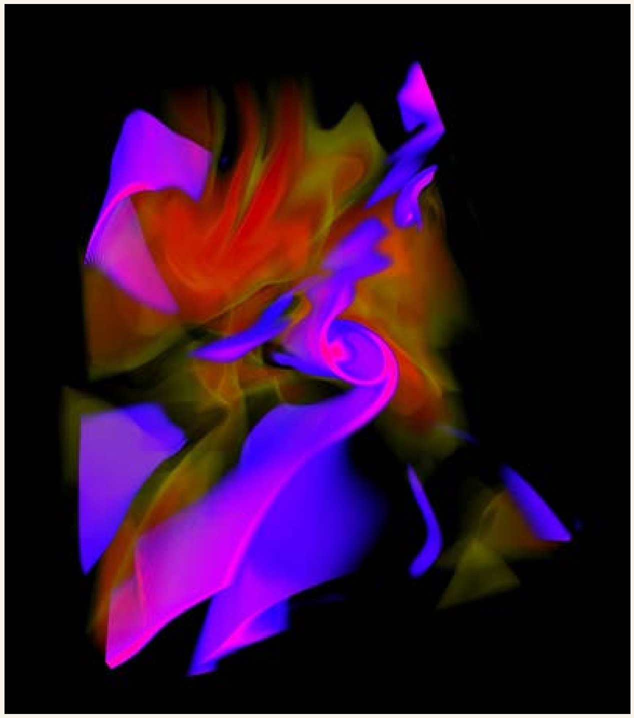
Very large computational experiments: Accelerating science

The success of FY2007's Breakthrough Science initiative in providing increased opportunities for very large computational experiments has encouraged CISL to expand this program with the installation of bluefire in FY2008. Mechanisms were put in place to increase the size of computational experiments that could be accomplished with CISL supercomputing resources by the university, NCAR, and Climate Simulation Laboratory (CSL) communities. These mechanisms included:

- Solicit proposals for the Accelerated Scientific Discovery (ASD) initiative from universities, the NSF, and NCAR to use almost 3 million bluefire processor hours during September, October, and November 2008.
- Encourage universities to submit very large proposals to the October CISL HPC Panel (CHAP) by emphasizing the very large requests that the CHAP approved in April 2008 and the increased availability of HPC resources to the university community.
- Encourage NCAR research based on very large computational experiments by reserving and allocating some computing resources through the NCAR Executive Committee.
- Establish a minimum allocation award size for the Climate Simulation Laboratory (CSL) during the next round of CSL proposals and publicize it in the FY2008 announcement of opportunity to encourage larger proposals.



This figure was produced in FY2008 from computational experiments carried out as part of FY2007's Breakthrough Science initiative and shows volume rendering of the amount of alignment between magnetic field and velocity in a 1536^3 direct numerical simulation of magnetohydrodynamic (MHD) turbulence. Alignment is strong (blue-to-hot-pink) in the both rolled-up (and surrounding) sheets, but weak in between (salmon). This property helps explain the formation of such structures as the roll-up in turbulent MHD flows, and may lead to an understanding of the effect of these small-scale structures on the large-scale dynamics. (Figure courtesy Annick Pouquet, NCAR and Pablo Mininni, NCAR).

The focus on very large computational experiments supports NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools" to the university and NCAR communities. In addition, the research performed supports NCAR's strategic goal to "Improve understanding of the atmosphere, the Earth System, and the Sun."

FY2008 accomplishments

Accelerated Scientific Discovery:

- In April 2008 CISL announced the 2008 Accelerated Scientific Discovery at NCAR program using the IBM POWER6, bluefire, to be installed in the summer of 2008.
- Applications were accepted for research requiring more than 200,000 bluefire processor hours from universities with active NSF awards in the atmospheric or closely related sciences. Applications were also accepted from NCAR for research requiring more than 200,000 processor hours.
- The CHAP reviewed and selected three university projects and a back-up project in case one of the university projects did not start on time. The NSF selected two projects. NCAR selected three projects and a back-up project.
- Applicants were notified in early June, so selected projects would have sufficient time to set-up their code for the proposed computational experiments.
- All selected and back-up projects were required to provide benchmarks showing the efficiency of their production code on bluefire by August 8, 2008 or risk losing 80% of their allocation. Each project was assigned a person from CISL's Consulting Services to assist them in tuning their code so they could make efficient use of bluefire. With this assistance, all projects met the deadline.
- All selected projects also met the deadline to begin computations in September 2008.

- CISL has contacted each ASD project on their data analysis and visualization needs and has already provided large amounts of disk space for those who need it for data analysis on CISL's dedicated data analysis computers.

CHAP proposals:

- The NSF-supported university community in the atmospheric and related sciences was encouraged to submit very large proposals for the October 2008 CHAP meeting by noting the largest proposals that had been approved by the CHAP in April 2008 and noting the large increase in resources available to the university community on bluefire. A reminder was sent this year to university researchers approximately one week before the deadline highlighting this opportunity to propose large computational experiments.
- The university community responded in September 2008 with an unexpectedly large number of proposals, more than double the usual number of panel requests. The largest proposals were similar in size to the ASD proposals at 400,000 bluefire processor hours, although they will be accomplished over a longer time period. Most university proposals envisioned completing their large computational experiments over 12 months.

NCAR allocations:

- The supercomputing resources available to NCAR researchers has been under pressure for a number of years resulting in too much fragmentation of computing resources. In September 2008 NCAR management expanded the resources for very large computational experiments performed by NCAR researchers by expanding the NCAR Capacity Computing (NCC) pool of resources in proportion to the increase in computing delivered by bluefire.

CSL allocations:

- During 2007 the CSL Allocation Panel, an NSF-appointed panel, suggested that some of the CSL proposals were requesting too few processor hours.
- In 2008 a new, minimum request size was announced as part of the 2009 CSL Announcement of Opportunity issued by CISL.

FY2009 plans

Accelerated Scientific Discovery:

- ASD projects will complete their computations on November 30, 2008. CISL staff will continue to provide a high level of service to these projects throughout their computing campaigns.
- CISL will provide extensive assistance to the ASD projects with their data analysis and visualization needs. This effort is expected to continue through May 2009.

CHAP proposals:

- The CHAP will meet on October 9, 2008 to review and make allocations to 45 university projects requesting large computing allocations.
- Based on CISL's work with the ASD projects, CISL will implement a new code efficiency program for the university projects receiving the largest CHAP allocations. Each project receiving more than 150,000 bluefire processors hours will be asked to provide benchmarks of their production code showing good utilization of bluefire, prior to receiving their full allocation. CISL support staff will be assigned to each of these very large university projects to assist in tuning and optimization of the production code. These projects will be given a medium-size testing allocation to set up their production codes and run benchmarks. When the projects submit a satisfactory benchmark, the full allocation recommended by the CHAP will be provided.

NCAR allocations:

- On December 1, 2008, NCAR's NCC program for very large computational experiments will begin. The first two projects have been selected from ASD projects submitted in 2008 by NCAR researchers. NCC projects are run one at a time for several months until completion to accelerate the scientific research process.

CSL allocations:

- Thirteen projects were awarded large allocations in 2007, representing 45% of CISL's total supercomputing resources. The CSL projects will receive a 2.4-times increase in their monthly allocation on December 1, 2008 because of the additional resources provided by bluefire.
- The CSL Allocation Panel will meet in January 2009 to select the CSL projects for the next 18 months with allocations beginning June 2009. The new minimum award size will ensure that the CSL provides resources for very large computational experiments in support of the U.S. Climate Change Science program.

Sponsorship

The ASD initiative is sponsored by the National Science Foundation through the provision of computational and support

resources. The university researchers using these resources are funded by NSF awards from ATM and OCE. NCAR researchers utilizing the ASD computational resources were also sponsored by the NSF.

The Climate Simulation Laboratory (CSL) is a multiagency computing facility established in 1995 and is dedicated to climate modeling in support of the U.S. Climate Change Science Program. The CSL is administered by the National Science Foundation and hosted by NCAR.

Director's Message

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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Cybersecurity enhancement

UCAR manages and maintains a large and diverse set of compute, data, data storage, email, web, and network servers that form the core information technology within the institution. Not only are these systems valuable monetarily, they comprise vital scientific research tools and business continuation systems used by the UCAR organization and university communities. To pursue the scientific mission of the organization in an unobstructed manner, CISL is committed to maintaining a security posture that represents an enterprise to the community and adheres to NSF security best practices and recommendations.

Providing secure information technology systems within CISL and across UCAR supports the NCAR strategic priority of "Developing and providing advanced services and tools." It is vital to the organization that we protect systems, data, and intellectual property at the highest level possible that keeps usability and security in balance.

During FY2008, these factors are vital to the continued security of IT systems at UCAR:

- Coordinated consistent security policies and procedures across UCAR by the Computer Security Advisory Committee (CSAC), with the goal of achieving the appropriate balance between reasonable protection and pursuit of the scientific mission of the institution
- Staff participation in the community-wide, NSF-sponsored Cybersecurity Summit 2008 held in May 2008 (NCAR hosted a breakout session in this year's summit)
- Initiating a redesign of the UCAR-wide token authentication service moving critical services to use One Time Password Tokens
- Placing increased importance on computer and network security when acquiring and configuring new equipment (computers, storage, network routers, etc.)
- Coordinated and presented security training for system administrators throughout UCAR

To maintain a meaningful security posture and to fulfill the near-term security objectives of CISL, the following plans for FY2009 are in place:

- Produce a UCAR/NCAR Cybersecurity Strategic Plan for 2009-2012
- Perform in a leadership role at the NSF-sponsored Cybersecurity Summit 2009
- Complete implementation of one-time password (OTP) technology across UCAR including the new gateway to bluefire
- Enhance our aggressive network and host monitoring tools to support increased traffic loads and provide redundancy by taking advantage of our other campuses
- Engage in collaborative efforts with peer and TeraGrid centers to share cybersecurity information, best practices, and incident notification
- Optimize our central logging system to incorporate all of UCAR

Cybersecurity at NCAR is supported by a combination of NSF Core funding and UCAR Communications Pool indirect funds.

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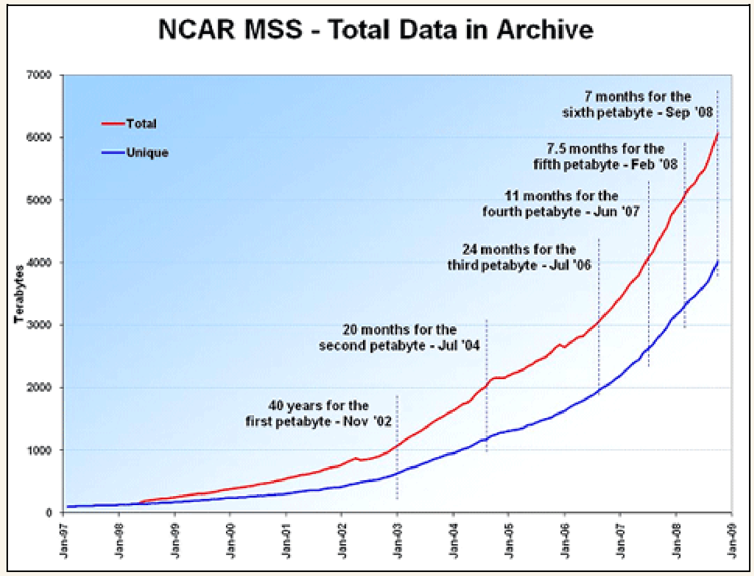
Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

NCAR is sponsored by the National Science Foundation.

Mass Storage System (MSS) improvement: AMSTAR

The NCAR Mass Storage System (MSS) has been a high performance, reliable, and scalable system over the past 20 years. It has demonstrated high availability and accessibility and proven its cost effectiveness.



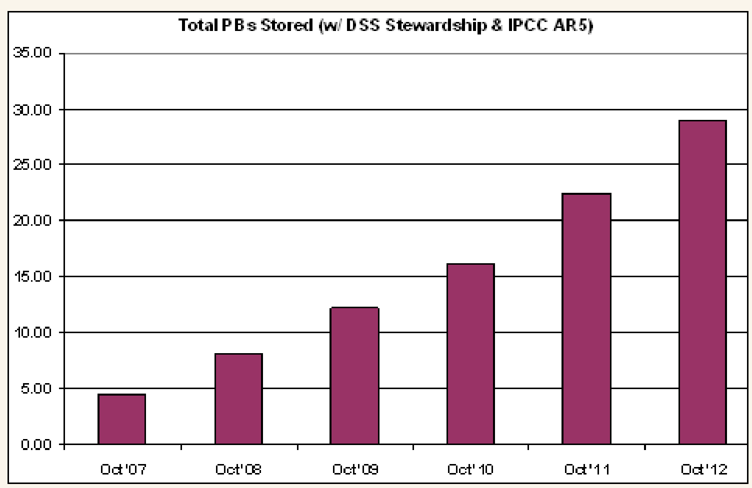
This chart of the past 12 years of NCAR MSS growth shows unique and total (includes duplicate copies) bytes. This exponential growth of the NCAR MSS is expected to continue with the annual growth rate exceeding 5 petabytes by 2012.

The MSS in many ways has been what has distinguished computing at NCAR from computing elsewhere, and the system continues to be highly regarded by users and by peers at other centers. MSS maintenance and development supports the NCAR strategic priority of "Enhancing capability and capacity of NCAR supercomputing."

Today, the NCAR MSS remains one of the most capacious archives. At the end of FY2008, it surpassed 6 petabytes (PB) of total data (4 PB of unique data), transfers more than 10 terabytes (TB) of data per day in response to user requests, and transfers another 10 TB of data per day for internal data migration and data movement to new media. The MSS is growing at a net rate of more than 200 TB per month.

The future development and deployment of the NCAR Mass Storage System is constrained by both the need to continue providing traditional file storage and access to Mass Storage services in the context of a full 7 by 24 production environment, as well as adopting new roles as an integrated component of larger UCAR-wide data management efforts. The MSS's traditional role will continue: to reliably preserve UCAR, NCAR, and university community data while serving a wide client base on multiple levels.

The MSS must scale up to meet an ever-growing demand for secure, reliable data storage and high-performance access. This requires the constant evaluation and periodic deployment of the latest, highest-performance, and most cost-effective hardware and software technologies available.



This chart projects the unprecedented MSS growth estimated over the next four fiscal years FY2009-FY2012. These estimates were used as the capacity increase requirement for AMSTAR.

The completion of the CISL Integrated Computing Environment for Scientific Simulation (ICESS) Phase 2 deployment more than quadrupled NCAR's peak computing capacity. With the ICESS supercomputing upgrade combined with the planned growth of CISL's Data Support Section's scientific data holdings and the upcoming Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), CISL is expecting an unprecedented increase in the capacity of the MSS over the next four years. Additionally, the tape library robotics currently in production are nearing end-of-life. The vendor of those tape libraries has set an end-of-service date of December 2010. This allows only two years to deploy replacement tape technology and migrate more than six petabytes of data to the new technology.

To accomplish this upgrade, CISL initiated a Request For Proposal (RFP) at the beginning of FY2008 named "Augmentation of the Mass Storage Tape Archive Resources" (AMSTAR). Released in late November 2008, AMSTAR is a four-year subcontract awarded to replace the MSS StorageTek Powderhorn tape libraries (silos) and 9940x tape drives and media with new robotic tape libraries, tape drives, and media that will increase MSS data storage capacity to beyond 30 petabytes. The AMSTAR offeror proposals were evaluated in mid-FY2008, and a competitive range was determined. The offerors in the competitive range provided equipment for an on-site Live-Test-Demonstration (LTD) where CISL staff evaluated the equipment. A final recommendation was made to the CISL Directorate based on the proposals and LTD results, approval to negotiate with the offeror was obtained, and contract negotiations were completed at the end of August 2008.

Production deployment of the new technology is expected in early FY2009. To complement the new AMSTAR tape technology and support the increased ICESS computing capacity, the following MSS enhancements occurred in FY2008:

- The MSS disk cache capacity was doubled from 50 terabytes to 100 terabytes.
- The MSS data connection to the new ICESS supercomputer, bluefire, was upgraded from 1 Gigabit Ethernet to 10 Gbps.
- Enterprise-class tape technologies were evaluated in preparation for AMSTAR.

FY2009 MSS plans include the production deployment of AMSTAR and the start of the two-year data migration to the new tape technology. Additional MSS server capacity upgrades will be deployed to support the increased data transfer and metadata workload required by bluefire.

The NCAR MSS is managed by CISL under the UCAR/NSF Cooperative Agreement and is supported by NSF Core funds including CSL funding.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog
NCAR is sponsored by the National Science Foundation.

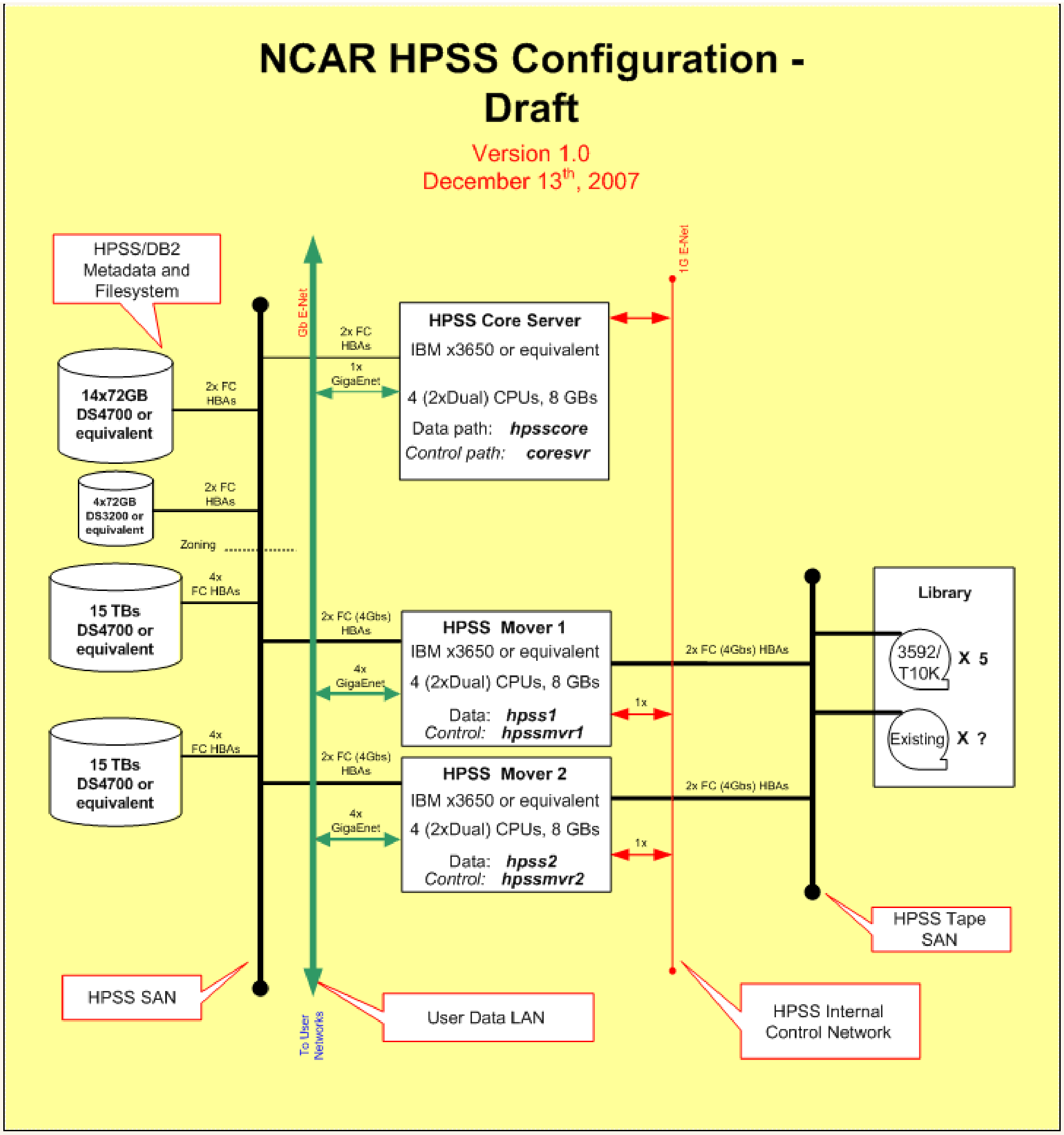
Deploy a development High Performance Storage System (HPSS) system for evaluation

The National Science Foundation TeraGrid uses high-performance networks to integrate supercomputers, data archives, and data analysis facilities around the country. Its coordinated work environment enables researchers throughout the United States to collaborate on especially challenging scientific questions, and to process vast amounts of data that would not be manageable on smaller or isolated computing systems.

In FY2007 CISL deployed a portion of its IBM Blue Gene/L supercomputer, frost, on the TeraGrid. Frost has been an operational TeraGrid resource since August 1, 2007, and can provide 4.5 million CPU hours annually to the TeraGrid research community.

In FY2008 CISL began deployment of an IBM High Performance Storage System (HPSS) to complement frost as a TeraGrid resource to the research community and to evaluate HPSS as a future CISL data archive solution. HPSS has been deployed by a number of the TeraGrid Resource Providers. The deployment of HPSS at NCAR will enable a homogeneous storage solution for the TeraGrid, enable potential data archive connectivity directly with Wide Area Network (WAN) filesystems on the TeraGrid, provide a data management system administration learning opportunity in a security environment external to the UCAR security perimeter, and provide CISL staff hands-on experience with HPSS which will be used to evaluate HPSS as a future CISL data archive solution.

This effort supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Engaging a broader and more diverse community."



The figure shows the initial HPSS deployment configuration sized to support 1 petabyte of total storage. Working with the IBM HPSS support team, the initial HPSS deployment configuration was developed to support the HPSS evaluation system. This entry-level configuration will enable the CISL deployment of HPSS as a TeraGrid resource and HPSS evaluation as a future CISL data archive solution.

A modestly sized HPSS configuration was developed in concert with the IBM HPSS support team. The configuration included a minimal number of HPSS servers, minimal amount of disk cache space, and minimal tape resources. The HPSS servers and HPSS service support agreement were purchased in FY2008. The HPSS servers were installed within the confines of the UCAR security perimeter and will be moved outside the perimeter in FY2009. The HPSS software was loaded and operationally validated. The initial disk cache space will be acquired in early FY2009. The tape resources composed of an automated tape library, five tape drives, and 1 petaByte of tape media are included in the Augmentation of the Mass Storage Tape Archive Resources (AMSTAR) Request For Proposals. It is anticipated that the AMSTAR equipment will also be installed in early FY2009.

An initial 30 terabytes of disk cache will be acquired and deployed in early FY2009. The disk cache will buffer active data on low latency storage, thus reducing end-user access time to that set of data. AMSTAR deployment in early FY2009 will complete the initial HPSS system configuration with tape library, drive, and media technology. A soon-to-be-released enhanced version of HPSS will be installed after the disk cache and tape resources are in place providing optional Hierarchical Storage Management (HSM) integration with the IBM General Parallel File System (GPFS). GPFS is currently deployed as a WAN filesystem resource on the TeraGrid. Final deployment of the HPSS system outside the UCAR security perimeter will then commence, resulting in a fully operational HPSS system ready for TeraGrid use and CISL evaluation. End user interfaces will be one of the first evaluation efforts. Standard HPSS user interfaces, custom interface options, and HSM capabilities will be investigated over the four-year life of the project.

The NCAR HPSS is managed by CISL under the UCAR/NSF Cooperative Agreement and is supported by NSF Core funds including CSL funding.

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Network engineering and telecommunications

The Network Engineering and Telecommunications Section (NETS) is responsible for the planning, engineering, installation, operation, maintenance, strategy, and research regarding the state-of-the-art data networking and telecommunications facilities for NCAR/UCAR. NETS provides a vital service to the atmospheric and oceanographic research communities by ensuring supercomputing resources are linked to scientists at NCAR and throughout the university research community. These activities are essential to the effective use of NCAR/UCAR's scientific resources, and they foster the overall advancement of scientific inquiry. This work supports NCAR's strategic priority of "Developing and providing advanced services and tools."

NETS pursued these LAN projects in FY2008:

- UCAR network infrastructure recabling
- Network monitoring
- Multicast support activities
- UPS, grounding, wireless networking, Voice over IP
- CISL LAN and SAN projects
- Security redesign project

NETS pursued these MAN projects in FY2008:

- Boulder Point-Of-Presence (BPOP)
- Boulder Research and Administration Network (BRAN)
- Boulder Valley School District fiber partnership
- Remote-working and home-access

NETS pursued these WAN projects in FY2008:

- Front Range GigaPOP (FRGP)
- UCAR Point of Presence (UPoP)
- National LambdaRail (NLR)
- Internet2
- Bi-State Optical Network (BiSON)
- TeraGrid

In FY2009, NETS will continue to provide support and enhancements for these essential networking services.

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Phone upgrade/GigE to the desktop

NETS converted to and has since supported a Voice over Internet Protocol (VoIP) phone system for the past six years. The system has exceeded its projected five-year life, and technical advancements are now available that justify the upgrades to the VoIP system.

NETS is in the process of upgrading all UCAR phones to 1-Gbps capable, and therefore enabling 1 Gbps to the desktop as standard service when complete. This project began in spring 2008 and will be completed in 2009. This is part of the larger IPT teams plans for implementing a number of upgrades to the VoIP deployment at NCAR. This is a phased approach to migrate existing applications to new hardware, upgrade the applications to the Linux OS, and provide additional features to users. We will review and enhance the overall redundancy, reliability, and security of the production IPT network.

This work addresses NCAR's strategic priority of "Developing and providing advanced services and tools" and is supported through UCAR Communications Pool indirect funds.

This shows the new Cisco phone that will be installed. This phone has an optical hook switch, a color display, and supports GigE (versus the current 100 Mbps) to the connected machine. Users will benefit from the additional speed and features the new phones provide.

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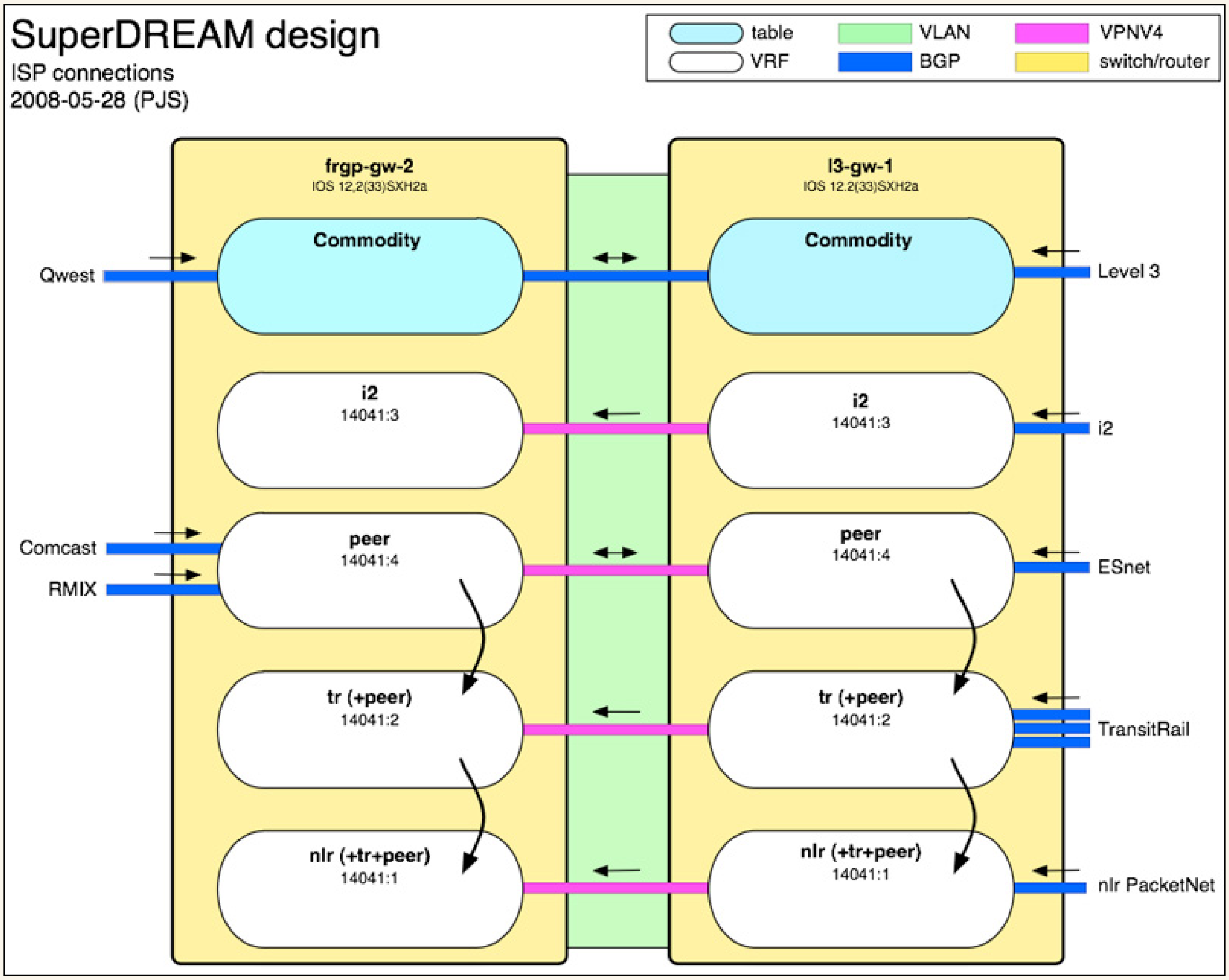
SuperDREAM

SuperDREAM is a project to upgrade the equipment and networks of the Front Range GigaPoP. SuperDREAM builds on the foundation of DREAM, a successful project that linked the two FRGP sites in Denver with a fiber ring. SuperDREAM is underway and all hardware has been upgraded and is operational. About half the FRGP members have been cut over to the new routing infrastructure. The remaining FRGP and UPoP members will be cut over by the end of 2008.



This is the new conceptual routing design of SuperDREAM. The new routing design optimizes and simplifies the FRGP routing infrastructure. The new routing will benefit the FRGP and UPoP members while simplifying and improving support by the FRGP engineers.

The goals of SuperDREAM are to:

1. Reduce single points of failure (SPoFs)
   Currently, the main routers and switches are SPoFs for some FRGP services. SuperDREAM will provide redundant paths from the FRGP routers to the commodity Internet. SuperDREAM will also allow members to connect at both FRGP routers, removing the member connections themselves as SPoFs.

2. Optimize routing
   Currently, I2 Abilene and Level3 commodity traffic arrives at the l3-gw-1 router and is sent to the frgp-gw-1 router, where it is rate-limited and then forwarded to FRGP members. This traffic could go straight out to the members that connect to the l3-gw-1 router. It is sent to frgp-gw-1 only because the frgp-gw-1 router applies rate limits. SuperDREAM will allow this traffic to flow straight to the FRGP members that have connections on l3-gw-1. This will remove a hop and reduce the load on frgp-gw-1.

3. Reduce load on the DREAM ring
   DREAM is the fiber ring that connects the two FRGP routers. It is approaching its 2 Gbps capacity. SuperDREAM will upgrade the 2x1

Gbps etherchannel to a 2x10 Gbps etherchannel. Improved routing will also reduce the traffic that traverses the DREAM ring.

4. Simplify rate limit
   FRGP rate limits are applied per-service, per-member. Some traffic is not rate-limited. Currently, rate limits are applied on the frgp-gw-1 router by careful application of complex policies. SuperDREAM will apply rate limits on both routers the same way, on the service-specific paths, so that each limit is applied directly on the proper traffic. The engineering of rate limits will be considerably simpler than it is now.

5. Homogenize the routers
   The original core router for the FRGP is frgp-gw-1, located in UCD's 1200 Larimer building. It routes all commodity and I2 traffic. When the FRGP joined NLR, a 6509 switch/router named l3-gw-1 was added at the Level3 co-location facility at 1850 Pearl Street. The frgp-gw-1 router was considered the "main" router, and the l3-gw-1 router was considered the "NLR" router.

   The functions of the routers became less distinct when the FRGP connected to TransitRail through l3-gw-1 and when the Abilene/I2 service was moved from Denver to UEN through the l3-gw-1 router. The l3-gw-1 router became something more than just the "NLR" router. SuperDREAM will homogenize the two routers so that they both provide the same basic functions. SuperDREAM also replaces a Juniper router with a Cisco switch/router, so that all the equipment at the FRGP is of the same type.

6. Improve member control over traffic
   Members will have explicit paths to the FRGP for each major service, providing more granular statistical information and more control over route selection.

This work directly supports NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools" and is supported through UCAR Communications Pool indirect funds.

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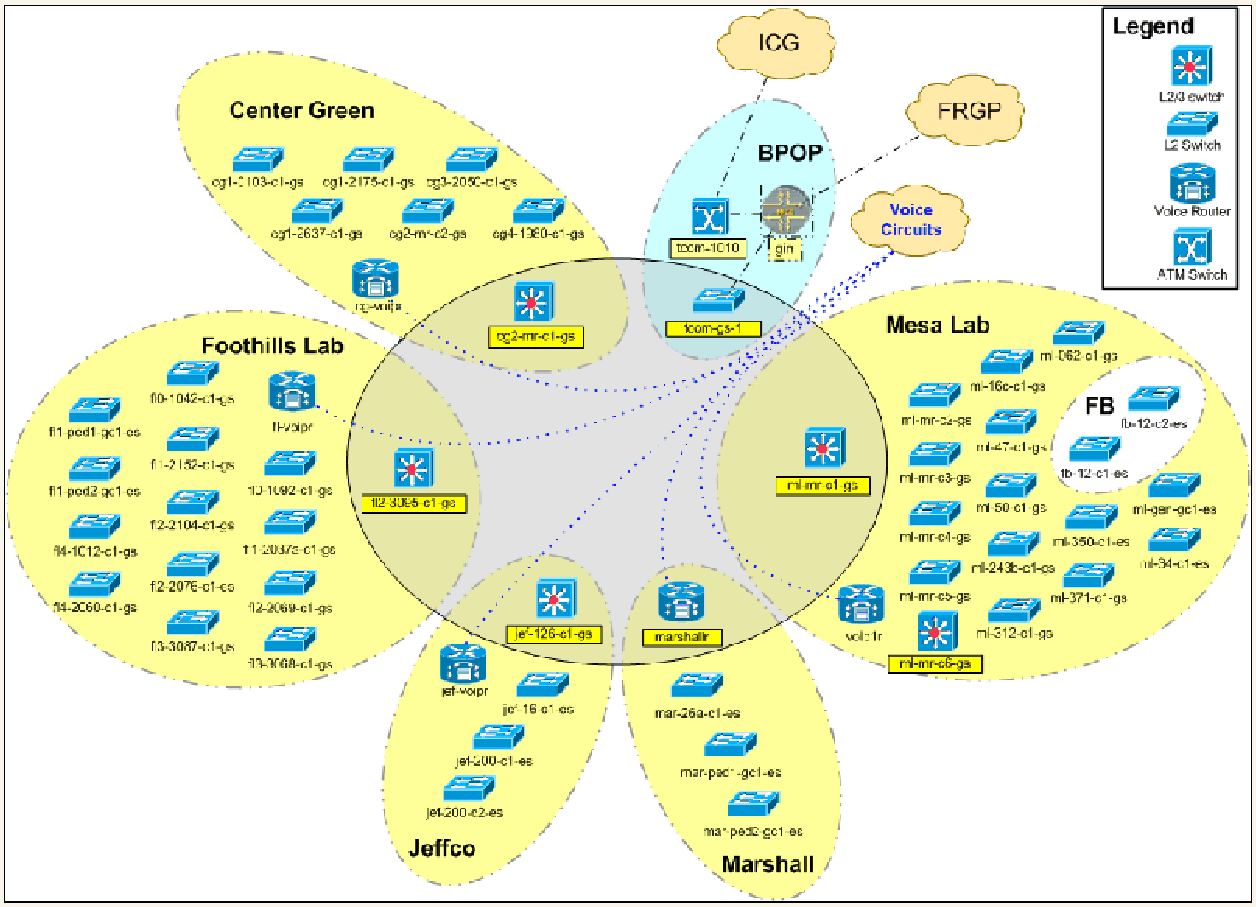
NCAR Annual Report | ASP report | CISL report | EOL report | ESSL report | RAL report

Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

NCAR is sponsored by the National Science Foundation.

Intercampus redundancy/redundant router project

The goal of this project is to implement redundant routing in the core UCAR network so that the failure of a single switch does not take the entire campus down. Another benefit of redundant routers is that upgrades are less impacting to the campus. Part of the project includes optimizing spanning tree for fast convergence and protection. This project also involved a UCARnet backbone upgrade to 10 Gbps for improved performance and reliability.



This image shows the UCARnet router topology with redundancy in place. The UCARnet routing infrastructure supports the entire network infrastructure across campuses and to the outside world. This new topology provides increased speed, robustness, and resiliency to the network

This work directly supports NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools" and is supported through UCAR Communications Pool indirect funds.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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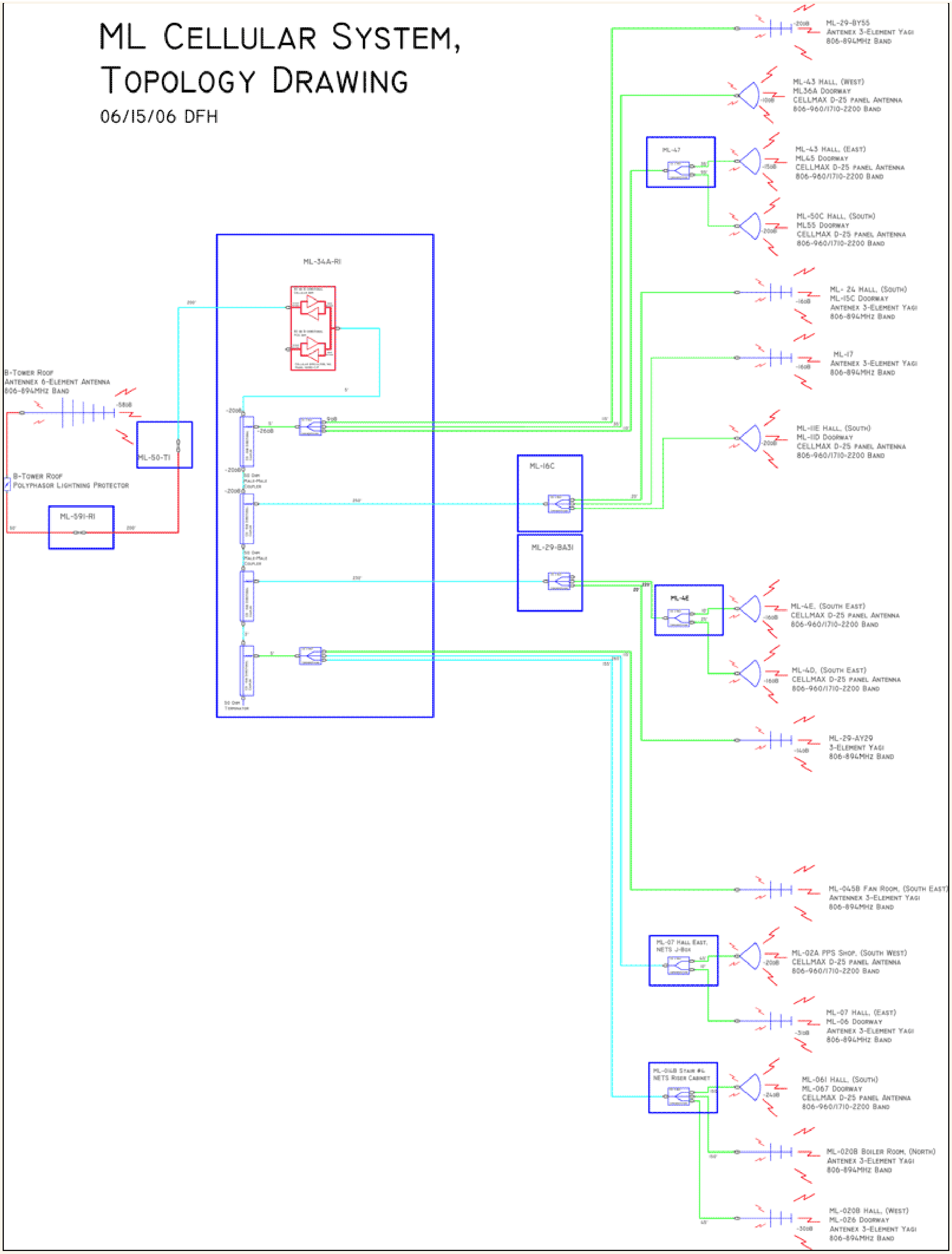
Cell phone infrastructure upgrade

NETS has replaced/enhanced the existing in-building cell system that supported only Sprint/Nextel cell phones. The FCC changes to the Nextel cell band frequencies forced us to make this change.

Along with the FCC frequency changes, Nextel has been decreasing its market share to the point where Nextel's future is uncertain. In light of these current events, NETS decided to move forward and support larger cellular carriers. Initially only Verizon and AT&T carrier phones will be supported at this this time. NETS hopes to add support for T-mobile and others in the future.

The system is now in place and operational.

This work addresses NCAR's strategic priority of "Developing and providing advanced services and tools" and is supported through UCAR Communications Pool indirect funds.



This image shows the design of the new cellular network infrastructure as it is installed. The cellular network infrastructure provides AT&T and Verizon cellular support in areas of the UCAR campus, especially the Mesa Lab, where public cellular service does not reach. This service has enhanced the business continuity and emergency capabilities of UCAR as well as providing a service that enhances communication for those UCAR employees who support networking, computing, and safety services.

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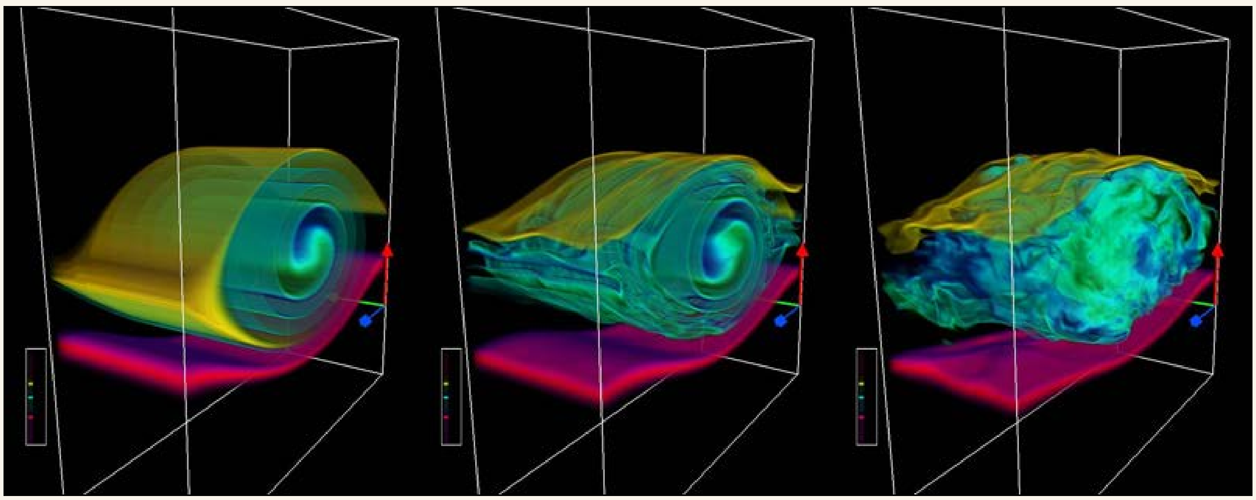
Data analysis and visualization environment advancements

The Data Analysis and Visualization Lab enhances scientific workflow by providing UCAR's research community with a highly advanced computing environment tailored for the specialized needs of interactive data post-processing, analysis, and visualization. This evolving environment provides a unified state-of-the-art computing environment comprised of powerful, closely coupled, interactive processing and visualization engines and large-capacity high-performance global file systems. We provide direct support to the research community by developing algorithms for relevant visualization and analysis methods and by producing animations and imagery on behalf of the scientific staff.



Generated by Benjamin Jamroz, Ed Lee, and Thorwald Stein, this image illustrates the Kelvin-Helmholtz instability. DASG helped host the TOY summer school where 30 Ph.D. students spent three weeks at NCAR learning about computation and visualization of scientific data sets. DASG's remote visualization services and VAPOR software provided students a unique opportunity to work with 3D visualizations of their computational data. The CISL Data Analysis and Visualization Lab provides computing resources and consulting expertise to meet the interactive data exploration needs of the entire UCAR scientific community. CISL's state-of-the-art data analysis capabilities play an integral role in the scientific discovery process for groundbreaking research in the geosciences.

The goals of this effort are focused on addressing the growing sizes and complexity of scientific problems being researched at UCAR. We have seen a significant increase in resolution and data set sizes that require not only the enhancement of NCAR computational resource capability and capacity, but that also challenge us to provide advanced services and tools. The Data Analysis Services Group works not only to provide a suitable computational environment but also works directly with users to help develop new techniques and algorithms that allow scientists to push the boundaries of discovery. This work supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Maintaining an innovative and creative workplace."

The evolution of this facility from a collection of dedicated standalone resources into a tightly coupled unified computing environment has been a multi-year process. In FY2008 we made great strides in aquiring and integrating a large-scale shared storage solution and powerful computational and graphics resources. We have enhanced the visualization capabilites through the use of remote desktop graphics software that expands this service into the data post-processing and analysis arena and powerful servers capable of handling today's large data sets. We have begun centralizing a high-performance storage cluster to provide high bandwidth data access shared between NCAR's supercomputer, data analysis cluster, and visualization cluster, significantly enhancing the scientific workflow.

By continuing this integration in FY2009 with additional computational, visualization, and storage enhancements, we will offer the data post-processing, analysis, and visualization community an entirely new and well-designed facility to tackle the larger challenges on the horizon.

This ongoing service is supported by NSF Core funds including CSL funding.

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Director's Message

Table of Contents

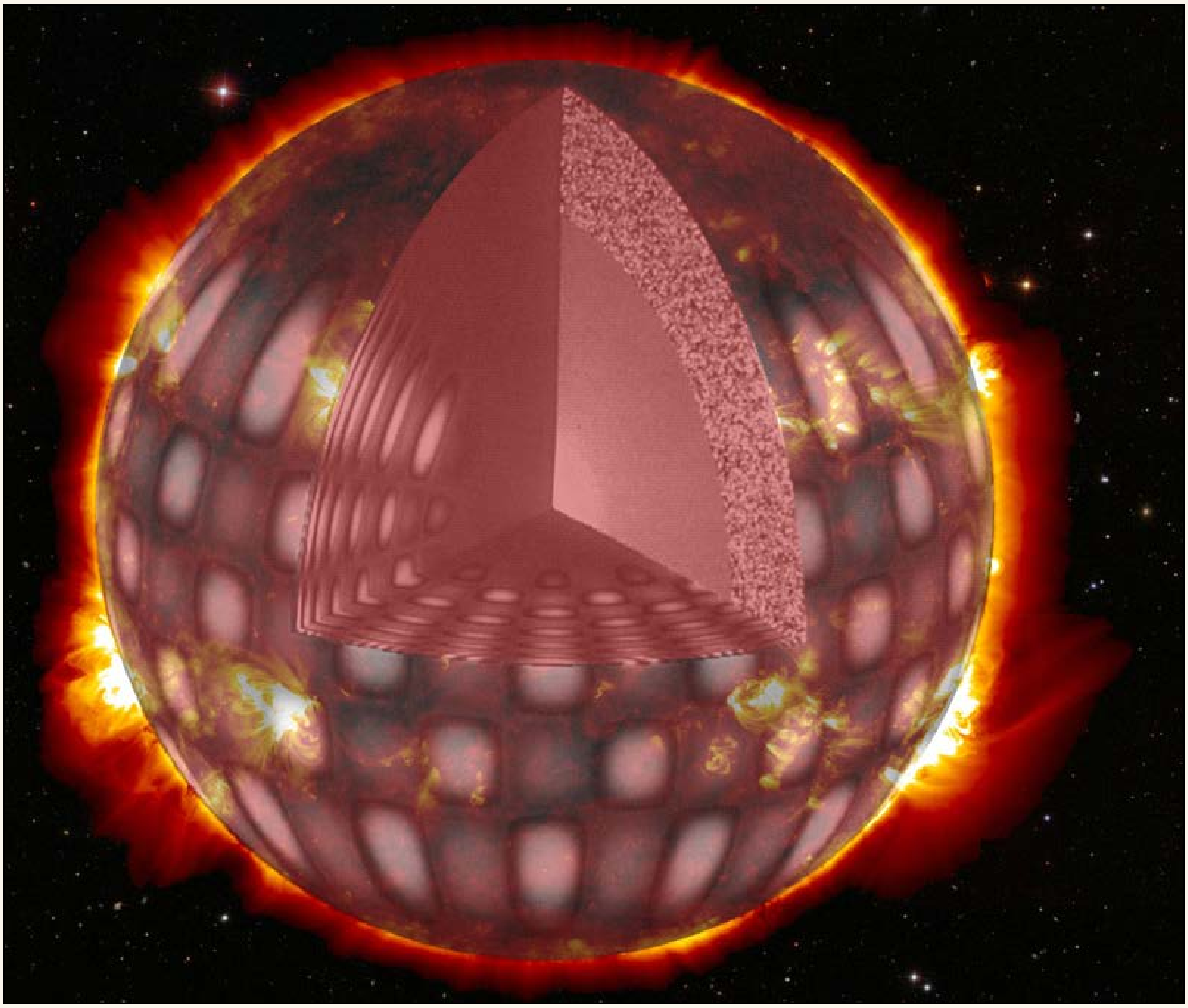
Strategic Goals: Science, Facilities & Technology

Research Catalog

NCAR is sponsored by the National Science Foundation.

TeraGrid operations at NCAR

By integrating with the TeraGrid as a resource provider (RP), NCAR has gained operational expertise and confidence in Grid computing, stimulated new strategic thinking about the design of cyberinfrastructure systems, changed how atmospheric and related science gets done, and enabled new opportunities for collaboration.



Scientists are gathering unprecedented quantities of data from sophisticated ground-based networks and space-based missions designed that look at the global oscillations of the Sun and other stars. This asteroseismology data can be used to deduce the age and internal structure of stars. Supercomputers provide an answer to the problem of analyzing this vast amount of information, and scientists are utilizing TeraGrid resources at NCAR's Computational and Information Systems Laboratory to delve deeper into stellar properties. The NCAR team is working to make the pipeline available to the asteroseismology community as a TeraGrid Science Gateway, called Asteroseismic Modeling Pipeline, and expects to have a working prototype of the system by the end of Fy2008.

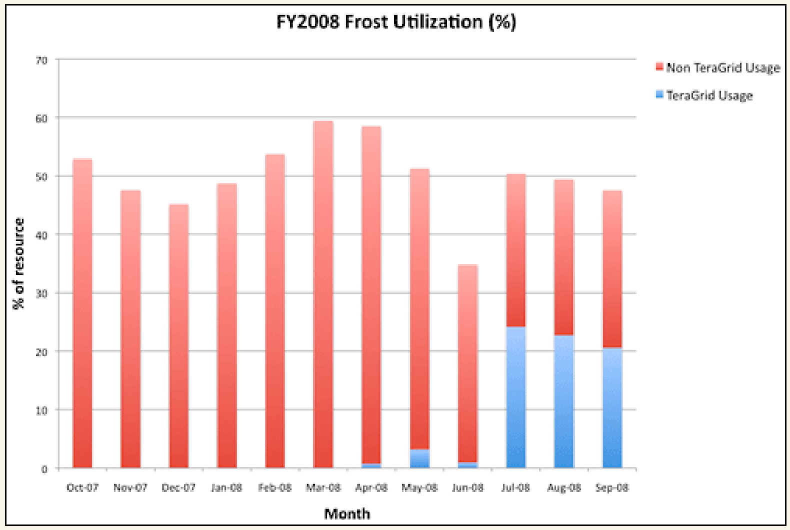
Coupled with these benefits to NCAR, the long-range broader impacts for NSF include:

- Access to new resources:
  These resources promise to accelerate climate and weather research on many fronts. These opportunities are already influencing NCAR's science priorities and objectives.
- High-speed, remote access to data:
  Wide area parallel filesystems promise to change how science campaigns and workflows are constructed by enabling cross-site data sharing.
- Opportunities to form new collaborations:

The TeraGrid continues to bring CISL staff and NCAR researchers into contact with not only the staffs of other resource providers but also scientists in disciplines as varied as solar physics and seismology -- collaborative relationships that most likely would never have formed without the TeraGrid connection.

- Data preservation:
  Safeguarding critical datasets, such as the ECMWF reanalysis archive at NCAR, is a high priority. To that end, NCAR and SDSC have duplicated critical data on each other's archives under a Memorandum of Understanding between the two organizations. To date, over 80 TB of NCAR research datasets have been archived at SDSC over a Storage Resource Broker (SRB) connection to SDSC.

Resource statistics



While overall utilization of frost hovered around 50% in FY2008, utilization by TeraGrid users has increased to around 20% of the resource in recent months. This trend is expected to continue in FY2009 with the award of a handful of mid-sized TeraGrid resource allocations to NCAR. These allocations are effective on 1 October 2008.

While the 2,048-processor IBM Blue Gene/L system frost was available an impressive 99.5% of the time, overall utilization of the system did not approach that level. As shown in the figure at right, total utilization of frost hovered around 50% throughout the year. This relatively low rate of resource utilization is, in part, an artifact of the ability of the Cobalt job scheduler to efficiently schedule parallel jobs on a 3D torus network topology under the constraint that jobs must be allocated in contiguous 32-processor blocks. This constraint results in a kind of knapsack problem for the job scheduler that it is currently unable to solve. This inherent limitation of the Cobalt scheduler cannot avoid creating "unschedulable islands" of computational nodes on an architecture like Blue Gene's.

Overall, TeraGrid users have used 24% of the cycles available to them on frost. As shown by the blue bars on the graph, TeraGrid usage was effectively zero during the first six months of frost's operation on the TeraGrid, but then began rising throughout the summer, presumably as TeraGrid users became aware of the existence of this resource and began applying for cycles via the TeraGrid's MRAC and LRAC allocation processes. Other factors that may explain this period of low utilization include:

- The excess computing cycles on the TeraGrid during this timeframe
- The infrequent TeraGrid resource allocation cycle (LRACs make allocations on a quarterly basis, and MRACs make allocations on a semi-annual basis)
- The reticence of NCAR users to voluntarily spend time on the TeraGrid application and account activation processes
- The availability of significantly more BG/L cycles at SDSC
- For the full TeraGrid user community, possibly an unwillingness to use or lack of awareness of this new, small resource
- Because the per-processor memory of the system is small, perhaps a perceived difficulty in using the BG/L architecture
- The relative age and single-processor speed of the BG/L system

During the period of August through September 2008, utilization by TeraGrid users suddenly jumped above 20%. This jump resulted from actively migrating important users on frost to the TeraGrid. Since NCAR makes only 25% of the frost resource available to TeraGrid users, this represents a 90% utilization of the frost allocation by TeraGrid users since July. In the most recent allocation, 773,000 CPU-hours were allocated to TeraGrid users on frost.

Cyberinfrastructure development

The resource manager and scheduler used on frost is Cobalt, an open-source project hosted at Argonne National Laboratory (ANL). We have been heavily involved in Cobalt development for several years, being one of the first sites outside ANL to use it. Contributions have included bug fixes, feature testing, and component development. NCAR and ANL also hold a weekly conference call in support of this collaboration, where discussion includes long-term planning in support of our TeraGrid initiatives. Our Cobalt development activities for the TeraGrid in CY2007 have focused mainly on the accounting and logging facilities. For example, we added the facility to run scripts both before jobs start running and after jobs complete. This gave us the ability to collect accounting information such as storage and network utilization on a per-job basis. All of our code modifications have been pushed back upstream to the Cobalt source repository, and are therefore made available to other sites that use Cobalt.

User support

NCAR prepared an announcement that appeared in *TeraGrid News* on August 1. We participated in the activities of the TeraGrid Services Working Group and the ARCH Working Group, including conducting surveys of users, reviewing new documents in the TeraGrid Knowledge Base, and testing new tools such as the User Portal and the TeraGrid News system. Support staff obtained login accounts on most TeraGrid platforms and familiarized themselves with the trouble ticket system. We wrote a web-based user guide for frost. We invited NCAR users of frost to obtain DAC accounts to familiarize themselves with the TeraGrid. Support staff attended TeraGrid 08, TeraGrid quarterly planning meetings, and Supercomputing 07 Birds-of-a-Feather sessions.

Security

The security posture of NCAR's TeraGrid systems has remained strong and is getting stronger. The NCAR/UCAR security group has been upgrading our network monitoring infrastructure. We are developing filtering strategies that allow us to process all of the traffic that enters or leaves the UCAR network, and we have improved our ability to scale up to handle a much greater volume of traffic.

We have also prepared a transition plan to shift our data acquisition from port mirroring in the production network switches to passive optical splitters. This will eliminate any possibility of a performance impact on the production network due to the monitoring infrastructure, and it will provide greater reliability if our network infrastructure is ever the target of an attack.

Frost itself has been diligently patched for each new vulnerability, and we have participated in the TeraGrid Security Working Group incident response process throughout the year. Our ReSET group implemented an account management system for frost, and we have verified that it works correctly for both new account creation and removal.

Asteroseismology Modeling Portal (AMP)

In February 2009, NASA is scheduled to launch the Kepler satellite -- a mission designed to discover habitable Earth-like planets around distant Sun-like stars. Hundreds of scientists from around the globe will be involved in the analysis of asteroseismic data from this mission, and interpreting the observations using state-of-the-art stellar models will present a significant data analysis challenge. NCAR has proposed to make these modeling capabilities available via a new Asteroseismology Science Gateway that utilizes TeraGrid resources.

TeraGrid build and test system

NCAR is evaluating and testing the TeraGrid Build and Test Service, based on the Metronome software package from the University of Wisconsin, by employing it to run the exhaustive test suite of a community software framework, namely the Earth System Modeling Framework (ESMF) regression test suite. So far the ESMF regression test suite has been installed on systems at NCSA and SDSC and is being installed on frost at NCAR. ESMF staff at NCAR are learning how to use Metronome.

Alignment with NCAR's strategic plan

This effort supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Engaging a broader and more diverse community." NCAR's TeraGrid RP operations are funded by NSF Core funds and UCAR Communications Pool indirect funds. The asteroseismology and TeraGrid build and test system activities are receiving $144K of funding from the TeraGrid Integration Group (GIG) through the University of Chicago for project year 4 of the TeraGrid (Aug 2008 - Aug 2009).

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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Blue Gene/L system operations

The IBM Blue Gene/L computer at NCAR (right) is designed for high performance and low power consumption. CISL and its collaborators performed significant R&D to make it a useful tool for geosciences research. Frost is now operating at a high level in multiple roles for universities, NCAR, and the TeraGrid.

The IBM Blue Gene/L (BG/L) supercomputing system named frost consists of a single BG/L rack containing 2,048 compute processors for 5.73 teraflops peak performance. This low-power system (25 KW) is managed by CISL's Research Systems Evaluation Team (ReSET) and is now a production supercomputer on the TeraGrid.

Frost was purchased as an experimental system to support researchers from NCAR, the University of Colorado at Boulder, and the University of Colorado at Denver who are investigating and addressing the technical obstacles to achieving practical petascale computing in geoscience, aerospace engineering, and mathematical applications. The opportunity to experiment with systems like BG/L is absolutely essential for NCAR to maintain its ability to provide capability and capacity supercomputing to the community.

In FY2008, frost was enhanced with additional storage and networking equipment. This additional equipment tripled the storage capacity from 6 TB to 23.2 TB and is used to support special projects, such as the collection, distribution, and analysis of the results of high-resolution CCSM runs. Frost was also used as a platform for evaluating the performance of a variety of new networking and storage systems at scale. As part of the evaluation, frost was connected to several storage systems, including a 100 TB storage cluster and several commercial storage solutions, using both Infiniband and 10 Gigabit Ethernet networking.

Also in FY2008, ReSET developed software to support the new IBM BlueGene/L High-Throughput Computing mode, which is being used to provide the capability for processing grid workflows consisting of large numbers of small tasks. ReSET continues to collaborate with Argonne National Laboratory to further develop Cobalt, the queuing system currently used on frost, by incorporating alternate scheduling strategies and interfacing it with the Coordinated TeraGrid Software and Services software stack.

Frost continues to be used by a broad community of researchers. Frost is also used as one of the primary computational resources for the University of Colorado's High Performance Scientific Computing course, including 38 doctoral students, 19 graduate students, and 12 undergraduate students. Frost was also used as the IMAGE Summer School in Geophysical Turbulence.

Frost continues to be available as a TeraGrid resource. The system now has 13 active users that were created through the TeraGrid's central account request system. Frost will be maintained through FY2009 to support users at NCAR and the University of Colorado as well as the larger TeraGrid community.

As an advanced supercomputing tool, frost enhances NCAR's capability and capacity to "conduct computer science, computational science, and applied mathematics research and development." The acquisition and operation of frost was made possible through NSF MRI Grants CNS-0421498, CNS-0420873, and CNS-0420985; through the IBM Shared University Research (SUR) program with the University of Colorado; and NSF core funding.

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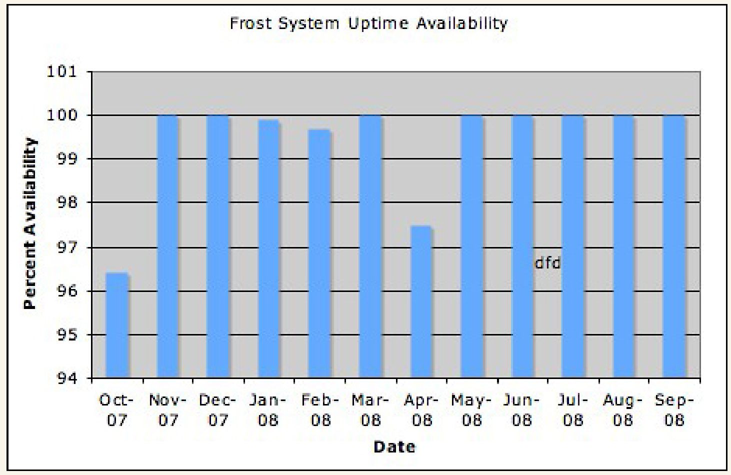
Blue Gene/L system uptime availability

The transition of the Blue Gene/L system frost from an experimental platform into a full production computational resource for the TeraGrid placed additional uptime requirements on the hardware, software, and operational policies of the machine. Even though frost demonstrated a proportionately low hardware failure rate and fairly robust management software suite since delivery, multiple opportunities existed to improve on the original system design, software configuration, and procedures to provide an increased quality of service to the expanded frost user community.



This chart shows the percent of frost uptime for each month in FY2008. The scheduled semi-annual machine room power-down periods were in October 2007 and April 2008. The overall system uptime availability for FY2008 including these periods was 99.46%.

During FY2008, CISL staff planned and implemented multiple system upgrades and modifications to the system configuration that focused on providing increased system uptime. Though the system and operational staff had already provided a high level of system availability, these improvements addressed known issues in the system software and offered additional insulation against a variety of failures.

Through FY2008, these modifications reduced unanticipated downtimes due to software component failures, and provided for a more robust operational environment.

The following availability-related activities occurred in FY2008:

- Careful planning allowed for the full operating system, file system, scheduler, and control system software upgrades and reconfiguration to be implemented during the scheduled semi-annual machine room power-down periods (October 2007 and April 2008). A single additional two-hour downtime was taken for a series of patches to the Cobalt scheduler to fix issues identified following a major upgrade.
- A new 17.2 TB file system was brought online using a custom high-availability design that eliminated all single points of failure. CISL engineers provided custom software engineering to implement support for this design under the IBM GPFS file system, as well as custom support scripts to improve management and provide a consistent interface for ongoing operation.
- Expansion of the user home directory storage space.
- Development of disaster recovery and continuity plans for multiple critical components and services.

FY2009 plans include developing disaster recovery procedures for several remaining single points of failure, including further development of the process to completely replace the service node in case of a catastrophic failure of that hardware.

The acquisition and operation of frost was made possible through NSF MRI Grants CNS-0421498, CNS-0420873, and CNS-0420985; through the IBM Shared University Research (SUR) program with the University of Colorado; and NSF Core funding.

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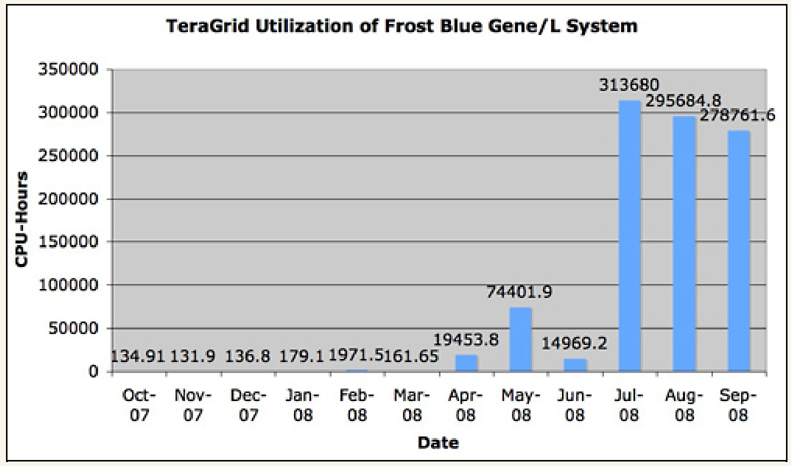
TeraGrid utilization at NCAR

By policy, 25% of frost is allocated for TeraGrid work. Historically, the TeraGrid use of the machine has been much less. As users and projects slowly added the frost resource to their allocation and began using the machine, the monthy TeraGrid utilization increased, although still at relatively low levels.



This plot shows the total CPU hours consumed by TeraGrid-specific jobs for each month in FY2008 for frost, the Blue Gene/L TeraGrid computational resource. As was noted in the "TeraGrid operations at NCAR" section of this report, the usage in the later months are equivalent to about 20% of the total CPU hours available on the machine (100% utilization would be between about 1.38M and 1.52M CPU hours each month, depending on the number of days in that month).

From August 2008 through September 2008, the TeraGrid utilization of frost dramatically increased. This increase was primarily due to actively migrating existing frost users to the TeraGrid. This sudden increase in TeraGrid activity since July actually represents a 90% utilization of frost's 25% TeraGrid allocation. In the most recent allocation, 773,000 CPU hours were allocated to TeraGrid users on frost.

The projects that have active allocations on frost have only used an average of 10% of their total project allocation, so the TeraGrid utilization of frost is expected to remain high throughout FY2009.

The acquisition and operation of frost was made possible through NSF MRI Grants CNS-0421498, CNS-0420873, and CNS-0420985; through the IBM Shared University Research (SUR) program with the University of Colorado; and NSF Core funding.

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TeraGrid support

Since NCAR's IBM BlueGene/L platform frost went live on the TeraGrid in August 2007, CISL has:

- Provided user services
- Supported the TeraGrid infrastructure on frost
- Collaborated in planning, resource allocations, and accounting
- Extended our scientific computational tools to a broader scientific community

CISL Consulting Services Group wrote and published the user documentation for frost, NCAR's computing resource on the TeraGrid. This document provides a complete set of introductory information for new users of the system.

This effort supports NCAR's strategic goal to "provide robust, accessible, and innovative services and tools" and NCAR's strategic goal of "enhancing capability and capacity of NCAR supercomputing."

In FY2008 CISL provided user support by reviewing and handling 29 NCAR-related TeraGrid user tickets. We also provided advanced consulting support for users with MRAC allocations. We wrote a frost user guide to include instructions for TeraGrid users and participated in weekly Services-WG teleconferences. We coordinated NCAR-related documentation on the TeraGrid portal, handling 23 requests for documentation upgrades or corrections. We assisted CISL ESMI personnel with practical advice for getting started with their build and test facility on the TeraGrid. We presented a poster at TeraGrid 08 conference, "Early Experiences with Performance and Scaling with CAM, WRF, and CCSM on Ranger."

In FY2008 CISL operated a proof-of-concept Data Analysis and Visualization (DAV) resource that was limited to a small number of friendly users. User support for the prototype system was provided in an ad-hoc manner by the Data Analysis Services Group. CISL's plans call for the deployment of a production DAV service in FY2009. A formal user support mechanism, more consistent with CISL's broader TG support policies, will be established in conjunction with the deployment of the new NCAR resource.

Also in FY 2009, we plan to provide the Community Atmosphere Model (CAM) and Weather and Regional Forecast (WRF) models to the TeraGrid for use in benchmarking. We are also participating in porting and validating the Community Climate System Model (CCSM4) on the Ranger system at the Texas Advanced Computing Center.

These ongoing services are supported by NSF Core funds.

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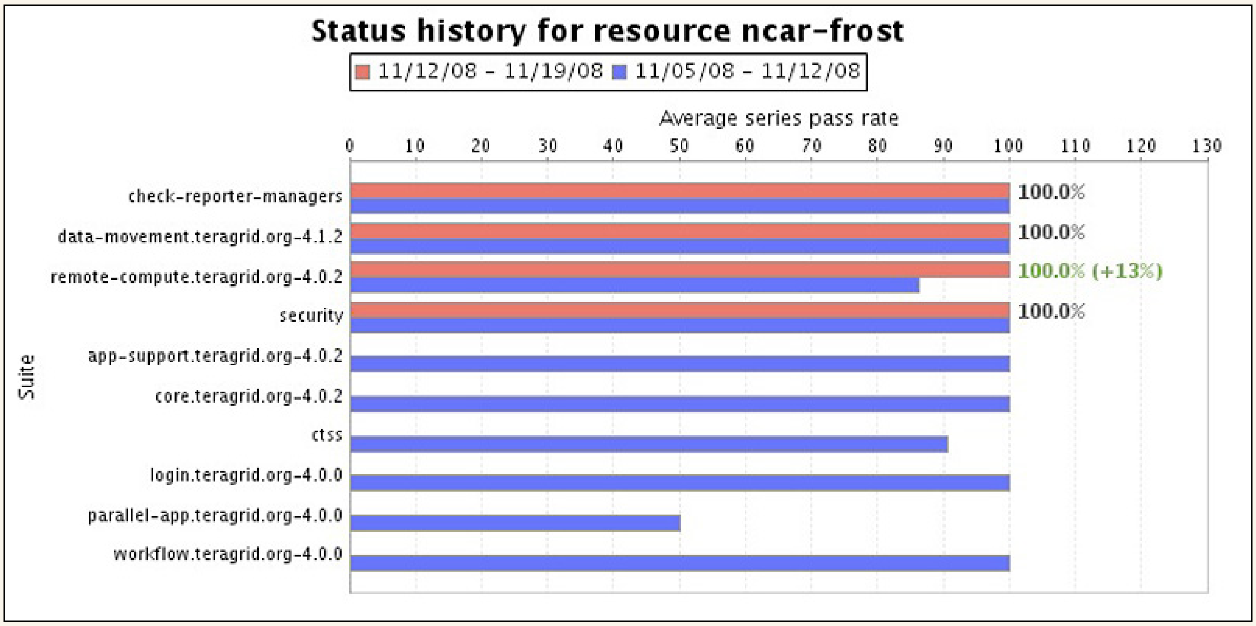
CTSS capabilities on Blue Gene/L

Coordinated TeraGrid Software and Services (CTSS) is bundled into individual kits, each enabling resource functionality for a specific set of services and user and system interfaces. Individual resource providers choose the kits they want to support for their resources, and thus select the services and components provided to the community.

Frost supports the following CTSS kits: Core Integration, Remote Login, Remote Compute, Application Development and Runtime Support, Data Movement, Parallel Application Support, Science Workflow Support, and the Wide Area GPFS File Systems Kit. These kits comprise the full set of functionality expected for a computational resource.



This image shows a two-week sample of automated test suite results for a portion of the supported kits on frost, NCAR's computational resource on the TeraGrid. The GPFS-WAN kit does not have an automated test suite. Additionally, some software components are not supported by the Blue Gene/L architecture, which is reflected in the sub-100% status results shown for the Parallel Application Support kit. The change in results between successive Remote Compute results reflects a transient error in the test during the previous period.

During FY2008, several of these kits were upgraded as part of the normal upgrade process: Data Movement (upgraded twice), Remote Compute, Core Integration, and Application Development and Runtime Support.

For the FY2009 period, the CISL ReSET team will continue to track updates and developments to these kits and upgrade when necessary, as well as provide input and feedback on modifications to the current kits and the development of new kits.

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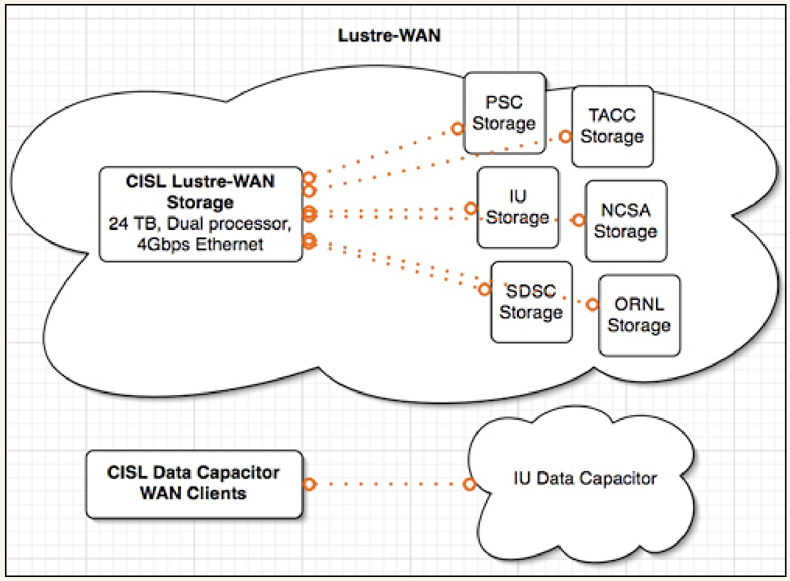
Parallel wide-area file system testing

The collaborative nature of the TeraGrid stresses the need for unified and global name spaces across participating centers and systems. Currently this is provided by a WAN file system exported by SDSC using the multicluster capabilities of GPFS, and NCAR's computational resource frost provides access to this file system on the frost front-end nodes. Although this is a production file system that provides a modicum of the desired features, there are multiple technical and licensing issues with a GPFS controlled central pool of storage which limits performance and client support, and thus restricts broad client access across the TeraGrid.



This image shows the locally provided Lustre-WAN storage pool and the connections between it and the remote storage pools provided by the other organizations participating in the Lustre-WAN development and evaluation. The image also shows the Data Capacitor WAN clients. The Lustre-WAN clients, from the same and other TeraGrid organizations, are not shown.

There are currently two TeraGrid-based projects to evaluate the capabilities of the Lustre file system to provide a similar service: the Data Capacitor WAN file system from Indiana Univerisity that is similar in design to GPFS-WAN, and the Lustre-WAN project that aims to provide a kerberos-secured global namespace which aggregates storage pools from across the TeraGrid. Over the past several years, CISL engineers in the ReSET group have deployed and evaluated Lustre to continue to track its development and develop the operational expertise to support production implementations, and this work has allowed us to participate in the ongoing TeraGrid evaluations of Lustre over the WAN.

Over the course of FY2008, ReSET engineers participated in the planning and organization of the Lustre-WAN project, as well as work to evaluate the underlying technologies and prepare local resources for inclusion in the Lustre-WAN file system.

During FY2008, CISL's ReSET engineers:

- Worked with CISL and UCAR security staff to provide a kerberos realm to the TeraGrid systems
- Evaluated Lustre kerberos support
- Configured and allocated local storage resources for integration with the larger Lustre-WAN efforts, which consists of a dual-processor system with an attached 24 TB of storage

In FY2009, CISL will continue to deploy the 24 TB of local storage as part of Lustre-WAN, as well as track and evaluate other Lustre-WAN developments. There are also plans to more fully evaluate the Data Capacitor WAN file system by implementing the required custom patches on dedicated local clients.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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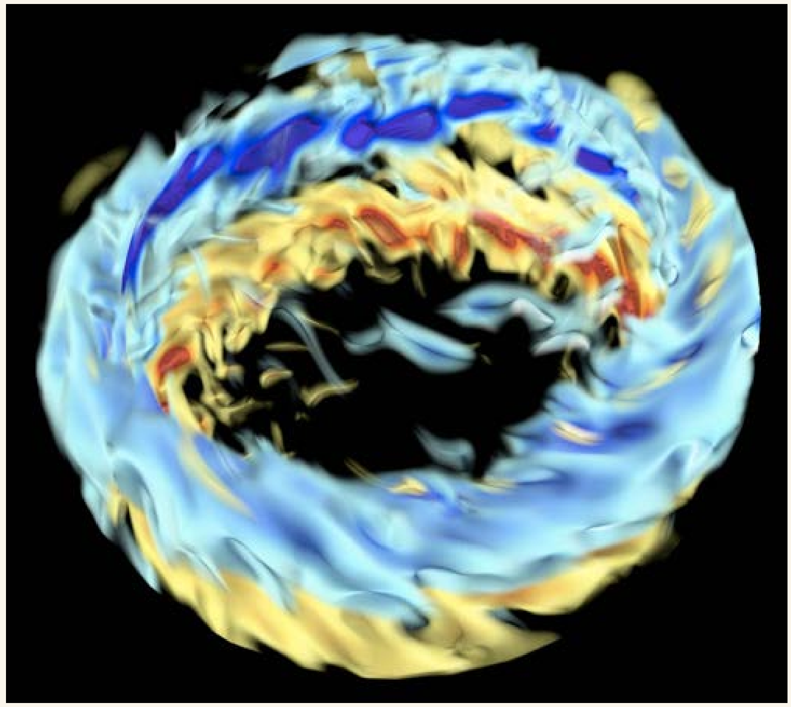
Twister visualization server deployment



Toroidal magnetic fields generated by dynamo action in the convection zone of a star like our sun, but rotating more rapidly at three times the current solar rate, as our own sun did when younger. This image was produced on twister, CISL's prototype TeraGrid visualization resource, by Ben Brown, University of Colorado.

In FY2007 a visualization computer named "twister" was procured, security hardened, and deployed as a prototype TeraGrid Data Analysis and Visualization (DAV) node. The system was a prototype in the sense that it was not a fully integrated TeraGrid resource (e.g. lacking the CTSS software stack), used primarily for GPFS WAN and remote visualization evaluation purposes, and available only to a limited number of users. Nevertheless, throughout much of FY2007 and FY2008 twister provided VAPOR-based visualization services to researchers at the University of Colorado who were exploring terabytes of astrophysical fluid flow simulation data computed and stored at SDSC. These data, outputs from the Anelastic Spherical Harmonic (ASH) model, were mounted at NCAR using GPFS-WAN and analyzed remotely from CU via HP's Remote Graphics Service.

In FY2008 CISL began the process of fully integrating twister into the TeraGrid as a production DAV resource. The integration process has been somewhat onerous and time consuming, as the TeraGrid lacks provisions (e.g. templates, scripts, or documentation) to facilitate standing up new resources. Integration of twister is nearing completion, and twister is expected to be announced as a new TeraGrid resource at end-FY2008.

Twister, purchased primarily to enable proof-of-concept work, offers only meager computation resources, capable of supporting only a very small number of simultaneous users. In FY2009, assuming utilization warrants, we will acquire and deploy a more capable DAV system. We will also deploy a resource scheduling mechanism suitable for interactive use, an activity that dovetails with broader CISL plans.

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NCAR TeraGrid integration efforts

Initial integration of NCAR computing resources with the TeraGrid is complete: frost has been an operational TeraGrid resource since August 1, 2007, and it provides up to 4.5 million CPU hours annually to the TeraGrid research community.

NCAR continues its efforts to develop and integrate other resources, primarily data storage, management, and visualization for the TeraGrid. NCAR operates a 100 TB Lustre storage testbed and is participating with other TeraGrid sites in evaluating Lustre-WAN. NCAR has a provisional visualization resource, called twister, to provide experimental VAPOR 3D visualization capabilities across the TeraGrid.

NCAR is also in the process of acquiring and deploying a new Earth System Grid (ESG) server cluster to provide secure ESG services over the 10 Gbps link to other TeraGrid sites such as Oak Ridge National Laboratory. NCAR has also acquired and is deploying an HPSS tape archive system for evaluation over the next few months, and intends to integrate it with the frost TeraGrid resource.

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TeraGrid accounting connector code

The TeraGrid accounting Connector Code (TGCC) was updated several times throughout 2008 to support small changes in TeraGrid accounting procedures. Plans for 2009 are to implement support for a TeraGrid storage accounting model once a specification is published and to support the replacement for the frost supercomputer.

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UCAR Point of Presence (UPoP)

The UPoP is a consortium of universities, K-20s, non-profit corporations, and government agencies that cooperate in an aggregation point (the UPoP) to share Wide Area Networking (WAN) services, access to the commodity Internet, access to the Abilene (I2) research network, and access to the National LambdaRail (NLR).

UPoP won a UCAR Performance Award, a special recognition award, and a CALET Award. The Board of Directors for the Colorado Association of Leaders in Educational Technology (CALET) voted unanimously to award Jeff Custard and Marla Meehl, as representatives of UCAR, the 2008 CALET Outstanding Friend of Technology Award. CALET is a department of the Colorado Association of School Executives (CASE) and represents CIOs, CTOs, and Directors of Technology statewide.

This project is now fully operational and ongoing. The costs of UPoP are shared among the consortium members, and funding is managed through the UCAR Communications Pool indirect funds.

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10 Gbps end-to-end technology implemented at NCAR

The configuration of 10 Gbps network service from UCARnet to the wide area was accomplished in FY2007. Reconfigured routers on the CU-Boulder campus now route all traffic through our 10 Gbps-capable Cisco router. This continues to improve network service including data transport, especially to the Internet2 and NLR research networks.

Work on this project is now complete.

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Mesa Lab and Foothills Lab WAN wireless upgrade

NETS replaced the wireless network system that operated between the Mesa Lab and Foothills Lab. This new licensed-spectrum 1-Gbps BridgeWave wireless system will provide backup should the fiber optic system be damaged between the Mesa Lab and Foothills. It will ensure that network and phone service remains operational while the fiber is repaired.

Work on this project is now complete.

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LAN wireless upgrade

NETS upgraded NCAR/UCAR's local area network wireless system including 123 wireless access points over seven months using IEEE 802.11g technology. The new access points provide broader coverage that provides more than five times the bandwidth available before.

Work on this project is now complete.

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Storage Area Network (SAN) deployment for CDP/ESG

In FY2009, DSG plans to make data available on our SAN to TeraGrid users via a web interface for downloading datasets formatted specifically for popular models used today. Changes in our existing infrastructure will make these data available to a broader user community at much higher transfer speeds.

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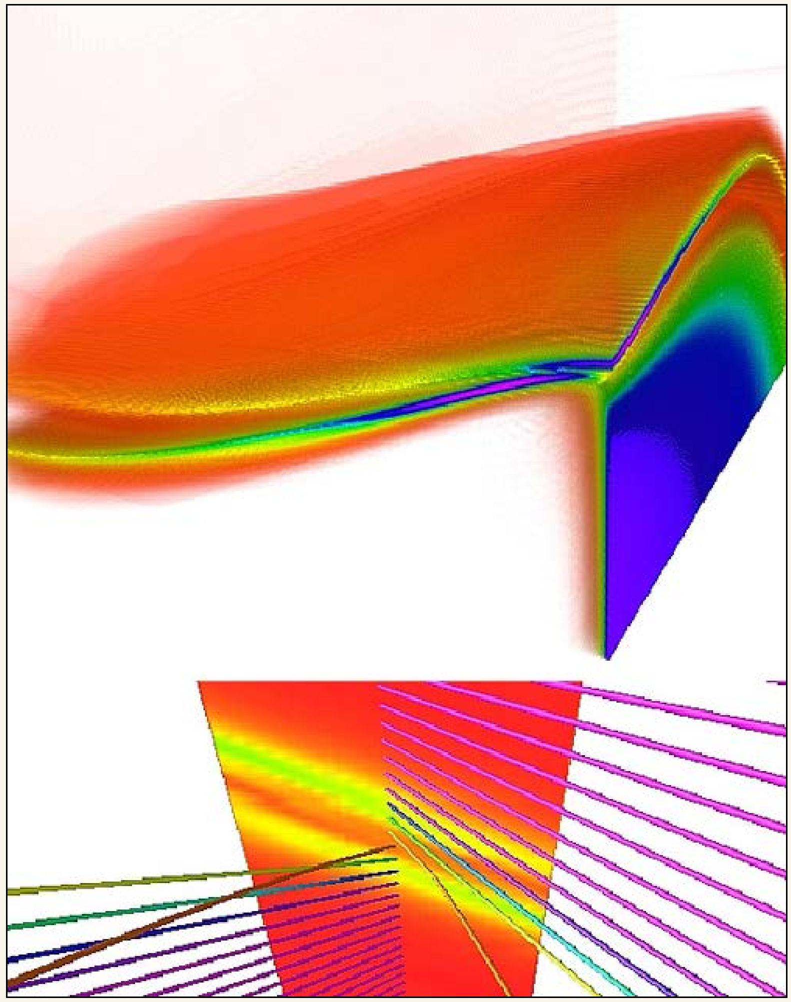
Research in computational science and math for geophysics: TDD and IMAGe

The research activities within CISL's Technology Development Division (TDD) and Institute for Mathematics Applied to Geosciences (IMAGe) support scientific computation, numerical methods, geophysical modeling, and the analysis of geophysical data and model experiments. This research is important to maintain an innovative computational and modeling facility at NCAR, and more broadly, to lead the geophysics community in adopting new computational methods and mathematical tools that enhance scientific research. This mission is aligned with NCAR's strategic priority of "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D."



Nonlinear structures in a magnetohydrodynamic simulation: these two figures visualize the current in a simulation of the flow of a charged fluid. The sheets are being forced together based on magnetic pressure. Also of interest is that the magnetic field lines associated with each sheet are not aligned. Creating this interaction among coherent structures is possible due to the high resolution of this simulation that allows for the thinning of current sheets. An analagous feature has been observed in the Earth's magentosphere, and it is important that this effect can be captured using a direct numerical simulation but with less complex physical processes.

Given this broad priority, the research in CISL must span several disciplines and address computational science at many levels. These range from improvements to network flow and scalability of existing codes to simulating the flow of geophysical fluids using high performance computational platforms. Integrated with the computational science are areas of applied mathematics that include data analysis, models for multiscale processes, and techniques for assimilating data into numerical models. Because these different elements are coordinated through a single lab, there is an easy transfer of technology and ideas from prototypes and theoretical results in IMAGe, to issues of implementation, efficiency, and workflow in TDD, and finally incorporation as tools and models for the communities served by CISL. There is also a valuable reverse transfer whereby emerging computational capability and data storage spur particular research that takes advantage of these features.

Support by funding agencies other than the NSF is indicated in the individual reports in this section of the CISL annual report.

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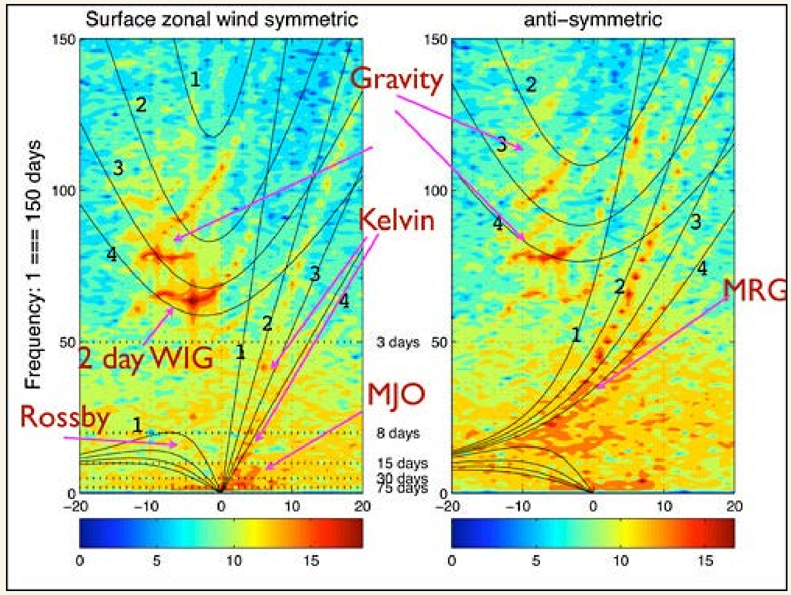
IMAGe research: New algorithms, tools, and geophysical models

The power of mathematical science is that similar methods and models can be used to solve problems in very different contexts. The Institute of Mathematics Applied to Geosciences (IMAGe) was formed in October 2004 to develop tools, methods, and models that can address some of NCAR's fundamental science problems. IMAGe is also actively introducing the mathematics community to new problems that are posed by geophysical processes and observations. Two important vehicles that support this interdisciplinary activity are the Theme of the Year workshops and publically available software for numerical and statistical methods. IMAGe contributes to the NCAR strategic priorities of "Conducting research in computer science, applied mathematics, statistics, and numerical methods" and "Engaging a broader and more diverse community."



This image summarizes preliminary results from an aqua-planet simulation using the HOMME global atmospheric model and an approximation of atmospheric physics that includes a new method for representing convection. The Earth's Madden-Julian Oscillation (MJO) is approximated by a traveling wave of convection in the tropical ocean with a period of approximately 30-60 days. Convection processes such as tropical thunderstorms are very important to the Earth's climate because they distribute heat from the surface into the troposphere. Therefore, accurate simulation of the MJO helps us understand this fundamental geophysical process.

The figure is a standard summary of the dynamical properties of the atmosphere where the energy from traveling waves is decomposed into the spatial size of the waves (horizontal axis in wave number) and their speed (vertical axis in period). The color scale indicates the kinetic energy that can be attributed to different combinations of scales and speeds, and the labeling indicates several well-known atmospheric waves. The MJO is more difficult to detect as it has a relatively long period. However, preliminary evidence for its presence appears in this simulation.

This experiment is important because the precise mechanisms of the MJO are still unknown, and past numerical models have had difficulty simulating it.

Geophysical-Astrophysical Spectral-Element Adaptive Refinement code has been extended to use adaptive three-dimensional grids and has been tested under an advection/diffusion solver. Turbulence was studied in rotating, neutral fluids, and the interactions between rotation, helicity, and transfer of energy between scales was quantified. A promising MHD simulation exploiting Taylor-Green symmetries has produced features in current sheets observed in the solar wind.

The discontinuous Galerkin (DG) method was combined with a state-of-the-art mesh database to produce a code with excellent scaling to many processors. A third-order DG transport scheme was implemented within HOMME with a new monotonic limiter and was shown to eliminate spurious oscillations from the numerical solution.

A design study was completed that indicates the value of including an energy balance model as part of past climate proxy reconstructions. The multivariate, spatial lattice model was completed for interpreting in a joint manner the temperture and precipitation from climate model projections.

The Data Assimilation Research Testbed was successful for real-time forecast of CO concentrations in support for the ARCTUS field program. In addition, DART/CAM was able to produce specific reanalysis fields for the Arctic region for diagnosing mechanisms of sea ice formation and also for improving the filtering at high latitudes in the CAM finite volume dynamical core.

Multiscale modeling plans: A Boussinesq capability is being added in GASpAR to work on atmospheric flows. The FFT libraries in GHOST (Geophysical High Order Suite for Turbulence) are being extended to do pencil (1D) decompositions. Results of the Advanced Science and Discovery experiments on rotating flows with helicity will be compared to a subgrid-scale parameterization for the effect of eddys.

Numerics plans: The DG conservative transport will be tested in CAM/HOMME using the aqua-planet simulations. In addition, a multi-tracer transport algorithm based on conservative remapping will be studied for future implementation. Adaptive mesh refinement algorithms will be developed in the context of a two-dimensional solver for compressible fluids. A multi-grid algorithm will be included. Software infrastructure to perform three-dimensional simulations on general curvilinear domains will be built. Finally, algorithms will be developed for node placement in the context of using radial basis functions (RBF) for the adaptive solution of the shallow water equations.

Statistics plans: Bayesian methods for spatial paleoclimate reconstructions will be completed for North America using multiple proxies. Statistical analysis will be completed for a subset of the NARCCAP experiments for extreme precipitation and a multi-model synthesis that includes the skill in reproducing current climate and interactions among GCM/RCM pairings.

Data Assimilation plans: Development will continue on parallel implementations of DART with WRF and CAM interfaces. Adaptive inflation and localization data algorithms will be refined and applied to improve tropical cyclone analysis and prediction, as well as for organized convective systems over the continental U.S. and contiguous coastal oceans.

IMAGe is supported by NSF Core funding.

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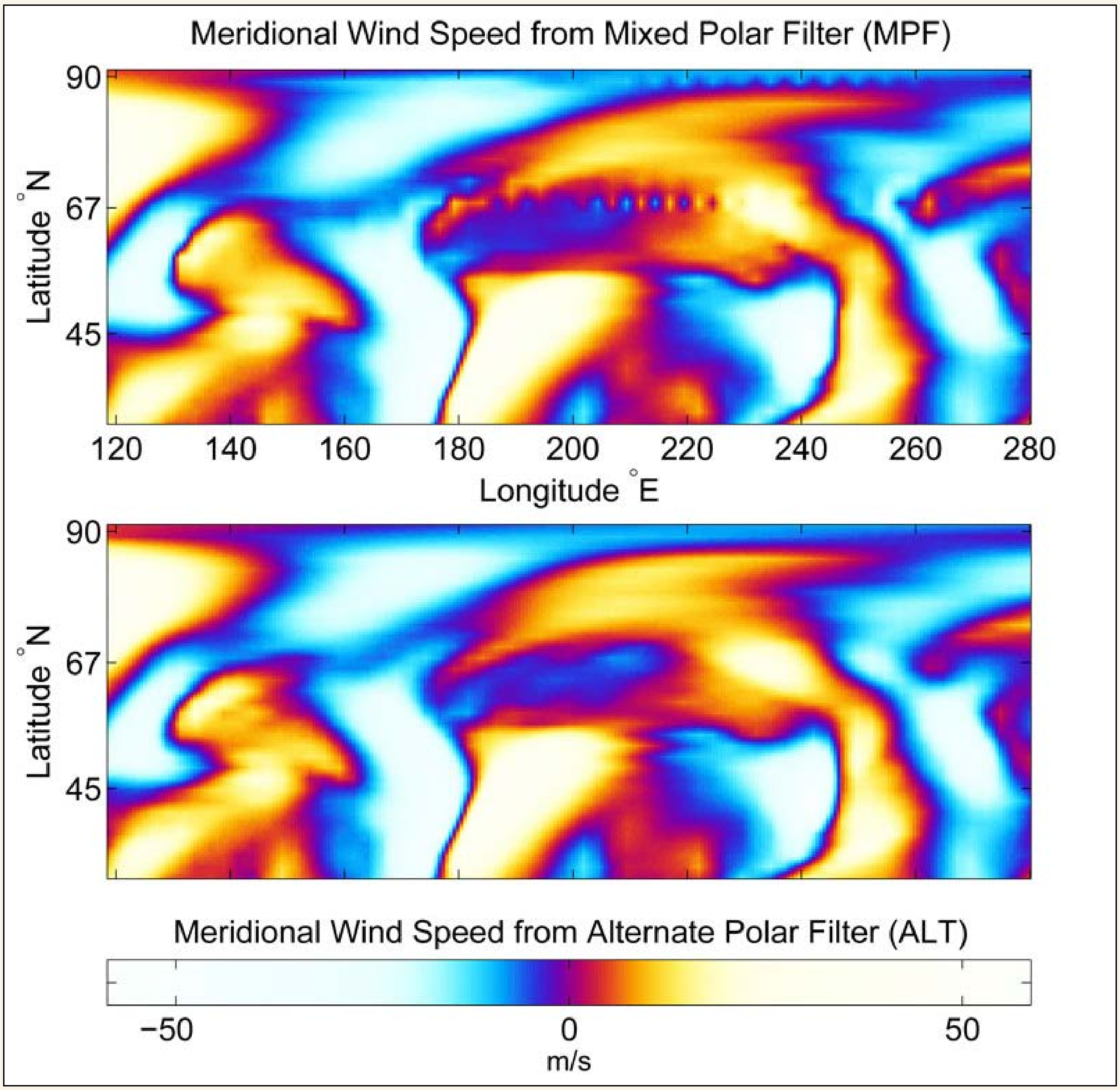
Data assimilation research

Data assimilation is the process of merging data from observations with computer models. It can transform diverse and incomplete observations to gridded estimates that can easily be used and interpreted. The assimilation process also produces quantitative information on model error, forecast skill, and observational errors, all of which allows us to improve models.

Data assimilation is providing rapid advances in geophysical studies. The Data Assimilation Research Section (DAReS) of IMAGe performs fundamental research on ensemble data assimilation methodologies for application across a wide range of geophysical problems. DAReS develops and maintains the Data Assimilation Research Testbed (DART), a software facility for doing ensemble data assimilation. DAReS also provides support to a growing community of NCAR, university, and government laboratory partners who are interested in applying ensemble data assimilation methods.



Doing data assimilation with DART/CAM has led to significant improvements in CAM. The analyzed 266 hPa meridional velocity at 12 GMT on 13 September 2007 is shown in the top panel. Comparing to the lower panel shows that the longitudinal grid scale noise along 67N and 87N was eliminated by introducing a revised polar filter in CAM. Latitudinal noise along 220E is due to a finite volume dynamical core numerical issue that is being studied by CAM developers. Both noise problems are present in climate runs of CAM, but were only identified through the use of DART assimilations.

DAReS supports three of NCAR's strategic priorities: "Developing community models," "Developing and providing advanced services and tools," and "Enhancing science education." The DART user community includes members from many NCAR divisions, more than a dozen universities, and many government labs. NCAR projects supported by DART during 2008 included:

- Year-long reanalyses with several versions of CGD's CAM climate model identified and led to the correction of errors in the polar filter.
- The impact of COSMIC GPS radio occultation measurements was evaluated for large scales in CAM and for hurricane predictions in MMM's WRF model.
- Researchers in ACD used DART with the CAM/CHEM model to provide real-time analyses of weather and carbon monoxide for the ARCTAS field campaign.
- Researchers in CGD are using DART/CAM analyses and forecasts to explore mechanisms for the rapid loss of Arctic sea ice observed in 2007.
- Researchers in MMM have developed DART-based forecast sensitivity tools and used them to address questions about the impact of observations on forecasts of hurricane position and strength.

A growing number of university groups are using both DART/WRF and DART/CAM for research and instruction. For instance, a joint DAReS/University of Wisconsin project is investigating the impact of advanced hyperspectral infrared retrievals on hurricane prediction. Research partners at Cal Tech have completed implementing a version of DART/WRF configured for prediction on Mars. At the University of Colorado, DART has been used to explore assimilating velocity observations of the flow exiting a laboratory slit jet.

DAReS has supported the incorporation of two new large geophysical models this year: a version of the MIT ocean GCM in partnership with Scripps Institution of Oceanography and the Navy's COAMPS® model in partnership with NRL Monterey. DART/WRF is also being evaluated for typhoon predictions in non-operational tests by the Central Weather Bureau in Taiwan. DAReS continues to incorporate feedback from all partners to develop more powerful and generic assimilation tools.

Fundamental ensemble data assimilation research has focused on dealing with non-Gaussian distributions of observational error. An algorithm developed last year has been further refined, used to produce year-long assimilations in CAM, and is being tested for assimilation of radar reflectivity in WRF. Research on designing filters that can tolerate both non-gaussianity and non-linearity will be the key focus during the next year. Such tools would improve analysis and prediction using radar and remote sensing observations in hurricanes and severe convection.

Data assimilation research in IMAGe is supported by NSF Core funding and NASA Grant NNX08A23G.

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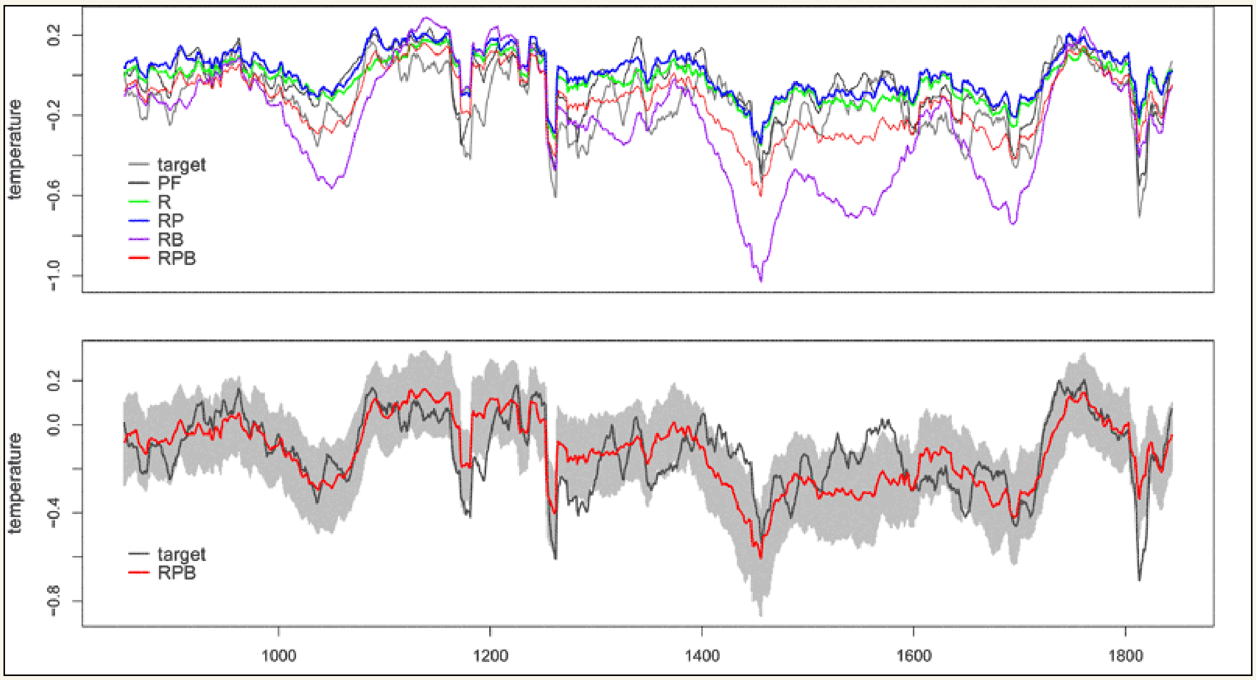
Geophysical Statistics Project

From our unique position within CISL and IMAGe, the Geophysical Statistics Project (GSP) has been a leader in training and research emphasizing the synergy between the geosciences and the statistical sciences. In addition to basic methodological and theoretical statistical research, GSP has a strong training component supporting graduate students and postdoctoral visiting scientists. These young researchers are immersed in research activities that not only focus their skills as applied statisticians but also expose them to important applications in the geosciences.

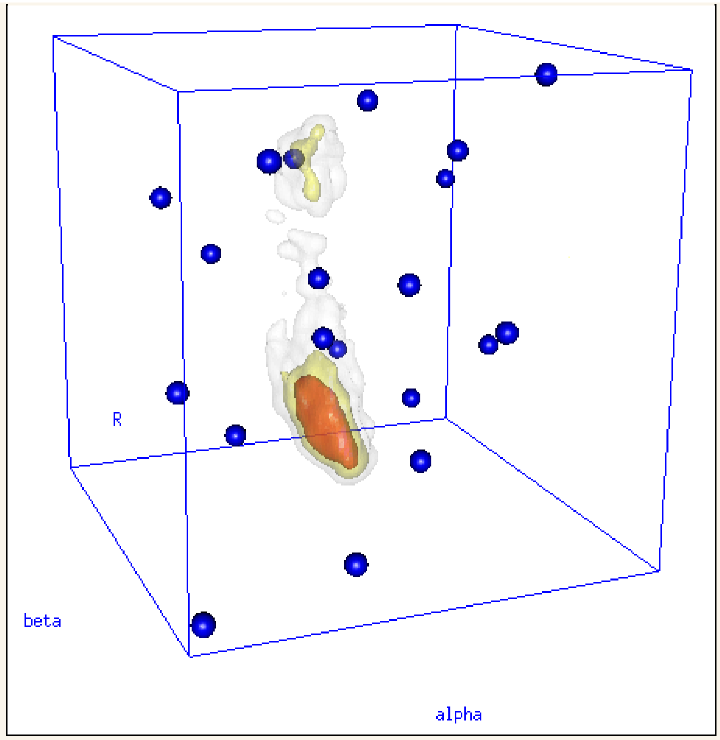


Northern Hemisphere mean temperature reconstructions based on synthetic proxies embedded in noise and forcings. The proxies are generated by the algorithms that approximate the relationship between proxies and temperatures using the synthetic temperatures from global climate model output. The top panel compares the reconstruction using different types of proxies: PF uses 15 local temperatures as proxies; R uses tree ring only; RP uses tree ring and pollen; RB uses tree ring and borehole; and RPB uses tree ring, pollen, and borehole. Among the four reconstructions from different combinations of proxies, RBP has lowest bias and mean squared error. So in the bottom panel, the reconstruction from RBP with its 95% uncertainty band (gray area) is displayed. The reconstruction follows the trend of the target fairly well, and the uncertainty band covers the target most of the time.

In addition to these core activities, GSP also has an active visitor program providing research opportunities for visiting faculty members from across the nation and abroad. Our goal is to foster collaboration between graduate students, postdocs, the permanent and visiting statistical staff, and NCAR scientists. These programs, as well as the research and training aspects of GSP that emphasize the interaction between statistics and the geosciences, embody the tenets of integration, innovation, and community building within the NCAR strategic plan. Specifically, this program supports the NCAR strategic priorities of "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D," "Supporting and enhancing formal science education at all levels," and "Engaging a broader and more diverse community in the atmospheric and geosciences."

During FY2008, GSP researchers have been involved in numerous important projects, including:

- Design and analysis of computer experiments, in particular focusing on regional climate models and models of the upper atmosphere and the magnetosphere
- Developing methodology for analyzing extremes of weather and climate
- Stochastic weather generators
- Modeling uncertainty in climate reconstruction



Results of a calibration experiment matching the output of the Lyon-Fedder-Mobary (LFM) computer model of the magnetosphere to observations from the Polar Ultraviolet Image (UVI) during a geomagnetic storm. The blue dots indicate the initial values of calibration parameters (alpha, beta, and R) based on space-filling experimental design. These parameters transform the standard MHD parameters into the average energy and flux of the precipitating electrons. The contours represent approximate 50 (red), 75 (yellow), and 95 (white) percent contour shells of the posterior distribution of the optimal calibration values for alpha, beta, and R based on a novel statistical approach to calibrating computer models with high-dimensional outputs.

- Impacts of climate and climate change on public health

GSP continues to develop theory and methodology for analyzing spatial data, including nonstationary covariance models, models for spatial lattice data, multivariate spatial observations, spatial-temporal models, as well as general methodology for computational statistics and Bayesian hierarchical models.

In FY2009, the scientific focus on computer models will continue, in particular through GSP scientists being involved in such NCAR programs as the North American Regional Climate Model Assessment Program (NARCCAP) as well as in collaborations with other computer modeling groups across NCAR. Beyond computer models, GSP scientists will continue to assess the impacts of climate and climate change on public health, to develop methodology for analyzing extremes, to develop methodology for modeling daily weather scenarios, to develop methodology for quantifying the uncertainty in climate reconstructions, and to develop statistical methodology for the analysis of complex, spatial and spatial-temporal data.

This project is made possible through NSF Core funding, as well as grants through NSF's Division of Mathematical Sciences and NSF's Collaboration in Mathematical Geosciences.

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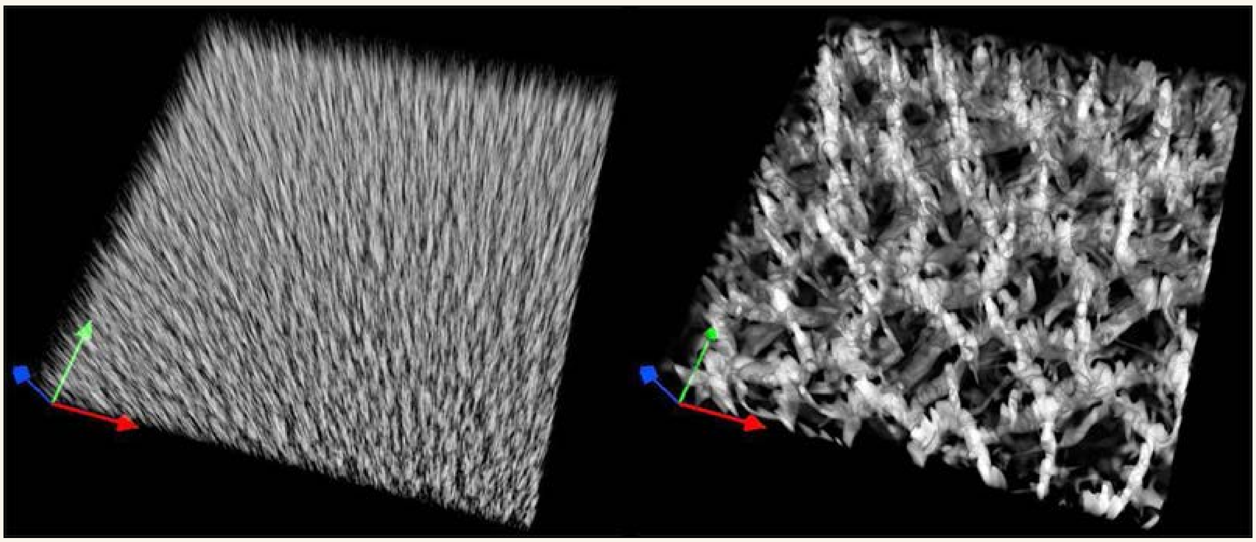
Geophysical turbulence program

Research on turbulence has been a significant part of the NCAR scientific program since its beginning in the early 1960s. The original scientific leaders of NCAR recognized that to understand the dynamics of the atmosphere, the oceans, the climate, the sun, and solar-terretrial interactions, understanding relevant turbulent processes would be essential. A number of scientific appointments in the first 10-15 years of NCAR's existence reflected this view and provided an in-house base from which to productively interact and collaborate with the world turbulence community. From these beginnings, a sustained emphasis on geophysical turbulence at NCAR has emerged in research, visitors, seminars, and workshops that continues to this day. Most of this emphasis manifests itself currently in the Geophysical Turbulence Program (GTP).



Structure of thermal convection over a heated plane. Vertical velocities after six hours of simulated time are shown within the boundary layer depth; bright and dark volumes denote updrafts and downdrafts, respectively. The only difference between the solutions in the left and right panels are the values of viscosity in the horizontal entries of the stress tensor, respectively, 2.5 versus 70 meter-squared per second. These results are part of research that addresses numerical effects that influence the structure of simulated convection in the planetary boundary layer, which becomes an increasingly important issue as numerical weather prediction models use increasingly higher resolutions.

By design, GTP is an interdiscplinary group of about 40 members that spans many divisions and laboratories at NCAR with a few external affiliates. It encompasses research at NCAR on multi-scale nonlinear processes with an array of applications in a broad variety of areas. GTP is also the outreach arm of this research, and is complementary to the Turbulence Numerics Team.

In FY2008, GTP sponsored eight seminars and hosted five long-term (greater that 1 week) visitors. Several of these visitors were students, where the research conducted formed part of the students' graduate requirements. The topics covered in collaboration with NCAR staff represent a broad variety of interests:

- Studies of turbulent enhancement of droplet formation
- Numerical thermal convection
- Improved trajectory schemes for Lagrangian methods in fluid dynamics
- Effects of turbulent entrainment and mixing on cloud dynamics
- Coupled dynamics of boundary layers and evolutionary landforms
- Research on cumulus convection and measurement
- Self-organized criticality-like representation of statistical measurements of turbulent MHD flows
- Studies of differences in turbulence statistics between canopy/roughness sublayers and intertial sublayers
- The statistical mechanics of fully developed turbulence

In FY2009, GTP will continue organizing workshops, holding seminars, and hosting short-term and long-term visitors. It will also provide a small amount of funds for a short (summer) visit by one or two graduate students who support the scientific agenda of research in multi-scale physics for geophysical flows.

GTP activities advance NCAR's strategic priorities of "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D" and "Engaging a broader and more diverse community in the atmospheric and geosciences." GTP activities are sponsored entirely by the NSF cooperative agreement through UCAR.

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GTP contributions by visiting collaborators

This is a collection of summaries of the work conducted by long-term visitors to the Geophysical Turbulence Program (GTP) in FY2008:

- **Brachet, Marc** summary of collaboration with Annick Pouquet (NCAR) and Duane Rosenberg (NCAR).
- **Cossette, Jean-Francois** summary of collaboration with Piotr Smolarkiewicz (NCAR).
- **Finnigan, John** summary of collaboration with Edward Patton (NCAR).
- **Jarecka, Dorota** summary of collaboration with Wojciech Grabowski (NCAR).
- **Jonker, H.** summary of collaboration with Peter Sullivan (NCAR).
- **Ortiz, Pablo** summary of collaboration with Piotr Smolarkiewicz (NCAR).
- **Piotrowski, Zbigniew** summary of collaboration with Piotr Smolarkiewicz (NCAR).
- **Wang, Lian-Ping** summary of collaboration with Wojciech Grabowski (NCAR).

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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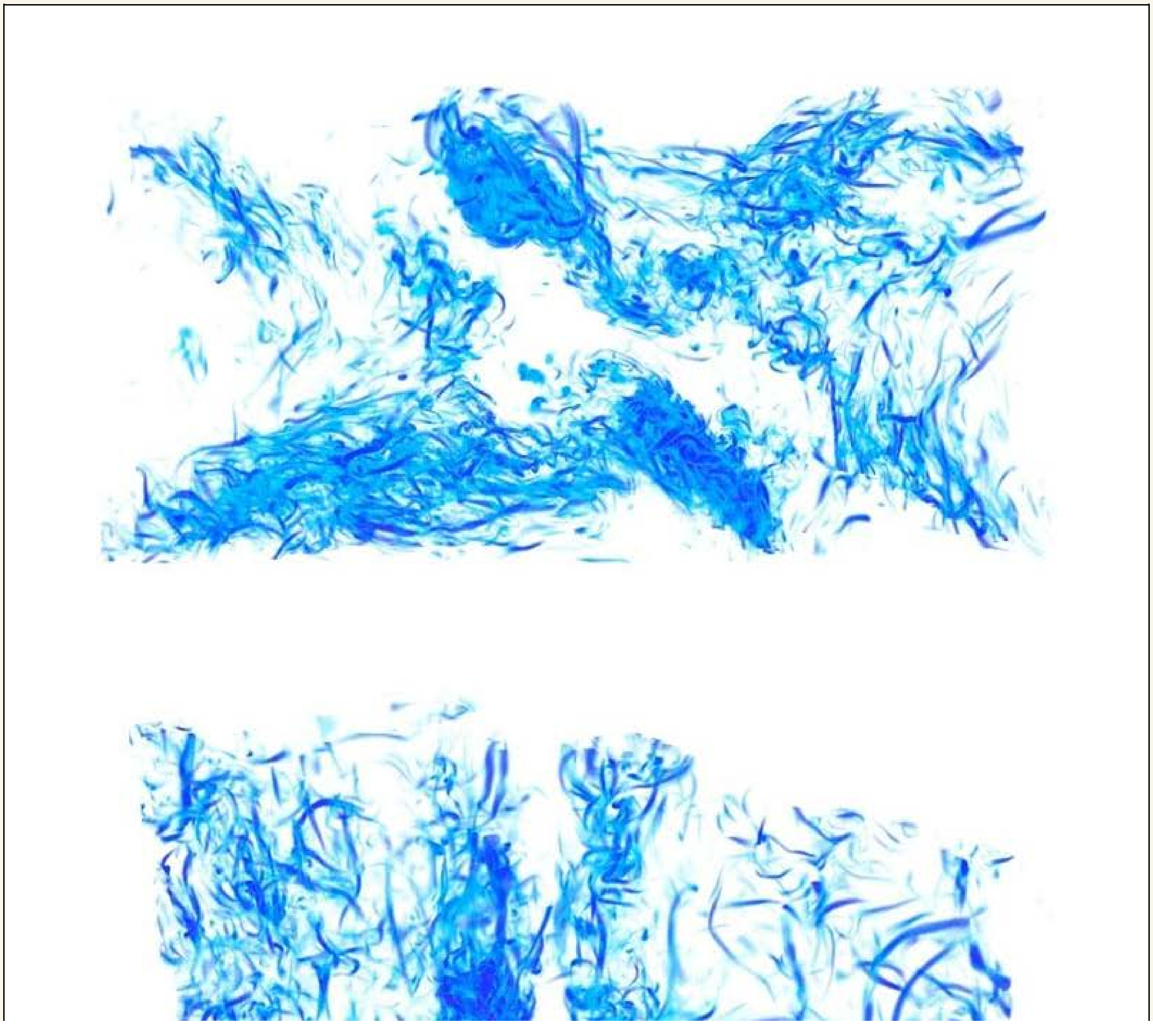
Turbulence science: Numerical algorithms and code development

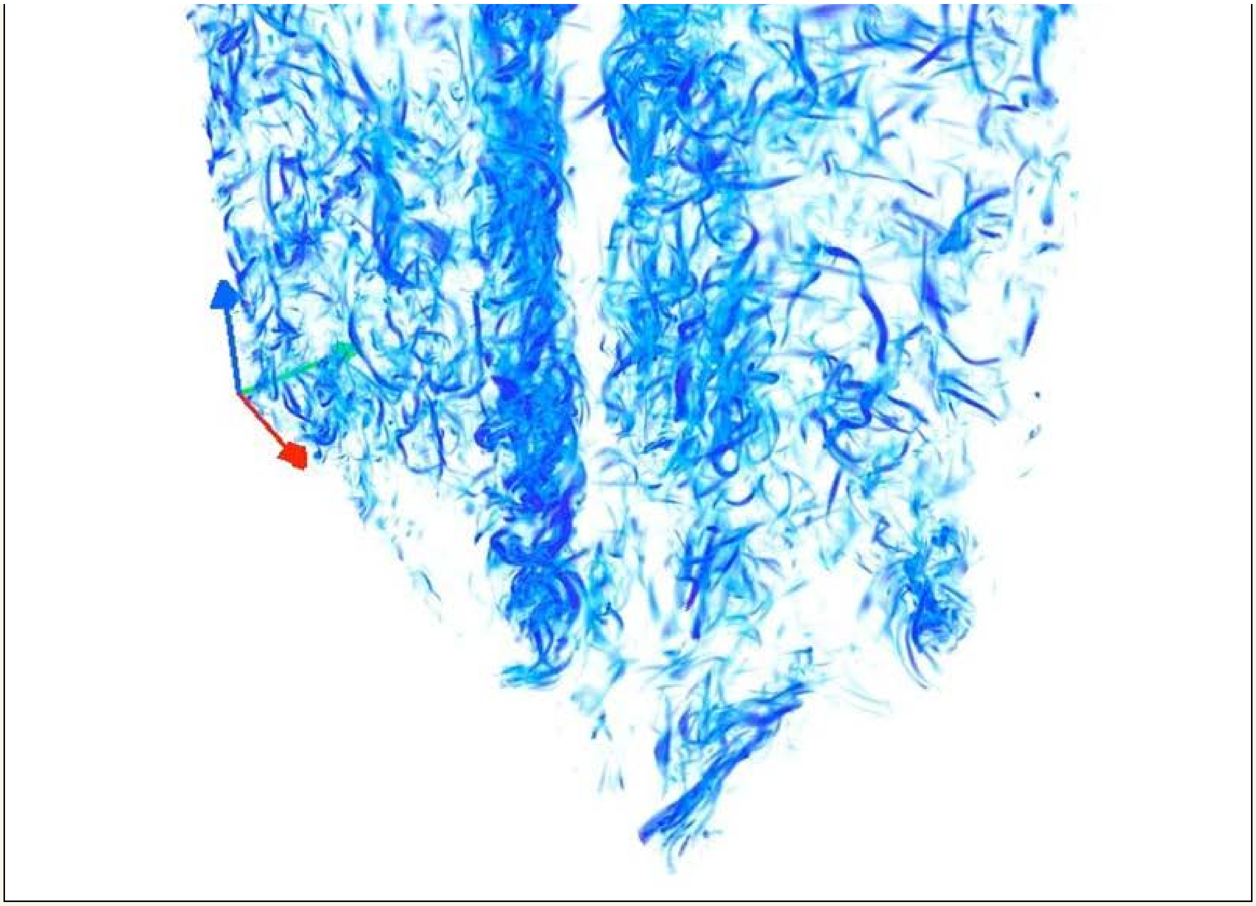
The Turbulence Numerics Team (TNT) is complementary to the Geophysical Turbulence Program (GTP) and is focused on the accurate simulation and understanding of turbulence for fluids such as the atmosphere, and for charged flows in the presence of magnetic fields. TNT research emphasizes simplified physical systems that still reproduce the complexity and multi-scale properties associated with turbulent flow.

TNT staff is composed of Julien Baerenzung (Postdoctoral researcher), Aimé Fournier (Project Scientist), Ed Lee (Graduate Student in Applied Mathematics, Columbia U.), Pablo Mininni (Scientist I, 25% FTE), Annick Pouquet (Senior Scientist and Section Head, 60% FTE) and Duane Rosenberg (Software Engineer). More information on what is reported below can be found in the Research Catalog items linked from the text, and also available under the names of the Team members.

Research on turbulent flows

We have pursued investigations of homogeneous, isotropic and non-isotropic turbulence and turbulent structures at high Reynolds numbers in a broad variety of fundamental contexts and of physical conditions (with or without magnetic fields, with or without rotation, with or without modeling). We have been active this year in studying rotating flows from both the perspective of direct numerical simulation (DNS) and that of modeling. Rotational effects are expected to become important when the Rossby number, Ro, (the ratio of the convective to the Coriolis acceleration) is sufficiently small.





Zoom-in visualization of vorticity magnitude in a low Rossby (strong rotation) three-dimensional simulation showing the top view of the computational domain (top figure), and a side view (bottom figure). Both a direct (to smaller scales) and inverse cascade (to larger scales) of energy appear to occur simultaneously with rapid rotation although some intermittency behavior is similar to homogeneous, non-rotating turbulence. Note the large-scale columns comprised of small-scale structures. Similar features are found in high-resolution hurricane simulations, suggesting that studies of hurricane formation and development may benefit from such detailed analysis of rotating turbulence.

We have explored with DNS rotating non-magnetic flows at high Reynolds number, Re, down to Ro=0.03 (note that Ro~0.1 in the atmosphere). It is found that in the non-helical case (i.e. in the absence of correlation between the velocity field and its curl, the vorticity), energy transfer between wavemodes parallel to the rotation is strongly quenched, so that the direct transfer of energy to small scales is mediated by interactions with eddies whose wave vectors are perpendicular to the rotation direction. For rapid rotation, direct and indirect cascades appear to take place simultaneously. For the helical case, it is found that at small Ro, there is a direct cascade of energy (as expected), but that helicity can dominate the cascade to small scales and alter the dynamics.

We are also beginning to consider rotating flows from the point of view of modeling. This work will be extended in the upcoming year; it stems from efforts carried out with our postdoc on a conceptual framework for modeling non-rotating turbulent flows. This work will be generalized to anisotropic non-magnetohydrodynamic (non-MHD) rotating flows, using as a guide a closure model (the Eddy Damped Quasi Normal Markovian, or EDQNM) written for rotating flows by Cambon and Jacquin (JFM 202, 1989), variants and simplifications.

The group continues to explore facets of turbulent flows with magnetic fields also from the modeling perspective. EDQNM spectral modeling has been developed that uses an eddy viscosity independent of the form of the energy spectrum, and that utilizes an eddy noise that follows the closure instead of being an arbitrary stochastic forcing. In addition, we continue to work on regularization procedures of the primitive equations viewed as models of flows and as discussed in the FY2007 CISL annual report. We have found that for MHD that there is no enhanced bottlneck effect, contrary to fluids, and thus that we can reach a reduction factor of ~200 in the number of required degrees of freedom when compared to a DNS of MHD on a large grid of 1536^3 points at the same Reynolds number. These results suggest that the use of this type of subgrid scale (SGS) model may offer significant computational savings for MHD simulations, and yield models that can be used for a better understanding of the Earth core dynamics, the interplanetary medium and space weather or the solar convection zone, all topics of interest within the NCAR community.

Finally in the MHD modeling context, we have shown that Clebsch variables can be used as a diagnostic for reconnection events in neutral fluid and MHD flows in two dimensions (2D), and we have initiated a study in which we investigate the scaling laws of linear size and energy distributions of 3D structures in the manner of self-organized criticality (SOC) models of MHD.

One promising avenue of MHD DNS research has been carried out in which the velocity and magnetic field have spatial symmetries that are preserved by the dynamical equations as the system evolves. We have developed a new code (MAYTAG) and have begun to conduct high-resolution runs of a non-dissipative case up to an equivalent resolution of 2048^3 grid points, and found by considering the logarithmic decrement of the energy spectrum that there is no appearance of a singularity. We do find, however, evolving structures that are similar to those observed in the solar wind. We have also considered the dissipative case with grids up to 2048^3, and find that global temporal evolution is accelerated compared to the corresponding neutral fluid case.

Lastly, we have used a variable high-order adaptive mesh refinement DNS scheme to model turbulent flows in 2D-MHD, and have demonstrated the statistical accuracy of the technique (see below) by comparing with a pseudo-spectral simulation of a nearly inviscid initially strongly randomized broad-spectrum state that evolves to a very smooth maximum-entropy state through the process of selective decay.

Algorithms, numerics, and code development

TNT develops both tools and models that enhance our capability to investigate geophysical turbulence, and applies these capabilities to fundamental scientific objectives. TNT members have broad experience in developing a variety of algorithms, numerical schemes, and large development efforts for studying turbulence.

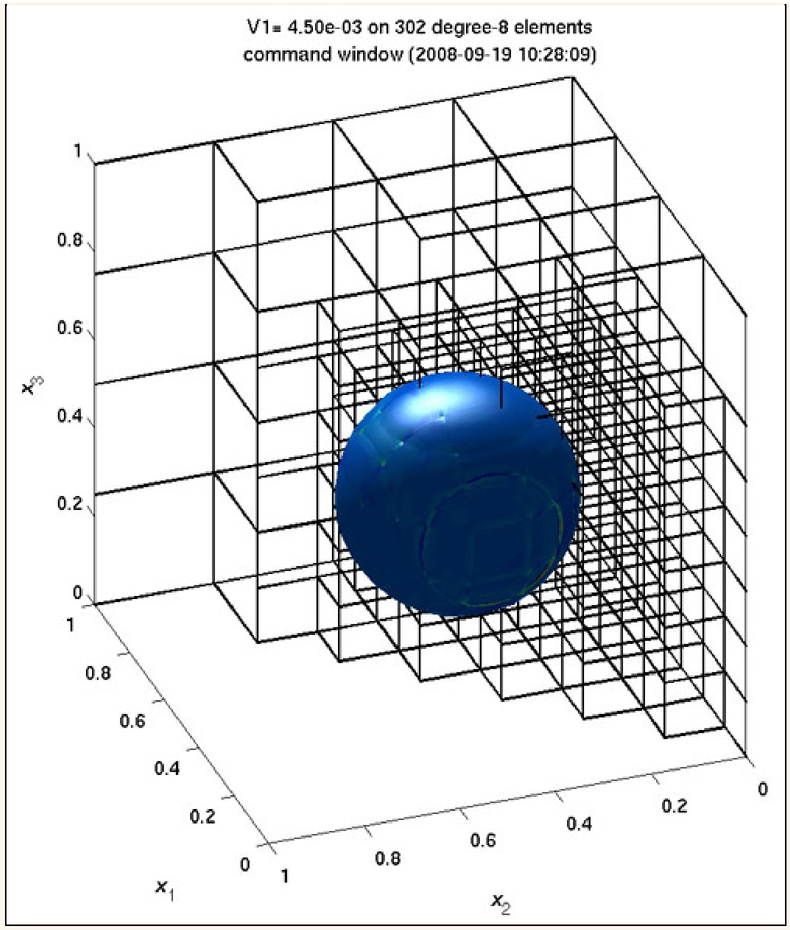
The algorithms, numerics, and code development undertaken by TNT all pertain directly to several NCAR strategic goals. Under the strategic goal to "Improve understanding of the atmosphere, the Earth System, and the Sun," TNT works to: (1) Explore atmospheric, Earth System, and solar processes, variability, and change, and (2) Develop community models. Under the strategic goal to "Provide robust, accessible, and innovative information services and tools," we also work heavily toward the NCAR strategic priority of "conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D."

The Geophysical High Order Suite for Turbulence (GHOST) code is a highly scalable code used to numerically integrate the hydrodynamic, magnetohydrodynamic, or Hall-magnetohydrodynamic equations in three dimensions with periodic boundary conditions. GHOST was recently selected for an Accelerated Scientific Discovery award, to make a high-resolution (1536^3) study of turbulent rotating flows. We have invested efforts this year into providing support for rotating flows by including a Coriolis force and testing the results of rotating turbulent simulations rigorously.

Currently, GHOST uses a slab domain decomposition method in which the N^3 computational cube is decomposed into N-N^2-sized slabs and distributed to the processors. This decomposition will prevent us from running jobs on systems with processor counts greater than N. Thus, we will begin in FY2009 to modify this distribution method to allow for a pencil distribution, in which the cube is decomposed into 1D arrays of length N and distributed. In this way we will be prepared to run on the large-processor, small-memory-footprint petascale systems that will be available in the near future. In addition, we will begin the modifications necessary in GHOST to allow the code to be operated in single and double precision so that roundoff errors at extremely small scale do not adversely impact the solution in very high Reynolds computations afforted by this new generation of systems.

TNT continues its long-term commitment to develop high-order adaptive methods for use in problems of relevance to the turbulence phenomenology community. This work is carried out using the Geophysical-Astrophysical Spectral-Element Adaptive Refinement (GASpAR) code, which is a framework for solving PDEs using the spectral element method (SEM).

In FY2008, we completed a detailed comparison between GASpAR and a fixed low-order scheme used often in the literature, and demonstrated explicitly that there are some problems where high-order is simply required for any reasonable number of computational degrees of freedom. In collaboration with the Computational Math Group, we completed the first phase of an optimized restricted additive Schwarz preconditioner, and showed that it confirms the asymptotic theory even for the case of staggered grids used in the MHD and Navier-Stokes solvers. In a significant accomplishment in FY2008, the code was modified to include 3D adaptive elements and connectivity, and preliminary tests have been made using the advection-diffusion solver in 3D (please see the accompanying figure). This entailed substantial modification of the existing connectivity code interfaces as well as some re-architecting of the mesh dynamics code. We were able to progress a good deal further than we had anticipated in the FY2007 program plan and include nonconforming -- as well as conforming -- connectivity and grid adaption.



Isosurface rendering of a linearly-advected 3D spherical Gaussian distribution with adaptive refinement of the grid. The sphere starts in the corner (0,0), and is advected along the cube diagonal to coordinates (1,1). This is a preliminary result using the 3D mesh dynamics of the GASpAR (see text) code that demonstrates the ability of the mesh to track isolated distributions properly, and it also highlights the operation of the advection-diffusion solver in three dimensions. The capability encapsulated in this figure is essential for correct adaptively refined solutions to all nonlinear partial differential equations for which the code serves as a framework.

We have also developed a low-storage Runge-Kutta scheme that preserves conservation properties for nonlinear problems, and is accurate for the pseudo-spectral and SEM codes to third and fourth order.

We continue to pursue other aspects of SEMs as well. We have formulated an SEM using globally continuous test & trial functions for arbitrary spatial dimensions, and we have also demonstrated a SEM-based Fourier analysis that includes domain partitioning in the context of a GASpAR study of vortex interactions characterized by strong nonlinear interactions. Finally, in collaboration with Sandia National Laboratory, we discovered that the SEM can be formulated as a conservative scheme that preserves vector-calculus identities after discretization.

There are a large number of SEM numerical issues we will address and GASpAR developments we anticipate in the upcoming year. Here we provide some details as to our current thinking, but add that scientific, technical, and other influences may alter the feasibility of carrying out any particular item or otherwise limit their scope. In FY2009, we intend to add a coarse-grid solver to precondition the long-wavelength modes in the optimized RAS preconditioner. If there is time, we will effect the modifications required to enable the entire optimized precondioner to operate with non-conforming discretizations, for which there is no direct mathematical theory at present. We will continue a program to optimize the adaptive mesh refinement algorithms, and, time permitting, we will add partitioning (including load balancing) software, some of which involves modification of existing code.

We will, in FY2009, test the Navier-Stokes or MHD solvers (or both) on 3D adaptive grids, and address any problems that arise due to the operator application in our Krylov solvers, such as the lack of symmetric-positive-definiteness, which can be a time-consuming effort. We currently plan to also begin development of a 3D (2D is a subset automatically) Boussinesq solver (which will immediately take advantage of the adaptive grid) to begin a long-term project on atmospheric boundary layer flows.

Finally, we will either implement a multi-resolution based adaptivity criterion (which guarantees a prescribed mean-square accuracy), or implement an exactly mass- and energy-conserving spectral element formulation that will enable more robust long-time-scale simulations; the choice will depend on priorities emerging from both technical and scientific considerations.

Community service and outreach

TNT was heavily involved in community service and outreach activities in FY2008. The IMAGe Theme of the Year (TOY) 2008 was designed to support the geophysical and mathematical communities through a series of workshops exploring turbulence from the perspectives of mathematical and physical modeling, computational science, observation and experiment. The overarching goal of the 2008 TOY was to make manifest and increase the interconnections among theory, computation, and experiment.

TOY 2008, co-directed by Keith Julien (CU), consisted of three workshops and a summer school held at NCAR. The titles and dates were:

- W1 "Turbulent Theory and Modeling," 27-29 February 2008
- W2 "Petascale Computing: Its Impact on Geophysical Modeling and Simulation," 5-7 May 2008
- W3 "Observing the Turbulent Atmosphere: Sampling Strategies, Technology, and Applications," 28-30 May 2008
- S4 "Summer School: Geophysical Turbulence," 14 July - 1 August 2008

The workshops accommodated 20-30 people and were a blend of research presentations along with ample time for discussion and more informal interactions. The summer school drew on the material from the preceding workshops and featured prominent researchers in turbulence.

In addition to this extensive effort, TNT was largely responsible for organizing a mini-symposium, the Symposium on Turbulence and Dynamos at Petaspeed in October 2007, hosted jointly by IMAGe and by the Joint Institute for Laboratory Astrophysics at the University of Colorado (JILA). The intent of this effort was to elucidate the challenges of scientific computing at the petascale, and to offer potential solution paths for them. The speakers were notable researchers in the field of high-end scientific and engineering computing, and the symposium was very well received. Partial funding for the symposium was provided by the NSF cooperative agreement and by the NASA Heliophysics Theory Program grant to JILA.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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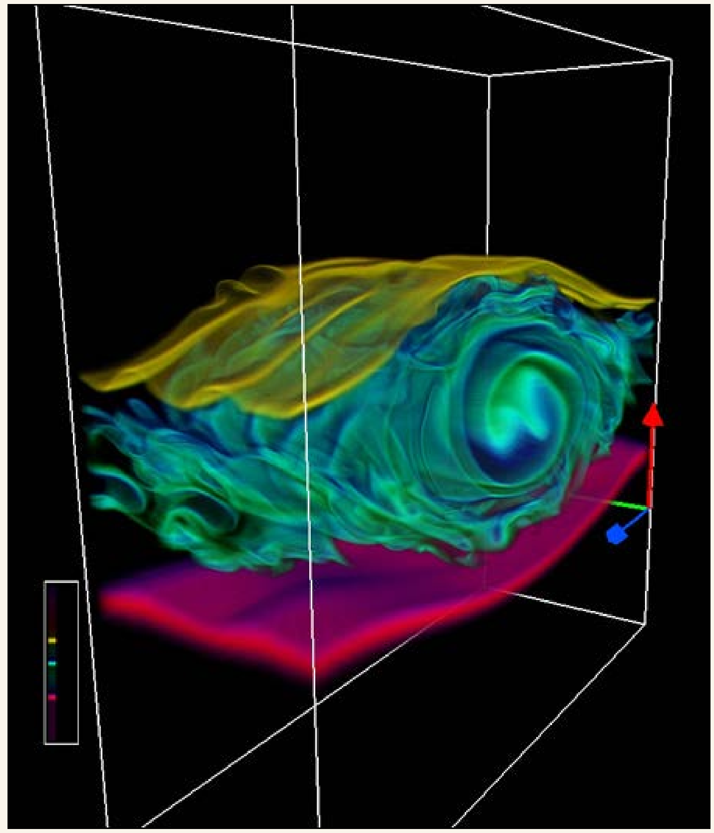
IMAGe theme for 2008: Geophysical turbulence phenomena

The Theme-of-the-Year (TOY) is a program that focuses on specific areas of research that will benefit from intense collaborative effort. The topics are selected by the IMAGe external advisory panel and are coordinated by a visiting co-director. The scientific leaders of NCAR recognized early on that to understand the dynamics of the atmosphere and oceans and the planetary boundary layer, the sun and solar-terrestrial interactions, investigating relevant turbulent processes at a fundamental level would be essential.



Rendering of a 3D Kelvin-Helmholtz instability using the VAPOR visualization and analysis platform. This image was created by Benjamin Jamroz, Ed Lee, and Thorwald Stein, while participating in the IMAGe Theme-of-the-Year 2008 Summer School on Geophysical Turbulence. Students of the summer school received hands-on experience performing the end-to-end processes of numerical simulation, visualization, and analysis using state-of-the-art resources.

Turbulence has remained both a vital and challenging field, taking on added importance as the geosciences tackles the multi-scale interactions that characterize the Earth-Sun system. The difficulty of solving classical problems in turbulence through direct mathematical analysis has engendered a multidisciplinary approach where mathematical and physical models, computational science, observations, and experiments are combined to make advances.

The Theme-of-the-Year (TOY) for 2008 was designed to support the geophysical and mathematical communities in this effort through a series of workshops exploring turbulence from these different perspectives with the goal of increasing the interconnections among theory, computation, and experiments. The final activity of the 2008 TOY was a summer school designed to bring new researchers into this field and give them a multidisciplinary perspective.

The 2008 TOY was led by Keith Julien (Applied Mathematics, University of Colorado at Boulder) and Annick Pouquet (Geophysical Turbulence Program, NCAR). They convened three workshops and a summer school in Boulder, Colorado:

- W1 "Turbulent Theory and Modeling," 27-29 February 2008
- W2 "Petascale Computing: Its Impact on Geophysical Modeling and Simulation," 5-7 May 2008
- W3 "Observing the Turbulent Atmosphere: Sampling Strategies, Technology, and Applications," 28-30 May 2008
- S4 "Summer School: Geophysical Turbulence," 14 July - 1 August 2008

The workshops accommodated 30-50 people and were a blend of research presentations along with ample time for discussion and more informal interactions. The summer school included about 30 Ph.D. students from around the globe, drew on the material from the preceding workshops, and featured prominent researchers in turbulence. There were a total of 150 workshop and summer school participants from outside NCAR, including 53 first-time visitors to NCAR and 54 new researchers.

The main lecturers

The organizing committee of W1 included Jeffrey Weiss (CU) and Elizabeth Wingate (LANL).

The invited speakers at W1 were Peter Bartello (McGill), Raffaele Ferrari (MIT), Uriel Frisch (OCA, Nice), Andrew Majada (Courant), James McWilliams (UCLA), David Nolan (Miami), Alan Norton (NCAR), Antonello Provenzale (Turin), Leslie Smith (Wisconsin), and Geoffrey Vallis (GFDL). The organizing committee of W2 included Bjorn Stevens (UCLA) and Joe Werne

(CORA).

The principal lecturers at W2 were Mark Berliner (Ohio), Éric Chassignet (Florida State), John Clyne (NCAR), Bengt Fornberg (CU), Hassan A. Hassan (North Carolina), Phillip Jones (LANL), Yukio Kaneda (Nagoya), Edward Kansa (U. Davis), Yoshifumi Kimura (Nagoya), Steve Krueger (Utah), Ed Lee (NCAR), Rich Loft (NCAR), Thomas Lund (CORA), Scott McRae (North Carolina), Mark Rast (CU), Damian Rouson (Sandia), Piotr Smolarkiewicz (NCAR), Amik St. Cyr (NCAR), Peter Sullivan (NCAR), Chenning Tong (Clemson U.), Joe Werne (CORA), Grady Wright (Boise State U.), John Wyngaard (Penn State), and David Yuen (Minnesota).

The organizing committee of W3 included Larry Cornman (RAL, NCAR), Don Lenschow (ESSL, NCAR), Tom Horst (EOL, NCAR), and Steven Oncley (EOL, NCAR).

The keynote speakers at W3 were Jakob Mann (Risøo), Harm Jonker (Delft U.), Andreas Muschinski (Amherst), Hans Peter Schmid (U. of Karlsruhe), and Joe Fernando (Arizona).

Finally, the organizing committee of the school included Jeff Weiss (CU) and Beth Wingate (LANL). The principal lecturers at the three-week school were John Clyne (NCAR), Joe Fernando (Arizona), Andrew Majda (Courant), Leslie Smith (Wisconsin) and Joseph Werne (CORA).

FY2008 accomplishments

Each workshop set the stage for the next ones and for the school. A lengthier report is in preparation for NSF. The workshops and school were made successful not only by the quality of the presentations from all the speakers, but also through the intense interactions that took place between students and lecturers and between sessions. The organizers would like to thank all of the participants, IMAGe, CISL, EOL, ESSL, and RAL at NCAR, and the National Science Foundation for their continuing support on research into the nature of geophysical turbulence.

We cite week three of the school as an example of the effort and scale of the summer school and the participation it elicited from students. Week three was an intensive computational lab coorganized by CISL's Data Analysis Services Group (DASG) and NorthWest Research Associates (NWRA). Intermixed with lectures on practical issues in numerical modeling and data analysis, students were provided a hands-on experience with end-to-end computational science: from numerical simulation to presentation of results. Divided into small groups, each was tasked with exploring a problem in atmospheric turbulence modeling (either Kelvin-Helmholtz instability or breaking gravity waves) using one of two numerical methods: Direct Numerical Simulation or Large Eddy Simulation. Students relied on knowledge gained during the previous two weeks of the school to help them parameterize a 3D simulation code provided by NWRA. Tens of thousands of CPU hours on CISL's Blue Gene/L supercomputer, frost, were then brought to bear to run the students' experiments.

After conducting their simulations and archiving results to NCAR's Mass Storage System, the groups focused on analyzing the hundreds of gigabytes of data generated, using CISL's visualization cluster, storm. The centerpiece of the students' data analysis toolkit was the NCAR-developed VAPOR software. Finally, the students presented the results of their efforts to their peers and to the summer school organizers and instructors.

FY2009 plans

The Theme of the Year program is chosen each year by the IMAGe Council together with affiliated members. TOY09 will focus on numerics with scientific leadership from the computational mathematics group in IMAGe. Following our plan of alternating large and small TOYs, the numerics year will be a smaller effort than TOY08, consisting of two or three small workshops focused on adaptive methods in computation. The format will use working groups where a small group of researchers are brought to NCAR to outline specific approaches to solving a particular problem. Adaptive numerics resonates with the need for increasing or decreasing resolution of the numerical computation to adapt to the multiscale structure of a complex geophysical flow. There are also plans for longer-term visitors who will reinforce the adpative numerics theme.

Solicitations will also be made for TOY10 through advertisements in mathematics and geophysical newsletters and also through an e-mailing to potential codirectors. Having cycled through the IMAGe sections, the topic for TOY10 is open and will be selected through outside proposals and discussion with the IMAGe advisory board.

Rationale and sponsorship

By enhancing collaborations with the university community and by performing valuable education and outreach activities at the highest available level, this work supports the NCAR strategic priorities "Engaging a broader and more diverse community in the atmospheric and geosciences" and "Supporting and enhancing formal science education at all levels." TOY workshops and schools are sponsored by the NSF cooperative agreement through UCAR and by NSF funding through the division of mathematical sciences.

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Numerical methods: Application of radial basis functions to modeling

While computer technology has advanced dramatically in recent years, numerical schemes currently used for climate and solar modeling fall drastically short of scientists' expectations. Spherical harmonics require large grids to resolve small features, and this is computationally impractical. Spectral element methods can resolve small features, but they require higher resolution near artificial boundaries to achieve high accuracy.

Both methods involve high algorithmic complexity and are impossible or awkward to apply to irregular geometries. As a result, geoscientists and computational mathematicians are searching for new options. Radial basis functions (RBFs) offer the geosciences a novel numerical approach for solving time-dependent partial differential equations (PDEs).

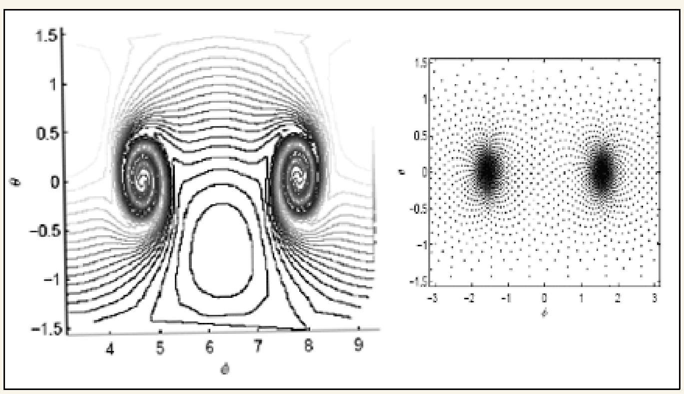
Building on the accomplishments of FY2007, the IMAGe Computational Mathematics Group together with Boise State University, University of Colorado-Boulder, Arizona State University, and Uppsala University, Sweden continue research in the developing area of RBFs for climate and solar modeling.

This year saw the completed development of the first-ever RBF shallow-water model on the sphere. The table at right summarizes the results for one of the test cases: a forced translating low-pressure center that is superimposed on a westerly jet stream (see 8 MB movie). The system is modeled by the unsteady nonlinear shallow water equations. RBFs are compared with spherical harmonics (SH), double Fourier series (DF), spectral elements on a cube (SE), and spectral elements with mesh refinement (SE/MR).

The table shows that RBFs easily outperform the other methods as measured by the L2 error both with regard to the number of node points *N* they use and the large time step they can take.

In 2008, our efforts furthered the topic of applying RBFs to the geosciences by performing the first-ever local node refinement on the sphere. The scheme was tested by following the wrap-up of two vortices on the sphere as they are advected at a 45° angle to the polar axis (see 14 MB movie). The nodes were distributed according to the gradient of the angular velocity, being most concentrated where the gradient was the largest as shown in the figure below.

Method	*N*	L2 error	Time step
RBF	1849	3e-3	24 minutes
	3136	8e-6	15 minutes
	4096	3e-7	8 minutes
	5041	4e-8	6 minutes
SH	8192	2e-3	3 minutes
DF	2048	4e-1	6 minutes
	8192	8e-4	3 minutes
	32768	4e-4	90 seconds
SE	6144	6e-3	90 seconds
	24576	4e-5	45 seconds
SE/MR	31104	7e-4	1 minute



Left: Final state of vortex wrap-up test case after 12 days (1 revolution around sphere) on an unrolled sphere. Vertical axis is latitude with 0 being the equator. Right: Local node refinement corresponding to vortex wrap-up test case.

In the coming year, we will focus on various areas of RBF mathematical development, from adaptive local node refinement to non-uniform fast Fourier transforms and filtering methods, to hybrid RBF-pseudospectral and RBF-finite difference schemes.

This work advances NCAR's strategic priority of "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D" and is supported by NSF grant ATM-0620100.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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Multiscale simulation techniques

To continue its scientific leadership, NCAR needs a unified simulation environment that can dynamically resolve time and space scales on petascale computers. A framework that encompasses such an environment relieves the scientists from becoming fluent in advanced scalable numerical methods and enables them to focus on their research issues. We are progressing toward a unified simulation environment by pursuing novel developments in the areas of adaptive h-p grids, multi-method time-stepping, and Jacobian-free techniques.

Current work toward this goal in IMAGe's Computational Mathematics Group includes the development of a linearly implicit Runge-Kutta time-stepping procedure to accelerate integrations of PDEs common in atmospheric and oceanic models. We are also coupling an h-p discontinuous Galerkin solver to a state-of-the-art library for mesh adaptation. The latter has shown excellent scalability on the IBM Blue Gene/L system, and is currently being coupled with a prototypical time-implicit nonhydrostatic fluid flow solver. Preliminary results with the coupled solver promise unprecedented scalability. Future work includes completion of a 2D AMR compressible solver, inclusion of the multigrid algorithm, and the capacity to perform 3D simulations on general curvilinear domains.

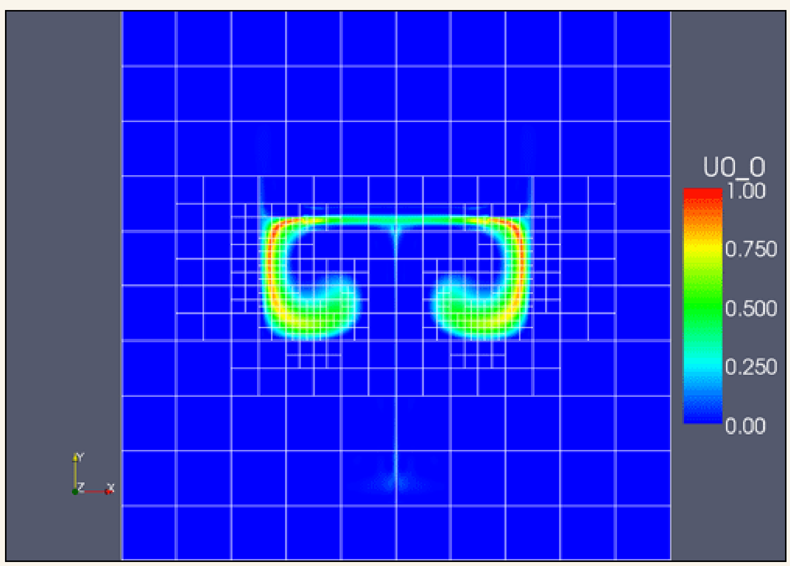
This research intends to develop efficient computational methods for solving multiscale, multidisciplinary physics on petascale systems by using numerical methods that satisfy the following criteria:

1. Highly scalable: strong scaling enabling
2. A well-defined mathematical background
3. Multiphysics capable: generic enough to solve more than a single problem
4. Multiscale capable: locally change the resolution for time and space scales

Developing these techniques spawned various subprojects.

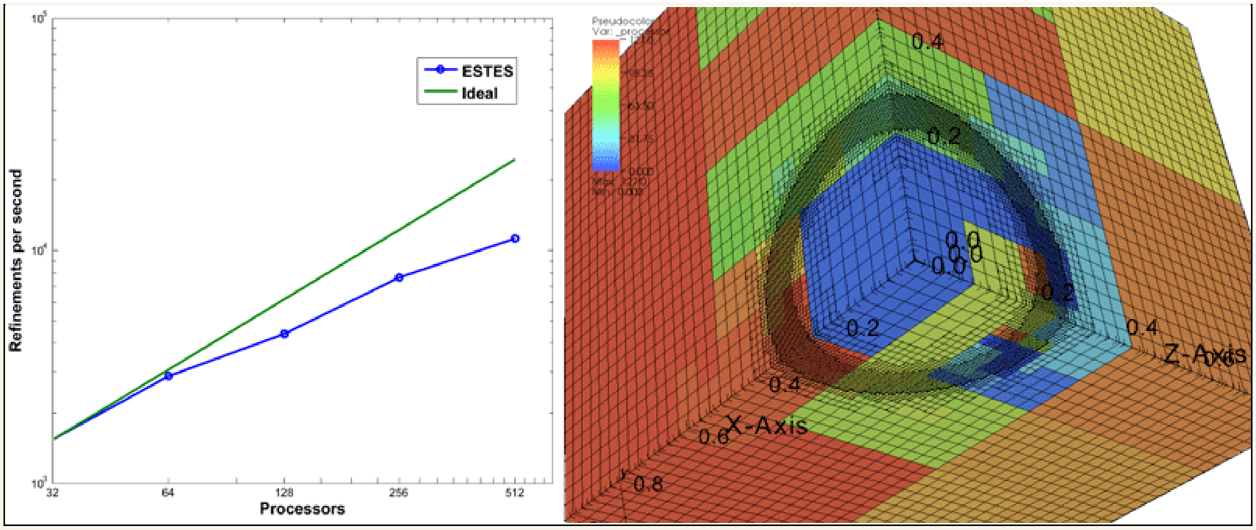
Spatial scales project

To develop the capacity for increasing the spatial resolution during a simulation, a flexible method is required for the spatial discretization of equation (1). The approach must efficiently exploit cache-based memory architectures and be highly parallelizable. It is widely accepted that high-order methods are very effective for solving wave-propagation-type problems. When spectral convergence occurs, either in a compute cell or in a part of the simulation domain, no method can provide more resolution for the same given number of grid points. The discontinuous Galerkin method (DGM) is somewhere between a finite element (FE) and a finite volume (FV) method. The technique lay dormant for several years, but it has recently become popular for solving fluid dynamics or electromagnetic problems.

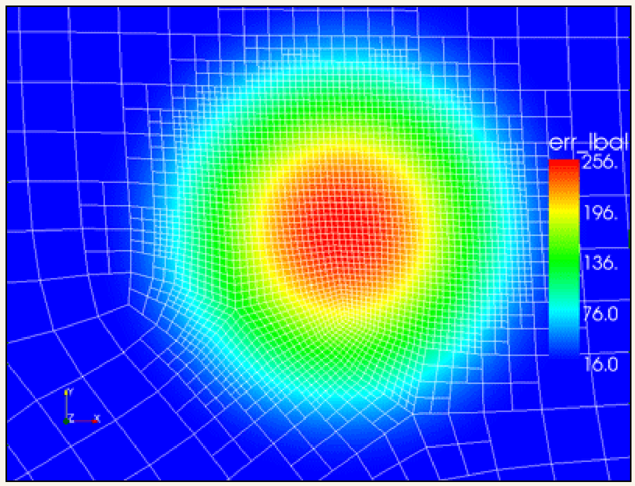


This animation depicts the simple convection of a cone using a prescribed flow that deforms the initial cylinder in two spirals. This test can be employed to measure the built-in dissipation of our proposed approach. Compared to non-conforming spectral elements, the DG approach is much simpler and necessitates a single exchange between elements instead of two. (Click image for animation.)

DG was then quickly used to solve a variety of physical problems with great success and is thus our method of choice for an all-scales multiphysics solver. We are currently investigating a high-order, high-performance DG method on unstructured meshes combined with non-conforming mesh adaptation. Also, when it is possible to resolve a wider range of scales with new techniques, different equation sets representing more realistic physics need to be employed. Future work will couple the high-performance adaptive techniques to the compressible Euler equations.



The high-order h-p DG solver adaptation is driven by a state-of-the-art mesh database with excellent scalability properties. Left: Number of elements refined/de-refined per second as a function of processor count. Right: Spherical shell used for 3D test in the mesh database.



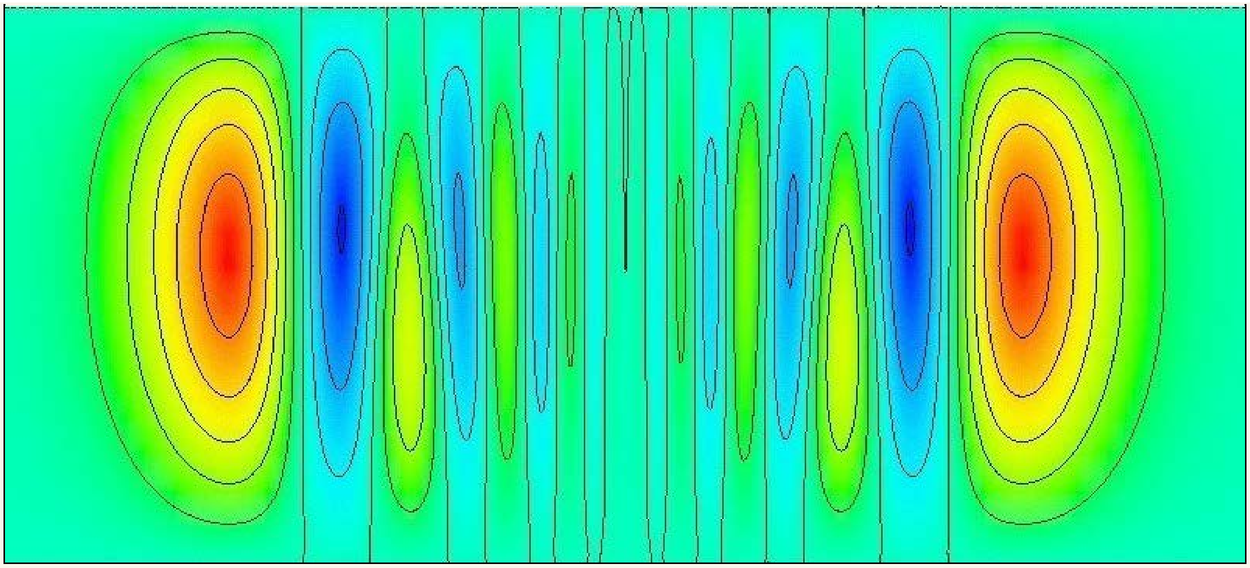
Advection of a simple cosine bell in an unstructured adaptive mesh using the h-p DG prototype with isoparametric elements.

Temporal scales project

Time-stepping techniques create one of the bottlenecks in numerical simulation today. These techniques inhibit the ability of current climate, weather, and other models to achieve strong parallel scaling. We are investigating various approaches to improve time-stepping methods:

1. Linearly implicit methods: Rosenbrock w-methods
2. Multirate techniques and spectral deferred corrections
3. The Parareal algorithm

The linearly implicit technique seems promising because it has a lower computational cost compared to traditional non-linear solvers. When applied to the fully compressible Euler equations, accelerations are observed with respect to fully explicit techniques.

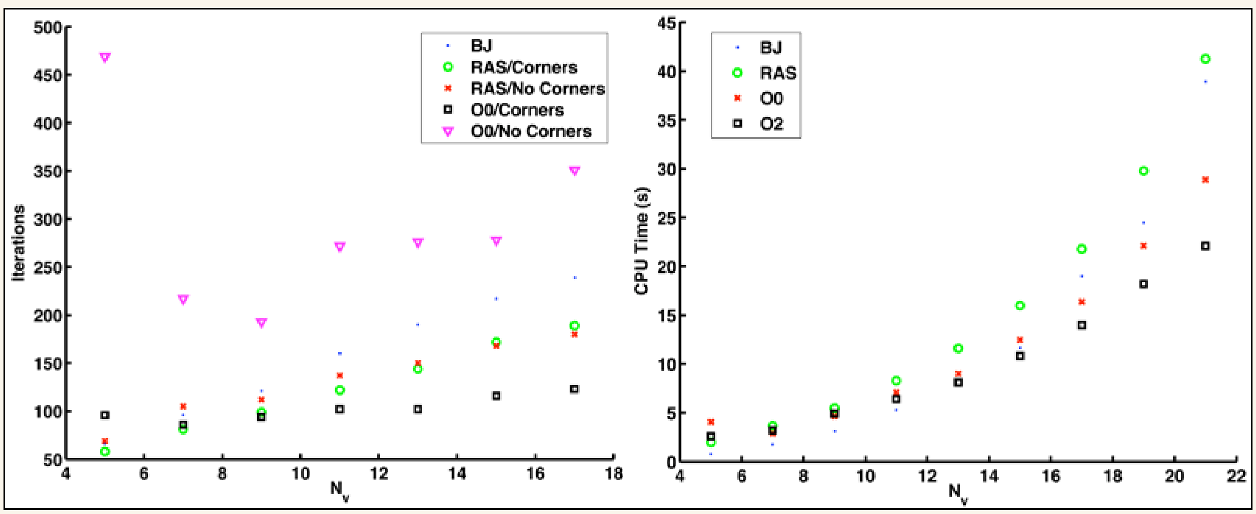


The unabridged equations of the atmosphere are solved using the proposed DG solver. The solver employs a linearly implicit (Rosenbrock W-methods) in a Jacobian-free fashion. The inertia gravity wave in a channel has a fast-moving gravity wave on top of a background velocity. (Click image to see four time steps in this simulation.) The code is four times faster using this technique.

Scalable elliptic solvers project

The quest for a correct coarse-grid correction for optimized Schwarz techniques started in FY2008. The coarse correction is required to obtain an iterative elliptic solver that yields a number of iterations independent of the number of spectral elements employed or their local polynomial orders. Initial experiments with the GASpAR code exhibited some problems concerning the treatment of corners with the optimized Schwarz algorithm. However, when high-order is employed and the corners are kept in the formulation of the optimized Schwarz, a factor of two reduction of the time to solution is observed.

Recent results for two-dimensional grids with the optimized Schwarz algorithm applied to spectral elements coupled to a coarse solver show that the number of iterations is fixed independently of the resolution of the mesh. The theoretical basis for modifying the penalty terms present in the optimized Schwarz algorithm is not yet fully understood, but a first approach is being explored.



Left: Plot of iteration count vs. polynomial degree for different preconditioners with and without corner communication on an 8x8-element grid. Right: Comparison of CPU time vs. polynomial degree preconditioners with corner communication on a 16x16-element grid (note that the optimized version is twice as fast for high Nv).

Support

This work supports NCAR's strategic priorities of "Conducting research in computer science, applied mathematics, statistics, and numerical methods," "Developing community models," and "Improving prediction of weather, climate, and other atmospheric phenomena." It will yield more efficient and accurate models, help reinforce NCAR's image as a leader in cutting-edge numerical methods, and may set the standard for next-generation climate and weather models. These projects are made possible through NSF Core funding.

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CISL research: Computational science

The CISL Computer Science Section tracks and evaluates new computing technologies, makes early adoption decisions, and performs systems research. Section staff is actively pursuing research in the following areas:

- High-performance computing
- Grid computing
- Experimental systems
- Linux clusters
- Experimental networking and evaluation of high-performance interconnects
- System and network performance analysis
- High-performance file systems and archival storage systems
- Parallel Algorithms and Architectures
- Model development

These efforts support NCAR's strategic priorities of "Providing capability and capacity supercomputing to the community," "Developing and providing advanced services and tools," and "Creating an Earth system knowledge environment." These CISL research projects and programs are supported by NSF Core funding, with other support as indicated by the individual reports in this section.

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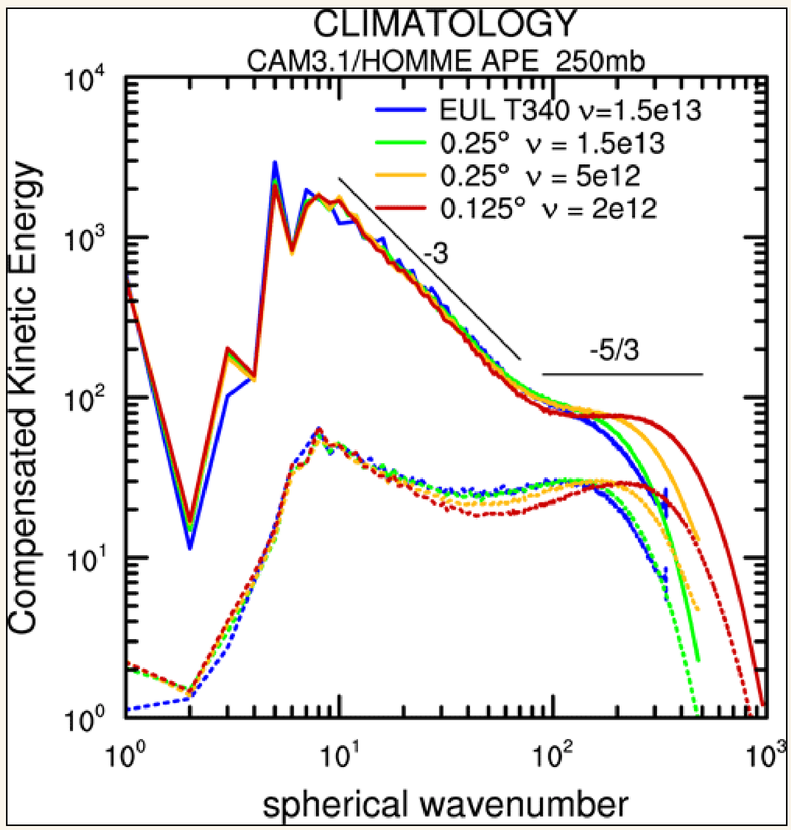
HOMME-CAM integration using HOMME's spectral-element dynamical core

Petascale computing facilities are being planned for the near future, and models must be developed to exploit these new architectures. NCAR, IBM, and DOE researchers are addressing this need by integrating the spectral element dynamical core in HOMME (High-Order Method Modeling Environment) with the physics of the Community Atmosphere Model (CAM 3.5.29). HOMME's spectral element dynamical core is well developed and ensures high parallel efficiency when running on computers with very large numbers of processors. CAM is a sophisticated model that realistically simulates the physics of Earth's atmosphere. The goal of the HOMME-CAM integration project is to prepare a highly accurate and efficient model that will provide capabilities such as full carbon cycle representation in climate simulations when petascale computing systems become available.

The spectral element dynamical core in HOMME is continually being revised and further parallelized to run more efficiently on the architectures of the most capable supercomputers available. Software engineers in the Climate and Global Dynamics division of NCAR's Earth and Sun Systems Laboratory modified the structure of CAM to simplify the integration of new dynamical cores. These efforts were facilitated by collaborations with an IBM software engineering consultant. This work made it possible to address the biggest challenge of the project: integrating HOMME with all the physical processes in CAM.

In collaboration with Sandia Laboratories (DOE), CISL, CGD, and IBM researchers produced significant results from the HOMME-CAM prototype using the IBM Blue Gene/L system at Lawrence Livermore National Laboratories. The transition in the kinetic energy spectrum that appears at the mesoscale boundary (see -3 and -5/3 trend lines on figure) has been approximated by the NEC Earth System Simulator in Japan, but the fidelity of the HOMME-CAM simulation is unprecedented.



This plot depicts the kinetic energy spectra near the tropopause. From measurements and experiments conducted by Nastrom and Gage (1985), it is known that this spectrum exhibits a transition from a -3 slope to a shallower -5/3 slope near the 100-km scale. Many competing theories are trying to explain this transition. The -3 slope is well understood and is related to geostrophic turbulence theory (Charney 1971) while the -5/3 slope corresponding to mesoscale (weather scale) is difficult to explain. To understand and validate theories, models need to reproduce this transition.

The plot was obtained using HOMME's spectral element dynamical core coupled with CAM's physics at a global resolution of 12.5 km running an aqua-planet experiment (planet surface is water). The HOMME-CAM model was run using 57,600 processors of the Blue Gene/L system at Lawrence Livermore National Laboratories. This is the first time this transition has been reproduced with such fidelity by an atmospheric general circulation model. It also vindicates HOMME's numerical methods.

In FY2008, nearly complete integration of HOMME's spectral-element dynamical core with CAM physics was achieved. An aqua-planet integration at 1/8-degree resolution produced the most realistic simulation to date of a little-understood feature in the kinetic energy spectrum of the Earth's atmosphere.

For FY2009, work will focus on refining surface processes to account for the effects of topography, ice, and oceans. FY2009 work will also improve the mapping of the CAM lat-lon grid to the HOMME cubed-sphere grid. The revised model will then serve as a testbed for new numerical algorithms to increase the simulation rate and produce results more quickly. After FY2009, the production version of CAM may begin using the HOMME dynamical core.

HOMME was developed by CISL to provide a foundation for building a new generation of atmospheric general circulation models for the atmospheric science community. HOMME is a vehicle to investigate using high-order-element-based methods to build conservative and accurate dynamical cores that efficiently scale to hundreds-of-thousands of processors, achieve scientifically useful integration rates, and can easily couple to community physics packages. Currently, HOMME employs the Discontinuous Galerkin and spectral element methods on a cubed-sphere tiled with quadrilateral elements.

This effort to accurately simulate observed processes in Earth's atmosphere supports NCAR's mission "to understand the behavior of the atmospheric and related systems and the global environment," NCAR's strategic goal of "Developing community models for weather, climate, atmospheric chemistry, and solar-terrestrial research," and NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment." This work is supported by NSF Core funds and DOE's Scientific Discovery through Advanced Computing (SciDAC) program.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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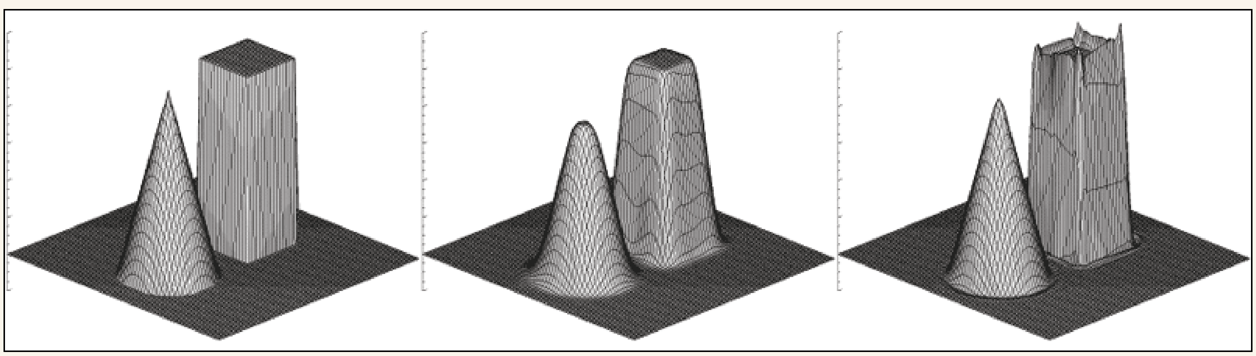
HOMME: Discontinuous Galerkin method

The future evolution of the Community Climate System Model (CCSM) into an Earth System model will require a highly scalable and accurate flux-form formulation of atmospheric dynamics. Flux form is required to conserve long-lived trace species in the stratosphere. Accurate numerical schemes are essential to ensure high-fidelity simulations capable of capturing the convective dynamics in the atmosphere and their contribution to the global hydrological cycle. Scalable performance is necessary to exploit the massively parallel petascale systems that will dominate high-performance computing (HPC) for the foreseeable future. This activity directly supports NCAR's strategic goal of "Developing community models for weather, climate, atmospheric chemistry, and solar-terrestrial research."

The High-Order Method Modeling Environment (HOMME) is a vehicle to investigate using high-order-element-based methods to build conservative and accurate dynamical cores. Currently, HOMME employs the Discontinuous Galerkin (DG) and spectral element methods on a cubed-sphere tiled with quadrilateral elements. HOMME can be configured to solve the shallow water or the dry/moist primitive equations, and has been shown to efficiently scale to nearly 100,000 processors of an IBM BlueGene/L.

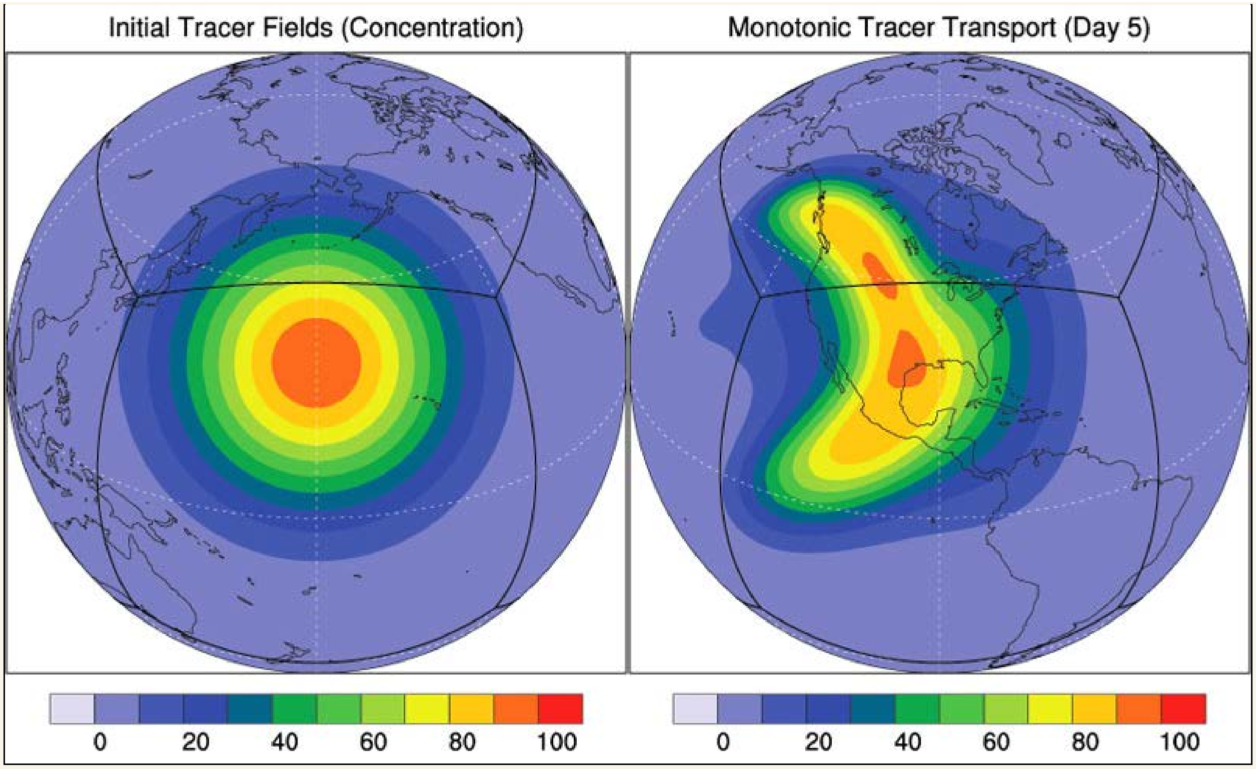
The objective of this project is to extend HOMME to a framework capable of providing the atmospheric science community with a new generation of atmospheric general circulation models (AGCMs) for CCSM based on high-order numerical methods on the cubed-sphere that efficiently scale to hundreds of thousands of processors, achieve scientifically useful integration rates, provide monotonic and mass-conserving transport of multiple species, and easily couple to community physics packages such as Community Atmosphere Model (CAM) physics. Achieving these objectives will allow climate scientists to take full advantage of the extraordinary petascale computing capabilities being deployed by NSF in the next five years, and will lead to dramatic increases in climate science productivity. The development timeline is designed to make the proposed technology freely available to the community for the Intergovernmental Panel on Climate Change (IPCC) fifth assessment science runs, currently scheduled to begin in April 2010. To achieve this requires work in four areas: physics, validation and verification, time integration, and scalability.

A fully fledged climate model is required to transport moisture variables and dozens of chemical tracers. The transport (advection) schemes must have several essential properties such as accuracy, efficiency, mass conservation, and non-oscillatory (monotonic) properties. A monotonic transport scheme avoids the creation of spurious unrealistic oscillations (e.g., negative humidity or pressure, etc.) in the transported solution. For the HOMME transport scheme, all these features except the monotonic property are available by the model design. Since HOMME is based on high-order spectral elements, implementing monotonic limiters is a big challenge.



This figure shows the solid-body rotation test of a non-smooth scalar (tracer) field after one revolution. A third-order discontinuous Galerkin (DG) transport scheme combined with a monotonic limiter was used for testing. The left panel shows the initial field, the central panel shows the monotonic (non-oscillatory) solution, and the right panel shows the oscillatory solution (without limiter). The monotonic limiter conserves mass and preserves the positivity of the advecting scalar field, and it completely eliminates spurious oscillations.

To address this issue, a new monotonic transport scheme based on a third-order DG method was developed in FY2008. This scheme can also preserve the positivity of the solution while being mass conservative. The first figure shows the solid-body rotation test results with the new scheme that eliminates spurious overshoots and undershoots from the numerical solution. The monotonic DG transport in a more realistic (divergent flow) simulation is shown in the second figure.



This figure shows an example of monotonic tracer transport in a non-linear divergent flow as in the case of real atmosphere. The left panel shows the initial tracer field which is an idealized "Gaussian plume" with concentration ranging from 0 to 100%, and the right panel shows the simulated tracer field transported to the east direction after 5 days. A 2D version of the HOMME-DG model (shallow water model) with horizontal resolution of approximately 1 degree is used for this simulation.

For FY2009, more comprehensive tests are being developed, such as aqua-planet simulation with the new transport scheme in the HOMME-DG version. This scheme will be tested further in HOMME/CAM simulations during FY2009.

This research and development effort supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment." In addition to NSF Core funding support, two Department of Energy programs sponsor this research: the Climate Change Prediction Program (CCPP) and the Scientific Discovery through Advanced Computing (SciDAC) program.

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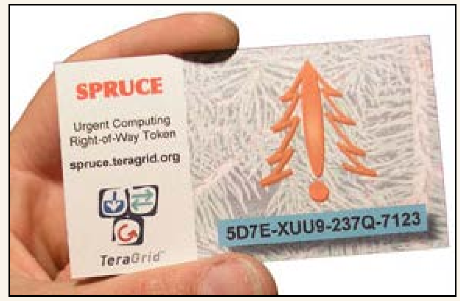
Urgent computing



SPRUCE is a computing environment on the TeraGrid that supports urgent or event-driven computing on both traditional supercomputers and distributed Grids. Scientists use transferable Right-of-Way tokens with varying urgency levels during an emergency. A token is activated at the SPRUCE portal, then urgent access is negotiated with the available resources. Local policies at the resource provider dictate the response, which may include providing "next-to-run" status for the urgent job or immediately pre-empting other jobs. (Image courtesy of SPRUCE.)

The urgent computing project at NCAR provides computing and data resources for timely predictions to support decision making during life-threatening events such as hurricanes, floods, and wildfires. In an emergency, NCAR's TeraGrid resource, the IBM Blue Gene/L supercomputer frost, is now capable of being automatically retasked to run the urgent computing task immediately. This new capability runs without human intervention to suspend as much of frost's multiuser, shared workload as necessary, then dedicate all required processing power and data resources to provide accurate and timely forecasts. NCAR is part of the TeraGrid Special PRiority Urgent Computing Environment (SPRUCE) with six other TeraGrid centers. The authorization mechanism uses "Right-of-Way tokens" to allow users to run on any urgent computing resource on the TeraGrid.

The challenges to providing this service included:

- Supporting a cohesive set of functions across a distributed set of heterogeneous resources with many interfaces both locally and via Grid computing tools
- Authorizing users in a way that is secure and prevents abuse
- Monitoring the various urgent computing resources

The goal of this project is to apply computational science, modeling, and high-performance computing infrastructure to mitigate the loss of life and property in time-critical situations. This capability supports NCAR's strategic goal to "Increase societal resilience to weather, climate, and other atmospheric hazards" and the strategic priority of "Developing and providing advanced services and tools."

In FY2008, we developed an urgent computing capability to support frost resources using the Cobalt resource manager. We also deployed capability on frost in "next-to-run" mode for urgent computing jobs. Frost can now support urgent computing applications that can utilize frost.

The goal for 2009 is to expand the data management capabilities for data-intensive urgent computing workflows. This includes providing resources for transferring large datasets across networks, locally storing or manipulating large datasets, and replicating or staging data to another urgent computing site on demand. These capabilities will ensure that data-intensive applications execute in a timely manner and do not fail to execute because of missing data or a lack of storage resource availability. Finally, we will also evaluate potential urgent computing candidate applications for frost, such as wildfire modeling and forecasting.

This work is supported by NSF Core funding.

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Director's Message

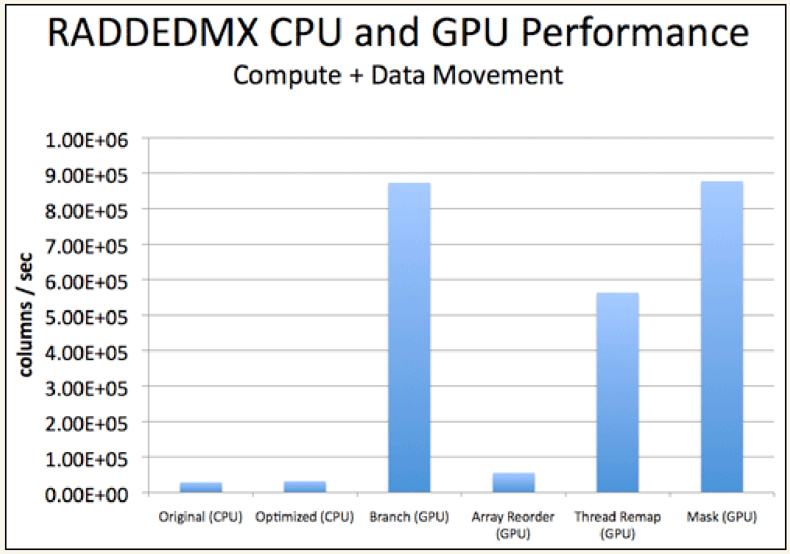
Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

NCAR is sponsored by the National Science Foundation.

Accelerator card R&D



This chart compares the performance of the RADDEDMX routine on a CPU with multiple GPU implementations. The GPU is able to achieve column processing rates an order of magnitude greater than the host CPU, leading to a faster overall simulation time.

In FY2008, the performance of several accelerator card technologies was explored by implementing select application kernels on multiple hardware accelerators. The kernels selected included both benchmark kernels designed to measure and compare specific dimensions of accelerator card performance (e.g. data transfer bandwidth, elementary function performance, etc.) as well as portions of larger applications taken from the atmospheric science community.

One such application kernel implemented on accelerator hardware was the raddedmx routine from the Community Atmosphere Model (CAM). The raddedmx routine computes layer reflectivities and transmissivities from the top down to the surface using the delta-Eddington solutions for each layer. Optimized versions of the source were created for both a traditional microprocessor (3.0 GHz AMD Opteron) and a graphics card (NVIDIA GeForce 9800). The NVIDIA graphics card was able to provide substantial speedup for the raddedmx routine, executing the purely computational portion over 300x faster than the Opteron, and executing the overall routine, including data transfer time, over 30x faster. This increased the total processing rate from 28,595 columns per second to over 861,000 columns per second.

Plans for FY2009 include both continued technology tracking as well as targeting new science applications for implementation on accelerator cards. On the technology-tracking side, accelerator cards are advancing rapidly and on multiple fronts. Continued refinements and new product releases are expected from companies such as NVIDIA, AMD/ATI and Intel (GPGPUs and stream processors), Xilinx and SRC (FPGAs), and IBM (Cell BE), among others.

In addition, new compilers, debuggers, languages, and tools will continue to be released, promising improvements in both performance and developer productivity. On the application implementation side, one major goal for FY2009 is the acceleration of a Cloud Resolving Convection Parameterization (CRCP) model on a GPU. The CRCP method had the potential to improve climate simulation through explicitly capturing sub-grid-scale cloud dynamics by embedding 2D cloud scale models within the columns of a global 3D atmosphere model. Currently, CRCP methods are thought to be too computationally expensive for traditional CPUs, but their high ratio of computation to data transfer and embarrassingly parallel nature makes them good candidates for accelerator cards. The successful acceleration of a CRCP model promises not only to reduce model simulation time, but also to enable new methods in atmospheric science modeling and to provide improved model simulations.

This work supports NCAR's strategic priorities of "Enhancing capability and capacity of NCAR supercomputing" and "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D." In addition to NSF core funding, this project is supported by equipment grants from the NVIDIA and AMD corporations.

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Computationally intensive science gateway development

Setting up and running modern computational models is often an involved process for scientists. Performing a complete simulation consists of gathering required data from various storage systems, running preprocessing software to prepare data for the target model, executing the simulation itself, and gathering output data for analysis and visualization. This process must be repeated for each experiment and may vary between different computer systems. As such, the overhead to simply running a computational model is quite high, and scientists must perform many manual tasks and possess substantial platform-specific computer expertise.

Science gateways, also called "portals," simplify the use of complex software models by providing an intuitive web-based user interface and automating the computational tasks required to run the code. In a typical gateway, scientists can choose to upload original input data or select from popular community datasets, configure the experimental run parameters, run the job, and view results. All of this can be done in an intuitive web-based environment without knowledge of the scripts and environmental parameters for each computer that was used to run the simulation. By reducing the amount of computer expertise required to execute models, gateways increase the efficiency of scientific inquiry through mature computational models.

In FY2008, the Computer Science Section (CSS) commenced work on two science gateways. The first gateway, Grid-BGC, was originally developed during FY2003-2006 with funding from NASA. The gateway provides an automated interface to configure and run the Daymet surface observation interpolation engine and the Biome-BGC terrestrial carbon cycle model. As several years have passed since its development, CSS has undertaken an effort to update and modernize the Grid-BGC gateway, including hosting it on current computer systems and updating several software components, to provide the service to a new community of users.

Primary work will begin in FY2009 for the new Asteroseismic Modeling Portal (AMP) science gateway. AMP provides a web-based interface for astronomers to use the Aarhus Stellar Evolution Code (ASTEC) to derive the properties of Sun-like stars from observations of their pulsation frequencies. As ASTEC runs are highly computationally intensive, requiring over 40,000 CPU hours on the frost supercomputer, the AMP architecture has been developed to also support execution on remote TeraGrid resources. AMP is scheduled to be released to an initial user community in early 2009.

These gateways play an important role in supporting NCAR's strategic priority of "Developing and providing advanced services and tools." Research and development of computationally intensive science gateways is funded by NSF Core funds with supplemental funding for the Asteroseismic Modeling Portal provided by NSF through the TeraGrid's Grid Integration Group.

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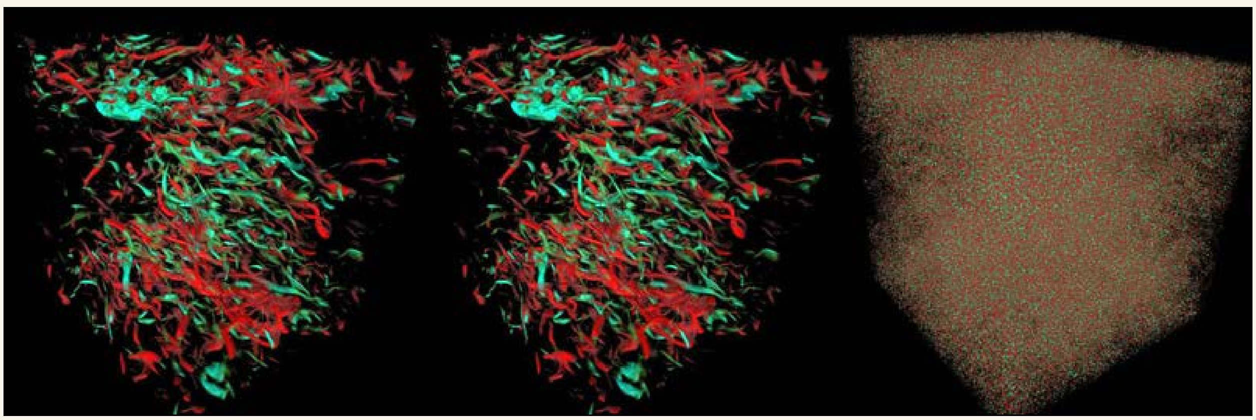
Scientific data compression research

The Scientific Data Compression Research project began in FY2006. It is built on the success of CISL's VAPOR work, which employs a simple wavelet-based progressive data access scheme to facilitate interactive analysis of terascale data sets. CISL began investigating the application of wavelet-based lossy data compression and more advanced progressive refinement techniques applied across a broader domain of computational science.

The methods employed in our data compression research are similar to those now widely used in the compression of digital media. The goals of this work are to:

- Determine whether, and to what degree, scientific data sets can tolerate information loss
- Investigate a variety of compression methods and their suitability for geoscience data
- Develop user tools for data compression and improved, more general, progressive data access



Denoised vorticity data derived from a 1024^3 Taylor-Green turbulence simulation. Shown from left to right are the original data, the denoised signal, and the extracted noise field. The denoised signal is represented by approximately 1% of the original data.

Exponential growth in transistor density in computers is producing ongoing increases in computer processing power. These increases enable computational scientists to create numerical simulations of physical phenomena at unprecedented scales, and thus generate extraordinary amounts of data. Yet while microprocessor performance continues to advance in accordance with Moore's law, other computing technologies are improving at much more modest rates. In particular, storage and networking bandwidths have lagged behind. As a result, the challenge of storing, analyzing, managing, and sharing large simulation data sets is becoming increasingly problematic. Lossy signal compression techniques, such as those ubiquitously used for digital media and now being investigated by CISL, may provide relief for researchers drowning in data.

Incremental progress was made on this project on a number of fronts. With the assistance of a summer student intern funded through CISL's SIParCS program, the foundation for a distributed-memory, MPI-based data compressor were laid. This parallel, C- and Fortran-callable API will enable the data encoding process to be performed *in situ* as part of a running simulation: a numerical model will be able to directly output lossy compressed, or lossless progressively accessible data. Hence, the expensive post-processing step presently required will be eliminated; this is a necessity for current and future grand-scale simulations, whose size may limit or preclude movement of the raw data. Similarly, to further improve performance of the data encoder, the compressor kernel has been threaded to take full advantage of multi-core computing nodes.

As part of our continued efforts to identify broader applications for this work, CISL partnered with domain scientists from the University of Colorado for a summer project, also aided by a SIParCS student intern. While the main focus of the summer project was to examine the sensitivity of scientific data compression to wavelet family choice, the collaboration presented an opportunity to explore another potential application of wavelets: facilitating feature identification in turbulent fluid flow.

Building on the previous work of Schneider et al.[1], we explored denoising the solutions, and their derived quantities, from a 1024^3 Taylor-Green turbulence simulation. The goal is to improve feature detection in two areas: 1) reducing the substantial amount of data to be processed by computationally expensive feature identification algorithms, and 2) improving the operation of the feature detection algorithm by enhancing the contrast between features and background flow. Work this summer included:

- Investigating numerous coefficient thresholding strategies
- Investigating sensitivity of denoising to wavelet family choice and filter tap width
- Investigating separable and non-separable wavelets
- Reproducing results of Schneider et al. using the Taylor-Green data

In FY2009 we will complete a first release of the parallel data compressor API. The first release of this API will support the simple, frequency-truncation progressive access method currently employed by VAPOR. We will also work toward incorporating a more aggressive coefficient prioritization-based progressive access scheme into the API, and adding accompanying decoding support in VAPOR.

We will continue our collaboration with the University of Colorado on feature detection. We will attempt to publish our findings on the Taylor-Green data, and we will begin experimenting with feature detection algorithms on the denoised fields.

This research supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Conducting research in computer science, applied mathematics, statistics, and numerical methods." It is made possible by NSF Core funding.

References

[1] Schneider, K., Farge, M., Azzalini, A., and Ziuber, J. Coherent vortex extraction and simulation of 2D isotropic turbulence, Journal of Turbulence, 7 (44), 2006.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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Networking research projects and technology tracking

CISL's Network Engineering and Telecommunications Section (NETS) is a principal collaborator in number of nationally recognized networking and data communications research and development projects. NETS hosts and presents at national and regional meetings on a variety of networking projects. NETS continued work on an NSF STI award for the Network Path and Applications Diagnosis (NPAD) project, and NETS contributed to the NIH BRIN (National Institutes of Health) (Biomedical Research Infrastructure Network) Lariat project. The NPAD project completed with the publication of *Pathdiag: Automated TCP Diagnosis*.

Participants at the bi-annual Westnet Meeting coordinated by NCAR/UCAR, Arizona State University, Tempe, Arizona, January 2008.

NETS staff serve on the board and the executive committee of the National LambdaRail, Inc. (NLR), a consortium of leading U.S. research universities and private-sector technology companies building and operating a network infrastructure for new forms and methods for research in science, engineering, health care, and education as well as for research and development of new Internet technologies, protocols, applications, and services. NETS has continued to manage network connections between the NCAR computing facility and the TeraGrid, an open scientific discovery infrastructure combining leadership-class resources at partner sites to create an integrated, persistent computational resource.

NETS staff serve in a number of leadership roles in the Quilt, including the Quilt, Inc. Board of Directors, Steering Committee, Executive Committee, the Peering Committee, the Commodity Internet Services Committee, the VoIP RFI Committee, the Lambda RFI Committee, and the NOC Tools Committee. The Quilt's specific purposes and objectives are to promote the delivery and geographical aggregation of advanced network services to the broadest possible research and educational community; promote end-to-end continuity, consistency, reliability, interoperability, efficiency, and cost-effectiveness in the development and delivery of advanced network services that reflect the diversity of its participants and foster innovation; and represent the participants' common interests to national advanced research and educational networking organizations, backbone network service providers, industry, government, standard-setting organizations, and other organizations involved in or influencing the development and delivery of advanced network services. Through NETS involvement in the Quilt, we are able to effect and track technology trends in networking equipment, fiber optic technologies and implementation methods, regulation, and commodity Internet services and technologies.

Westnet is an affinity group that grew out of the NSFnet regional network called Westnet. Westnet holds bi-annual meetings that include technical presentations from members and vendors. Westnet provides powereful political and technical contacts with universities that share common concerns. The current Westnet participants include University of Colorado - Boulder, University Colorado - Denver, Colorado State University, University of Wyoming, University of Utah, Utah State University, Colorado School of Mines, University of Arizona, Arizona State University, University of New Mexico, New Mexico State University, Idaho State University, Denver University, South Dakota School of Mines and Technology, New Mexico Technet, Boise State University, and the National Center for Atmospheric Research (NCAR). NETS provides leadership for Westnet. NETS provides agenda development and logistical support for the Westnet and Westnet CIO meetings.

NETS will continue their leadership roles in these areas in FY2009 and use the experience and knowledge gained to advance UCAR, the FRGP, and the UPoP networking technology and infrastructure.

NETS' research activities support NCAR's strategic priority of "Developing and providing advanced services and tools." This work has many funding sources: NSF Core funds, FRGP, UPoP, and UCAR Communications Pool indirect funds.

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Layer 2 networking for researchers

This project is now fully operational and ongoing. This work has many funding sources: FRGP, U.S. Department of Commerce, and UCAR Communications Pool indirect funds.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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Network Path and Applications Diagnosis (NPAD)

NETS continued work on an NSF STI award for the Network Path and Applications Diagnosis (NPAD) project, and NETS contributed to the NIH BRIN (National Institutes of Health) (Biomedical Research Infrastructure Network) Lariat project. The NPAD project completed with the publication of *Pathdiag: Automated TCP Diagnosis*.

This work was supported by NSF award 0334061 through subaward 1120444-145302 with the Pittsburgh Supercomputing Center.

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Adaptive-mesh grid techniques for climate modeling on millennial time scales

Weather and climate simulation are extremely complex problems that require many long-duration computer simulations of the Earth's atmosphere. Recently, attempts have been made to improve the accuracy of long-duration models by simulating localized flow structures such as hurricanes. Simulating such details requires higher resolution and is required by applications in the atmospheric and air-quality communities, at operational centers attempting to forecast significant weather events, and for research endeavors that focus on the dynamics of severe storms and tornadoes.

Discussion of this work is incorporated into Multiscale simulation techniques.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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Scalable numerical methods for partial differential equations

To reach scientifically significant integration rates, implicit or semi-implicit time integration is required. This approach invariably leads to a large sparse matrix, representing an elliptic operator, needing to be inverted at each time step using iterative methods. Traditionally, because of the numerical techniques in use, especially for climate modeling, this problem was trivially invertible. Now, with efforts made toward using the latest available numerical methods, finding a solution to the linear system is a non-trivial challenge. Iterative methods converge quickly only if good preconditioning is available. One approach uses recently developed techniques like the optimized Schwarz method or algebraic multigrid.

Discussion of this work is incorporated into Multiscale simulation techniques.

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Toward an Earth System knowledge environment

The development of an Earth System Knowledge Environment (ESKE) is a cornerstone of the strategic plans for both NCAR and CISL. The goal is to continually develop new cyberinfrastructure that may be integrated into powerful, collaborative problem-solving environments that accelerate the community's ability to engage in research and scientific discovery and construct complex workflows. Our efforts span modeling frameworks, critical scientific data archives, federated data and knowledge systems, digital preservation, collaboration, and analysis and visualization environments.

In many cases our efforts are tied to major interagency, national, and international initiatives, including, for example, the World Meteorological Organization (WMO), the Intergovernmental Panel on Climate Change (IPCC), the International Polar Year (iPY), the Earth System Modeling Framework (ESMF), the World Climate Research Program (WCRP), the National Digital Information and Infrastructure Preservation Program (NDIIPP), and the THORPEX Interactive Grand Global Ensemble (TIGGE).

Our strategy is to cultivate opportunities to advance the state of the art through R&D grants complemented by core funding, transition the most promising and effective results into production capabilities that we support and distribute, and *integrate across capabilities to amplify our investments*. This integration theme requires strategy and co-development across major initiatives such as the ones described in this section of our report, and there is substantial activity already underway in this regard. For example, the TIGGE effort reflects collaboration and joint development between our Research Data Archive (RDA) activity and the Community Data Portal (CDP). Similarly, our NCL/Python development group will be developing applications that can work with the Earth System Grid. We have begun to explore possibilities for integrating NCAR Command Language and PyNGL/Python capabilities with the VAPOR application, and we've allocated resources in FY2009 to undertake new development work in this area.

One of the best examples of our cross-project integrative work is in Cyberinfrastructure for next-generation atmospheric models. This effort reflected a collaboration between CISL and the Advanced Studies Program (ASP), as well as highly collaborative work across the Earth System Curator (ESC) effort, the Earth System Grid (ESG), and the Cyberinfrastructure Strategic Initiative (CSI). The following reports describe CISL's portfolio of strategic activities and future plans that contribute to the realization of an Earth System Knowledge Environment (ESKE).

These efforts support a broad range of NCAR's strategic goals and priorities. NSF Core funding, with other support as indicated by the individual reports in this section, sustains this ongoing work.

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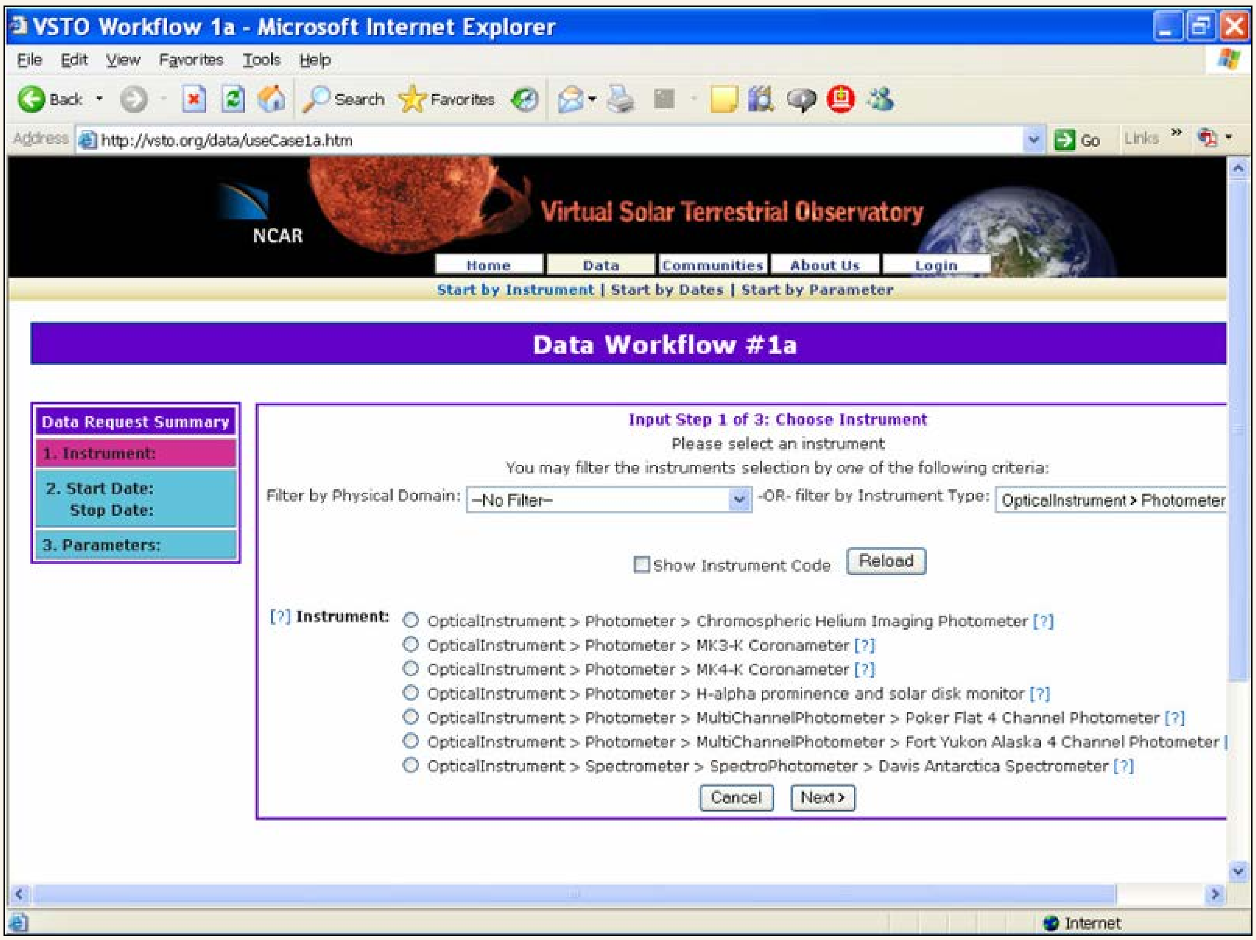
The Virtual Solar Terrestrial Observatory (VSTO)

The Virtual Solar Terrestrial Observatory (VSTO) is an NSF-funded collaboration of the NCAR High Altitude Observatory (HAO), NCAR's Computational and Information Systems Laboratory (CISL), and McGuinness & Associates. The goal of the project is to research and develop a next-generation knowledge environment that will allow seamless integration and data access in the areas of solar, solar-terrestrial and space physics (SSTSP). By providing a higher-level semantic layer on top of the current array of data formats, services, and repositories, the project is aimed at facilitating and empowering data providers, scientists, researchers and educators across all these domains. The goal of the three-year project was to deliver a fully functional prototype allowing virtual access to selected services comprising observational and model data, different data formats, and different data archives.



This is a snapshot of the VSTO portal's data search and query interface, which exposes an ontology-based instrument selection capability. The Virtual Solar-Terrestrial Observatory (VSTO) is a production semantic web data framework providing access to observational datasets from fields spanning upper atmospheric terrestrial physics to solar physics. The observatory allows virtual access to a highly distributed and heterogeneous set of data that appears as if all resources are organized, stored, and retrieved/used in a common way.

Semantic data integration is increasingly important across all of our areas of science and technology, especially as we strive to provide capabilities that bridge domains and disciplines. VSTO thus occupies an important strategic position in NCAR and CISL's cyberinfrastructure R&D portfolio. The same technologies, design patterns, and interfaces that are being developed for VSTO have substantial promise for other scientific disciplines such as climate, weather and forecast, and further on to the biogeosciences, geochemistry, and water/carbon cycles. VSTO primarily addresses two NCAR strategic priorities: "Improving understanding of the atmosphere, the Earth System, and the Sun;" and "Providing robust, accessible, and innovative information services and tools."

In FY2008 CISL completed development activities for the NSF grant that supported the work and came to a close during the fiscal year. We moved into a production mode for the VSTO system, which is depicted in the image above. VSTO now effectively integrates the holdings of the Mauna Loa Solar Observatory (MLSO) and the CEDAR databases, and it represents a first example of broad semantic integration in its field. During FY2008 we prototyped the integration of the Community Spectro-polarimetric Analysis Center (CSAC) data into the VSTO system.

In FY2009 we will be looking for opportunities to expand data integration through the VSTO system in the solar-terrestrial realm, while we also explore opportunities to broaden our disciplinary focus.

VSTO is primarily supported through a grant from the National Science Foundation, along with NSF Core funding, and support from the NCAR Cyberinfrastructure Strategic Initiative (CSI).

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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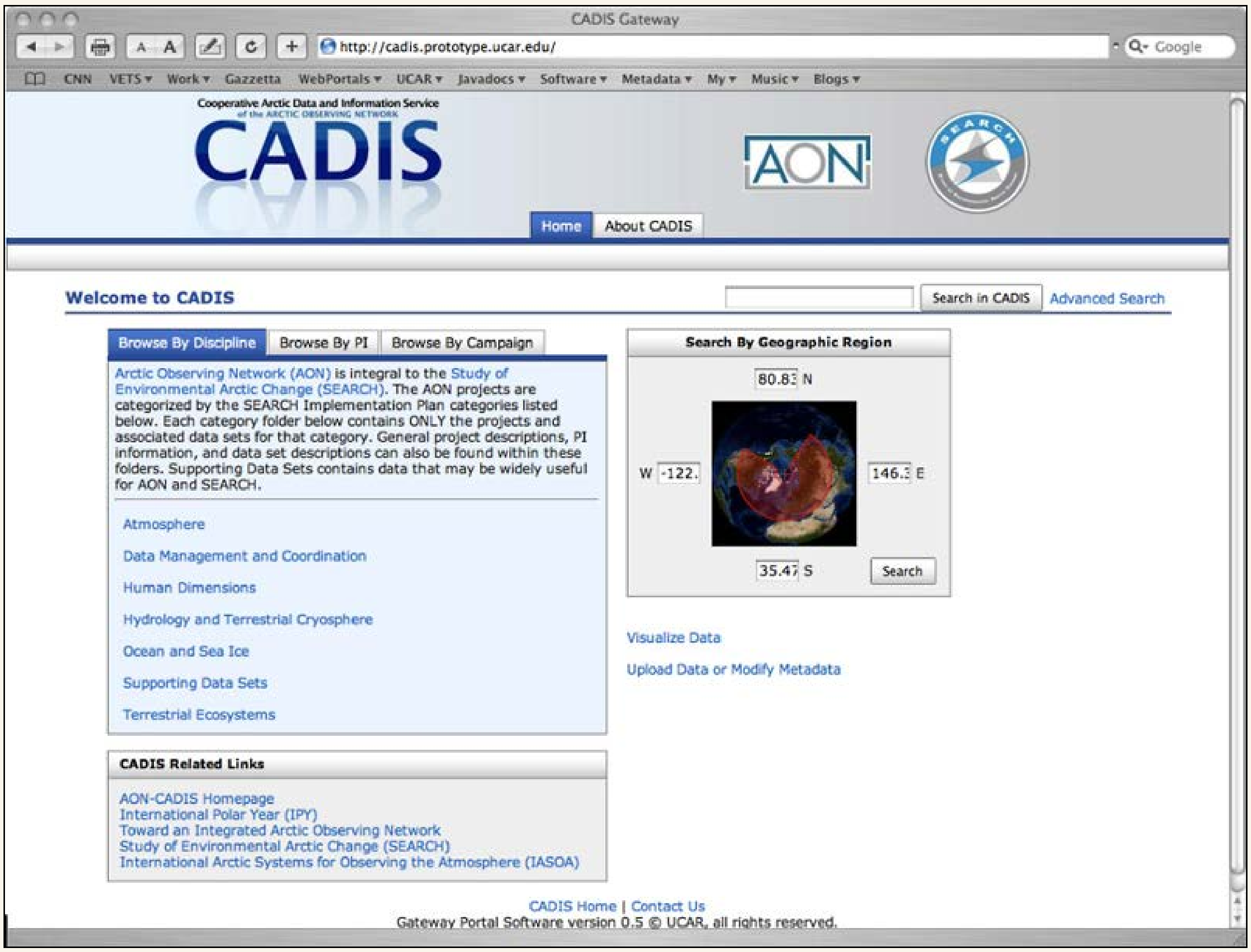
The Cooperative Arctic Data and Information Service (CADIS)

Arctic science in the U.S. lacks a single coordinated force setting a data management direction. This needs to change to address the challenges of data management for Arctic-wide observing systems; to meet scientists' growing expectations for sharing and working with data across diverse disciplines and in the broad Pan-Arctic geographic domain; to encourage the international exchange of data; and to reduce overlap and wasted effort spent developing data management solutions for small numbers of users.



This image shows a new prototype science portal for CADIS; it will serve the Arctic Observing Network (AON) and other research efforts. One of CADIS' challenges is to provide data discovery, access, and visualization capabilities that are appropriate for polar research; these are characterized by very heterogeneous data collections and special requirements for data selection. The portal shown above is built on the new Science Gateway Framework (SGF), which is aimed at supporting multiple scientific endeavors. CADIS provides an opportunity to deliver a broad and diverse collection of research datasets to a multidisciplinary community in support of the International Polar Year (IPY).

AON is supported by the National Science Foundation and consists of more than 30 land, atmosphere, and ocean observation programs, some existing and some as new observing capabilities. This IPY initiative will succeed in supporting the science envisioned by its planners only if it functions as a system and not as a collection of independent observation programs. AON planners envision a data management system through which scientists can find all data relevant to a location or process; all data have browse imagery and complete documentation; time series or fields can be plotted online; and all metadata are in a relational database so that multiple data sets and sources can be queried.

CADIS is a joint effort of the University Corporation for Atmospheric Research (UCAR), the National Snow and Ice Data Center (NSIDC), and the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. Working with NCAR's Earth Observing Laboratory and Unidata partners, CISL's contributions to CADIS include the application, integration, and enhancement of Community Data Portal (CDP) infrastructure to support the needs of the Arctic research community. CADIS addresses several NCAR strategic priorities including "Exploring atmospheric, Earth System, and solar processes, variability, and change;" "Developing advanced tools and services;" and "Building an Earth System Knowledge Environment."

During FY2008 we refactored the existing Community Data Portal system to support the publishing of CADIS data and metadata, such that PIs involved in AON and IPY experiments were able to self-manage their data collections. We moved this into a production operation during the year. In parallel with this, we incorporated CADIS and polar requirements into the design of the ESKE SGF and prototyped a CADIS portal as depicted and described in the image above. As part of this effort, we also prototyped a visualization environment for Arctic datasets using an SGF-integrated implementation of NOAA's Live Access Server (LAS), including global GRIB model datasets and netCDF point data.

In FY2009 we will integrate the publishing environment with the SGF and then transition the CADIS system onto the new SGF infrastructure. In parallel with that activity, we will continue to advance the web-based visualization capabilities to address the challenges posed by the datasets being collected by AON researchers. The new SGF provides powerful semantic capabilities for dynamically organizing and searching data, and during FY2009 we will be exploiting these approaches for CADIS data collections.

CADIS is supported via a combination of NSF special support and NSF Core funding.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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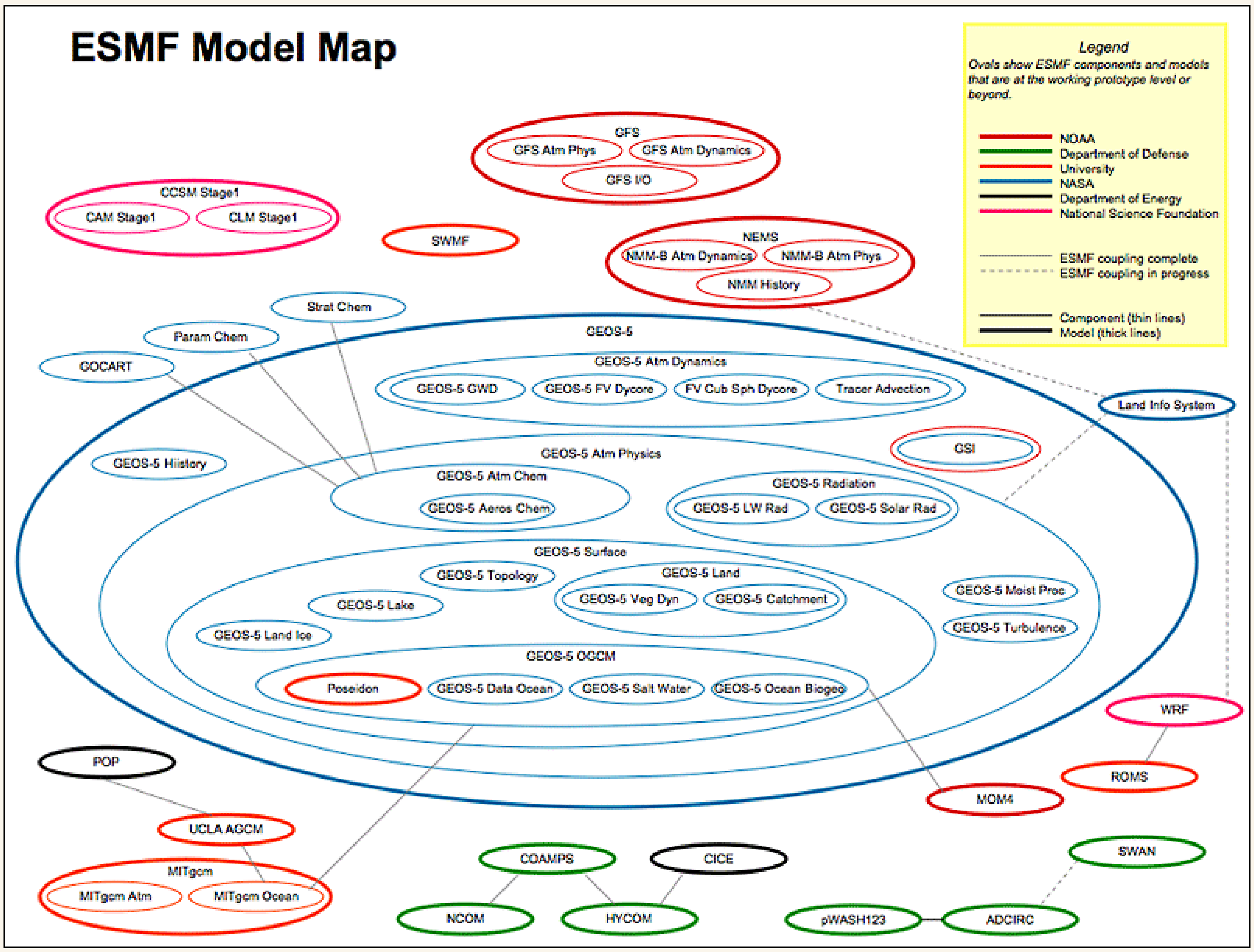
Earth System Modeling Framework (ESMF) and ESMF-based initiatives

The Earth System Modeling Framework (ESMF) was motivated by the growing complexity of developing Earth system models. These are constructed of separate software components representing physical domains and processes; for example, atmosphere, ocean, and sea ice. The components, which are often developed at separate sites, are coupled into integrated systems on supercomputers to create realistic simulations. To make this process easier, ESMF provides standard component interfaces and high-performance tools for common functions, such as grid interpolation. Now in its sixth year, the ESMF project has transitioned from NASA funding to multi-agency support. ESMF is the chosen infrastructure for the consortium of U.S. operational weather and space weather prediction centers (known as the National Unified Operational Prediction Capability, or NUOPC), the DoD Battlespace Environments Institute, the NASA Modeling Analysis and Prediction Program, and a host of smaller programs and projects.



This model map shows the growing use of ESMF in the Earth science community. Each oval is a model component with a standard interface to facilitate interoperability. Use of ESMF enables modelers to add and exchange model components more easily, and encourages collaborations across institutions and agencies.

ESMF is a key element of the NCAR strategic priority "creating an Earth System knowledge environment." The ESMF team has been interacting closely with the data services community via the Earth System Curator project to create workflows that span modeling and data services. ESMF is also a key piece of the NCAR strategic priority "developing community models for weather, climate, atmospheric chemistry, and solar-terrestrial research." Through ESMF, the climate and weather research models at NCAR and elsewhere are interfacing with space weather models, hydrological models, and operational prediction systems. Looking beyond NCAR, ESMF is a realization of the goals expressed by the broader community to develop cross-institutional and cross-agency cyberinfrastructure for the collective re-use and exchange of components.

The number of ESMF science components in the community is an important metric, since more standard components mean more options for researchers creating coupled modeling systems. The adoption of ESMF continued to increase steadily this year, with the number of available science components growing from 58 at end-FY2007 to 69 at end-FY2008.

The ESMF software completed the transition to a new set of central data structures in FY2008. The aim of this redesign effort, which has been ongoing for several years, was support for a wider variety of supported grid types and general, parallel regridding. Internal (beta) release ESMF v3.1.1, completed in September 2008, contains classes that represent unstructured meshes and observational data streams. Users can now represent physical fields based on meshes, observational data, or logically rectangular grids. Also in this release, the framework can generate bilinear and higher-order interpolation weights in parallel, for grid/grid, mesh/grid, and mesh/mesh transformations in up to three dimensions.

The usability, performance, and portability of the ESMF software continued to improve in FY2008. Several performance reports were released this year showing good scaling to thousands of processors. ESMF public releases are now supported on more than 30 platform/compiler combinations. The ESMF team continued standardization of behavior and interfaces, and it released C bindings sufficient to perform a basic coupling between C and Fortran applications. New capabilities for storing and using knowledge about models were implemented: ESMF users can now associate metadata with fields, grids, and other framework classes, aggregate the metadata, and write it out in a standard exchange format. This enables descriptions of ESMF applications to be stored in archives along with model datasets. Robustness also increased, as about half of the open bugs in ESMF were closed. The number of outstanding feature requests decreased significantly.

Application development during FY2008 focused on the incorporation of additional components into existing ESMF modeling applications at the National Weather Service, NASA centers, and the Army, Navy, and Air Force. Work progressed on development of an ESMF-compliant version of the Community Climate System Model (CCSM), although, as expected, this will not be completed until FY2009.

A primary goal for FY2009 is delivery of an ESMF public release that includes meshes, observational data streams, and online regridding. These features, which were delivered in beta release v3.1.1 during FY2008, require additional testing, optimization, and standardization. With this public release, the ESMF development team will have satisfied most of the project's initial requirements. The development focus then will be on completing the ESMF package and preparing it for full deployment at operational centers throughout the U.S. in 2010 as part of the NUOPC program.

The ESMF team also anticipates completing the ESMF-compliant version of CCSM in FY2009. Key features to be added in support of this and other applications are a conservative regridding option and parallel IO. ESMF will continue to work toward an integrated Earth System Knowledge Environment by continuing collaborations with the Earth System Grid, Earth System Curator, and other projects implementing workflow and knowledge systems.

Core ESMF development is sponsored by the National Science Foundation, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and the Department of Defense. In addition, a variety of ESMF-based application adoption projects have been sponsored by NASA, NOAA, the U.S. Geological Survey/Department of the Interior, and other agencies and institutions.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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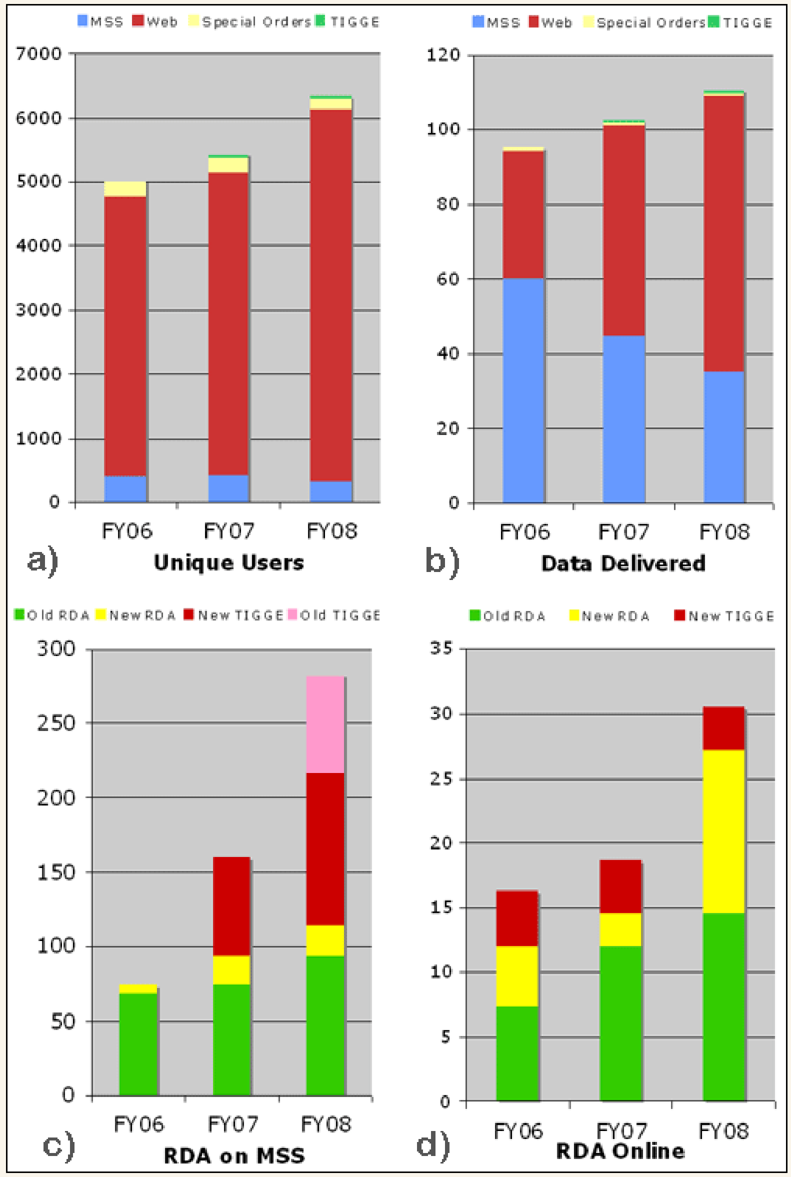
Research Data Archive

The Research Data Archive (RDA) is a key part of the NCAR strategic priority to create an Earth System Knowledge Environment, because it provides an information resource through a large collection of datasets that support scientific studies in climate, weather, Earth Systems modeling, and increasingly other related geosciences. The RDA is developed to serve the research needs at NCAR and in the associated UCAR community, but since it is an open resource, the worldwide community also uses it. The RDA activities can be viewed from two different perspectives: user data access and archive content development, both of which are equally important.

In FY2008, about 6,300 unique persons were provided 110 TB of data through various primary access pathways: the NCAR MSS, public servers on the web, one-time special requests prepared for individuals, and the TIGGE (THORPEX (THe Observing system Research and Predictability Experiment) Interactive Grand Global Ensemble) archive (see charts a and b). The web user group is the largest and is growing most rapidly; there were 5,800 people downloading 74 TB of data in FY2008 compared to 4,700 and 57 TB in the previous year. The number of users that access the data directly at NCAR from the MSS is smaller, 330 individuals, but they use much more data on a per-person basis: 106 GB per person at NCAR versus 13 GB per person on the web. These metrics indicate that the RDA is known as a world data resource on the web, and when it comes to accessing large significant reference datasets, working directly on CISL computational resources is more effective; the top user at NCAR accessed 10 TB from the MSS. Complementary, but not shown in these metrics, is the fact that the RDA support staff also use the MSS to specifically help users; annually more than 25 TB are accessed from the MSS to prepare special orders for individual requests.



These charts show the data access and growth metrics for the Research Data Archive (RDA) during FY2006-FY2008:
a) The number of unique users specified by access pathway: the NCAR MSS, publicly available web servers, one-time special requests prepared for individual users, and TIGGE.
b) The amount of data delivered to customers, by access pathway.
c) The amount of data in the MSS archive, showing annual growth.
d) The amount of data on public servers (a high-demand subset of the RDA archive), showing annual growth.
Charts a) and b) indicate the RDA's great significance to the community, and charts c) and d) show the annual progress toward building more valued content into the RDA.

A simple measure of data content development is archive growth. The RDA expanded by over 120 TB in FY2008 (see chart c). TIGGE is part of the RDA, but it is shown separately because it alone added 100 TB. This overshadows the 20 TB increase in the remaining part of the RDA, which is nevertheless very important and consistent with growth in previous years (chart c). The most-requested datasets from the RDA are available online through web servers. The current online data is 30 TB (chart d), an increase of nearly a factor of two over the previous year. Again, TIGGE is shown separately and does not change between years, because it is capped at a rolling 3-week archive with only the most current data. Older TIGGE data are copied and managed from the MSS.

As a whole, the RDA is constantly changing, curation extends and adds to existing datasets, stewardship improves the documentation, creates systematic organization, applies data quality assurance and verification, and develops access for the users. Many routine tasks and background infrastructure developments are necessary to maintain the RDA. Some of the major accomplishments for FY2008 were:

- Completed the archiving and access systems for the Japanese 25-year Reanalysis and its operational extension.
- Enabled a new RDA "Look for Data" discovery interface and developed tools to create and use file content metadata that helps users find and acquire the data files they need.
- Finalized all major software components for the TIGGE archive system at NCAR.
- Expanded the use of database technology to efficiently manage many RDA functions and services: archiving files, capturing metadata, controlling user access, monitoring user metrics, and standardizing GUI appearance and functions.

Some major activities for FY2009 include:

- Maintain frequent updates of NCEP data streams in the RDA. NCEP model output is the most-demanded data from the web server; 50% of all data downloaded (37 TB) are from the NCEP final global analysis archive.
- Receive, archive, and build user access to the ERA-Interim Reanalysis. This next-generation reanalysis from ECMWF will have many uses; one is to serve as boundary conditions for the Arctic System Reanalysis project, an NCAR and multi-institution effort.
- Complete a joint EOL and CISL data management evaluation that could define new ways to transition field project data into long-term archives.
- World-class data resources are built through collaborations, a few major projects are:
    - Unique RDA datasets are being shared with NOAA/NCDC to make a more complete Integrated Surface Dataset.
    - The 20th Century Global Reanalysis from NOAA/ESRL will be added to the RDA.
    - A new release of the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) is scheduled for completion. ICOADS is a long-standing collaboration (20+ years) between NOAA and NCAR/CISL.
    - Several efforts will evolve that support objectives of the WCRP Working Group on Data Sets for Reanalysis: continued effort to clean up and provide easy access to RDA upper-air atmospheric sounding observations, collaborate with WG members to create a suitable data format for international data exchanges, and participate in joint projects in CISL and with EOL and ECMWF to improve the quality and quantity of upper-air atmospheric soundings.
    - Activate a data and data management sharing project with the China Academy of Science (CAS) Computer Networking and Information Center (CNIC). This will include hosting a CAS/CNIC staff member at NCAR for six weeks as part of the CISL Research and Supercomputer Visitor Program.

The RDA maintenance and development within CISL is supported entirely by NSF Core funding.

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The North American Regional Climate Change Assessment Program

NARCCAP is an international program that will serve the climate scenario needs of both the United States and Canada. We are systematically investigating the uncertainties in regional-scale projections of future climate and producing high-resolution climate change scenarios using multiple regional climate models (RCMs) and multiple global model responses to future emissions scenarios, by nesting the RCMs within multiple atmosphere-ocean general circulation models (AOGCMs) forced with the A2 and A1B SRES scenarios, over a domain covering the conterminous U.S. and most of Canada. The plan also includes a validation aspect through nesting the participating RCMs within reanalyses.

In February 2008 the NARCCAP project hosted a user workshop at NCAR in Boulder, Colorado. The well-attended event provided an overview of the NARCCAP project and its research and community service goals, along with briefings on scientific progress. One of the highlights of the meeting was hands-on training sessions on how to find and access data produced by NARCCAP, and how to use various tools, such as the NCAR Command Language, to process and analyze these data. In this image, Seth McGinnes of ISSE speaks to the group about data access and analysis.

CISL's contribution to this project is primarily in providing data management and community access for NARCCAP-produced datasets. This aspect of the work is a collaborative effort with NCAR/SERE, Lawrence Livermore National Lab (LLNL), and Iowa State University. NARCCAP plans to heavily leverage existing Earth System Grid (ESG) infrastructure as well as established data management practices developed for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

NARCCAP is aligned with several NCAR strategic priorities. Relative to core science as well as societal impacts, it contributes to developing community models, improving prediction of global and regional climate, and supporting and conducting integrated regional-scale investigations of climate and weather impacts. CISL's contributions additionally align with our goals of "Developing advanced services and tools" and "Developing an Earth System Knowledge Environment."

One primary accomplishment for FY2008 was the implementation of the NARCCAP Operational Data Management Plan, which we developed and launched in FY2007. This included running the production process of validating datasets, shipping storage arrays, receiving data, quality-controlling it, and publishing online and archival versions of data for the general NARCCAP community. We are now running production large-scale publishing transfers between NCAR and our partner LLNL. Over the course of the year we completed integration of NARCCAP-specific registration and access control requirements, and we established a registration and approval workflow that includes ISSE authorities in the process. One of the highlights for this year, noted in the figure above, was the NARCCAP User Workshop, held in Boulder, Colorado early in 2008.

In FY2009 we will transition the existing NARCCAP data environment into the new ESKE Science Gateway Framework (SGF) environment. This will result in a lot of new capabilities for the regional climate modeling community, including much more flexible subsetting, enhanced queries by means of semantic infrastrucuture, and web-based visualization capabilities. We will also continue to publish data collections from various regional climate modeling experiments that are currently underway. Current plans call for us to complete the core NARCCAP work in FY2009, but we will continue to run the data services portion as long as the data resources are of value to the community.

NSF, DOE, NOAA, and OURANOS are providing initial funding for the program.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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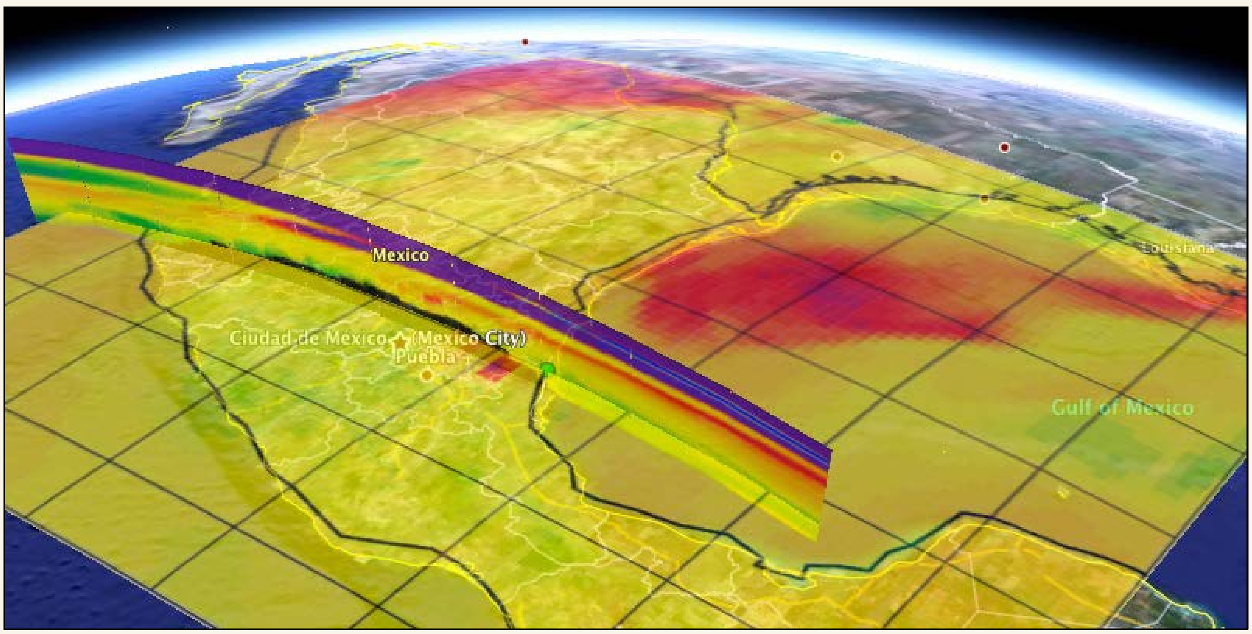
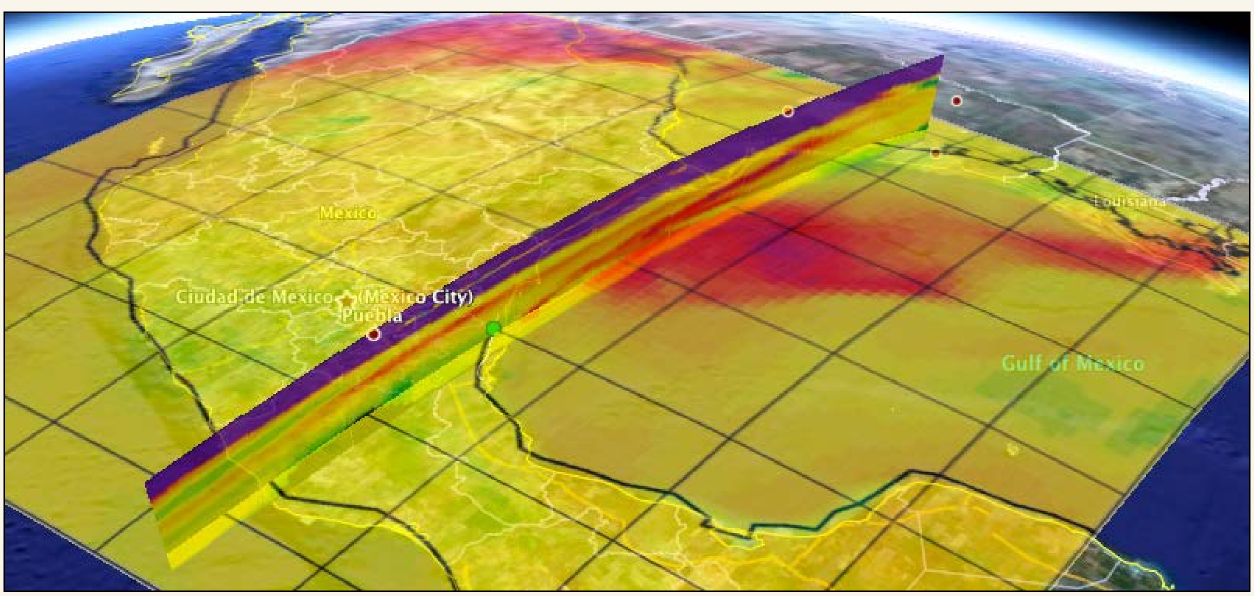
Bringing new functionality to data visualization using Google Earth

We are developing a set of tools that will exploit the capabilities of commercial "virtual globes" software, in particular the Google Earth product (which is freely available to anyone). Using a variety of information types (gridded three-dimensional model results, surface observations, and aircraft-based observations), we are writing software to provide scientists with additional information about the overall structure of the chemical conditions at the time and location of the observations. Our goal is to explore the feasibility and usefulness of this approach for helping scientists refine their models. The tool will be extended to provide visualizations in a 3D regime, such as comparing the predictions of model outputs to an aircraft track or a dropsonde.



These images show comparisons of WRF-CHEM model outputs to aircraft measurements of O_3 near Veracruz, Mexico. The figure shows vertical and horizontal slices through the model data that correspond to the altitude of the aircraft taking the measurement (which is shown as a marker at the intersection of the two planes). Because the concentration color maps are coordinated, this image allows a researcher or student to visually compare concentrations of a pollutant to the values produced by the model, and to track this comparison over time. This visualization technique is significant because it easily allows visual comparisons of scientific datasets to be made in a rich geographic context.



Because these visualizations use readily available commercial tools, they can be easily distributed to scientific colleagues, educational institutions, and the public. We anticipate that schools will be interested in downloading these files with an easy interface and useful information about scientifically stimulating data.

This project supports NCAR's strategic plan in several respects. It is "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment" while "Engaging a broader and more diverse community in the atmospheric and geosciences" and "Supporting and enhancing formal science education at all levels."

In FY2007, we began leveraging an existing NCAR visualization tool, the NCAR Command Language (NCL), to create the visualizations. Existing scientific codes that perform complex operations on data were leveraged to create visualizations that are then placed in the Google Earth context.

In FY2008, this project completed software applications that support automated extraction of data, visualizations, and KML (Google code) descriptions that interface to Google Earth software. One application of the software allowed aircraft data to be compared to model results as illustrated in the image. These results were presented to the scientific community at AGU and to a workshop supported by Google engineers. The result is the beginning of a working relationship with Google that can lead to opportunities to distribute NCAR data to a much wider audience.

A web tool that will allow users to create custom visualizations of comparisons of selected IPCC AR4 model data and corresponding measured parameters is currently under development, and is expected to be available in 1Q FY2009.

This work, performed in collaboration with scientists from NCAR's Atmospheric Chemistry Division, is being funded under the FY2007 NCAR Director's Opportunity fund, which is derived from NSF Core funds.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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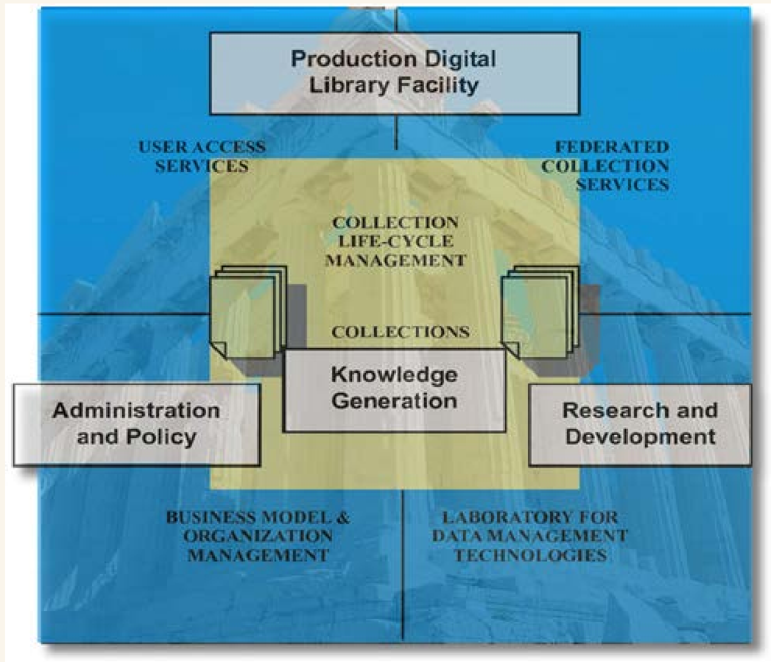
Chronopolis: Federated digital preservation across space and time

There is a critical and growing need to organize, preserve, and make accessible the increasing number of digital holdings that represent vital intellectual capital, much of which is precious and irreplaceable. Chronopolis is a strategic collaboration among the San Diego Supercomputing Center (SDSC, lead organization), NCAR/CISL, the University of California Library System, and the University of Maryland; it is aimed at developing national-scale digital preservation infrastructure that has the potential to broadly serve any community with digital assets -- science, engineering, humanities, and more. This new effort encompasses studying viable models and effective systems that facilitate establishing standard reference datasets, preserving collections that evolve over time, and establishing preservation resources "of last resort" for digital assets that might become lost. Digital collections that must persist for 100 or more years are one important focus of this activity. It is also worth noting the special synthesis of relationships and capabilities required to approach this problem: scientists, librarians, curators, computer scientists, and long-term distributed cyberinfrastructure.



This image represents a conceptual architecture for the Chronopolis Digital Preservation Environment. Through a combination of advanced data management technologies, geographic replication, and policy instruments, Chronopolis is aimed at providing cyberinfrastructure for national-scale digital preservation.

The problem spans the gamut of academic scientific disciplines, historical collections, and digital library content. Though broadly useful, new capabilities developed in Chronopolis are expected to be powerful services that we can potentially offer to the Earth System sciences community through, for example, our Community Data Portal (CDP). This activity addresses NCAR's strategic goal of "Providing robust, accessible, and innovative information services and tools."

In FY2008, under the terms of our Memorandum of Understanding with SDSC, we continued the process of replicating some of our unique observational and reanalysis datasets, and these activities have made good use of our new TeraGrid connections. We also continued to work with the National Library of Congress (LOC) and its National Digital Information Infrastructure and Preservation program (NDIIPP) regarding our expressed interest in developing a funded NDIIPP-supported Chronopolis pilot project. Early in 2008 we finalized a 1.5-year contract with NDIIPP for NCAR to co-develop core preservation infrastructure for the effort. Our pilot project is framed initially as an R&D activity aimed at prototyping a preservation environment for the California Digital Library's (CDL) Web-at-Risk project, and the Interuniversity Consortium for Political and Social Research's (ICPSR) data archive. We acquired a suite of new computational and storage systems and integrated these into CISL's infrastructure along with connectivity to the TeraGrid backbone. Layering on this, we integrated the Storage Resource Broker (SRB) application along with publishing, replication, and monitoring capabilities and began testing end-to-end Chronopolis functionality with some of our data collections.

In FY2009 we will bring our Chronopolis infrastructure and digital preservation systems to full operational status and optimize them relative to storage and wide-area data transfer performance. Once this is accomplished, we will simulate a "disaster" to investigate the performance and effectiveness of resurrecting a lost, multi-terabyte data resource. We will also continue our efforts to broaden our support base and associated scope in the upcoming year.

CISL is engaging in Chronopolis as an important strategic thrust, supporting it through a combination of NSF Core funding, NCAR's Cyberinfrastructure Strategic Initiative (CSI), and focused funding from the National Library of Congress.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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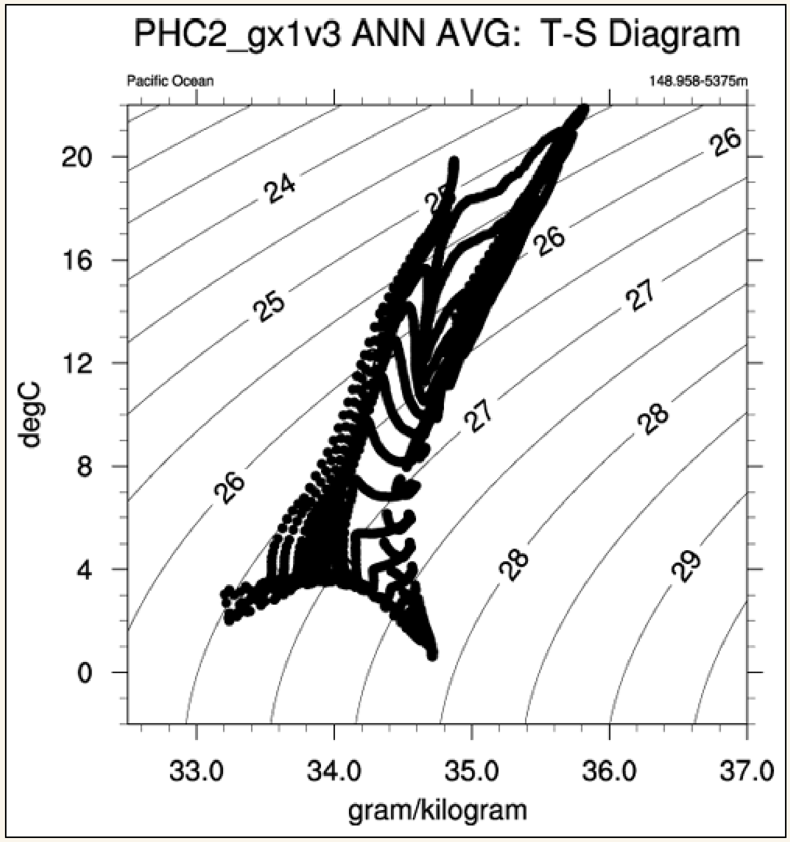
Community tools and frameworks for geoscientific analysis and visualization

The NCAR Command Language (NCL) is a data analysis and visualization environment developed primarily at NCAR/CISL with deep collaboration with a number of core scientific groups. NCL enables scientists to easily and effectively read, analyze, and visualize their geoscientific data on platforms ranging from personal systems to high performance computers. PyNGL and PyNIO are Python modules based on NCL's file input/output and visualization capabilities, thereby enabling NCL's software components to be exposed to a wider and more mainstream user base. The NCL and Python tools have been embraced broadly across an international Earth System sciences community spanning research, education, military, government, and commercial organizations. They are used by thousands of people in 115 countries.



A T-S diagram is a graph showing the relationship between temperature and salinity as observed together at, for example, specified depths in a water column. Isopleths of constant density are often also drawn on the same diagram as a useful additional interpretation aid. In the ocean, certain T-S combinations are preferred, leading to the procedure of identification via the definition of water types and water masses and their distributions. Image contributed by Christine Shields, CGD.

We are seeing an increasing trend with scientific organizations moving to free tools to supplement their research. A major goal in FY2008 was to release this software under an open source license, therefore increasing its accessibility and opening the door for potential new collaborations. NCL was released under an open source license in November 2007, and PyNGL and PyNGL followed with a similar license in August 2008. In mid FY2008, these tools were chosen to be part of the core framework for CCMval, an international climate chemistry model validation effort that is expected to grow into a more broadly applicable multi-model diagnostic/analysis environment. NCL is one of the top choices in NPOESS' competition for a suite of tools for its Data Exploitation Systems, and the CCSM POP model processor may be moved to NCL for public use.

In an effort to embrace the rapidly growing WRF community and their requirements for post-processing capabilities, the NCL team collaborated closely with WRF software engineers to enhance and develop a second generation of visualization and analysis capabilities (WRF-NCL) for WRF-ARW data. WRF-NCL was released in time for the annual WRF tutorials and workshops in summer 2008.

PyNGL and PyNIO were overhauled to be compatible with the new masked array features of NumPy, a fundamental package needed for scientific computing with Python. Extensive subscripting capability was added to PyNIO through collaboration with a scientist in MMM. PyNIO has the same powerful ability as NCL to read several complex scientific data formats using a simple and user-friendly interface. These PyNIO features are unique in the Python world and will enable us to engage a broader scientific community.

A top priority for FY2008 was to ramp up our software in an effort to support petascale computing, a rapidly growing international community, and a new class of complex scientific data formats. To this end we:

- Began a major re-engineering of the NCL software to add support for greater than 2 gigabyte variables
- Completed an overhaul of the map databases to create new map projections, update all the political boundaries, and add internal boundaries for countries like China, India, and Brazil
- Significantly upgraded our GRIB2 reader code, and began preparations for supporting new data types that are inherent to

NetCDF-4 and HDF-5

Future plans for NCL and Python software development and support are largely based on continuous dialogs with the scientific community and feedback from our training workshops. Goals for FY2009 include:

- Add full support for more data formats (NetCDF-4 and HDF-5)
- Begin in earnest the integration of VAPOR and NCL
- Research the scalability of NCL to address issues pertaining to large files, data aggregation, and 64-bit machine addressing
- Continue to enhance the Python suite of analysis functions
- Integrate interfaces for generating vectors and streamlines on non-uniform grids to the NCL/PyNGL level
- Integrate a new display model on which the visualization tools are built to address future enhancements required
- Continue providing high-quality consulting support and training services for the user community

These efforts support NCAR's strategic priorities of developing and providing robust and accessible tools, engaging a broader and more diverse community, and creating an Earth System knowledge environment.

Our development and deployment of community tools and frameworks for geoscientific analysis and visualization is supported by NSF Core funding.

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CISL Portal (was SCD portal)

The CISL portal was enhanced in FY2008 to support One-Time Passwords (OTP) for increased security. Plans for 2009 include integration of NCAR's People Search web application into the Portal and additional data entry delegation for system administrators.

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Grid-BGC

Grid-BGC is a collaborative project to develop an end-to-end solution that seamlessly couples models, data, and resources to allow geoscientists to simulate terrestrial biogeochemistry over large domains at high spatial resolution. The Grid-BGC project's external funding concluded in October 2006 with the release of a production-grade version of the Grid-BGC science portal to the biogeochemistry community along with user and system documentation. The project received a no-cost extension until 12/31/06, and thus concluded in FY2007.

While development of BGC itself has completed, its workflows remain a primary motivation for continued work in the area of Grid-based service oriented architectures (SOAs). These services form the back end to the Grid-BGC science portal that allow scientists to interactively set up simulations used to model the global carbon cycle. Experiments with the POP, CAM, and WRF models have shown that this SOA can indeed integrate these applications into a grid environment. Grid-BGC is the first working computational grid for carbon cycle simulations, and the SOA designed to support it provides a seamless set of services from which the geoscience community can potentially build other end-to-end solutions. We are generalizing these SOA components into an Extensible Service Provider (ESP) toolkit supporting rapid service deployment for new applications.

This effort supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment." NASA has provided funding for the Grid-BGC project through the Advanced Information Systems Technology Office (NASA AIST Grant NAG2-1646) and the Terrestrial Ecology Program.

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Cultivating a scientifically engaged citizenry: Education and outreach

CISL supports numerous programs that foster improved awareness and understanding of geosciences and research methods for a variety of research and educational communities. These activities are supported through internships, seminars and workshops, visually compelling 3D presentations in CISL's Visualization Lab, conference exhibits, partnership with the NCAR Public Visitor Program, a training and outreach program for the NCAR Command Language (NCL) and other visualization tools, and security training for system administrators.

Doug Nychka (IMAGe, with notebook) and students of the Statistics and Climate Summer School view instruments at the Colorado Mountain Research Station. This school for 20 graduate students and faculty was offered as a credit course at the University of British Columbia (sponsored by the Pacific Institute of Mathematical Sciences, University of Washington, and NCAR) and covered statistical methods for interpreting the large and complex data sets from climate observing systems and models. A highlight of the school was a field trip to the Niwot Ridge Long-Term Ecological Research Site for first-hand experience collecting climate data in a subalpine environment.

Accomplishments and plans in CISL's education and outreach efforts are discussed in these sections:

- Summer Internships in Parallel Computational Science (SIParCS) program
- IMAGe Theme of the Year education and outreach
- Vislab outreach program
- Training in geoscientific tools
- Conference outreach
- Security administrators training

CISL's work across all of these areas broadly supports NCAR's strategic goal to "Cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce." This work is supported by NSF Core funding.

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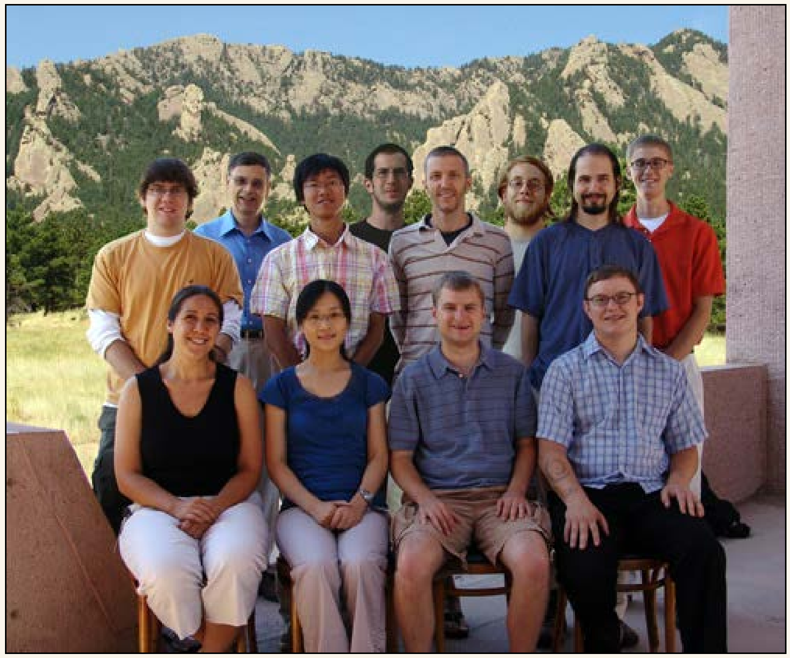
Summer Internships in Parallel Computational Science program



CISL's SIParCS program aims to improve the size, quality, and diversity of the U.S. computational science workforce. The SIParCS class of 2008 represents the largest and most diverse group in the program's brief history. The students came from seven different universities for the intensive summer program. Front row, left to right: Adriana Gillman, Li Wang, Rocky Dunlap, Nick Bailey; back row, left to right: Paul Ullrich, Rich Loft (SIParCS Director), Tao Lin, Michael Levy, Chris McKinlay, Sean Santos, James Robinson, and Daniel Whitenack.

The Summer Internships in Parallel Computational Science (SIParCS) program seeks to develop students with a background in computational science, applied mathematics, computer science, or the computational geosciences. The 10-12-week internships provide opportunities for exceptional students to gain practical experience with a wide variety of parallel computational science problems by working with the HPC systems and applications related to NCAR's Earth System science mission. Ultimately, SIParCS aspires to help address shortages of trained scientists and engineers capable of maintaining and using these high-end systems to achieve the goals of 21st-century computational geoscience research.

In the summer of 2008 the SIParCS program brought 11 student interns from seven universities to NCAR -- up from seven interns in 2007. The universities represented by this year's class of interns included the Colorado School of Mines, the University of Colorado, Boulder, University of California, Los Angeles (UCLA), the University of Michigan, Georgia Tech University, the University of Wyoming, and San Diego State University (SDSU). CISL staff made outreach and recruiting trips to SDSU and UCLA over the past two years to include students outside the Colorado/Wyoming Front Range corridor.

Additionally, 2008 brought a broadening and deepening of the SIParCS experience in a number of ways. For example, for the first time the students worked with mentors from all three CISL divisions including the Operations and Services Division, Technology Development Division, and IMAGe. This year, SIParCS student interns received, for the first time, training on the supercomputing systems and parallel programming, and in some cases, were able to attend conferences and workshops, including the SciComp-14 IBM user conference in Poughkeepsie, NY and the ASP Dynamical Core Colloquium held at NCAR. Finally, the student interns in 2008 were a more diverse group: this year four students (36%) were from backgrounds traditionally under-represented in the CISL workforce -- in 2007, none of the interns were. Of these four students, two were women, one was Hispanic, and two were Asian.

CISL places a high priority on these summer internships and will continue the program in FY2009. CISL will strive to maintain the size of the program at 10-12 interns. SIParCS will focus on further enriching the quality of the interns' scientific and technical experience, for example by providing opportunities for them to attend scientific and technical conferences, receive expanded, hands-on training with HPC systems and tools, or experience HPC technology through unique activities such as HPC facility tours. Annual SIParCS recruitment and outreach campaigns will be repeated in the first quarter of FY2009, including advertisement activities aimed at raising awareness of the program in the university community and especially among under-represented groups.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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Vislab outreach program

Many CISL outreach efforts are conducted through its Visualization Lab, a visual computing facility that supports collaborative technologies, data analysis and visualization, and theater-style presentations in wide-format, high-resolution, stereo 3D. The room comfortably seats 20 to 30 people and is used for general meetings, videoconferences, and many education and outreach efforts. This facility, with five high-resolution projectors and a 24-by-9-foot (8-by-3.5-meter) display, is used as a 3D presentation platform for education and outreach activities and has seen continual and increased usage since its inception seven years ago. The room also provides an AccessGrid capability that helps foster geographically distributed research by providing a virtual meeting place to connect NCAR staff with remote collaborators at universities and other research labs.

Participants in NCAR's annual Undergraduate Leadership Workshop meet in the Visualization Lab to participate in a 3D virtual science tour provided by the NCAR Public Visitor Program. Visualization Lab staff facilitate many demos and workshops, and they collaborate with the Public Visitor Program in education and outreach efforts to help foster public awareness and understanding of the atmospheric and related sciences. Photo courtesy Susan Foster.

Visualization Lab outreach efforts contribute to NCAR strategic priorities that include "Engaging a broader and more diverse community in the atmospheric and geosciences," "Fostering public awareness and understanding of atmospheric and related sciences," and "Providing robust, accessible, and innovative information services and tools." Public awareness and understanding of atmospheric and related sciences are facilitated through media-rich demonstrations of 3D visualizations and presentations to K-12 audiences as well as scientific, corporate, and government visitors. The Visualization Lab is frequently used as a venue by film crews who perform on-site interviews with NCAR scientific staff.

The Lab routinely provides media organizations with digital media and scientific visualizations for use in film and broadcast productions that potentially reach millions of viewers to help raise public awareness about important and pressing environmental issues. The Lab is also used to maintain an innovative workplace and to provide an advanced technical infrastructure that enhances productivity and reflects our environmental values. Visualization Lab staff support and maintain video conferencing technologies such as the Access Grid collaboration environment, helping to enhance communication and minimize the need for travel between campuses as well as between geographically distributed teams collaborating on cross-institutional projects.

In FY2008, the Visualization Lab continued its successful partnership with the Public Visitor Program and supported approximately 170 presentations, AccessGrid sessions, and general meetings involving over 2,700 participants (an almost 30% increase from last year). These events included presentations to K-12 audiences, scientific and corporate visitors, and government officials including VIP visitors from the Democratic National Convention, National Science Foundation, the USDA, the AMS, the Russian Judicial System, and the Israeli Air Force, to name a few.

The CISL Visualization Lab also continued its important role as an outreach liaison with film and television organizations by providing a venue for television interviews with NCAR staff and by developing digital media that was used in productions by CNN, National Geographic, and the Discovery Channel, among others. In October 2007, Visualization Lab staff provided ABC News 20/20 with a Big Elk Fire visualization that was broadcast during a prime time special report called "California Burning." The Visualization Lab staff also developed a new strategic plan for upgrading lab facilities and capabilities, and began implementing it, along with re-engineering existing AccessGrid functions to improve interaction quality.

In FY2009, the CISL Visualization Lab will continue to provide support for 3D demonstrations to help educate NCAR visitors and the public about NCAR research and environmental and scientific issues. We will continue to provide Access Grid capabilities and a venue for scientific interviews with the broadcast media as well as digital materials upon request for broadcast and educational purposes. We will also continue our productive partnership with the NCAR Public Visitor Program to provide K-12 audiences with engaging 3D visualizations of environmental and Earth science. The CISL Visualization Lab will also begin a multi-year upgrade of its AV systems and integrate a new h.323 video conferencing system that will enhance our ability to communicate and collaborate with key partners at NSF and other institutions. We will also expand on our initial experiments to test new presentation platforms, display technologies, and software utilities to continually enhance our presentation capabilities including tests to present material in an Augmented Reality format to provide more engaging and interactive material for visitors.

This project is supported by NSF Core funding.

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Training in geoscientific tools

Staff in CISL and ESSL have collaborated for several years to provide a series of training workshops for NCL, a free, interpreted language designed specifically for geoscientific data analysis and visualization. A total of 38 local and non-local workshops have been offered since the year 2000, with 485 students in attendance. These free workshops are four days in length with morning lectures and afternoon hands-on labs. Students are encouraged to bring their own datasets to the class so that by the end of the workshop they have produced meaningful results from their data.

In FY2008, we offered six of these workshops, and expanded the material to include some training for PyNIO and PyNGL, our Python modules based on NCL's file input/output and visualization software components.

The Eurasia Institute of Earth Sciences in Istanbul, Turkey hosted an NCL/PyNGL workshop in March 2008. Nuzhet Dalfes, is a professor of Climate and Marine Sciences at the Istanbul Technical University and the Dean of the Informatics Institute of the same university, is also a former postdoc at NCAR; he invited Dennis Shea of ESSL and Mary Haley of CISL to teach the workshop to a group of his graduate students.

It is important to note that our community contribution in this area is not simply training to use these tools: it is fundamental training in the important practice of Earth System data analysis. This work advances NCAR's strategic goal to "cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce."

These training workshops have been highly successful, and have resulted in invitations from the international scientific community to teach similar workshops at their organizations. In FY2008, one of our six workshops was held at the Eurasia Institute of Earth Sciences in Istanbul, Turkey. Plans are well underway for a workshop in December 2008 at the Max Planck Institute for Meteorology in Hamburg, Germany. Our international efforts here touch on a second NCAR strategic goal of "engaging a broader and more diverse community."

A core NCAR value is partnership with the university community. In FY2008, we started a program of offering one free annual workshop to a qualifying UCAR member university. The University of Wisconsin at Madison hosted the first of these workshops in August 2008, with the largest class we've had yet. There are plans to provide this opportunity again in FY2009.

In December 2007 CISL partnered with a graduate student at CU and a computational neuroscientist at Tradelink to host a local "Practical Python for Scientific Computing" workshop. This provided scientific programmers at NCAR with a unique professional development opportunity.

This series of training workshops is supported by NSF Core funds.

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Conference outreach

Nancy Collins, IMAGe, presents "Parallel implementation of ensemble filter algorithms for data assimilation" in the NCAR booth at SC07 on November 15, 2007. CISL conducts outreach activities through booths at the yearly Supercomputing conference, at the yearly TeraGrid conference, and at other venues. By representing NCAR's science and technology efforts at gatherings of researchers every year, CISL shares its expertise with and gains valuable insights from the research community.

Since 1989, CISL has deployed a series of exhibit booths for a variety of scientific and technical conferences. In these booths, CISL staff demonstrates supercomputing capabilities, scientific visualization, and other NCAR research in science, computer science, mathematics for the geosciences, and technology. At the height of its conference outreach program, CISL staff provided demonstrations and presentations at several conferences each year, including Supercomputing, the American Meteorological Society, the American Geophyscial Union, and others.

In recent years, CISL has focused energy and resources on providing NCAR outreach at the annual Supercomputing and TeraGrid conferences and on local Vislab presentations and outreach activities. In FY2008 and in coming years, CISL is also providing TeraGrid external relations support at the Supercomputing and TeraGrid conferences.

CISL hosts and provides planning and logistics support for conferences and workshops such as SC07. Also in FY2008, CISL supported the new Colorado Women's Computational Conference.

CISL's conference outreach program supports NCAR's strategic priority of "Engaging a broader and more diverse community in the atmospheric and geosciences" and "Fostering public awareness and understanding of atmospheric and related sciences." Specifically, this work advances understanding of the underlying computational and software technologies that are used in geoscience research today. Further, these outreach efforts are "Supporting and enhancing formal science education at all levels" by educating conference attendees from around the world about supercomputing resources and cyberinfrastructure services that enable the geoscience community conduct research.

These efforts are undertaken using NSF Core funds.

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Security administrators training

In 2006, the UCAR Computer Security Advisory Committee (CSAC) approved policy 20060104-01 requiring all system administrators and other UCAR staff responsible for computer security to participate in eight hours of relevant training each year. To keep the training costs manageable for divisions and programs, CSAC decided to develop much of that training in-house, although administrators were encouraged to seek training in other venues as appropriate.

This work supports NCAR's strategic priority of "Developing and providing advanced services and tools." Developing and maintaining appropriate cyberinfrastructure security enables all of UCAR's organizational units to "Maintain an innovative and creative workplace."

CSAC sponsored five 2-hour training sessions for eligible UCAR staff to meet their training requirements. The offerings included a mandatory Security Essentials course and their choice of: Securing UNIX/Linux, Securing Services, Securing Windows, and Securing MacOS X. These courses were developed in FY2007 by a former UCAR/CSAC member with the assistance of the UCAR Security Team and a focus group within CSAC based on a system administrator survey to determine areas where our system administrators needed more education and development.

Two training sessions were delivered in FY2007. The remaining three were delivered in early FY2008. At the end of FY2008 a video reprise of these sessions was offered to ensure that all designated system administrators at NCAR meet their security training requirements. Training sessions will be updated and repeated as needed under the guidance of CSAC and the security advisory group.

This ongoing training series is supported by UCAR Communications Pool indirect funds.

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Analyses and applications of three spatial discretization methods

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NCAR/CISL Annual Report 2008

1 Historical & scientific context and strategic alignment

As detailed in recent reports [2 §1; 3; & op. cit. therein], a need has long been well established and many investigations undertaken at NCAR and elsewhere, to create high-resolution numerical simulation methods for atmospheric dynamics, that are accurate similarly to spectral methods and computationally efficient similarly to finite-element type methods. Two research codes that demonstrate the strengths of the spectral-element method (SEM) with static-conforming or dynamic-nonconforming adaptive mesh refinement (AMR) are the spectral-element atmosphere model (SEAM) [9, & op. cit. therein] and the geophysical-astrophysical spectral-element adaptive refinement (GASpAR) code [7, 8], respectively. Especially for long-time, potentially parameter-sensitive simulations such as climate, spatial discretizations should accurately validate physical conservation laws such as mass and energy; this motivates another part of our research (§§2.2, 2.3). Finally, for high-resolution data assimilation, ordinary spatial discretizations yield impractically large systems, so to remedy this we have developed special 2D wavelet analyses in a limited-area atmosphere model (§2.4).

2 2008 accomplishments

This author was on leave of absence for 12 months ending 2008 June, to be a supported Visiting Scientist at the U. Reading Meteorology Department and contracted Research Investigator for the UK Met Office, with whose staff and others two collaborative projects were performed, §2.3 [11] and §2.4 [4]. Work performed in FY2008 that was also substantially supported by NCAR is described in §§2.1, 2.2, 2.5 & 3.

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2.1 GASpAR application to decaying 2D vortex interactions at high Reynolds number

The work presented earlier [3, & op. cit. therein] has been further analyzed and submitted [5]. For a case characterized by strong nonlinear interactions between vortex structures similar to those in the atmosphere, dynamic-AMR GASpAR simulations illustrated the accuracy of GASpAR compared to several well-resolved standard spectral simulations in the literature. We also were apparently the first to formulate SEM using *explicit* globally continuous test & trial functions, including non-conformity and including space dimension d as an arbitrary parameter. We demonstrated SEM-based Fourier analysis including domain partitioning [1]. Finally, we presented a (possibly new) time-dependent piecewise power-law model for KE spectrum:

$$E_{\vec{k}}\left[t\right] = C\left[t\right] \begin{cases} |\vec{k}/K\left[t\right]|^{-\beta_{\rm l}[t]}, & |\vec{k}| \leq K\left[t\right] \\ |\vec{k}/K\left[t\right]|^{-\beta_{\rm s}[t]}, & |\vec{k}| \geq K\left[t\right]. \end{cases} \tag{1}$$

Eq. 1 represented about 99% of the empirical KE spectrum at any but the very earliest t.

2.2 Compatibility based exact semi-discrete local conservation properties for continuous SEM

As suggested by earlier studies [3, op. cit. therein], in ongoing collaboration with M. Taylor we more recently derived a formulation of SEM that is compatible on fully unstructured 3D grids. Here *compatible* means that the method retains discrete analogs of 4 key properties of the operators gradient ($\vec{\nabla}$), divergence ($\vec{\nabla}\cdot$) and curl ($\vec{\nabla}\times$): $\vec{\nabla}\cdot$ and $\vec{\nabla}$ are adjoints, $\vec{\nabla}\times$ is self-adjoint, $\vec{\nabla}\times\vec{\nabla} = \vec{0}$ and $\vec{\nabla}\cdot\vec{\nabla}\times = 0$. The adjoint relations hold globally and at the element level if appropriate element-boundary terms are included. We then use the cubed-sphere grid to discretize the shallow-water equations (the simplest atmosphere model that includes realistic nonlinearities) and show that compatibility allows us to conserve mass, energy and relative vorticity. Conservation is obtained without requiring the equations to be in conservation form. For cubic quantities, like the energy in the shallow-water equations, the conservation is semi-discrete, meaning exact with exact time integration. For linear and quadratic quantities like mass, tracer mass, the discrete approximation to the conserved quantity is conserved exactly.

2.3 A polyhedral finite-volume model of the global atmosphere

We performed analyses of conforming AMR methods that improve unstructured finite-volume simulation of shallow-water and similar flows in spherical and more general geometries. In this work a new FV model AtmosFOAM is introduced, created by H. Weller [10, 11]. It uses an implicit FV technique in parallel on 3D polyhedral meshes, is second-order on all meshes, free of spurious computational modes and conserves mass and divergence exactly and momentum, energy, potential enstrophy and potential vorticity accurately. This feature combination has not been achieved before on unstructured or block-structured meshes and may prove crucial for operational value of AMR applied to atmosphere modeling. AtmosFOAM was thoroughly compared with several models in the literature. This author also conducted analyses of a range of strategies for blending A-grid and C-grid approaches.

2.4 Wavelet representation of multiscale structures in variational data assimilation

This author proposed multiresolution approaches to improving the UK Met Office data-assimilation system and lead our collaborators in a novel application of 2D wavelets that were optimized for signal and image processing, to analysis of multiscale covariance structures in atmospheric flow simulated by the UKMO Unified Model. High-efficiency representations were obtained, of very large ($76N \times 76N$ with $N \approx 10^5$) 3D streamfunction-covariance matrices $\mathbf{B}$ [4]. We obtained that at least 98% of the information of representative columns of $\mathbf{W}(\mathbf{I}^N \otimes \boldsymbol{F}^\mathsf{T})\mathbf{B}$ (where $\boldsymbol{F}$ is the leading of 76 given horizontally uniform vertical-structure vectors) is represented in its leading $2N\% \approx 10^3$ rows, using no typical (prohibitively expensive) empirical covariance diagonalization methods but instead a special data-independent $N \times N$ 2D biorthogonal wavelet-transform matrix $\mathbf{W}$ adapted to a limited-area atmosphere model.

2.5 Static, conforming AMR in coupled global-regional climate modeling with SEAM

This work was summarized before [3] and has finally appeared from Wang et al. [9]. With this author's and others' contributions, Dr Wang coupled SEAM with the CAM2 (Community Atmosphere Model version 2) physical parameterizations and CLM2 (Community Land Model version 2) in such a way that it can be used as an alternative dynamical core in CAM2.

3 2009 Plans

Projects currently underway include completing writing up our selective-decay simulations [3, & op. cit. therein] that illustrated statistical accuracy of GASpAR compared to spectral simulations in the literature, of a nearly inviscid, initially strongly randomized broad-spectrum turbulent state that evolves to a very smooth maximum-entropy state. Also, this author's continuing development of multiresolution analysis & simulation using spectral elements (MASUSE) is well aligned with NCAR strategic priorities [2, §2]. Finally, this author continues to study and write up an application exploiting SEM-based explicit Fourier-series coefficients [1] to decompose the Poisson problem, a technique independently found by Iskandarani [6].

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Exploiting the symmetries of the Taylor-Green (TG) flow in the case of coupling to a magnetic field

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August 15, 2008

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in collaboration with J. Clyne and A. Norton (CISL), and M.E. Brachet (ENS, Paris)

Scientific context Astrophysical and geophysical flows are highly turbulent, with strong coupling between a wide range of spatial and temporal scales. The complex behavior of such flows is far from understood, and their study through direct numerical simulation (DNS) in three space dimensions is limited to modest scale separation, even at the largest resolution achieved today. We propose sets of initial conditions for magnetohydrodynamics (MHD) in which both the velocity and the magnetic fields have spatial symmetries that are preserved by the dynamical equations as the system evolves. When implemented numerically, they allow for substantial savings in CPU time and memory storage requirements for a given resolved scale separation.

The ideal case The non-dissipative case is studied up to the equivalent of 2048^3 grid points for one of these flows. The temporal evolution of the logarithmic decrements δ of the energy spectrum remains exponential at the highest spatial resolution considered, for which an acceleration is observed briefly before the grid resolution is reached. Up to the end of the exponential decay of δ, the behavior is consistent with a regular flow with no appearance of a singularity. The subsequent short acceleration in the formation of small magnetic scales can be associated with a near collision of two current sheets driven together by magnetic pressure. It leads to strong gradients with a fast rotation of the direction of the magnetic field, a feature also observed in the solar wind (see Fig. 1, left and middle) (1). A higher resolution ideal run on an equivalent grid of 4096^3 points encounters some difficulties with simple precision computations, leading to the (expected) need of modifying the code, a useful feature as we prepare for petascale.

The dissipative case In the presence of dissipation at high Reynolds number and for a unit magnetic Prandtl number, again on grids equivalent to 2048^3 points, we take as initial condition the TG flow which is globally non-helical and with equal kinetic and magnetic energies and concentrated in the large scales. The energetics of this dissipative flow are studied up to a magnetic Taylor Reynolds number of ~ 1700. We find that the global temporal evolution is accelerated, compared to the corresponding neutral fluid case. We also observe a sizable interval of time during which the flow is semi-stationary with quasi-constant total dissipation, time during which statistical properties

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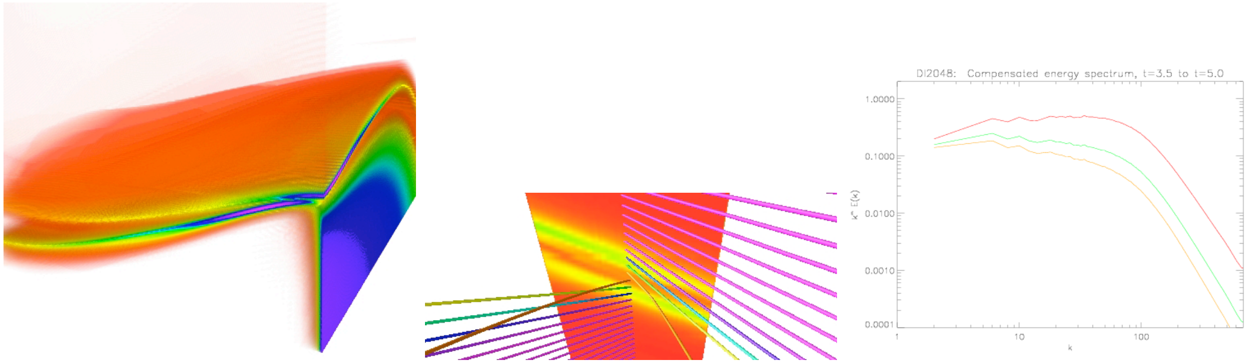

Figure 1: *Left:* Current density intensity in a $200 \times 200 \times 120$ subvolume of the 2048^3 ideal run at $t = 2.5$. Note the two current sheets approaching each other. *Middle:* Magnetic field lines in the same structure (viewed from the back). The current intensity in a slice is given as a reference. To the right and left of the slice, the magnetic field is strong (purple color), whereas in the transition region it decreases to $\approx 1/6$ of the maximum (yellow), corresponding to a strong local drop in intensity. Note also the rapid spatial rotation of the field lines (in approximately 6 grid spacing) between the two current sheets (1). Visualization using VAPOR (3). *Right:* Energy spectra, averaged in the plateau of total dissipation, compensated by k^2 (red), $k^{5/3}$ (green) and $k^{3/2}$ (orange) corresponding respectively to weak turbulence, Kolmogorov and IK spectra; dissipative 2048^3 run. Note that wave turbulence seems to dominate in this flow possibly at all scales (2).

are analyzed after averaging. An anisotropic investigation of energy spectra confirms the findings of a non-symmetric fully helical flow with a tendency toward (anisotropic) weak turbulence in the small scales (see Fig. 1, right), with a complex spatial structure of current and vorticity sheets and with possibly bursty reconnection events at later times (2).

This work supports the strategic priorities of NCAR by performing and analyzing very high resolution direct numerical simulations of fundamental flows, in preparation of petascale.

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MHD turbulence at high Reynolds number

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August 15, 2008

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Scientific context Magnetic fields are important dynamically in a variety of situations in geophysics and astrophysics. Numerous observations are appearing, e.g. thanks to remote sensing and in particular to the CLUSTER ensemble of 4 satellites, allowing for an estimation of fields and of their derivatives in the Solar Wind close environment. In the magnetohydrodynamic (MHD) approximation valid for velocities small compared to the speed of light, the dynamical equations are quite close to the Navier-Stokes case for fluids (advection-diffusion), and thus MHD also represents a testing ground for ideas on turbulent flows in the incompressible case, in the presence of waves.

The weakening of nonlinearities One remarkable feature of MHD flows is the tendency for the velocity $\mathbf{v}$ and the magnetic field $\mathbf{b}$ to align globally with time, the $\mathbf{v} \cdot \mathbf{b}$ correlation decaying more slowly than total energy. This has been known for quite a while but evidence is growing that this phenomenon occurs on a fast time scale (the eddy turn-over time) and locally in space, when the magnetic field aligns itself with the pressure gradient or shear (see Fig. 1, left). Such a phenomenon has been observed recently in the Solar Wind. A similar effect obtains for the vorticity ω (under the name of Beltramisation), with $\mathbf{v} \parallel \omega$, a feature known to occur both experimentally and in numerical simulations in the small-scale intense vortex filaments. In both cases, an ensuing weakening of nonlinearities follows, a feature not fully exploited in models of turbulent flows (1).

And yet ... The question of singularities in turbulent flows in the limit of vanishing dissipation is an open problem of importance for astrophysical flows for which Reynolds numbers are large. One side effect is whether there is or not a finite dissipation of energy (and of other ideal invariants) in that limit. In two dimensions (2D), it has been known numerically since the mid '80s that there is indeed a finite dissipation, at least at a unit magnetic Prandtl number (ratio of viscosity to magnetic diffusivity). It is now shown (see Fig. 1, middle) that this result extends to three dimensions (3D). Moreover, the question of the energy spectra in MHD is still open: are they the same or different as for fluids? Again, this question was studied in 2D in the past and it is only recently that we can tackle it in 3D; one clear result, both in 2D and in 3D, is that when examining structure function scaling at higher order than second order, MHD is more intermittent ! than fluids; perhaps more surprisingly except to observers having reported this result recently for the Solar Wind, the velocity and magnetic field scaling are measurably different (see Fig. 1, right) (2).

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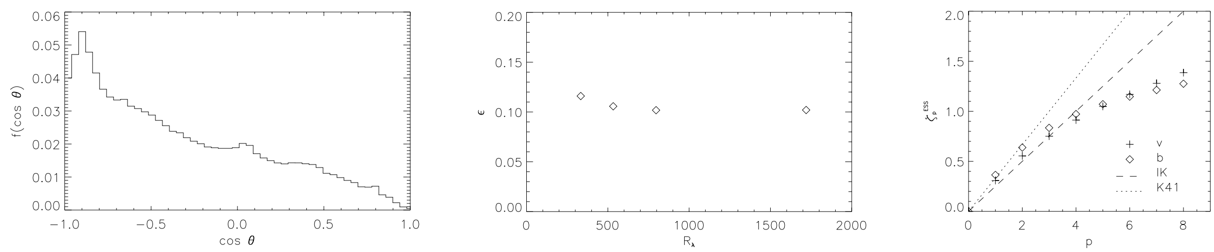

Figure 1: *Left*: Pdfs of $\cos(\mathbf{v}, \mathbf{b})$ in the vicinity of a current sheet (sub-volume of 150^3 grid points) in a 1536^3 simulation with ABC plus noise initial conditions (1). *Middle*: Energy dissipation as a function of Taylor Reynolds number for runs with the same initial conditions (2); note its leveling-of. *Right*: Anomalous scaling exponents for the velocity and magnetic fields; note the measurable difference in scaling, corresponding to a steeper magnetic energy spectrum (close to Kolmogorov scaling), as observed recently in the Solar Wind (2).

More results of this run performed thanks to a special allocation of computing resources in the framework of the BTS (Breakthrough Science) at NCAR are being analyzed presently, and will be reported in a subsequent paper (3); note that visualizations capabilities are enhanced by an extension of the VAPOR software (4) (see also research catalog on the Taylor-Green flow).

This work supports NCAR strategic priorities by developing codes for petascale and using them for discoveries that will lead to better modeling (see modeling research catalog text).

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Modeling of turbulent flows with magnetic fields

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Scientific context Since direct numerical simulations (DNS) of geophysical flows at realistic (high) Reynolds number Re exceed technological limits, and since simple truncation may remove important physics, some sort of closure is required to model the effects of the unresolvable small scales on the numerically resolved scales. Large Eddy Simulations (LES) are widely used but the Reynolds number is not known; instead, one attempts to model the behavior of the flow in the limit of large Re. As Kolmogorov assumption of strict self-similarity in turbulence is known to break down, the magnitude of Re can be important. Newer approaches model the effects of turbulence at higher Re than are possible with a DNS on a given grid, by e.g. filtering of the small scales.

Spectral modeling A classical approach to modeling turbulent flows is to use two-point closure equations – and specifically here the EDQNM (Eddy Damped Quasi Normal Markovian) developed in the mid 70's – in order to derive transport coefficients (both eddy diffusivities and eddy noise) and use them as a LES. Two new features of this methodology were introduced: (i) an eddy viscosity that is independent of the particular form of the energy spectrum and which thus can allow for non Kolmogorovian spectra as may be found in MHD; (ii) an expression for eddy noise which follows the closure instead of being an arbitrary stochastic forcing. Furthermore, the eddy-damping times, introduced for MHD in a rather ad-hoc fashion 30 years ago, are generalized following the dynamical evolution of the cumulant expansion equations. The resulting model reproduces the features of a DNS (Fig. 1, right) and will be used to study the generation of magnetic fields at low magnetic Prandtl number as encountered in liquid metals in the laboratory, the liquid core of the earth, the solar wind or the solar convection zone (3).

Regularization of the primitive equations Regularization is meant as a modification of the nonlinear terms in such a way that the new equations can be proven to have unique, smooth solutions, ensuring their computability. Furthermore, as only the spectral distribution of energy (not the dissipative processes as in many LES) is modified, a well-defined Reynolds number is retained. We show that such a model for MHD displays no increased accumulation of energy at small scale (no enhanced bottleneck), rendering it more useful in MHD than it is for the pure fluid

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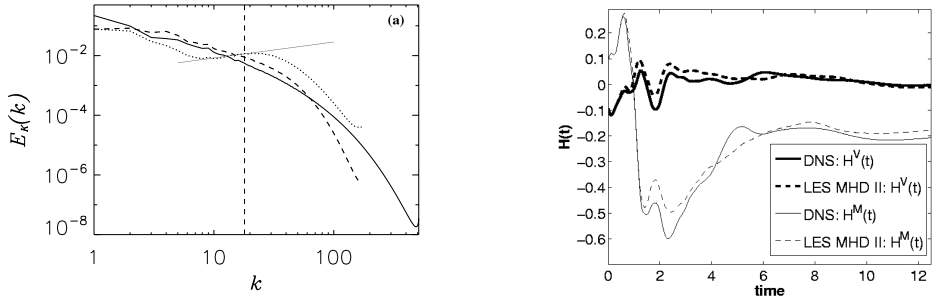

Figure 1: *Left*: Kinetic energy spectra for the Lagrangian-averaged Navier-Stokes (dots) and MHD equations (dash), and DNS for MHD (solid line); the vertical dash line corresponds to the filter width. Note the absence of positive-slope spectral range in the MHD model (1). *Right*: Kinetic and magnetic helicity for a DNS and two spectral models (see inset); the temporal evolution is recovered in both models (2).

case (see Fig. 1, left); indeed, we find a reduction factor of ≈ 200 in the number of needed degrees of freedom when compared to a DNS of MHD on a large grid of 1536^3 points at the same *Re* (1).

Clebsch variables in 2D MHD New generalized equations of motion for the Weber-Clebsch potentials that describe both Navier-Stokes and MHD are derived; they depend on a new parameter which is used to detect reconnection in several paradigmatic flows. Periods of intense activity in the magnetic dissipation are correlated with increasingly frequent resettings of the Clebsch variables which thus offer a new diagnostic for reconnection, both for fluids and for MHD (4).

Self-Organized Criticality (SOC) in MHD We plan to search statistically for structures in high *Re* MHD flows, in the context of SOC, in particular investigating the scaling laws of linear size and energy distributions of 3D structures, e.g. looking for 1D precursors to sheet roll-up, with possible applications to bursty reconnection in solar and magnetospheric plasmas (with V. Uritsky).

This work supports the strategic priorities of NCAR by performing fundamental research that will lead to enhanced modeling of geophysical and astrophysical flows.

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Rotating flows, waves, eddies and helicity

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and with A. Alexakis, H. Politano & Y. Ponty (OCA, Nice), M-E. Brachet & G. Krstulovic (ENS-Paris)

Scientific context Strong rotation is present in many geophysical and astrophysical flows. Its effect is considered to become important when the Rossby number (the ratio of the convective to the Coriolis acceleration) is sufficiently small. The large scales high Reynolds number Re of atmospheric and oceanic flows for example are affected by the rotation of the Earth; the Rossby number for mid-latitude synoptic scales in the atmosphere is $Ro \approx 0.1$ whereas in the solar convective zone, $Ro \approx$ 0.1-1. For rapid rotation, significant progress has been made by applying resonant wave theory, two-point spectral closures, and weak turbulence theory; in such approaches, the flow is considered as a superposition of inertial waves with a short period, and the evolution of the system for long times is derived considering the effect of resonant triad interactions. For large Re, small scales are excited with a characteristic timescale proportional to the eddy turnover time, that decreases as the scales become smaller. Therefore the approximations made in such theories can break down at sufficiently small scales. We thus resorted to direct numerical simulations (DNS) to explore rotating (non MHD) flows at high Reynolds number in the presence of forcing and down to $Ro \approx 0.03$.

The non-helical case At late times, the direct transfer of energy at small scales is mediated by interactions with the largest scale in the system, the energy containing eddies with $k_\perp \approx 1$, where $\perp$ refers to wavevectors perpendicular to the axis of rotation; the transfer between modes with wavevector parallel to the rotation is strongly quenched. The inverse cascade of energy at scales larger than the energy injection scale is non-local, and energy is transferred directly from small scales to the largest available scale. We observe both a direct and inverse cascade of energy at high rotation rate, indicative that these cascades can take place simultaneously. As energy piles up at the large scales, the intermittency of the direct cascade is preserved while intermittency corrections are found to be the same as in homogeneous non-rotating turbulence (1) (see Fig. 1; visualization uses VAPOR, *http://www.cisl.ucar.edu/hss/dasg/software/vapor*).

The helical case The effect of helicity (velocity-vorticity correlations) is presently being studied down to Rossby numbers of 0.02. Preliminary results suggest that helicity plays a role in the dynamics of the flow. In particular, at high rotation rates, the energy cascades to large scales, as expected, but helicity then can dominate the cascade to small scales and modify the dynamics (2).

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[2] NCAR is sponsored by the NSF cooperative agreement through UCAR

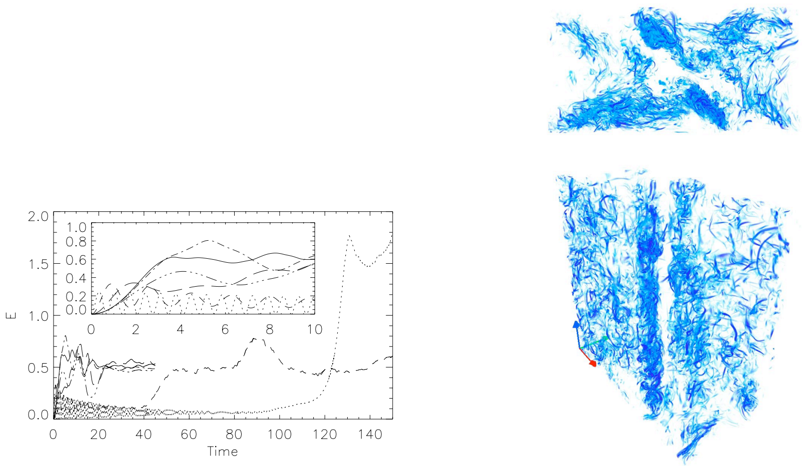

Figure 1: *Left*: Energy as a function of time (with zoom in inset) for flows with little rotation (solid line) down to $Ro = 0.03$ (dots); for high rotation, the clear early oscillatory phase (see inset) is followed by turbulence with an inverse cascade of energy (1) with pile-up at the lowest mode. *Right*: Zoom on vorticity magnitude (with a threshold; *top: top view; bottom: side view)*, with large-scale columns made up of small-scale vortices, a feature also found in high-resolution runs of hurricane (Rotunno, private communication).

A large resolution run is under way (Accelerated Scientific Discovery allocation) in order to unravel the details of the scaling properties of these flows.

Modeling of rotating flows We obtained for the first time transient energy and helicity cascades leading to Kraichnan helical absolute equilibrium at small scales. The observed different behaviors of truncated Euler and (constant viscosity) Navier-Stokes are qualitatively understood using the concept of eddy viscosity. The large scale of truncated Euler are shown to follow quantitatively an effective Navier-Stokes dynamics based on a variable eddy viscosity (3). Furthermore, the conceptual framework for modeling turbulent fluids developed recently (4) will be generalized to anisotropic non-MHD rotating flows, using a closure model written by Cambon and Jacquin (JFM **202**, 1989). *This work supports the strategic priorities of NCAR by unraveling the small-scale properties of simplified rotating flows and their link to large-scale dynamics to lead in the future to better modeling.*

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IMAGe Theme-of-the-Year 2008

A. Pouquet

August 19, 2008

in collaboration with Keith Julien (Applied mathematics, CU-Boulder)

Scientific context The Theme-of-the-Year is a program to focus on specific areas of research that will benefit from intense collaborative effort. The topics are be selected by the IMAGe external advisory panel and are be coordinated by a Visiting Co-director.

The scientific leaders of NCAR[1] recognized early on that in order to understand the dynamics of the atmosphere and oceans and the planetary boundary layer, the sun and solar-terrestrial interactions, investigating relevant turbulent processes at a fundamental level would be essential. Turbulence has remained both a vital and challenging field, taking on added importance as the geosciences tackles the multi-scale interactions that characterize the Earth-Sun system. The difficulty of solving classical problems in turbulence through direct mathematical analysis has engendered a multidisciplinary approach where mathematical and physical models, computational science, observations and experiments are combined to make advances.

The Theme-of-the-Year (TOY) for 2008 was designed to support the geophysical and mathematical communities in this effort through a series of workshops exploring turbulence from these different perspectives with the goal of increasing the interconnections among theory, computation and experiments. The final activity of the 2008 TOY was a summer school with the intent of bringing new researchers into this field and giving them a multidisciplinary perspective.

The events The TOY-08 was led by Keith Julien (Applied Mathematics, University of Colorado at Boulder) and Annick Pouquet (Geophysical Turbulence Program, NCAR) with three workshops and a summer school being held in Boulder, Colorado:

- W1 "Turbulent Theory and Modeling," 27-29 February 2008
- W2 "Petascale Computing: Its Impact on Geophysical Modeling and Simulation," 5-7 May
- W3 "Observing the Turbulent Atmosphere: Sampling Strategies, Technology, and Applications," 28-30 May 2008
- S4 "Summer School: Geophysical Turbulence. "14 July - 1 August 2008

The workshops accommodated 20-30 people and were a blend of research presentations along with ample time for discussions and more informal interactions. The summer school included about 30 Ph. D. students from around the globe, and drew on the material from the preceding workshops and featured prominent researchers in turbulence.

[1] NCAR is sponsored by the NSF cooperative agreement through UCAR

The main lecturers The organizing committee of W1 included Jeffrey Weiss (CU) and Elizabeth Wingate (LANL). The invited speakers at W1 were Peter Bartello (McGill), Raffaele Ferrari (MIT), Uriel Frisch (OCA, Nice), Andrew Majada (Courant), James McWilliams (UCLA), David Nolan (Miami), Alan Norton (NCAR), Antonello Provenzale (Turin), Leslie Smith (Wisconsin) and Geoffrey Vallis (GFDL).

The organizing committee of W2 included Bjorn Stevens (UCLA) and Joe Werne (CORA). The principal lecturers at W2 were Mark Berliner (Ohio), Éric Chassignet (Florida State), John CLune (NCAR), Bengt Fornberg (CU), Hassan A. Hassan (North Carolina), Phillip Jones (LANL), Yukio Kaneda (Nagoya), Edward Kansa (U. Davis), Yoshifumi Kimura (Nagoya), Steve Krueger (Utah), Ed Lee (NCAR), RIch Loft (NCAR), Thomas Lund (CORA), Scott McRae (North Carolina), Mark Rast (CU), Damian Rouson (Sandia), Piotr Smolarkiewicz (NCAR), Amik St Cyr (NCAR), Peter Sullivan (NCAR), Chenning Tong (Clemson U.), Joe Werne (CORA), Grady Wright (Boisé U.), John Wyngaard (Penn State) and David Yuen (Minnesota).

The organizing committee of W3 included Lasrry Cornman (RAL, NCAR), Don Lenschow (ESSL, NCAR), Tom Horst (EOL, NCAR) and Steven Oncley (EOL, NCAR). The keynote speakers at W3 were Jakob Mann (Risøo), Harm JOnker (Delft U.), Andreas Muschinski (Amherst), Hans Peter Schmid (Karsruhe) and Joe Fernando (Arizona).

Finally, the organizing committee of the school included Jeff Weiss (CU) and Beth Wingate (LANL). The principal lecturers at the three-week school were John Clyne (NCAR), Joe Fernando (Arizona), Andrew Majda (Courant), Leslie Smith (Wisconsin) and Joseph Werne (CORA).

Each workshop set the stage for the next ones and for the School. More details on outcomes can be found on the web at http://www.image.ucar.edu/ThemeOfTheYear/2008/. A lengthier report is in preparation for NSF. The workshops and school were made successful not only by the quality of the presentations from all the speakers, but also through the intense interactions which took place between sessions and between students and lecturers. The organizers would like to thank all of the participants, IMAGe, the CISL, EOL, ESSL and RAL laboratories at NCAR and the National Science Foundation for their continuing support on research into the nature of geophysical turbulence.

We cite week three of the school as an example of the effort and scale of the summer school and the participation it elicited from students. Week three was an intensive computational lab co-organized by CISLs Data Analysis Services Group (DASG) and the NorthWest Research Associates (NWRA). Intermixed with lectures on practical issues in numerical modeling and data analysis, students were provided a hands-on experience with end-to-end computational science: from numerical simulation to presentation of results. Broken into small groups, each was tasked with exploring a problem in atmospheric turbulence modeling (either Kelvin-Helmholtz instability or breaking gravity waves) using one of two numerical methods: Direct Numerical Simulation or Large Eddy Simulation. Students relied on knowledge gained during the previous two weeks of the school to help them parameterize a 3D simulation code provided by NWRA. Tens of thousands of CPU hours on CISLs Blue Gene/L supercomputer, Frost, were then brought to bear to run the students experiments. After conducting their simulations and archiving results to NCARs Mass Storage System, the groups focused on analyzing the hundreds of Gigabytes of data generated, using CISLs Storm visualization cluster. The centerpiece of the students data analysis toolkit was the NCAR developed VAPOR software. Finally, the students presented the results of their efforts to their peers and to the summer school organizers and instructors

This work supports NCAR strategic priorities by enhancing collaborations with the university community and by performing valuable education and outreach activities at the highest available level.

GASpAR Development

Duane Rosenberg

August 13, 2008

Turbulence Numerics Team

in collaboration with Aime´ Fournier and Annick Pouquet (TNT))

Sponsored by the NSF cooperative agreement through UCAR

1 Historical and scientific context

Accurate and efficient simulation of strongly turbulent flows is a prevalent challenge in many atmospheric, oceanic, and astrophysical applications. New simulation codes are needed to investigate such flows in the parameter regimes that interest the geophysics communities. Turbulent flows are linked to many issues in the geosciences, for example, in meteorology, oceanography, climatology, ecology, solar-terrestrial interactions, and solar fusion, as well as dynamo effects, specifically, magnetic-field generation in cosmic bodies (and the earth!) by turbulent motions. Nonlinearities prevail when the Reynolds number Re (the ratio of the nonlinear to diffusive terms in the Navier–Stokes equations) is large. The number of 3-dimensional degrees of freedom (d.o.f.) increases as $\mathsf{Re}^{9/4}$ as $\mathsf{Re} \to \infty$ in the Kolmogorov 1941 framework (6, §7.4) . For aeronautic flows often $\mathsf{Re} > 10^6$, but for geophysical flows often $\mathsf{Re} \gg 10^8$ (3; 8)

Computations of turbulent flows must contain enough scales to encompass the energy-containing and dissipative scale ranges *distinctly*. Uniform-grid convergence studies on 3D compressible-flow simulations show that in order to achieve the desired scale content, uniform grids must contain at least 2048^3 cells (13). Today such computations can barely be accomplished. A pseudo-spectral Navier-Stokes code on a grid of 4096^3 uniformly spaced points has been run on the Earth Simulator (7), but the Taylor Reynolds number ($\propto \sqrt{\mathsf{Re}}$) is still no more than ≈ 700, very far from what is required for most geophysical flows. The *main goal of our efforts* is to ask, if the significant structures of the flow are indeed sparse, so that their dynamics can be followed accurately even if they are embedded in random noise, then does dynamic adaptivity offer a means for achieving otherwise unattainable large Re values.

Thus, we have undertaken a long-term development program to provide a dynamic geophysical and astrophysical spectral-element adaptive refinement (GASpAR) code for simulating and studying turbulent phenomena.

Several properties of spectral-element methods (SEMs, 1; 10) make them desirable for direct numerical simulation of geophysical turbulence. Perhaps most significant is the fact that SEMs performed at high polynomial degree are inherently minimally diffusive and dispersive. The extent of the spatial and temporal scales that characterize turbulence depends critically on Re, so to draw conclusions we must be certain of this number in our computations. Thus, we cannot allow the numerical methods themselves to introduce diffusion.

Also, because SEMs use finite elements, they can be used efficiently in high-resolution turbulence studies in domains with complicated boundaries. These qualities, together with their good scalability properties (e.g., 5), suggest that spectral element methods may a good basis for high-order adaptive modeling of turbulent flows.

2 How this work supports NCAR strategic priorities

This development work relates directly to at least two of NCAR's strategic proritities: (1) Conducting research in computer science, applied mathematics, statistics, and numerical methods; and (2) Developing and providing advanced services and tools. The connection to both priorities is quite clear, as we are indeed trying to establish the ability of these new high-order adaptive methods to model turbulence, and this has necessitated a good deal of innovation in applied mathematics and numerical methods. Furthermore, the code was first released in December 2005, in direct support of priority (2), and, periodic updates are provided.

3 FY2008 accomplishments

FY2008 has seen that the plans outlined in the FY2007 Annual Report were met. We completed a comparison of the (statically) adaptive SEM explicit MHD solver with a low–order (statically) adaptive finite difference (FD) code (9), by simulating a challenging problem in the coronal heating context, the so–called MHD island coalescence instability problem. We found that, indeed, for incompressible flows, the SEM will almost always provide better global solution accuracy for a given number of dof than a fixed order FD method, and we showed that simply increasing the number of dof in the simpler FD method is not always a viable strategy.

In FY2008, we did not pursue additional work on the compressible solver, as had been indicated as a possibility in the 2007 Report. Instead, we focused on preconditioning and on adding 3D capability to the code.

In collaboration with the Computational Mathematics Group we completed the first stage of a optimized preconditioning strategy outlined in the 2007 Report. This implementation utilized an important theoretical result on optimized Schwarz algorithms demontrated at the algebraic level to modify a Restricted Additive Schwarz (RAS) algorithm which had been implemented in the code. While the current scheme only works with conforming discretizations, the novelty is that it shows that the asymptotics of the theory are achieved even in the presence of the staggered grid used by the GASpAR MHD and Navier–Stokes solvers (12), which had not been demonstrated previously.

As stated in the 2007 Report, we also made the modifications to the code required to solve 3D PDEs using conforming discretizations. Currently, only the advection–diffusion equation has been tested. The architecture for 3D subsumes the 2D cases with a compiler switch. These modifications afforded us an opportunity to improve memory access, reduce the memory footprint, and to re-architect the basic element class to accommodate a larger number of element types more easily.

Lastly, GASpAR has been used (4) in a study of decaying 2D vortex dynamics at high Reynolds number, in which the adaptive SEM is again compared with a pseudo–spectral treatment, and found to compare extremely well. More significantly, it was shown in this study that by way of a SEM–customized Fourier analysis, there is a power–law scaling over about one decade of wavenumber, indicating a broad range of nonlinearly interacting scales that are accurately captured by the grid dynamics.

4 2009 plans

There are a large number of issues we will address and GASpAR developments we anticipate in the upcoming year. Here we provide some details on our current thinking, but add that scientific, technical, and other influences may alter the feasibility of carrying out any particular item or otherwise limit their scope. In FY2009, we intend to add a coarse grid solver to precondition the long wavelength modes in the optimized RAS preconditioner. It was found in the results described briefly above that this is required. If there is time, we will effect the modifications required to enable the entire optimized precondioner to operate with non–conforming discretizations, for which there is no direct mathematical theory at present.

We will modify the GASpAR code to operate with 3D adaptivity. This will entail the modification of the existing connectivity code interfaces as well as some re-architecting of the mesh dynamics and, time permitting, the partitioning (including load balancing) software. We will in FY2009, test the Navier–Stokes or MHD solvers (or both) on 3D adaptive grids, and address any issues that arise due to our operator application in our Krylov solvers. We plan currently to also begin development of a 3D (2D is a subset automatically) Boussinesq solver (which will immediately take advantage of the adaptive grid) in order to begin a long–term project on atmospheric flows.

Finally, we will either implement a multi-resolution based adaptivity criterion (which guarantees a prescribed mean-square accuracy), or implement an exactly mass- and energy-conserving spectral-element formulation (derived in collaboration with Sandia National Laboratory) which will enable more sensitive long-time-scale simulations; the choice will depend on priorities emerging from both technical and scientific considerations.

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Symposium on Turbulence and Dynamos at Petaspeed

Duane L. Rosenberg

August 13, 2008

in collaboration with Mark Miesch (HAO, NCAR[1]), Annick Pouquet (TNT/IMAGe, NCAR), and Juri Toomre (CU/JILA)

1 Description and context

In the spring of 2007, a series of informal meetings was held between TNT/IMAGe, HAO, and CU/JILA in order to discuss various computational approaches to deal with fluid dynamics simulations in the petascale era. These meetings were organized due to a confluence of two particular events: the then-pending annoncement by NSF for a "Track 1" leadership–class petascale system; and the first "PetaApps" funding opportunity announcement by NSF, as well as by similar initiatives from DOE.

It was recognized that the new petascale technologies will likely have a significant impact on many areas of scientific research, but that there are also substantial obstacles to overcome in using these new systems efficiently.

In an effort to elucidate these challenges, we organized a mini–symposium on the issue entitled Symposium on Turbulence and Dynamos at Petaspeed. This meeting was hosted jointly by the Institute for Math Applied to Geosciences (IMAGe) at NCAR and by the Joint Institute for Laboratory Astrophysics at the University of Colorado (JILA). The intention of the symposium was to bring together practitioners of scientific computing in which ideas and experiences could be shared regarding the difficulties encountered in large–scale scientific and engineering computations, and what problems were likely to arise in the petascale era. The scientific areas that were highlighted included many of the core research areas at NCAR: fundamental turbulence, solar dynamos, space physics, and ocean and atmosphere dynamics. Implementation of scalable numerical methods were discussed, as were data storage and potential solution paths to analysis and visualization of large datasets.

This symposium supported a number of NCAR strategic prorities. Directly, the symposium supported the priority of conducting research in computer science, applied mathematics, statistics, and numerical methods, but indirectly, it also supported the broader priority of developing community models, as well as the research these models enable to satify other NCAR strategic goals.

[1]NCAR is sponsored by the NSF cooperative agreement through UCAR

Multiscale techniques

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Multi-scales means a lot of different things to a wide-span of researchers. In what follows we are interested in the ability to resolve scales from the numerical and physical modeling standpoints. First, numerical techniques for resolving scales in space (AMR: adaptive mesh refinement) are studied and compared with the state of the art in geosciences **(1)**. It is shown that the high-order approach is the a technique that exhibits a correct convergence behavior. For a given accuracy, the method is also faster for a more realistic shallow water test involving a mountain. Secondly, the calculation power of supercomputers has increased to such levels that the unabridged flow equations might now be employed in climate and weather modeling. However, this implies dealing with sound waves in a way or another. In **(2)**, a linearly implicit method is combined with a high-order discontinuous Galerkin solver to solve non-hydrostatic model problems. The novelty of the approach resides in the use of a Jacobian-free approach and is thus one step towards a multi-physics solver. On the physical modeling side, a new convective parameterization named multicloud is investigated in a full general circulation model **(3)** (this is a first). The idea behind the multicloud scheme is to employ only a couple of modes, or scales, of the vertical structure matrix of the atmosphere. The approach seems to trigger the correct wave phenomena: in particular a MJO is observable. Finally the scalability of the High-Order Methods Modeling Environment, coupled to CAM-3 physics is reported in **(4)** and establishes that modern numerical techniques is the only path towards petascale simulations.

(1) Comparison of Two Shallow-Water Models with Non-conforming Adaptive Grids

Joint work with: *C. Jablonowski (University of Michigan), J.M. Dennis, H.M. Tufo, and S.J. Thomas*:

Summary. In an effort to study the applicability of adaptive mesh refinement (AMR) techniques to atmospheric models, an interpolation-based spectral el-

ement shallow-water model on a cubed-sphere grid is compared to a block-structured finite-volume method in latitudelongitude geometry. Both models utilize a nonconforming adaptation approach that doubles the resolution at finecoarse mesh interfaces. The underlying AMR libraries are quad-tree based and ensure that neighboring regions can only differ by one refinement level. The models are compared via selected test cases from a standard test suite for the shallow-water equations, and via a barotropic instability test. These tests comprise the passive advection of a cosine bell and slotted cylinder, a steady-state geostrophic flow, a flow over an idealized mountain, a RossbyHaurwitz wave, and the evolution of a growing barotropic wave. Both static and dynamics adaptations are evaluated, which reveal the strengths and weaknesses of the AMR techniques. Overall, the AMR simulations show that both models successfully place static and dynamic adaptations in local regions without requiring a fine grid in the global domain. The adaptive grids reliably track features of interests without visible distortions or noise at mesh interfaces. Simple threshold adaptation criteria for the geopotential height and the relative vorticity are assessed.

(2) A Fully Implicit High-Order Discontinuous Galerkin Solver for Mesoscale Flows

Joint work with: *D. Stanescu (University of Wyoming) and D. Neckels*:
Summary. It this work it is shown how to discretize the compressible Euler equations around a vertically stratified base state using the discontinuous Galerkin approach on collocated Gauss type grids. The spatial integration is performed exactly thanks to the block-wise invertible mass matrix. Exact integration enables the solution of the resulting discrete system for any polynomial order. A stiffly stable Rosenbrock W- method is combined with an approximate evaluation of the Jacobian to integrate in time the resulting system of ODEs. Simulations with fully compressible equations for a rising thermal bubble due are performed. Also included are simulations of an inertia gravity wave in a periodic channel. The proposed time-stepping method accelerates the simulation times with respect to explicit Runge-Kutta time stepping procedures having the same number of stages.

(3) The Multicloud parametrization models for tropical convection: Implementation in a GCM

Joint work with: *B. Khouider (University of Victoria), A. Majda (Courant institute) and J. Tribbia*:
Summary. (In progress) We report results concerning the multicloud parameterization scheme of Khouider-Majda and its coupling to a next generation AGCM based on the spectral element method (HOMME: High-Order Method Modeling Environment). The latter is ran in a stand-alone aquaplanet mode to examine the organization of coherent convection in the simplest possible

setting. Hopefully, this will help understand the role of bimodal heating in the upscale organization of equatorial wave modes and the Madden Julian Oscillation (MJO).

(4) Petascale atmospheric models for the Community Climate System Model: new developments and evaluation of scalable dynamical cores

Joint work with: *M.A. Taylor (Sandia National laboratories) and J. P. Edwards (IBM)*

Summary. We present results from the integration and evaluation of the spectral finite-element method into the atmospheric component of the Community Climate System Model (CCSM). This method overcomes the atmospheric scalability bottleneck by allowing the use of a true two-dimensional domain decomposition for the first time in the CCSM. Scalability is demonstrated out to 86,200 processors with an average grid spacing of 0.25 (25 km). We present initial evaluations results using a standardized test problem with the full suite of CCSM atmospheric model forcings and subgrid parametrizations but without the CCSM land, ice, or ocean models. For this realistic setting, the true solution is unknown. Even convergence under mesh refinement is not expected, so we cannot rely on high-resolution reference solutions. Instead we focus on intermodel comparisons and use the Williamson equivalent resolution methodology to evaluate the results

Scalable preconditioning techniques

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The demise of the pseudo-spectral method in numerical models involved with the solving of geophysical problems is a direct consequence of the computer architectures currently available. In spectral space, elliptic operators are trivially inverted. For instance, a Laplacian in Fourier space is represented as k^2 with a corresponding inverse of $1/k^2$. With element based or stencil based methods like spectral elements and finite-differences, elliptic problems (like the Poisson problem, Helmholtz etc.) are not trivially invertible. They necessitate the use of iterative methods like Krylov accelerators (CG, GMRES, ...) and good preconditioning techniques in order to have the smallest number of iterations as possible (the lower the faster).

One of the most important technique for preconditioning large linear systems of elliptic equations is the Schwarz method. It consists into solving identical elliptic subproblems (one subproblem per processor generally) with artificial Dirichlet boundary conditions that are imposed using the previous iteration. A more recent version is the so called *optimized Schwarz method* (OSM). The latter changes the boundary conditions in the original Schwarz method and tries to optimize the free parameter in Fourier space. This can be understood as an optimization of the spectrums of the local subproblems. For certain problems, closed forms or asymptotic formulas for the optimizable parameter were obtained.

A contribution to the field of OSM was obtained in **(1)** were completely algebraic conditions are obtained in order to show *how simple* it is to modify an existing Schwarz method into its optimized version. Application with a spectral element dynamical core up to 2048 processors demonstrate the efficiency of the method. The result lead to a modification of the GASpAR adaptive code (see **(2)** below) were an approach originally proposed by Fischer in 1997 is optimized. The results show that for high-order elements the code is, after modification, twice faster. The algebraic results of **(1)** are augmented with a novel *discovery algorithm* in **(3)** that probes matrices for their elliptic nature in a line-by-line fashion. Then, if optimized parameters are available, that particular line is solved with optimized Schwarz. If no parameters are available, a classical Schwarz iteration is performed. Recently in **(4)**, for the first time, an analysis is performed for a two levels optimized Schwarz method. Numerous numerical experiments vindicate the analysis.

Finally, one of the competitor of the two level optimized Schwarz method is the acclaimed multigrid method. For high-order methods like spectral elements, it is impossible in terms of memory to assemble the complete matrix representing an elliptic operator/problem at the discrete level. Thus, building a low-order problem on the same grid is more cost efficient. However a complete proof by construction that the resulting system is *spectrally equivalent* was not available for finite-difference based preconditioning. Contribution **(5)** is the technical proof of the latter.

(1) Optimized multiplicative, additive and restricted additive Schwarz preconditioning

Joint work with: *M.J Gander (University of Geneva) and S.J. Thomas*:
Summary. We demonstrate that a small modification of the multiplicative, additive and re- stricted additive Schwarz preconditioner at the algebraic level, motivated by optimized Schwarz methods defined at the continuous level, leads to a significant reduction in the iteration count of the iterative solver. Numerical experiments using finite difference and spectral element discretizations of the positive definite Helmholtz problem and an idealized climate simulation illustrate the effectiveness of the new approach.

(2) Optimized Schwarz preconditioning for SEM based MHD

Joint work with: *D. Rosenberg (NCAR) and Sang Dong Kim (Kyungpook National University)*:
Summary. A recent theoretical result on optimized Schwarz algorithms demonstrated at the algebraic level enables the modification of an existing Schwarz procedure to its optimized counterpart. In this work, it is shown how to modify a bilinear FEM based Schwarz preconditioning strategy originally presented in [**?**] to its optimized version. The latter is employed to precondition the pseudo–Laplacian operator arising from the spectral element discretization of the magnetohydrodynamic equations in Elsässer form.

(3) A Discovery Algorithm for the Algebraic Construction of Optimized Schwarz Preconditioners

Joint work with: *M.J. Gander (University of Geneva)*:
Summary. Optimized Schwarz methods have been developed at the continuous level; in order to obtain optimized transmission conditions, the underlying partial differential equation (PDE) needs to be known. Classical Schwarz methods on the other hand can be used in purely algebraic form, which made

them popular. However their performance can be largely inferior compared to the performance of optimized Schwarz methods. We present in this paper a discovery algorithm, which, based purely on algebraic information, allows us to obtain an optimized Schwarz preconditioner for a large class of numerically discretized elliptic PDEs. The algorithm detects the nature of the elliptic PDE, and then modifies at the algebraic level a classical algebraic Schwarz preconditioner, using existing optimization results from the literature on optimized Schwarz methods. Numerical experiments using elliptic problems discretized by Q_1-FEM, P_1-FEM, and FDM demonstrate the algebraic nature and the effectiveness of the discovery algorithm.

(4) Optimized Schwarz Method with a Coarse Grid Correction

Joint work with: *O. Dubois (University of Minnesota), M.J. Gander (University of Geneva), S. Loisel and D. Szyld (Temple University)*:
Summary. Domain decomposition methods are iterative methods for solving large linear problems typically arising from the discretization of elliptic boundary value problems. One of the important advantages of these methods is that they parallelize well. To maintain good performance for the elliptic case, one usually must use a coarse-grid correction. Optimized Schwarz Methods are a variant of the Schwarz iteration which replaces the Dirichlet transmission conditions across the subdomain interfaces by Robin transmission conditions across the subdomain interfaces, with the goal of obtaining an algorithm which converges faster. We present such an algorithm with a coarse grid correction and analyze its convergence rate in a simple scenario.

(5) Finite difference preconditioners for Legendre based spectral element methods: elliptic boundary value problems

Joint work with: *Seonhee Kim, Sand Dong Kim (Kyungpook National University)*:
Summary. Finite difference type preconditioners for spectral element discretizations based on Legendre-Gauss-Lobatto points are analyzed. The latter are employed for the approximation of uniformly elliptic partial differential problems. In this work, it is shown that the condition number of the resulting preconditioned system is bounded independently of both of the polynomial degrees used in the spectral element method and the element sizes. Several numerical tests verify the $h-p$ independence of the proposed preconditioning.

GTP Visit Description: Marc Brachet

August 15, 2008

Geophysical Turbulence Program – 2008 NAR

with Annick Pouquet (NCAR) Pablo D. Mininni (NCAR), and Duane Rosenberg (NCAR)

Sponsored by the NSF cooperative agreement through UCAR

Dr. Brachet's visit yielded progress in several distinct, but related, areas. First, new generalized equations of motion for the Weber-Clebsch potentials that describe both Navier-Stokes and MHD were derived; they depend on a new parameter which is used to detect reconnection in several paradigmatic flows. Periods of intense activity in the magnetic dissipation are correlated with increasingly frequent resettings of the Clebsch variables which thus offer a new diagnostic for reconnection, both for fluids and for MHD (1).

We completed the implementation of a robust, low storage, third and fourth–order accurate Runge–Kutta algorithm in both scalable TNT/GTP codes, GHOST and GASpAR, which are, respectively, a 2D/3D pseudo–spectral code, and a 2D/3D adaptive spectral element code. This algorithm, developed during Dr. Brachet's visit, replaces an algorithm cited often in the literature that we show to be valid only to second order for nonlinear problems (2), and which respects energy conservation for very long time integrations.

Finally, using a newly developed parallel version of a symmetric FFT algorithm for use in pseudo-spectral studies of problems that have the same symmetries as the so-called Taylor–Green vortices, we have studied the ideal and dissipative magnetohydrodynamic (MHD) flows at equivalent resolutions of up to 2048^3 grid points. These smulations were carried out with a new code based on the new FFT alorIn the ideal, which preserves the symmetries numerically during the dynamical evolution. In the ideal case we find that the temporal evolution of the logarithmic decrements δ of the energy spectrum remains exponential at the highest spatial resolution considered, for which an acceleration is observed briefly before the grid resolution is reached. Up to the end of the exponential decay of δ, the behavior is consistent with a regular flow with no appearance of a singularity (3). We also observe in the ideal case evolving structures similar to those observed in the solar wind as in Fig. 1 For the dissipative case, we find that global temporal evolution is accelerated, compared to the corresponding neutral fluid case (4).

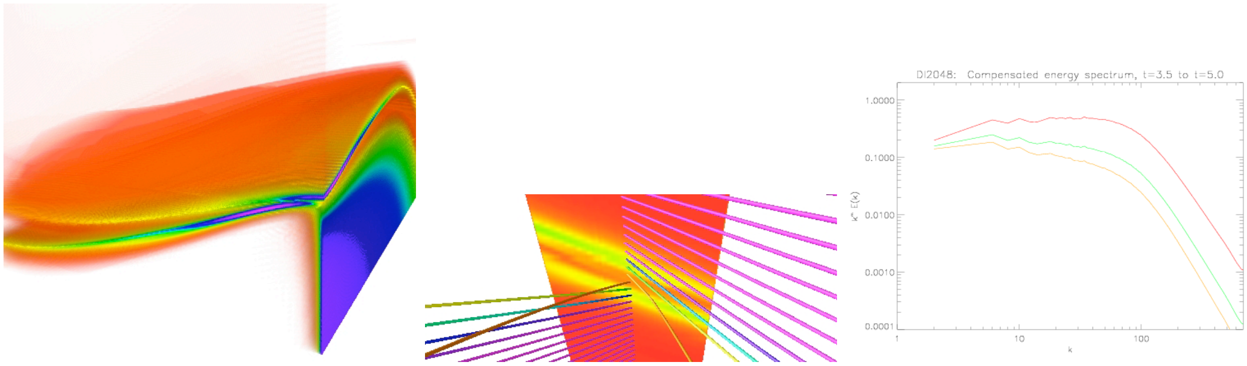

Figure 1: *Left:* Current density intensity in a $200 \times 200 \times 120$ subvolume of the 2048^3 ideal run at $t = 2.5$. Note the two current sheets approaching each other. *Middle:* Magnetic field lines in the same structure (viewed from the back). The current intensity in a slice is given as a reference. To the right and left of the slice, the magnetic field is strong (purple color), whereas in the transition region it decreases to $\approx 1/6$ of the maximum (yellow), corresponding to a strong local drop in intensity. Note also the rapid spatial rotation of the field lines (in approximately 6 grid spacing) between the two current sheets (3). Visualization using VAPOR (5). *Right:* Energy spectra, averaged in the plateau of total dissipation, compensated by k^2 (red), $k^{5/3}$ (green) and $k^{3/2}$ (orange) corresponding respectively to weak turbulence, Kolmogorov and IK spectra; dissipative 2048^3 run. Note that wave turbulence seems to dominate in this flow possibly at all scales (4).

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GTP Visit Description: Jean-Francois Cossette

August 21, 2008

Geophysical Turbulence Program – 2008 NAR

with Piotr Smolarkiewicz (NCAR)

Sponsored by the NSF cooperative agreement through UCAR

Jean-Francois Cossette (a graduate-student visitor from the Department of Physics at the University of Montreal) continued his study of improved trajectory schemes for semi-Lagrangian integrations of fluid equations. In contrast to Eulerian finite-volume methods — which typically ensure that velocities transporting dependent fluid variables satisfy the mass continuity equation — semi-Lagrangian models commonly disregard the mass continuity constraint in the evaluation of the departure points of flow trajectories. Jean-Francois evolved an original scheme that improves on this aspect of semi-Lagrangian models. The key element of the approach is solving a Monge-Ampere nonlinear elliptic equation. To prove the concept, Jean-Francois developed an effective Monge-Ampere solver for incompressible fluids, where the continuity constraint div V = 0 amounts to the flow Jacobian equal unity. A series of numerical experiments ranging from elementary passive scalar advection (see figure 1) to 3D turbulent flows indicates that the approach may benefit the conservativity and overall accuracy of semi-Lagrangian models. Jean-Francois presented preliminary results of his research at the NCAR Summer School on Geophysical Turbulence, 14 July - 1 August 2008, Boulder, Colorado; http://www.image.ucar.edu/Workshops/TOY2008/focus4/lectures.shtml. This long-term interdisciplinary project is a part of a cooperative graduate thesis, with Paul Charbonneau (University of Montreal) and Piotr Smolarkiewicz (NCAR) as co-directors.

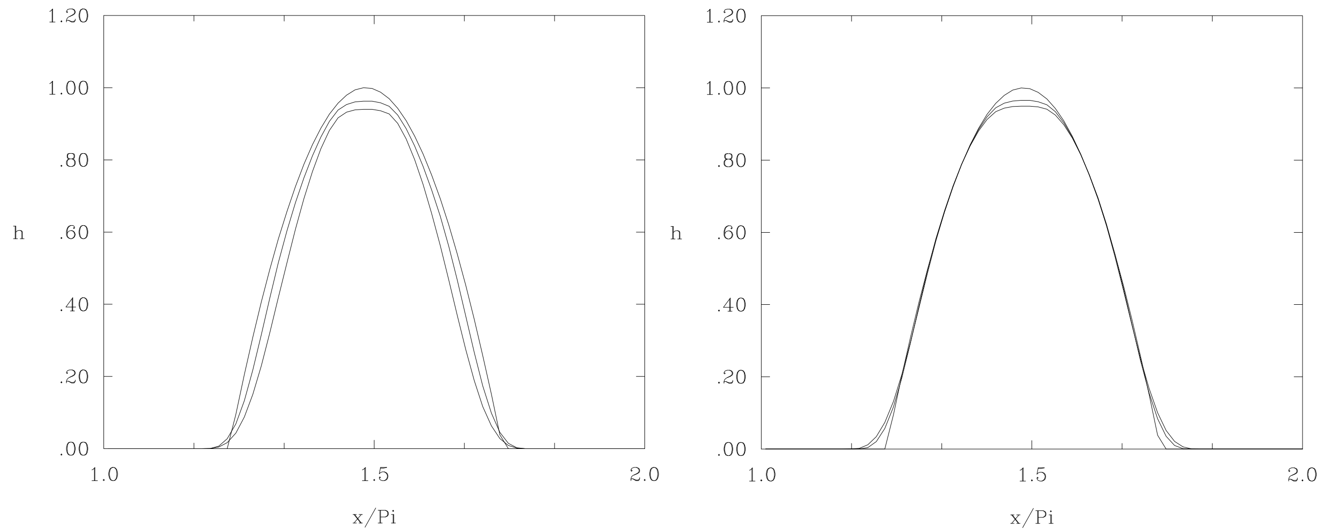

Figure 1: Semi-Lagrangian advection of a passive scalar in a vortical flow. The left and right plates show the results, respectively, with and without trajectory correction via Monge-Ampere solver. The three curves displayed in each panel are for the exact result and numerical solutions after 16 and 31 rotations of the tracer, in the order of decreasing height (h) respectively.

GTP Visit Description: John J. Finnigan

August 18, 2008

Geophysical Turbulence Program – 2008 NAR
with Edward Patton (NCAR)
Sponsored by the NSF cooperative agreement through UCAR

We have compared (1) the turbulence statistics of the canopy/roughness sub layer (RSL) and the inertial sub layer (ISL) above and showed that in the RSL, turbulence is more coherent, more efficient at transporting momentum and scalars, and in most ways resembles a turbulent mixing layer rather than a boundary layer. To understand these differences we analyzed the eddy structure of a Large Eddy Simulation of the flow above and within a vegetation canopy. The 3D velocity and scalar structure of a characteristic eddy was educed by compositing, using local maxima of static pressure at canopy top as a trigger. The characteristic eddy was also reconstructed by Empirical Orthogonal Function (EOF) analysis, prompting a re-evaluation of earlier results based on EOF analysis of wind tunnel data. A phenomenological model was proposed to explain both the structure of the characteristic eddy and the key differences between turbulence in the canopy/RSL and the ISL above. This model suggests a new scaling length that can be used to collapse turbulence moments over vegetation canopies. It was emphasized throughout this work that the results derived have relevance to rough wall boundary layers in general.

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GTP Visit Description: Dorota Jarecka

September 8, 2008

Geophysical Turbulence Program – 2008 NAR

with Wojciech Grabowski (NCAR)

Sponsored by the NSF cooperative agreement through UCAR

Dorota Jarecka, a PhD student from the University of Warsaw (UW, Poland) jointly advised and mentored by Grabowski and his colleague from UW, Prof. Hanna Pawlowska, spent 6 month at NCAR between February and August 2008, supported jointly by GTP, UW, and Grabowski's NOAA outside funds. Jarecka attended 2008 IMAGE Theme of the Year workshop in May and summer school in July. She also analyzed model simulations of shallow tropical convection with the emphasis on representation of turbulent entrainment and mixing on cloud dynamics. Since these clouds are strongly diluted by entrainment, this has far reaching consequences as discussed, for instance, in Grabowski (J. Climate 2006, pp. 4664-4682). These simulations apply a novel approach to represent the effects of entrainment and mixing on in-cloud buoyancy (Grabowski, J. Atmos. Sci. 2007, pp. 3666-3680; see Figure 1 below for an explanation). Jarecka extended this approach and refers to the improved model as the $\lambda - \beta$ model, where the variables λ (the scale of cloudy filaments associated with turbulent mixing introduced by Grabowski) and β (the fraction of the gridbox occupied by the cloudy air; added by Jarecka) allow for a better representation of turbulent cloud dynamics. Figure 2 illustrates the impact of the new model by comparing results from simulation of a field of shallow convective clouds using the $\lambda - \beta$ model with results from a traditional bulk cloud model. See figure caption for the explanation. Jarecka will be involved in future development of this model to combine it with a more sophisticated representation of cloud microphysics.

While at NCAR, Jarecka drafted a conference paper for the International Conference on Clouds and Precipitation (Cancun, Mexico, July 7-11 2008) and prepared a poster with her results. This poster received a student poster award at the conference. With help from Grabowski and Pawlowska she extended the conference paper into a journal manuscript that has been submitted to publication in J. Atmos. Sci. These publications are listed below.

Jarecka, D., W. W. Grabowski, and H. Pawlowska, 2008: Modeling of subgrid-scale mixing in large-eddy simulation of shallow convection. *J. Atmos. Sci.* (submitted).

Jarecka, D., W. W. Grabowski, and H. Pawlowska, 2008: Modeling of subgrid-scale mixing in large-eddy simulation of shallow convection. Proceedings of the International Conference on Clouds and

Precipitation (ICCP), July 7-11, 2008, Cancun, Mexico.

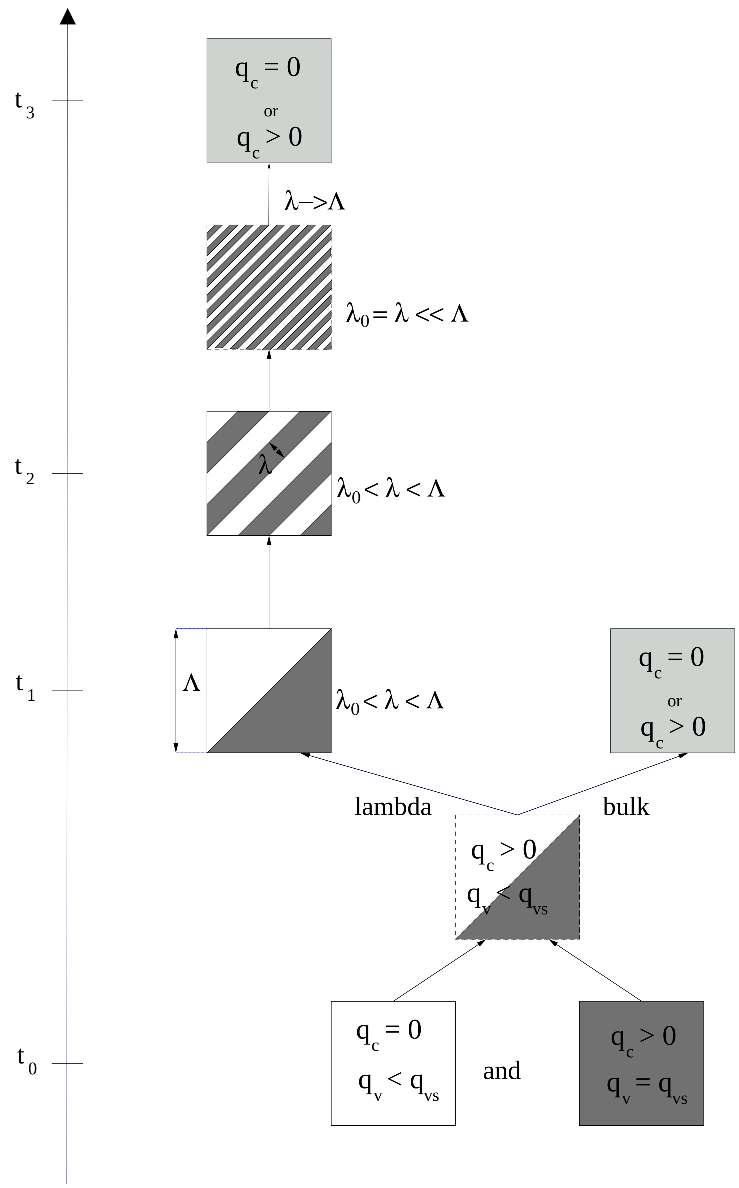

Figure 1: Evaporation of cloud water as a result of turbulent mixing between cloudy and cloud-free gridboxes. The vertical axis represents time. The two gridboxes are shown at the bottom of the figure, at time t_0. During a model time step, from t_0 to t_1, parameterized turbulent mixing creates a gridbox containing both cloudy and cloud-free air. The traditional bulk model immediately homogenizes the gridbox, resulting in either a saturated and cloudy or a subsaturated and cloud-free gridbox at time t_1. In the modified bulk model, homogenization is only possible once turbulent stirring reduces the filament width λ from the initial value $\sim \Lambda$ (taken as the model gridlength) to the value corresponding to the microscale homogenization λ_0. This process may take several time steps as illustrated on the left side of the figure.

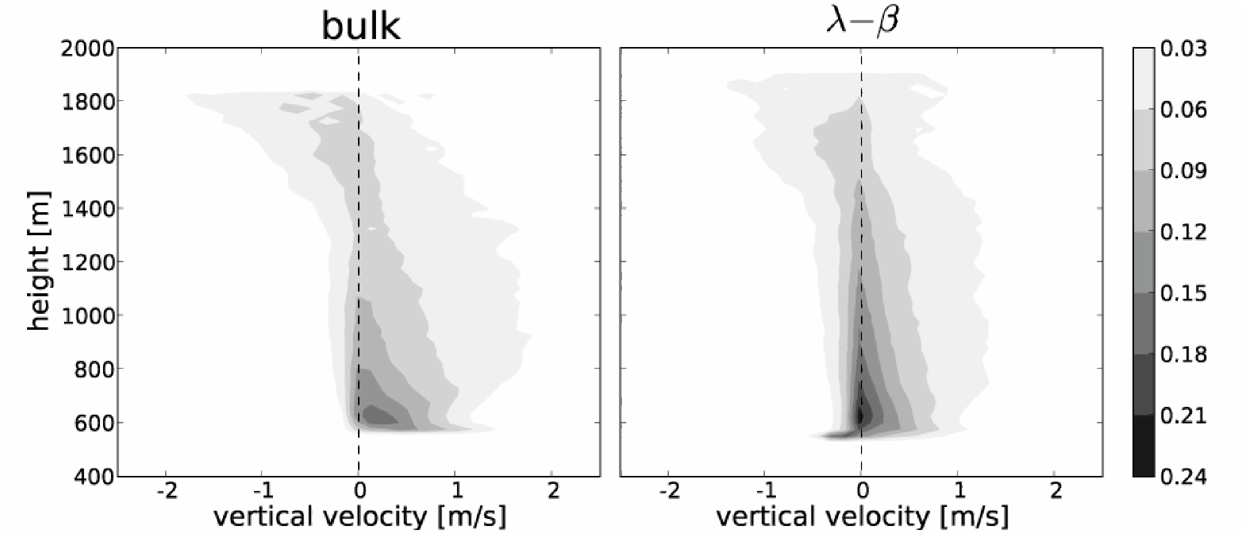

Figure 2: Contoured frequency by altitude diagrams (CFADs) of the vertical velocity (calculated with 0.15 m s^{-1} wide bins) for the $\lambda - \beta$ model (right panel) and the traditional bulk model (left panel) in a simulation of a field of shallow convective clouds applying EULAG model with 25 m horizontal and vertical gridlength. Results represent statistics gathered over 4 hour period. The gray-scale bar details the frequency-of-occurrence scale. Only model gridpoints with a cloud water mixing ratio larger than 10^{-2} g kg^{-1} are included in the analysis. Clouds in the $\lambda - \beta$ model are slightly deeper than in the bulk approach; this can be argued to result from delayed evaporation of cloud water due to entrainment and mixing, resulting in more in-cloud buoyancy. Also, there are more points with positive vertical velocities in the range of 0 to 1 m s^{-1} in the $\lambda - \beta$ model across most of the depths of the cloud field. This is again consistent with the expectation that cloud evaporation (and thus buoyancy reversal and subsequent downward acceleration) is delayed when the $\lambda - \beta$ approach is used.

GTP Visit Description: H. Jonker

August 15, 2008

Geophysical Turbulence Program – 2008 NAR
with Peter Sullivan (NCAR)

Sponsored by the NSF cooperative agreement through UCAR

Dr. Jonker's visit began at the end of FY2008. He will collaborate again on several aspects of the convective atmospheric boundary layer, including the entrainment law, and Large Eddy Simulations of penetrative convection. This work seeks to continue and extend the scope of work conducted in FY2007.

GTP Visit Description: Pablo Ortiz

August 21, 2008

Geophysical Turbulence Program – 2008 NAR
with Piotr Smolarkiewicz (NCAR)

Sponsored by the NSF cooperative agreement through UCAR

Prof. Pablo Ortiz (University of Granada, Spain) and Piotr Smolarkiewicz (NCAR) continue their long-term collaborative effort on numerical simulation of sediment transport, set in a broad context of flows past complex time-dependent boundaries. During earlier visits to NCAR, Pablo and Piotr developed a variant of the nonhydrostatic model EULAG (Prusa et al., 2008, Comput. Fluids, 37, 1193-1207) which couples the internal flow with a lower boundary evolving in response to the sand saltation (Ortiz and Smolarkiewicz, 2006, Numerical simulation of sand dune evolution in severe winds, Int. J. Numer. Meth. Fluids, Vol 50, 1229–1228). Their present research focuses on physical aspects of the problem including: scaling laws for dune propagation; shape preservation, coupled dune/flow response to the character of the underlying surface, dune formation and instability (see figure 1), sand mobilization and transition to dust storms, formation and evolution of sand ripples, and evolution of sand dune fields. This unique interdisciplinary effort combines expertise of several different areas (meteorology, environmental engineering, numerical methods, and applied mathematics) leading to, potentially, significant advancements in predicting the impact of all-scale (micro to planetary) sediment transport and dust storms on the environment, under extreme flow conditions.

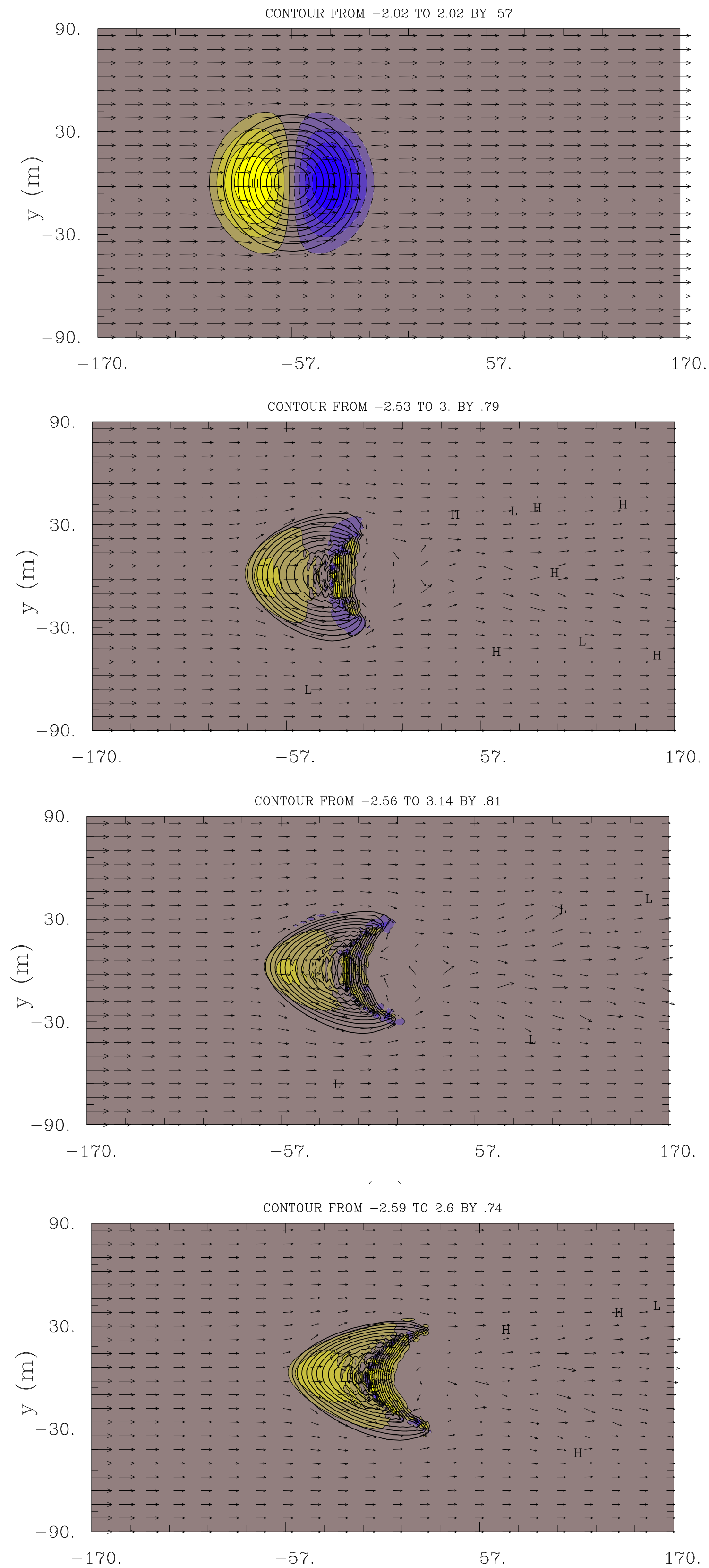

Figure 1: Surface flow and vertical velocity past evolving sand dune.

GTP Visit Description: Zbigniew Piotrowski

August 21, 2008

Geophysical Turbulence Program – 2008 NAR
with Piotr Smolarkiewicz (NCAR)

Sponsored by the NSF cooperative agreement through UCAR

Zbigniew Piotrowski (a Ph.D. candidate from the Department of Physics, University of Warsaw, Poland) conducted a systematic study of thermal convection as realized in large-scale high-resolution numerical models. With rapid progress in computer technology, the global numerical weather prediction (NWP) with 10 km horizontal resolution (or better) will become standard in the near future; cf. recent calculations by the Frontier Research Center group in Japan (Satoh et al, J. Comput. Phys. 2008, 227, 3486-3514) conducted at 3.5 km resolution. While such resolutions are impressive by the standards of NWP, they are still too coarse (by two orders of magnitude at least) to represent convection up to the standards of cloud-resolving models. In effect, NWP is entering a new regime where traditional convection parameterization is already obsolete, but large-eddy-simulation is still beyond the reach. In this regime the convection realization is sensitive to filtering embedded in the numerical model — e.g., via subgrid-scale models and/or numerical approximations employed — and can take variety of forms. This in turn reflects on simulated weather and climate due to their dependence on cloud field structure via precipitation and radiation. Zbigniew's research addresses numerical effects influencing the structure of simulated convection at its roots; i.e., in the planetary boundary layer (see figure 1). In particular, its focus is on effective viscosity and diffusivity representative of contemporary numerical models. Zbigniew compared and classified flow responses to various realizations of viscous effects, and examined them against predictions of linear theories. Looking forward toward petascale computing, he drew conclusions regarding potential utility of selected modern numerical approaches for cloud-resolving NWP. He has presented the results of his research at the NCAR Summer School on Geophysical Turbulence, 14 July - 1 August 2008, Boulder, Colorado; the presentation is available at http://www.image.ucar.edu/Workshops/TOY2008/focus4/lectures.shtml. This project forms a cooperative Ph.D. thesis, with Szymon Malinowski (University of Warsaw) and Piotr Smolarkiewicz (NCAR) as co-advisors.

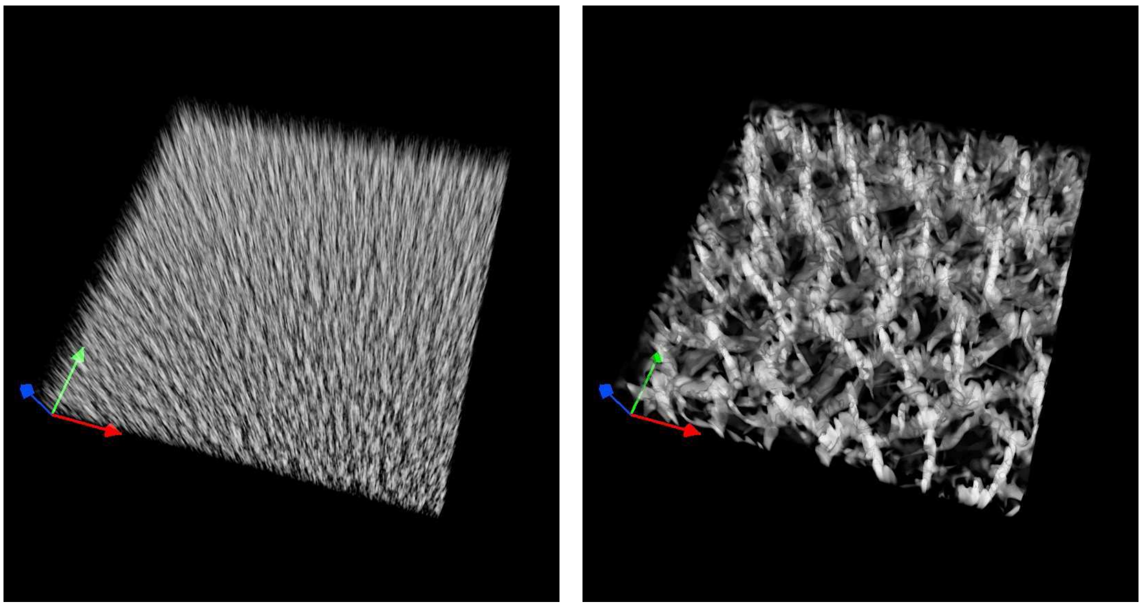

Figure 1: Figure Caption: Structure of thermal convection over heated plane. Vertical velocities after 6h of simulated time are shown within the boundary layer depth. Bright and dark volumes denote updrafts and downdrafts, respectively. The only difference between the solutions in the left and right panels are the values of viscosity in the horizontal entries of the stress tensor, respectively, 2.5 versus 70 meter-squared per second.

GTP Visit Description: Lian-Ping Wang

August 22, 2008

The report summarizes the collaborative research between Dr. Grabowski at NCAR and Dr. Lian-Ping Wang of the University of Delaware (UD), for the period of October 2007 to August 2008. Their research continued to focus on turbulent collision-coalescence of cloud droplets and its impact on warm rain initiation. The work has been supported by NSF (ATM-0527140), GTP, and MMM visitors program.

The main accomplishments include: (1) study of turbulent geometric collision and collision efficiency using a hybrid direct numerical simulation approach, (2) preliminary impact study of turbulent enhanced collision on warm rain initiation using a parcel model, (3) assimilation of results in the form of journal papers, and (4) development of related MPI codes to extend the capabilities of previous OpenMP codes.

In the last year, six papers have been submitted (3 published, 3 currently in review, see references 1-6 below).

A second, collaborative research proposal involving Professor Alberto Aliseda of University of Washington, entitled "Turbulence enhanced droplet growth by collision-coalescence" was funded by NSF in December 2007.

Under the UCAR's visitors program, Dr. Wang and his postdoc Dr. Bogdan Rosa each made two visits to NCAR. Dr. Wang delivered one MMM seminar [7]. In the summer of 2008, his graduate student Mr. Hossein Parishani also made a two-week visit to NCAR.

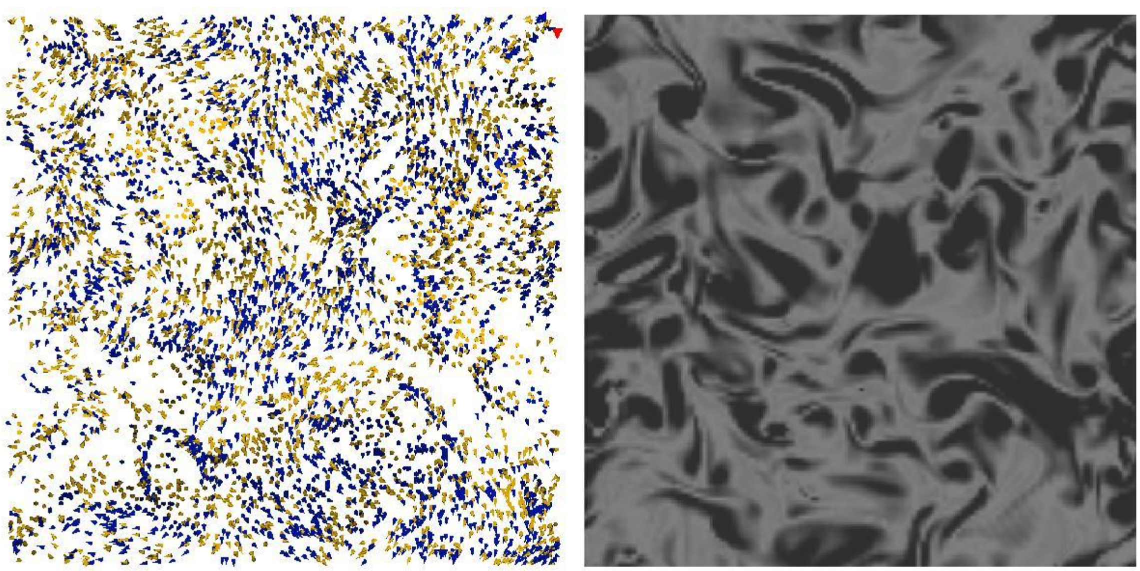

Figure caption: *A snapshot from DNS of droplet position (left panel) and normalized flow enstrophy (right panel) on a same planar slice. Left panel: the locations of droplets of 20 μm radius are shown by yellow cones and those of 30 μm by blue cones. The flow dissipation rate is 400 cm^2/s^3. Note that the 30 μm droplets show much higher levels of preferential concentration and 20 μm droplets display only a weak clustering. Gravity is pointing vertically down. This figure is taken from [6].*

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Director's Message

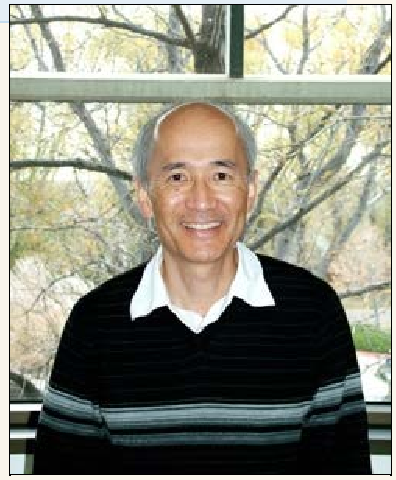
Table of Contents

Strategic Goals: Science, Facilities & Technology

NCAR is sponsored by the National Science Foundation.

DIRECTOR'S MESSAGE

Welcome to the Earth Observing Laboratory's 2008 Annual Report



Dr. Roger Wakimoto is Assistant Director of NCAR for the Earth Observing Laboratory

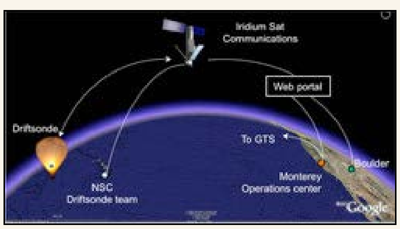
EOL is known as a community hub for the collection of data and transfer of knowledge pertaining to observations. The Laboratory also develops new measurement tools to extend community understanding of the atmosphere. EOL specifically fulfills three critical needs:

1. To lead and serve the community in the provision of observational facilities infrastructure, and services needed by the atmospheric and related sciences.
2. To play a leadership role in the development community-inspired next generation instrumentation and infrastructure while providing existing instruments and infrastructure in support of science.
3. To coordinate all aspects of field deployment from pre-project planning through the field phase and subsequent data stewardship.

Central to EOL's success is our world-class scientific, engineering and project management staff that is respected by the community. Our staff responses to new directions in atmospheric research technology play a leadership role in the development and application of new technology to science objectives.

Field Campaigns Going Global

EOL was extremely busy in FY2008 fulfilling our mission to support the NCAR goal #5, "Provide World-Class Observational Facilities": during 42 out of 52 weeks this year we coordinated and participated in seven field campaigns, three of which were international, and spent over 3000 person-days in field. Every platform was deployed this year, some more than once, which was a first for us.



This Google Earth diagram shows the complex communications schema necessary for the remote and autonomous deployment of Miniature In-situ Sounding Technology (MIST) sondes from the Driftsonde during T-PARC.

As we come closer to realizing the full operational capability of the NSF/NCAR GV we are addressing the drastically shifting expectations of field campaigns towards longer, larger-scale events. In order to meet the new challenges posed by global operations, EOL has begun to reframe the way we prepare for and manage field deployments. To perform global operations at the level our community has come to expect also requires advances in the instrumentation technology. A good deal of progress was made in the area of remote operation of airborne instrumentation with the development of the Miniature In-situ Sounding Technology (MIST) sonde for the Driftsonde platform, used in the THORPEX Pacific Asian Regional Campaign (T-PARC). The development of this autonomous deployment capability will have a profound positive effect in global campaigns and applications with the HAIS instruments and Unmanned Autonomous Systems (UAS), such as the NOAA Global Hawk, are already being explored.

EOL launched a strategic partnership with Colorado State University (CSU) to develop an integrated radar facility that will expand the capabilities that either entity can currently provide. Both EOL and CSU support 10-cm, multiparameter Doppler radars (NSF/NCAR S-Pol and CSU CHILL radars, respectively) that will be jointly operated in this new partnership, as well as other, smaller radars. A key objective of this partnership is to create a national test bed that other institutes and agencies can use for research and education.

The NSF Facilities Assessment database was officially launched this year and will continue to garner input from the community. The intent is provide descriptive information on atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science and related communities.

Understanding the Earth & Sun System

In support of Goal #1, Understanding the Earth & Sun System, EOL participated in three field campaigns: for the Stratosphere-Troposphere Analyses of Regional Transport (START-08) EOL operated the NSF/NCAR GV to study the chemical and transport characteristics of the extratropical upper tropospheric and lower stratospheric (ExUTLS) region; for the Terrain-influenced Monsoon Rainfall Experiment (TiMREX) we deployed the S-Pol radar to Taiwan in May to study heavy rain and flood-producing convective events and evaluate the skill of numerical weather prediction systems to forecast these complex

S-Pol, EOL's transportable, ground-based Doppler radar, on site for Terrain-influenced Monsoon Rainfall Experiment (TiMREX) in Taiwan.

systems; and in September we participated in the mammoth multinational T-PARC with the C-130, ELDORA radar, Dropsondes, Driftsondes, and the new MIST sondes, not to mention the project management, data management and communications technology necessary to meet the science objectives and keep the campaign running smoothly across nine time zones and the international date line. The objectives of T-PARC were to sample typhoons through their lifecycle and document three primary phases from formation through maturity to extra-tropical transition.

Improving Resilience to Weather, Climate and Atmospheric Hazards

In support of Goal #2, Improving Resilience to Weather, Climate and Atmospheric Hazards, EOL scientists, working with researchers at the Naval Research Laboratory, developed the VORTRAC technique to continually monitor landfalling storms in the United States. In March 2008 the National Hurricane Center officially adopted VORTRAC as a technique to monitor hurricane intensity. In time, VORTRAC may also help improve long-range hurricane forecasts by using data from airborne Doppler radars or spaceborne radars to produce detailed information about a hurricane that is far out to sea. Forecasters could input the data to computer models to improve three- and five-day forecasts.

Cultivate a Scientifically Literate and Engaged Citizenry and a Diverse and Creative Workforce

In November 2008 the Doppler on Wheels will be deployed to the University of Nebraska for the first Educational Deployment. The professor will teach students radar fundamentals and will use the radar to give students hands-on experience.

EOL places major emphases on Goal #3, diversity and education and outreach activities. At the advice taken from the 2007 NSF Facilities Users' Workshop, in 2008 we instituted a process through which universities can officially request NSF Lower Atmospheric Observing Facilities through the NSF Deployment Pool for educational purposes. In FY2008 we received five requests and the interest in opportunity continues to grow. The first such official project will be a deployment of the Doppler on Wheels Radar to a meteorology class at the University of Nebraska in Lincoln for a two-week period in November 2008. We will continue our efforts to support SOARS and the EOL Engineering Intern Program, as well as numerous education and outreach activities for K-12 students and the general public.

Provide Robust, Accessible, and Innovative Information Services and Tools

EOL is committed to data processing, quality control, and archival for field projects as part of our expanding services that will be provided to the community, Goal #4. This includes efforts to complete development of the Metadata Database and Cyberinfrastructure (EMDAC, formerly known as CODIAC) to access and browse products and data from field projects while integrating with the Community Data Portal. In FY2008 EOL has been leading data management support for a series of NSF-funded Arctic programs. Finally, our Atmospheric Sounding Processing Environment (ASPEN) software underwent extensive modifications in order to create a better match to processing results produced by quality control software developed by the National Hurricane Center. These changes focus on the last 5 seconds of dropsonde sounding data, which are critical to hurricane surface condition assessment. The modified Aspen was deployed for 2008 hurricane season in T-PARC.

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EOL Annual Report 2008

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Science: Strategic Goal 5

Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

NCAR is sponsored by the National Science Foundation.

GOAL 5, PRIORITY 2: DEVELOPING NEW INSTRUMENTATION

Advances in research on weather, climate, water cycle, chemistry and dynamics of the upper troposphere/lower stratosphere, and biogeosciences all require capabilities beyond our current suite of airborne and ground-based instruments. EOL is tasked with developing this new generation of robust, inexpensive, easily deployable, and versatile instrument systems to address these needs. Our extensive pool of talented scientific, engineering, technical and machine staff continually conceptualize, develop and test new instrumentation for studying the links between atmospheric composition and the biogeosciences, with systems for quantifying the surface-atmosphere exchange of gases and aerosols on whole-plant, whole-canopy, and regional scales using mobile laboratories and deployments of our fleet of research aircraft.

EOL has been involved in a variety of efforts to support this strategic priority in FY 2008. The Technology Development Facility continues to manage major development projects and our Design and Fabrication Services was busy developing MIST sondes and a new gondola for the Driftsonde, new wing pods and optical view ports for the NSF/NCAR GV.

See other priorities in this goal:

- Enabling Innovative Field Experiments and Field Measurement Campaigns
- Installing the Initial Instrument Suite and Beginning Operations for the GV

Technology Development Facility

The Technology Development Facility's (TDF) mission is to identify, foster, implement, and help manage the development of advanced technologies leading to an improved understanding of the earth system. TDF is currently involved in seven major developments and two smaller projects.

Lidar Wind Profiler

This effort, which began in Jan. 2007, explores the possibility of utilizing EOL-developed eye-safe lidar technology to measure winds and possibly turbulence using a rotating wedge. Such a system potentially offers better time resolution, altitude resolution while reducing the effects of clutter (such as signals from the ground, birds, etc.) and interference from radio waves than is possible from current radar wind profilers and SODAR systems.

Significant progress has been achieved in FY 2008. The wedges, which are used to transmit and receive 3 horizontally displaced beams at different altitudes, have been received and the rotation assembly has been completed along with preliminary tests of this system with the wedges installed. Rotational speeds up to the operational speed of 333 rpm have successfully been demonstrated with no wobble and speed variations less than 0.25 rpm. Performance testing of the rotation timing and control data collection software is in progress. Hardware completion is tentatively scheduled for early FY 2009 when data collection and system performance analysis will formally begin.

CAMS Instrument for the GV

EOL began development of the Compact Atmospheric Multi-species Spectrometer (CAMS) for the GV in FY 2007. This new instrument will rely on the same state-of-the-art advancements employing difference frequency generation (DFG) technology as other EOL airborne infrared absorption spectrometers, but with major upgrades and innovations for operation on

Related Links or Images

This shot of the NASA DC-8 was taken during the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) experiment in March 2008. EOL's new Difference Frequency Generation (DFG) spectrometer was operated from this platform and acquired ambient measurements of formaldehyde, an important trace gas involved in ozone and hydrogen radical production.

NAR Highlight: NCAR/EOL Design and Fabrication Services: Where Art Meets Science

650 Miniature In-situ Sounding Technology (MIST) sondes were produced for the THORPEX Pacific Asian Regional Campaign (T-PARC) EOL's Design and Fabrication Services (DFS) Machine Shop.

the GV platform. It is one of many important trace gas chemistry instruments being developed for the NSF/NCAR GV for a proposed DC-3 study (Deep Clouds, Convection & Chemistry) as well as other airborne studies in the upper troposphere/lower stratosphere. This new instrument is being specifically developed for detection of formaldehyde and potentially other trace gases such as methanol, acetylene, ethylene, formic acid, and/or ethanol.

The predecessor system to CAMS, the Difference Frequency Generation Airborne Spectrometer (DFGAS), was deployed this past spring and summer during the ARCTAS study on the NASA DC-8 to measure the trace gas formaldehyde. In addition to contributing to important science, this study provided an excellent opportunity to test the efficacy of the latest engineering and software improvements that have been incorporated to address a number of noise issues during actual airborne operation. As CAMS will operate autonomously on the GV and GV design changes are both costly and time consuming, it is important that all such issues are resolved before the final design has been established. One of the lessons learned during ARCTAS was the importance of pressure sealing the entire optical module to avoid added noise during cabin pressure changes. Although it was not possible to pressure seal all the optical components during ARCTAS, significant reduction in both short term and long term noise was achieved by pressure sealing many of the important components. In addition, the DFGAS design is being further leveraged by incorporating a number of other improvements, including multi-species detection capabilities. An initial design review is tentatively scheduled for early FY 2009.

NO/NOy for the GV

In FY 07 EOL funded the completion of this instrument for measuring NO and NOy (the sum of various gas phase nitrogen oxide species) on the GV. This instrument will be used in many chemistry campaigns, including the proposed DC-3 experiment. A version of this instrument has recently flown on the NASA WB-57 during the TC4 study and a serious problem discovered in that study is now being corrected.

The modified instrument worked very well on the GV during START-08 and the project is now completed. During this process a number of modifications were implemented, including: replacement of spectral filters; the instrument was re-built using certified foam insulation; the data acquisition system was completed; the containment vessel was assembled, tested, and installed; new interconnect cables were made; and a modified HIMIL inlet was fabricated and installed.

Development of a plan for long-wave radiation for the GV

In our efforts to continually produce state of the art observing technology, EOL staff is leading a development effort for an instrument to measure long-wave radiation emitted by the earth's surface from the GV platform. Measurements of terrestrial emissions are an essential element in understanding the earth's radiative budget. Personnel in EOL are conducting surveys to define community needs for such instrumentation and devise a plan to improve upon what currently exists. Ultimately, this will lead to the development of new GV instrument with this important capability.

A sensor of interest has been identified from a specific vendor. Specifications and a quote for this sensor have been received. In addition, a user of this sensor has been contacted in an effort to learn firsthand the sensor operational characteristics. This user is also providing invaluable information on construction of a stabilized platform and sensor modifications for aircraft operations. Discussions with this user are underway to explore potential collaborations on a proposal in developing and carrying out an implementation plan.

SATCOM software products for the GV

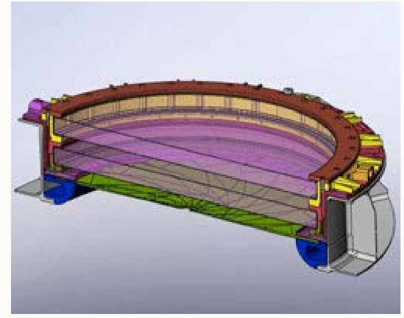
In F07 EOL started gathering input from the NCAR/NSF user community about what products they desire relative to what is currently available in regards to Satcom software products. This project has been discussed at inter-agency working groups, but owing to difficulties in coordinating field schedules in FY 2007, no workshop other than that at the NSF-User Workshop in September was planned. A breakout session at this workshop

DFS Machinist smiles in front of a wall of material to be used in Driftsonde gondola production for the THORPEX Pacific Asian Regional Campaign (T-PARC). 13 Driftsondes were launched during T-PARC.

The Driftsonde "sled" carries the gondola (left) and the balloon control system (right.)

A machinist in the DFS Machine Shop hand-cuts windows in the GV Wing Pods. A full sheet of metal must be cut and shaped before the windows are cut, otherwise the integrity of the metal would be destroyed.

DFS staff stand in front of a complete GV Wing Pod. Notice the windows, that were being cut in the photo above, in the central portion of the pod.



A design for the GV Optical Port. This design is for the port on the bottom of the GV aircraft - notice the green "iris" in the bottom of the structure. Upon takeoff and landing, this iris could close to protect the window from getting pelted with debris from the landing gear.

was held, and many technical people (~ 15 - 20) with few users attended. A number of workshop suggestions were received just as the HIAPER hardware issues were being solved (increased bandwidth and solved Iridium issues).

This project has been completed and based upon some limited feedback during the User Workshop the following recommendations have been implemented: 1) explicit wording in the Facility Request Form has been added indicating what is offered at no cost and what will cost more; and 2) an effort has begun to make more reliable what is offered. The third thrust, implementing collaborative software (video conferencing, shared display in flight planning mode, etc.) has not been pushed due to a lack of time caused by extensive field commitments, planning mode, etc.) are being considered. After receipt of a final report in early FY 2009, this project will be completed.

Water Vapor Reference Sounding System

This collaboration between NSF/EOL and South West Sciences Incorporated (SWI) is aimed at exploring the feasibility of balloon-borne tunable diode laser (TDL) technology for in-situ water vapor measurements with verifiable accuracy. Such measurements are badly needed by the climate community.

Significant progress has been achieved on this project. A test facility that will be used to introduce known water vapor mixing ratios at a variety of pressures and temperatures indicative of the surface to ~ 30 km has been designed and a design review carried out. Valuable suggestions for improvements to this design are now being incorporated in the final design. This facility will challenge two TDL systems from SWI at various intervals over a yearlong time period. Completion of the test facility is anticipated in early FY 2009 and the formal tests will commence.

Meteorological Satellite Data Collection and Processing

Funding was provided to improve satellite imager and sounder data collection and processing capabilities. This objective was completed at the end of the 2006 calendar year.

As indicated, the core project has been completed. A second thrust, which was not part of this project, involves collection of feedback from the broader scientific community with regard to future needs for satellite products and services. This activity has been taken over by a broader NCAR/UCAR committee, but to date progress has been slow.

WISARD: Wireless Integrated Sensor ARray Demonstration

In contrast to the other 7 development efforts this past year, the WISARD effort represents the first small emerging investigative request designed for small exploratory projects and feasibility studies. The WISARD effort seeks to demonstrate the viability of a next-generation near-surface facility that would wirelessly network a multi-disciplinary array of off-the-grid sensors on a highly portable, readily deployable tower. Following this proof-of-concept (Phase I) and subsequent input from the geoscientific community (through a survey) a Phase II TDF proposal would be pursued.

The telescoping tower system for fast field deployment has been received and the study to define the soil and radiation sensors to be used has been completed along with the conceptual designs for communications and the hardware to interface to the sensors. A commercial wireless system is now being considered, as the present wireless system has not work as expected. A number of tasks remain to be completed, including testing of this new wireless system, design of the microprocessor and front end circuitry that interfaces to the sensors, integration of components, and lab and field system tests.

HOLODEC: Holographic Detector for Clouds

The HOLODEC development is an aircraft instrument designed to obtain a 2-D profile, 2-D size and 3-D position of cloud particles in the size range of around 15 microns to 1 mm using digital holography. This type of instrument fills an important size measurement gap between instruments that size and count cloud particles by scattering (particles in the size range of 1 to 50 microns) and instruments that do the same by imaging (particles in the size range of > 100 microns). Further, it is uniquely able to detect shattering of ice crystals on leading parts of probe housing, because it can detect the 3-D clustering of shards of shattered particles in the sample volume. This is important as it allows us to estimate how much other instruments overestimate cloud particle densities due to counting shards of shattered particles.

Lenses for the optical system have been specified and ordered and the mechanical design for the lens housing has started. Materials for both components were carefully assessed to minimize focal length changes due to the large temperature excursions both components will be exposed to. An autocollimator has been specified and ordered to facilitate lens alignment and provide data on angular deviations in the presence of vibrations. The imaging lens assembly will be completed by around mid October and performance laboratory testing will begin thereafter.

High Precision carbon dioxide isotopic ratio instrument - CILAS

This long-standing development project that began in FY 2002 with NSF Biocomplexity Special Funds progressed rapidly in FY 2007. This instrument will provide continuous (seconds to minutes time resolution) high precision measurements of 13CO2 to 12CO2 using a new infrared spectroscopic instrument utilizing the same DFG technology as the airborne CAMS instrument. This will augment more traditional measurements of this ratio from high precision isotopic ratio mass spectrometry, leading to an enhanced understanding of the carbon cycle.

Significant progress has been achieved on this instrument over the past several months employing a number of modifications, which will be discussed at length in an upcoming Optics Letters paper. Comprehensive precision and accuracy tests have been carried out in the laboratory using isotopic standards validated by the University of Colorado Stable Isotope Laboratory based upon isotope ratio mass spectrometry. The current performance exceeds 0.02 per mil precision for 150 seconds of averaging and achieves an accuracy of 0.05 per mil on these standards. Additional laboratory tests will be carried out to study the effects of water vapor and variable ambient carbon dioxide concentrations on the retrieved measurement accuracy. Future field tests and scientific measurements employing this instrument are yet to be determined.

Development of a high efficiency waveguide DFG instrument

TDF personnel have been working with Japanese scientists and engineers from the NTT Photonics Laboratory, NTT Corporation in developing and assessing a new high performance optical frequency conversion technology based upon wave-guide DFG devices. This group published a paper on the first phase of this instrument development and assessment in FY 2007.

A second phase study using an improved device based upon EOL input has been tested and the results look very promising. A new paper describing these results will be forthcoming and plans for a third phase with additional device improvements are being formulated. Ultimately, it is anticipated that these efforts will lead to DFG devices with significantly improved performance, both in terms of higher output powers and conversion efficiencies. If successful, this will open up many new detection methods for instruments on the GV.

Design and Fabrication Services

Whether creating something from scratch based on conversations with a principal investigator, or rendering into physical form a researcher’s hand-drawn interpretation of an instrument, EOL's Design and Fabrication Services staff can design it, build it, and provide seasoned counsel on use, based on years of experience.

Miniature In-situ Sounding Technology (MIST) sondes

In preparation for the THORPEX Pacific Asian Regional Campaign (T-PARC), DFS produced over 650 MIST sondes, refining the design to simplify the production process. The smaller sonde allows for up to 56 sondes to be deployed from a gondola and Typical flights will have 38 sondes on board for T-PARC. With the In-Situ Sensing (ISF) Facility EOL Driftsonde operators in Hawaii launched 13 Driftsonde gondolas that floated westward toward the weather events and deployed over 250 MIST sondes along their trajectories. For more information on T-PARC see entry under Improving the Prediction of Weather, Climate and other Atmospheric Phenomena.

The design of the MIST sonde was completed in early 2008 with extensive testing during a Driftsonde flight from the Seychelles in February and again in May from Hawaii. This version of the MIST sonde is designed specifically for Driftsonde, but the core design will be used for the next generation of a small dropsonde for aircraft use. Software engineers from EOL's Computing, Data and Software (CDS) Facility developed the ability to deploy the sondes from the gondola remotely through a simple web interface - the first ever such capability in an EOL platform. This new automous operation will have a profound effect in global campaigns - imagine being able to launch a sonde from a gondola or from an airplane from a cell phone half-way around the world! Applications with the HAIS instruments and Unmanned Autonomous Systems (UAS), such as the NOAA Global Hawk, are already being explored.

Wing Pods and Optical Viewports for the NSF/NCAR GV

The DFS team is also in the process of creating pods that will be attached beneath the wings of the GV (see entry under Installing the Initial Instrument Suite and Beginning Operations for the GV.) Based on an idea originated and patented by DFS manager Jack Fox, DFS engineer Steve Rauenbuehler, and EOL Research Application Facility’s Mark Lord, the pods can carry up to an additional 800 pounds of scientific instruments. These innovative, tear-drop-shaped pods are designed with a detachable middle portion that is easily accessible from beneath the wing. When pod-mounted instruments are employed, more room is available on board for additional personnel or instruments a critical function in a plane where space is at a premium. Alternatively, instrumentation can be attached directly to the pod to gather data during flights.

DFS is designing two 22-inch diameter double-paned optical view ports for the GV - one on the top of the aircraft and one on the bottom. Several designs are being explored, including one with an "iris" that could close upon takeoff and landing to protect the glass panes from getting pelted with debris from the landing gear. Pending issues involved with certification requirements, production and testing of the view ports will begin in FY 2009.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

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GOAL 1, UNDERSTANDING THE EARTH & SUN SYSTEM

Investigating the Interactions of the Atmosphere, the Broader Earth System and Human Society

Developing a fuller understanding of the complex interactions among the Earth's atmosphere, oceans, land masses, ice masses, and biosphere; the interconnection of human activities with the Earth's physical, chemical, and biological processes is a major focus of our national center. EOL is tasked mainly with the mission to develop innovative instrumentation and data acquisition technology and lead scientific campaigns that make such understanding possible. Even so, EOL scientists often find themselves in the thick of data analysis that contribute directly to the goal of improving our understanding of the atmosphere and earth system, specifically by investigating the interactions of the atmosphere and the broader earth system.

Stratosphere-Troposphere Analyses of Regional Transport (START-08)

EOL operated the NSF/NCAR GV from the Research Aviation Facility in Broomfield, CO in support of START-08 to study the chemical and transport characteristics of the extratropical upper tropospheric and lower stratospheric (ExUTLS) region. A total of 18 flights and 123 GV hours was flown within 6 flight weeks that covered Spring (April 15-May 15) and Summer (June 16-28) seasons.

The objective of the experiment is to use in-situ chemical, microphysical, and dynamical measurements, satellite data, and models to better understand the multi-scale dynamical processes that control the chemical composition of the ExUTLS, particularly the behavior of the extratropical tropopause as a transport boundary and on key chemical transport pathways and the related dynamical processes that couple the UT and LS.

START-08 shared the payload and flight operations with the test flights of the HIPAER Pole-to-Pole Observation of Atmosphere Tracers (pre-HIPPO) experiment. Both projects shared a similarity in payload and missions that address the science of both projects. HIAPER Pole to Pole Observations (HIPPO) begins in January 2009 and is the first comprehensive, global survey of atmospheric trace gases, covering the full troposphere in all seasons and multiple years.

This project also allowed EOL to test new Google Earth real-time flight tracking system available through the Laboratory Home Page. Weekly updates of the flight schedules were sent to members of our community and UCAR staff, and a sign-up function was made available to the general public. This real-time viewing and tracking capability was modified to allow tracking of Driftsondes launched from Hawaii during T-Parc and will eventually extend to include all of our facilities.

The Computing, Data and Software Facility provided an on-line Field Catalog to support daily operations and forecasting tasks, coordinated overall data management and will provide long-term data archival and dissemination of START-08 data and metadata to the scientific community. START-08 was another successful deployment of the new NIDAS-based ADS3 data system. The system continues to mature, and configuration and operation were the most routine yet experienced to date.

Terrain-influenced Monsoon Rainfall Experiment (TiMREX)

TiMREX, part of the Southwest Monsoon Experiment (SoWMEX) is joint U.S.-

Related Links and Images

Image from GV wing-mounted camera, GISMOS

TIMREX

(l-r) EOL's Tammy Weckwerth, Joe VanAndel, Gordon Farquaharson, Jim Wilson and RAL's Mike Dixon look at S-Pol data in Taiwan during TiMREX

S-Pol, EOL's transportable, ground-based Doppler radar, on site in Taiwan.

TiMREX Slideshow

T-PARC

Taiwan multi-agency field program that was conducted from 15 May to 30 June 2008 in the northern South China Sea, western coastal plain and mountain slope regions of southern Taiwan to study heavy rain and flood-producing convective events and evaluate the skill of numerical weather prediction systems to forecast these complex systems. Their goal was to create better forecasting abilities and quantitatively estimate rainfall in mountainous regions prone to intense orographic precipitation events, both in Taiwan and elsewhere globally. Policy makers, government officials, and regional residents will also benefit since better weather nowcasts will provide more advanced warning of floods and landslides.

As part of TiMREX, the U.S. team, led by EOL scientist Wen-Chau Lee, deployed the NCAR/EOL S-Pol polarimetric, Doppler radar (S-Pol) for intensive observations, data assimilation and numerical modeling studies. “There are places in Taiwan that typically have heavy rainfall, but it varies from year to year and from storm to storm,” explains EOL scientist Tammy Weckwerth, one of the project’s investigators. “What we’re trying to do with TiMREX is understand the processes better so that we can better predict where that rain is going to fall.”

The larger SoWMEX will continue for the next five years with smaller experiments which will build on this year’s global effort.

Improving the Prediction of Weather, Climate and other Atmospheric Phenomena

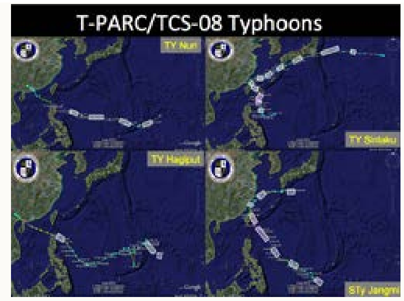
Over the last several decades, the skill of numerical weather prediction is generally considered to have increased at an average rate of about one day per decade. Thus, the skill of today’s four-day forecast is equivalent to the skill of a three-day forecast of a decade earlier. The rate of improvement is even slower for the forecast variables needed most by society, such as the prediction of heavy rainfall. This relatively slow, linear rate of improvement is not sufficient to keep place with the demand for accurate weather information in the world today, where an exponentially growing world population places an ever-increasing number of people in areas at risk for weather disasters.

THORPEX Pacific Asian Regional Campaign (T-PARC)

The THORPEX Pacific Asian Regional Campaign (T-PARC) is a multi-national field campaign that studied the formation, intensification, structure change, motion, and extratropical conversion of typhoons as they move out of the tropics to improve the forecast skill of one region (Eastern Asian and the western North Pacific) and its downstream impact on the medium-range dynamics and forecast skill of another region (in particular, the eastern North Pacific and North America). It was the first systematic targeting operation in the western Pacific Ocean, comparing several methods from a variety of operational and research organizations.

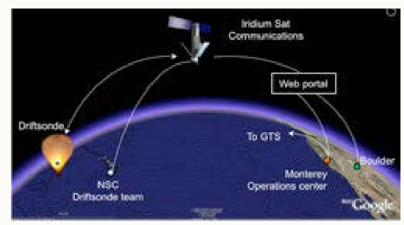
The field phase of T-PARC leveraged the efforts of nine nations to address these themes, and was the first global project across the Pacific rim in which EOL played a major support role. EOL project leaders worked from an Operations Center in Monterey, California from where they managed the Driftsonde launch facility in Hawaii and an aircraft coordination center at Andersen Air Force Base in Guam. The aircraft also had forward deployment sites in Japan and Taiwan to accommodate for on-the-fly adjustments in flight plans based on storm data.

The operational challenges presented by a field campaign that spanned nine time zones as well as the international date line, were, in the words of EOL Field Project Services staff and T-PARC project manager Jim Moore, "not for the faint of heart." Of the 11 storm events that were flown during the two month campaign, four were major typhoons. To coordinate aircraft operations so they were timed properly to intersect the storms, the T-PARC operations team in Monterey used a variety of tools such as Google Earth, data from the aircraft and satellite downlinks to create near real-time displays of missions in their command center. The ability to quickly synthesize and communicate all this information was central to the success of the program, and there was major improvement here: for example, data uploads from the NRL P-3 took only 90 seconds during T-PARC as compared with the eight minutes the same task took during the Hurricane Rainband



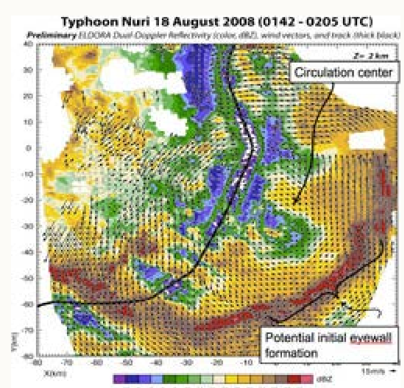
T-PARC researchers were able to gather data from 11 unique storm events during the two-month campaign. Four were named typhoons, and one, Jangmi, was a "Super Typhoon" or a Category 5. (enlarge)

Launching a Driftsonde.



Overview of Driftsonde Communications used during T-PARC (see larger)

Naval Research Lab (NRL) P-3 with the ELectra DOppler RAdar (ELDORA) in Guam for T-PARC. Dropsondes were launched from this aircraft as well.



An image of Typhoon Nuri from ELDORA (enlarge) showing refractivity, wind vectors and the storm track.

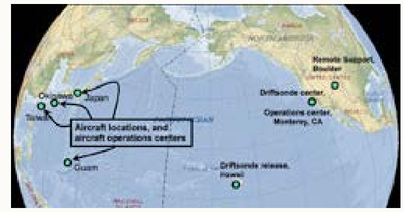
and Intensity Change Experiment (RAINEX) in 2005.

EOL staff operated the ELectra DOppler RAdar (ELDORA) and deployed 343 Dropsondes from the Naval Research Lab (NRL) P-3 aircraft, and deployed over 600 dropsondes from the NSF/NCAR C-130 aircraft. The C-130 flew over 200 hours (23 missions) during the two-month field phase and operated at its highest altitude yet - 31,000 feet - in order to get fullest range of dropsonde data possible.

EOL Driftsonde operators in Hawaii launched 13 Driftsonde gondolas that floated westward toward the weather events and deployed over 250 MIST sondes along their trajectories. T-PARC was the second deployment for the Driftsondes, the first being the THORPEX - African Monsoon Multidisciplinary Analyses (T-AMMA) in Summer of 2006. In preparation for T-PARC, major improvements were made to the dropsondes deployed from the Driftsondes, the most notable of which is the development of autonomous operation of the system through a simple web interface, including launching the sondes from the gondola. This work will have profound effects on the development of the remotely controlled instrumentation aboard research aircraft, including the HAIS instruments and the Unmanned Aircraft Systems (UAS) used for atmospheric research. A fuller explanation of this can be found in Developing New Instrumentation.

(l-r) EOL's Laura Tudor and Errol Korn launching Dropsondes from the NRL P-3 during T-PARC. (more here)

T-PARC article in UCAR Staff Notes



This graphic (enlarge) shows the locations of the seven operations centers of the T-PARC field campaign. The campaign spanned nine time zones and the international date line.

Science: Strategic Goal 1

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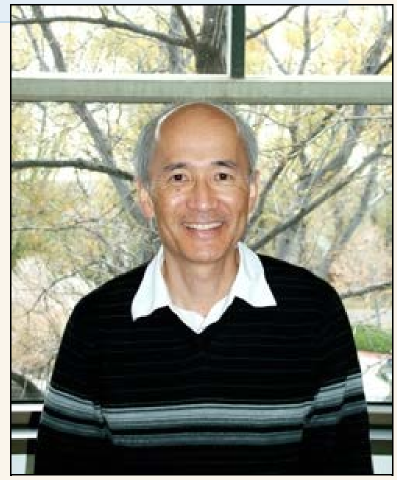
DIRECTOR'S MESSAGE

Welcome to the Earth Observing Laboratory's 2008 Annual Report



Dr. Roger Wakimoto is Assistant Director of NCAR for the Earth Observing Laboratory

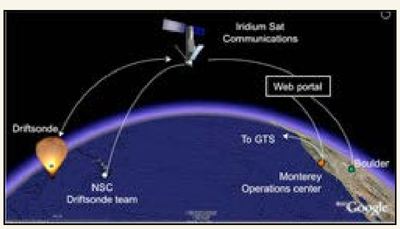
EOL is known as a community hub for the collection of data and transfer of knowledge pertaining to observations. The Laboratory also develops new measurement tools to extend community understanding of the atmosphere. EOL specifically fulfills three critical needs:

1. To lead and serve the community in the provision of observational facilities infrastructure, and services needed by the atmospheric and related sciences.
2. To play a leadership role in the development community-inspired next generation instrumentation and infrastructure while providing existing instruments and infrastructure in support of science.
3. To coordinate all aspects of field deployment from pre-project planning through the field phase and subsequent data stewardship.

Central to EOL's success is our world-class scientific, engineering and project management staff that is respected by the community. Our staff responses to new directions in atmospheric research technology play a leadership role in the development and application of new technology to science objectives.

Field Campaigns Going Global

EOL was extremely busy in FY2008 fulfilling our mission to support the NCAR goal #5, “Provide World-Class Observational Facilities”: during 42 out of 52 weeks this year we coordinated and participated in seven field campaigns, three of which were international, and spent over 3000 person-days in field. Every platform was deployed this year, some more than once, which was a first for us.



This Google Earth diagram shows the complex communications schema necessary for the remote and autonomous deployment of Miniature In-situ Sounding Technology (MIST) sondes from the Driftsonde during T-PARC.

As we come closer to realizing the full operational capability of the NSF/NCAR GV we are addressing the drastically shifting expectations of field campaigns towards longer, larger-scale events. In order to meet the new challenges posed by global operations, EOL has begun to reframe the way we prepare for and manage field deployments. To perform global operations at the level our community has come to expect also requires advances in the instrumentation technology. A good deal of progress was made in the area of remote operation of airborne instrumentation with the development of the Miniature In-situ Sounding Technology (MIST) sonde for the Driftsonde platform, used in the THORPEX Pacific Asian Regional Campaign (T-PARC). The development of this autonomous deployment capability will have a profound positive effect in global campaigns and applications with the HAIS instruments and Unmanned Autonomous Systems (UAS), such as the NOAA Global Hawk, are already being explored.

EOL launched a strategic partnership with Colorado State University (CSU) to develop an integrated radar facility that will expand the capabilities that either entity can currently provide. Both EOL and CSU support 10-cm, multiparameter Doppler radars (NSF/NCAR S-Pol and CSU CHILL radars, respectively) that will be jointly operated in this new partnership, as well as other, smaller radars. A key objective of this partnership is to create a national test bed that other institutes and agencies can use for research and education.

The NSF Facilities Assessment database was officially launched this year and will continue to garner input from the community. The intent is provide descriptive information on atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science and related communities.

Understanding the Earth & Sun System

In support of Goal #1, Understanding the Earth & Sun System, EOL participated in three field campaigns: for the Stratosphere-Troposphere Analyses of Regional Transport (START-08) EOL operated the NSF/NCAR GV to study the chemical and transport characteristics of the extratropical upper tropospheric and lower stratospheric (ExUTLS) region; for the Terrain-influenced Monsoon Rainfall Experiment (TiMREX) we deployed the S-Pol radar to Taiwan in May to study heavy rain and flood-producing convective events and evaluate the skill of numerical weather prediction systems to forecast these complex


S-Pol, EOL's transportable, ground-based Doppler radar, on site for Terrain-influenced Monsoon Rainfall Experiment (TiMREX) in Taiwan.

systems; and in September we participated in the mammoth multinational T-PARC with the C-130, ELDORA radar, Dropsondes, Driftsondes, and the new MIST sondes, not to mention the project management, data management and communications technology necessary to meet the science objectives and keep the campaign running smoothly across nine time zones and the international date line. The objectives of T-PARC were to sample typhoons through their lifecycle and document three primary phases from formation through maturity to extra-tropical transition.

Improving Resilience to Weather, Climate and Atmospheric Hazards

In support of Goal #2, Improving Resilience to Weather, Climate and Atmospheric Hazards, EOL scientists, working with researchers at the Naval Research Laboratory, developed the VORTRAC technique to continually monitor landfalling storms in the United States. In March 2008 the National Hurricane Center officially adopted VORTRAC as a technique to monitor hurricane intensity. In time, VORTRAC may also help improve long-range hurricane forecasts by using data from airborne Doppler radars or spaceborne radars to produce detailed information about a hurricane that is far out to sea. Forecasters could input the data to computer models to improve three- and five-day forecasts.

Cultivate a Scientifically Literate and Engaged Citizenry and a Diverse and Creative Workforce


In November 2008 the Doppler on Wheels will be deployed to the University of Nebraska for the first Educational Deployment. The professor will teach students radar fundamentals and will use the radar to give students hands-on experience.

EOL places major emphases on Goal #3, diversity and education and outreach activities. At the advice taken from the 2007 NSF Facilities Users' Workshop, in 2008 we instituted a process through which universities can officially request NSF Lower Atmospheric Observing Facilities through the NSF Deployment Pool for educational purposes. In FY2008 we received five requests and the interest in opportunity continues to grow. The first such official project will be a deployment of the Doppler on Wheels Radar to a meteorology class at the University of Nebraska in Lincoln for a two-week period in November 2008. We will continue our efforts to support SOARS and the EOL Engineering Intern Program, as well as numerous education and outreach activities for K-12 students and the general public.

Provide Robust, Accessible, and Innovative Information Services and Tools

EOL is committed to data processing, quality control, and archival for field projects as part of our expanding services that will be provided to the community, Goal #4. This includes efforts to complete development of the Metadata Database and Cyberinfrastructure (EMDAC, formerly known as CODIAC) to access and browse products and data from field projects while integrating with the Community Data Portal. In FY2008 EOL has been leading data management support for a series of NSF-funded Arctic programs. Finally, our Atmospheric Sounding Processing Environment (ASPEN) software underwent extensive modifications in order to create a better match to processing results produced by quality control software developed by the National Hurricane Center. These changes focus on the last 5 seconds of dropsonde sounding data, which are critical to hurricane surface condition assessment. The modified Aspen was deployed for 2008 hurricane season in T-PARC.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

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TABLE OF CONTENTS

Table of Contents

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NCAR'S STRATEGIC GOAL'S

NCAR's Strategic Plan, ***NCAR as an Integrator, Innovator and Community Builder***, outlines five Strategic Goals, and the priorities for achieving each. In the following sections we report on progress made in FY 2008 toward each scientific goal and priority.

NCAR's has 5 Strategic Goals. Follow the links below to learn about EOL's contribution to these goals.

1. Improve understanding of the atmosphere, the Earth system, and the Sun,
2. Increase societal resilience to weather, climate, and other atmospheric hazards,
3. Cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce,
4. Provide robust, accessible, and innovative information services and tools, and
5. Provide world-class ground, airborne, and space-borne observational facilities and services.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology

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GOAL 2: INCREASE SOCIETAL RESILIENCE TO WEATHER, CLIMATE AND OTHER ATMOSPHERIC HAZARDS

Priority: Building Capacity for Coping with Weather and Climate Hazards

To help society cope with weather and climate hazards, decision makers must be made aware of threats and vulnerabilities so that options of mitigation and adaptation can be developed. EOL has contributed to this strategic priority in 2008 with Vortex Objective Radar Tracking and Circulation (VORTRAC) to continually monitor storms approaching U.S. coasts.

VORTRAC

Communities along the Atlantic Basin's Hurricane Alley are all too aware how quickly a tropical cyclone can intensify mere hours upon making landfall. In 2004 Hurricane Charley's windspeeds bolted from 110 mph to 145 mph only six hours before slamming into the coast of southwestern Florida, costing taxpayers over $16 billion dollars. Katrina grew from a Category 3 to a Category 5 hurricane in just nine hours before staking its claim as the costliest, and one of the deadliest storms in history.

EOL scientists, working with researchers at the Naval Research Laboratory, developed the VORTRAC technique to continually monitor landfalling storms in the United States and in March 2008 the National Hurricane Center officially adopted VORTRAC as a technique to monitor hurricane intensity. It uses the Doppler radar network established by NOAA in the 1990s. About 20 of these radars are scattered along the Gulf and Atlantic coastlines from Texas to Maine. Each radar can measure winds blowing toward or away from it, but no single radar could provide an estimate of a hurricane's rotational winds and central pressure until now.

The VORTRAC team developed a series of mathematical formulas that combine data from a single radar near the center of a landfalling storm with general knowledge of Atlantic hurricane structure in order to map the approaching system's rotational winds. VORTRAC also infers the barometric pressure in the eye of the hurricane, a very reliable index of its strength.

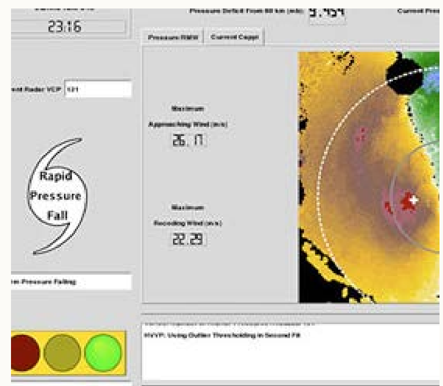
Forecasters using VORTRAC can update information about a hurricane each time a NOAA Doppler radar scans the storm, which can be as often as about every six minutes. Without such a technique, forecasters would need at least two coastal radars in close proximity to each other in order to obtain the same information. But most of the network's radars are too far apart to qualify.

Each radar can sample conditions out to about 120 miles. This means VORTRAC can track an incoming hurricane for at least several hours, and possibly even as long as a day or more, depending on the storm's speed, trajectory, and size.

To monitor the winds of a landfalling hurricane, forecasters now rely on aircraft to drop instrument packages into the storm that gather data on winds and pressure. Due to flight logistics, the aircraft can take readings no more than every hour or two, which means that a sudden drop in barometric pressure, and the accompanying increase in winds, may be difficult to anticipate.

In time, VORTRAC may also help improve long-range hurricane forecasts by using data from airborne Doppler radars or spaceborne radars to produce detailed information about a hurricane that is far out to sea. Forecasters could input the data to computer models to improve three- and five-day

Related Images



VORTRAC will provide forecasters at the National Hurricane Center with frequent, detailed updates on hurricanes as they approach land. The VORTRAC interface (above - enlarge) includes a display of winds derived from Doppler radar data (right, with the hurricane center marked with an X), an estimate of the hurricane's central pressure (top), and a warning message that displays if the pressure is dropping rapidly (left). (Illustration courtesy Michael Bell, NCAR.)

forecasts.

In addition, many nations along the Pacific Rim and Indian Ocean have their own emerging Doppler radar networks. Those nations, which are vulnerable to tropical cyclones, may also be able to make use of VORTRAC.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

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GOAL 3, CULTIVATE A SCIENTIFICALLY LITERATE AND ENGAGED CITIZENRY AND A DIVERSE AND CREATIVE WORKFORCE

Priority: Engaging a Broader and More Diverse Community in the Atmospheric and Geosciences

EOL recognizes that the overall health of our institution lay in ensuring that those with aptitude and determination have opportunities in the atmospheric science and engineering disciplines, and that they are welcomed and nurtured, regardless of gender, ethnic background, nationality, or physical ability. EOL addresses this NCAR strategic priority in a number of ways, including our highly successful Student Engineering program, now in its ninth year, our hiring practices, our EOL Women's Professional Development Group and our Education and Outreach efforts that reach the general public..

Undergraduate Engineering Internships

2008 was a record year in terms of applicants for EOL's Summer Undergraduate Engineering program, which focuses EOL's outreach efforts on the engineering community in a manner analogous to what UCAR/NCAR currently does for young scientists.

EOL received resumes from mechanical, electrical and computer, aerospace, optical, environmental, chemical, and industrial engineering students. A total of 200 applications were received, the most applications ever received for any position at UCAR.

Three interns were hired and worked with EOL engineers during the summer of 2008: Prerna Bang is an electrical engineering student from the Georgia Institute of Technology in Atlanta, and Andrew Leung is an electrical engineering student, from the University of Colorado, Boulder. Both worked with Eric Lowe in EOL's Research Aviation Facility on a synchro to digital converter for an antenna controller. Rose-Gaëlle Belinga is an electrical and computer engineering student from the Auburn University in Alabama. Rose will be working with Charlie Martin in the Computer, Data and Software Facility on upgrading and documenting the Atmospheric Sounding Processing Environment (Aspen) software which is used for analysis and quality control (QC) of sounding data. Continuation of the undergraduate intern program will be a priority in FY09 and 10.

Girl Scout Science Program

In May, EOL scientist Kate Young participated in the "Climate and Weather: The Two Go Together" event at the NCAR Mesa Lab. This yearly event allows girls from the Girl Scouts Colorado to spend one day at NCAR learning about weather and climate, participating in hands-on activities and interacting with female scientists. Kate launched a weather balloon and taught the girls about weather and data.

Diversity in EOL Hiring Process

EOL emphasizes the inclusion of diversity in its hiring practices and follows internal practices to ensure that a measurable and fair process is followed for every new hire. We have established checks and balances to ensure proper advertisement of new positions in order to solicit the widest variety of applicants. Hiring managers must complete a form outlining how and where the job was advertised, what effort was made to solicit applications from females and underrepresented minorities, and justification for final interview pool and hire. EOL firmly believes these efforts to ensure diversity within its ranks will strengthen our organization as a whole.

Related Links or Images

EOL scientist Kate Young launches a balloon for "Climate and Weather: The Two Go Together" program with NCAR and Girl Scouts of Colorado. (more)

EOL Women's Professional Development Group

The EOL Women's group continues to bring together women at all levels in the laboratory - mechanics, technicians, administrators, scientists, data managers, managers, etc., to provide a forum in which women can share experiences and discuss lab topics of mutual interest. Management is interested to foster this communication in order to work on making EOL a supportive place in which women professionals work.

Priority: Enhancing Scientific Education

EOL attaches a high value to Education and Outreach and currently infuses all EOL programs, whether in the laboratory or field with an E&O component. EOL encourages a general interest in earth science, and particularly tries to foster advanced understanding in the science and process of atmospheric research measurements. EOL accepts its responsibility to encourage the growth of the next generation of observational engineers and scientists, and continually seeks new ways to do this. 2008 saw the advent of a new way of making NSF/NCAR Observing Facilities to the community for educational purposes.

MGAUS Tour

In October, EOL technician Tim Lim took the Mobile GPS Advanced Upper-air Sounding System (MGAUS) to Purdue University and the University of Illinois at Urbana-Champaign to demonstrate the facility to students and faculty.

The idea for this project was born during the NSF Facilities Users' Workshop in September 2007. There was a request from the community for educational field trips to universities with various facilities to familiarize students with what EOL does, and Tim's trip to these two universities was the pilot for this developing educational program. The result? "Very successful," said Tim. "Lots of students showed up. The data the students collected during the demos were used in class for analysis only hours later."

The implications of such a program could be far-reaching. Some of the students at the demos told Tim they were taking instrumentation classes as an elective. "The opportunity to get their hands on a weather instrument and see how it is used and see how the data can be analyzed definitely made some of them more interested in studying atmospheric sciences." Tim also used the opportunity to drum up interest in the EOL Summer Undergraduate Engineering Program, which will ran its ninth year in 2008.

Requesting NSF Facilities for Education

With the excitement generated by the two university visits, EOL worked with NSF to develop a new request process for NSF facilities for educational tours. University educators wishing to gain access to observational facilities for classroom instruction and a hands-on learning experience may request the facility deployment to their school for a short period of time. Proposals are judged on criteria such as: actual educational activity, the planned use of date being collected, the number of students involved and the length and dates of the deployment. Submission of proposals by students are also being requested when they have faculty approval.

In FY2008 EOL received five facility proposals educational purposes. The first official deployment for educational purposes will be in November 2008 for the the DOW6 at the University of Nebraska. For two weeks students will benefit from hands-on experience to reinforce their lessons on radar basics.

Requesting NSF Facilities for Education

University of Illinois at Urbana-Champaign (UIUC) coverage of the MGAUS balloon launches.

Movie of one of the launches at UIUC

In November 2008 the Doppler on Wheels will be deployed to the University of Nebraska for the first Educational Deployment. The professor will teach students radar fundamentals and will use the radar to give students hands-on experience.

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GOAL 4, PROVIDE ROBUST, ACCESSIBLE, AND INNOVATIVE INFORMATION SERVICES AND TOOLS

Priority: Developing data management tools to the support Earth and atmospheric sciences

In addition to providing and supporting instrumentation that help scientists obtain critical observational data, EOL also supports data packaging, storage, and management.

EOL Metadata Database and Cyber Infrastructure (EMDAC)

In FY08, EOL began laying the groundwork for the EMDAC development through summarizing community input received through data workshops, the NSF User Workshop, data management committees, proposal reviews and other sources. Major development issues have been identified and prioritized, and an online site for the project status tracking has been published. In FY09, NCAR will solicit community feedback in order to continue developing the EMDAC to meet user requirements, and enhance current infrastructure to streamline overall internal data management activities.

Atmospheric Sounding Processing Environment (ASPEN) Software

As a result of the April 2008 AVAPS User Conference, Aspen underwent extensive modifications in order to create a better match to processing results produced by quality control software developed by the National Hurricane Center. These changes focus on the last 5 seconds of dropsonde sounding data, which are critical to hurricane surface condition assessment. The modified Aspen was deployed for 2008 hurricane season in T-PARC (see section on Improving the Prediction of Weather, Climate and other Atmospheric Phenomena.)

Arctic Data Projects

EOL has been leading data management support for a series of NSF-funded Arctic programs such as the Arctic Observing Network (AON), Bering Sea Ecosystem Study (BEST), various U.S. Coast Guard Healy ship cruises, and the development of the long-term ARCtic System Science (ARCSS) archives. EOL has been working closely with other UCAR and external groups (CISL, Unidata, and NSIDC) in developing an AON archive system (Cooperative Arctic Data and Information Service [CADIS]) using the NCAR Community Data Portal (CDP) for data submission and access. It is envisioned that EOL collaboration and development with the CDP will result in standardized future EOL project data collection, tracking, management, and dissemination within the broader EMDAC system.

Related Links or Images

NAR Highlight: Adding Value to Weather Data: Atmospheric Sounding Processing Environment (ASPEN) software

The Cooperative Arctic Data and Information Service (CADIS) - supports the Arctic Observing Network (AON). It will be a portal for data discovery, and provide near-real-time data delivery, a repository for data storage, and tools to manipulate data.

Website

CADIS in the NCAR Annual Report

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

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GOAL 5, PRIORITY 1: ENABLING INNOVATIVE FIELD EXPERIMENTS AND FIELD MEASUREMENT CAMPAIGNS

The precision, robustness, and performance of weather, climate, and chemistry models depend on sound theory as well as accurate observations and measurements. NCAR leadership in the area of field-program planning and implementation is a critical community service, and we are proud of our achievements in this area. Toward this end, EOL maintains a large suite of NSF-funded, state-of-the-art Lower Atmospheric Observing Facilities (LAOF), which collect data that will advance understanding of atmospheric and Earth processes in support of community research.

FY2008 was an extremely busy year for EOL: during 42 out of 52 weeks this year we coordinated and participated in seven field campaigns, three of which were international, and spent over 3000 person-days in field. Every platform was deployed this year, some more than once, which was a first for us. Also, as we come closer to realizing the full operational capability of the NSF/NCAR GV we must address the drastically shifting expectations of field campaigns towards longer, larger-scale events. In order to meet the new challenges posed by global operations, EOL has begun to reframe the way we prepare for manage field deployments.

See other priorities in this goal:

- Developing New Instrumentation
- Installing the Initial Instrument Suite and Beginning Operations for the GV

Global Operations

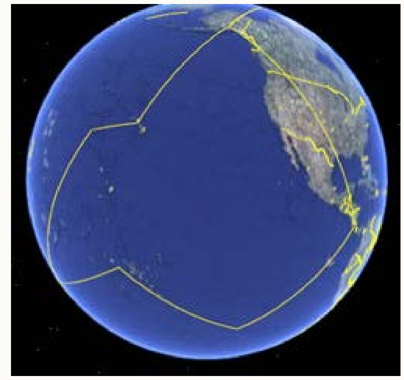
The advent of NSF/NCAR GV operations has had a profound impact on field deployment planning and operations. Because the GV has a much larger range, sampling areas of the earth that are relevant to global scale issues, such as climate change, long term transport, or seasonal changes in carbon cycle gases, have become more scientifically attractive. Through the challenges posed by these and other kinds of new global operations - such as T-PARC (See section on Improving the Prediction of Weather, Climate and other Atmospheric Phenomena) and to a larger extent the HIAPER Pole-to-Pole Observations (HIPPO) in 2009 - EOL is expanding and refining our ability to support multiple sites.

Challenges

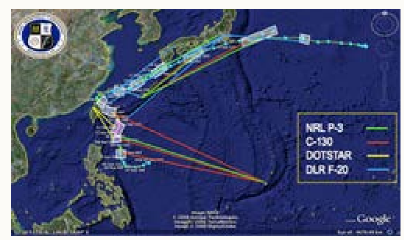
In projects that have a single airport and operations center, pilots, support staff and scientists return to a fixed operational base after each flight mission. In a larger campaign such as the kind the GV was designed for, there could be multiple airports (HIPPO will have 11) or no base to return to at all. EOL usually stations a significant number of staff – technicians, mechanics, hardware and software engineers as well as instrument specialists with the aircraft to deal with technical issues related to the aircraft itself, instrumentation or the data system. Without a main base to come back to and limited space on the aircraft, the number of support staff has to be scaled down to the number of seats available in the aircraft, and possibly a few personnel who would be stationed ahead of time at selected sites.

The time necessary to obtain flight, research and customs clearances varies from country to country. The number of diplomatic clearances, embassy and government interactions will significantly increase with the number of nations involved. The time and effort involved add to the workload of the individual aircraft project manager, which usually focuses primarily on

Related Links or Images



Google Earth map shows flight planning for HIAPER Pole-to-Pole Observations (HIPPO). With many of EOL's field campaigns turing global in nature, new tools are emerging to assist with planning, data access, and real-time communications.



Flight tracks of the four aircraft during Super Typhoon Jangmi in T-PARC. (enlarge) With farther ranging instrument platforms, the trend in field campaigns is towards global operations. EOL addressing this by developing autonomous operations systems.

A key objective in creating the National Radar Facility is to create a national test bed that other institutes and agencies can use for research and education

The NSF Facilities Assessment Database provides descriptive information on atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science and related communities.

interactions with the project scientists and their instrumentation, and on getting the aircraft ready to go into the field.

Data sample analysis is another challenge: EOL routinely makes arrangements for local lab space to allow investigators to analyze samples in the field after a flight. Analysis of samples during global operations would be very limited and
dependent on local infrastructure, such as at a local research lab or university.

Global operations involve coordinating efforts among staff and outside collaborators (e.g. Air Traffic Control, university groups, government labs from multiple governments, etc.) across multiple time zones. Appropriate scheduling of staff resources is essential. For example, running an operations center will be different for global operations, requiring 24 hour/7 days per week operations during critical phases of the mission. A higher level of coordination between the various parties, and reliable sharing of information (e.g., forecasting products) is essential for the decision making process and smooth operations.

New Strategies

Earlier interactions with PIs is perhaps the single most important step to ensure proper planning of a large scale global operation. Experimental Design Overviews, part of the OFAP process, are being considered with regards to the locations we have to support, the kinds of information available.

Since storing caches of equipment at each location isn't feasible, onboard airborne mission-support packages will be developed for each distinct payload, as well as a general "flyaway" package with tools for instrument repair that will go with scientists on research missions.

Improvements in information support and communications technology will prove to be crucial to the success of any global operation. EOL/CDS continues to develop and improve upon Real-time Display and Coordination Center (RDCC) components including the chat/instant messaging system, real time display software, the satcom system, and the Field Catalog, all of which are essential elements of global operations. Additional existing components consisting of efficient networking software for worldwide participation in data exchange, web/audio/video conferencing, including integrated data displays (e.g. aircraft, radar, model, and satellite products) are being modified to specifically to support global or remote operations.

National Radar Facility

In 2008, EOL launched a strategic partnership with Colorado State University (CSU) to develop an integrated radar facility that will expand the capabilities that either entity can currently provide. Both EOL and CSU support 10-cm, multiparameter Doppler radars (NSF/NCAR S-Pol and CSU CHILL radars, respectively) that will be jointly operated in this new partnership, as well as other, smaller radars. A key objective of this partnership is to create a national test bed that other institutes and agencies can use for research and education.

Initial activities have been identified, including plans to implement (on the S-Pol Radar) the new digital receiver and transmit waveform synthesis hardware that have recently been installed and tested on CHILL, and the identification of software development required to integrate both facilities. The radars will be in continuous operation, and university students will be encouraged to propose small (less than 20-hour) projects for collecting thesis-related research data.

As of 2009, remote operation between deployments will begin for NCAR’s S-band Dual Polarization Doppler Radar (S-Pol), a state-of-the-art polarimetric weather radar, ensuring wider community access to S-Pol. Remote operation capability will also be realized with VCHILL (Virtual CHILL), CSU’s dual-polarized S-band radar.

Shared engineering and scientific activities between CHILL and NCAR/EOL S-band research radars will provide the scientific community with a number of opportunities that range from conducting scientific field experiments to

Secure within its gondola, the Sunrise telescope hangs suspended from its crane-like launch vehicle at dawn.

Slender hoses, blown into arcs by the wind, partially fill the balloon with helium before the Sunrise Solar Telescope launch. A large portion of the balloon is left unfilled so it can expand as it ascends into the stratosphere, where air pressure is considerably lower.

The Sunrise gondola being retrieved after landing in a flat, newly harvested wheat field. The gondola sustained a little damage to the roll cage but the telescope remained unharmed.

Video: *A video camera onboard the Sunrise Solar Telescope shows Earth's surface. The balloon, about two hours into flight, is cruising at about 120,000 feet over the U.S. Southwest.*

maintaining a long-term mesoscale test bed for assessing radar and other instruments, data quality procedures, sensor integration, numerical models, networking capabilities and derived products. Additionally, this partnership will provide a framework or magnet for local field campaigns, and provides a method for offering continuous hands-on educational opportunities.

Facilities Database

The NSF Facilities database was launched in March 2008 and continues to garner input from the community. This interactive Web-accessible database is intended to provide descriptive information on atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science and related communities.

Observing Facilities Assessment Panel

Twice a year, EOL hosts the Observing Facilities Assessment Panel (OFAP) and coordinates among panel members, PIs, facility providers, EOL staff and NSF to assess the feasibility and cost of NSF-funded field projects. The OFAP is an NCAR-driven community process that provides technical and operational assessment of requests associated with the use of NSF's Lower Atmospheric Observing Facilities (LAOF) in the field. The panel, which is composed of a diverse pool of scientists with broad experience in observational studies of earth system sciences, meets at NCAR to provide valuable feedback and evaluation to facility managers and the user community concerning experiment design, data management issues and the appropriate and efficient use of NSF resources as related to a specific field campaign. The comments and technical evaluation presented by the OFAP, together with feasibility analyses and cost estimates provided by Facility Managers, are considered before a final decision is made by NSF whether to approve a project.

Field Projects

Sunrise Solar Telescope

In a landmark test flight in October 2007, NCAR and a team of research partners successfully launched a solar telescope to an altitude of 120,000 feet, borne by a balloon larger than a Boeing 747 jumbo jet. The test clears the way for long-duration polar balloon flights beginning in 2009 that will capture unprecedented details of the Sun's surface.

The Sunrise project has presented engineers with a number of extraordinary challenges. The balloon is designed to carry 6,000 pounds of equipment, including a 1-meter (39-inch) solar telescope, additional observing instruments, communications equipment, computers and disk drives, solar panels, and roll cages and crush pads to protect the payload on landing. The equipment must be able to withstand dramatic changes in temperature, and the steel and aluminum gondola, built by EOL's Design and Fabrication Services, cannot vibrate in ways that could interfere with the operation of the telescope.

One of the most difficult aspects of the engineering work was to design the gondola in such a way that the telescope in flight would remain focused on a specific and relatively tiny area of the Sun, even while twisting on a soaring balloon for a week or longer during the full-scale research missions. To accomplish this, the gondola includes both a torque motor drive to keep the gondola and telescope in the correct orientation and a precision guiding and compensation system to constantly correct the telescope's aim.

Because the gondola is designed to withstand considerable force when it lands, the instruments can be launched on repeated missions.

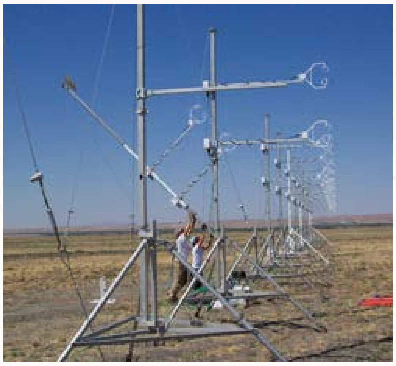
Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)

ARCTAS is part of the international International Polar Year/POLARCAT arctic field program for atmospheric composition. The ARCTAS experiment took place during two 1-month aircraft deployments, in March-April and June-July 2008. The primary platform was the NASA DC-8, from which EOL's new Difference Frequency Generation (DFG) spectrometer acquired ambient measurements of formaldehyde, an important trace gas involved in ozone and hydrogen radical production. The spring deployment targeted arctic

More Photos and movies from the Sunrise Launch.

Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)

The suns sets on another hot day in the San Joaquin Valley, CA during the Advection Horizontal Array Turbulence Study (AHATS).



Setting up for AHATS: An array of sonic anemometers perched on tripods collected data on atmospheric turbulence close to the earth's surface.

University of Miami students launching a radiosonde next to the ISS-MAPR trailer at the University's CSTARS satellite receiving station.

EOL's Integrated Sounding System set up at the University of Miami for CPS.

haze, anthropogenic pollution in general, stratosphere-troposphere exchange, and sunrise photochemistry. The summer deployment targeted boreal forest fires, stratosphere-troposphere exchange, and summertime photochemistry.

The Ice In Clouds Experiment (ICE-L)

EOL provided the NSF/NCAR C-130 for the Ice In Clouds Experiment (ICE-L) between November 11 and December 16, 2007. Researchers conducted 12 flights from the Rocky Mountain Municipal Airport in Broomfield Colorado to sample upslope conditions in the northeast Colorado/southeast Wyoming area. in November 2007. The scientific goal of the project was to show that under given conditions, direct ice nucleation measurements, or other specific measurable characteristics of aerosols, can be used to predict the number of ice particles formation by nucleation mechanisms in selected clouds. The investigators seek improved quantitative understanding of the roles of thermodynamic pathway, location within the cloud, and temporal dependency.

HEFT/GISMOS

See section on Installing the initial instrument suite and beginning operations for the GV.

Stratosphere-Troposphere Analyses of Regional Transport (START-08)

See section on Investigating the Interactions of the Atmosphere, the Broader Earth System and Human Society.

Terrain-influenced Monsoon Rainfall Experiment (TIMREX)

See section on Investigating the Interactions of the Atmosphere, the Broader Earth System and Human Society.

Advection Horizontal Array Turbulence Study (AHATS)

EOL's In-situ Sensing Facility deployed one of each In-situ Surface Flux System and Integrated Sounding System for deployment to the San Joaquin Valley, CA for AHATS, lead by C. Tong from Clemson University, the fourth in the series of Horizontal Array of Turbulence Studies (HATS). This series of experiments aims to improve large-eddy simulations (LES) of turbulence close to the Earth's surface, by collecting data that can be spatially filtered into scales that can be simulated by LES and those that must be parametrized. AHATS built upon previous field programs (HATS, OHATS, CHATS). The first 3 experiments all used two horizontal lines of 9 sonic anemometers to provide cross-stream filtered velocity and temperature statistics.

AHATS returned to the original HATS site, but a third line was added upwind to provide spatial differences in the streamwise direction. In addition, two horizontal lines of turbulent pressure sensors were added to AHATS to investigate, for the first time, resolved and parameterized pressure correlation terms in the turbulence transport equations. Those capabilities were unavailable in previous field programs but are important for understanding the SGS turbulence and for testing SGS models that are based on the SGS physics.

THORPEX Pacific Asian Regional Campaign (T-PARC)

See section on Improving the Prediction of Weather, Climate and other Atmospheric Phenomena.

Clouds and Precipitation Study (CPS)

CPS took place at the University of Miami Rosential School of Marine and Atmospheric Science (RSMAS). Observations from a 94 GHz Doppler radar with supporting observations from lower-frequency radars and in situ instruments will be used to improve knowledge and understanding of key cloud and precipitation processes and provide high resolution observations needed to evaluate cloud resolving and explicit cloud models and techniques for measuring precipitation remotely. The focus is on both shallow and deep convection and stratiform precipitation observed in a tropical/subtropical environment. Bruce Albrecht from the University of of Miami will use the ISS/MAPR to conduct his measurements from 1 August through 30

September 2008 in Southern Florida. RSMAS and collaborators are deployed a variety of systems including their W-Band and X-Band radars and disdrometers. The site for the project was the university's CSTARS satellite receiving station in southwest Miami, which has impressive 11-meter and 20-meter dishes tracking meteorological and other satellites.

During the project Tropical Cyclone Fay passed north of the site, providing plenty of the tropical storm rain-bands data. The MAPR radar's fast wind profiling capability measured strong wind gusts aloft, occasionally around 100 mph. Fortunately it was calmer near the surface and the ISS survived with just a few rain-water leaks into our container.

The Physics Of Stratocumulus Tops (POST)

EOL's CDS provided data management support in the form of assistance with the pre-field data management planning, an on-line Field Catalog to collect data products for operational decision making during the field phase of the The Physics Of Stratocumulus Tops (POST) Field Project, and established a long-term data and metadata archive following the field phase. The goal of POST was to study the stratocumulus (Sc) clouds found frequently at the top of the maritime stratocumulus-topped boundary layer off the coast of California. The POST field study took place from 14 July to 8 August 2008, with the Twin Otter aircraft operating out of the airport at Marina, CA (just north of Monterey).

Future Field Deployments

Vamos Ocean-Cloud-Atmosphere-Land Study (VOCALS)

The first field campaign in FY 2009, VOCALS will focus on a better understanding of physical and chemical processes central to the climate system of the southeast Pacific (SEP). VOCALS will target interactions between clouds, aerosols, marine boundary layer processes, upper ocean dynamics and thermodynamics, coastal current and upwelling, large-scale subsidence and regional diurnal circulations. The field experiment is driven by the need for improved model simulations of the coupled climate system in both the SEP and over the wider tropics and subtropics. The lead PI is Rob Wood from the University of Washington. The project, which will involve the NSF/NCAR C-130 and the GPS Advance Upper-Air Sounding system (GAUS), will take place from 15 October through 15 November 2008 in Northern Chile.

Collaborative Research: HIAPER Pole-to-Pole Observations (HIPPO) of Carbon Cycle and Greenhouse Gases Study

Flying from the arctic to the antarctic, spanning the globe to cover different seasons during different years. The "Collaborative Research: HIAPER Pole-to-Pole Observations (HIPPO) of Carbon Cycle and Greenhouse Gases Study" will measure cross sections of atmospheric concentrations approximately pole-to-pole, from the surface to the tropopause, four times during different seasons over a 2 year period. A comprehensive suite of atmospheric trace gases pertinent to understanding the Carbon Cycle will be measured. HIPPO will transect the mid-Pacific ocean and return either over the Eastern Pacific, or over the Western Atlantic. The program will provide the first comprehensive, global survey of atmospheric trace gases, covering the full troposphere in all seasons and multiple years. EOL will provide the NSF/NCAR GV for this project, and the PI is Prof. Steve Wofsy from Harvard University.

Wyoming Airborne Integrated Cloud Observations (WAICO)

The overall goal of WAICO is to explore a new integrated airborne cloud observation platform by installing and testing elastic lidar, microwave radiometer, and the Wyoming Cloud Radar from the UW King Air along with in situ cloud probes and collecting data for cloud microphysical properties algorithm development and products validation. The project will take place in Laramie Wyoming from February to April 2009 and the PI is Zhien Wang from the University of Wyoming.

Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX) II

In spring 2009, VORTEX II will investigate tornadogenesis, tornado structure and the relationships between tornados, their parent thunderstorms and the larger-scale environment by using an armada of ground-based, mobile measurement systems including the DOWs, Mobile GPS Advanced Upper-Air Sounding System and Mobile Integrated Sounding System. The PI is Josh Wurman from the Center for Severe Weather.

CONCORDIASI

EOL will deploy the Driftsonde in support of Concordiasi, a multi-national project involving Météo-France, Centre National d'Etudes Spatiales (CNES), (French Polar Institute) IPEV, Italian Programme of National Research in Antarctica (PNRA), Institut national des sciences de l'Univers (CNRS/INSU), NSF, NCAR, Concordia consortium, University of Wyoming, Purdue University and University of Colorado. The Driftsonde will be deployed from August - November 2009, or Austral Spring, which is autumn in the northern hemisphere. Within the framework of the International Polar Year (IPY), the Concordiasi field experiment will take place in Antarctica. The most outstanding goals are:

1. To improve the assimilation of satellite data over the southern polar region, with an emphasis on the data provided by hyperspectral sounders, such as AIRS and IASI. The enhancements in the skill of weather predictions and accuracy of climate records resulting from such improvements will contribute to the IPY's legacy.
2. To assess the improvements brought by these analyses and forecasts on chemical-transport models and on the fine-scale description of meteorological processes.
3. To improve the understanding of the stratospheric ozone budget looking into the interaction of ozone observations and stratospheric nitric acid trihydrate (NAT) clouds, together with the improved characterization of the polar vortex.
4. To advance the understanding of the Earth system by examining the two-way interactions between the climates of Antarctica and lower latitudes.

Up to sixteen Driftsondes will be deployed from McMurdo station and will drop the new MIST dropsondes on command measuring atmospheric parameters over Antarctica. Some of the Driftsondes will be dedicated to chemistry and microphysics and will carry flight-level instruments, including temperature, pressure and ozone sensors, particle counters and GPS receivers.

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GOAL 5, PRIORITY 3: INSTALLING THE INITIAL INSTRUMENT SUITE AND BEGINNING OPERATIONS FOR THE GV

A relatively new addition to the suite of research tools that NCAR provides the wider science community, GV instrument installation and testing continued in FY08. EOL is fast approaching a time where we can realize the full capabilities of the GV. In FY2009, Collaborative Research: HIAPER Pole-to-Pole Observations (HIPPO) will use the GV's long-range capabilities to make global scale measurements, and we will use many HAIS instruments to do this.

In FY2008 EOL completed the remaining electronic design, mechanical design, fabrication and subsystem testing of the HIAPER cloud radar (HCR). This airborne millimeter-wavelength radar will provide remote sensing capabilities to the GV aircraft. System integration began in FY08 and will be complete in FY09, with flight-testing to be completed in mid FY 2009.

See other priorities in this goal:

- Enabling Innovative Field Experiments and Field Measurement Campaigns
- Installing the Initial Instrument Suite and Beginning Operations for the GV

HIAPER Airborne Instrumentation Solicitation (HAIS) Instrumentation

HAIS consists of 14 instrument projects supported as part of the initial GV aircraft acquisition project, and they are good example of partnership with community. HAIS instruments foster expansion of the research capabilities that EOL can provide to Earth system investigators. With these new instruments in place, researchers will be able to conduct vital studies in currently inaccessible regions of the Earth's atmosphere.

Delivery

As of October 2008 the NCAR Small Ice Detector, Version 2 (SID-2H), The Harvard Quantum Cascade Laser Spectrometer (QCLS), the Purdue University GNSS Instrument System for MultiStatic and Occultation Sensing (GISMOS), the JPL Microwave Temperature Profiler (MTP), the University of Miami Automated Whole Air Sampler (AWAS), the Southwest Sciences Vertical Cavity Surface Emitting Laser (VCSEL) hygrometer, the NCAR HIAPER Atmospheric Radiation Package (HARP), and the NCAR fast ozone instrument have been received. AWAS, MTP, SID-2H, VCSEL, QCLS and Fast Ozone have already been flown and they are succeeding, making valuable measurements in support of project science objectives.

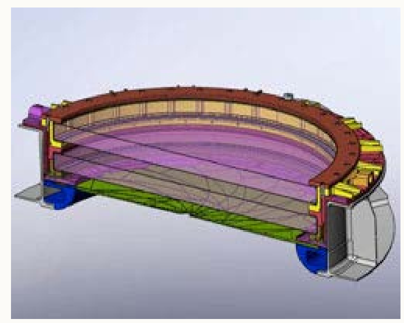
EOL is on track to accept the remainder of the HAIS instruments by 2009.

Testing

EOL/RAF supported a flight test program in February 2008 that was used for the joint purposes of testing new instrumentation and preparing for the START-08 field project that followed. In those two projects, the following HAIS instruments were operated successfully: the Harvard Quantum Cascade Laser Spectrometer, the Purdue GPS receiver (GISMOS), the JPL Microwave Temperature Profiler (MTP), the University of Miami Automated Whole Air Sampler (AWAS), the Southwest Sciences Vertical Cavity Surface Emitting Laser (VCSEL) hygrometer, and the NCAR/ACD fast ozone instrument. We continue to plan for another test program to be conducted in the summer of 2009, when many of the remaining HAIS instruments will be flown.

Related Links or Images

Image taken from the GV wing-mounted camera during the HAIS Instrument flight testing, February 2008



A design for the GV Optical Port. This design is for the port on the bottom of the GV aircraft - notice the green "iris" in the bottom of the structure. Upon takeoff and landing, this iris could close to protect the window from getting pelted with debris from the landing gear.

DFS staff stand in front of a complete GV Wing Pod. Notice the windows, that were being cut in the photo above, in the central portion of the pod.

Wing Pod Installation

In FY2008 EOL installed, tested, and obtained certification for six under-wing pylons carrying a total of 12 instrument canisters. We have now undertaken a similar project to install and test two larger (20" diameter) under-wing instrument pods, and have developed a plan and contract with Gulfstream Aerospace Corporation to accomplish this project.

The pods are designed and are in the process of being built by EOL's Design and Fabrication Services (see entry on Design and Fabrication Services). Our target is to complete this installation by July 2009. These wing pods will be used to carry the HIAPER cloud radar, now being designed and built by EOL's Remote Sensing Facility (RSF), and some chemistry instruments that need direct exposure to the airstream.

Optical View Ports

See entry on Design and Fabrication Services.

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ABOUT THIS GOAL: IMPROVE UNDERSTANDING OF THE ATMOSPHERE, THE EARTH SYSTEM, AND THE SUN

Priority 1: Exploring Atmospheric, Earth System, and Solar Processes, Variability and Change

Priority 2: Investigating the Interactions of the Atmosphere, the Broader Earth System and Human Society

Developing a fuller understanding of the complex interactions among the Earth's atmosphere, oceans, land masses, ice masses, and biosphere; the interconnection of human activities with the Earth's physical, chemical, and biological processes is a major focus of our national center. EOL is tasked mainly with the mission to develop innovative instrumentation and data acquisition technology and lead scientific campaigns that make such understanding possible. Even so, EOL scientists often find themselves in the thick of data analysis that contribute directly to the goal of improving our understanding of the atmosphere and earth system, specifically by investigating the interactions of the atmosphere and the broader earth system.

Priority 3: Improving the Prediction of Weather, Climate and other Atmospheric Phenomena

Over the last several decades, the skill of numerical weather prediction is generally considered to have increased at an average rate of about one day per decade. Thus, the skill of today's four-day forecast is equivalent to the skill of a three-day forecast of a decade earlier. The rate of improvement is even slower for the forecast variables needed most by society, such as the prediction of heavy rainfall. This relatively slow, linear rate of improvement is not sufficient to keep place with the demand for accurate weather information in the world today, where an exponentially growing world population places an ever-increasing number of people in areas at risk for weather disasters.

- Link to specific accomplishment page
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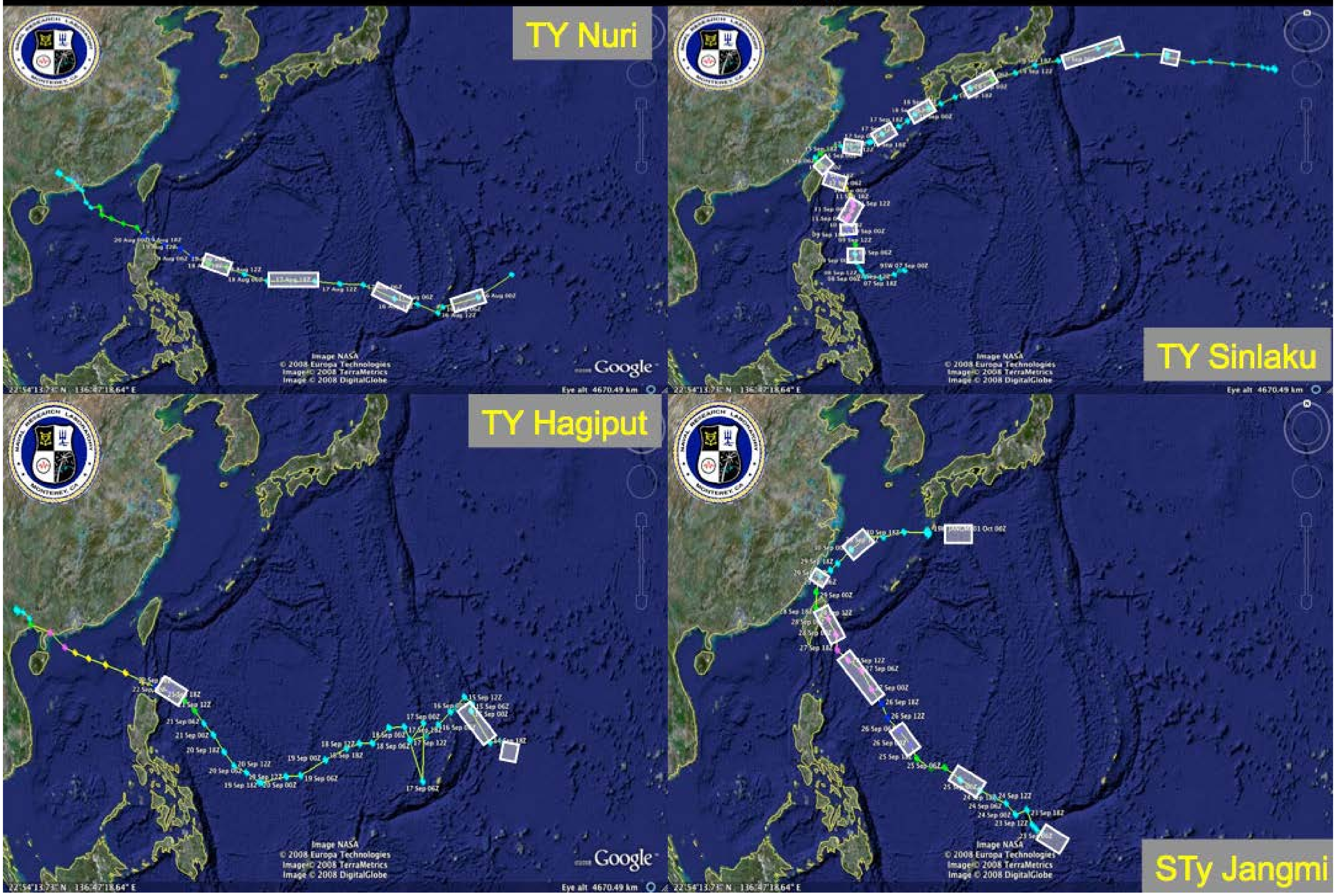
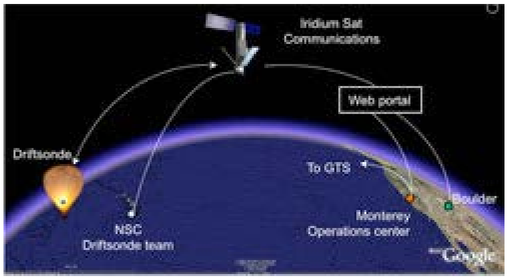
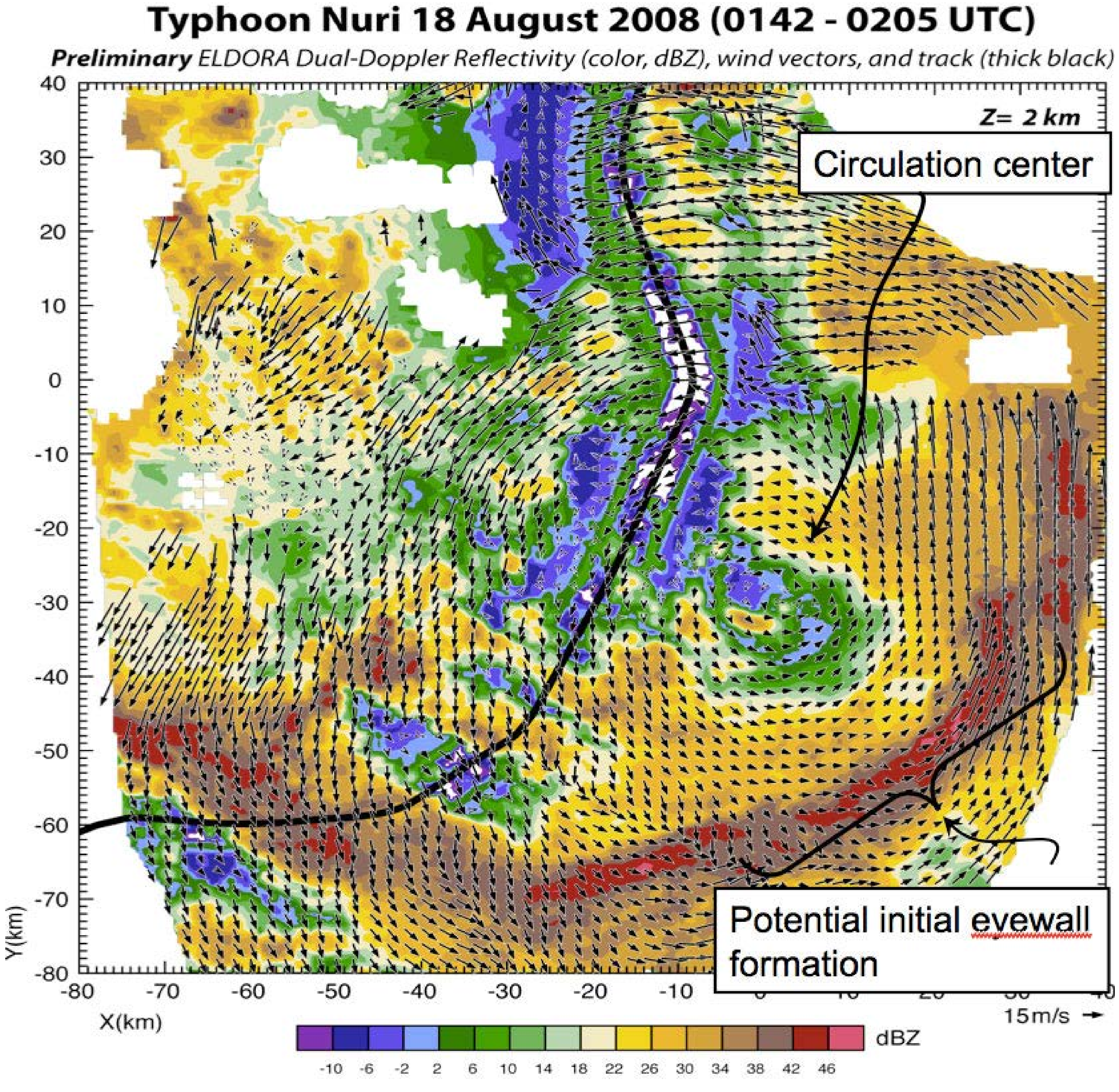
T-PARC/TCS-08 Typhoons

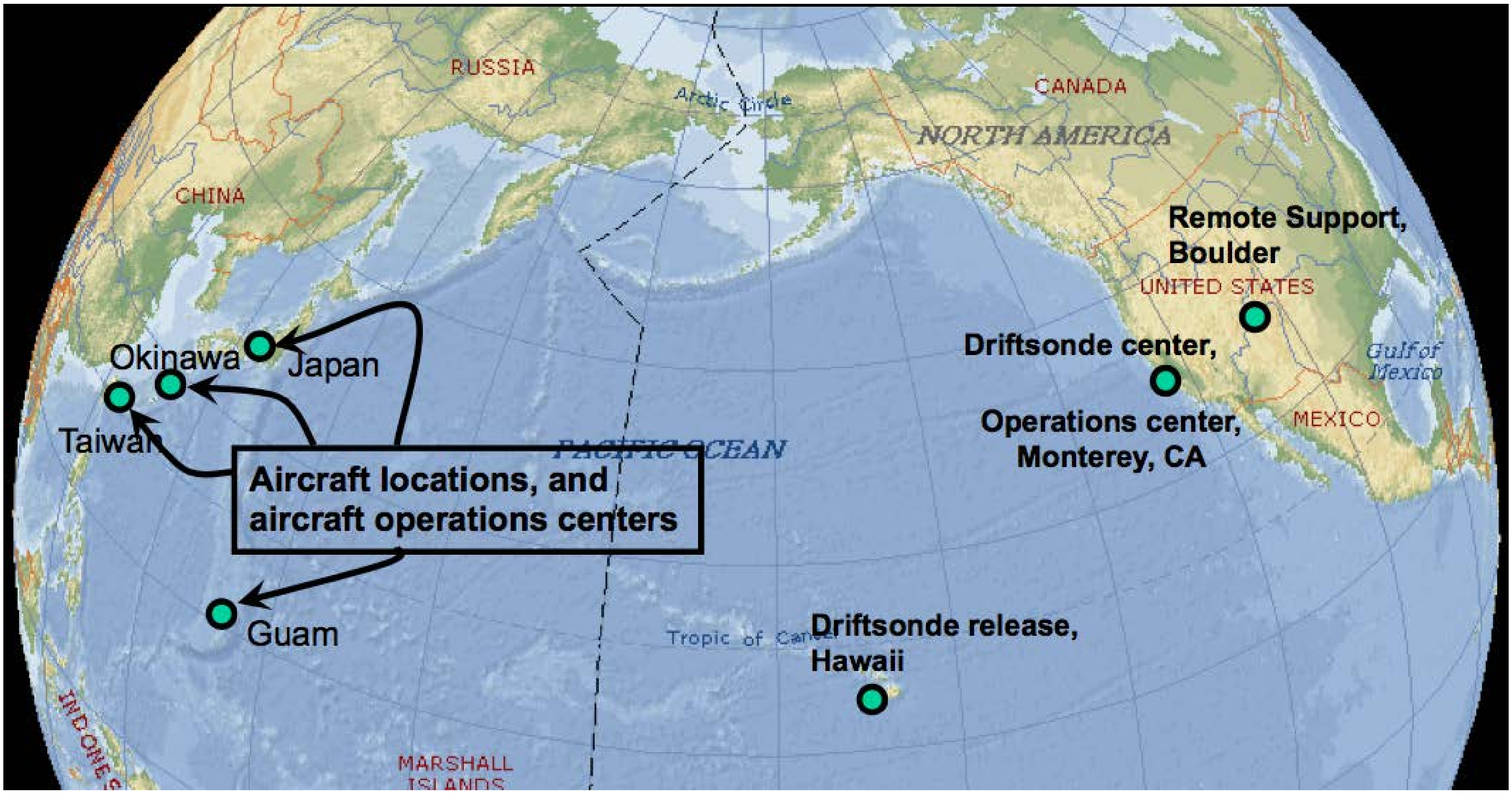




http://www.nar.ucar.edu/2008/EOL/images/driftsonde-operationssm.jpg[7/6/2015 3:31:17 PM]



Typhoon Nuri 18 August 2008 (0142 - 0205 UTC)
Preliminary ELDORA Dual-Doppler Reflectivity (color, dBZ), wind vectors, and track (thick black)
Z= 2 km
Circulation center
Potential initial eyewall formation
Y(km)
X(km)
15m/s
dBZ


RUSSIA
Arctic Circle
CANADA
NORTH AMERICA
CHINA
Remote Support, Boulder
UNITED STATES
Okinawa
Japan
Driftsonde center,
Gulf of Mexico
Taiwan
Operations center, Monterey, CA
MEXICO
PACIFIC OCEAN
Aircraft locations, and aircraft operations centers
Guam
Driftsonde release, Hawaii
MARSHALL ISLANDS

ABOUT THIS GOAL: INCREASE SOCIETAL RESILIENCE TO WEATHER, CLIMATE, AND OTHER ATMOSPHERIC HAZARDS

Priority 2: Building Capacity for Coping with Weather and Climate Hazards

To help society cope with weather and climate hazards, decision makers must be made aware of threats and vulnerabilities so that options of mitigation and adaptation can be developed. EOL has contributed to this strategic priority in 2008 by enabling hurricane specialists, for the first time, to continually monitor the trend in central pressure as a dangerous storm nears land with the VORTRAC (Vortex Objective Radar Tracking and Circulation) algorithm.

- VORTRAC

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ABOUT THIS GOAL: CULTIVATE A SCIENTIFICALLY LITERATE AND ENGAGED CITIZENRY AND A DIVERSE AND CREATIVE WORKFORCE,

Priority 1: Engaging a Broader and More Diverse Community in the Atmospheric and Geosciences

EOL recognizes that the overall health of our institution lay in ensuring that those with aptitude and determination have opportunities in the atmospheric science and engineering disciplines, and that they are welcomed and nurtured, regardless of gender, ethnic background, nationality, or physical ability. EOL addresses this NCAR strategic priority in a number of ways, including our highly successful Student Engineering program, now in its eighth year, our hiring practices, our EOL Women's Professional Development Group and our Education and Outreach efforts that reach the general public.

Priority 2: Supporting and Enhancing Formal Science Education at all Levels

EOL attaches a high value to Education and Outreach and currently infuses all EOL programs, whether in the laboratory or field with an E&O component. EOL encourages a general interest in earth science, and particularly tries to foster advanced understanding in the science and process of atmospheric research measurements. EOL accepts its responsibility to encourage the growth of the next generation of observational engineers and scientists, and continually seeks new ways to do this. Our major event in 2007 that supports this priority was our first-ever NSF Facilities Users' Workshop.

Priority 3: Maintaining an Innovative and Creative Workplace

EOL knows we cannot fulfill our scientific, engineering and service objectives without capable, intelligent, dedicated and effective personnel. We find a variety of ways to keep our staff challenged, including our pilot sabbatical program for scientific staff.

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ABOUT THIS GOAL: PROVIDE ROBUST, ACCESSIBLE, AND INNOVATIVE INFORMATION SERVICES AND TOOLS

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Phasellus vehicula massa eu eros. Suspendisse tristique hendrerit felis. Donec sollicitudin. Aliquam tempor urna ac nunc. Aliquam et eros. Donec sit amet nisl. Fusce fermentum felis elementum erat. Suspendisse massa magna, ultrices ac, pretium et, hendrerit vel, leo. Aliquam luctus libero eu eros. Vivamus vestibulum eros porttitor justo.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

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ABOUT THIS GOAL: PROVIDE WORLD-CLASS GROUND, AIRBORNE, AND SPACE-BORNE OBSERVATIONAL FACILITIES AND SERVICES

NCAR's Earth Observing Laboratory provides state-of-the-art atmospheric observing systems and support services to the university-based research community for climate and weather research. Among the many services and tools provided to our user community, is the exciting NSF-owned GV (formerly known as HIAPER), the world's most advanced research aircraft. EOL also operates the NSF/NCAR C-130 and a suite of airborne radars, and radiometers. Among the many surface-based systems are several mobile radars and a wide variety of in situ instruments.

- Enabling Innovative Field Experiments and Measurement Campaigns
- New Instrumentation
- Installing Initial Instrument Suite and Beginning Operations of the NSF/NCAR G-V Aircraft

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NCAR'S STRATEGIC GOAL'S

NCAR's Strategic Plan, ***NCAR as an Integrator, Innovator and Community Builder***, outlines five Strategic Goals, and the priorities for achieving each. In the following sections we report on progress made in FY 2008 toward each scientific goal and priority.

NCAR's has 5 Strategic Goals. Follow the links below to learn about EOL's contribution to these goals.

1. Improve understanding of the atmosphere, the Earth system, and the Sun,
2. Increase societal resilience to weather, climate, and other atmospheric hazards,
3. Cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce,
4. Provide robust, accessible, and innovative information services and tools, and
5. Provide world-class ground, airborne, and space-borne observational facilities and services.

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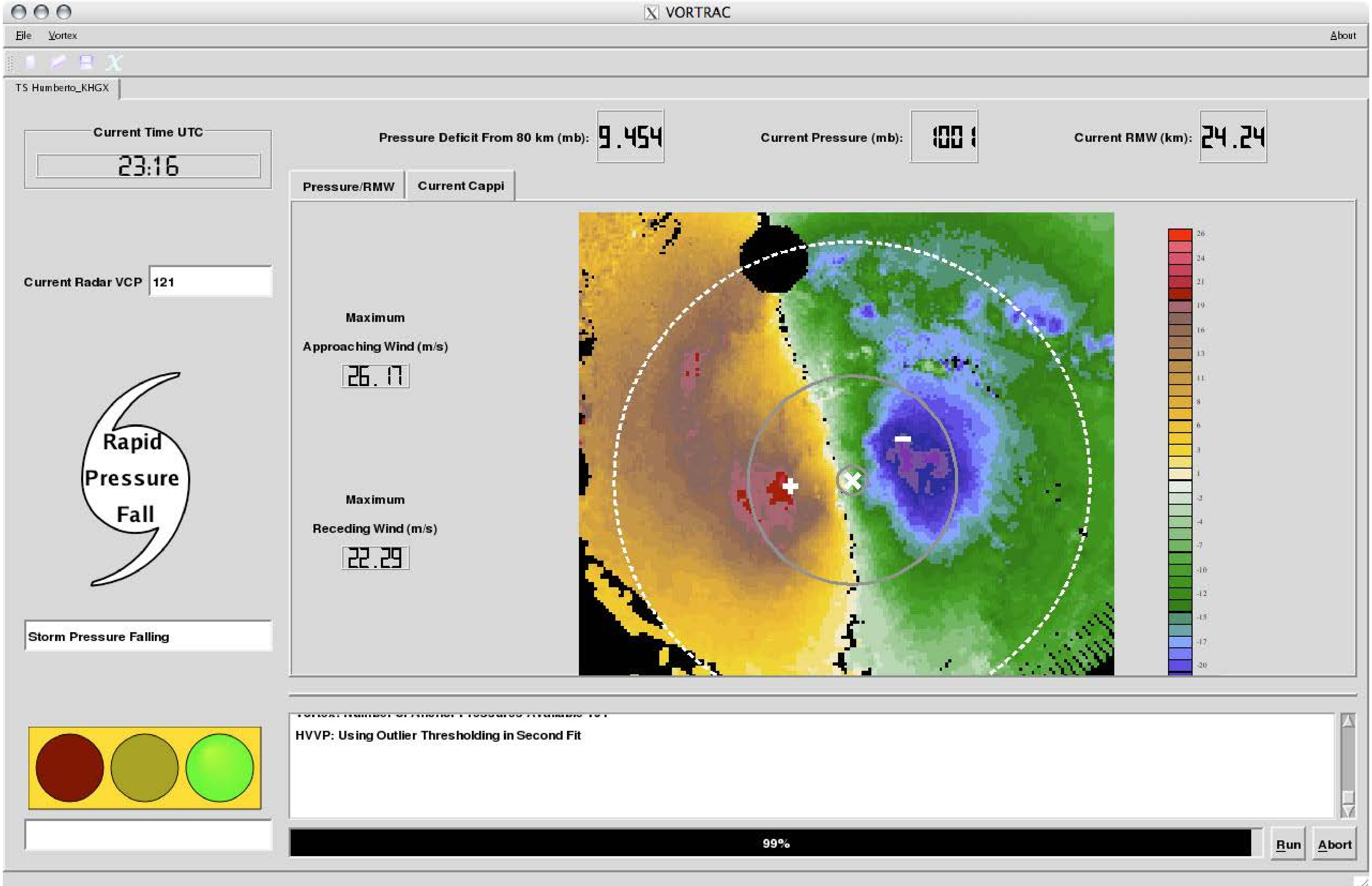
VORTRAC
File
Vortex
About
TS Humberto_KHGX
Current Time UTC
23:16
Pressure Deficit From 80 km (mb):
9.454
Current Pressure (mb):
1001
Current RMW (km):
24.24
Pressure/RMW
Current Cappi
Current Radar VCP
121
Maximum
Approaching Wind (m/s)
26.17
Maximum
Receding Wind (m/s)
22.29
Rapid
Pressure
Fall
Storm Pressure Falling
HVVP: Using Outlier Thresholding in Second Fit
99%
Run
Abort

Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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ESSL LAR 2008: DIRECTOR'S MESSAGE

Dear Colleagues:

Guy Brasseur
NCAR Associate Director
Director, Earth and Sun Systems Laboratory

The Earth and Sun Systems Laboratory (ESSL) was established in October 2004 to develop an ambitious research program and to address some of the fundamental scientific questions that are directly related to major environmental challenges the world is facing. The overall objective of the Laboratory is *to perform fundamental studies of the dynamics of the Earth and Sun Systems across spatial and temporal scales, and to assess how natural forcing and human-driven perturbations affect the evolution of the Earth's Systems and ultimately the habitability of our planet.*

By performing an integrated study of the Earth and Sun Systems and the changes occurring in these systems, ESSL will provide key knowledge needed to develop a sustainable future for humankind and to respond to environmental crises such as climate change. Specifically, the Laboratory will study the fundamental processes that determine the evolution of the Earth and Sun Systems, develop the tools and community facilities needed to observe and analyze these processes, and to predict their evolution. This requires a full understanding of the processes that determine the variations in the Sun's radiative energy, of the mechanisms that determine the effects of solar radiation on the Earth's environment as well as of the interactions that exist between the physical, biological and chemical processes in the coupled atmosphere, land and ocean system. The ultimate goal is *to acquire the fundamental knowledge necessary to respond to global and regional environmental changes and to help societies to develop a sustainable future.*

The Earth and Sun Systems laboratory (ESSL) includes four scientific Divisions (the Atmospheric Chemistry Division (ACD), the Climate and Global Dynamics Division (CGD), the High Altitude Observatory (HAO), and the Mesoscale and Microscale Meteorology Division (MMM)) as well as the Institute for Integrative and Multidisciplinary Earth Studies (TIIMES).

As you will notice from the different detailed web pages that constitute the 2009 Annual Report, ESSL scientists accomplished a lot of exciting science in the last year. Substantial progress has been made in the development of the Community climate System Model (CCSM), and a new and improved version of this complex model will provide new climate projections for the next assessment of the Intergovernmental Panel for Climate Change (IPCC).

The development of the *Weather and Research Forecast Model* (WRF) has continued; this model is now used in many countries as a community tool by a large number of researchers in academic institutions and by operational weather forecast centers. New, exciting results are emerging from the observations made during the field campaign in Mexico City (MIRAGE/MILAGRO). The purpose of this project was to characterize the chemical/physical transformations and the ultimate fate of pollutants exported from large urban areas, and to assess the current and future impacts of these exported pollutants on regional and global air quality, ecosystems, and climate.

TIIMES was created to conduct and promote Earth science research across disciplines. The Institute promotes interactions for new and current initiatives associated with multidisciplinary Earth studies to be fostered, grown, and integrated. Beside managing cross-divisional Projects with large university participation, including the Biogeosciences initiative, the project on Water Across Scales, the Upper Troposphere/Lower Stratosphere initiative, and THORPEX, an international program aimed at improving weather forecasts, TIIMES started to plan for a major multidisciplinary field and modeling study called BEACHON, whose purpose is to better quantify the interactions between the physical climate and the biogeochemical systems in a water-limited environment.

ESSL has, of course, great plans for the future. In 2009, priority themes have been identified by the Laboratory:

The Earth as a System

- Prediction Across Scales and Earth Teleconnections
    - Decadal Global and Regional Climate Prediction
    - Nested Regional Climate Modeling

  - Towards Earth System Modeling
- Hydrosphere-Biosphere Interactions
- Polar Dynamics: Ice and Chemical Composition

The Sun as a System

- Towards an Integrated Model of the Sun
- Space Weather

In addition, the development of version 4 of the CCSM in preparation for the Intergovernmental Panel on Climate Change Assessment Report 5 (IPCC AR5) is on the agenda of the Laboratory. Another important priority is the development of a Nested Regional Climate Model (NRCM) to study the seamless transition between weather and climate processes. Implementation of *field observations* such as BEACHON, addressing interdisciplinary questions, including the interactions between dynamical, chemical, radiative and microphysical processes in the upper troposphere and lower stratosphere are also important priorities for the next years. Using field observations to improve model formulations and parameterizations is a key aspect of our research.

Guy P. Brasseur
NCAR Associate Director
Director, Earth and Sun Systems Laboratory

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ESSL LAR 2008: RESEARCH CATALOGS

ESSL Staff and Section Profiles By Division

- ACD - The Atmospheric Chemistry Division
- CGD - The Climate and Global Dynamics Division
- HAO - The High Altitude Observatory
- MMM - The Mesoscale and Microscale Meteorology
- TIIMES - The Institute for Integrative and Multidisciplinary Earth Studies

ESSL Individual Staff Profiles

INFORMATION KEY:
ACD: Group research reports and graphics
CGD: Summary of achievements and publication abstracts and graphics
HAO: Research summary and graphics
MMM: Publication abstracts and graphics
TIIMES: Research summary, graphics, news coverage, community service, presentation and publication lists

David Ahijevych: MMM

Caspar Ammann: CGD

Rebecca (Becky) Anderson: ACD - TIIMES

Eric Apel: ACD

Julie Arblaster: CGD

Avelino Arellano: ACD

David Bailey: CGD

Aaron Bansemer: MMM - TIIMES

Dale Barker: MMM

Kelley Barsanti: ACD

Mary Barth: ACD - MMM - TIIMES

Ramit bhattacharyya: HAO

Gordon Bonan: CGD - TIIMES

Mercy Borbor-Cordova: TIIMES

Esther Brady: CGD

Grant Branstator: CGD

James Bresch: TIIMES

Bruce Briegleb: CGD

Frank Bryan: CGD

Donald Lenschow: MMM - TIIMES

Samuel Levis: CGD - TIIMES

Keith Lindsay: CGD - TIIMES

Bruce Lites: HAO

Changhai Liu: MMM - TIIMES

Hanli Liu: TIIMES

Xiaoli Luan: HAO

Xianfang Ma: TIIMES

Keith MacGregor: HAO

Monica Madronich: ACD

Sasha Madronich: ACD

Natalie Mahowald: CGD - TIIMES

Kevin Manning: MMM

Daniel Marsh: ACD

Steven (Steve) Massie: ACD - TIIMES

Dallas Masters: ACD

Roy (Lee) Mauldin: ACD

Scott McIntosh: HAO

Daniel McKenna: ACD

George Bryan: MMM

Joan Burkepile: HAO

Sean Burns: MMM - TIIMES

Teresa Campos: ACD - TIIMES

Christopher (Chris) Cantrell: ACD - TIIMES

Terri Cantrell: TIIMES

Rit Carbone: TIIMES

Julie Caron: CGD - TIIMES

Rebecca Centeno: HAO

Fei Chen: TIIMES

Jack Chen: CGD

Yongsheng Chen: MMM

Michael Coffey: ACD

Dani Coleman: CGD

Andrew Conley: ACD

Aiguo Dai: CGD - TIIMES

Gokhan Danabasoglu: CGD

Christopher Davis: MMM - TIIMES

Giuliana de Toma: HAO

Alfred de Wijn: HAO

Merritt Deeter: ACD

Clara Deser: CGD

Mausumi Dikpati: HAO

Jimy Dudhia: MMM

Tiffany Duhl: ACD

Thomas Eden: ACD

David Edwards: ACD

Fred Eisele: ACD

Louisa Emmons: ACD

Yuhong Fan: HAO

John Fasullo: CGD

Mark Flanner: TIIMES

Frank Flocke: ACD - TIIMES

Peter Fox: HAO

Gene Francis: ACD

Alan Fried: TIIMES

Hans Friedli: ACD

Rolando Garcia: ACD

Gerald Meehl: CGD

Aimee Merkel: ACD

Travis Metcalfe: HAO

John Michalakes: MMM

Mark Miesch: HAO

Larry Miloshevich: MMM

Chin-Hoh Moeng: MMM

Mitchell Moncrieff: MMM - TIIMES

Denise Montzka: ACD

Hugh Morrison: MMM

Rebecca Morss: MMM

Bruno Nardi: ACD

Rich Neale: CGD - TIIMES

Doug Nychka: TIIMES

Keith Oleson: CGD - TIIMES

Steven Oncley: TIIMES

John Orlando: ACD

Bette Otto-Bliesner: CGD

Liwen (Laura) Pan: ACD - TIIMES

Mijeong Park: ACD - TIIMES

Edward Patton: MMM - TIIMES

Synte Peacock: CGD

Gabriele Pfister: ACD

Adam Phillips: CGD

Tanya Phillips: ACD

Jasna Pittman: TIIMES

Ilana Pollack: ACD

Lying Qian: HAO

William (Bill) Randel: ACD - TIIMES

Phil Rasch: CGD

Roy Rasmussen: TIIMES

Matthias Rempel: HAO

Jadwiga Richter: CGD - TIIMES

Teresa Rivas: TIIMES

Luciana Rizzo: TIIMES

Raymond Roble: HAO

David Rogers: TIIMES

Nan Rosenbloom: CGD

Peter Gent: CGD

Andrew Gettelman: ACD - CGD - TIIMES

Sarah Gibson: HAO

John Gille: ACD

David Gochis: TIIMES

Wojciech Grabowski: MMM

Jim Greenberg: ACD - TIIMES

Vanda Grubišić: TIIMES

Alex Guenther: ACD - TIIMES

Ethan Gutmann: ASP - TIIMES

Samuel Hall: ACD

William (Bill) Hall: ACD - TIIMES

Chris Halvorson: ACD

Cecile Hannay: CGD

James Hannigan: ACD

Peter Harley: ACD - TIIMES

Craig Hartsough: ACD

Sherri Heck: TIIMES

Andy Held: TIIMES

Irina Herdlinger: ACD

Peter Hess: ACD

Andrew Heymsfield: MMM - TIIMES

Kathy Hibbard: CGD

Alan Hills: ACD

Shu-Peng (Ben) Ho: ACD

Alma Hodzic: ACD

Elisabeth (Beth) Holland: ACD - TIIMES

Greg Holland: MMM

Marika Holland: CGD

Aixue Hu: CGD

James Hurrell: CGD

Kyoko Ikeda: TIIMES

Markus Jochum: CGD

Thomas (Tom) Karl: ACD - TIIMES

Rashid Khosravi: ACD

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David Schimel: CGD

Carl Schmidt: MMM - TIIMES

Andrea Sealy: TIIMES

Dennis Shea: CGD

Stephen Shertz: TIIMES

Richard (Rick) Shetter: ACD

Christine Shields: CGD

William Skamarock: MMM

Anne Smith: ACD

James (Jim) Smith: ACD - TIIMES

Lesley Smith: ACD - CGD

Piotr Smolarkiewicz: MMM

Chris Snyder: MMM

Stan Solomon: HAO

Guan Song: TIIMES

Britton Stephens: TIIMES

Peter Sullivan: MMM

Jielun Sun: MMM - TIIMES

Juanzhen (Jenny) Sun: MMM

Yongxin Tang: ACD

Haiyan Teng: CGD

Mukul Tewari: TIIMES

Peter Thornton: CGD - TIIMES

Xuexi Tie: ACD

Simone Tilmes: ACD - TIIMES

Mari Titcombe: ACD

Robert Tomas: CGD

Kevin Trenberth: CGD - TIIMES

Joe Tribbia: CGD

Stanley Trier: MMM - TIIMES

Andrew Turnipseed: ACD - TIIMES

John Tuttle: MMM - TIIMES

Geoff Tyndall: ACD

Kirk Ullmann: ACD

Mariana Vertenstein: CGD

Joseph Klemp: MMM

Joanie Kleypas: TIIMES

David Knapp: ACD

Charles Knight: MMM

Edward Kosciuch: ACD

Charles Krinsky: ACD

Masahito Kubo: HAO

Ying-Hwa (Bill) Kuo: MMM - TIIMES

Arlene Laing: MMM - TIIMES

Jean-Francois Lamarque: ACD

William Large: CGD

John Latham: MMM

Peter Lauritzen: CGD

David Lawrence: CGD - TIIMES

Yen-Huei (Jeff) Lee: ACD

Julia Lee-Taylor: ACD - TIIMES

Margaret LeMone: MMM - TIIMES

Francis Vitt: ACD

Junhong Wang: TIIMES

Wei Wang: MMM

Warren Washington: CGD

Andrew Watt: TIIMES

Andrew (Andy) Weinheimer: ACD - TIIMES

Morris Weisman: MMM

Christine Wiedinmyer: ACD - TIIMES

Tom Wigley: CGD

Dave Williamson: CGD

Mike Wiltberger: HAO

Helen Worden: ACD

Qingnong Xiao: MMM

Stephen Yeager: CGD

Valery Yudin: ACD

Jun Zhao: ACD

Wengang Zheng: ACD

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ESSL LAR 2008: STRATEGIC GOAL #1, PRIORITY #1

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #1, Improve understanding of the atmosphere, the Earth system, and the Sun. This Strategic Goal encompasses four Strategic Priorities, each of which is dependent on the efforts and accomplishments of ESSL staff.

ESSL developed an action plan with seven priority themes which involve direct partnerships with the university community and contribute directly to the ESSL Strategic Vision and to several priority items of the NCAR Strategic Plan.

ESSL's seven priority themes:

1. Climate projection, with emphasis on short-term prediction.
2. Biosphere-Atmosphere-Hydrosphere interactions and specifically development of BEACHON Project (Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, Hydrology, Organics and Nitrogen).
3. Water system research, specifically the development of the Society, Water, Atmosphere and Natural Systems Project (SWANS).
4. An advanced Weather Research and Forecasting system, specifically the development of the Hurricane Intensity and Forecasts (HiFi) Project.
5. Space Weather, specifically the development of the Coronal Solar Magnetism Observatory Project (COSMO).
6. Chemical Weather, including interpretation of observed data gathered during the Megacity Impact on Regional and Global Environments (MIRAGE) campaign, and the development of a capability for chemical data monitoring and prediction.
7. Prediction across scales, specifically the development of an advanced next-generation, climate-weather modeling system and an integrated Earth system model of intermediate complexity.

Goal # 1, Strategic Priority #1: Exploring atmospheric, Earth system, and solar processes, variability, and change, is defined in the NCAR Strategic Plan as follows: "Developing a better understanding of atmospheric, Earth system, and solar processes, as well as the variability and change associated with these processes....Exploration of these "Priority 1" areas focuses on three key activities: simulating the Earth system's natural variability, investigating the Sun's magnetic-flux eruptions, and understanding effects of gravity waves, including related interactions between the upper troposphere and lower stratosphere."

This NCAR priority, driven by ESSL's themes 2, 5, 6, & 7, is critical to achieving NCAR's first strategic goal.

The section below describes specific research conducted by ESSL staff relevant to Priority 1. The major ESSL activities in this area are studies of paleoclimate, solar dynamo and solar cycle, chemistry and dynamics of the UTLS and middle and upper atmosphere, solar magnetic flux emergence and CME initiation, global air quality, the impact of environmental changes on tropical cyclones, climate variability, and various aspects of the solar interior, the lower solar atmosphere, and the solar corona and wind.

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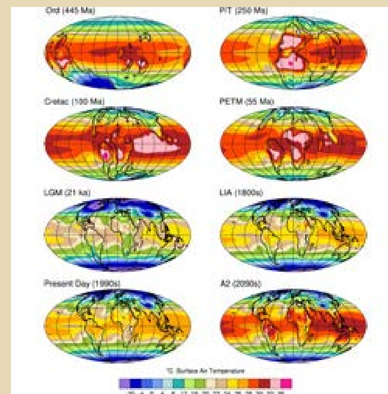
12. MHD physics of the solar corona and wind - HAO
13. Chemistry and dynamics of the middle and upper atmosphere - ACD
14. UTLS dynamics, trends, and composition - ACD
15. Gravity waves - TIIMES
16. Weather Research and Forecast model coupled with Chemistry (WRF-Chem) - MMM
17. Stratospheric ozone recovery [Whole-Atmosphere Community Climate Model (WACCM)] group - ACD
18. WACCM - ACD
19. Intense photochemistry in the Antarctic troposphere - ACD
20. Severe atmosphere convection - MMM
21. Intraseasonal/tropical climate variability - CGD
22. RT/MHD modeling of the solar surface layers - HAO

Paleoclimate

Overview



High resolution figure

Paleoclimates offer a unique perspective to understand both Earth's climate sensitivity and stability. Observational data tell us that Earth has experienced a wide range of climates over various time scales, and that transitions in Earth's climate can take place rapidly. We know that many of these past climates were determined by changes in external forcing factors. To the extent that climate models can reasonably simulate past warm and cold climates, we gain confidence that the models can be used to study Earth's future climate.

A strong test of the Community Climate System Model (CCSM) is to simulate past climate against records from ice cores, tree rings, and other proxy data. Magnitudes and rates of past change also provide an important context for future climate changes. Within ESSL, we are exploring past changes over many different time periods: from the distant geologic past, with radically different continental configurations, when the Earth's surface temperature and latitudinal gradients were significantly different from present and levels of atmospheric carbon dioxide, methane, and other greenhouse gases reached levels up to ten or more times present levels; the last million years, when the Earth experienced a waxing and waning of ice ages and levels of atmospheric carbon dioxide, methane, and other greenhouse gases during the ice ages were reduced by half or more from present levels; and the last few millennia with colder periods extensively documented in the proxy record associated with solar fluctuations and volcanic eruptions. Each of these geologic periods gives us an improved understanding of the natural variability of the Earth system and our ability to model feedbacks in the climate system. By comparing climate simulations of Earth's past to the data from geological and geochemical archives, we can evaluate the accuracy of climate models such as CCSM that are used to look at Earth's future. At the same time, geologists have started to use CCSM to understand how their specific data can be understood in a more large scale, dynamical context. CCSM has become a valuable partner to field-based geological research.

Recent Accomplishments

CCSM has been applied to all these different time periods. The Late Ordovician (445 Ma) was a time of elevated carbon dioxide, but extremely cold climates. The first major extinction on Earth took place at this time. The CCSM3 has been configured to simulate the climate of this time period, in order to study the role that climate played in the mass extinction. The model will also be used to explore the growth of large continental glaciers on Gondwana, a large land-mass that occupied the southern hemisphere at this time. A CCSM3 simulation of the warm mid Cretaceous (100 Ma) has also been carried out to study how well the model can replicate the pole to equator gradient in surface temperature for this time period. Proxy records for the deglaciation that started 21 thousand years ago indicate events with large freshwater inputs to the Atlantic Ocean basin as iceberg discharges into the high-latitude North Atlantic, Laurentide meltwater input to the Gulf of Mexico, or meltwater diversion to the North Atlantic via the St. Lawrence River and other eastern outlets. The climate responded, in the North Atlantic region and globally, to these freshwater events, but the responses varied among the events and are not completely understood. The sensitivity of the climate system to the magnitude and location of freshwater input into the North Atlantic has been studied using the fully coupled version of CCSM3 for glacial conditions. The results suggest that the response of the North Atlantic meridional overturning circulation is proportional, though not linearly, to the size of the freshwater added. On the other hand, the southward migration of the ITCZ over the tropical Atlantic displays a threshold response to the amount of freshwater forcing and hysteresis in the response versus recovery from the event. This has implications for detecting freshwater events using the Cariaco Basin records.

2009 and Beyond

Future plans include further CCSM3 simulations of the climate of the Late Ordovician, a time of great cold and a time of the earliest mass extinctions of life. Future plans also include deep time simulations of the Latest Cretaceous a time period just prior to the massive asteroid impact that led to the demise of the dinosaurs. A CCSM3 run will be carried out of the first synchronously coupled transient ocean-atmosphere-dynamic vegetation GCM simulation of the past 21,000 years. Under the auspices of the Paleoclimate Modeling Intercomparison Project (PMIP), a CCSM3 simulation of the mid-Pliocene will be carried out. This time period is possibly the closest paleo analog for an equilibrium climate with current CO_2 levels. There will also be a focus on simulating the magnitudes and rates of past climate change on many time scales using the planned NCAR Earth System Model, which will allow us to explore more completely feedbacks with vegetation and ice sheets, atmospheric chemical changes, and the carbon and nitrogen cycles.

return to top

High Resolution Dynamics Limb Sounder (HIRDLS) recovery and application

The High Resolution Dynamics Limb Sounder (HIRDLS) is a 21 channel infrared limb scanning radiometer, jointly developed by ACD, the University of Colorado, and the Physics Department of Oxford University. It is designed to make observations of temperature, ozone, water vapor, and 8 other trace species, as well as PSC's, aerosols and cirrus clouds, from the upper troposphere to the mesosphere, with higher vertical resolution than has previously been available from space observations. HIRDLS was launched on the Aura spacecraft in July 2004. Despite an obstruction that limited the view to the atmosphere to a small fraction of the width of the optical beam, HIRDLS scientists demonstrated that there is recoverable atmospheric information in the signals, and worked hard to develop algorithms to correct for the effects of the obstruction, as discussed under Goal 5, section 4.

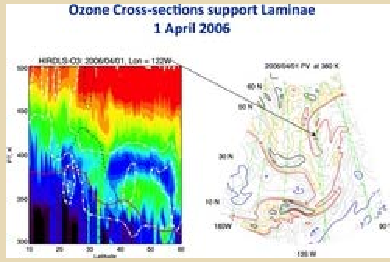


Figure 1.a. Cross-section of ozone as a function of latitude and potential temperature along a HIRDLS scan track at 122°W (Eastern Pacific). Blue indicates mixing ratios <= 0.3 ppmv, green is near 0.8 ppmv, and red approaches 1.8 ppmv. Broken white lines indicate contours of potential vorticity (PV) at 6 and 10 PVU, the red line is the tropopause location, both from the Goddard Modeling and Assimilation Office (GMAO) Earth Observing System (GEOS5.1) data, which is also the source of the dashed lines indicating contours of zonal wind.
Figure 1.b. Plot of GEOS 5.1 PV on the 380K surface from 90-180°W, and 10-70°N at 12Z on 1 April 2006. Contours highlighted in color are 2 PVU (blue), 6 PVU (red) 8 PVU (yellow) and 10PVU (black). Green dash-dot lines show the HIRDLS scan tracks this day. The tracks through 122°W can be seen.

High resolution figure

As a result of these efforts, Version 4 of the data, providing high resolution retrievals of temperature, ozone, nitric acid, CFC 11, CFC 12, aerosol extinction plus cloud top location and types was made available to the community. Five papers describing the validation of V3 data were published. V4 data has improved cloud detection, leading to more reliable ozone data in the UTLS region. In addition, the mean accuracy of the temperature and ozone data has improved.

An example of what can be seen is shown in Figure 1.a, which shows a latitude-potential temperature cross-section along a HIRDLS scan track near 122°W on 1 April 2006. This shows a region of low ozone at 380K in mid latitudes, originally from low latitudes that has been injected across the tropopause, but here has been separated by atmospheric motions, believed to be related to baroclinic waves in the troposphere. Here it remains as a thin layer that is associated with a potential vorticity (PV) contour of 6 10^{-6} m2/s K/kg, (6 PVU) as shown in the PV map on the 380K surface in Figure 1.b. Following this air mass shows that the low ozone air remains close to the 6PVU contour for several days, before the PV contour relaxes to a lower altitude, leaving the air to mix with its surroundings. This can only be seen because of the high vertical resolution of the HIRDLS data.

Summarizing the accomplishments, the radiance correction algorithms were improved, adding the CFC's and aerosol extinction to be retrieved, as well as improving the accuracy and usefulness of temperature and ozone. A study of gravity waves was published, and several talks on UT/LS processes and strat-trop exchange were presented. An anomaly with the HIRDLS chopper prevented participation in START08, or the ARCTAS field experiment.

The plans for FY09 call for increased emphasis on the application of these unique, high resolution data to a range of scientific applications, as well as continuation of work to further refine the correction and retrieval algorithms to retrieve additional species, and extend the altitude range of the results.

This work was supported by NASA and the NSF.

return to top

Solar Dynamo Modeling And Solar Cycle Prediction

The magnetic fields that are ultimately the source of the activity that takes place in the solar atmosphere have their origin inside the Sun, where convective, rotational, and other flows of highly electrically conducting plasma contribute to the operation of the dynamo. Work by HAO scientists has shown that the meridional circulation, a large-scale flow directed from the equator to the N and S poles at the solar surface and completing the circuit from the poles to the equator near the bottom of the convection

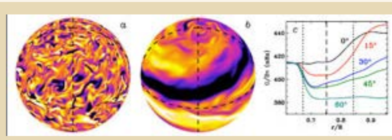


Figure 1: Turbulent pumping, organization, and amplification of magnetic fields in a

zone, plays a fundamental role in in the dynamo process. It continuously transports poloidal magnetic fields from the surface to the tachocline at the base of the convective envelope where they are differentially stretched by the rotational shear therein to produce new toroidal magnetic fields. Buoyant magnetic flux tubes formed from these fields become the source for new poloidal fields at the surface, thus completing the dynamo cycle. HAO researchers have pioneered the development of the so-called flux-transport dynamo model that is based on this physical picture, and have had remarkable success in applying it to the problem of simulating and predicting solar cycle amplitudes.

During the last year, HAO scientists made significant progress in efforts to understand the physical processes contributing to dynamo action in the Sun, and to further develop the predictive capabilities of the flux-transport dynamo model. M. Miesch, together with J. Toomre, B. Brown (both CU), A. S. Brun (CEA-Saclay), and M. Browning (CITA), continued to develop global three-dimensional models of convection and dynamo processes in the Sun and in other stars. Their work focused mainly on simulations of rapidly-rotating solar-type stars which exhibit modulated convection patterns wherein columnar convective cells group together in one or more localized longitudinal patches with relatively quiescent flow elsewhere . Magnetohydrodynamic simulations of such stars show strong dynamo action, with prominent, persistent bands of toroidal magnetic fields and quasi-periodic polarity reversals. The recent solar simulations of Miesch and collaborators have demonstrated that the presence of a tachocline of rotational shear has a profound influence on dynamo action in the convective envelope, promoting mean-field generation. Strong toroidal flux structures are formed in the tachocline through turbulent pumping and shear that then feed back on the poloidal field component, enhancing and stabilizing the dipole moment.

M. Dikpati, P. Gilman, and G. de Toma investigated the well-known "Waldmeier effect", that is, the anti-correlation between the magnitude of the peak in the sunspot number of a cycle, and the time from minimum to reach that peak. It has been suggested that the Waldmeier effect can be used to predict the peak of a cycle shortly after the onset of that cycle. They have shown that the Waldmeier effect is not present in the sunspot area data. Hathaway et al. (2002) had previously shown that the Waldmeier effect is much weaker (correlation r = -0.34) in sunspot group number. Thus the Waldmeier effect may be specific to only the Wolf sunspot number. Given the near coincidence of solar minima in the two data sets, the main differences in rise-time of spot number data and spot area data occur from the differences in timing of maxima (see the positions of the green and yellow crosses in Figure 2). Dikpati, de Toma, and Gilman have also evaluated the relative skill of the polar magnetic flux, the magnetic flux crossing the solar equator, and the toroidal magnetic flux in the tachocline as predictors of solar cycle amplitude, using observations as well as a calibrated flux-transport dynamo model. On the verge of the upcoming solar cycle 24, these three cycle indicators have all received attention. Dikpati, de Toma, and Gilman have shown that in the context of a flux-transport solar dynamo, the (n-1)th cycle's tachocline toroidal flux and the (n-1)th cycle's equator-crossing flux can be good predictors of the nth cycle's peak, but the polar flux of (n-1)th cycle correlates poorly with the peak of the nth cycle. In flux-transport dynamos, the polar magnetic flux is a follower of the cycle rather than being a precursor to it.

simulation of solar convection that incorporates a tachocline of rotational shear. The longitudinal field component is shown in an orthographic projection in (a) the mid convection zone and (b) the tachocline, with dashed lines denoting the equator and two meridians. The field in the convection zone is turbulent whereas the tachocline field is dominated by strong toroidal bands, antisymmetric about the equator. Frame (c) shows the angular velocity as a function of radius at different latitudes as indicated. The dashed line denotes the base of the convection zone while dotted lines denote the horizontal surfaces illustrated in frames (a) and (b).

High resolution figure

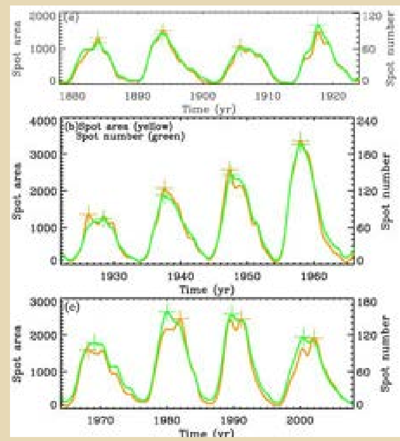


Figure 2: Comparison of Zürich sunspot number (green curves) and sunspot area (yellow curves, in millionths of the visible hemisphere) for cycles 12-23. Colored crosses denote the amplitude and time of cycle maxima for each type of data. To place the curves on the same scale, we multiply the y-axis for sunspot number by 16.5.

High resolution figure

During the next year, Miesch and collaborators will continue global-scale, 3D simulations of magnetized convection in a rotating spherical shell with an underlying stable region, in order to further study how dynamo action is affected by the presence of a tachocline. He will also add a surface poloidal magnetic field source term to create a 3D Babcock-Leighton-type dynamo which will be used to study the origin of magnetic cycles, the competition between magnetic pumping and transport of fields by circulation, and the interactions between the Babcock-Leighton source term and the convective generation of mean fields. Dikpati and collaborators will work to further refine the flux-transport dynamo-based prediction tool she has developed. At present, the onset timing and amplitude of a future cycle are predicted separately by applying a very simplified data-assimilation technique, "data-nudging", over the entire simulation run. In order to simultaneously predict the amplitude, timing, and shape of a cycle, a more sophisticated "sequential" data-assimilation technique, rather than just "data-nudging", will be developed. As in atmospheric weather prediction models, the dynamo model output at a certain cycle phase can be compared with the observed cycle at the same phase, and then the model can be updated with adjusted time-varying dynamo ingredients, to proceed forward in time. Dikpati and co-workers will also continue work on a 3D kinematic flux-transport dynamo, splitting the axisymmetric and non-axisymmetric flow and field components and representing the the non-axisymmetric components as a Fourier decomposition in longitude with a few low-order longitudinal modes. Thus this model will focus only on the large-scale, 3D, magnetic field evolution of the

Sun, such as the evolution of "active longitudes."

return to top

Upper Troposphere and Lower Stratosphere (UTLS) Initiative

The upper troposphere and lower stratosphere (UTLS) is a sensitive region of Earth's climate, because water vapor, ozone, cirrus clouds and aerosols in this region strongly contribute to radiative forcing of the climate system. The dynamical processes of broad range of scales, from deep convection and gravity waves, to synoptic weather systems and the stratospheric large-scale circulation, redistribute the chemical species and create unique conditions for microphysical, chemical and radiative processes. Studies of the UTLS seek to determine the role of distinct processes and feedbacks in this region, and how the system will evolve in a changing climate.

During the last 5 years, the UTLS initiative has successfully conducted the Stratosphere-Troposphere Analyses of Regional Transport (START-05 and START-08) experiments using the Gulfstream V (GV). These data in combination with satellite and model analysis provide a new level of quantification and characterization of transport pathways across the tropopause and their linkage to the synoptic scale weather system. These field experiments have also set the stage for a large, unique field campaign focusing on the chemical transport and processing of continental convective storm systems, Deep Convective Clouds & Chemistry Experiment (DC3). START-08 and DC3 are further discussed under Goal 5: Planning of DC3 field program & Planning of START08 field program.

return to top

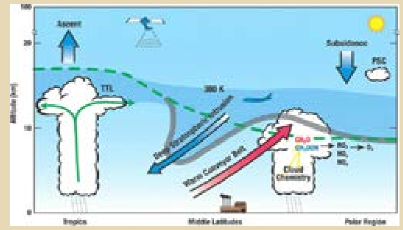


Figure 1: This schematic figure (adapted from Stohl et al. 2003) highlights the important processes coupling dynamics, chemistry and cloud microphysics in the UTLS region... The green line denotes the time average tropopause. In the tropics, maximum outflow from deep convection occurs near ~12-14 km, while the cold point tropopause occurs near 17 km. The intervening region has characteristics intermediate between the troposphere and stratosphere, and is termed the tropical transition layer (TTL). Extratropical stratosphere-troposphere exchange occurs in tropopause folds and intrusions linked with synoptics weater systems; these events transport stratospheric ozone into the troposphere. In addition, convection brings near-surface pollutants (from boimass burning or anthropogenci emissions) into the upper troposphere, strongly influencing global-scale chemistry.

High resolution figure

Simulations and Observations Of Magnetic Flux Emergence, CME Initiation and Evolution, and Interplanetary Consequences

Solar-driven space weather can have significantly adverse consequences for the Earth and near-Earth environment. Coronal mass ejections (CMEs) are the principal solar drivers of space weather. Using 3D magnetohydrodynamic simulations of the coronal magnetic field driven by the emergence of a twisted flux rope, HAO scientists have made significant advances in understanding the origin and dynamic evolution of CMEs and what makes a CME geoeffective.

Connecting interplanetary coronal mass ejections (ICMEs) to their coronal pre-eruption source requires a clear understanding of how that source may have evolved during eruption. In previous work S.Gibson and Y. Fan, (2006a,2006b) presented a three-dimensional numerical magnetohydrodynamic simulation of a CME, which showed how, in the course of eruption, a coronal flux rope may writhe and reconnect both internally and with surrounding fields in a manner that leads to a partial ejection of only part of the rope as a CME. They have now (Gibson and Fan 2008) explicitly determined how such evolution during eruption would lead to alterations of the magnetic connectivity, helicity, orientation, and topology of the ejected portion of the rope so that it differs significantly from that of the pre-eruption rope. Moreover, because a significant part of the magnetic helicity remains behind in the lower portion of the rope that survives the eruption, the region is likely to experience further eruptions (Figure 1). These changes complicate how ICMEs embedded in the solar wind relate to their solar source. In particular, the location and evolution of transient coronal holes (Figure 2), the topology of magnetic clouds ("tethered spheromak") (Figure 3), and the likelihood of interacting ICMEs would differ significantly from what would be predicted for a CME which did

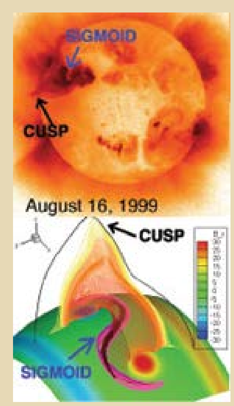


Figure 1: If a part of a twisted flux rope survives a solar eruption, it means that magnetic energy is still stored, and another eruption may soon be triggered. These Yohkoh SXT observations show an active region which erupted multiple times between August 15-21, 1999 (image is in negative color-table, dark indicates strong soft-X-ray (SXR) emission). Cusped field-lines resulting from eruptions apparently overlie sigmoid-shaped loops throughout the active regions disk passage, in the manner predicted by the

not undergo writhing and partial ejection during eruption.

The formation of twisted magnetic flux ropes in the solar corona which contains free magnetic energy and drives solar eruptions has its origin from the solar interior through the emergence of twisted active region magnetic flux. To understand the origin of CME precursor structures in the solar corona, Fan is carrying out 3D numerical simulations of the dynamic emergence of a twisted magnetic flux tube from the top layer of the solar convection zone into the solar atmosphere and the corona. She is investigating how the emergence, the resulting photosphere evolution, and the coronal magnetic field depend on the properties of the subsurface emerging tube. The simulations show that it is difficult for a twisted flux tube to emerge bodily into the corona as a whole due to the heavy mass trapped at the bottom concave parts of the twisted field lines. However, it is found from the simulations that on the photosphere, after a brief stage of shearing motion during which the two polarities of the bipolar region become separated, significant rotational motion develops within each polarity (Figure 4a), similar to the observed sunspot rotations, which transport significant amount of twist into the corona. The rotational motions of the two polarities are found to twist up the inner field lines of the emerged fields such that they change their orientation into an inverse configuration (i.e. pointing from the negative polarity to the positive polarity over the neutral line). As a result, a flux rope with sigmoid-shaped dipped core fields forms in the corona (Figure 4b). Sunspot rotation has been observed in many events preceding X-ray sigmoid brightening and the onset of eruptive flares. The simulations show that such rotational motions take place during flux emergence as a result of the propagation of torsional Alfven waves along the flux tube which transport significant twist from the interior portion towards the expanded coronal portion. These results provide insight into the nature of the observed processes that lead up to solar eruptions.

return to top

partially-ejected flux rope model (bottom panel). Such repeated partial ejections from a single region may have space weather significance, if for example their interaction leads to particularly strong solar energetic particle (SEP) events (Gopalswamy et al., 2004).

High resolution figure

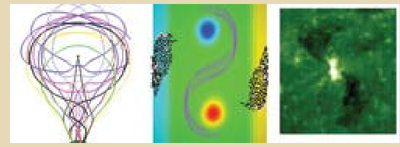


Figure 2: From Gibson and Fan (2008). Transient coronal holes (TCHs) are associated with CMEs, and appear as dimmings in soft X-ray and extreme ultraviolet (e.g. right-most image). They have been proposed to be the footpoints of expanding magnetic flux ropes. The left-most image shows sample field lines from the escaping portion of the flux rope in the Gibson and Fan (2006a, 2006b) simulation. The middle image shows colored diamonds corresponding to the footpoints of these escaping rope fieldlines, and the black dots show more footpoints of escaping rope fieldlines obtained by tracing all fieldlines exiting the top of the simulation box (10 Rsun) down to the lower boundary. The central purple fieldlines show the surviving rope as seen in projection against the solar surface, which is illustrated by colored iso-contours showing radial magnetic flux. The model predicts that the escaping flux rope footpoints lie outside the original (and surviving) rope's boundary, which compares well to the observations of the SOHO/EIT 195 transient coronal holes of May 12, 1997 that is shown in the right-most image.

High resolution figure

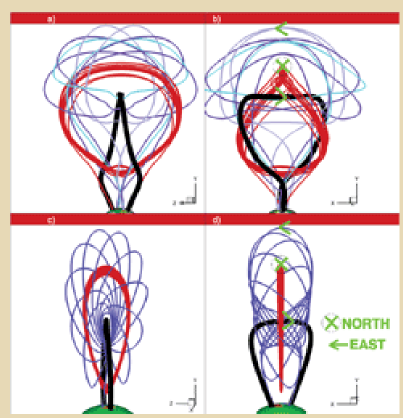


Figure 3: From Gibson and Fan (2008). Model predictions of magnetic fields within magnetic clouds (interplanetary manifestations of CMEs). The top images show sample field lines of the escaping portion of a partially-ejected flux rope, which we demonstrate is topologically equivalent to a "tethered spheromak" described in the analytic model of Gibson and Low (1998)

(bottom images). The thick black field lines in (a-b) and (c-d) represent the poloidal axes of the partially-ejected rope and tethered spheromak, respectively. The red torus shown in (c-d) is formed by a single field line ergodically covering a magnetic flux surface which encloses the spheromak toroidal axis. The partially-ejected rope possesses a similarly toroidally-winding single red field line, although it is not completely detached from the lower boundary.

High resolution figure

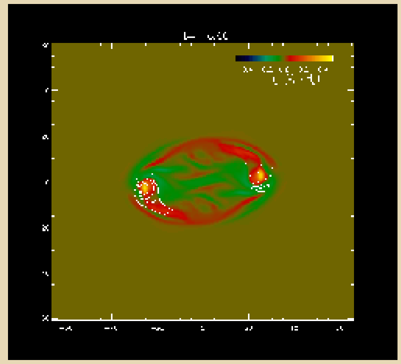


Figure 4a: The distribution of vertical vorticity at the photosphere in an emerging flux region resulting from a 3D MHD simulation of the emergence of a twisted magnetic flux tube from the solar interior into the solar atmosphere. It shows concentration of positive vertical vorticity, i.e. counter-clockwise rotational motion, centered at the peaks of the vertical magnetic field (shown as white contours, with solid and dotted contours indicating positive and negative magnetic polarities respectively) of the two polarities.

High resolution figure

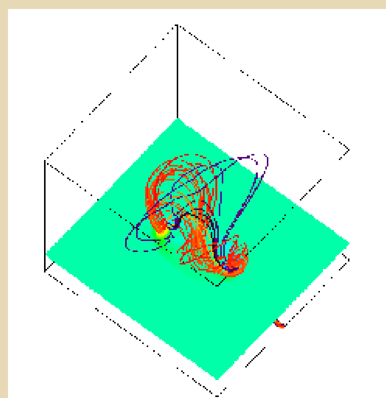


Figure 4b: The 3D coronal magnetic field resulting from a 3D MHD simulation of the emergence of a twisted magnetic flux tube from the solar interior into the solar atmosphere. A flux rope with sigmoid-shaped, dipped core-fields (as represented by the red field lines) has formed in the corona. Significant rotational motions are present at the footpoints of these field lines at the photosphere (as shown in Figure 4a) as a result of the propagation of torsional

Alfven waves along the flux tube which transport significant twist from the interior portion towards the expanded coronal portion.

High resolution figure

Globalization of air quality and intercontinental transport

Transpacific Pollution Transport during INTEX-B: Spring 2006 in Context to Previous Years

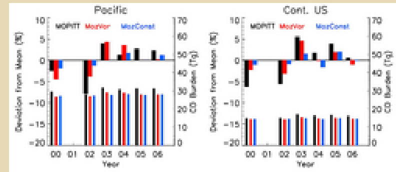


Figure 1. Variability in the tropospheric CO burden over the Pacific and continental US as derived from MOPITT and two MOZART simulations (MozVar: varying emissions; MozConst: constant emissions).

High resolution figure

We analyze the transport of pollution across the Pacific during the NASA INTEX-B (Intercontinental Chemical Transport Experiment) campaign in spring 2006 and examine how this year compares to the time period 2000-2006. In addition to aircraft measurements collected during INTEX-B, we include multi-year satellite observations of CO from the Measurements of Pollution in the Troposphere (MOPITT) instrument. We integrate these measurements with simulations from the chemistry transport model MOZART-4. Model tracers are used to examine the contributions of different regions to pollution levels over the Pacific and to estimate the O_3 production from NO_x sources in Asia to O_3 loadings over the Pacific and North America. Additional modeling studies are performed to separate the impacts of inter-annual variability in meteorology and dynamics from changes in source strength. Figure 1 shows the variability in the tropospheric CO burden (relative deviation from mean and absolute amounts) over the Pacific and the contiguous US as derived from MOPITT data and two model simulations, one with emissions that vary by year (MozVar) and one with constant emissions (MozConst).

This work was funded by NASA and NSF. This work will be published in FY09 and similar studies made in the analysis of the NASA ARCTAS aircraft experiment.

return to top

MOZART in the analysis of tropospheric observations

Impacts of the Fall 2007 California Wildfires on Surface Ozone: Integrating Local Observations with Global Model Simulations

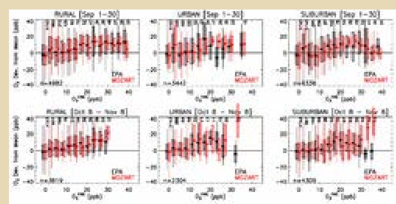


Figure 1. Deviation from the mean of observed and modeled midday 8-hour O_3 concentrations binned by the model fire tracer. Results are sorted by rural, urban and suburban sites, and for the two main fire periods.

High resolution figure

In this study we quantified the impact of the fires in California in fall 2007 on regional air quality and in particular on surface ozone by analyzing surface observations of ozone concentrations together with MOZART simulations (Pfister et al., GRL, in press). The simulations include a synthetic tracer providing information about the amount of ozone produced from the fires. A clear increase in observed ozone is found when the model predicts a strong impact of pollution from the fires, where measured afternoon 8-hour concentrations increased, on average, by about 10 ppb. The findings demonstrate that intense wildfire periods can significantly increase the frequency of ozone concentrations exceeding current U.S. health standards, and might cause violations also during photochemically less active seasons. The study also demonstrates the far-reaching impact of ozone production from the fires.

Figure 1 shows observed and modeled 8-hour O_3 concentrations for 10-18 LT, 11-19LT and 12-20 LT binned by the model fire tracer O_3^{FIRE}. Shown is the deviation from the mean concentrations (ppb) separately for rural, urban and suburban sites, and for the two main fire periods (Sep 1-30 and Oct 8 - Nov 8).

This work was funded by NSF and NASA. In FY09 similar studies will be made of the extensive California fires of Summer 2008 as part of the analysis of the NASA/ARCTAS-CARB aircraft experiment.

Contribution of fires to ozone from Mexico City pollution

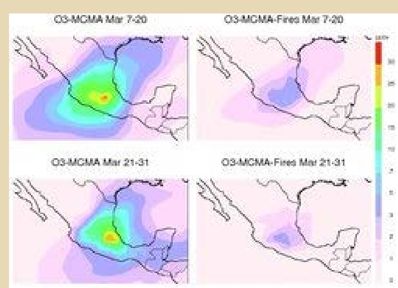


Figure 2. Ozone from all Mexico City emissions (left panels) and from just fire emission (right panel) for before (top row) and after (bottom row) the significant rain event.

During the MIRAGE experiment during March 2006, numerous wildfires were evident in the hillsides surrounding Mexico City, complicating the characterization of the urban emissions and resulting pollution. Using the MOZART global chemical transport model run at a horizontal resolution of 0.7 degrees, the ozone burden resulting from the total emissions in the Mexico City region, as well as only from open fires, has been simulated. By tagging the NO emissions from a single type or region of sources in the model, the ozone produced from that source can be quantified. In the middle of the MIRAGE experiment (on March 20) a period of rainy weather began, significantly dampening the fire activity around Mexico City. Figure 2 shows the ozone produced from all of the NO emissions from Mexico City and its environs (urban and fires) and ozone from only the fire emissions, for the periods before and after the rain event.

High resolution figure

These results show that, for ozone, the open fires in the vicinity of Mexico City are a fairly small, but non-negligible contribution (20%) to the regional ozone pollution. Other studies have shown, however, that other components of Mexico City pollution, in particular particles, have significant contributions from fire emissions. Some of these sources could be cooking, heating and trash burning, which are not included in the tagged fire emissions in the MOZART simulations.

This work was funded by NSF and NASA. Analysis of the MIRAGE observations using MOZART will continue in FY09.

return to top

Hurricanes

As the current high level of Atlantic hurricane activity continues to cause major disruption and damage, research at NCAR is both expanding and becoming of greater societal importance. Research and applications work within ESSL and in collaboration with our colleagues in RAL and CISL, the Willis Research Network, Georgia Tech, SUNY, RSMAS, Cal Tech, and Mississippi State has:

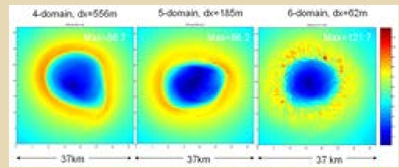


Figure: Wind speeds 10 m above the sea surface in an idealized AHW hurricane simulation, showing the development of a turbulent structure for horizontal resolution beyond 100 m.

High resolution figure

• Expanded our understanding of cyclone formation in both tropical and subtropical conditions, wind-pressure relationships, hurricane structural evolution and the impacts of climate variability and change;
• Led to several improvements in the Advanced research Hurricane WRF (AHW);
• Enabled participation in the NOAA Hurricane Intensity Forecast Improvement Program (HIFIP) with the Advanced Hurricane-research WRF (AHW); and,
• Commenced a study to improve the communication of forecast information to vulnerable communities.

High-resolution simulations of the 2005 hurricane season have enabled a demonstration of an hypothesis that tropical cyclone formation can be enhanced by wave accumulation processes when easterly waves move into a region in which the easterly flow is decreasing westward. The simulations have also indicated that mesoscale interactions may be an important contributor to enhanced cyclogenesis. This represents a move away from earlier assumptions that such interactions were largely stochastic and could equally enhance or reduce cyclogenesis potential. These factors are considered to be major contributors to the highly active 2005 season. The role of upper-trough interactions and in subtropical development of tropical cyclones has been further investigated. An important conclusion is that strong vertical shear enhances such developments, quite the opposite of the requirement for low shear in equatorial developments. Tropical cyclones moving into higher latitudes and environments with stronger vertical shear were also investigated. Emerging frontal structures, asymmetric rainfall patterns, and responses to the deleterious structural effects of vertical shear were simulated and analyzed. A major field program to further study this process has been proposed. NCAR also participated in the TPARC field program for cyclone development in the western North Pacific, and the WRF modeling system will be used to develop a comprehensive reanalysis for subsequent research.

A new wind-pressure relationship has been derived that updates an older relationship used widely in developing synthetic hurricane climatologies for design and planning of coastal and offshore structures. This relationship was able to confirm an earlier study that major hurricanes in the 1950s were overestimated in intensity, and to extend this to include the period through to the 1970s.

An NCAR Breakthrough Science (BTS) study used AHW for extremely high resolution simulations of an idealized hurricane to assess the impacts of increasing resolution on structure and intensity (Fig. 1). This showed that there was only a slight variation of intensity with resolution below 1 km. However, at an unprecedented horizontal resolution of 62 m, the AHW was able to resolve turbulent structures (Fig. 1), The subsequent analysis found a marked sensitivity of intensity to the specified horizontal mixing length in axisymmetric models and showed that earlier studies of potential increases in hurricane intensity by migration of high-entropy surface air in the eye into the eye wall were incorrect. One additional outcome was the development of a revised hurricane maximum potential intensity relationship that did not require the need for approximations employed in earlier versions.

The AHW has been further improved based on experience with real-time and research simulations over the past several years. This included upgrades to the cloud microphysics and boundary-layer parameterizations an ocean mixing and upwelling parameterization based on a 1-D configuration, and further developments of the data assimilation system. The ocean parameterization successfully reproduces much of the negative feedback associated with oceanic cooling during a cyclone passage. Preparations have been completed for participation in the NOAA HIFIP program. AHW will use the Ensemble Kalman Filter data assimilation and parameterized ocean that reproduces much of the observed negative feedback arising from cooling by upwelling and mixing associated with the cyclone passage. NCAR will be a full participant in HFIP, with post-event forecasts of all the cases recommended by NOAA.

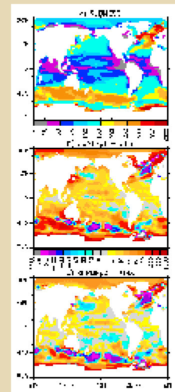
Recent experience has shown quite clearly that coastal residents do not respond adequately to the risk from an approaching hurricane. Building on preliminary investigations, a substantial study has now commenced at NCAR to examine the way in which such communities interpret warning information and develop improved methods of communication and response to the hurricane threat.

return to top

Climate Variability and Predictability World Climate Research Program (CLIVAR)

Climate Process Teams (CPTs)

ESSL scientists remain actively involved in leadership of the Climate Variability and Predictability (CLIVAR) initiative of the World Climate Research Programme (WCRP) through membership on various national and international CLIVAR panels, as well as through research contributions to CLIVAR goals and objectives. The purpose of CLIVAR is to investigate climate variability and predictability on time-scales from months to decades, as well as the response of the climate system to anthropogenic forcing. CLIVAR, as one of the major components of the WCRP, started in 1998 with a 15-year charter, which focuses on the role of the coupled ocean and atmosphere within the overall climate system, with emphasis on variability, especially within the oceans, on seasonal to centennial time scales. CLIVAR aims to explore predictability and improve projections of climate variability and climate change using existing, reanalyzed, as well as new global observations, enhanced coupled ocean-atmosphere-land-ice models, and paleoclimate records.



Winter-mean Mixed Layer Depth (MLD) in meters: a) from an experiment with the new submesoscale physics parameterization (SUBMESO); b) MLD difference between a CONTROL experiment without the submesoscale parameterization and observations; and c) MLD difference between experiment SUBMESO and observations.

High resolution figure

A major effort of the U.S. CLIVAR program has been the introduction and fostering of Climate Process Teams (CPTs). A CPT is a team of theoreticians, observationalists, process modelers, and coupled climate modelers formed around specific issues or uncertainties. CPTs aim to link process-oriented research to modeling for the purpose of addressing key uncertainties in coupled climate models. Expediting the incorporation of new parameterizations into ocean models and assessing their climate impacts are among their primary goals. Within ESSL, major ocean model developments are proceeding under the auspices of the CPTs on both gravity current entrainment and eddy mixed layer interaction in collaboration with the external university and laboratory community.

For the CPT on the eddy mixed layer interaction, we implemented a new submesoscale physics parameterization in the ocean component of the Community Climate System Model version 4 (CCSM4), following Fox-Kemper, Ferrari, and Hallberg (2008, J. Phys. Oceanogr., v38, 1145-1165). The submesoscale represents the range of scales between the mesoscale (typical scales of a month and 100 km) and the fine-scale (typical scales of inertial or faster time and up to hundreds of meters). The submesoscale dynamics are dominated by the development of fronts and the ageostrophic circulations associated with the fronts. Some recent studies indicate that both the depth and the stratification of the surface mixed layer are significantly modified by these ageostrophic circulations. Fox-Kemper, Ferrari, and Hallberg (2008) present a parameterization scheme to represent the mixed-layer stratification associated with these frontal instabilities and frontogenesis. Inclusion of this new physics in the ocean model leads to some improvements compared to a control integration without this parameterization. In particular, due to the restratification by the parameterized mixed layer eddies, generally deep bias of the simulated mixed layer depths are significantly reduced, thus producing more favorable comparisons with the available observations in most regions of the globe (see Figure 1).

Some preliminary results from this study are reported in Fox-Kemper, Danabasoglu, Ferrari, and Hallberg (2008, CLIVAR Exchanges, v13, 3-5).

The results from the successful implementation of an overflow parameterization for the Mediterranean overflow (PMO; Parameterized Mediterranean Overflow) through the Strait of Gibraltar in CCSM3 were documented in Wu, Danabasoglu, and Large (2007, Ocean Modelling, v19, 31-52). This parameterization, based on the marginal sea boundary condition scheme of Price and Yang (1998, in Ocean Modeling and Parameterization, Kluwer Academic, 155-170), represents exchanges through narrow straits / channels, associated entrainment and intrusion of overflow product water into the open ocean. These overflow processes occur on very small spatial scales, essentially prohibiting their explicit representation in ocean circulation models used in climate studies. Therefore, their effects must be parameterized. The PMO is applicable only to overflows from enclosed seas.

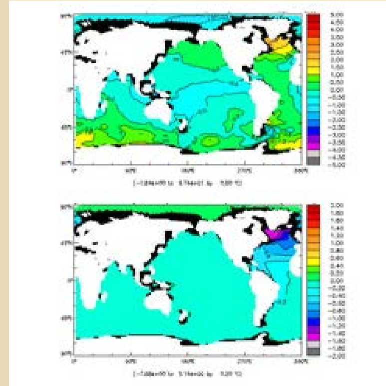
Therefore, we have developed a new parameterization that can be used in open-ocean overflow applications such as the Denmark Strait and Faroe Bank Channel overflows.

A particularly novel aspect of the parameterization is a new treatment of the baroclinic / barotropic mode split. This new open-ocean overflow parameterization was first implemented and tested in the Parallel Ocean Program version 1.4 (POP1.4). It has now been incorporated in the new version of the ocean model (POP2.0). Newly obtained results show that inclusion of the Denmark Strait Overflow (DSO) and Faroe Bank Channel overflow via this new scheme significantly reduces some long standing model biases in the North Atlantic. Potential temperature difference distributions at a depth of 2000 m (see Figure 2) clearly show that the CONTROL case warm bias is significantly reduced with the new parameterization which is used to represent only the DSO in this particular experiment.

A primary purpose of these CPTs is to document climate impacts of these new parameterizations using fully coupled simulations. To this end, we have already completed several simulations that also include CFCs. In FY2009, the final year of these projects, we will perform additional integrations to complete the suit of necessary experiments and document any climate impacts due to these new parameterizations.

The observational MLD data are based on the Polar Science Center Hydrographic Climatology (PHC2) data sets (a blending of the Levitus et al. 1998 and Steele et al. 2001 data). The MLD is defined as the depth at which the local density is higher then the surface density by 0.125 kg / m^3. The experiments SUBMESO and CONTROL are forced with the Coordinated Ocean-ice Reference Experiments (COREs) Normal-Year atmospheric forcing data from Large and Yeager (2004). The winter-mean represents January-March and July-September means in the Northern and Southern Hemispheres, respectively. In SUBMESO, the root-mean-square MLD difference from observations is reduced by more than 20% compared to the CONTROL - OBS difference.

The figures clearly show the substantial elimination of the model warm bias of the CONTROL case with the new parameterization in the DSO experiment.



Time-mean potential temperature model - observations difference distributions at 2000-m depth: (top) CONTROL case - observations and (bottom) DSO case - observations. The DSO case uses the new overflow parameterization to represent the Denmark Strait Overflow (DSO) physics which is largely absent in the CONTROL experiment. In top and bottom panels, the contour intervals are 0.5 and 0.2 degree C, respectively. The observations are from the PHC2 data set. Both CONTROL and DSO experiments use the CORE Normal-Year atmospheric forcing data sets from Large and Yeager (2004).

High resolution figure

return to top

Convection, Flux Tubes, And Waves In The Solar Interior

The energy liberated through the nuclear burning of hydrogen in the core of the Sun is transported outward by radiative diffusion for radii less than about 0.7 R_sun, and by convection within that portion of the interior located between 0.7 R_sun and the photosphere. The structure and dynamics of this outer convective envelope, the nature of the interface between it and the underlying stably stratified radiative interior, and the hydrodynamical and magnetohydrodynamical (MHD) processes that take place within these layers are critical to understanding the operation of the solar dynamo, the transport and emergence of dynamo-generated magnetic fields, and the properties of the Sun's differential rotation and meridional circulation. During 2008, HAO researchers made substantial progress on plans to study the dynamics and evolution of buoyant magnetic flux ropes in the convection zone, and to investigate the nature and properties of the instabilities and waves that can exist in the the solar tachocline and radiative interior.

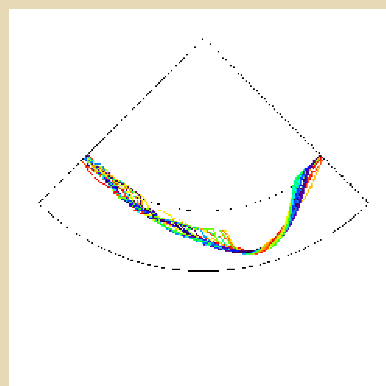


Figure 1: Selected field lines in an emerging Omega-shaped flux tube resulting from a 3D simulation of the rise of a 100 kG buoyant flux tube from the base of the convective envelope towards the top boundary located at 16 Mm below the visible solar surface. One can clearly see the asymmetry where the leading side is more cohesive while the field lines in the following side are fraying out.

High resolution figure

Y. Fan carried out a set of 3D, spherical-shell, MHD simulations of the buoyant rise of active region flux tubes in a model solar convective envelope. The results of these computations put new constraints on the initial twist of the flux tubes in order for them to emerge with tilt angles consistent with the observed Joy's law of the mean tilt of solar active regions. Asymmetric stretching of an Omega-shaped rising tube by the Coriolis force causes the leading side (leading in the direction of rotation) to have a stronger field and to thus be more cohesive compared to the following side (Figure 1). There is also significant asymmetry between the twist and the upward helicity flux along the leading and following legs of the emerging tube. The values of the local twist of the magnetic field lines in the leading leg show modest variations with height in the convection zone, while the field lines in the following leg are frayed and show large fluctuations and mixed signs of twist (Figure 2). In addition, in the upper half of the convection zone, the upward helicity flux along the leading leg is significantly greater than that in the following leg (Figure 3), a property which has been reported in a recent observational study of emerging active regions by Tian and Alexander (2008).

M. Dikpati, P. Gilman, M. Miesch, and P. Cally (Monash University) have used a 3D, thin-shell model of the tachocline to investigate the occurrence and properties of axisymmetric (m=0), MHD instabilities inside the Sun. They find that bands of toridal magnetic fields become unstable to axisymmetric perturbations for solar-like field strengths (100 kG) with e-folding times that can be months, or even a few hours if the field strength is a million Gauss or higher, as might occur in the solar core, white dwarfs, or neutron stars. These instabilities exist with and without rotation, although differential rotation has a stabilizing effect. The onset of an m=0 instability occurs from the poleward shoulder of banded toroidal field profiles. Unlike the non-axisymmetric instability which tips or deforms a band, in the axisymmetric instability, the fluid can roll in latitude and radius, and can break up bands in the radial direction. The velocity produced by this instability in the case of low-latitude bands crosses the equator and hence can provide a mechanism for hemispheric coupling. T. Rogers and K. MacGregor continued their study of internal gravity waves (IGW) in the radiative interior of the Sun. These disturbances are generated by the overshoot of flows from the convection zone into the underlying stably stratified layers of the solar interior. They used numerical simulations to investigate the interaction of IGW with a layer of toroidal magnetic field, located just below the base of the convection zone. Their results indicate that the wave energy present in the deep radiative interior is severely diminished by the reflection and absorption of downwardly propagating waves in the magnetic layer. It is found that for field strengths in the range of 1-100 kG, the wave energy in the radiative zone is decreased by 4-5 orders of magnitude, independent of field strength. This poses significant challenges to models which rely on angular momentum transport by IGW to account for the uniform rotation of the solar radiative interior, as well as for observational searches for g-modes.

In the coming year, simulations of magnetized convection in a 3D, rotating, spherical shell with an underlying stable region will be carried out, in an effort to study how dynamo action is affected by the presence of a tachocline. Studies of magnetic flux concentrations in the convection zone will continue with simulations of the formation of flux tubes by the occurrence of the magnetic buoyancy instability in dynamo-generated mean fields. These simulations will be conducted in 3D, rotating, spherical geometry, with distributions of poloidal and toroidal fields obtained from the dynamo model of M. Rempel for different solar cycle phases. Further studies of MHD instabilities of tachocline fields and rotation will include exploration of the linear growth and nonlinear evolution of instabilities in stars, particularly those having anti-solar differential rotation. The investigation will be directed toward determining whether the poleward side of a band of toroidal field is stable in the case of anti-solar differential rotation rather than the equatorward side as in the case of the Sun. Examination of gravity waves in the solar radiative interior will proceed with additional simulations intended to further clarify mode properties and background interactions in the presence of buoyancy, magnetic, and rotational forces.

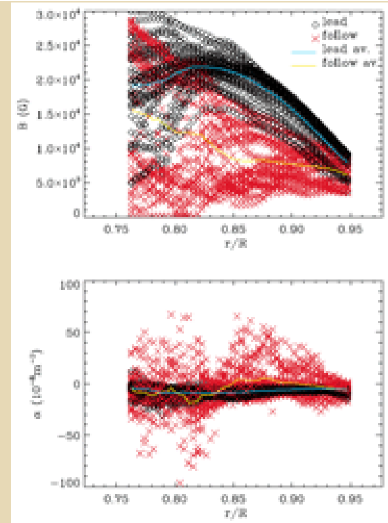


Figure 2: Values of total field strength B (upper panel) and twist alpha (defined as J*B/B^2 where J is the vector current density) as a function of height along each of the selected field lines shown in Figure 1, with black diamond points (red crosses) showing the values of the leading (following) side of the field lines. The blue (yellow) curve shows an average of the leading (following) field line values. Field lines in the leading leg show systematically stronger field strengths and also show a more coherent values of (negative) local twist.

High resolution figure

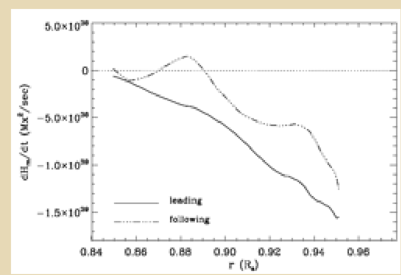


Figure 3: Upward helicity flux along the leading and following legs of the emerging tubes for heights in the upper half of the convection zone. The upward transport of a negative helicity flux (for the left-hand twisted flux tube) along the leading leg is systematically greater than that along the following.

High resolution figure

return to top

Spectro-polarimetric studies of magnetic fields in the lower solar atmosphere

The Lower Solar Atmosphere (LSA) section studies the evolution of the solar magnetic field and its interactions with the plasma from its emergence through the photosphere up to the chromosphere. The magnetic flux rises from the interior due to buoyancy and becomes directly measurable at the photospheric level by means of spectro-polarimetric observations. In this layer the dynamical state is dominated by convective plasma motions and the magnetic field is forced to follow these flows. As it moves upwards into the upper photosphere and lower chromosphere, a transition occurs to a completely different physical regime in which magnetic forces take over and dominate the dynamics. Understanding the implications of this transition is the main challenge of the LSA section, which is heavily driven by observations of the polarimetric signatures imprinted by magnetic fields on photospheric and chromospheric spectral lines.

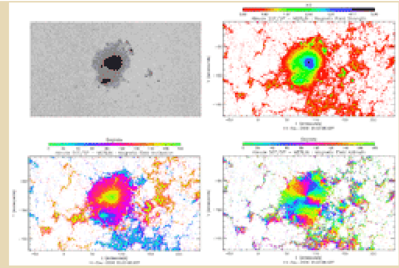


Figure 2: Color-coded maps of the inferred vector magnetic field (strength, inclination, and azimuth) of the sunspot and associated solar active region shown in the white-light image (upper left panel). This is an example of the observations taken with the SOT/SP onboard Hinode, which can now be accessed and interactively inverted through the CSAC-MERLIN web client.

High resolution figure

The most significant achievement of the LSA during the past year has been the release of the MERLIN code for the inversion of spectro-polarimetric observations of the solar photosphere. This code interprets the polarized solar radiation in the two Fe I lines at 630.2 nm, and outputs the vector magnetic field and the thermodynamic properties of the observed solar region. The development of the code and of its web client was supported through the CSAC initiative. Through the CSAC website it is now possible to access pre-inverted spectro-polarimetric data selected from a continuously updated database of observations from the SOT/SP instrument on-board the Hinode spacecraft. Currently these observations represent the best available data for synoptic measurements of the vector magnetic field on the Sun, thanks to the high spatial resolution, stability of image quality, and extended time coverage attainable from space. The MERLIN web client allows a web user to access these pre-inverted observations, or to initiate a completely new inversion of a solar region of choice. The user is notified by e-mail when the inversion is completed, and the results ready for display and download (see figure 2).

For next year we plan to work towards the release of the next community-inversion code LILIA on the CSAC website. This code will allow a significantly more refined analysis of spectro-polarimetric data than to MERLIN, including the derivation of magnetic-field and thermodynamic gradients in the solar atmosphere. This type of information will prove essential for comparing observations to recent advances in the magneto-hydrodynamic convection modeling of the solar photosphere (M. Rempel). With the completion of SPINOR, there will also be an effort towards adding observations taken with this instrument to the CSAC database. We expect to achieve a complete debugging of ProMag, successful deployment of the instrument, and start of science operation within the next year.

return to top

MHD Physics Of The Solar Corona And Wind

The solar corona, heated by various mechanisms to million-degree temperatures is fully ionized. Embedded with a magnetic field of about 10 Gauss at the coronal base, this atmosphere is an excellent conductor of both heat and electric current. Outward thermal conduction of heat, aided by MHD and plasma waves, drives the outer corona to expand continuously into the solar wind, filling interplanetary space. High electrical conductivity enables the magnetic fields to store significant amounts of energy which is released through the resisitive dissipation of thin sheets of electric current. Such an MHD process heats the corona ubiquitously and produces the impulsive flares, but we still have much to learn about its basic physical nature. The corona is not static, of course. Its magnetic field changes in time, reversing its global polarity once every 11 years in concert with dynamo action in the solar interior. Thus, the dynamo rejuvenates the corona in each cycle, producing flares and sending daily coronal mass ejections into the more slowly varying solar wind. This is the dynamical origin of space weather. The NCAR program described below investigates the basic MHD of the corona as an essential component of national space-weather research.

Under coronal conditions of extremely high electrical conductivity, magnetic fields evolve with no change in their field topologies unless the ordinarily weak effect of electrical resistivity is enormously amplified via the spontaneous formation of current sheets, as described by the theory of Parker (1994). Plasma parcels embedding distinct magnetic flux systems cannot mix freely, and current sheets would develop as tangential field discontinuities at the boundaries between the flux systems. The nonlinear mathematical problems posed by this fundamental effect are formidable in general, but have been found to be tractable for the topologically untwisted magnetic fields defined by Low (2006a, b). Ase Marit Janse (ASP) and B. C. Low (HAO) presented two explicit examples of current-sheet formation in this special class of magnetic fields. The first example considers a topologically untwisted field inside a cylinder of perfectly conducting fluid (Janse & Low 2009). The field is anchored by its magnetic footpoints fixed at the cylinder ends, so that its topology is invariant to a continuous change in the length of the cylinder. Whereas this field of a fixed topology may have a continuous equilibrium state, as a potential field, for a particular length of the cylinder, no continuous equilibrium state is available to the field when the cylinder is given other lengths. In the latter case, magnetic discontinuities or current sheets must form throughout the field, whose dissipation can then change the field topology into one compatible with a continuous state. An important aspect of this demonstration is that magnetic neutral points are not essential to the process, as implied by the Parker theory.

The second example treats the topological change brought about by the dissipation of a pre-existing current sheet embedded under equilibrium conditions in a topologically untwisted field (Low & Janse 2009). This dissipation produces a reconnected potential field whose field topology implies that other current sheets, in addition to the sheet in the initial state, must have formed and dissipated throughout the field in order to arrive at its potential state. These demonstrations offer basic physical explanation of the ubiquitous heating observed in both the quiescent corona and energetically explosive events like the flares. The Parker theory needs to be incorporated into the MHD simulation models in use in solar and space-weather research.

Natasha Flyer (IMAGe), Bengt Fornberg (University of Colorado), Ken Miller (Wichita State University),and Low investigated the turbulently-relaxed state of a magnetic structure following a flare-like release of magnetic energy. The theory of Taylor (1974) points out that the formation and dissipation of current sheets in this relaxation is subject to an approximate conservation of the total magnetic helicity under the condition of extremely high electrical conductivity in the corona. Extending this idea originally developed for a contained laboratory plasma to an open astrophysical atmosphere is essential but has been neglected in current solar research. This extension was carried out by solving a free-boundary problem in a two-dimensional atmosphere. A numerical solver was developed to construct the relaxed equilibrium state, seeking as an unknown the boundary separating the flared magnetic structure from the surrounding part of the atmosphere not involved in the flare. The flared structure contains the initial flaring magnetic field as well as the surrounding field that has reconnected with it, subject to the conservation law on magnetic helicity. A hydromagnetic implosion effect first pointed out by Hudson (2000) is cleanly demonstrated by these numerical computations (Miller et al. 2008). As the stored magnetic energy is transformed into escaping radiation and high-energy particles during a flare, the magnetic pressure of the flaring magnetic field is reduced, leading to an inward collapse as the surrounding plasma and field push in with their superior pressure. This work motivates observations to look for the signatures of the Hudson implosion, and paves the way for numerical modeling of coronal relaxed structures in realistic 3D modeling.

Flyer, Mei Zhang (National Astronomical Observatory, Beijing & NCAR Affiliate Scientist) and Low continue with their theoretical study of magnetic helicity accumulation in an open hydromagnetic atmosphere. Progress has been made towards an analytical proof of an upper bound on the total magnetic helicity contained in a global force-free magnetic field. Exceeding this upper bound is a sufficient condition for a loss of equilibrium that must open up the field to let trapped magnetic twist escape. In this manner, the total helicity can be brought down to within the bound for equilibrium to be re-established. This possible hydromagnetic origin of coronal mass ejections has been investigated by Zhang & Flyer (2008).

A two-year effort initiated by Piotr Smolarkiewicz (MMM/IMAGe) and Low to simulate 3D MHD evolution leading to the formation of current sheets has produced interesting first results. The challenge of numerically describing sheet formation developing as singularities in a 3D magnetic field is handled by describing the field in terms of its flux surfaces as opposed to the usual Eulerian specification of the field vector as a function of space. Joined by Ramit Bhattacharyya (ASP), Smolarkiewicz and Low investigated a periodic field in an incompressible, viscous, electrically perfectly-conducting fluid. The field is drained of its free energy as its Lorentz force drives a flow whose kinetic energy is viscously dissipated. The equilibrium end-state so produced requires the existence of a set of global magnetic flux surfaces each containing a constant fluid pressure. Although the initial field is untwisted with well defined global flux surfaces, it is the nature of 3D fields that, in general, it is topologically not possible for any set of these flux surfaces to be arranged into global isobaric surfaces. This impossibility manifests in the formation of magnetic tangential discontinuities. The above initial-value simulations show a first-stage extended smooth evolution followed by an evolutionary change identifiable with the formation of current sheets and their unavoidable artifical dissipation via the loss of numerical spatial and temporal resolution. These simulations provide the most direct illustration of sheet formation via the explicit representation of magnetic flux surfaces. The numerical codes developed by Smolarkiewicz (2006) have opened the way to further developments, to treat compressibility; boundary conditions of interest to solar coronal magnetic fields; and, twisted magnetic fields in the description of Low (2007a) using two pairs of flux surfaces. A problem of fundamental interest to be addressed is whether magnetic discontinuities can form in finite time (see Kerr & Brandenburg 1999) and (Grauer and Marliani 2000).

In an ongoing effort, Janse and her collaborators Oeystein Lie-Svendsen (Norwegian Defence Research Establishment & University of Oslo) and Ruth Esser (University of Tromsoe) investigated the heating of minority ions (carbon, oxygen and silicon) in the solar wind, using a multi-fluid numerical model developed at the Institute of Theoretical Astrophysics, University of Oslo. The goal is to compare the different solar-wind solutions, produced by varying the theoretical heat input in the model corona, for comparison with observations.

Resources:

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- H. Hudson 2000, ApJ 531, L75
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E. N. Parker 1994, Spontaneous current sheets in magnetic fields, Oxford U Press

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return to top

Chemistry and dynamics of the middle and upper atmosphere

ACD scientists have worked with data from the TIMED (Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics) satellite to investigate the dynamics and chemistry of the middle atmosphere. Much of this research has been done in collaboration with US and international colleagues.

The diurnal tide gives large amplitude variations over 24-hours of temperature and winds in the mesosphere. ACD scientists have worked on the characterization of variations in the tidal amplitudes and phases using temperature and wind data from TIMED and ground-based radar. The results indicate that there are large variations of tidal amplitude on semi-annual and annual timescales. The tide at the equator also varies on a multi-year timescale in concert with the quasi-biennial oscillation in equatorial lower stratospheric winds. This study will continue, using small differences in the tides to derive the eddy diffusion rate in the mesosphere.

Up to now, the chemistry of the mesosphere has been poorly constrained by observations. This is beginning to change, and analysis by ACD scientists is contributing. A new measurement from the SABER instrument on TIMED gives the distribution of atomic hydrogen. These global, multi-year measurements show a drop in the hydrogen in the summer mesosphere that is inconsistent with transport. However, a closer look indicates that this drop is consistent with the vertical redistribution of hydrogen due to the freezing of water in polar mesospheric clouds and subsequent vertical displacement and sublimation of the ice particles.

Ozone observations by SABER also reveal some unusual aspects. At the location of the ozone secondary maximum near 95 km, SABER observations show occasional very high mixing ratios of over 20 ppmv, and as high as 50 ppmv, during night. Analysis indicates that these are associated with unusually large amplitudes of the diurnal tide. The large tide leads to low nighttime temperatures at 95 km at the equator; the low temperatures affect the photochemistry of ozone in such a way that the ozone is high. The magnitude and occurrence of the high ozone fit well with current understanding of ozone photochemistry.

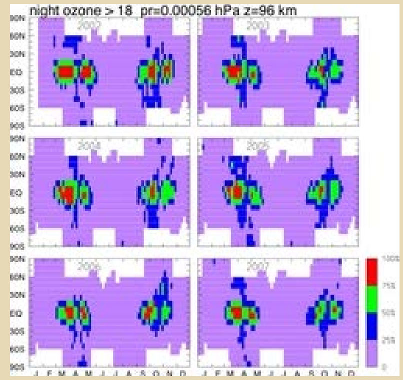


Figure 1: Latitude and day distribution of the incidence of ozone mixing ratio over 18 ppm at about 96 km (near the mesopause). The observations are from TIMED/SABER, nighttime only. The high ozone occurs near the equator during equinoxes, which is when the diurnal tide has its largest amplitude. At this altitude, the tidal phase is such that the coldest temperatures occur during the night. With colder temperature, the ozone production rate is faster and the loss rate is slower so the overall amount increases.

High resolution figure

return to top

UTLS dynamics, trends, and composition

Stratospheric temperature trends

ACD scientists helped organize an updated assessment of stratospheric temperature trends, based on radiosonde, satellite and lidar measurements. This work was performed over the last several years in collaboration with a group organized under the WCRP SPARC Program. Satellite data include measurements from the series of NOAA operational instruments, including the Microwave Sounding Unit (MSU) covering 1979-2007 and the Stratospheric Sounding Unit (SSU) covering 1979-2005. Radiosonde results were compared for six different data sets, incorporating a variety of homogeneity adjustments to account for changes in instrumentation and observational practices. Temperature changes in the lower stratosphere show cooling of ~0.5 K/decade over much of the globe for 1979-2007. Substantially larger cooling trends are observed in the Antarctic lower stratosphere during spring and summer, in association with development of the Antarctic ozone hole. Trends in the middle and upper stratosphere have been derived from updated SSU data, taking into account changes in the SSU weighting functions due to observed atmospheric CO2 increases. The results show mean cooling of 0.5-1.5 K/decade during 1979-2005, with the greatest cooling in the upper stratosphere near 40-50 km. Temperature anomalies throughout the stratosphere were relatively constant during the decade 1995-2005. These observations will be utilized for detailed

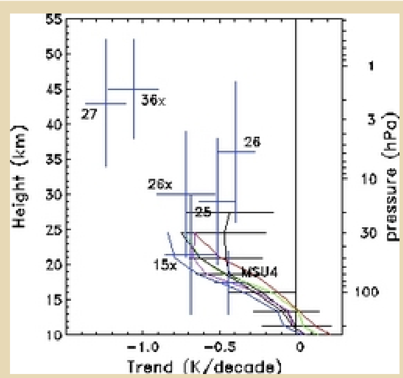


Figure 1. Vertical profile of near-global (60° N-S) stratospheric temperature trends for 1979-2005 derived from satellite and radiosonde measurements. Blue crosses denote results derived from MSU and SSU satellite data, with the vertical bars denoting the approximate altitudes covered by

comparisons to model results within the SPARC CCMval Project.

Forcing of the tropical Brewer-Dobson circulation

The Brewer-Dobson upwelling in the tropical lower stratosphere is a dynamically-forced phenomenon, with a pronounced annual cycle leading to seasonal variations in stratospheric temperature, water vapor and other constituents. ACD scientists used diagnostic studies to quantify the dynamical forcing of large-scale upwelling in the tropical lower stratosphere, based on circulation statistics from ERA40 and NCEP/NCAR reanalysis data. Zonal mean upwelling derived from momentum balance and continuity (so-called downward control) was found to be in reasonable agreement with independent calculations based on thermodynamic balance. The detailed momentum balances associated with the dynamical upwelling were investigated, in particular the contributions to climatological wave forcing (EP flux divergence) in the subtropics. Results showed that the equatorward extension of extratropical waves (baroclinic eddies and, in the NH, quasi-stationary planetary waves) contribute a large component of the subtropical wave driving near the tropical tropopause. Additionally, there is a significant contribution of forcing from equatorial planetary waves forced by tropical convection. The observed balances demonstrate that the strong annual cycle in upwelling across the tropical tropopause is forced by subtropical eddy momentum flux convergence associated with waves originating in both the tropics and extratropics. Additionally, tropical upwelling is found to systematically increase in simulations of future climate. (link)

Transport and chemistry of the Asian monsoon anticyclone

The Asian monsoon anticyclone is a region of persistent pollution in the upper troposphere during Northern Hemisphere summer, resulting from vertical transport of surface pollution in deep convection, and confinement by the strong anticyclonic circulation. This circulation extends into the lower stratosphere, and may be an important mechanism for troposphere-stratosphere coupling. ACD scientists used short-lived chemical species measured by Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) to explore chemical behavior of the Asian monsoon anticyclone. The climatology of carbon monoxide (CO) measured by ACE-FTS shows a local maximum in the Asian monsoon anticyclone region (Fig. 1). Other short-lived species measured by ACE-FTS, such as hydrogen cyanide (HCN), ethane (C_2H_6) and acetylene (C_2H_2), which have common sources of biomass burning, show maximum enhancement inside the anticyclone near the tropopause (Fig. 2a). The photochemical age of air was estimated by the ratio of C_2H_2/CO, indicating that air inside the anticyclone is relatively young (Fig. 2b), i.e. this air has was recently transported from lower altitudes. Ongoing work is aimed at understanding the transport pathways within the monsoon region, and quantifying the effect of convective transport and large-scale circulation in the UTLS region.

Microphysics parameterization for CAM

ACD and CGD scientists have been leading a collaborative development effort for a new microphysics parameterization for CAM. The goal of this effort is to develop an advanced microphysics package which can represent the size of cloud drops, and simulate how cloud drops are influenced by the distribution of aerosols. The ultimate goal is to quantify aerosol indirect effects in CAM and CCSM. This work dovetails with other studies in ACD, MMM and CGD of cloud microphysics, both in observations and in models. An important component of the broader activity is the development of better satellite data sets of cloud microphysical properties for comparing the CAM and WACCM simulations to observations. This work has recently been extended to treat the effects of ice clouds and ice cloud aerosol interactions.

Evaluating model simulations of the Tropical Tropopause Layer

ACD scientists and collaborators also analyzed the representation of the Tropical Tropopause Layer (TTL) in global models. Comparisons of a number of diagnostics with observations indicate that global models are capable of representing TTL structure and variability well on many scales. TTL structure in 13 different chemistry - climate models has been analyzed, and the performance of the models and their representation of the past and future explored. Comparisons indicates that convection within the TTL itself is not

separate instrument channels. Colored curves show trends derived from different radiosonde data sets up to ~25 km. Horizontal bars denote 2-sigma statistical trend uncertainties.

High resolution figure

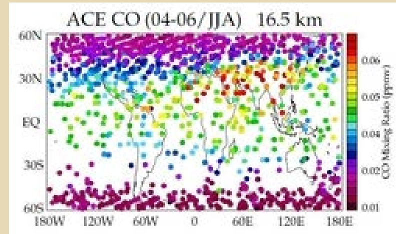


Figure 2. Carbon monoxide (CO) mixing ratios at 16.5 km (~100 hPa) obtained from Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) from June to August 2004-2006. The upper tropospheric CO is enhanced over the Asian monsoon anticyclone (From Park et al., 2008).

High resolution figure

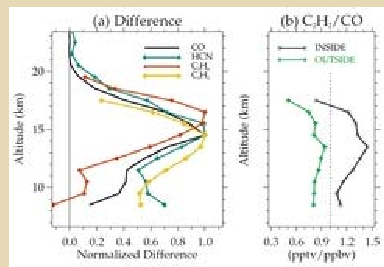


Figure 3. (a) Normalized difference between average profiles of carbon monoxide (CO), hydrogen cyanide (HCN), ethane (C_2H_6) and acetylene (C_2H_2) inside and outside of the Asian monsoon anticyclone. (b) Vertical profiles of ratio of C_2H_2/CO inside and outside of the anticyclone (From Park et al., 2008).

High resolution figure

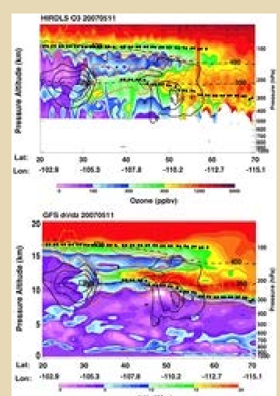


Figure 4. Cross section along the HIRDLS FOV track (shown on the NA map in Figure 5a) on May 11, 2007. The layer structure of the intrusion is consistently shown in the ozone cross section measured by HIRDLS (upper) and the PTLR cross section based on the GFS

critical for TTL structure, though convection below the TTL is important. Most models predict the tropical tropopause will get higher and slightly warmer in the 21st century. ACD scientists are continuing this work on evaluating tropopause behavior in global models within the SPARC CCMval Project.

ACD scientists are also leading an effort to develop a community model diagnostic package for use internally and by the community for coupled chemistry climate models. This includes developing advanced techniques for modifying model output, and utilizing satellite simulators to better represent observations and evaluate model simulations.

Transport from troposphere to stratosphere associated with the secondary tropopause

It has long been recognized that the temperature lapse rate based thermal tropopause definition produces breaks and multiple tropopauses in the extratropics. Recent analyses using global high resolution GPS data has shown that the area of double tropopause is much more extensive than previously realized. ACD scientists used newly available satellite data from HIRDLS to explore the connection between the occurrence of the secondary tropopause and chemical transport from troposphere to stratosphere. Figure 4 shows an example of low ozone layer above the primary extratropical tropopause and below the secondary tropopause, which is an extension of the tropical tropopause. A similar structure is also found in the potential temperature lapse rate, derived from the NCEP/GFS meteorological analyses, for the same cross section. (Pan et al., submitted, 2008)

This observation of relationship between the chemical structure and the meteorological field made it possible for the development of a forecast tool for aircraft observations, which in turn allowed successful in situ observations of this intruding tropospheric layer during the START08 experiment. Figure 5 shows an example measurement from the NCAR GV research flight on April 18, 2008, including meteorological analyses and in situ measurements. As indicated by Figure 4, the flight successfully observed an extensive layer of intruding tropospheric-like air between the two tropopauses. The large suite of chemical species measured will help characterizing the chemical impact of this type of event. The analyses of these new data will be the focus of next year.

Linking pollution with aerosols and clouds

In collaboration with Jonathan Jiang (Jet Propulsion Laboratory), ACD scientists analyzed MLS and MODIS data to quantify relationships between CO in the upper troposphere (an indicator of pollution) and cloud characteristics (MLS ice water content and MODIS effective cloud radii). Figure 7 shows the relationships between MODIS ice effective radii and MLS ice water content (IWC) for clean and polluted clouds over the Amazon during the wet and dry seasons. “Clean clouds” are those for which (by definition) MLS CO at 215 hPa is less than 120 ppbv, while “polluted clouds” have CO greater than 240 ppbv. MODIS aerosol is fairly constant during the wet season for the full range of MLS CO (since precipitation process scavenge aerosol). In the dry season MODIS aerosol increases as MLS CO increases. Therefore, differences in the dry and wet season panels are expected and observed. The results show that MODIS effective radii are systematically smaller in polluted clouds, demonstrating the so-called aerosol indirect effect.

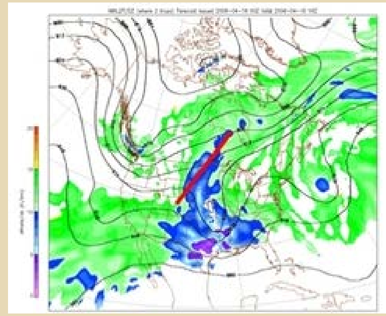
HIRDLS cloud measurements

ACD scientists also led validation and analysis efforts for measurements of clouds from HIRDLS data. Figure 6 presents a comparison of cloud frequency in the tropical upper troposphere from HIRDLS and CALIPSO measurements. The magnitudes and geographical distributions are very similar, which demonstrates that both experimental data sets can be used to determine the occurrence and seasonal variations of cirrus near the tropopause in a convincing manner.

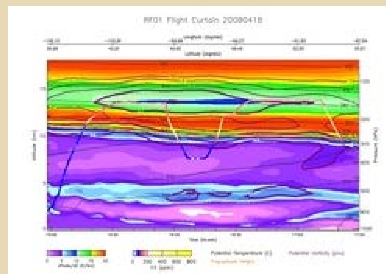
return to top

analyses (lower). The GFS analyses thermal tropopause (black dots), zonal wind (black contour), 350 and 400 K isentropes (black broken) and PV (2, 4, 6, and 8 pvu) contours are shown on the cross sections.

High resolution figure



High resolution figure 5a



High resolution figure 5b

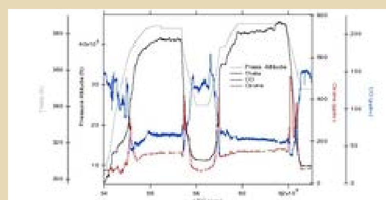


Figure 5. Sandwiched stratosphere sampled by NCAR GV during START08 April 18, 2008. **(a)** The region of double tropopause over North America based on high resolution NCEP/GFS meteorological analyses. The colors represent the minimum potential temperature lapse rate (dq/dz (K/km)) between the two tropopauses. The red line marks the segment of the flight track shown in panel (b and c). **(b)** Cross along the flight track with potential temperature lapse rate (color image), potential vorticity (purple contours), potential temperature (black contours) and the GV flight track (colored by the ozone values). **(c)** GV measurements during the segment including pressure altitude (gray), potential temperature (black), ozone (red) and carbon monoxide (blue).

High resolution figure 5c

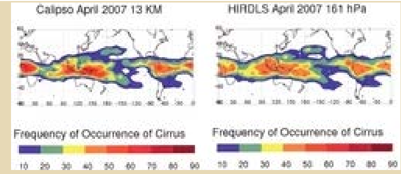


Figure 6. Comparison of HIRDLS and CALIPSO cloud occurrence frequency in April 2007.

High resolution figure

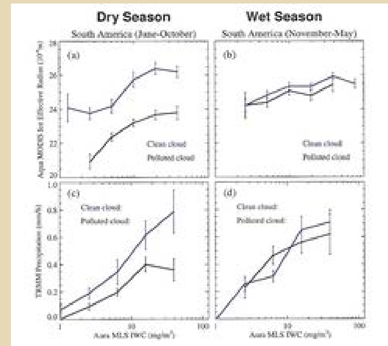


Figure 7. MODIS ice effective radii for clean and polluted clouds.

High resolution figure

Gravity Waves

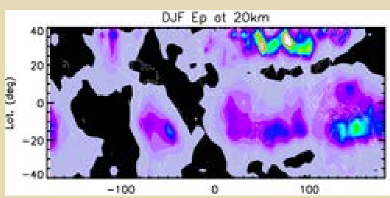


Figure 1: Potential energy density of gravity waves with zonal scales between 100-1600km averaged over December-February, derived from NRCM simulations.

High resolution figure

The goal of the NCAR Nested Regional Climate Model (NRCM) is to study processes across a wide spectrum of scales in the climate system. In the current NRCM setup, the NCAR Weather Research and Forecast (WRF) model is one-way nested in the NCEP reanalysis between 45S-45N, with vertical domain between the ground and ~10hPa. The horizontal resolution of the model is 36km (with two level nesting over Indonesia archipelago at horizontal resolution of 12km and 4km). Afforded by the high spatial resolution, we would like to explore gravity waves generated from the NRCM simulations, especially their spatial distribution and seasonal variability, and compare them with observations.

Han-Li Liu (HAO/TIIMES) and Jimy Dudhia (MMM) analyzed one year of NRCM (Columbia) simulations. Using wavelet method, they studied the global distribution and seasonal variability of the potential energy density, momentum flux and energy flux of gravity waves with zonal scales between 100-1600km. They also compare these results with those derived from satellite observations (GPS, SABER, CRISTA, and HIRDLS), and found good agreement between model results and observations. For example, strong gravity waves are identified over Western Pacific/South East Asia, Indian Ocean, West Africa, and Central America at low latitudes, similar to those revealed by GPS measurements and most likely related to tropical convection. Peak momentum flux of ~2x10-3 Pa over the Western Pacific/South East Asia is consistent with estimate from HIRDLS measurement. Their analysis also shows that the gravity waves display clear scale dependence: The potential energy density of gravity waves at low latitudes increases with zonal scale while those associated with orographic waves at mid-latitudes decreases with zonal scale. They also found that the quality of the simulation results deteriorates above ~20km because of the rapid decrease in vertical resolution and significant wave reflection from the model top.

They plan to compare the gravity wave sources from NRCM with those obtained from physics based gravity wave parameterizations recently implemented in WACCM. This will help improving gravity wave parameterization used in global models.

Gravity Wave Forcing and Wind Balance in the Mesosphere and Lower Thermosphere

Gravity waves are believed to significantly impact the mesosphere and lower (MLT) thermosphere and drive it off radiative equilibrium. This has been predicted by theoretical and general circulation models, but direct measurement or inference of gravity wave forcing prove to be a challenge.

In this study by Han-Li Liu (HAO/TIIMES), Dan Marsh (ACD), Qian Wu

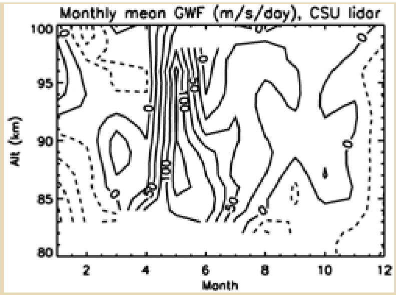


Figure 2: Monthly mean gravity wave forcing in the zonal direction derived from CSU lidar wind measurements. Contour interval: 25ms-1day-1. Solid contour: eastward forcing.

High resolution figure

(HAO), Chiao-Yao She (Colorado State University), and Jiyao Xu (Chinese Academy of Sciences), the wind balance in the mesosphere and lower thermosphere is revisited. Using simulation results from the NCAR Whole Atmosphere Community Climate Model (WACCM), they demonstrate geostrophic balance is no longer valid in the zonal direction due to the large zonal gravity wave foricng. As a result, the zonal mean geostrophic meridional wind is significantly different from the actual zonal mean meridional wind, and the residual mean merdional circulation derived from geostrophic winds is much weaker than that derived from model winds. It is also shown that the ageostrophic contribution in the MLT at middle and high latitudes comes primarily from gravity wave forcing, and it is possible to infer gravity wave forcing in the MLT from wind measurements. As a proof of concept, this wind balance relationship is applied to both the TIMED/TIDI winds and wind climatology obtained from the CSU Na-lidar to derive gravity wave forcing (Figure 2).

The next step in the research is to obtain wind climatology from multiple radar site at middle and high latitudes and also from more comprehensive satellite measurements to obtain a more comprehensive climatology of gravity wave forcing at middle and high latitudes.

return to top

Weather Research and Forecast model coupled with Chemistry (WRF-Chem)

The Weather Research and Forecasting (WRF) model coupled with Chemistry (WRF-Chem) has been and continues to be developed by NOAA scientists, in collaboration with the WRF community including NCAR/ESSL scientists. The model is used for investigation of regional-scale air quality, field program analysis, and cloud-scale interactions between clouds and chemistry. ESSL scientists and staff provide support by integrating and maintaining the chemistry components in the evolving WRF modeling system, as well as contributing new code in the development of WRF-Chem. Models such as WRF-Chem are used to further the understanding of precipitation and chemical processes, including multiscale atmospheric chemical constituent transport, dispersion and transformations. Because WRF-Chem is able to simulate the coupling between dynamics, radiation, chemistry and aerosols, science issues that depend on these interactions are being pursued.

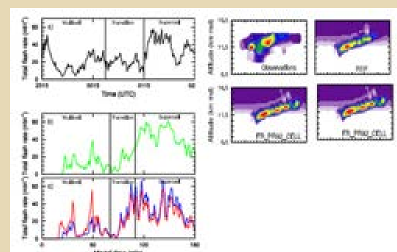


Figure: Left panel: a) Observed flash rate for the 10 July 1996 STERAO storm, b) flash rate predicted by WRF-AqChem as a function of the flux of ice crystals multiplied by the flux of precipitating ice, c) flash rate predicted by WRF-Chem using the Price and Rind (1993) equation based on maximum vertical velocity. The new parameterization based on the flux product has good agreement with the observations. Right panel: Nitric oxide (NO) mixing ratio (pptv) across the observed storm anvil and the simulated storm anvil. The location of the cross-section is 50 km downwind of the convective storm core. The production of nitrogen oxide from lightning as predicted using the flux product lightning flash rate results in good agreement with observations and reinforces the need to use parameterizations that are physically-based with the processes occurring in nature. The role of convection as a source of nitrogen oxides is important for understanding the sources and sinks of ozone in the upper troposphere where ozone affects the radiation balance and oxidizing power of the atmosphere.

High resolution figure

In April 2008, version 3 of WRF-Chem was released to the community. This version included new modules provided by NCAR/ESSL scientists. These modules are the Model of Emissions of Gases and Aerosols from Nature (MEGAN) which allows scientists to study interactions between the biosphere and atmosphere with impacts on air quality and climate, and the photolysis rate module, fast TUV, which performs a simplified, but accurate, radiation calculation of actinic fluxes. With this addition, WRF-Chem now has 3 options for the photolysis rate calculation. ESSL scientists are currently evaluating these 3 options with the MIRAGE field campaign measurements and are improving the coding to be more efficient.

Continued development of new modules for WRF-Chem addresses several aspects of the model. These include evaluating the new dust module, creating a framework to test different secondary organic aerosol chemistry schemes from complex to simple, developing a chemical tracer package that allows more flexibility for investigating sources of key chemical constituents, and creating a new and implementing old parameterizations of lightning-production of nitrogen oxides to be used at both the cloud scale and continental scale. In addition, the chemistry mechanism from the NCAR/ACD global model MOZART is being incorporated in WRF-Chem. This will allow us to contrast regional-scale and global-scale analyses of field campaigns and chemical weather using the same chemistry at both scales.

Simulations performed with WRF-Chem making use of the version 3 modules and ongoing development are focused on megacity impacts on the regional-scale air quality, the effects of thunderstorms on the upper troposphere composition, and the impact of wildfires on regional air quality. MIRAGE field campaign analysis with WRF-

Chem has shown the importance of dust in cleansing the atmosphere via uptake of nitric acid and the significant role of secondary volatile organic compounds on ozone production downwind of Mexico City. Simulations of thunderstorms and chemistry have shown that air mass thunderstorms simulated for the northern Alabama region transport boundary layer CO throughout the free troposphere while more organized storms simulated for Oklahoma and northeastern Colorado transport CO directly to the upper troposphere. These simulations are being done in preparation for the Deep Convective Clouds and Chemistry field experiment. Other WRF-Chem simulations are addressing deep convection during the North American monsoon, wildfires in Greece affecting European air quality, and air quality in the Shanghai region to prepare for a future mega-city field campaign. This work is supported by the NSF, NCAR-MIRAGE strategic initiative funds, and NASA.

return to top

Stratospheric ozone recovery

A study using WACCM and other models with interactive chemistry looked at the predictions for climate change in the Southern Hemisphere. In particular, the study addressed the predictions for winds in the SH middle and high latitudes. There is a clear difference in the climate predictions of models that do not include interactive stratospheric chemistry and those that do. The difference can be traced to the simulation of the ozone hole. When interactive chemistry is not included, winds continue to accelerate in a manner consistent with observations in recent years. However, in model simulations with interactive chemistry and a full stratosphere, the Antarctic ozone hole recovers during the 21st century due to the predicted drop in halogens in the stratosphere. This changes the thermal structure since ozone is an important radiative gas. With ozone recovery, polar temperatures warm and winds decelerate such that the overall prediction for the climate in the southern high latitudes is significantly different.

return to top

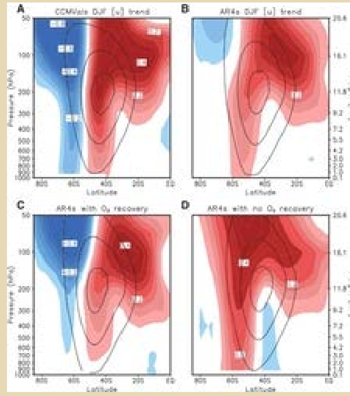


Figure 1: Trends in December-to-February zonal-mean zonal wind. The multimodel mean trends between 2001 and 2050 are shown for four groups of models. A) CCMVal models, which include interactive stratospheric chemistry. B) AR4 models, most of which have a model top below the stratopause and only about half of which specify recovering ozone for the future. C) a subset of the AR4 models with prescribed ozone recovery. D) AR4 models with no ozone recovery. Shading and contour intervals are 0.05 ms-1 decade-1. Deceleration and acceleration are indicated with blue and red colors, respectively, and trends weaker than 0.05 ms-1 decade-1 are omitted. Superimposed black solid lines are DJF zonal-mean zonal wind averaged from 2001 to 2010, with a contour interval of 10 ms-1, starting at 10 ms-1. EQ, equator. Note that AR4 models with prescribed ozone recovery (panel C) perform better, as compared to CCMVal models, than those without (panel D), but still do not reproduce the full extent of the prediction.

High resolution figure

WACCM (Whole-Atmosphere Community Climate Model)

ACD work using the WACCM model involves an extensive set of collaborators from other ESSL divisions and externally from US and international institutions.

The model was used for a global simulation of dust particles from meteors hitting the Earth's atmosphere. The simulations show that the summer high-latitude mesosphere is relatively depleted in these particles due to large scale upwelling. The number of particles may still be sufficient to supply the necessary condensation nuclei to account for the formation of polar mesospheric clouds.

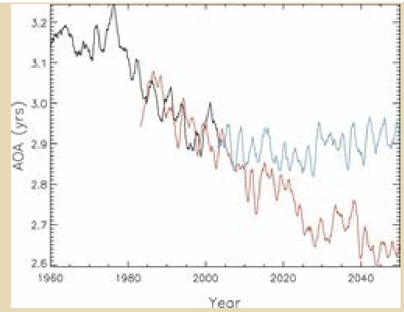


Figure 1: Evolution of the age of air near 10 hPa averaged over +/-22° for three-member ensemble simulations (i.e., three integrations of WACCM) of the climate of the twentieth century (black curve); the climate of the twenty-first century under increasing loading of greenhouse gases (red); and the climate of the twenty-first century with greenhouse gases held constant at 1995 values (blue). The decreasing age of air is an indication that the circulation is faster.

High resolution figure

Another set of simulations used WACCM to assess the impact of the insertion of sulfur into the stratosphere: one of several suggested "geo-engineering" activities to counteract the predicted climate change from greenhouse gases. The sulfur would form particles that absorb and reflect sunlight, thereby reducing the solar heating at the Earth's surface in a manner similar to large volcanic eruptions. As shown by the WACCM simulations, the sulfate particles do delay the warming at the surface compared to other simulations without the injected sulfur. However, the sulfur would also accelerate the ozone loss that occurs in late winter over Antarctica and would increase the ozone loss over the northern polar region.

According to WACCM simulations, a regional nuclear conflict could also have severe consequences for stratospheric ozone. In this case, the primary effect would be the heating of the lower stratosphere due to thick and persistent smoke. The heating leads to photochemical loss of ozone. A conflict involving 100 bombs could lead to ozone losses of 20% globally, with predictions of more than 50% at high latitudes.

return to top

Intense photochemistry in the Antarctic troposphere

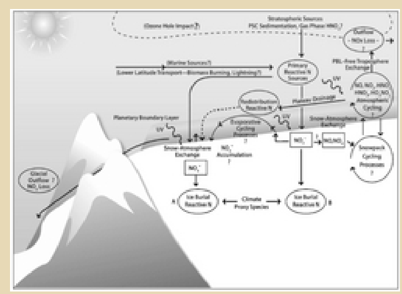


Figure 1. Schematic diagram illustrating the critical processes encompassing the reactive nitrogen budget for the Antarctic plateau. These include: primary sources, post-depositional loss mechanisms, and atmospheric/snow recycling. The symbol "?" displayed throughout the diagram suggests that currently there is only a qualitative understanding of many processes (from D.D. Davis et al., Atmospheric Environment, 42, 2831-2848, 2008).

High resolution figure

Antarctic Tropospheric Chemistry Investigation (ANTCI) was a collaborative four-year study of the sulfur chemistry in the antarctic atmosphere, including two antarctic summer field seasons in 2003-04 and 2005-06. The overall project involved thirteen principal and senior investigators at seven institutions. The broad based goal of this program was to enhance our understanding of the processes that control tropospheric levels of reactive hydrogen radicals, reactive nitrogen, sulfur, and other trace species over the Antarctic continent for the further purpose of improving the climatic interpretation of sulfur-based signals in antarctic ice core records. ANTCI was designed to address the many questions arising from the surprising findings of two earlier studies: Investigation of Sulfur Chemistry in the Antarctic Troposphere (ISCAT) and Sulfur Chemistry in the Antarctic Troposphere Experiment (SCATE). The former effort involved two field investigations (i.e., 1998 and 2000) at the South Pole (SP); whereas the latter study was carried out at Palmer Station on the coast of Antarctica. The general picture that emerged from these earlier studies was that although the oxidation of sulfur at coastal sites was a major component of the overall chemical system, one of the critical steps (e.g., involving the intermediate oxidation product dimethyl sulfoxide, DMSO) was largely controlled by heterogeneous processes. By contrast, at SP reactive gas phase sulfur was a rather minor chemical player with its oxidation being controlled by intense HOx/NOx photochemistry prior to reaching the pole. In fact, based on the ISCAT studies, much of the chemical environment at SP appeared to be dominated by fast photochemical processes. ANTCI was designed to further explore the mechanisms controlling the oxidation of sulfur under the quite different environmental conditions presented by these two sites. However, it was equally important to gain a more complete understanding of the detailed atmospheric processes controlling reactive nitrogen and HOx radical levels, and to determine the extent of the enhanced levels of these compounds.

ANTCI 2003 was the first of two studies designed to address the above issues. The first phase of ANTCI 2003 had both a large ground-based chemistry component and a limited set of aircraft chemistry measurements. The second phase (e.g., ANTCI 2005, to be discussed in later publications) was largely aircraft based with a far more complete set of aircraft photochemistry measurements, but it also had a ground-based winter-over sampling component at the SP. ANTCI 2005 was designed to study HOx/NOx chemistry over a substantial portion of the Antarctic plateau and coast under a range of different conditions. An additional goal was to explore possible primary sources of reactive nitrogen to the plateau.

Results from the ANTCI 2003 study were published in 2008 in Atmospheric Environment. The papers have a strong focus on the oxidative characteristics of the plateau's near surface atmosphere because it is this oxidation process that determines the products of reactive nitrogen, sulfur, mercury, and other gases that will characterize the trace composition of the Antarctic atmosphere, snow, and ultimately the ice core record. Model results show amazingly high OH concentrations for this dry, remote area with high solar zenith angle and 24 h of continuous solar activity. These are mainly driven, as previously shown at the SP during ISCAT, by highly elevated NO levels. The latter were a major surprise as were the enhanced concentrations found for other OH/HOx precursors, including H2O2 and CH2O. In each case, these precursors were found to be emitted from the snow surface. The aircraft observations supplied the first extensive horizontal and vertical distributions for NO on the plateau. In so doing, they demonstrated that the major enhancements observed at SP are not an artifact of the station area but rather tend to be typical of a significant region of the plateau. They also provided the first upwind history of NO emissions, allowing estimates of how NO and O3 concentrations can grow during transport to the SP.

return to top

Severe atmosphere convection

Severe convective weather, including tornadoes and severe wind gusts, impacts life and property throughout the world. In the United States, severe convective weather results in hundreds of deaths every year. ESSL scientists study the processes by which thunderstorms produce severe weather with the goal of understanding and better predicting their occurrence.

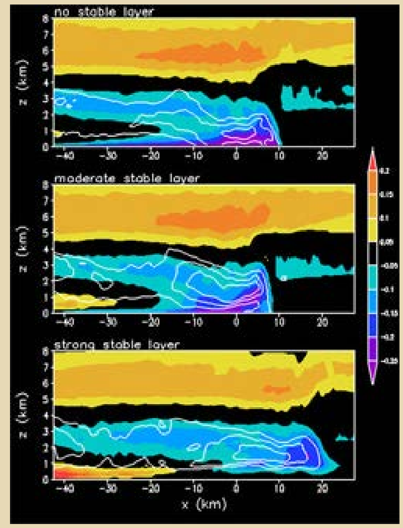


Figure: Vertical cross sections through three simulated convective systems. Top: no surface stable layer. Middle: a moderate stable layer. Bottom: a strong stable layer. Shading is buoyancy with respect to the environment, showing how cold air develops in the near-neutral layer above the surface, but only reaches the ground if the stable layer is not too strong. White contours show strong wind speeds, which also reach the ground if the stable layer is not too strong.

High resolution figure

Several ESSL scientists participated in the 2008 Spring Experiment, which is held annually in Norman, Oklahoma. This program brings together researchers and forecasters to evaluate experimental severe weather forecasting techniques in real-time. In support of the experiment, ESSL scientists developed a real-time WRF forecasting system using a 3-km grid. A significant advancement this year was the use of mesoscale data assimilation based on the WRF-3DVAR system, which allows for detailed representation of severe convection in the model’s initial conditions. Results show that inclusion of mesoscale data assimilation improved many forecasts, even in the 24-36 hour timeframe. However, in some cases the modeling system initialized storms that were too intense and lasted too long, which had a detrimental effect on some forecasts. Further work is planned to identify and eliminate the sources of this anomalous convection.

Through the STEP (Short Term Explicit Prediction) program, ESSL scientists collaborated with EOL and RAL scientists to develop new methods for producing 0-12 hour forecasts of high-impact weather. For example, one method being investigated is ensemble forecasting with numerical models that produce convective storms explicitly. One of the recent highlights for the STEP program was the IHOP retrospective study, in which experimental nowcasting and forecasting systems were demonstrated for a one-week period of active weather in June 2002. Results show that the ensemble forecasting system is able to accurately predict the regions where supercell thunderstorms occurred.

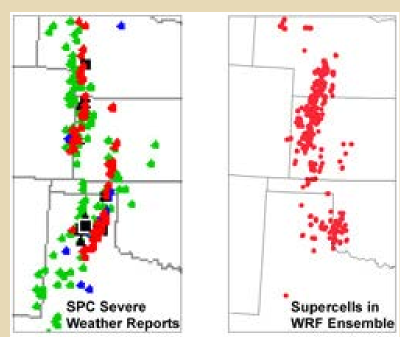


Figure: (Left) Severe weather reports logged by the Storm Prediction Center for 28 March 2007. Observed tornado locations are indicated in red. (Right) Supercell locations (red dots) at hourly intervals in a 3-5 hour WRF ensemble forecast. (Supercells are often associated with tornadoes.) The ensemble included 30 members, each employing 3-km

The production of severe convective winds at night remains a forecasting challenge. One reason is the formation of strong stable layers near the surface caused by radiative cooling. A study has investigated severe convective systems in these environments by analyzing observations and by conducting idealized numerical simulations. The study found that near-neutral layers above the stable layer are favorable for severe wind production. These near-neutral layers help increase conditional instability, but they also allow for the formation of cold pools above the stable layer. In some numerical simulations, cold pools develop downward from these near-neutral layers, sometimes leading to severe winds at the surface. The simulated convective systems are structurally similar to severe bow echoes even if they do not produce severe winds, which helps to explain the difficulty in identifying severe convective storms at night. Further research is planned to clarify the environmental conditions that can be used to better predict these events and the numerical model settings needed to accurately simulate them.

ESSL scientists have been collaborating with other scientists at NCAR, NOAA, universities, and private companies to plan the Verification of the Origins of Rotation in Tornadoes Experiment 2 (VORTEX2). This field experiment in the US Great Plains in May and June of 2009-2010 will investigate tornadogenesis, near-ground winds in tornadoes, relationships between tornadic storms and their environments, and numerical weather prediction of supercells and tornadoes. In addition to going to the field, ESSL scientists will be supporting this experiment through real-time high-resolution WRF numerical weather prediction.

model horizontal grid spacing.

High resolution figure

return to top

Intraseasonal/tropical climate variability

This year has seen considerable progress in understanding the interaction between organized precipitating convection and the large scales of motion. Our approach involves cloud-system resolving models (CRM), dynamical models, and observational analysis. The following summarizes work in which the organization of precipitating convection is a common factor.

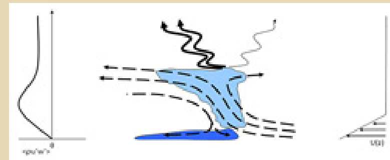


Figure: Variation in Major Hurricanes, Cat 4 and Cat 5 Hurricanes and Cat 5 Hurricanes for the North Atlantic as percentage change from the long-term mean (smoothed by a running 5-y filter, showing the unprecedented recent increase in category 5 hurricanes.

High resolution figure

a) Parameterization of convective organization in global models

The parameterization of convective organization in global models is a problem that has confounded the parameterization community for over three decades. It will be at least another decade before computational facilities are sufficient to enable convection to be represented explicitly in contemporary climate models, so parameterization is necessary. The new hybrid parameterization for next-generation global models (grid-spacing ~10 km) reported last year is relevant in the context of the Community Atmospheric Model (CAM) and the Community Climate System Model (CCSM). In the hybrid approach, mesoscale convective organization is represented explicitly by grid-scale circulations while small-scale convection is parameterized. Along with CRM analysis, this hybrid approach is a basis for constructing a parameterization of mesoscale convective organization. As a first step, the plan is to estimate the free parameters in the parameterization framework of Moncrieff and Liu (2006) using CRM simulations. A proposal has been written (PIs: Yaga Richer, CGD and Mitch Moncrieff, MMM) for support to develop and test the mesoscale parameterization. This is a collaborative effort between MMM, CGD, and the TIIMES Water Systems Program. This work is supported by NSF and, if the proposal is successful, will be supported by NOAA.

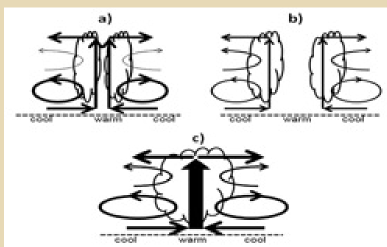


Figure: Variation in Major Hurricanes, Cat 4 and Cat 5 Hurricanes and Cat 5 Hurricanes for the North Atlantic as percentage change from the long-term mean (smoothed by a running 5-y filter, showing the unprecedented recent increase in category 5 hurricanes.

High resolution figure

b) Stratospheric gravity waves generated by multiscale organized tropical convection.

The objective here is to numerically simulate and model stratospheric gravity waves generated by organized precipitating systems, contrasting with previous work on wave generation by single clouds. This year the effects of tropospheric shear on convective organization and stratospheric gravity waves were investigated. The objective of this new study is to examine how mesoscale momentum transport (MMT) by organized convection relates to momentum transport by convectively-generated gravity waves in the stratosphere. (Gravity wave energy absorption is a major uncertainly in models of the deep atmosphere, such as WACCM.) Figure 1 shows that the convective momentum transport in the troposphere has the same sign as the gravity-wave transport in the troposphere. Consequently, when organized convection is represented in global models (see above item); the gravity-wave response in the stratosphere can be predicted. This research is collaborative with Todd Lane, The University of Melbourne, Melbourne, Australia. This work is sponsored by NSF.

c) Madden-Julian Oscillation (MJO) and convectively-coupled waves

A new study of explicitly simulated tropical convection over idealized warm pools aims at quantifying the relationship between the spatial pattern of organized tropical convection and sea-surface temperature (SST), and explaining the observation that the strongest convection is not located where SST is highest. The reason hinges on the effects of cloud-radiative interaction and surface friction on convective organization. Figure 2a, the control simulation contains both cloud-interactive radiation and surface friction. In Fig. 2b, where the radiative heating is horizontally uniform, organized convection shown by the cloud outlines is far displaced from the maximum SST in the center of the domain. In Fig. 2c, where surface friction is omitted, the convection occurs over the warmest SST. This shows that spatial pattern of convective organization is sensitive to the parameterization cloud-radiation interaction and surface friction. A paper by Liu and Moncrieff has been submitted to *J.G.R - Atmospheres.*

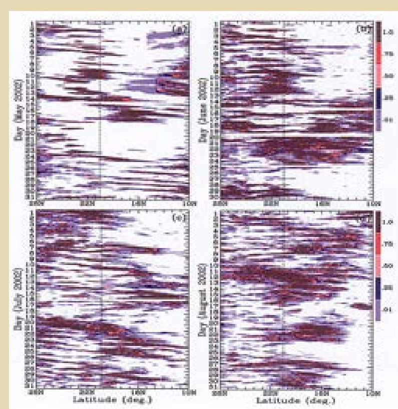


Figure: Time-space diagrams of the longitudinally-averaged rain rate over the Bay of Bengal, during part of the monsoon season. The streaks are mesoscale convective systems (MCS) propagating southward. Irregularly, the episodes cluster into larger-scale precipitation systems similar to the MJO. On these diagrams the broken lines show the average position of the northern coast of the Bay. [Courtesy Liu et al. 2008.]

High resolution figure

Propagating rainfall episodes associated with convectively-coupled waves over the Bay of Bengal analyzed from satellite data indicate multiscale convective organization similar to the MJO, suggesting a scale-invariance between the MJO and the episodes in the Bay. Figure 3 shows multiscale convective organization over the Bay during the monsoon season. The rainfall streaks consist of organized rainfall episodes (mesoscale convective systems) originating over the Indian continent and subsequently propagating southward over the Bay. Irregularly, the propagating episodes cluster into larger-scale systems morphologically similar to the multiscale structure of the MJO. Interestingly, the propagation direction of the MCS over the Bay of Bengal is parallel to the shear vector, which contrasts with the perpendicular orientation of MCSs at large. The shear-parallel organization stems the hydraulic effect of the convectively-generated pressure gradient on propagating systems, somewhat similar to density-current dynamics. The results were published in Liu et al. (2008).

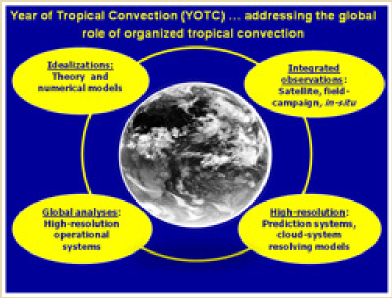


Figure: YOTC aims to improve the predictive skill of operational models by addressing convective organization on spatial scales up to global and time scales up to sub-seasonal (the intersection of weather and climate) using: i) global analyses from high-resolution operational systems; ii) high-resolution prediction systems and cloud-system resolving models; iii) integrated satellite, field-campaign and in situ observations; iv) theoretical and idealized models.

High resolution figure

The above research was supported by NSF.

d) Year of Tropical Convection (YOTC)

Incomplete knowledge and practical issues relating to tropical convection severely disadvantage the skill of numerical weather prediction models and climate models Furthermore, tropical convection has long-range effects on stratospheric-tropospheric exchange, the large-scale circulation of the upper-atmosphere, and the variability of weather and climate around the world. In order to address this major challenge, WCRP and WWRP/THORPEX proposed a year of coordinated observing, modeling, and forecasting, which led to the Year of Tropical Convection, YOTC. The theme of YOTC is the role of organized tropical convection at large scales. Together with accompanying research activities, the YOTC seeks to advance knowledge, diagnosis, modeling, parameterization, and prediction of multi-scale tropical convection and two-way interaction between the tropics and extra-tropics. The YOTC project will exploit the vast amounts of existing and emerging observations, the expanding computational resources, the new, high-resolution modeling frameworks, and theoretical insights (see Fig. 4). This activity involves unprecedented collaboration between international programmatic activities, the operational prediction, research laboratory, and academic communities. Global databases of satellite data, in-situ data, and high-resolution model analysis and forecasts will be constructed. Emphasis is on timescales ranging from days-to-months; that is, the intersection of weather and climate. The following objectives were achieved this year: i) the ECMWF T799 (25 km) global analysis, forecast products, and special diagnostics being archived at ECMWF will be available to the community; ii) the YOTC Science Plan was drafted; iii) the YOTC Implementation Plan is in the first stage of development. Started in May 2008, YOTC will contribute to the Asian Monsoon Year (AMY), the THORPEX Pacific Area Regional Campaign (TPARC), the United Nations Year of Planet Earth, and the International Polar Year. The scientific basis for YOTC is published in Moncrieff et al (2007), and a brief summary is published in Waliser and Moncrieff (2007). The YOTC work is collaborative between MMM and TIIMES.

return to top

RT/MHD modeling of the solar surface layers

The solar photosphere is a transition region in which the primary energy transport mechanism switches from convection to radiative transfer. At the same time the plasma becomespartially ionized, due to the lower temperatures requiring a more complicated equation of state. Also, the role of the magnetic field is changing: while the interior of the sun is dominated by the gas pressure, in or above the photosphere the magnetic pressure becomes the dominant contribution. Due to the rather short density scale height the photosphere is a highly stratified medium in which convective motions easily steepen up to supersonic flows and shock waves. The combination of all these conditions make numerical modeling of the photosphere challenging, but also extremely interesting due to the strong interaction between convection, magnetic field; and radiation, and the possibility for in depth comparison with high resolution observations.

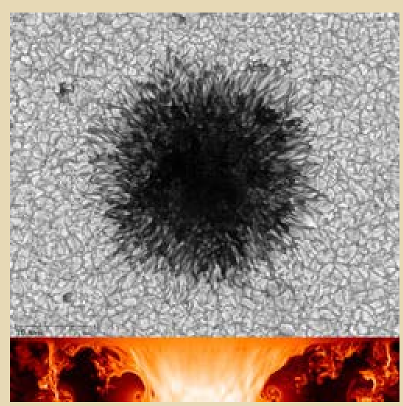


Figure 1: Snapshot of a numerical simulation in a domain of 50x50x8 Mm containing a sunspot of about 25 Mm diameter. The top shows an intensity map (visible light image) of the simulated spot showing the central dark umbra with a few bright umbral dots.

During the past year,HAO, in collaboration with the Max-Planck Institute for Solar System Research (MPS) in Germany, modified the MURaM MHD code to specially deal with the numerical challenges encountered in regions of strong magnetic field in the photosphere. This new code has been used to study the fine structure of sunspots, especially the filamentary structure of the penumbra. The numerical simulations have identified a magneto-convective origin of penumbral filaments in which expansion and flux expulsion due to overturning convective motions leads to a filamentary structure characterized by reduced magnetic field strength, increased inclination angle and horizontal outflows. The simulated penumbral structure corresponds well to the observationally inferred interlocking-comb structure of the magnetic field with Evershed outflows along dark-laned filaments with nearly horizontal magnetic field and roll-type perpendicular motions, which are embedded in a background of stronger and less inclined field.

Future research in this field will focus on high resolution simulations that allow for more detailed comparison to observations such as Hinode. Simulations of full sunspots in larger domains will address the global structure of sunspots and their surroundings. Results from these simulations are also essential for the development of more advanced helioseimic inversion methods.

return to top

The umbra is surrounded by a filamentary penumbral region formed by filaments of a few Mm in length. The outer parts of the domain show granulation with a few pores formed from magnetic flux that got eroded of the sunspot. The bottom panel shows the field strength on a vertical slice through the center of the spot. The maximum field strength at the bottom of the domain is 8kG, the field strength in the umbra of the spot reaches a peak value of 3.5 kG in the center.

High resolution figure

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ESSL LAR 2008: STRATEGIC GOAL #1, PRIORITY #1

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #1, Improve understanding of the atmosphere, the Earth system, and the Sun. This Strategic Goal encompasses four Strategic Priorities, each of which is dependent on the efforts and accomplishments of ESSL staff.

ESSL developed an action plan with seven priority themes which involve direct partnerships with the university community and contribute directly to the ESSL Strategic Vision and to several priority items of the NCAR Strategic Plan.

ESSL's seven priority themes:

1. Climate projection, with emphasis on short-term prediction.
2. Biosphere-Atmosphere-Hydrosphere interactions and specifically development of BEACHON Project (Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, Hydrology, Organics and Nitrogen).
3. Water system research, specifically the development of the Society, Water, Atmosphere and Natural Systems Project (SWANS).
4. An advanced Weather Research and Forecasting system, specifically the development of the Hurricane Intensity and Forecasts (HiFi) Project.
5. Space Weather, specifically the development of the Coronal Solar Magnetism Observatory Project (COSMO).
6. Chemical Weather, including interpretation of observed data gathered during the Megacity Impact on Regional and Global Environments (MIRAGE) campaign, and the development of a capability for chemical data monitoring and prediction.
7. Prediction across scales, specifically the development of an advanced next-generation, climate-weather modeling system and an integrated Earth system model of intermediate complexity.

Goal # 1, Strategic Priority #1: Exploring atmospheric, Earth system, and solar processes, variability, and change, is defined in the NCAR Strategic Plan as follows: "Developing a better understanding of atmospheric, Earth system, and solar processes, as well as the variability and change associated with these processes....Exploration of these "Priority 1" areas focuses on three key activities: simulating the Earth system's natural variability, investigating the Sun's magnetic-flux eruptions, and understanding effects of gravity waves, including related interactions between the upper troposphere and lower stratosphere."

This NCAR priority, driven by ESSL's themes 2, 5, 6, & 7, is critical to achieving NCAR's first strategic goal.

The section below describes specific research conducted by ESSL staff relevant to Priority 1. The major ESSL activities in this area are studies of paleoclimate, solar dynamo and solar cycle, chemistry and dynamics of the UTLS and middle and upper atmosphere, solar magnetic flux emergence and CME initiation, global air quality, the impact of environmental changes on tropical cyclones, climate variability, and various aspects of the solar interior, the lower solar atmosphere, and the solar corona and wind.

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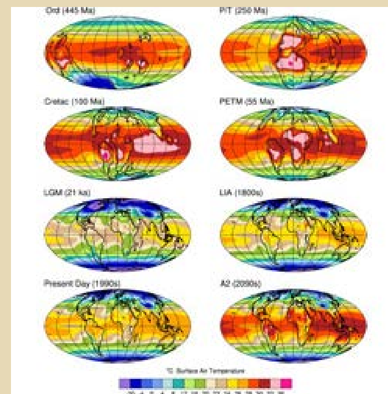
12. MHD physics of the solar corona and wind - HAO
13. Chemistry and dynamics of the middle and upper atmosphere - ACD
14. UTLS dynamics, trends, and composition - ACD
15. Gravity waves - TIIMES
16. Weather Research and Forecast model coupled with Chemistry (WRF-Chem) - MMM
17. Stratospheric ozone recovery [Whole-Atmosphere Community Climate Model (WACCM)] group - ACD
18. WACCM - ACD
19. Intense photochemistry in the Antarctic troposphere - ACD
20. Severe atmosphere convection - MMM
21. Intraseasonal/tropical climate variability - CGD
22. RT/MHD modeling of the solar surface layers - HAO

Paleoclimate

Overview



High resolution figure

Paleoclimates offer a unique perspective to understand both Earth's climate sensitivity and stability. Observational data tell us that Earth has experienced a wide range of climates over various time scales, and that transitions in Earth's climate can take place rapidly. We know that many of these past climates were determined by changes in external forcing factors. To the extent that climate models can reasonably simulate past warm and cold climates, we gain confidence that the models can be used to study Earth's future climate.

A strong test of the Community Climate System Model (CCSM) is to simulate past climate against records from ice cores, tree rings, and other proxy data. Magnitudes and rates of past change also provide an important context for future climate changes. Within ESSL, we are exploring past changes over many different time periods: from the distant geologic past, with radically different continental configurations, when the Earth's surface temperature and latitudinal gradients were significantly different from present and levels of atmospheric carbon dioxide, methane, and other greenhouse gases reached levels up to ten or more times present levels; the last million years, when the Earth experienced a waxing and waning of ice ages and levels of atmospheric carbon dioxide, methane, and other greenhouse gases during the ice ages were reduced by half or more from present levels; and the last few millennia with colder periods extensively documented in the proxy record associated with solar fluctuations and volcanic eruptions. Each of these geologic periods gives us an improved understanding of the natural variability of the Earth system and our ability to model feedbacks in the climate system. By comparing climate simulations of Earth's past to the data from geological and geochemical archives, we can evaluate the accuracy of climate models such as CCSM that are used to look at Earth's future. At the same time, geologists have started to use CCSM to understand how their specific data can be understood in a more large scale, dynamical context. CCSM has become a valuable partner to field-based geological research.

Recent Accomplishments

CCSM has been applied to all these different time periods. The Late Ordovician (445 Ma) was a time of elevated carbon dioxide, but extremely cold climates. The first major extinction on Earth took place at this time. The CCSM3 has been configured to simulate the climate of this time period, in order to study the role that climate played in the mass extinction. The model will also be used to explore the growth of large continental glaciers on Gondwana, a large land-mass that occupied the southern hemisphere at this time. A CCSM3 simulation of the warm mid Cretaceous (100 Ma) has also been carried out to study how well the model can replicate the pole to equator gradient in surface temperature for this time period. Proxy records for the deglaciation that started 21 thousand years ago indicate events with large freshwater inputs to the Atlantic Ocean basin as iceberg discharges into the high-latitude North Atlantic, Laurentide meltwater input to the Gulf of Mexico, or meltwater diversion to the North Atlantic via the St. Lawrence River and other eastern outlets. The climate responded, in the North Atlantic region and globally, to these freshwater events, but the responses varied among the events and are not completely understood. The sensitivity of the climate system to the magnitude and location of freshwater input into the North Atlantic has been studied using the fully coupled version of CCSM3 for glacial conditions. The results suggest that the response of the North Atlantic meridional overturning circulation is proportional, though not linearly, to the size of the freshwater added. On the other hand, the southward migration of the ITCZ over the tropical Atlantic displays a threshold response to the amount of freshwater forcing and hysteresis in the response versus recovery from the event. This has implications for detecting freshwater events using the Cariaco Basin records.

2009 and Beyond

Future plans include further CCSM3 simulations of the climate of the Late Ordovician, a time of great cold and a time of the earliest mass extinctions of life. Future plans also include deep time simulations of the Latest Cretaceous a time period just prior to the massive asteroid impact that led to the demise of the dinosaurs. A CCSM3 run will be carried out of the first synchronously coupled transient ocean-atmosphere-dynamic vegetation GCM simulation of the past 21,000 years. Under the auspices of the Paleoclimate Modeling Intercomparison Project (PMIP), a CCSM3 simulation of the mid-Pliocene will be carried out. This time period is possibly the closest paleo analog for an equilibrium climate with current CO_2 levels. There will also be a focus on simulating the magnitudes and rates of past climate change on many time scales using the planned NCAR Earth System Model, which will allow us to explore more completely feedbacks with vegetation and ice sheets, atmospheric chemical changes, and the carbon and nitrogen cycles.

return to top

High Resolution Dynamics Limb Sounder (HIRDLS) recovery and application

The High Resolution Dynamics Limb Sounder (HIRDLS) is a 21 channel infrared limb scanning radiometer, jointly developed by ACD, the University of Colorado, and the Physics Department of Oxford University. It is designed to make observations of temperature, ozone, water vapor, and 8 other trace species, as well as PSC's, aerosols and cirrus clouds, from the upper troposphere to the mesosphere, with higher vertical resolution than has previously been available from space observations. HIRDLS was launched on the Aura spacecraft in July 2004. Despite an obstruction that limited the view to the atmosphere to a small fraction of the width of the optical beam, HIRDLS scientists demonstrated that there is recoverable atmospheric information in the signals, and worked hard to develop algorithms to correct for the effects of the obstruction, as discussed under Goal 5, section 4.

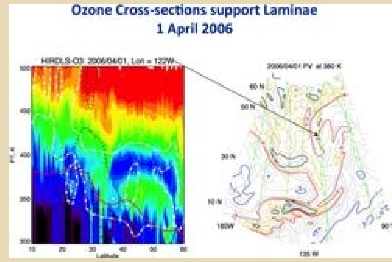


Figure 1.a. Cross-section of ozone as a function of latitude and potential temperature along a HIRDLS scan track at 122°W (Eastern Pacific). Blue indicates mixing ratios <= 0.3 ppmv, green is near 0.8 ppmv, and red approaches 1.8 ppmv. Broken white lines indicate contours of potential vorticity (PV) at 6 and 10 PVU, the red line is the tropopause location, both from the Goddard Modeling and Assimilation Office (GMAO) Earth Observing System (GEOS5.1) data, which is also the source of the dashed lines indicating contours of zonal wind.
Figure 1.b. Plot of GEOS 5.1 PV on the 380K surface from 90-180°W, and 10-70°N at 12Z on 1 April 2006. Contours highlighted in color are 2 PVU (blue), 6 PVU (red) 8 PVU (yellow) and 10PVU (black). Green dash-dot lines show the HIRDLS scan tracks this day. The tracks through 122°W can be seen.

High resolution figure

As a result of these efforts, Version 4 of the data, providing high resolution retrievals of temperature, ozone, nitric acid, CFC 11, CFC 12, aerosol extinction plus cloud top location and types was made available to the community. Five papers describing the validation of V3 data were published. V4 data has improved cloud detection, leading to more reliable ozone data in the UTLS region. In addition, the mean accuracy of the temperature and ozone data has improved.

An example of what can be seen is shown in Figure 1.a, which shows a latitude-potential temperature cross-section along a HIRDLS scan track near 122°W on 1 April 2006. This shows a region of low ozone at 380K in mid latitudes, originally from low latitudes that has been injected across the tropopause, but here has been separated by atmospheric motions, believed to be related to baroclinic waves in the troposphere. Here it remains as a thin layer that is associated with a potential vorticity (PV) contour of 6 10^{-6} m2/s K/kg, (6 PVU) as shown in the PV map on the 380K surface in Figure 1.b. Following this air mass shows that the low ozone air remains close to the 6PVU contour for several days, before the PV contour relaxes to a lower altitude, leaving the air to mix with its surroundings. This can only be seen because of the high vertical resolution of the HIRDLS data.

Summarizing the accomplishments, the radiance correction algorithms were improved, adding the CFC's and aerosol extinction to be retrieved, as well as improving the accuracy and usefulness of temperature and ozone. A study of gravity waves was published, and several talks on UT/LS processes and strat-trop exchange were presented. An anomaly with the HIRDLS chopper prevented participation in START08, or the ARCTAS field experiment.

The plans for FY09 call for increased emphasis on the application of these unique, high resolution data to a range of scientific applications, as well as continuation of work to further refine the correction and retrieval algorithms to retrieve additional species, and extend the altitude range of the results.

This work was supported by NASA and the NSF.

return to top

Solar Dynamo Modeling And Solar Cycle Prediction

The magnetic fields that are ultimately the source of the activity that takes place in the solar atmosphere have their origin inside the Sun, where convective, rotational, and other flows of highly electrically conducting plasma contribute to the operation of the dynamo. Work by HAO scientists has shown that the meridional circulation, a large-scale flow directed from the equator to the N and S poles at the solar surface and completing the circuit from the poles to the equator near the bottom of the convection

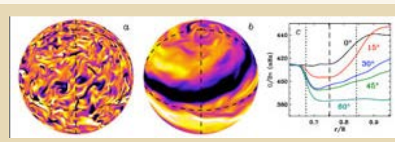


Figure 1: Turbulent pumping, organization, and amplification of magnetic fields in a

zone, plays a fundamental role in in the dynamo process. It continuously transports poloidal magnetic fields from the surface to the tachocline at the base of the convective envelope where they are differentially stretched by the rotational shear therein to produce new toroidal magnetic fields. Buoyant magnetic flux tubes formed from these fields become the source for new poloidal fields at the surface, thus completing the dynamo cycle. HAO researchers have pioneered the development of the so-called flux-transport dynamo model that is based on this physical picture, and have had remarkable success in applying it to the problem of simulating and predicting solar cycle amplitudes.

simulation of solar convection that incorporates a tachocline of rotational shear. The longitudinal field component is shown in an orthographic projection in (a) the mid convection zone and (b) the tachocline, with dashed lines denoting the equator and two meridians. The field in the convection zone is turbulent whereas the tachocline field is dominated by strong toroidal bands, antisymmetric about the equator. Frame (c) shows the angular velocity as a function of radius at different latitudes as indicated. The dashed line denotes the base of the convection zone while dotted lines denote the horizontal surfaces illustrated in frames (a) and (b).

High resolution figure

During the last year, HAO scientists made significant progress in efforts to understand the physical processes contributing to dynamo action in the Sun, and to further develop the predictive capabilities of the flux-transport dynamo model. M. Miesch, together with J. Toomre, B. Brown (both CU), A. S. Brun (CEA-Saclay), and M. Browning (CITA), continued to develop global three-dimensional models of convection and dynamo processes in the Sun and in other stars. Their work focused mainly on simulations of rapidly-rotating solar-type stars which exhibit modulated convection patterns wherein columnar convective cells group together in one or more localized longitudinal patches with relatively quiescent flow elsewhere . Magnetohydrodynamic simulations of such stars show strong dynamo action, with prominent, persistent bands of toroidal magnetic fields and quasi-periodic polarity reversals. The recent solar simulations of Miesch and collaborators have demonstrated that the presence of a tachocline of rotational shear has a profound influence on dynamo action in the convective envelope, promoting mean-field generation. Strong toroidal flux structures are formed in the tachocline through turbulent pumping and shear that then feed back on the poloidal field component, enhancing and stabilizing the dipole moment.

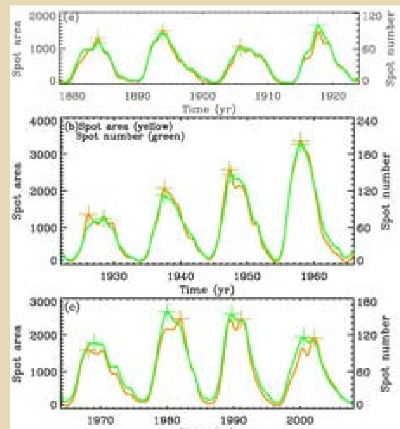


Figure 2: Comparison of Zürich sunspot number (green curves) and sunspot area (yellow curves, in millionths of the visible hemisphere) for cycles 12-23. Colored crosses denote the amplitude and time of cycle maxima for each type of data. To place the curves on the same scale, we multiply the y-axis for sunspot number by 16.5.

High resolution figure

M. Dikpati, P. Gilman, and G. de Toma investigated the well-known "Waldmeier effect", that is, the anti-correlation between the magnitude of the peak in the sunspot number of a cycle, and the time from minimum to reach that peak. It has been suggested that the Waldmeier effect can be used to predict the peak of a cycle shortly after the onset of that cycle. They have shown that the Waldmeier effect is not present in the sunspot area data. Hathaway et al. (2002) had previously shown that the Waldmeier effect is much weaker (correlation r = -0.34) in sunspot group number. Thus the Waldmeier effect may be specific to only the Wolf sunspot number. Given the near coincidence of solar minima in the two data sets, the main differences in rise-time of spot number data and spot area data occur from the differences in timing of maxima (see the positions of the green and yellow crosses in Figure 2). Dikpati, de Toma, and Gilman have also evaluated the relative skill of the polar magnetic flux, the magnetic flux crossing the solar equator, and the toroidal magnetic flux in the tachocline as predictors of solar cycle amplitude, using observations as well as a calibrated flux-transport dynamo model. On the verge of the upcoming solar cycle 24, these three cycle indicators have all received attention. Dikpati, de Toma, and Gilman have shown that in the context of a flux-transport solar dynamo, the (n-1)th cycle's tachocline toroidal flux and the (n-1)th cycle's equator-crossing flux can be good predictors of the nth cycle's peak, but the polar flux of (n-1)th cycle correlates poorly with the peak of the nth cycle. In flux-transport dynamos, the polar magnetic flux is a follower of the cycle rather than being a precursor to it.

During the next year, Miesch and collaborators will continue global-scale, 3D simulations of magnetized convection in a rotating spherical shell with an underlying stable region, in order to further study how dynamo action is affected by the presence of a tachocline. He will also add a surface poloidal magnetic field source term to create a 3D Babcock-Leighton-type dynamo which will be used to study the origin of magnetic cycles, the competition between magnetic pumping and transport of fields by circulation, and the interactions between the Babcock-Leighton source term and the convective generation of mean fields. Dikpati and collaborators will work to further refine the flux-transport dynamo-based prediction tool she has developed. At present, the onset timing and amplitude of a future cycle are predicted separately by applying a very simplified data-assimilation technique, "data-nudging", over the entire simulation run. In order to simultaneously predict the amplitude, timing, and shape of a cycle, a more sophisticated "sequential" data-assimilation technique, rather than just "data-nudging", will be developed. As in atmospheric weather prediction models, the dynamo model output at a certain cycle phase can be compared with the observed cycle at the same phase, and then the model can be updated with adjusted time-varying dynamo ingredients, to proceed forward in time. Dikpati and co-workers will also continue work on a 3D kinematic flux-transport dynamo, splitting the axisymmetric and non-axisymmetric flow and field components and representing the the non-axisymmetric components as a Fourier decomposition in longitude with a few low-order longitudinal modes. Thus this model will focus only on the large-scale, 3D, magnetic field evolution of the

Sun, such as the evolution of "active longitudes."

return to top

Upper Troposphere and Lower Stratosphere (UTLS) Initiative

The upper troposphere and lower stratosphere (UTLS) is a sensitive region of Earth's climate, because water vapor, ozone, cirrus clouds and aerosols in this region strongly contribute to radiative forcing of the climate system. The dynamical processes of broad range of scales, from deep convection and gravity waves, to synoptic weather systems and the stratospheric large-scale circulation, redistribute the chemical species and create unique conditions for microphysical, chemical and radiative processes. Studies of the UTLS seek to determine the role of distinct processes and feedbacks in this region, and how the system will evolve in a changing climate.

During the last 5 years, the UTLS initiative has successfully conducted the Stratosphere-Troposphere Analyses of Regional Transport (START-05 and START-08) experiments using the Gulfstream V (GV). These data in combination with satellite and model analysis provide a new level of quantification and characterization of transport pathways across the tropopause and their linkage to the synoptic scale weather system. These field experiments have also set the stage for a large, unique field campaign focusing on the chemical transport and processing of continental convective storm systems, Deep Convective Clouds & Chemistry Experiment (DC3). START-08 and DC3 are further discussed under Goal 5: Planning of DC3 field program & Planning of START08 field program.

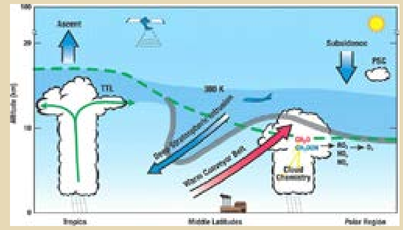


Figure 1: This schematic figure (adapted from Stohl et al. 2003) highlights the important processes coupling dynamics, chemistry and cloud microphysics in the UTLS region... The green line denotes the time average tropopause. In the tropics, maximum outflow from deep convection occurs near ~12-14 km, while the cold point tropopause occurs near 17 km. The intervening region has characteristics intermediate between the troposphere and stratosphere, and is termed the tropical transition layer (TTL). Extratropical stratosphere-troposphere exchange occurs in tropopause folds and intrusions linked with synoptics weater systems; these events transport stratospheric ozone into the troposphere. In addition, convection brings near-surface pollutants (from boimass burning or anthropogenci emissions) into the upper troposphere, strongly influencing global-scale chemistry.

High resolution figure

return to top

Simulations and Observations Of Magnetic Flux Emergence, CME Initiation and Evolution, and Interplanetary Consequences

Solar-driven space weather can have significantly adverse consequences for the Earth and near-Earth environment. Coronal mass ejections (CMEs) are the principal solar drivers of space weather. Using 3D magnetohydrodynamic simulations of the coronal magnetic field driven by the emergence of a twisted flux rope, HAO scientists have made significant advances in understanding the origin and dynamic evolution of CMEs and what makes a CME geoeffective.

Connecting interplanetary coronal mass ejections (ICMEs) to their coronal pre-eruption source requires a clear understanding of how that source may have evolved during eruption. In previous work S.Gibson and Y. Fan, (2006a,2006b) presented a three-dimensional numerical magnetohydrodynamic simulation of a CME, which showed how, in the course of eruption, a coronal flux rope may writhe and reconnect both internally and with surrounding fields in a manner that leads to a partial ejection of only part of the rope as a CME. They have now (Gibson and Fan 2008) explicitly determined how such evolution during eruption would lead to alterations of the magnetic connectivity, helicity, orientation, and topology of the ejected portion of the rope so that it differs significantly from that of the pre-eruption rope. Moreover, because a significant part of the magnetic helicity remains behind in the lower portion of the rope that survives the eruption, the region is likely to experience further eruptions (Figure 1). These changes complicate how ICMEs embedded in the solar wind relate to their solar source. In particular, the location and evolution of transient coronal holes (Figure 2), the topology of magnetic clouds ("tethered spheromak") (Figure 3), and the likelihood of interacting ICMEs would differ significantly from what would be predicted for a CME which did

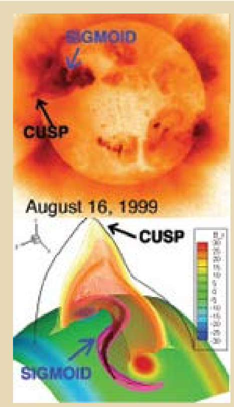


Figure 1: If a part of a twisted flux rope survives a solar eruption, it means that magnetic energy is still stored, and another eruption may soon be triggered. These Yohkoh SXT observations show an active region which erupted multiple times between August 15-21, 1999 (image is in negative color-table, dark indicates strong soft-X-ray (SXR) emission). Cusped field-lines resulting from eruptions apparently overlie sigmoid-shaped loops throughout the active regions disk passage, in the manner predicted by the

not undergo writhing and partial ejection during eruption.

The formation of twisted magnetic flux ropes in the solar corona which contains free magnetic energy and drives solar eruptions has its origin from the solar interior through the emergence of twisted active region magnetic flux. To understand the origin of CME precursor structures in the solar corona, Fan is carrying out 3D numerical simulations of the dynamic emergence of a twisted magnetic flux tube from the top layer of the solar convection zone into the solar atmosphere and the corona. She is investigating how the emergence, the resulting photosphere evolution, and the coronal magnetic field depend on the properties of the subsurface emerging tube. The simulations show that it is difficult for a twisted flux tube to emerge bodily into the corona as a whole due to the heavy mass trapped at the bottom concave parts of the twisted field lines. However, it is found from the simulations that on the photosphere, after a brief stage of shearing motion during which the two polarities of the bipolar region become separated, significant rotational motion develops within each polarity (Figure 4a), similar to the observed sunspot rotations, which transport significant amount of twist into the corona. The rotational motions of the two polarities are found to twist up the inner field lines of the emerged fields such that they change their orientation into an inverse configuration (i.e. pointing from the negative polarity to the positive polarity over the neutral line). As a result, a flux rope with sigmoid-shaped dipped core fields forms in the corona (Figure 4b). Sunspot rotation has been observed in many events preceding X-ray sigmoid brightening and the onset of eruptive flares. The simulations show that such rotational motions take place during flux emergence as a result of the propagation of torsional Alfven waves along the flux tube which transport significant twist from the interior portion towards the expanded coronal portion. These results provide insight into the nature of the observed processes that lead up to solar eruptions.

return to top

partially-ejected flux rope model (bottom panel). Such repeated partial ejections from a single region may have space weather significance, if for example their interaction leads to particularly strong solar energetic particle (SEP) events (Gopalswamy et al., 2004).

High resolution figure

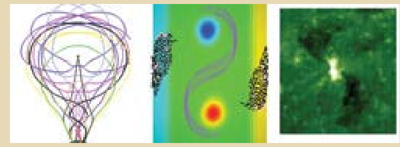


Figure 2: From Gibson and Fan (2008). Transient coronal holes (TCHs) are associated with CMEs, and appear as dimmings in soft X-ray and extreme ultraviolet (e.g. right-most image). They have been proposed to be the footpoints of expanding magnetic flux ropes. The left-most image shows sample field lines from the escaping portion of the flux rope in the Gibson and Fan (2006a, 2006b) simulation. The middle image shows colored diamonds corresponding to the footpoints of these escaping rope fieldlines, and the black dots show more footpoints of escaping rope fieldlines obtained by tracing all fieldlines exiting the top of the simulation box (10 Rsun) down to the lower boundary. The central purple fieldlines show the surviving rope as seen in projection against the solar surface, which is illustrated by colored iso-contours showing radial magnetic flux. The model predicts that the escaping flux rope footpoints lie outside the original (and surviving) rope's boundary, which compares well to the observations of the SOHO/EIT 195 transient coronal holes of May 12, 1997 that is shown in the right-most image.

High resolution figure

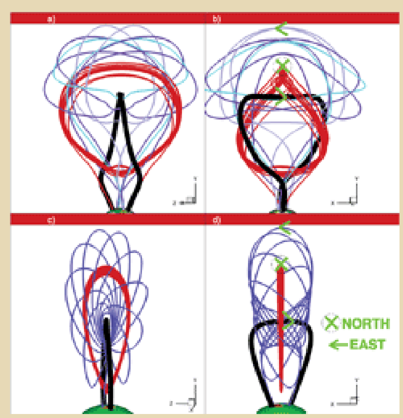


Figure 3: From Gibson and Fan (2008). Model predictions of magnetic fields within magnetic clouds (interplanetary manifestations of CMEs). The top images show sample field lines of the escaping portion of a partially-ejected flux rope, which we demonstrate is topologically equivalent to a "tethered spheromak" described in the analytic model of Gibson and Low (1998)

(bottom images). The thick black field lines in (a-b) and (c-d) represent the poloidal axes of the partially-ejected rope and tethered spheromak, respectively. The red torus shown in (c-d) is formed by a single field line ergodically covering a magnetic flux surface which encloses the spheromak toroidal axis. The partially-ejected rope possesses a similarly toroidally-winding single red field line, although it is not completely detached from the lower boundary.

High resolution figure

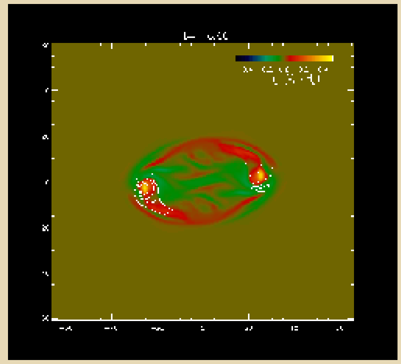


Figure 4a: The distribution of vertical vorticity at the photosphere in an emerging flux region resulting from a 3D MHD simulation of the emergence of a twisted magnetic flux tube from the solar interior into the solar atmosphere. It shows concentration of positive vertical vorticity, i.e. counter-clockwise rotational motion, centered at the peaks of the vertical magnetic field (shown as white contours, with solid and dotted contours indicating positive and negative magnetic polarities respectively) of the two polarities.

High resolution figure

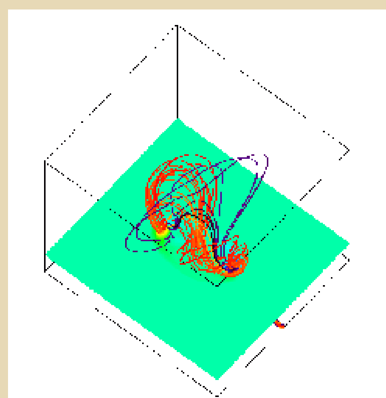


Figure 4b: The 3D coronal magnetic field resulting from a 3D MHD simulation of the emergence of a twisted magnetic flux tube from the solar interior into the solar atmosphere. A flux rope with sigmoid-shaped, dipped core-fields (as represented by the red field lines) has formed in the corona. Significant rotational motions are present at the footpoints of these field lines at the photosphere (as shown in Figure 4a) as a result of the propagation of torsional

Alfven waves along the flux tube which transport significant twist from the interior portion towards the expanded coronal portion.

High resolution figure

Globalization of air quality and intercontinental transport

Transpacific Pollution Transport during INTEX-B: Spring 2006 in Context to Previous Years

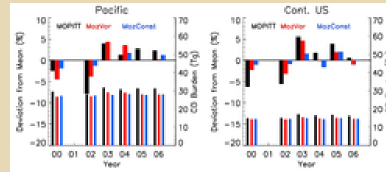


Figure 1. Variability in the tropospheric CO burden over the Pacific and continental US as derived from MOPITT and two MOZART simulations (MozVar: varying emissions; MozConst: constant emissions).

High resolution figure

We analyze the transport of pollution across the Pacific during the NASA INTEX-B (Intercontinental Chemical Transport Experiment) campaign in spring 2006 and examine how this year compares to the time period 2000-2006. In addition to aircraft measurements collected during INTEX-B, we include multi-year satellite observations of CO from the Measurements of Pollution in the Troposphere (MOPITT) instrument. We integrate these measurements with simulations from the chemistry transport model MOZART-4. Model tracers are used to examine the contributions of different regions to pollution levels over the Pacific and to estimate the O_3 production from NO_x sources in Asia to O_3 loadings over the Pacific and North America. Additional modeling studies are performed to separate the impacts of inter-annual variability in meteorology and dynamics from changes in source strength. Figure 1 shows the variability in the tropospheric CO burden (relative deviation from mean and absolute amounts) over the Pacific and the contiguous US as derived from MOPITT data and two model simulations, one with emissions that vary by year (MozVar) and one with constant emissions (MozConst).

This work was funded by NASA and NSF. This work will be published in FY09 and similar studies made in the analysis of the NASA ARCTAS aircraft experiment.

return to top

MOZART in the analysis of tropospheric observations

Impacts of the Fall 2007 California Wildfires on Surface Ozone: Integrating Local Observations with Global Model Simulations

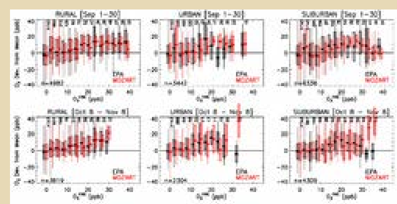


Figure 1. Deviation from the mean of observed and modeled midday 8-hour O_3 concentrations binned by the model fire tracer. Results are sorted by rural, urban and suburban sites, and for the two main fire periods.

High resolution figure

In this study we quantified the impact of the fires in California in fall 2007 on regional air quality and in particular on surface ozone by analyzing surface observations of ozone concentrations together with MOZART simulations (Pfister et al., GRL, in press). The simulations include a synthetic tracer providing information about the amount of ozone produced from the fires. A clear increase in observed ozone is found when the model predicts a strong impact of pollution from the fires, where measured afternoon 8-hour concentrations increased, on average, by about 10 ppb. The findings demonstrate that intense wildfire periods can significantly increase the frequency of ozone concentrations exceeding current U.S. health standards, and might cause violations also during photochemically less active seasons. The study also demonstrates the far-reaching impact of ozone production from the fires.

Figure 1 shows observed and modeled 8-hour O_3 concentrations for 10-18 LT, 11-19LT and 12-20 LT binned by the model fire tracer O_3^{FIRE}. Shown is the deviation from the mean concentrations (ppb) separately for rural, urban and suburban sites, and for the two main fire periods (Sep 1-30 and Oct 8 - Nov 8).

This work was funded by NSF and NASA. In FY09 similar studies will be made of the extensive California fires of Summer 2008 as part of the analysis of the NASA/ARCTAS-CARB aircraft experiment.

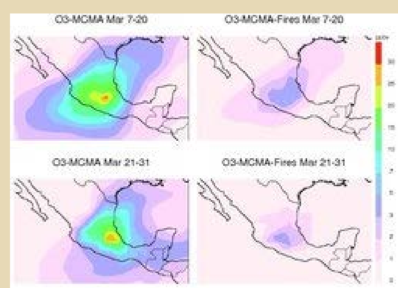


Figure 2. Ozone from all Mexico City emissions (left panels) and from just fire emission (right panel) for before (top row) and after (bottom row) the significant rain event.

Contribution of fires to ozone from Mexico City pollution

During the MIRAGE experiment during March 2006, numerous wildfires were evident in the hillsides surrounding Mexico City, complicating the characterization of the urban emissions and resulting pollution. Using the MOZART global chemical transport model run at a horizontal resolution of 0.7 degrees, the ozone burden resulting from the total emissions in the Mexico City region, as well as only from open fires, has been simulated. By tagging the NO emissions from a single type or region of sources in the model, the ozone produced from that source can be quantified. In the middle of the MIRAGE experiment (on March 20) a period of rainy weather began, significantly dampening the fire activity around Mexico City. Figure 2 shows the ozone produced from all of the NO emissions from Mexico City and its environs (urban and fires) and ozone from only the fire emissions, for the periods before and after the rain event.

High resolution figure

These results show that, for ozone, the open fires in the vicinity of Mexico City are a fairly small, but non-negligible contribution (20%) to the regional ozone pollution. Other studies have shown, however, that other components of Mexico City pollution, in particular particles, have significant contributions from fire emissions. Some of these sources could be cooking, heating and trash burning, which are not included in the tagged fire emissions in the MOZART simulations.

This work was funded by NSF and NASA. Analysis of the MIRAGE observations using MOZART will continue in FY09.

return to top

Hurricanes

As the current high level of Atlantic hurricane activity continues to cause major disruption and damage, research at NCAR is both expanding and becoming of greater societal importance. Research and applications work within ESSL and in collaboration with our colleagues in RAL and CISL, the Willis Research Network, Georgia Tech, SUNY, RSMAS, Cal Tech, and Mississippi State has:

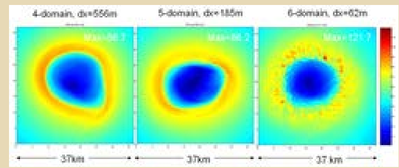


Figure: Wind speeds 10 m above the sea surface in an idealized AHW hurricane simulation, showing the development of a turbulent structure for horizontal resolution beyond 100 m.

High resolution figure

- Expanded our understanding of cyclone formation in both tropical and subtropical conditions, wind-pressure relationships, hurricane structural evolution and the impacts of climate variability and change;
- Led to several improvements in the Advanced research Hurricane WRF (AHW);
- Enabled participation in the NOAA Hurricane Intensity Forecast Improvement Program (HIFIP) with the Advanced Hurricane-research WRF (AHW); and,
- Commenced a study to improve the communication of forecast information to vulnerable communities.

High-resolution simulations of the 2005 hurricane season have enabled a demonstration of an hypothesis that tropical cyclone formation can be enhanced by wave accumulation processes when easterly waves move into a region in which the easterly flow is decreasing westward. The simulations have also indicated that mesoscale interactions may be an important contributor to enhanced cyclogenesis. This represents a move away from earlier assumptions that such interactions were largely stochastic and could equally enhance or reduce cyclogenesis potential. These factors are considered to be major contributors to the highly active 2005 season. The role of upper-trough interactions and in subtropical development of tropical cyclones has been further investigated. An important conclusion is that strong vertical shear enhances such developments, quite the opposite of the requirement for low shear in equatorial developments. Tropical cyclones moving into higher latitudes and environments with stronger vertical shear were also investigated. Emerging frontal structures, asymmetric rainfall patterns, and responses to the deleterious structural effects of vertical shear were simulated and analyzed. A major field program to further study this process has been proposed. NCAR also participated in the TPARC field program for cyclone development in the western North Pacific, and the WRF modeling system will be used to develop a comprehensive reanalysis for subsequent research.

A new wind-pressure relationship has been derived that updates an older relationship used widely in developing synthetic hurricane climatologies for design and planning of coastal and offshore structures. This relationship was able to confirm an earlier study that major hurricanes in the 1950s were overestimated in intensity, and to extend this to include the period through to the 1970s.

An NCAR Breakthrough Science (BTS) study used AHW for extremely high resolution simulations of an idealized hurricane to assess the impacts of increasing resolution on structure and intensity (Fig. 1). This showed that there was only a slight variation of intensity with resolution below 1 km. However, at an unprecedented horizontal resolution of 62 m, the AHW was able to resolve turbulent structures (Fig. 1), The subsequent analysis found a marked sensitivity of intensity to the specified horizontal mixing length in axisymmetric models and showed that earlier studies of potential increases in hurricane intensity by migration of high-entropy surface air in the eye into the eye wall were incorrect. One additional outcome was the development of a revised hurricane maximum potential intensity relationship that did not require the need for approximations employed in earlier versions.

The AHW has been further improved based on experience with real-time and research simulations over the past several years. This included upgrades to the cloud microphysics and boundary-layer parameterizations an ocean mixing and upwelling parameterization based on a 1-D configuration, and further developments of the data assimilation system. The ocean parameterization successfully reproduces much of the negative feedback associated with oceanic cooling during a cyclone passage. Preparations have been completed for participation in the NOAA HIFIP program. AHW will use the Ensemble Kalman Filter data assimilation and parameterized ocean that reproduces much of the observed negative feedback arising from cooling by upwelling and mixing associated with the cyclone passage. NCAR will be a full participant in HFIP, with post-event forecasts of all the cases recommended by NOAA.

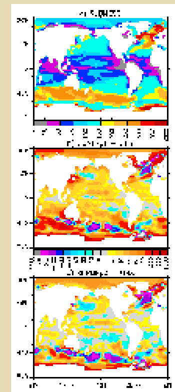
Recent experience has shown quite clearly that coastal residents do not respond adequately to the risk from an approaching hurricane. Building on preliminary investigations, a substantial study has now commenced at NCAR to examine the way in which such communities interpret warning information and develop improved methods of communication and response to the hurricane threat.

return to top

Climate Variability and Predictability World Climate Research Program (CLIVAR)

Climate Process Teams (CPTs)

ESSL scientists remain actively involved in leadership of the Climate Variability and Predictability (CLIVAR) initiative of the World Climate Research Programme (WCRP) through membership on various national and international CLIVAR panels, as well as through research contributions to CLIVAR goals and objectives. The purpose of CLIVAR is to investigate climate variability and predictability on time-scales from months to decades, as well as the response of the climate system to anthropogenic forcing. CLIVAR, as one of the major components of the WCRP, started in 1998 with a 15-year charter, which focuses on the role of the coupled ocean and atmosphere within the overall climate system, with emphasis on variability, especially within the oceans, on seasonal to centennial time scales. CLIVAR aims to explore predictability and improve projections of climate variability and climate change using existing, reanalyzed, as well as new global observations, enhanced coupled ocean-atmosphere-land-ice models, and paleoclimate records.



Winter-mean Mixed Layer Depth (MLD) in meters: a) from an experiment with the new submesoscale physics parameterization (SUBMESO); b) MLD difference between a CONTROL experiment without the submesoscale parameterization and observations; and c) MLD difference between experiment SUBMESO and observations.

High resolution figure

A major effort of the U.S. CLIVAR program has been the introduction and fostering of Climate Process Teams (CPTs). A CPT is a team of theoreticians, observationalists, process modelers, and coupled climate modelers formed around specific issues or uncertainties. CPTs aim to link process-oriented research to modeling for the purpose of addressing key uncertainties in coupled climate models. Expediting the incorporation of new parameterizations into ocean models and assessing their climate impacts are among their primary goals. Within ESSL, major ocean model developments are proceeding under the auspices of the CPTs on both gravity current entrainment and eddy mixed layer interaction in collaboration with the external university and laboratory community.

For the CPT on the eddy mixed layer interaction, we implemented a new submesoscale physics parameterization in the ocean component of the Community Climate System Model version 4 (CCSM4), following Fox-Kemper, Ferrari, and Hallberg (2008, J. Phys. Oceanogr., v38, 1145-1165). The submesoscale represents the range of scales between the mesoscale (typical scales of a month and 100 km) and the fine-scale (typical scales of inertial or faster time and up to hundreds of meters). The submesoscale dynamics are dominated by the development of fronts and the ageostrophic circulations associated with the fronts. Some recent studies indicate that both the depth and the stratification of the surface mixed layer are significantly modified by these ageostrophic circulations. Fox-Kemper, Ferrari, and Hallberg (2008) present a parameterization scheme to represent the mixed-layer stratification associated with these frontal instabilities and frontogenesis. Inclusion of this new physics in the ocean model leads to some improvements compared to a control integration without this parameterization. In particular, due to the restratification by the parameterized mixed layer eddies, generally deep bias of the simulated mixed layer depths are significantly reduced, thus producing more favorable comparisons with the available observations in most regions of the globe (see Figure 1).

Some preliminary results from this study are reported in Fox-Kemper, Danabasoglu, Ferrari, and Hallberg (2008, CLIVAR Exchanges, v13, 3-5).

The results from the successful implementation of an overflow parameterization for the Mediterranean overflow (PMO; Parameterized Mediterranean Overflow) through the Strait of Gibraltar in CCSM3 were documented in Wu, Danabasoglu, and Large (2007, Ocean Modelling, v19, 31-52). This parameterization, based on the marginal sea boundary condition scheme of Price and Yang (1998, in Ocean Modeling and Parameterization, Kluwer Academic, 155-170), represents exchanges through narrow straits / channels, associated entrainment and intrusion of overflow product water into the open ocean. These overflow processes occur on very small spatial scales, essentially prohibiting their explicit representation in ocean circulation models used in climate studies. Therefore, their effects must be parameterized. The PMO is applicable only to overflows from enclosed seas.

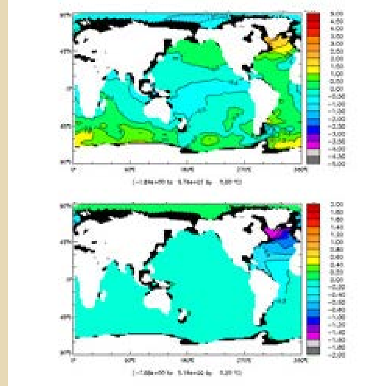
Therefore, we have developed a new parameterization that can be used in open-ocean overflow applications such as the Denmark Strait and Faroe Bank Channel overflows.

A particularly novel aspect of the parameterization is a new treatment of the baroclinic / barotropic mode split. This new open-ocean overflow parameterization was first implemented and tested in the Parallel Ocean Program version 1.4 (POP1.4). It has now been incorporated in the new version of the ocean model (POP2.0). Newly obtained results show that inclusion of the Denmark Strait Overflow (DSO) and Faroe Bank Channel overflow via this new scheme significantly reduces some long standing model biases in the North Atlantic. Potential temperature difference distributions at a depth of 2000 m (see Figure 2) clearly show that the CONTROL case warm bias is significantly reduced with the new parameterization which is used to represent only the DSO in this particular experiment.

A primary purpose of these CPTs is to document climate impacts of these new parameterizations using fully coupled simulations. To this end, we have already completed several simulations that also include CFCs. In FY2009, the final year of these projects, we will perform additional integrations to complete the suit of necessary experiments and document any climate impacts due to these new parameterizations.

The observational MLD data are based on the Polar Science Center Hydrographic Climatology (PHC2) data sets (a blending of the Levitus et al. 1998 and Steele et al. 2001 data). The MLD is defined as the depth at which the local density is higher then the surface density by 0.125 kg / m^3. The experiments SUBMESO and CONTROL are forced with the Coordinated Ocean-ice Reference Experiments (COREs) Normal-Year atmospheric forcing data from Large and Yeager (2004). The winter-mean represents January-March and July-September means in the Northern and Southern Hemispheres, respectively. In SUBMESO, the root-mean-square MLD difference from observations is reduced by more than 20% compared to the CONTROL - OBS difference.

The figures clearly show the substantial elimination of the model warm bias of the CONTROL case with the new parameterization in the DSO experiment.



Time-mean potential temperature model - observations difference distributions at 2000-m depth: (top) CONTROL case - observations and (bottom) DSO case - observations. The DSO case uses the new overflow parameterization to represent the Denmark Strait Overflow (DSO) physics which is largely absent in the CONTROL experiment. In top and bottom panels, the contour intervals are 0.5 and 0.2 degree C, respectively. The observations are from the PHC2 data set. Both CONTROL and DSO experiments use the CORE Normal-Year atmospheric forcing data sets from Large and Yeager (2004).

High resolution figure

return to top

Convection, Flux Tubes, And Waves In The Solar Interior

The energy liberated through the nuclear burning of hydrogen in the core of the Sun is transported outward by radiative diffusion for radii less than about 0.7 R_sun, and by convection within that portion of the interior located between 0.7 R_sun and the photosphere. The structure and dynamics of this outer convective envelope, the nature of the interface between it and the underlying stably stratified radiative interior, and the hydrodynamical and magnetohydrodynamical (MHD) processes that take place within these layers are critical to understanding the operation of the solar dynamo, the transport and emergence of dynamo-generated magnetic fields, and the properties of the Sun's differential rotation and meridional circulation. During 2008, HAO researchers made substantial progress on plans to study the dynamics and evolution of buoyant magnetic flux ropes in the convection zone, and to investigate the nature and properties of the instabilities and waves that can exist in the the solar tachocline and radiative interior.

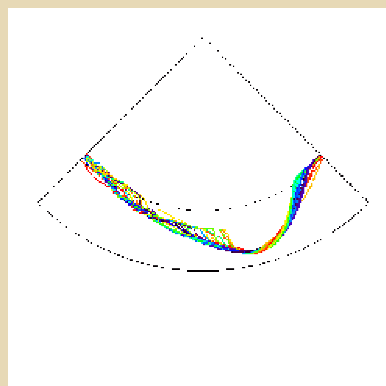


Figure 1: Selected field lines in an emerging Omega-shaped flux tube resulting from a 3D simulation of the rise of a 100 kG buoyant flux tube from the base of the convective envelope towards the top boundary located at 16 Mm below the visible solar surface. One can clearly see the asymmetry where the leading side is more cohesive while the field lines in the following side are fraying out.

High resolution figure

Y. Fan carried out a set of 3D, spherical-shell, MHD simulations of the buoyant rise of active region flux tubes in a model solar convective envelope. The results of these computations put new constraints on the initial twist of the flux tubes in order for them to emerge with tilt angles consistent with the observed Joy's law of the mean tilt of solar active regions. Asymmetric stretching of an Omega-shaped rising tube by the Coriolis force causes the leading side (leading in the direction of rotation) to have a stronger field and to thus be more cohesive compared to the following side (Figure 1). There is also significant asymmetry between the twist and the upward helicity flux along the leading and following legs of the emerging tube. The values of the local twist of the magnetic field lines in the leading leg show modest variations with height in the convection zone, while the field lines in the following leg are frayed and show large fluctuations and mixed signs of twist (Figure 2). In addition, in the upper half of the convection zone, the upward helicity flux along the leading leg is significantly greater than that in the following leg (Figure 3), a property which has been reported in a recent observational study of emerging active regions by Tian and Alexander (2008).

M. Dikpati, P. Gilman, M. Miesch, and P. Cally (Monash University) have used a 3D, thin-shell model of the tachocline to investigate the occurrence and properties of axisymmetric (m=0), MHD instabilities inside the Sun. They find that bands of toridal magnetic fields become unstable to axisymmetric perturbations for solar-like field strengths (100 kG) with e-folding times that can be months, or even a few hours if the field strength is a million Gauss or higher, as might occur in the solar core, white dwarfs, or neutron stars. These instabilities exist with and without rotation, although differential rotation has a stabilizing effect. The onset of an m=0 instability occurs from the poleward shoulder of banded toroidal field profiles. Unlike the non-axisymmetric instability which tips or deforms a band, in the axisymmetric instability, the fluid can roll in latitude and radius, and can break up bands in the radial direction. The velocity produced by this instability in the case of low-latitude bands crosses the equator and hence can provide a mechanism for hemispheric coupling. T. Rogers and K. MacGregor continued their study of internal gravity waves (IGW) in the radiative interior of the Sun. These disturbances are generated by the overshoot of flows from the convection zone into the underlying stably stratified layers of the solar interior. They used numerical simulations to investigate the interaction of IGW with a layer of toroidal magnetic field, located just below the base of the convection zone. Their results indicate that the wave energy present in the deep radiative interior is severely diminished by the reflection and absorption of downwardly propagating waves in the magnetic layer. It is found that for field strengths in the range of 1-100 kG, the wave energy in the radiative zone is decreased by 4-5 orders of magnitude, independent of field strength. This poses significant challenges to models which rely on angular momentum transport by IGW to account for the uniform rotation of the solar radiative interior, as well as for observational searches for g-modes.

In the coming year, simulations of magnetized convection in a 3D, rotating, spherical shell with an underlying stable region will be carried out, in an effort to study how dynamo action is affected by the presence of a tachocline. Studies of magnetic flux concentrations in the convection zone will continue with simulations of the formation of flux tubes by the occurrence of the magnetic buoyancy instability in dynamo-generated mean fields. These simulations will be conducted in 3D, rotating, spherical geometry, with distributions of poloidal and toroidal fields obtained from the dynamo model of M. Rempel for different solar cycle phases. Further studies of MHD instabilities of tachocline fields and rotation will include exploration of the linear growth and nonlinear evolution of instabilities in stars, particularly those having anti-solar differential rotation. The investigation will be directed toward determining whether the poleward side of a band of toroidal field is stable in the case of anti-solar differential rotation rather than the equatorward side as in the case of the Sun. Examination of gravity waves in the solar radiative interior will proceed with additional simulations intended to further clarify mode properties and background interactions in the presence of buoyancy, magnetic, and rotational forces.

return to top

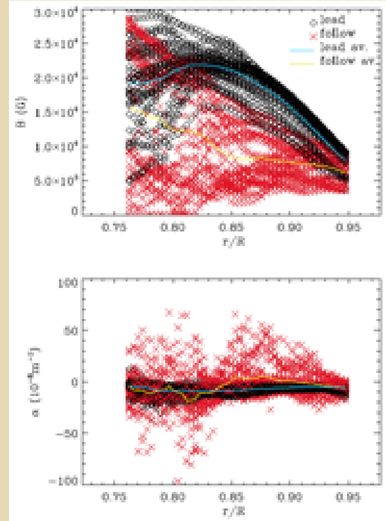


Figure 2: Values of total field strength B (upper panel) and twist alpha (defined as J*B/B^2 where J is the vector current density) as a function of height along each of the selected field lines shown in Figure 1, with black diamond points (red crosses) showing the values of the leading (following) side of the field lines. The blue (yellow) curve shows an average of the leading (following) field line values. Field lines in the leading leg show systematically stronger field strengths and also show a more coherent values of (negative) local twist.

High resolution figure

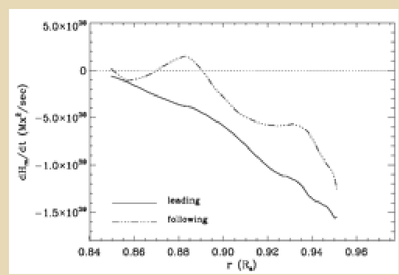


Figure 3: Upward helicity flux along the leading and following legs of the emerging tubes for heights in the upper half of the convection zone. The upward transport of a negative helicity flux (for the left-hand twisted flux tube) along the leading leg is systematically greater than that along the following.

High resolution figure

Spectro-polarimetric studies of magnetic fields in the lower solar atmosphere

The Lower Solar Atmosphere (LSA) section studies the evolution of the solar magnetic field and its interactions with the plasma from its emergence through the photosphere up to the chromosphere. The magnetic flux rises from the interior due to buoyancy and becomes directly measurable at the photospheric level by means of spectro-polarimetric observations. In this layer the dynamical state is dominated by convective plasma motions and the magnetic field is forced to follow these flows. As it moves upwards into the upper photosphere and lower chromosphere, a transition occurs to a completely different physical regime in which magnetic forces take over and dominate the dynamics. Understanding the implications of this transition is the main challenge of the LSA section, which is heavily driven by observations of the polarimetric signatures imprinted by magnetic fields on photospheric and chromospheric spectral lines.

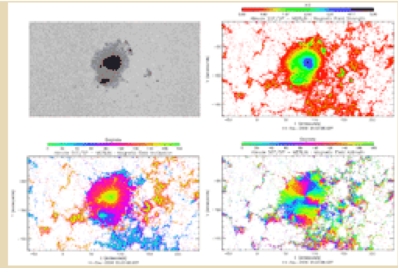


Figure 2: Color-coded maps of the inferred vector magnetic field (strength, inclination, and azimuth) of the sunspot and associated solar active region shown in the white-light image (upper left panel). This is an example of the observations taken with the SOT/SP onboard Hinode, which can now be accessed and interactively inverted through the CSAC-MERLIN web client.

High resolution figure

The most significant achievement of the LSA during the past year has been the release of the MERLIN code for the inversion of spectro-polarimetric observations of the solar photosphere. This code interprets the polarized solar radiation in the two Fe I lines at 630.2 nm, and outputs the vector magnetic field and the thermodynamic properties of the observed solar region. The development of the code and of its web client was supported through the CSAC initiative. Through the CSAC website it is now possible to access pre-inverted spectro-polarimetric data selected from a continuously updated database of observations from the SOT/SP instrument on-board the Hinode spacecraft. Currently these observations represent the best available data for synoptic measurements of the vector magnetic field on the Sun, thanks to the high spatial resolution, stability of image quality, and extended time coverage attainable from space. The MERLIN web client allows a web user to access these pre-inverted observations, or to initiate a completely new inversion of a solar region of choice. The user is notified by e-mail when the inversion is completed, and the results ready for display and download (see figure 2).

For next year we plan to work towards the release of the next community-inversion code LILIA on the CSAC website. This code will allow a significantly more refined analysis of spectro-polarimetric data than to MERLIN, including the derivation of magnetic-field and thermodynamic gradients in the solar atmosphere. This type of information will prove essential for comparing observations to recent advances in the magneto-hydrodynamic convection modeling of the solar photosphere (M. Rempel). With the completion of SPINOR, there will also be an effort towards adding observations taken with this instrument to the CSAC database. We expect to achieve a complete debugging of ProMag, successful deployment of the instrument, and start of science operation within the next year.

return to top

MHD Physics Of The Solar Corona And Wind

The solar corona, heated by various mechanisms to million-degree temperatures is fully ionized. Embedded with a magnetic field of about 10 Gauss at the coronal base, this atmosphere is an excellent conductor of both heat and electric current. Outward thermal conduction of heat, aided by MHD and plasma waves, drives the outer corona to expand continuously into the solar wind, filling interplanetary space. High electrical conductivity enables the magnetic fields to store significant amounts of energy which is released through the resisitive dissipation of thin sheets of electric current. Such an MHD process heats the corona ubiquitously and produces the impulsive flares, but we still have much to learn about its basic physical nature. The corona is not static, of course. Its magnetic field changes in time, reversing its global polarity once every 11 years in concert with dynamo action in the solar interior. Thus, the dynamo rejuvenates the corona in each cycle, producing flares and sending daily coronal mass ejections into the more slowly varying solar wind. This is the dynamical origin of space weather. The NCAR program described below investigates the basic MHD of the corona as an essential component of national space-weather research.

Under coronal conditions of extremely high electrical conductivity, magnetic fields evolve with no change in their field topologies unless the ordinarily weak effect of electrical resistivity is enormously amplified via the spontaneous formation of current sheets, as described by the theory of Parker (1994). Plasma parcels embedding distinct magnetic flux systems cannot mix freely, and current sheets would develop as tangential field discontinuities at the boundaries between the flux systems. The nonlinear mathematical problems posed by this fundamental effect are formidable in general, but have been found to be tractable for the topologically untwisted magnetic fields defined by Low (2006a, b). Ase Marit Janse (ASP) and B. C. Low (HAO) presented two explicit examples of current-sheet formation in this special class of magnetic fields. The first example considers a topologically untwisted field inside a cylinder of perfectly conducting fluid (Janse & Low 2009). The field is anchored by its magnetic footpoints fixed at the cylinder ends, so that its topology is invariant to a continuous change in the length of the cylinder. Whereas this field of a fixed topology may have a continuous equilibrium state, as a potential field, for a particular length of the cylinder, no continuous equilibrium state is available to the field when the cylinder is given other lengths. In the latter case, magnetic discontinuities or current sheets must form throughout the field, whose dissipation can then change the field topology into one compatible with a continuous state. An important aspect of this demonstration is that magnetic neutral points are not essential to the process, as implied by the Parker theory.

The second example treats the topological change brought about by the dissipation of a pre-existing current sheet embedded under equilibrium conditions in a topologically untwisted field (Low & Janse 2009). This dissipation produces a reconnected potential field whose field topology implies that other current sheets, in addition to the sheet in the initial state, must have formed and dissipated throughout the field in order to arrive at its potential state. These demonstrations offer basic physical explanation of the ubiquitous heating observed in both the quiescent corona and energetically explosive events like the flares. The Parker theory needs to be incorporated into the MHD simulation models in use in solar and space-weather research.

Natasha Flyer (IMAGe), Bengt Fornberg (University of Colorado), Ken Miller (Wichita State University),and Low investigated the turbulently-relaxed state of a magnetic structure following a flare-like release of magnetic energy. The theory of Taylor (1974) points out that the formation and dissipation of current sheets in this relaxation is subject to an approximate conservation of the total magnetic helicity under the condition of extremely high electrical conductivity in the corona. Extending this idea originally developed for a contained laboratory plasma to an open astrophysical atmosphere is essential but has been neglected in current solar research. This extension was carried out by solving a free-boundary problem in a two-dimensional atmosphere. A numerical solver was developed to construct the relaxed equilibrium state, seeking as an unknown the boundary separating the flared magnetic structure from the surrounding part of the atmosphere not involved in the flare. The flared structure contains the initial flaring magnetic field as well as the surrounding field that has reconnected with it, subject to the conservation law on magnetic helicity. A hydromagnetic implosion effect first pointed out by Hudson (2000) is cleanly demonstrated by these numerical computations (Miller et al. 2008). As the stored magnetic energy is transformed into escaping radiation and high-energy particles during a flare, the magnetic pressure of the flaring magnetic field is reduced, leading to an inward collapse as the surrounding plasma and field push in with their superior pressure. This work motivates observations to look for the signatures of the Hudson implosion, and paves the way for numerical modeling of coronal relaxed structures in realistic 3D modeling.

Flyer, Mei Zhang (National Astronomical Observatory, Beijing & NCAR Affiliate Scientist) and Low continue with their theoretical study of magnetic helicity accumulation in an open hydromagnetic atmosphere. Progress has been made towards an analytical proof of an upper bound on the total magnetic helicity contained in a global force-free magnetic field. Exceeding this upper bound is a sufficient condition for a loss of equilibrium that must open up the field to let trapped magnetic twist escape. In this manner, the total helicity can be brought down to within the bound for equilibrium to be re-established. This possible hydromagnetic origin of coronal mass ejections has been investigated by Zhang & Flyer (2008).

A two-year effort initiated by Piotr Smolarkiewicz (MMM/IMAGe) and Low to simulate 3D MHD evolution leading to the formation of current sheets has produced interesting first results. The challenge of numerically describing sheet formation developing as singularities in a 3D magnetic field is handled by describing the field in terms of its flux surfaces as opposed to the usual Eulerian specification of the field vector as a function of space. Joined by Ramit Bhattacharyya (ASP), Smolarkiewicz and Low investigated a periodic field in an incompressible, viscous, electrically perfectly-conducting fluid. The field is drained of its free energy as its Lorentz force drives a flow whose kinetic energy is viscously dissipated. The equilibrium end-state so produced requires the existence of a set of global magnetic flux surfaces each containing a constant fluid pressure. Although the initial field is untwisted with well defined global flux surfaces, it is the nature of 3D fields that, in general, it is topologically not possible for any set of these flux surfaces to be arranged into global isobaric surfaces. This impossibility manifests in the formation of magnetic tangential discontinuities. The above initial-value simulations show a first-stage extended smooth evolution followed by an evolutionary change identifiable with the formation of current sheets and their unavoidable artifical dissipation via the loss of numerical spatial and temporal resolution. These simulations provide the most direct illustration of sheet formation via the explicit representation of magnetic flux surfaces. The numerical codes developed by Smolarkiewicz (2006) have opened the way to further developments, to treat compressibility; boundary conditions of interest to solar coronal magnetic fields; and, twisted magnetic fields in the description of Low (2007a) using two pairs of flux surfaces. A problem of fundamental interest to be addressed is whether magnetic discontinuities can form in finite time (see Kerr & Brandenburg 1999) and (Grauer and Marliani 2000).

In an ongoing effort, Janse and her collaborators Oeystein Lie-Svendsen (Norwegian Defence Research Establishment & University of Oslo) and Ruth Esser (University of Tromsoe) investigated the heating of minority ions (carbon, oxygen and silicon) in the solar wind, using a multi-fluid numerical model developed at the Institute of Theoretical Astrophysics, University of Oslo. The goal is to compare the different solar-wind solutions, produced by varying the theoretical heat input in the model corona, for comparison with observations.

Resources:

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- A. M. Janse & B. C. Low 2009, ApJ, in press
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- B. C. Low & A. M. Janse ApJ, submitted
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E. N. Parker 1994, Spontaneous current sheets in magnetic fields, Oxford U Press

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return to top

Chemistry and dynamics of the middle and upper atmosphere

ACD scientists have worked with data from the TIMED (Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics) satellite to investigate the dynamics and chemistry of the middle atmosphere. Much of this research has been done in collaboration with US and international colleagues.

The diurnal tide gives large amplitude variations over 24-hours of temperature and winds in the mesosphere. ACD scientists have worked on the characterization of variations in the tidal amplitudes and phases using temperature and wind data from TIMED and ground-based radar. The results indicate that there are large variations of tidal amplitude on semi-annual and annual timescales. The tide at the equator also varies on a multi-year timescale in concert with the quasi-biennial oscillation in equatorial lower stratospheric winds. This study will continue, using small differences in the tides to derive the eddy diffusion rate in the mesosphere.

Up to now, the chemistry of the mesosphere has been poorly constrained by observations. This is beginning to change, and analysis by ACD scientists is contributing. A new measurement from the SABER instrument on TIMED gives the distribution of atomic hydrogen. These global, multi-year measurements show a drop in the hydrogen in the summer mesosphere that is inconsistent with transport. However, a closer look indicates that this drop is consistent with the vertical redistribution of hydrogen due to the freezing of water in polar mesospheric clouds and subsequent vertical displacement and sublimation of the ice particles.

Ozone observations by SABER also reveal some unusual aspects. At the location of the ozone secondary maximum near 95 km, SABER observations show occasional very high mixing ratios of over 20 ppmv, and as high as 50 ppmv, during night. Analysis indicates that these are associated with unusually large amplitudes of the diurnal tide. The large tide leads to low nighttime temperatures at 95 km at the equator; the low temperatures affect the photochemistry of ozone in such a way that the ozone is high. The magnitude and occurrence of the high ozone fit well with current understanding of ozone photochemistry.

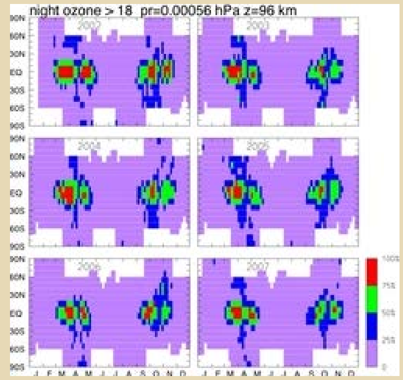


Figure 1: Latitude and day distribution of the incidence of ozone mixing ratio over 18 ppm at about 96 km (near the mesopause). The observations are from TIMED/SABER, nighttime only. The high ozone occurs near the equator during equinoxes, which is when the diurnal tide has its largest amplitude. At this altitude, the tidal phase is such that the coldest temperatures occur during the night. With colder temperature, the ozone production rate is faster and the loss rate is slower so the overall amount increases.

High resolution figure

return to top

UTLS dynamics, trends, and composition

Stratospheric temperature trends

ACD scientists helped organize an updated assessment of stratospheric temperature trends, based on radiosonde, satellite and lidar measurements. This work was performed over the last several years in collaboration with a group organized under the WCRP SPARC Program. Satellite data include measurements from the series of NOAA operational instruments, including the Microwave Sounding Unit (MSU) covering 1979-2007 and the Stratospheric Sounding Unit (SSU) covering 1979-2005. Radiosonde results were compared for six different data sets, incorporating a variety of homogeneity adjustments to account for changes in instrumentation and observational practices. Temperature changes in the lower stratosphere show cooling of ~0.5 K/decade over much of the globe for 1979-2007. Substantially larger cooling trends are observed in the Antarctic lower stratosphere during spring and summer, in association with development of the Antarctic ozone hole. Trends in the middle and upper stratosphere have been derived from updated SSU data, taking into account changes in the SSU weighting functions due to observed atmospheric CO2 increases. The results show mean cooling of 0.5-1.5 K/decade during 1979-2005, with the greatest cooling in the upper stratosphere near 40-50 km. Temperature anomalies throughout the stratosphere were relatively constant during the decade 1995-2005. These observations will be utilized for detailed

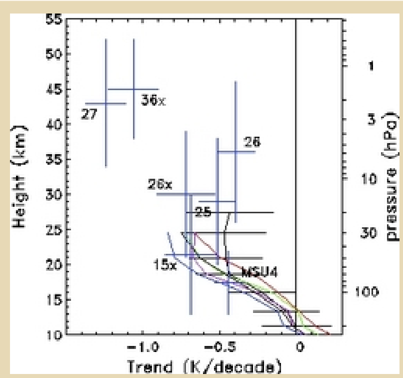


Figure 1. Vertical profile of near-global (60° N-S) stratospheric temperature trends for 1979-2005 derived from satellite and radiosonde measurements. Blue crosses denote results derived from MSU and SSU satellite data, with the vertical bars denoting the approximate altitudes covered by

comparisons to model results within the SPARC CCMval Project.

Forcing of the tropical Brewer-Dobson circulation

The Brewer-Dobson upwelling in the tropical lower stratosphere is a dynamically-forced phenomenon, with a pronounced annual cycle leading to seasonal variations in stratospheric temperature, water vapor and other constituents. ACD scientists used diagnostic studies to quantify the dynamical forcing of large-scale upwelling in the tropical lower stratosphere, based on circulation statistics from ERA40 and NCEP/NCAR reanalysis data. Zonal mean upwelling derived from momentum balance and continuity (so-called downward control) was found to be in reasonable agreement with independent calculations based on thermodynamic balance. The detailed momentum balances associated with the dynamical upwelling were investigated, in particular the contributions to climatological wave forcing (EP flux divergence) in the subtropics. Results showed that the equatorward extension of extratropical waves (baroclinic eddies and, in the NH, quasi-stationary planetary waves) contribute a large component of the subtropical wave driving near the tropical tropopause. Additionally, there is a significant contribution of forcing from equatorial planetary waves forced by tropical convection. The observed balances demonstrate that the strong annual cycle in upwelling across the tropical tropopause is forced by subtropical eddy momentum flux convergence associated with waves originating in both the tropics and extratropics. Additionally, tropical upwelling is found to systematically increase in simulations of future climate. (link)

Transport and chemistry of the Asian monsoon anticyclone

The Asian monsoon anticyclone is a region of persistent pollution in the upper troposphere during Northern Hemisphere summer, resulting from vertical transport of surface pollution in deep convection, and confinement by the strong anticyclonic circulation. This circulation extends into the lower stratosphere, and may be an important mechanism for troposphere-stratosphere coupling. ACD scientists used short-lived chemical species measured by Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) to explore chemical behavior of the Asian monsoon anticyclone. The climatology of carbon monoxide (CO) measured by ACE-FTS shows a local maximum in the Asian monsoon anticyclone region (Fig. 1). Other short-lived species measured by ACE-FTS, such as hydrogen cyanide (HCN), ethane (C_2H_6) and acetylene (C_2H_2), which have common sources of biomass burning, show maximum enhancement inside the anticyclone near the tropopause (Fig. 2a). The photochemical age of air was estimated by the ratio of C_2H_2/CO, indicating that air inside the anticyclone is relatively young (Fig. 2b), i.e. this air has was recently transported from lower altitudes. Ongoing work is aimed at understanding the transport pathways within the monsoon region, and quantifying the effect of convective transport and large-scale circulation in the UTLS region.

Microphysics parameterization for CAM

ACD and CGD scientists have been leading a collaborative development effort for a new microphysics parameterization for CAM. The goal of this effort is to develop an advanced microphysics package which can represent the size of cloud drops, and simulate how cloud drops are influenced by the distribution of aerosols. The ultimate goal is to quantify aerosol indirect effects in CAM and CCSM. This work dovetails with other studies in ACD, MMM and CGD of cloud microphysics, both in observations and in models. An important component of the broader activity is the development of better satellite data sets of cloud microphysical properties for comparing the CAM and WACCM simulations to observations. This work has recently been extended to treat the effects of ice clouds and ice cloud aerosol interactions.

Evaluating model simulations of the Tropical Tropopause Layer

ACD scientists and collaborators also analyzed the representation of the Tropical Tropopause Layer (TTL) in global models. Comparisons of a number of diagnostics with observations indicate that global models are capable of representing TTL structure and variability well on many scales. TTL structure in 13 different chemistry - climate models has been analyzed, and the performance of the models and their representation of the past and future explored. Comparisons indicates that convection within the TTL itself is not

separate instrument channels. Colored curves show trends derived from different radiosonde data sets up to ~25 km. Horizontal bars denote 2-sigma statistical trend uncertainties.

High resolution figure

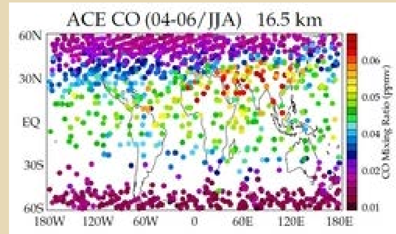


Figure 2. Carbon monoxide (CO) mixing ratios at 16.5 km (~100 hPa) obtained from Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) from June to August 2004-2006. The upper tropospheric CO is enhanced over the Asian monsoon anticyclone (From Park et al., 2008).

High resolution figure

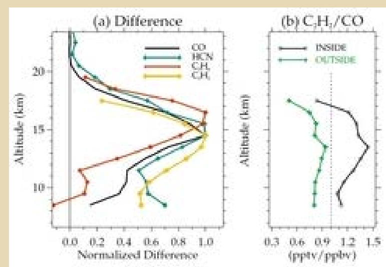


Figure 3. (a) Normalized difference between average profiles of carbon monoxide (CO), hydrogen cyanide (HCN), ethane (C_2H_6) and acetylene (C_2H_2) inside and outside of the Asian monsoon anticyclone. (b) Vertical profiles of ratio of C_2H_2/CO inside and outside of the anticyclone (From Park et al., 2008).

High resolution figure

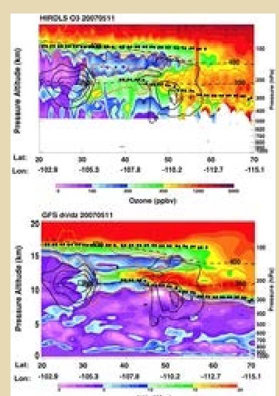


Figure 4. Cross section along the HIRDLS FOV track (shown on the NA map in Figure 5a) on May 11, 2007. The layer structure of the intrusion is consistently shown in the ozone cross section measured by HIRDLS (upper) and the PTLR cross section based on the GFS

critical for TTL structure, though convection below the TTL is important. Most models predict the tropical tropopause will get higher and slightly warmer in the 21st century. ACD scientists are continuing this work on evaluating tropopause behavior in global models within the SPARC CCMval Project.

ACD scientists are also leading an effort to develop a community model diagnostic package for use internally and by the community for coupled chemistry climate models. This includes developing advanced techniques for modifying model output, and utilizing satellite simulators to better represent observations and evaluate model simulations.

Transport from troposphere to stratosphere associated with the secondary tropopause

It has long been recognized that the temperature lapse rate based thermal tropopause definition produces breaks and multiple tropopauses in the extratropics. Recent analyses using global high resolution GPS data has shown that the area of double tropopause is much more extensive than previously realized. ACD scientists used newly available satellite data from HIRDLS to explore the connection between the occurrence of the secondary tropopause and chemical transport from troposphere to stratosphere. Figure 4 shows an example of low ozone layer above the primary extratropical tropopause and below the secondary tropopause, which is an extension of the tropical tropopause. A similar structure is also found in the potential temperature lapse rate, derived from the NCEP/GFS meteorological analyses, for the same cross section. (Pan et al., submitted, 2008)

This observation of relationship between the chemical structure and the meteorological field made it possible for the development of a forecast tool for aircraft observations, which in turn allowed successful in situ observations of this intruding tropospheric layer during the START08 experiment. Figure 5 shows an example measurement from the NCAR GV research flight on April 18, 2008, including meteorological analyses and in situ measurements. As indicated by Figure 4, the flight successfully observed an extensive layer of intruding tropospheric-like air between the two tropopauses. The large suite of chemical species measured will help characterizing the chemical impact of this type of event. The analyses of these new data will be the focus of next year.

Linking pollution with aerosols and clouds

In collaboration with Jonathan Jiang (Jet Propulsion Laboratory), ACD scientists analyzed MLS and MODIS data to quantify relationships between CO in the upper troposphere (an indicator of pollution) and cloud characteristics (MLS ice water content and MODIS effective cloud radii). Figure 7 shows the relationships between MODIS ice effective radii and MLS ice water content (IWC) for clean and polluted clouds over the Amazon during the wet and dry seasons. “Clean clouds” are those for which (by definition) MLS CO at 215 hPa is less than 120 ppbv, while “polluted clouds” have CO greater than 240 ppbv. MODIS aerosol is fairly constant during the wet season for the full range of MLS CO (since precipitation process scavenge aerosol). In the dry season MODIS aerosol increases as MLS CO increases. Therefore, differences in the dry and wet season panels are expected and observed. The results show that MODIS effective radii are systematically smaller in polluted clouds, demonstrating the so-called aerosol indirect effect.

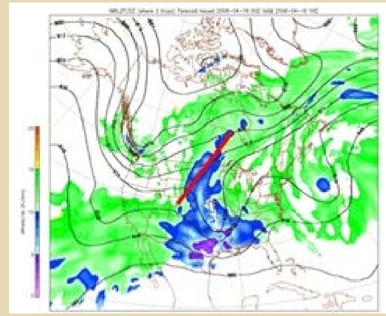
HIRDLS cloud measurements

ACD scientists also led validation and analysis efforts for measurements of clouds from HIRDLS data. Figure 6 presents a comparison of cloud frequency in the tropical upper troposphere from HIRDLS and CALIPSO measurements. The magnitudes and geographical distributions are very similar, which demonstrates that both experimental data sets can be used to determine the occurrence and seasonal variations of cirrus near the tropopause in a convincing manner.

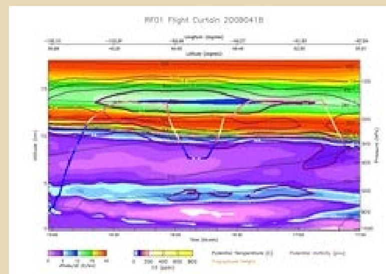
return to top

analyses (lower). The GFS analyses thermal tropopause (black dots), zonal wind (black contour), 350 and 400 K isentropes (black broken) and PV (2, 4, 6, and 8 pvu) contours are shown on the cross sections.

High resolution figure



High resolution figure 5a



High resolution figure 5b

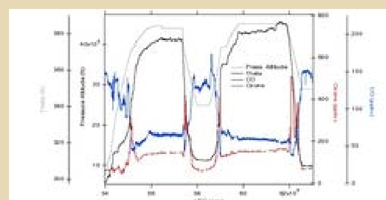


Figure 5. Sandwiched stratosphere sampled by NCAR GV during START08 April 18, 2008. **(a)** The region of double tropopause over North America based on high resolution NCEP/GFS meteorological analyses. The colors represent the minimum potential temperature lapse rate (dq/dz (K/km)) between the two tropopauses. The red line marks the segment of the flight track shown in panel (b and c). **(b)** Cross along the flight track with potential temperature lapse rate (color image), potential vorticity (purple contours), potential temperature (black contours) and the GV flight track (colored by the ozone values). **(c)** GV measurements during the segment including pressure altitude (gray), potential temperature (black), ozone (red) and carbon monoxide (blue).

High resolution figure 5c

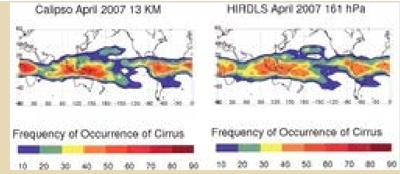


Figure 6. Comparison of HIRDLS and CALIPSO cloud occurrence frequency in April 2007.

High resolution figure

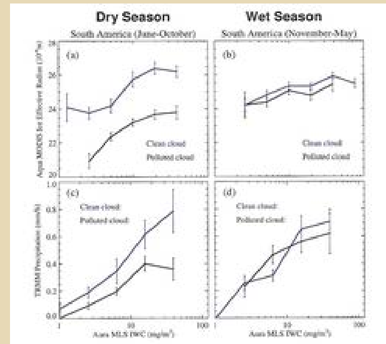


Figure 7. MODIS ice effective radii for clean and polluted clouds.

High resolution figure

Gravity Waves

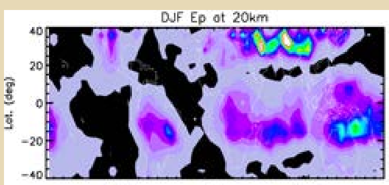


Figure 1: Potential energy density of gravity waves with zonal scales between 100-1600km averaged over December-February, derived from NRCM simulations.

High resolution figure

The goal of the NCAR Nested Regional Climate Model (NRCM) is to study processes across a wide spectrum of scales in the climate system. In the current NRCM setup, the NCAR Weather Research and Forecast (WRF) model is one-way nested in the NCEP reanalysis between 45S-45N, with vertical domain between the ground and ~10hPa. The horizontal resolution of the model is 36km (with two level nesting over Indonesia archipelago at horizontal resolution of 12km and 4km). Afforded by the high spatial resolution, we would like to explore gravity waves generated from the NRCM simulations, especially their spatial distribution and seasonal variability, and compare them with observations.

Han-Li Liu (HAO/TIIMES) and Jimy Dudhia (MMM) analyzed one year of NRCM (Columbia) simulations. Using wavelet method, they studied the global distribution and seasonal variability of the potential energy density, momentum flux and energy flux of gravity waves with zonal scales between 100-1600km. They also compare these results with those derived from satellite observations (GPS, SABER, CRISTA, and HIRDLS), and found good agreement between model results and observations. For example, strong gravity waves are identified over Western Pacific/South East Asia, Indian Ocean, West Africa, and Central America at low latitudes, similar to those revealed by GPS measurements and most likely related to tropical convection. Peak momentum flux of ~2x10-3 Pa over the Western Pacific/South East Asia is consistent with estimate from HIRDLS measurement. Their analysis also shows that the gravity waves display clear scale dependence: The potential energy density of gravity waves at low latitudes increases with zonal scale while those associated with orographic waves at mid-latitudes decreases with zonal scale. They also found that the quality of the simulation results deteriorates above ~20km because of the rapid decrease in vertical resolution and significant wave reflection from the model top.

They plan to compare the gravity wave sources from NRCM with those obtained from physics based gravity wave parameterizations recently implemented in WACCM. This will help improving gravity wave parameterization used in global models.

Gravity Wave Forcing and Wind Balance in the Mesosphere and Lower Thermosphere

Gravity waves are believed to significantly impact the mesosphere and lower (MLT) thermosphere and drive it off radiative equilibrium. This has been predicted by theoretical and general circulation models, but direct measurement or inference of gravity wave forcing prove to be a challenge.

In this study by Han-Li Liu (HAO/TIIMES), Dan Marsh (ACD), Qian Wu

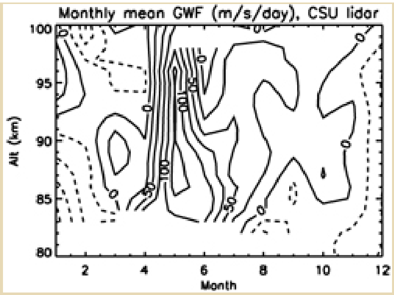


Figure 2: Monthly mean gravity wave forcing in the zonal direction derived from CSU lidar wind measurements. Contour interval: 25ms-1day-1. Solid contour: eastward forcing.

High resolution figure

(HAO), Chiao-Yao She (Colorado State University), and Jiyao Xu (Chinese Academy of Sciences), the wind balance in the mesosphere and lower thermosphere is revisited. Using simulation results from the NCAR Whole Atmosphere Community Climate Model (WACCM), they demonstrate geostrophic balance is no longer valid in the zonal direction due to the large zonal gravity wave foricng. As a result, the zonal mean geostrophic meridional wind is significantly different from the actual zonal mean meridional wind, and the residual mean merdional circulation derived from geostrophic winds is much weaker than that derived from model winds. It is also shown that the ageostrophic contribution in the MLT at middle and high latitudes comes primarily from gravity wave forcing, and it is possible to infer gravity wave forcing in the MLT from wind measurements. As a proof of concept, this wind balance relationship is applied to both the TIMED/TIDI winds and wind climatology obtained from the CSU Na-lidar to derive gravity wave forcing (Figure 2).

The next step in the research is to obtain wind climatology from multiple radar site at middle and high latitudes and also from more comprehensive satellite measurements to obtain a more comprehensive climatology of gravity wave forcing at middle and high latitudes.

return to top

Weather Research and Forecast model coupled with Chemistry (WRF-Chem)

The Weather Research and Forecasting (WRF) model coupled with Chemistry (WRF-Chem) has been and continues to be developed by NOAA scientists, in collaboration with the WRF community including NCAR/ESSL scientists. The model is used for investigation of regional-scale air quality, field program analysis, and cloud-scale interactions between clouds and chemistry. ESSL scientists and staff provide support by integrating and maintaining the chemistry components in the evolving WRF modeling system, as well as contributing new code in the development of WRF-Chem. Models such as WRF-Chem are used to further the understanding of precipitation and chemical processes, including multiscale atmospheric chemical constituent transport, dispersion and transformations. Because WRF-Chem is able to simulate the coupling between dynamics, radiation, chemistry and aerosols, science issues that depend on these interactions are being pursued.

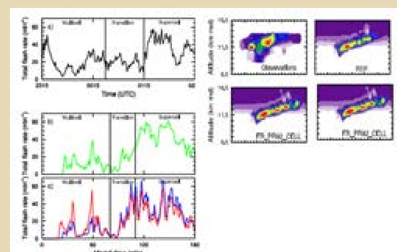


Figure: Left panel: a) Observed flash rate for the 10 July 1996 STERAO storm, b) flash rate predicted by WRF-AqChem as a function of the flux of ice crystals multiplied by the flux of precipitating ice, c) flash rate predicted by WRF-Chem using the Price and Rind (1993) equation based on maximum vertical velocity. The new parameterization based on the flux product has good agreement with the observations. Right panel: Nitric oxide (NO) mixing ratio (pptv) across the observed storm anvil and the simulated storm anvil. The location of the cross-section is 50 km downwind of the convective storm core. The production of nitrogen oxide from lightning as predicted using the flux product lightning flash rate results in good agreement with observations and reinforces the need to use parameterizations that are physically-based with the processes occurring in nature. The role of convection as a source of nitrogen oxides is important for understanding the sources and sinks of ozone in the upper troposphere where ozone affects the radiation balance and oxidizing power of the atmosphere.

High resolution figure

In April 2008, version 3 of WRF-Chem was released to the community. This version included new modules provided by NCAR/ESSL scientists. These modules are the Model of Emissions of Gases and Aerosols from Nature (MEGAN) which allows scientists to study interactions between the biosphere and atmosphere with impacts on air quality and climate, and the photolysis rate module, fast TUV, which performs a simplified, but accurate, radiation calculation of actinic fluxes. With this addition, WRF-Chem now has 3 options for the photolysis rate calculation. ESSL scientists are currently evaluating these 3 options with the MIRAGE field campaign measurements and are improving the coding to be more efficient.

Continued development of new modules for WRF-Chem addresses several aspects of the model. These include evaluating the new dust module, creating a framework to test different secondary organic aerosol chemistry schemes from complex to simple, developing a chemical tracer package that allows more flexibility for investigating sources of key chemical constituents, and creating a new and implementing old parameterizations of lightning-production of nitrogen oxides to be used at both the cloud scale and continental scale. In addition, the chemistry mechanism from the NCAR/ACD global model MOZART is being incorporated in WRF-Chem. This will allow us to contrast regional-scale and global-scale analyses of field campaigns and chemical weather using the same chemistry at both scales.

Simulations performed with WRF-Chem making use of the version 3 modules and ongoing development are focused on megacity impacts on the regional-scale air quality, the effects of thunderstorms on the upper troposphere composition, and the impact of wildfires on regional air quality. MIRAGE field campaign analysis with WRF-

Chem has shown the importance of dust in cleansing the atmosphere via uptake of nitric acid and the significant role of secondary volatile organic compounds on ozone production downwind of Mexico City. Simulations of thunderstorms and chemistry have shown that air mass thunderstorms simulated for the northern Alabama region transport boundary layer CO throughout the free troposphere while more organized storms simulated for Oklahoma and northeastern Colorado transport CO directly to the upper troposphere. These simulations are being done in preparation for the Deep Convective Clouds and Chemistry field experiment. Other WRF-Chem simulations are addressing deep convection during the North American monsoon, wildfires in Greece affecting European air quality, and air quality in the Shanghai region to prepare for a future mega-city field campaign. This work is supported by the NSF, NCAR-MIRAGE strategic initiative funds, and NASA.

return to top

Stratospheric ozone recovery

A study using WACCM and other models with interactive chemistry looked at the predictions for climate change in the Southern Hemisphere. In particular, the study addressed the predictions for winds in the SH middle and high latitudes. There is a clear difference in the climate predictions of models that do not include interactive stratospheric chemistry and those that do. The difference can be traced to the simulation of the ozone hole. When interactive chemistry is not included, winds continue to accelerate in a manner consistent with observations in recent years. However, in model simulations with interactive chemistry and a full stratosphere, the Antarctic ozone hole recovers during the 21st century due to the predicted drop in halogens in the stratosphere. This changes the thermal structure since ozone is an important radiative gas. With ozone recovery, polar temperatures warm and winds decelerate such that the overall prediction for the climate in the southern high latitudes is significantly different.

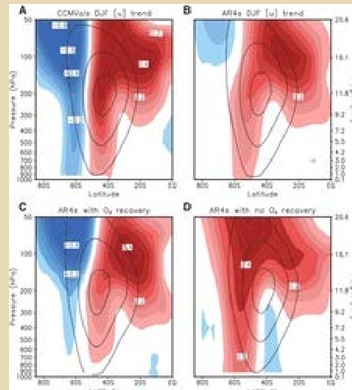


Figure 1: Trends in December-to-February zonal-mean zonal wind. The multimodel mean trends between 2001 and 2050 are shown for four groups of models. A) CCMVal models, which include interactive stratospheric chemistry. B) AR4 models, most of which have a model top below the stratopause and only about half of which specify recovering ozone for the future. C) a subset of the AR4 models with prescribed ozone recovery. D) AR4 models with no ozone recovery. Shading and contour intervals are 0.05 ms-1 decade-1. Deceleration and acceleration are indicated with blue and red colors, respectively, and trends weaker than 0.05 ms-1 decade-1 are omitted. Superimposed black solid lines are DJF zonal-mean zonal wind averaged from 2001 to 2010, with a contour interval of 10 ms-1, starting at 10 ms-1. EQ, equator. Note that AR4 models with prescribed ozone recovery (panel C) perform better, as compared to CCMVal models, than those without (panel D), but still do not reproduce the full extent of the prediction.

High resolution figure

return to top

WACCM (Whole-Atmosphere Community Climate Model)

ACD work using the WACCM model involves an extensive set of collaborators from other ESSL divisions and externally from US and international institutions.

The model was used for a global simulation of dust particles from meteors hitting the Earth's atmosphere. The simulations show that the summer high-latitude mesosphere is relatively depleted in these particles due to large scale upwelling. The number of particles may still be sufficient to supply the necessary condensation nuclei to account for the formation of polar mesospheric clouds.

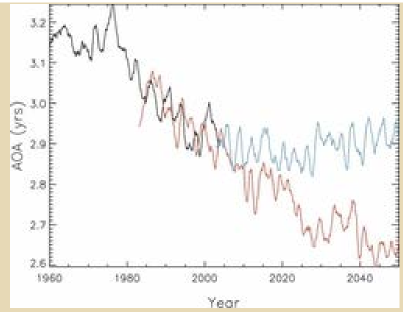


Figure 1: Evolution of the age of air near 10 hPa averaged over +/-22° for three-member ensemble simulations (i.e., three integrations of WACCM) of the climate of the twentieth century (black curve); the climate of the twenty-first century under increasing loading of greenhouse gases (red); and the climate of the twenty-first century with greenhouse gases held constant at 1995 values (blue). The decreasing age of air is an indication that the circulation is faster.

High resolution figure

Another set of simulations used WACCM to assess the impact of the insertion of sulfur into the stratosphere: one of several suggested "geo-engineering" activities to counteract the predicted climate change from greenhouse gases. The sulfur would form particles that absorb and reflect sunlight, thereby reducing the solar heating at the Earth's surface in a manner similar to large volcanic eruptions. As shown by the WACCM simulations, the sulfate particles do delay the warming at the surface compared to other simulations without the injected sulfur. However, the sulfur would also accelerate the ozone loss that occurs in late winter over Antarctica and would increase the ozone loss over the northern polar region.

According to WACCM simulations, a regional nuclear conflict could also have severe consequences for stratospheric ozone. In this case, the primary effect would be the heating of the lower stratosphere due to thick and persistent smoke. The heating leads to photochemical loss of ozone. A conflict involving 100 bombs could lead to ozone losses of 20% globally, with predictions of more than 50% at high latitudes.

return to top

Intense photochemistry in the Antarctic troposphere

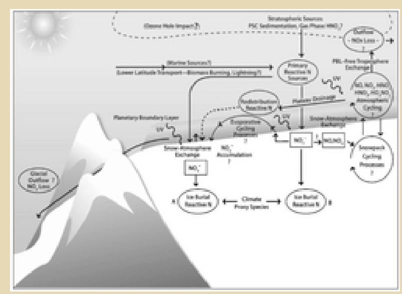


Figure 1. Schematic diagram illustrating the critical processes encompassing the reactive nitrogen budget for the Antarctic plateau. These include: primary sources, post-depositional loss mechanisms, and atmospheric/snow recycling. The symbol "?" displayed throughout the diagram suggests that currently there is only a qualitative understanding of many processes (from D.D. Davis et al., Atmospheric Environment, 42, 2831-2848, 2008).

High resolution figure

Antarctic Tropospheric Chemistry Investigation (ANTCI) was a collaborative four-year study of the sulfur chemistry in the antarctic atmosphere, including two antarctic summer field seasons in 2003-04 and 2005-06. The overall project involved thirteen principal and senior investigators at seven institutions. The broad based goal of this program was to enhance our understanding of the processes that control tropospheric levels of reactive hydrogen radicals, reactive nitrogen, sulfur, and other trace species over the Antarctic continent for the further purpose of improving the climatic interpretation of sulfur-based signals in antarctic ice core records. ANTCI was designed to address the many questions arising from the surprising findings of two earlier studies: Investigation of Sulfur Chemistry in the Antarctic Troposphere (ISCAT) and Sulfur Chemistry in the Antarctic Troposphere Experiment (SCATE). The former effort involved two field investigations (i.e., 1998 and 2000) at the South Pole (SP); whereas the latter study was carried out at Palmer Station on the coast of Antarctica. The general picture that emerged from these earlier studies was that although the oxidation of sulfur at coastal sites was a major component of the overall chemical system, one of the critical steps (e.g., involving the intermediate oxidation product dimethyl sulfoxide, DMSO) was largely controlled by heterogeneous processes. By contrast, at SP reactive gas phase sulfur was a rather minor chemical player with its oxidation being controlled by intense HOx/NOx photochemistry prior to reaching the pole. In fact, based on the ISCAT studies, much of the chemical environment at SP appeared to be dominated by fast photochemical processes. ANTCI was designed to further explore the mechanisms controlling the oxidation of sulfur under the quite different environmental conditions presented by these two sites. However, it was equally important to gain a more complete understanding of the detailed atmospheric processes controlling reactive nitrogen and HOx radical levels, and to determine the extent of the enhanced levels of these compounds.

ANTCI 2003 was the first of two studies designed to address the above issues. The first phase of ANTCI 2003 had both a large ground-based chemistry component and a limited set of aircraft chemistry measurements. The second phase (e.g., ANTCI 2005, to be discussed in later publications) was largely aircraft based with a far more complete set of aircraft photochemistry measurements, but it also had a ground-based winter-over sampling component at the SP. ANTCI 2005 was designed to study HOx/NOx chemistry over a substantial portion of the Antarctic plateau and coast under a range of different conditions. An additional goal was to explore possible primary sources of reactive nitrogen to the plateau.

Results from the ANTCI 2003 study were published in 2008 in Atmospheric Environment. The papers have a strong focus on the oxidative characteristics of the plateau's near surface atmosphere because it is this oxidation process that determines the products of reactive nitrogen, sulfur, mercury, and other gases that will characterize the trace composition of the Antarctic atmosphere, snow, and ultimately the ice core record. Model results show amazingly high OH concentrations for this dry, remote area with high solar zenith angle and 24 h of continuous solar activity. These are mainly driven, as previously shown at the SP during ISCAT, by highly elevated NO levels. The latter were a major surprise as were the enhanced concentrations found for other OH/HOx precursors, including H2O2 and CH2O. In each case, these precursors were found to be emitted from the snow surface. The aircraft observations supplied the first extensive horizontal and vertical distributions for NO on the plateau. In so doing, they demonstrated that the major enhancements observed at SP are not an artifact of the station area but rather tend to be typical of a significant region of the plateau. They also provided the first upwind history of NO emissions, allowing estimates of how NO and O3 concentrations can grow during transport to the SP.

return to top

Severe atmosphere convection

Severe convective weather, including tornadoes and severe wind gusts, impacts life and property throughout the world. In the United States, severe convective weather results in hundreds of deaths every year. ESSL scientists study the processes by which thunderstorms produce severe weather with the goal of understanding and better predicting their occurrence.

Several ESSL scientists participated in the 2008 Spring Experiment, which is held annually in Norman, Oklahoma. This program brings together researchers and forecasters to evaluate experimental severe weather forecasting techniques in real-time. In support of the experiment, ESSL scientists developed a real-time WRF forecasting system using a 3-km grid. A significant advancement this year was the use of mesoscale data assimilation based on the WRF-3DVAR system, which allows for detailed representation of severe convection in the model's initial conditions. Results show that inclusion of mesoscale data assimilation improved many forecasts, even in the 24-36 hour timeframe. However, in some cases the modeling system initialized storms that were too intense and lasted too long, which had a detrimental effect on some forecasts. Further work is planned to identify and eliminate the sources of this anomalous convection.

Through the STEP (Short Term Explicit Prediction) program, ESSL scientists collaborated with EOL and RAL scientists to develop new methods for producing 0-12 hour forecasts of high-impact weather. For example, one method being investigated is ensemble forecasting with numerical models that produce convective storms explicitly. One of the recent highlights for the STEP program was the IHOP retrospective study, in which experimental nowcasting and forecasting systems were demonstrated for a one-week period of active weather in June 2002. Results show that the ensemble forecasting system is able to accurately predict the regions where supercell thunderstorms occurred.

The production of severe convective winds at night remains a forecasting challenge. One reason is the formation of strong stable layers near the surface caused by radiative cooling. A study has investigated severe convective systems in these environments by analyzing observations and by conducting idealized numerical simulations. The study found that near-neutral layers above the stable layer are favorable for severe wind production. These near-neutral layers help increase conditional instability, but they also allow for the formation of cold pools above the stable layer. In some numerical simulations, cold pools develop downward from these near-neutral layers, sometimes leading to severe winds at the surface. The simulated convective systems are structurally similar to severe bow echoes even if they do not produce severe winds, which helps to explain the difficulty in identifying severe convective storms at night. Further research is planned to clarify the environmental conditions that can be used to better predict these events and the numerical model settings needed to accurately simulate them.

ESSL scientists have been collaborating with other scientists at NCAR, NOAA, universities, and private companies to plan the Verification of the Origins of Rotation in Tornadoes Experiment 2 (VORTEX2). This field experiment in the US Great Plains in May and June of 2009-2010 will investigate tornadogenesis, near-ground winds in tornadoes, relationships between tornadic storms and their environments, and numerical weather

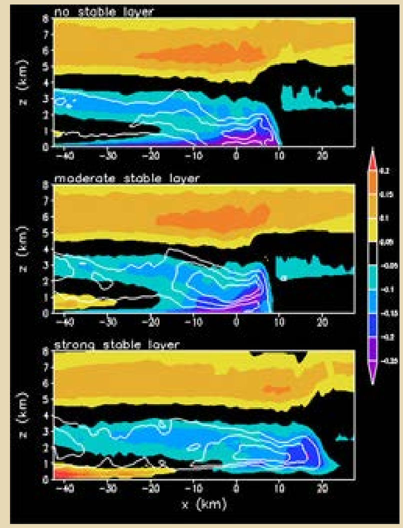


Figure: Vertical cross sections through three simulated convective systems. Top: no surface stable layer. Middle: a moderate stable layer. Bottom: a strong stable layer. Shading is buoyancy with respect to the environment, showing how cold air develops in the near-neutral layer above the surface, but only reaches the ground if the stable layer is not too strong. White contours show strong wind speeds, which also reach the ground if the stable layer is not too strong.

High resolution figure

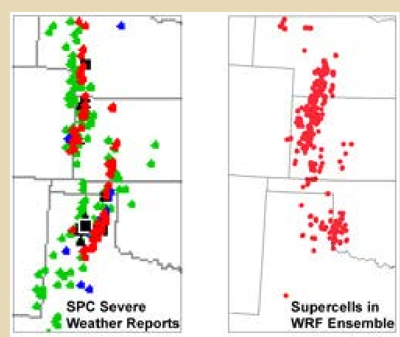


Figure: (Left) Severe weather reports logged by the Storm Prediction Center for 28 March 2007. Observed tornado locations are indicated in red. (Right) Supercell locations (red dots) at hourly intervals in a 3-5 hour WRF ensemble forecast. (Supercells are often associated with tornadoes.) The ensemble included 30 members, each employing 3-km prediction of supercells and tornadoes. In addition to going to the field, ESSL scientists will be supporting this experiment through real-time high-resolution WRF numerical weather prediction.

return to top

model horizontal grid spacing.

High resolution figure

Intraseasonal/tropical climate variability

This year has seen considerable progress in understanding the interaction between organized precipitating convection and the large scales of motion. Our approach involves cloud-system resolving models (CRM), dynamical models, and observational analysis. The following summarizes work in which the organization of precipitating convection is a common factor.

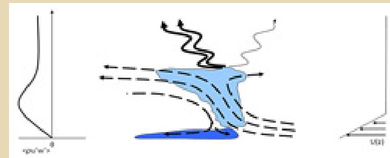


Figure: Variation in Major Hurricanes, Cat 4 and Cat 5 Hurricanes and Cat 5 Hurricanes for the North Atlantic as percentage change from the long-term mean (smoothed by a running 5-y filter, showing the unprecedented recent increase in category 5 hurricanes.

High resolution figure

a) Parameterization of convective organization in global models

The parameterization of convective organization in global models is a problem that has confounded the parameterization community for over three decades. It will be at least another decade before computational facilities are sufficient to enable convection to be represented explicitly in contemporary climate models, so parameterization is necessary. The new hybrid parameterization for next-generation global models (grid-spacing ~10 km) reported last year is relevant in the context of the Community Atmospheric Model (CAM) and the Community Climate System Model (CCSM). In the hybrid approach, mesoscale convective organization is represented explicitly by grid-scale circulations while small-scale convection is parameterized. Along with CRM analysis, this hybrid approach is a basis for constructing a parameterization of mesoscale convective organization. As a first step, the plan is to estimate the free parameters in the parameterization framework of Moncrieff and Liu (2006) using CRM simulations. A proposal has been written (PIs: Yaga Richer, CGD and Mitch Moncrieff, MMM) for support to develop and test the mesoscale parameterization. This is a collaborative effort between MMM, CGD, and the TIIMES Water Systems Program. This work is supported by NSF and, if the proposal is successful, will be supported by NOAA.

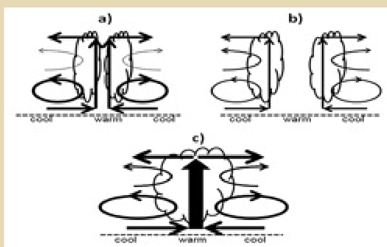


Figure: Variation in Major Hurricanes, Cat 4 and Cat 5 Hurricanes and Cat 5 Hurricanes for the North Atlantic as percentage change from the long-term mean (smoothed by a running 5-y filter, showing the unprecedented recent increase in category 5 hurricanes.

High resolution figure

b) Stratospheric gravity waves generated by multiscale organized tropical convection.

The objective here is to numerically simulate and model stratospheric gravity waves generated by organized precipitating systems, contrasting with previous work on wave generation by single clouds. This year the effects of tropospheric shear on convective organization and stratospheric gravity waves were investigated. The objective of this new study is to examine how mesoscale momentum transport (MMT) by organized convection relates to momentum transport by convectively-generated gravity waves in the stratosphere. (Gravity wave energy absorption is a major uncertainly in models of the deep atmosphere, such as WACCM.) Figure 1 shows that the convective momentum transport in the troposphere has the same sign as the gravity-wave transport in the troposphere. Consequently, when organized convection is represented in global models (see above item); the gravity-wave response in the stratosphere can be predicted. This research is collaborative with Todd Lane, The University of Melbourne, Melbourne, Australia. This work is sponsored by NSF.

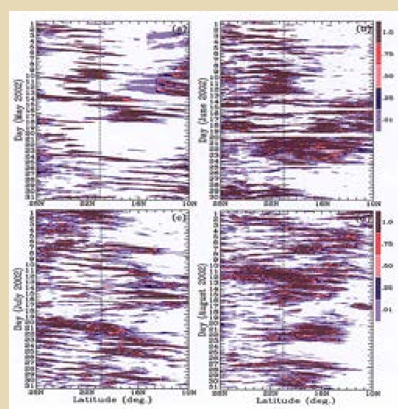


Figure: Time-space diagrams of the longitudinally-averaged rain rate over the Bay of Bengal, during part of the monsoon season. The streaks are mesoscale convective systems (MCS) propagating southward. Irregularly, the episodes cluster into larger-scale precipitation systems similar to the MJO. On these diagrams the broken lines

c) Madden-Julian Oscillation (MJO) and convectively-coupled waves

A new study of explicitly simulated tropical convection over idealized warm pools aims at quantifying the relationship between the spatial pattern of organized tropical convection and sea-surface temperature (SST), and explaining the observation that the strongest convection is not located where SST is highest. The reason hinges on the effects of cloud-radiative interaction and surface friction on convective organization. Figure 2a, the control simulation contains both cloud-interactive radiation and surface friction. In Fig. 2b, where the radiative heating is horizontally uniform, organized convection shown by the cloud outlines is far displaced from the maximum SST in the center of the domain. In Fig. 2c, where surface friction is omitted, the convection occurs over the warmest SST. This shows that spatial pattern of convective organization is sensitive to the parameterization cloud-radiation interaction and surface friction. A paper by Liu and Moncrieff has been submitted to *J.G.R - Atmospheres.*

show the average position of the northern coast of the Bay. [Courtesy Liu et al. 2008.]

High resolution figure

Propagating rainfall episodes associated with convectively-coupled waves over the Bay of Bengal analyzed from satellite data indicate multiscale convective organization similar to the MJO, suggesting a scale-invariance between the MJO and the episodes in the Bay. Figure 3 shows multiscale convective organization over the Bay during the monsoon season. The rainfall streaks consist of organized rainfall episodes (mesoscale convective systems) originating over the Indian continent and subsequently propagating southward over the Bay. Irregularly, the propagating episodes cluster into larger-scale systems morphologically similar to the multiscale structure of the MJO. Interestingly, the propagation direction of the MCS over the Bay of Bengal is parallel to the shear vector, which contrasts with the perpendicular orientation of MCSs at large. The shear-parallel organization stems the hydraulic effect of the convectively-generated pressure gradient on propagating systems, somewhat similar to density-current dynamics. The results were published in Liu et al. (2008).

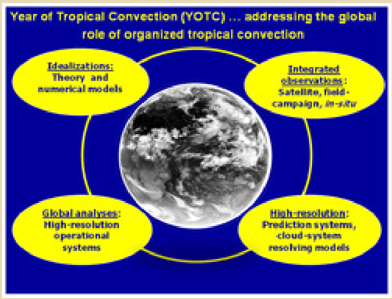


Figure: YOTC aims to improve the predictive skill of operational models by addressing convective organization on spatial scales up to global and time scales up to sub-seasonal (the intersection of weather and climate) using: i) global analyses from high-resolution operational systems; ii) high-resolution prediction systems and cloud-system resolving models; iii) integrated satellite, field-campaign and in situ observations; iv) theoretical and idealized models.

High resolution figure

The above research was supported by NSF.

d) Year of Tropical Convection (YOTC)

Incomplete knowledge and practical issues relating to tropical convection severely disadvantage the skill of numerical weather prediction models and climate models Furthermore, tropical convection has long-range effects on stratospheric-tropospheric exchange, the large-scale circulation of the upper-atmosphere, and the variability of weather and climate around the world. In order to address this major challenge, WCRP and WWRP/THORPEX proposed a year of coordinated observing, modeling, and forecasting, which led to the Year of Tropical Convection, YOTC. The theme of YOTC is the role of organized tropical convection at large scales. Together with accompanying research activities, the YOTC seeks to advance knowledge, diagnosis, modeling, parameterization, and prediction of multi-scale tropical convection and two-way interaction between the tropics and extra-tropics. The YOTC project will exploit the vast amounts of existing and emerging observations, the expanding computational resources, the new, high-resolution modeling frameworks, and theoretical insights (see Fig. 4). This activity involves unprecedented collaboration between international programmatic activities, the operational prediction, research laboratory, and academic communities. Global databases of satellite data, in-situ data, and high-resolution model analysis and forecasts will be constructed. Emphasis is on timescales ranging from days-to-months; that is, the intersection of weather and climate. The following objectives were achieved this year: i) the ECMWF T799 (25 km) global analysis, forecast products, and special diagnostics being archived at ECMWF will be available to the community; ii) the YOTC Science Plan was drafted; iii) the YOTC Implementation Plan is in the first stage of development. Started in May 2008, YOTC will contribute to the Asian Monsoon Year (AMY), the THORPEX Pacific Area Regional Campaign (TPARC), the United Nations Year of Planet Earth, and the International Polar Year. The scientific basis for YOTC is published in Moncrieff et al (2007), and a brief summary is published in Waliser and Moncrieff (2007). The YOTC work is collaborative between MMM and TIIMES.

return to top

RT/MHD modeling of the solar surface layers

The solar photosphere is a transition region in which the primary energy transport mechanism switches from convection to radiative transfer. At the same time the plasma becomespartially ionized, due to the lower temperatures requiring a more complicated equation of state. Also, the role of the magnetic field is changing: while the interior of the sun is dominated by the gas pressure, in or above the photosphere the magnetic pressure becomes the dominant contribution. Due to the rather short density scale height the photosphere is a highly stratified medium in which convective motions easily steepen up to supersonic flows and shock waves. The combination of all these conditions make numerical modeling of the photosphere challenging, but also extremely interesting due to the strong interaction between convection, magnetic field; and radiation, and the possibility for in depth comparison with high resolution observations.

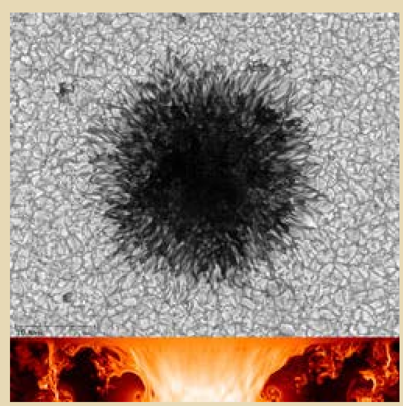


Figure 1: Snapshot of a numerical simulation in a domain of 50x50x8 Mm containing a sunspot of about 25 Mm diameter. The top shows an intensity map (visible light image) of the simulated spot showing the central dark umbra with a few bright umbral dots.

During the past year,HAO, in collaboration with the Max-Planck Institute for Solar System Research (MPS) in Germany, modified the MURaM MHD code to specially deal with the numerical challenges encountered in regions of strong magnetic field in the photosphere. This new code has been used to study the fine structure of sunspots, especially the filamentary structure of the penumbra. The numerical simulations have identified a magneto-convective origin of penumbral filaments in which expansion and flux expulsion due to overturning convective motions leads to a filamentary structure characterized by reduced magnetic field strength, increased inclination angle and horizontal outflows. The simulated penumbral structure corresponds well to the observationally inferred interlocking-comb structure of the magnetic field with Evershed outflows along dark-laned filaments with nearly horizontal magnetic field and roll-type perpendicular motions, which are embedded in a background of stronger and less inclined field.

Future research in this field will focus on high resolution simulations that allow for more detailed comparison to observations such as Hinode. Simulations of full sunspots in larger domains will address the global structure of sunspots and their surroundings. Results from these simulations are also essential for the development of more advanced helioseimic inversion methods.

return to top

The umbra is surrounded by a filamentary penumbral region formed by filaments of a few Mm in length. The outer parts of the domain show granulation with a few pores formed from magnetic flux that got eroded of the sunspot. The bottom panel shows the field strength on a vertical slice through the center of the spot. The maximum field strength at the bottom of the domain is 8kG, the field strength in the umbra of the spot reaches a peak value of 3.5 kG in the center.

High resolution figure

Strategic Goal #1, Priority #1

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ESSL LAR 2008: STRATEGIC GOAL #1, PRIORITY #2

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #1, Improve understanding of the atmosphere, the Earth system, and the Sun. This Strategic Goal encompasses four Strategic Priorities, each of which is dependent on the efforts and accomplishments of ESSL staff.

ESSL developed an action plan with seven priority themes which involve direct partnerships with the university community and contribute directly to the ESSL Strategic Vision and to several priority items of the NCAR Strategic Plan.

ESSL's seven priority themes:

1. Climate projection, with emphasis on short-term prediction.
2. Biosphere-Atmosphere-Hydrosphere interactions and specifically development of BEACHON Project (Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, Hydrology, Organics and Nitrogen).
3. Water system research, specifically the development of the Society, Water, Atmosphere and Natural Systems Project (SWANS).
4. An advanced Weather Research and Forecasting system, specifically the development of the Hurricane Intensity and Forecasts (HiFi) Project.
5. Space Weather, specifically the development of the Coronal Solar Magnetism Observatory Project (COSMO).
6. Chemical Weather, including interpretation of observed data gathered during the Megacity Impact on Regional and Global Environments (MIRAGE) campaign, and the development of a capability for chemical data monitoring and prediction.
7. Prediction across scales, specifically the development of an advanced next-generation, climate-weather modeling system and an integrated Earth system model of intermediate complexity.

Goal #1, Priority #2: Investigating the Interactions of the Atmosphere, the Broader Earth System and Human Society, is described as a combination of "...meteorology and climatology," which "were (previously) considered separate fields, largely because of disparate time and length scales. Today, the two fields are strongly coupled, not only because climate provides boundaries for investigating the weather, but also because localized events can influence larger climatological scales. The activities that NCAR scientists focused on this year ranged from collecting in situ data to better understand climate, weather and related phenomena, to developing and analyzing ways to better model natural processes and working with university partners to devise ways of tackling scientific questions."

This NCAR priority, driven by ESSL's themes 2, 3, 4, 6, & 7, is critical to achieving NCAR's first strategic goal.

The section below describes specific research conducted by ESSL staff under projects relevant to Priority 2. The major ESSL activities in this area are studies of the global and regional carbon, nitrogen, and water cycles and their coupling, feedbacks, and interactions. Additional major activities focus on climate change and variability, extreme weather events, and the impacts of climate, weather, and urbanization on society and ecosystems.

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11. Exploring the role of aerosols - ACD
12. Convection organization: Observational analysis and resolved simulations - MMM
13. Atmosphere/ocean interactions - MMM
14. Long-term climate change in the thermosphere - HAO
15. The impacts of climate and weather on society and ecosystems: Climate change - probabilistic climate change, and solar forcing of climate - CGD
16. Land-atmosphere coupling - MMM
17. Emission inventories and application - ACD
18. The impacts of climate and weather on society and ecosystems: Water cycle - CGD
19. Parameterization - MMM
20. Role of the oceans in climate - CGD
21. Structure and evolution of clear and cloudy atmospheric boundary layers - MMM
22. Fine mesh land model - TIIMES
23. NASA African Monsoon Multidisciplinary Analysis (NAMMA) - MMM
24. Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) contributions - ACD
25. Texas air quality study - ACD

Regional Carbon Cycle

TIIMES measurement and instrument development projects have advanced our understanding of regional carbon fluxes, particularly in the mountain west, and provided key NCAR contributions to the multi-agency North American Carbon Program (NACP). A central component of this effort is the Regional Atmospheric Continuous Carbon Dioxide Network in the Rocky Mountains (Rocky RACCOON).

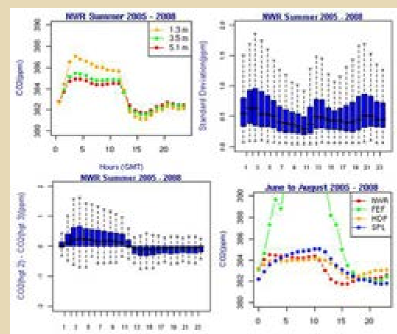


Figure 1: Summertime RACCOON data averaged over the months June-August. a) Calibrated CO_2 values from three heights at NWR b) Boxplot of the distribution of hourly standard deviations at NWR. c) Boxplot showing the distribution of 3.5 m to 5.1 m vertical gradients at NWR. d) Filtered diurnal cycles from four sites are generally representative of concentrations over large regions.

High resolution figure

In order to improve our understanding of regional carbon fluxes in the Rocky Mountain West, TIIMES scientists have developed and deployed autonomous, inexpensive, and robust CO_2 analyzers (AIRCOA) at six sites throughout Colorado, Utah, and Arizona over the past three years (http://raccoon.ucar.edu). Analysis of the diurnal cycles in CO_2 concentration and CO_2 variability at these sites provide insight as to when and under what conditions mountaintop CO_2 signals are regionally representative, as well as first-order constraints on boundary-layer heights and flux rates for use in evaluating model fidelity (Figure 1).

Comparisons between the RACCOON measurements and estimates of free-tropospheric background concentrations reveal regional-scale CO_2 flux signals that are generally consistent with one another and our expectation of peak CO_2 uptake in mountain forests during spring (Figure 2). Combining these differences with information on boundary-layer mixing can lead to quantitative estimates of monthly regional CO_2 fluxes. These data have also been used in the NOAA CarbonTracker flux estimation system as well as the GlobalView data product used by modeling groups around the world.

The RACCOON observations at Fraser Experimental Forest have occurred while the trees in the St. Louis creek drainage have experienced widespread mortality due to mountain pine bark beetle infestation. The CO_2 measurements at the base of this valley show large increases in CO_2 at night as the valley drainage flow pools respiration from a large area. This nocturnal build-up has decreased over the past three years (Figure 3), suggesting a decrease in ecosystem respiration in response to the insect outbreak. This decrease indicates that the reduction in autotrophic respiration is greater than any short-term increase in litter fall, and will be a valuable test of models predicting the impact of the recent outbreaks on regional scale carbon fluxes.

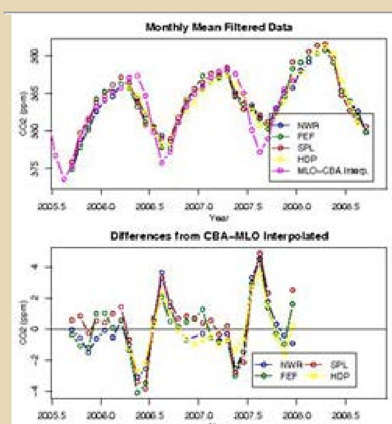


Figure 2: Monthly mean RACCOON CO_2

Future plans to address regional carbon fluxes include in depth analysis of ACME-07 and Rocky RACCOON data and synthesis with modeling efforts to:

1. define regional-scale monthly to interannual carbon fluxes for the U.S. Central

Rocky Mountains and Southwest,

2. assess key drivers of variability and trends including drought, fires, and insects, and
3. optimize community CO_2 observational efforts across the Mountain West.

return to top

concentrations at four sites and differences from marine boundary layer concentrations interpolated to the same latitude. The differences indicate strong CO_2 uptake during spring in the Central Rocky Mountains.

High resolution figure

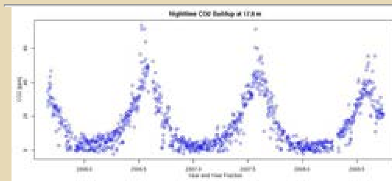


Figure 3: Nighttime valley CO_2 buildup measured at the Fraser Experimental Forest site. The decreasing trend indicates reduced ecosystem respiration following widespread beetle mortality.

High resolution figure

Landfall impacts of hurricanes

The 2005 Atlantic hurricane season is a vivid reminder of the economic and societal consequences of landfalling tropical cyclones. Improved forecasts of hurricane structure, intensity change, and time-extensions of skillful track prediction are vital for evacuation strategies. Progress requires solving difficult problems such as the inner-core hurricane dynamics and how it affects intensity, quantifying the net enthalpy flux from the ocean in high-wind-speed conditions, and incorporation of a variety of remotely sensed data into model initial conditions. The purpose of ESSL/MMM research in hurricane simulations is to create the next generation hurricane-prediction system, and a community hurricane-prediction model that can be used for process and predictability studies.

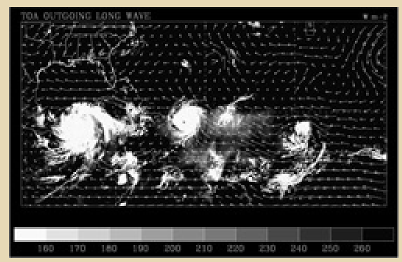


Figure: Snapshot of Outgoing Long wave Radiation (W/m2) and wind vectors at 700mb from the Nested Regional Climate Model. The figure shows two mature hurricanes in the Caribbean and the genesis of a tropical cyclone further east over the tropical North Atlantic Ocean.

High resolution figure

During the past year, analysis of the real-time forecasts for the 2007 North Atlantic hurricane season revealed that intensity prediction is currently limited by poor initialization of the hurricane vortex. Experimentation with the Ensemble Kalman Filter data assimilation technique shows this could be key in creating suitable initial conditions and improved intensity prediction. A breakthrough science project allowed a simulation of an idealized hurricane to be conducted at 62m grid spacing. At this resolution, the model was able to resolve turbulent eddies. The 1-minute mean wind field form this simulation showed lower maximum winds than a more coarse resolution simulation that was unable to resolve turbulence.

In a new application, WRF simulations of the major U.S. landfalling hurricanes of 2004 and 2005 were used as inputs into insurance-industry loss models to evaluate the potential utility of high-resolution winds for improving hazard assessment and loss estimation. The project revealed WRF can provide information on asymmetries and small-scale details of the wind field that are currently not included in most insurance loss models.

Nested Regional Climate Model simulations have been explored using a tropical-cyclone-detection algorithm. The model captured the general global and seasonal distributions of tropical cyclones but consistently overproduced the number of tropical cyclones. Two-way nesting down from 36km to 12km over the Atlantic region for the 2005 season improved both the number and spatial distribution. This dataset has been used to show the importance of the background flow in modulating easterly waves thereby creating favorable conditions for tropical cyclogenesis, and higher-resolution simulations of genesis have shown vortices merging during the period of genesis.

In the coming year, new ground will be broken with the Ensemble Kalman Filter technique by running this cycling assimilation system for an entire North Atlantic hurricane season to create initial conditions for high-resolution hurricane simulations. These simulations will make an important contribution to NOAA's Hurricane Forecast Improvement Project by providing a statistically significant comparison of the effect of high-resolution (~1km in the horizontal) on the accuracy of hurricane-intensity forecasts. Data from T-PARC will be analyzed and cycling assimilation will be run retrospectively for the period of the campaign. Finally, trends in hurricane activity in the North Atlantic, Caribbean and Gulf of Mexico regions will be examined through ensembles of high-resolution climate-change simulations using the Nested Regional Climate Model driven by boundary conditions from the Community Climate System Model. This ambitious project is providing for the first time, decadal climate simulations of hurricanes at a resolution sufficient to identify key intensity and structural details. It also provides a genuine test of the requirements for future supercomputing systems to enable decadal predictions of the regional detail required for planning and adaptation strategies. The work has strong community involvement and support, including financial support from the offshore oil industry.

return to top

Global and Regional Water Cycle

The Water Cycle Program has conducted research related to the Regional and Global water cycle since 2001. Using the diurnal cycle of precipitation as a focus, research has shown that current climate models do not accurately simulate the frequency, intensity, and timing of summer time convection over much of the globe, including continental regions, despite reasonable simulations of precipitation amount (see figure). This model deficiency greatly hampers climate models' ability to predict future changes in intense storms, flash floods, tornados, hurricanes, and other severe weather events that likely have the largest impact on the society under global warming. This model deficiency results from a variety of factors, including: 1) a lack of realistic representation of atmospheric convective inhibition processes, and 2) a poor representation of propagating systems of convection in the lee of major mountain ranges. This later deficiency is reflected in the high degree of uncertainty of current climate model runs in these regions.

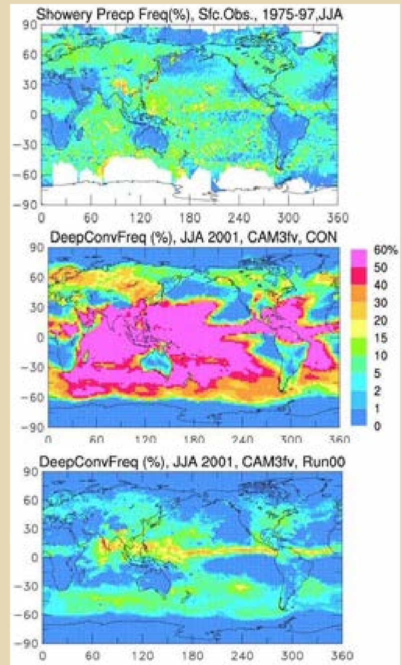


Figure 1: June-August moist convection frequency (in % of time) from surface observations (top), CAM3 with its standard convection scheme (middle) and a newly modified scheme (bottom) that significantly improves the simulated frequency of convection.

High resolution figure

The goals of the Water Cycle program are: 1) to reduce this uncertainty through focused research on the physical mechanisms leading to the onset of moist convection and the propagation of convective systems in the real world, 2) to test and improve new parameterizations of convection that improve simulations of these phenomena, 3) to improve our understanding of the coupling between the land surface, atmospheric boundary layer and convective parameterizations in climate models, and 4) to improve the representation of the cool season water cycle over complex terrain in climate models.

Current research has focused on the following areas supporting the goals mentioned above:

1. Further quantifying precipitation characteristics (frequency and intensity and their dependence on data resolution, temporal and spatial correlative structures, etc.) on global and large scales using high-resolution satellite data, and apply them to evaluate global models (Dai, Laing, Trier, Davis, Carbone, Trenberth, Wang).
2. Studying Upper Colorado Basin snowpack under projected climate change in the 21st century using high-resolution regional models (the Colorado Headwaters Project) (Rasmussen, Gochis, Chen, Liu, Ikeda, Arsenault, Houser, Liang, Dudhia, Yu, Tewari,Thompson).
3. Improving convective parameterizations in climate models for better simulations of the frequency, intensity, and diurnal timing of precipitation and the propagation of convective systems (Dai, Li, Neale, Liu, Moncrieff, Tulich, Grabowski, Davis, Rasmussen, Mapes, Neelin, Wu).
4. Conducting high resolution model simulations using boundary conditions with short waves removed. Investigate the role of the mountain-plains circulation in maintaining and initiating the propagating convection as well as other mechanisms (Trier, Wang, Tuttle, Carbone).
5. Percent of precipitation over the United States attributable to propagating convection. Twelve year radar dataset does not reveal a correlation of the intensity or phase of the propagating convection to ENSO (Tuttle, Carbone).
6. Diagnosing the water cycle in climate models and observations and in retrospective datasets (Dai and Trenberth).
7. Improving the hydrological cycle in CLM3 (Oleson and Lawrence).
8. Examine the role of the Great Plains nocturnal jet in modulating convection in CAM (Caron).
9. Examining the role of the land surface in modulating propagating convection (Chen, Tewari, LeMone).

Results to date show that short waves are not the dominant factor in initiating convection. Research is now focused on other mechanisms such as the mountain/plains diurnal circulation. Examination of the amount of precipitation attributed to propagating precipitation over the continental U.S. suggests that up to 70% of central U.S. precipitation is due to propagating systems. Research on the role of land surface impacts suggest that the land surface plays a secondary role in the formation and propagating of long-lived convective systems. Research related to the low-level jet over the central U.S. shows a strong coupling of the corridors of propagating convection to the low level jet. In support of improved simulation of these propagating systems in climate models, a new cross-NCAR convective parameterization scientific interest group has been formed and has been holding monthly meetings to discuss new work related to convection parameterization. The Colorado Headwaters project started, and was awarded 500,000 GAUs through the Accelerated Science Discovery competition.

The Water Cycle Program will focus on the following areas during the next few years:

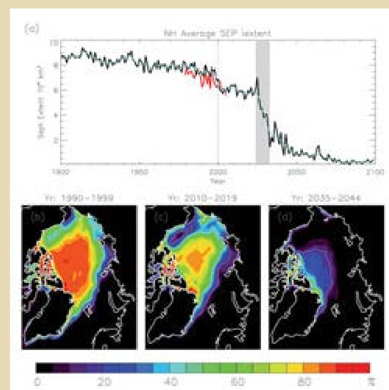
1. Continued emphasis on improving convective parameterizations in climate models, including the testing of various candidate schemes (including the new Moncreiff and Liu scheme developed under Water Cycle sponsorship) and testing different treatments of convective inhibition in models, with the aim to reduce the model bias related to precipitation frequency, intensity and diurnal cycle. The Convective Parameterization group will continue to meet and likely hold workshop.
2. Finalize work related to mechanisms that lead to the initiation of propagating systems.
3. Continue with Regional and Global Diagnostic studies of the water cycle.
4. Evaluate how to improve the coupling of land surface, boundary layer, and convective schemes in climate models.
5. Initiate and carry out the Colorado Headwaters cool season water cycle over complex terrain project.

return to top

The impacts of climate and weather on society and ecosystems: Polar climate

Overview

Over the past several decades, Arctic sea ice extent has been steadily shrinking. Due to the ice-albedo feedback, this reduction in ice cover has contributed to an observed amplification of Arctic warming relative to the rest of the world. Observed sea ice extent in September 2007 smashed the previous record low. Climate models project that sea ice decline will continue into the foreseeable future, with the possibility of summer ice-free conditions being reached later this century. Considerable effort is underway to examine these observed and projected changes in the sea ice system and the consequences of a seasonally ice-free Arctic ocean for the climate and ecological systems. An analysis of projected changes in the future ice cover suggests that gradual, linear changes are unlikely; rather, sea ice decline is likely to be punctuated by abrupt transitions such as that seen in 2007. Integrations with the Community Climate System Model (CCSM) exhibit abrupt reductions in the future summer sea ice cover, with the most extreme event going from 80% September ice coverage to 20% coverage in approximately 10 years (Figure 1). The mechanisms responsible for these transitions include: 1) an increased efficiency of open water production as the Arctic ice thins, 2) rapid increases in ocean heat transport that trigger the events, and 3) the surface albedo feedback, which accelerates the ice retreat. An analysis of additional models participating in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4) indicates that about 50% of them exhibit similar abrupt reductions in future Arctic summer ice cover for some future forcing scenarios, although the length and magnitude of the events vary. The presence of seasonally ice-free conditions has potential impacts on the Arctic and global systems and CCSM is being used to assess the impacts on global atmospheric circulation, the hydrological cycle as well as ocean and terrestrial conditions.



a) The time series of September Arctic ice extent from CCSM-3 (black), the CCSM-3 5-year running mean (blue) and the satellite observations (red), with the identified abrupt event shown by the grey shading. The sea ice conditions for the (b) 1990-1999 average, the (c) 2010-2019 average and the (d) 2035-2044 average are also shown and indicate the realistic present day ice cover simulated by CCSM-3 and the rapid decline that occurs by mid-century.

High resolution figure

Along with sea ice loss, there are strong indications that the permafrost is warming and thawing over large scales. Thawing of permafrost is likely to induce a number of feedbacks to the hydrologic and carbon cycles of the Arctic system. Of particular concern, especially from a global perspective, is how permafrost thaw will affect the carbon balance in the Arctic. The future carbon balance of the Arctic remains one of the largest uncertainties in climate change science.

Changing sea ice and permafrost conditions have important implications for the Arctic hydrological system change. Because of the proximity to deep water formation regions within the northern North Atlantic, this in turn can modify the global thermohaline circulation.

Finally, while changes in high northern latitudes are considerable, the Antarctic region generally remains quite stable. There are numerous and varied reasons for this different behavior in the southern high latitudes, including changes in the atmospheric circulation and ocean heat uptake that appear to mute an anthropogenic warming signal. However, the interactions and importance of these processes for the future Antarctic climate remain unclear.

Recent Accomplishments

In 2008, we made substantial progress on a variety of research topics, ranging from an evaluation of the role of external versus internal forcing of sea ice transitions, an assessment of the impact of sea-ice loss on polar bear habitat and on permafrost degradation. We also continue to evaluate the role of changes in freshwater forcing on the thermohaline circulation. We also made substantial progress improving the representation of polar processes in CCSM in preparation for CCSM4. For more information, see the following topics:

- Natural versus external forcing of rapid ice loss [M. Holland Profile]
- Polar bear habitat loss [M. Holland Profile]
- Accelerated terrestrial warming during rapid sea ice loss and permafrost degradation [C. Deser Profile] [M. Holland Profile] [D. Lawrence Profile]
- Role of atmospheric circulation in sea ice decline [C. Deser Profile] [H. Teng Profile]
- Impact of freshwater forcing on thermohaline circulation [G. Meehl Profile] [B. Otto-Bliesner Profile]
- Development and improvement of polar processes in CCSM4 [D. Lawrence]

2009 and Beyond

CCSM experiments exhibiting periods of abrupt sea ice loss and rapid permafrost thaw raise the question as to whether or not sea ice or permafrost loss exhibit characteristics of a so-called tipping point in the climate system. Experiments are underway to evaluate whether or not sea ice can thin to the point that its further loss is no longer dependent on further warming. Related work on the stability of seasonally ice free conditions is also in progress. Experiments are also planned to evaluate whether permafrost is sustainable or not once the ground has reached a thermal state in which talik, a perpetually unfrozen layer between seasonally frozen ground above and permafrost below, has formed.

Work is also underway to incorporate a dynamic wetland model that is capable of simulating the anticipated changes in wetland distribution associated with permafrost thaw induced soil subsidence. Additional efforts will focus on an integration of the CLM organic soil representation with the prognostic soil carbon calculated in the CLM carbon cycle model. We also intend to evaluate how a conversion of tundra to woody arctic shrubland will affect the carbon cycle and surface energy budgets, with an emphasis on the relative importance on these budgets.

Within the context of our longer term efforts to understand how and why permafrost degrades so rapidly in CCSM, we are conducting a series of prescribed snow experiments that will isolate how projected changes in snowfall, snow depth, and snow-season length affect the rate of soil temperature change in the model.

We also intend to continue to evaluate the climate response to Arctic sea ice loss, with a particular emphasis on the seasonal atmospheric, oceanic, and terrestrial response. The primary goal of this proposed project is to investigate the mechanisms underlying the seasonal response of the climate system to Arctic sea ice loss within the context of anthropogenic climate change. Additional studies on the marine ecosystem response to a changing sea ice melt season length are also planned.

The mechanisms involved in the relative stability of the Antarctic sea ice are also the subject of ongoing investigation. This includes studies on the influence of changing sea ice buoyancy forcing for ocean conditions and work that investigates the different sea ice behavior and feedbacks in the two hemispheres.

return to top

Megacities Impacts on Regional And Global Environments / Megacity Initiative: Local And Global Research Observatories (MIRAGE/MILAGRO)

MIRAGE is a NCAR Strategic Initiative designed to improve the understanding, numerical modeling, and predictability of the chemical and physical processes that occur when urban plumes are dispersed over larger geographic regions. Future urbanization of the global atmosphere could have wide-ranging consequences for human health and cultivated and natural ecosystems, visibility degradation, weather modification, changes in radiative forcing, and tropospheric oxidation (self-cleaning) capacity.

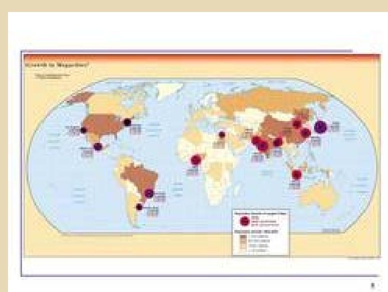


Figure 1. Population growth in megacities, defined as more than 10 million inhabitants, in 1950, 2000, and 2015. Colors within continents represent population growth during 1950-2000.

In the first phase of MIRAGE, NCAR organized and led a large field campaign to examine the atmosphere in and near Mexico City, with coordinated aircraft and ground-based measurements supported by extensive modeling and satellite observations. More than 400 researchers from 8 countries and 50 universities (35 U.S.), government labs, and other institutions participated in the intensive observational period during March 2006. Many others are collaborating in the ongoing analysis, interpretation, and modeling of the results.

ACD scientists plan to continue the analysis, interpretation, and modeling of the 2006 Mexico measurements, in collaboration with researchers from academia and government labs. This work is proceeding along three broad lines:

High resolution figure

- Characterization of the atmosphere in Mexico City and surroundings, including better quantification of different sources (urban, industrial, biomass burning, long-range transport), prevailing chemical regimes (VOC and NOx limitations), and radiative impacts of various aerosols.
- Model evaluation and improvement, particularly for the state-of-the-art chemistry transport models WRF-Chem (regional) and CAM-Chem (global). The Mexico data base is being used extensively in this activity. Areas of critical uncertainty include the formation of secondary aerosols, budget and partitioning of nitrogen oxides, daytime and nighttime boundary layer processes, plume transport, and interactions with background air. We are also using detailed process models to examine some of the more problematic processes, including the SGMM model for the formation of organic aerosols, and the TUV model for radiative closure at visible and ultraviolet wavelengths.
- Coordination and synthesis of the community-wide effort in data analysis and modeling.

Concurrently, we are planning to extend the MIRAGE initiative to other megacities that are representative of specific environments and economic development. In view of rapid growth in China and India, we are focusing our next efforts on these regions (Figure 1). We have established a collaboration with the Shanghai Meteorological Bureau to implement the WRF-Chem model for their region and to participate with chemical instrumentation in ground-based field campaigns scheduled for September 2009 and (tentatively) May 2010. This will allow us to evaluate and improve models in a very different environment (relatively shallow PBL, humid-polluted, with large regional contributions) with different impacts on oxidant formation, aerosol composition and sizes, radiative budgets, and pollution-cloud interactions. ACD will bring to the field campaigns instruments to measure NOx, O3, VOCs, and spectral actinic fluxes, and will lead an intercomparison with instruments currently used by Chinese scientists, in order to help build capacity and enhance the quality of their long-term data collection. Longer-term plans include an aircraft campaign (likely with extensive ground-based components), carried out in India. This campaign would aim at investigating convectively influenced outflow of polluted air from a mega-city. Aspects of convective outflow are the processing of air masses in clouds, the modification of local convection and weather by the pollution emitted from the mega-city itself, and the convective lifting of the pollution into the upper troposphere with its implications for global transport of pollution and its impact on UT/LS chemistry. This work is funded by NSF/NCAR.

return to top

Biosphere-Atmosphere Exchange of Aerosols with Cloud, Carbon, and Hydrologic cycles including Organics and Nitrogen (BEACHON) program objectives and plans

The Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, H_2O, Organics & Nitrogen (BEACHON) project is a broadly collaborative and interdisciplinary research effort being developed by researchers at NCAR and the university community. BEACHON will improve predictability of earth system behavior over the time scale of months to a decade based on a better understanding of the coupling between water, energy and biogeochemical cycles in a multi-scale modeling framework. This will be accomplished through coordinated modeling, observations and process studies that explicitly address the coupled water, energy and biogeochemical cycles at multiple temporal and spatial scales. The main goal of the BEACHON project is to provide a detailed and quantitative characterization of biosphere-hydrosphere-atmosphere interactions and to use that characterization to improve regional and global models of the earth system. A major focus will be measurement and interpretation of surface fluxes of energy, aerosols, CO_2, water, and organic and nitrogen compounds. Investigations will also address other fundamental processes including atmospheric aerosol production and growth processes, oxidant and cloud processes; landscape heterogeneity impacts on hydrological and biogeochemical cycles; and the response of ecological, hydrological, and physiological processes to ecohydrological disturbances. BEACHON is focusing on water-limited ecosystems but will work with international programs, such as IGBB-iLEAPS (see www.ileaps.org), to compare and contrast over a large range of water availability.

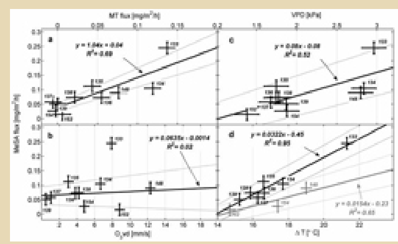


Figure 1: The figure illustrates BEACHON results from the 2007 CHATS study that are described in detail by Karl et al. Biogeosciences 2008. (a) MeSA flux plotted vs MT flux. (b) MeSA flux plotted vs O_3 deposition velocity (vd). (c) MeSA flux plotted vs VPD. (d) MeSA flux plotted versus ΔT before irrigation (black) and after irrigation (gray). Data point labels indicate Julian Day. Fitting equation and r^2 are shown for each x/y weighted fit. Dotted lines represent prediction bounds based on the standard deviation of the fitting parameters.

High resolution figure

ESSL scientists detected the first significant fluxes and concentrations of the signaling compound, methyl salicylate (MeSA), in a real forest atmosphere using micrometerological techniques in combination with highly sensitive mass spectrometry. These observations during the BEACHON CHATS study show that MeSA can make a major contribution to the total biogenic volatile organic compound (VOC) flux from a forest comes as a surprise. This finding may help to explain previous studies indicating that there is a *missing source* of biogenic VOCs. Due to the semivolatile nature of MeSA and similar plant hormones, these findings will influence future directions on biogenic VOC research in atmospheric sciences, for example the impact on secondary organic aerosol formation. The results also provide tangible proof that plant to plant communication occurs on the ecosystem level and connect two separate scientific communities on plant volatile research that have coevolved over the past years: One has historically focused on biogenic VOCs important for atmospheric chemistry (e.g. isoprene, monoterpenes); the second community has targeted the ecology of plant volatiles (e.g. floral scents). We expect this study will transform the research approaches of these separate scientific communities and result in more integrated and multi-disciplinary studies.

An initial BEACHON workshop was organized in FY08 for the purpose of developing a detailed implementation plan and was attended by more than 100 participants including more than 50 atmospheric scientists, ecologists and hydrologists from the university community. The workshop and following discussions defined four major scientific themes for the BEACHON project and identified NCAR and university leaders:

1. Biogenic aerosol, clouds, and water availability
2. Eco-hydrological disturbances: bark beetles and forest fires
3. Moisture and nutrient limitations of eco-hydrological processes
4. Landscape heterogeneity: topography and canopy structure

More than 50 scientists, including representatives of 12 universities, participated in the initial BEACHON study (July-September 2008) at the U.S. Forest Service Rocky Mountain Research Station MEF observatory (see www.tiimes.ucar.edu/beachon/srm/activities.html). Investigations focused on:

- The formation and growth of atmospheric nanoparticles
- Emissions and reactions of BVOCs and other important trace gases and oxidants
- The formation and hygroscopic properties of biogenic SOA and primary particles
- Terrestrial and canopy controls on the emission and deposition of water, nutrients and aerosols
- Characterize transport in canopy and from canopy to cloud
- Modeling of Aerosol-Cloud-Emissions Interactions

BEACHON FY09 objectives include the development of specific scientific and implementation plans for each of the four scientific themes. These efforts will include instrument and model (1D, LES and regional) development and application, long-term observations and intensive campaigns at BEACHON field sites, and process studies in NCAR and university laboratory facilities. FY09 activities will also include analysis of the CHATS and MEF-08 field study data. BEACHON instrument development will include airborne and tower flux measurements systems, Time-of-Flight Chemical Ionization Mass Spectrometry systems (TOF-CIMS), and aerosol measurement systems. Model development will include significant advances in land surface model parameterizations and implementation of improved biogenic emission, aerosol formation and growth, and cloud microphysics in the WRF regional model. Field observations will be used to characterize the processes controlling biosphere-atmosphere exchange and to evaluate model simulations of these processes. Laboratory studies will emphasize observations that will improve quantitative descriptions of atmospheric and ecological drivers (e.g., drought stress, insect infestation, climate driven ecosystem changes, solar radiation, and temperature) of biogeochemical cycling and their impact on atmospheric distributions of trace gases and aerosols.

return to top

Global biogeochemical cycles

As is clearly articulated in the Fourth Assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007), there is increasingly strong motivation to examine terrestrial and oceanic carbon fluxes on regional to continental scales, to understand the coupling of the carbon cycle to the climate system and to other biogeochemical cycles, to understand the processes responsible for present uptake of anthropogenic carbon, to predict future trends in these fluxes under various climate change scenarios, and to assess potential strategies for increasing carbon uptake and storage into the future. The challenges of scaling up from local measurements and scaling down from global constraints are being addressed in TIIMES through the development and application of advanced observational and modeling tools.

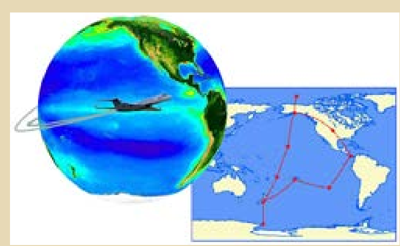


Figure 1: The project HIAPER Pole-to-Pole Observations of Atmospheric Tracers (HIPPO) will conduct five global loops over the next three years, profiling from the tropopause to the surface. Investigators from Harvard, NCAR, Scripps, and NOAA will measure CO_2, O_2, CH_4, CO, N_2O, H_2, SF_6, COS, CFCs, HCFCs, O_3, H_2O, black carbon, and selected hydrocarbons.

High resolution figure

As highlighted by the report of Stephens et al., (2007), there exists less than 100% uncertainty in localizing the terrestrial uptake of anthropogenic carbon to specific latitudinal zones and this uncertainty is directly linked to vertical transport biases in the coarse-resolution atmospheric transport models used in CO_2 inversion studies. Comprehensive measurements of atmospheric CO_2 and related tracers, particularly at altitude and in previously undersampled regions, are needed to challenge these models and improve our understanding of global carbon cycling. This is the aim of the project HIAPER Pole-to-Pole Observations of Atmospheric CO_2 and Related

Tracers (HIPPO), a Harvard-NCAR-Scripps-NOAA collaboration to measure cross sections of atmospheric concentrations approximately pole-to-pole, from the surface to the tropopause, five times during different seasons over the next three-years (see Figure 1).

A comprehensive suite of tracers of the carbon cycle and related species will be measured: CO_2, O_2:N_2 ratio, CH_4, CO, N_2O, $^{13}CO_2$:$^{12}CO_2$, H_2, SF_6, COS, CFCs, HFCs, HCFCs, black carbon, and selected hydrocarbons. HIPPO will transect the mid-Pacific ocean and return over the Eastern Pacific. The program will provide the first comprehensive, global survey of atmospheric trace gases, covering the full troposphere in all seasons and multiple years. HIPPO will quantify the sources of major carbon cycle and greenhouse gases by region at the global scale. Hypotheses to be tested include, as examples:

a. Northern mid-latitude terrestrial ecosystems are a major sink for CO_2

b. The Southern Ocean is a major sink for CO_2 and the driver for global seasonality of the O_2:N_2 ratio

c. Amazonia is a major source region for CH_4, CO, and N_2O

d. Upper tropospheric data can be used to challenge models used to derive inverse analysis of the global carbon cycle

TIIMES scientists are supporting several key systems on these flights, including the NCAR Airborne Oxygen instrument (AO2, see Figure 2) and the MEDUSA flask sampler. These systems flew during the START-08/pre-HIPPO campaign in April-June of 2008. In this campaign, AO2 made the first successful airborne measurements of oxygen variations. This vacuum-ultraviolet absorption instrument is based on an existing NCAR laboratory instrument, but has been designed specifically for airborne use to minimize motion and thermal sensitivity and with a pressure and flow controlled inlet system. AO2 has a precision of +/- 2 per meg on a 4-second measurement which is the equivalent to detecting the removal of one O_2 molecule from 2.5 million molecules of air. Such measurement are very useful in discriminating various influences on atmospheric CO_2 (see Figure 3). The flasks collected during this campaign are being analyzed at Scripps for O_2, Ar, and isotopes of CO_2. Both AO2 and MEDUSA are planned for long-term availability to community researchers.

Figure 2: The NCAR Airborne Oxygen Instrument (AO2) measures O_2 concentration (reported as O_2:N_2 ratio) using a vacuum-ultraviolet absorption technique. It consists of a pump module, a cylinder module, and an instrument module.

High resolution figure

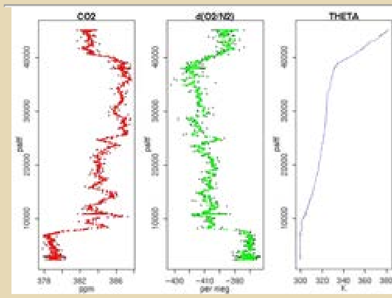


Figure 3: Measurements of atmospheric O_2 and CO_2, made by the AO2 instrument on the NCAR GV during the START-08/pre-HIPPO campaign, while descending from the stratosphere to the surface over Grand Forks, ND in the mid afternoon. Correlated O_2 and CO_2 variations reflect the influence of stratospheric air age across the tropopause, pollution and boundary-layer air plumes in the free troposphere, and photosynthetic CO_2 drawdown and O_2 enhancement in the boundary layer.

High resolution figure

Stephens et al., Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO_2, Science, 316, 22 June 2007.

return to top

Bioemissions and photochemical processing

Chemicals produced by the biosphere include volatile compounds that are emitted into the air where they can have a substantial impact on the chemistry of the atmosphere. These biogenic gases are dominated by volatile organic compounds (VOCs) both in total mass and number of compounds. The important role of biogenic VOCs in controlling global oxidant (e.g., OH and ozone) distributions has been demonstrated using global models while regional air quality models have shown that it is necessary to included biogenic VOC emissions in modeling efforts to develop regional ozone pollution control strategies. ACD and TIIMES scientists are investigating the processes controlling biogenic emissions and their role in tropospheric photochemistry and are developing numerical schemes for including this information in regional and global earth system models.

Observations of OH and other trace gases at rural and remote sites suggest that OH losses are considerably higher than what can be accounted for by the measured OH sinks. This may indicate that atmospheric chemistry models are missing some of the chemical species that are needed to accurately describe photochemical processing. In FY2008, ACD/TIIMES

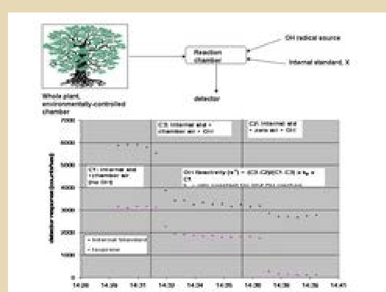


Figure 1 shows that isoprene comprised 85% of the OH reactivity (367 s-1) observed in chamber air surrounding an oak tree. Other reactants including CO, NOx and other VOC make up the balance. This suggests that this particular plant does not emit any OH reactive compounds that cannot be observed scientists collaborated with Prof. Yoshizumi Kajii's research group from Tokyo Metropolitan University to investigate OH lifetime and sinks associated with plants growing in NCAR foothills laboratory growth chamber and at the ESSL BEACHON research site in the Manitou Experimental Forest. Emissions and ambient concentrations of a wide range of compounds were measured to quantify their contributions to OH loss. The initial results suggest that observed compounds in the ambient air can account for some, but not all, of the missing OH sinks. The compounds emitted from enclosed vegetation can, at least in some cases, explain the observed OH reactivity (see Figure 1).

by standard analytical techniques.

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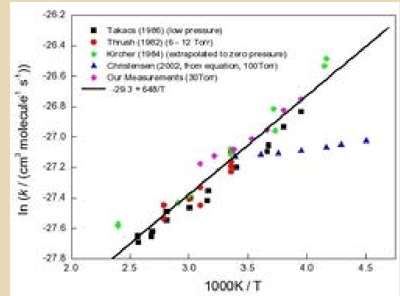


Figure 2. Arrhenius plot for the combination reaction of HO2 radicals. The natural logarithm of the rate coefficient is plotted against reciprocal temperature. Results of 5 studies pertaining to low pressures (P < 150 mbar) are shown.

High resolution figure

Tropical landscapes are thought to be responsible for about 80% of global biogenic VOC emissions and yet are among the least understood. Global chemistry and transport models often perform poorly when using the biogenic VOC emission rates recommended by current emission models. This could be due to uncertainties in emissions but could also be a result of inaccurate characterization of boundary layer meteorology and/or chemistry. ACD and TIIMES scientists participated in the January-March 2008 AMAZonian aerosol characterization experiment (AMAZE) in central Amazonia along with an international team of scientists that included Scot Martin (Harvard University), Jose Jimenez (U. Colorado) and Tony Prenni (Colorado State University). The NCAR scientists quantified the magnitude and variation of VOC, ozone and NOx fluxes and concentrations during the study and are using these observations to understand the processes controlling aerosol formation and growth in this region. ACD and TIIMES scientists also participated in the Oxidant and Particle Photochemical Processes (OP3, see http://badc.nerc.ac.uk/data/op3/) study in the south-east Asian tropical forests of Borneo. NCAR scientists measured biogenic VOC emissions using enclosures and tower based measurements.

FY2009 work will continue laboratory and field investigations of factors affecting biogenic emissions and their impact on oxidants. This work was funded by NSF/NCAR and EPA.

Laboratory Kinetics Studies

ACD scientists have been studying the reaction kinetics and mechanisms of hydroperoxy radicals, HO2, using a number of complementary techniques. HO2 radicals are a member of the HOx family, which is comprised of OH and HO2. Hydroxyl radicals, OH, are responsible for the oxidation of many organic and inorganic pollutants which are emitted into the troposphere. Following a series of reactions, HO2 is usually produced, and then cycled back to OH by its reaction with nitric oxide, NO. However, measurements of radical concentrations in forested areas have shown unexpectedly high levels of OH, suggesting that some recycling of radicals is taking place. Normally this requires the presence of NO, but in clean areas other mechanisms may dominate.

The reactions of HO2 radicals with organic peroxy radicals are being investigated in the laboratory using a combination of techniques (infrared spectrometry, gas chromatography and high performance liquid chromatography). These reactions were initially thought to form solely organic hydroperoxides, reasonably stable compounds that terminate the oxidative chain reactions. However, in a 2004 study in collaboration with Fresno State University [Hasson et al., 2004] it was shown that OH radicals could be produced in substantial yield from the reaction of HO2 with acetyl peroxy radicals.

$$HO_2 + CH_3C(O)O_2 \rightarrow CH_3CO_2 + OH + O_2$$

The potential for recycling of HO2 to OH in these reactions may be able to explain apparently high levels of OH radicals in relatively clean, forested areas. A systematic study of the OH yields from reaction of HO2 with oxygenated peroxy radicals is currently underway.

In the lower stratosphere, OH and HO2 radicals play a large role in controlling the concentration of ozone.

$$OH + O_3 \rightarrow HO_2 + O_2$$
$$HO_2 + O_3 \rightarrow OH + 2O_2$$

These oxidation chains can be terminated via the self reaction of HO2 radicals, which forms hydrogen peroxide as a product.

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$$

The rate coefficient for this particular reaction depends on both the temperature and pressure, and water vapor concentration. Scientists in ACD have measured the variation of the rate coefficient with temperature at low pressure. The HO2 radicals are produced by a pulse of ultraviolet laser radiation, which dissociates chlorine gas; the chlorine atoms then initiate the chemistry which forms the HO2. The radicals are then detected using tunable diode laser spectroscopy. The technique allows the decay of the radicals to be followed in real time over a time span of tens of milliseconds, from which the rate coefficient can be determined.

There have been 4 previous determinations of the temperature dependence of the rate coefficient at low pressure.

Whereas 3 measurements in the 1980s (Thrush and Tyndall, 1982; Kircher and Sander, 1984; Takacs and Howard, 1986) showed a dependence on temperature, a more recent one (Christensen et al, 2002) suggested that the reaction rate is independent of temperature. However, the new measurements indicate an increase in the rate coefficient at low temperature, in agreement with the earlier studies. A stronger temperature dependence to this reaction reduces the concentration of HO2 radicals in the upper troposphere and lower stratosphere, and consequently reduces the amount of ozone depletion due to HOx radicals.

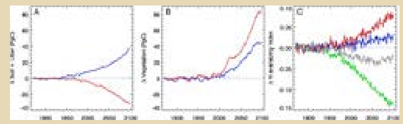
Laboratory studies of reaction kinetics and mechanisms will continue, with a focus on the formation mechanisms of organic nitrates. This work was funded by NSF/NCAR and NASA.

return to top

Ecosystem - biogeochemistry - climate interactions

Overview

As described by Friedlingstein et al. (2006), feedbacks between the climate and the carbon cycle have the potential to modify, perhaps enhance, climate change. In ESSL, we study these feedbacks to help understand projections of future climate. Our primary tool is CCSM, with the addition of parameterizations of terrestrial and marine biogeochemical cycles. The work happens within the context of the Biogeochemistry Working Group, whose overall goal is to improve our understanding of the interactions and feedbacks between the physical climate and biogeochemical systems under past, present and future climates.



Changes (due to multiple factors) in global total land carbon stocks for litter and soil organic matter (A), and vegetation (B), and in global mean nitrogen availability index (C). In all panels change due to climate change and anthropogenic mineral nitrogen deposition are shown in red and blue, respectively. In (C), change due to biogeochemical effects of increasing CO2 is shown in green, and all three effects at once in gray.

High resolution figure

Recent Accomplishments

CCSM scientists continued to develop models of the global carbon cycle, including oceanic and terrestrial ecosystems. Model experiments found that the coupling between the terrestrial carbon and nitrogen cycles significantly alters the carbon cycle-climate feedback. The nitrogen cycle leads to increased carbon storage on land under radiatively-forced climate change, and an overall negative climate-carbon cycle feedback. The primary mechanism responsible for increased land carbon storage is fertilization of plant growth by increased mineralization of nitrogen directly associated with increased decomposition of soil organic matter under a warming climate.

Additional analysis of these experiments has revealed deficiencies in the oceanic uptake of trace gases, including anthropogenic CO2 and CFCs, a class of purely anthropogenic chemicals that are well sampled in the ocean. In order to address this model bias, oceanic mixing parameterizations have been enhanced to include processes that were previously omitted. These efforts have significantly reduced the bias in CFC uptake and will presumably reduce the bias in anthropogenic CO2 uptake as well.mes more computational resource than the 2 degree run. The 0.5 degree version of the new CCSM 4 will be used to make the short-term climate projections for the next IPCC assessment.

2009 and Beyond

Continued development of the terrestrial carbon cycle model, including additional capabilities to simulate dynamic vegetation, anthropogenic land cover change, croplands, wildfire, and biogeochemical cycles is currently underway.

As the model matures, a primary scientific theme to examine will be natural and human-mediated changes in land cover and ecosystem functions and their effects on climate, water resources, and biogeochemistry.

return to top

Numerical simulation of turbulence

Large-Eddy Simulation (LES) has been widely used to examine turbulent processes in the PBL, however most LES applications have been limited to PBLs over horizontally uniform surfaces or idealized strip-like heterogeneous surfaces, which are uncommon in nature. The most logical way to expand our LES study for more complex and realistic PBLs is by nesting an LES code inside a regional mesoscale model. However, nesting a turbulence-resolving model (like LES) inside a turbulence-parameterizing model (like mesoscale or climate models) is difficult because at the nest boundaries the simulated flow fields change abruptly from non-turbulent to turbulent flows, or vice versa. We plan to explore the capability of nesting WRF-LES inside WRF-mesoscale domains.

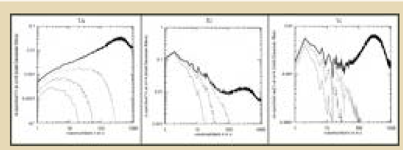


Figure: Spectra of (a) vertical velocity w and (b) total moisture q, and (c) co-spectrum of w and q. The solid curves are from the unfiltered field of the LES and other curves are from the filtered fields using three Gaussian filter widths.

High resolution figure

Another complex and important PBL regime is the one under cumulonimbi. We know precipitation can generate cold pools in the PBL due to evaporation, but how these cold pools affect turbulent transport in the PBL and how the change in the PBL affects the life cycle of deep convection remain uncertain. As part of the research funded by the new NSF Science and Technology Center for Multiscale Modeling for Atmospheric Processes (CMMAP), which is based at Colorado State University and led by Dave Randall, we began exploring the interaction between deep convection and the PBL. A benchmark LES of a tropical deep convection system (over a domain of about 205 km x 205 km x 27 km with a grid mesh of 100 m x 100 m in the horizontal and 50-150 m in the vertical) was performed by a CMMAP colleague (Marat Khairoutdinov at the Stony Brook University) in which deep and shallow convection, as well as energy-containing turbulent eddies are all resolved. A spectral analysis (Fig. 1) of the benchmark flow in the PBL shows that the vertical-velocity w variance peaks at the energy-containing turbulence scale (which is about 500 m, the average PBL depth), the moisture q variance peaks at the cloud-system cold-pool scale (on the order of 50 km), and the co-spectrum of w and q peaks at both scales. A systematic application of a low-pass filter separates the flow field into cloud-system scales and turbulence scales, and shows that about half of the moisture flux in the PBL is carried by turbulent motions smaller than 1-2 km and the other half by cloud-scale motions. The goal of this work is to find a way to represent the effects of turbulence inside a cloud-system-resolving model that has a grid mesh on the order of 1-2 km.

return to top

Exploring the role of aerosols

The effects of aerosols on climate represent the single largest source of uncertainty in our understanding of global warming. In order to reduce the uncertainty of the role of aerosols in climate and weather, ESSL scientists are conducting both experimental and modeling studies of aerosol formation, composition, and direct as well as indirect radiative forcing.

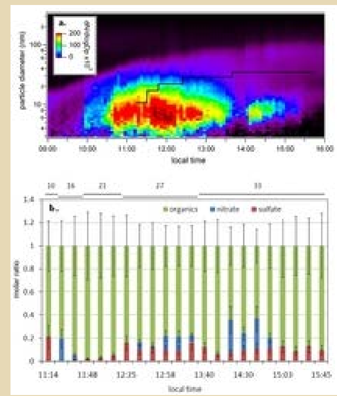


Figure 1. (a) Contour plot of the particle size distributions on 16 March 2006 in Tecamac, Mexico, during the MILAGRO campaign, showing a new particle formation event that started just before 10am local time. Also plotted in black is the particle diameter used for TDCIMS chemical composition measurements. (b) TDCIMS measurements of the ion molar ratio of sulfate, nitrate, and organics. Numbers at the top of the plot are the mass mean diameter of the analyzed aerosol.

High resolution figure

During 2008, ACD scientists collaborated with Peter McMurry (U. Minn.) to investigate the formation and growth of nanometer-sized particles in the atmosphere. These minute particles form from nucleation of low-volatility vapors, and grow by condensation by processes that are, as yet, not well understood. It's essential that we understand the processes by which particles form and grow in the atmosphere because nucleation is main global source of particle number, and subsequent condensational growth makes these particles important to the earth system by allowing them to be cloud condensation nuclei (CCN). Measurements performed at the ground site in Tecamac, Mexico, during the 2007 MILAGRO campaign suggest that current models that do not account for growth due to organic species most likely underpredict the growth of particles formed by nucleation, and thus underpredict the impact of new particle formation on climate. Figure 1 elucidates this point. The plot in Figure 1a shows a vigorous new particle formation event that occurred on March 16, 2007. The black trace on the plot shows the diameter analyzed using NCAR's Thermal Desorption Chemical Ionization Mass Spectrometer (TDCIMS), which can measure the chemical composition of size-selected particles as small as 8 nm. Figure 1b shows the results of TDCIMS measurements during the event with species broadly classified as sulfate, nitrate, and organics. The result is that about 84% of the detected ions are organic, comprising of organic acids, hydrocarbon-like species, and nitrogen-containing organic compounds. Particulate sulfate which arises from the condensation of sulfuric acid vapor constituted only 10% of the detected ions, and nitrate comprised 6%. Results such as those in Figure 1b suggest a prominent role of organic species in particle formation processes: unraveling the mechanism by which these organics create highly nonvolatile species through gas and particle phase chemistry is a major research goal in 2009.

During March - April 2008, ACD scientists led a field study to evaluate the chemical composition of the atmospheric aerosol, investigate primary biological particles in the atmosphere, and to explore relationships between the aerosols and clouds at a high altitude site. The Storm Peak Aerosol and Cloud Characterization Study (SPACCS) was funded in part by a unique two-year program, organized by scientists in ACD, to foster US/Nordic collaboration among early career scientists in the field of biogenic secondary organic aerosol.

Funded by: NSF, NOAA, USEPA, DOE, U. Nevada/DRI.

return to top

Convection organization: Observational analysis and resolved simulations

The propensity for deep, moist convection to organize and project onto larger spatial and temporal scales requires numerical simulations spanning convection-resolving scales to continental scales. Furthermore, simulation studies must be closely constrained by observational analysis of the organizing properties of convection. Prediction of tropical and warm-season higher-latitude convection, and the response of the synoptic-scale and planetary-scale flow is vital for increasing our ability to anticipate

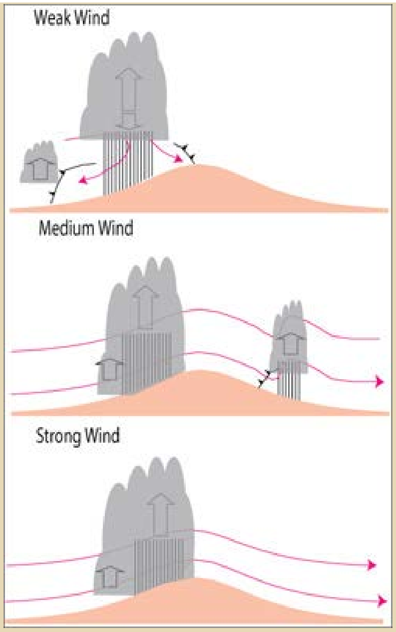


Figure: Schematic diagram of the along-ridge-average convective flow as a function of ambient wind speed. For weak wind, the solution is dominated by cold pools and there is no orgraphic rain in the steady-state solution; for moderate-to-strong wind, convective showers persist on the upwind side of the ridge with little net cold-air production since potentially cold rainy downdrafts must compete with advection of potentially warm environmental air. In the moderate-wind case, convective showers persist downwind on the "hydraulic-jump" feature know from past solutions of the dry orographic flow problem.

High resolution figure

significant weather events more than a day in advance. It is also vital for credible representations by models of regional climate.

Last year, simulations of convection episodes in E. Asia and the U.S. continued and simulations over Africa commenced. Initial results suggest that the Advance Research WRF was able to simulate the proper modes of African convection, though the latitude of maximum convective activity was biased southward during a 12-day simulation. Simulations of convection over North America, forced by only the mean diurnal cycle on the boundaries, showed a reasonable representation of a corridor of propagating convection with essentially no mesoscale perturbations in the initial state. An improved double-moment microphysics algorithm was tested in ARW and showed improved simulations of the trailing stratiform region of MCSs.

The Taiwan Island Mesoscale Rainfall Experiment (TIMREX) was conducted and obtained data on several cases of heavy coastal rainfall in Taiwan. Theoretical research on orographic rainfall showed a strong dependence of rainfall location on the impinging flow speed (FIG XX), but not on the nondimensional mountain height. Simulations of maritime convection in an idealized context showed the organized convection occurs over the gradient in sea-surface temperature, not where the temperature is greatest.

In the coming year, simulations of TIMREX cases will occur, focusing on mechanisms determining whether rainfall occurs on the coastal plain or over higher terrain. Analysis of TIMREX dropsonde and rawinsonde data will be performed to verify numerical simulations and enhance the thermodynamic interpretation of heavy rainfall cases. TIMREX work will also integrate the recent theoretical work on orographic rainfall. Simulations of convection episodes over North America and Africa will continue, emphasizing the diurnal cycle in the ARW model.

return to top

Atmosphere / ocean interactions

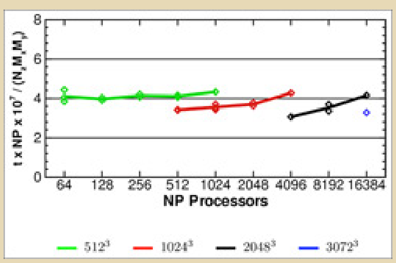


Figure: Scaling of parallel pseudospectral computational time per gridpoint for different combinations of problem size and 2-D domain decomposition for the Cray XT4. a) green lines and symbols problem size 5123; b) red lines and symbols 10243; c) black lines and symbols 20483; and d) blue symbol 30723. For a given number of total processors NP the symbols are varying vertical and horizontal decompositions, i.e., different combinations of processors in the x and y directions. Perfect scaling is represented by a level line across processors.

High resolution figure

Air-sea interaction occurs over a wide spectrum of scales ranging from millimeters (spray droplets and air bubbles) to hundreds of kilometers (synoptic-scale storms) and even larger (global climate). A goal of marine surface-layer research is to identify and quantify coupling mechanisms that connect the atmospheric and oceanic boundary layers (the ABL and OBL) and surface waves. Some of the specific problems of interest in the ABL include the effects of wave age, swell, surface roughness, and wind-wave misalignment. In the OBL, waves may induce mean currents and turbulence. Wave influences on the OBL are of particular importance under high-wind conditions. Turbulence-resolving simulations, and in particular large-eddy simulation (LES), with its ability to perform systematic process studies, play an important role in air-sea interaction research. LES has provided new insights into the couplings between imposed ocean waves and turbulence.

In the past year, MMM air-sea interaction research was directed towards developing LES models of the marine atmospheric and oceanic boundary layers applicable to high-wind regimes. For the atmospheric boundary layer MMM scientists began building an LES model to simulate turbulent flow over a general time-dependent moving wavy surface, i.e., over a spectrum of imposed surface waves. This algorithm is a generalization of the scheme used previously to simulate turbulent flow over 2-D waves. The wave field imposed at the lower boundary of the computational domain is constructed from a general set of plane waves; the wave heights can be chosen to match empirical spectra, e.g., the equilibrium Pierson-Moskowitz wave height spectrum, or can be smoothed wave-height measurements. The future turbulence simulations will be computationally intense as they require fine-mesh resolution and small time steps to resolve both small and large-scale surface waves. The basis of the wavy surface LES is a recently developed massively parallel algorithm. This parallel code, which utilizes a 2-D domain decomposition based on the Message Passing Interface, has been exercised on different machine architectures and can use as many as 16,384 processors (see Figure AA). The long term goal of the research is to utilize LES with resolved surface waves to help in the interpretation of observations collected in the High-Resolution Air-Sea Interaction (HRES) field campaign. Of particular interest is the pressure distribution over a spectrum of waves and the identification of the scales that support momentum transfer from the atmosphere to the ocean as a function of wind speed and wave age. HRES is sponsored by the Office of Naval Research and is tentatively planned for Spring 2010 off the California coast.

return to top

Long-term climate change in the thermosphere

Anthropogenic changes in "greenhouse gases" can increase temperature in the lower atmosphere due to their ability to absorb infrared radiation, but also affect the upper atmosphere through radiational cooling. Since the prediction by Roble and Dickinson [1989] that a consequence of increasing CO_2 levels would be to decrease the temperature of the upper atmosphere, NCAR researchers have been studying this effect and its consequences for the neutral density of the near-Earth space environment.

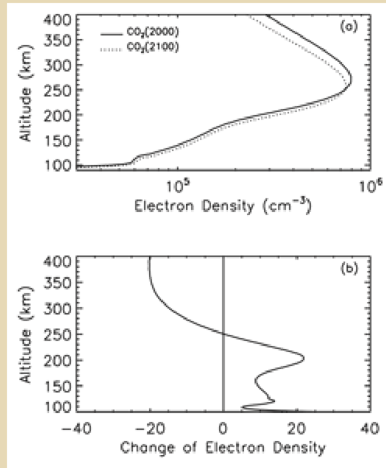


Figure 1: (a) Electron number density profiles for the base case and the doubled CO_2 case, under solar medium conditions ($F_{10.7} = \overline{F}_{10.7} = 150$). Solid line: base case; dotted line: doubled CO_2 case; (b) Percentage change of electron number density from the base case to the doubled CO_2 case, under solar medium conditions ($F_{10.7} = \overline{F}_{10.7} = 150$).

Qian, L., S. C. Solomon, R. G. Roble, and T. J. Kane (2008), Model simulations of global change in the ionosphere, *Geophys. Res. Lett.*, **35**, L07811, doi:10.1029/2007GL033156.

High resolution figure

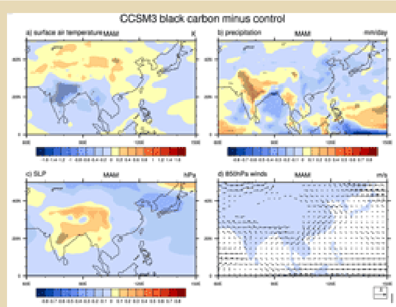
The thermosphere goes through natural, cyclical changes in density driven by the Sun's 11-year activity cycle, heating and expanding at solar maximum, cooling and contracting at solar minimum. Detection of the smaller and more gradual changes occurring due to increasing anthropogenic emissions in this context is therefore difficult, but during the last several years, three different groups have been able to measure thermospheric density changes by observing the effect of atmospheric drag on satellite orbits. These studies agreed that thermospheric density is systematically decreasing by several percent per decade near 400 km altitude, in general agreement with simulations conducted at the NCAR High Altitude Observatory using an extended and updated version of the Roble and Dickinson model. The modeled secular change under solar minimum and solar maximum conditions is variable, with larger trends at solar minimum and smaller change during solar maximum, and there is now observational support for these systematic differences.

A key question for thermosphere/ionosphere physics is how these changes in the thermosphere affect ionospheric densities and dynamics. Observations of secular trends in the E and F1 regions of the ionosphere indicate that electron densities have increased, and that the height of the E-region peak has decreased, during the past several decades. Detection of trends in the upper ionosphere through analysis of F2-layer parameters has been more complex and controversial. In order to facilitate observational detection of long-term trends in the ionosphere, simulations were performed by Qian et al. [2008] using CO_2 concentrations for the year 2000 and projected for the year 2100. Results show that increased CO_2 concentration increases electron density in the lower regions of the ionosphere, but decreases electron density in the upper ionosphere. The transition altitude occurs slightly below the F_2 peak altitude. The proximity of this peak to the transition altitude may explain why different analyses of long-term trends in F_2 peak density have shown both positive and negative trends.

return to top

The impacts of climate and weather on society and ecosystems: Climate change - probabilistic climate change, and solar forcing of climate

Overview



NCAR was one of the first centers to study anthropogenic climate change with global coupled climate models starting in the late-1970s. Consequently, the earliest climate change experiments done at that time were pioneer projects at a national and international level. Few groups were doing climate change modeling as it was considered to be a sidelight to other more highly regarded modeling problems. NCAR climate change modeling (funded by DOE and NSF) was prominent in the DOE State-of-the-Art climate change assessments in the late 1980s, and in the first IPCC assessment in 1990 and the 1992 IPCC update since only four groups in the world (including NCAR) had functioning global coupled climate models that were being used for climate change projections.

Since then, climate change modeling has become a very prominent activity at NCAR, most recently through the Community Climate System Model effort, and is now a headline activity for ESSL. As climate change modeling evolves to include more complexity, we are moving toward an earth system model-type activity. This crosses division boundaries in ESSL and requires close cooperation with the other science divisions since such earth system models will include not only the basic atmosphere-ocean-land surface-sea ice global coupled model, but also components of chemistry, aerosols, dynamic vegetation and carbon cycle.

Figure 1. Effects of BC aerosols during the pre-monsoon season of MAM on a) surface air temperature (°C), b) precipitation (mm day^{-1}), c) sea level pressure (SLP, hPa), and d) 850 hPa winds (scaling vector of 0.5 m sec^{-1} at lower right). Stippling indicates areas where the ensemble mean signal divided by the inter-ensemble standard deviation exceeds 1.0.

High resolution figure

Recent Accomplishments

CGD scientists and collaborators have been involved with research that has directly influenced and characterized national and international assessment activities. For example, there has been a growing awareness that anthropogenic black carbon aerosols, with their properties of both absorbing and reflecting solar radiation, may be contributing to significant climate change in the Indian monsoon region of south Asia. To address this problem, a six member ensemble of 20th century simulations with changes to only time-evolving global distributions of black carbon aerosols in a global coupled climate model was analyzed to study the effects of black carbon (BC) aerosols on the Indian monsoon. The BC aerosols act to increase lower tropospheric heating over south Asia and reduce the amount of solar radiation reaching the surface during the dry season. The increased meridional tropospheric temperature gradient in the pre-monsoon months of March-April-May, particularly between the elevated heat source of the Tibetan Plateau and areas to the south, contributes to enhanced precipitation over India in those months (Fig. 1). With the onset of the monsoon, the reduced surface temperatures in the Bay of Bengal, Arabian Sea, and over India that extend to the Himalayas act to reduce monsoon rainfall over India itself, with some small increases over the Tibetan Plateau (Fig. 2). During the summer monsoon season, the model experiments showed that BC aerosols have likely contributed to observed decreasing precipitation trends over parts of India, Bangladesh, Burma, and Thailand.

2009 and Beyond

Future research priorities in climate change modeling include further studies of extremes, studying decadal variability including understanding the relative contributions of inherent decadal variability and forced response in 20th century climate change, and mitigation scenario simulations of future climate change.

return to top

Land atmosphere coupling

Over the last forty years, atmospheric research has shown that land-atmosphere coupling is of critical importance for weather and climate prediction. Due to its diverse nature, a tall canopy's influence on turbulent exchange is extremely complex, e.g., because of their spatial distribution, seasonal variability, flexibility, porosity, etc. Within the layer of the atmosphere directly influenced by the canopy, turbulence varies dramatically depending on the detailed structure of the roughness elements and cannot be described by traditional similarity relationships. Where vegetation covers the surface, it becomes the important momentum sink and a key player in distributing sources and sinks of moisture, heat and trace atmospheric constituents. Parameterization of turbulent transport in and above tall canopies remains somewhat elusive but is essential for accurate weather and climate prediction. Large-eddy simulation (LES) is an important tool for studying the coupling between microscale and mesoscale motions. LES can also incorporate the influence of vegetation on momentum, energy, and scalars. Because observing three-dimensional and time-dependent fields of all quantities of interest is difficult, LES has become a direct link between currently observable quantities and larger-scale models which are forced to parameterize all of the turbulence.

LES needs to be validated and improved to deal with complex flows, especially for surface layers where dependence on the subfilter-scale (SFS) model increases. To address this issue, NCAR, in collaboration with several university groups, carried out three pioneering observational studies to improve subfilter-scale parameterizations over flat terrain with short sparse vegetation (Horizontal Array Turbulence Study, HATS, over the ocean (Ocean HATS; OHATS), and within and just above a tree canopy (Canopy HATS, http://www.eol.ucar.edu/rtf/projects/CHATS/isff/). These studies provide an observational basis for testing and improving closure approximations used in LES and they have substantially increased our confidence in parameterizations developed using LES as their basis.

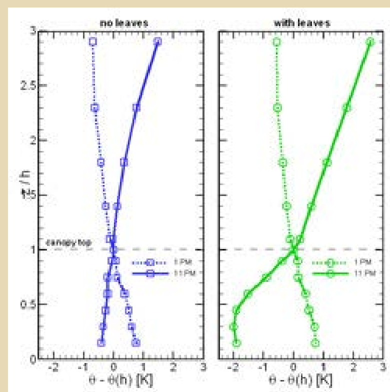


Figure: Spectra of vertical velocity multiplied by wavenumber and normalized by the convective velocity for 5, 6, and 12 August 1996 (top to bottom) versus wavenumber normalized by the CBL depth zi. Levels vary from ~0.25zi (dark blue) to ~0.75zi (yellow) every 30 m. Heavy smooth lines are von Kármán model spectra fitted to the lowest (dark blue) and highest (yellow) observed levels. The upturn at the right end of the spectra on 1 and 6 August is due to measurement noise. The dashed lines on 6 August are Kaimal model spectrum, which gives a more gradual transition between the low- and high-wavenumber spectral regions, fitted to the same levels. Although there is considerable day-to-day variability,

At this point, the character of within-canopy SFS motions is not known, nor the role that the eddies shed in the lee of the plant elements play, nor how these wake-scale motions affect scalar and momentum transport. CHATS has provided detailed measurements of SFS variables in a complex environment linking the biosphere, geosphere, and the atmosphere that will allow study of the fundamental interaction between vegetation and atmospheric turbulence, and validation of currently utilized SFS models and improvement of parameterizations representing this critical regime.

generally, the von Kármán spectra better fit the data, which tend to have an even sharper transition between low and high wavenumbers than the von Kármán spectra; the 6 August case is an exception.

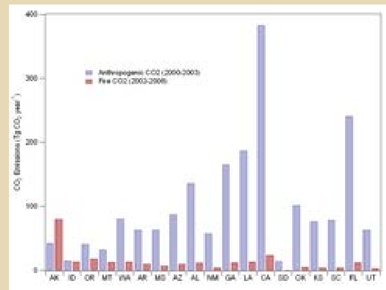
High resolution figure

Analysis currently underway includes: studying the impact of vegetation on sub-filter scale momentum/scalar fluxes and dissipation as a function of stability; establishing whether pressure correlates with canopy-scale coherent structures and evaluating the pressure destruction term in the scalar-flux equation; investigating heat storage within the canopy and the time-evolution and vertical variation of within-canopy stability; estimating horizontal length scales at the canopy-top using both helicopter and sonic-anemometer array data; studying canopy and stability influences on turbulent diffusion; and investigating sub-canopy processing and transport of biogenic reactive species (relate leaf-level to above-canopy fluxes); and exploring fine-scale turbulent coherent structures above the canopy using the Raman Eye-safe Aerosol Lidar (REAL) that was deployed in CHATS to delineate boundary-layer structure and motion. These studies will continue into the following year and beyond.

return to top

Emission inventories and application

Trace gas and aerosol emissions into the atmosphere are the major drivers of the chemical composition of the atmosphere. There is widespread concern about the effect of human activities on these emissions and their impact on atmospheric chemical composition. Changes in human activities are the underlying cause of the current increase in pollutant levels on regional and global scales. In some cases, changes in trace gas emissions are due to obvious pollutant sources including many technological sources. Other sources, including biomass burning and biogenic sources, have a natural component but are strongly influenced by humans. In order to understand these increases and to predict future changes, ACD/TIIMES scientists are quantifying emissions from various sources and improving our understanding of the natural and human influenced processes that control emissions.



This figure shows estimates of monthly, state-level total CO2 emissions and the contribution from fires (Wiedinmyer and Neff 2008).

High resolution figure

ACD/TIIMES scientists have completed a new version of the Model of Emissions of Gases and Aerosols from Nature (MEGAN), which is a modeling system for estimating the net emission of gases and aerosols from terrestrial ecosystems into the atmosphere. It is driven by landcover, weather, and atmospheric chemical composition. MEGAN is a global model with a base resolution of ~ 1 km. A stand-alone version of MEGAN is now available on the NCAR community data portal during the past year and has already been downloaded by > 100 users from more than 20 countries. MEGAN has also been incorporated as an on-line component of several regional and global models including MOZART, CCSM-CLM, GEOS-CHEM and WRF-CHEM. Continued development of MEGAN has resulted in a version that includes a detailed canopy environment model that will enable more realistic estimates of the response to landcover and climate change. MEGAN regional and global estimates of isoprene emissions are being evaluated by comparisons with satellite observations of HCHO which is a product of isoprene oxidation.

ACD/TIIMES scientists have also continued to improve a North American wildfire emission model and have used the model to forecast fire emission estimates for the NCAR MIRAGE field campaign. The model estimates daily emissions from fires for all of North America at a 1km resolution. More recently, emissions of mercury were included in the fire emissions model, and the first, state- and monthly resolved mercury emission estimates from fires have been produced. ACD/TIIMES scientists teamed with Jason Neff (U. Colorado) to quantify monthly, state-level CO2 emissions from fires and discuss the potential policy implications of these emissions (see figure).

FY2009 work will include continued improvements of MEGAN and the fire emissions model and enhanced support for the communities using these models. In addition, efforts will be focused on evaluating the model results and quantifying model uncertainties. The emission models will be used in regional chemical transport modeling studies to investigate the radiative impact of aerosols from fires and biogenic sources, interactions between direct particulate fire emissions and secondary organic aerosol formation, and mercury deposition. This work is funded by NSF/NCAR and EPA.

return to top

The impacts of climate and weather on society and ecosystems: Water cycle

Overview

As part of the Water Cycle Program, which involves scientists across ESSL and other national lab and university colleagues, various aspects of the water cycle have been examined in both in observations and climate models. The focus is on precipitation, atmospheric water vapor, and land

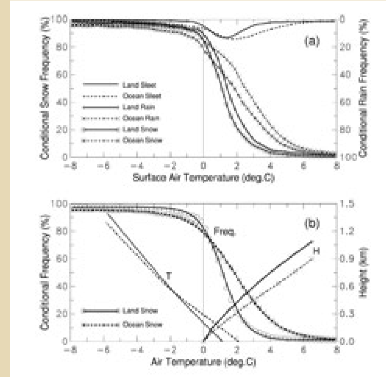


Figure 1. (a) Observed temperature-dependence of the conditional snow, rain, and sleet frequency (read on the right ordinate) during all seasons from 1977-2007 over global land (solid line) and ocean (dashed line). (b) The snow frequency over land (circles) and ocean (stars) from (a) overlaid by the fitted frequency (lines) using Eq.(1). Also shown in (b) is the mean temperature profiles (denoted by "T", right ordinate, which is the height above the surface) derived from the 6-hourly ERA-40 reanalysis [Uppala et al., 2005] from 1980-1989 by averaging over the land (solid line, slope=-5.1°C km^{-1} for the lowest 1km) and ocean (dashed line, slope=-6.6°C km^{-1}) areas where surface air temperature (T_s) is within the snow-rain transition range (-2°C to 4°C for land and -3°C to +6°C for ocean). The mean height of the freezing level as a function of T_s is also shown (denoted by "H", solid line=land, dashed=ocean). (Dai, A., 2008: Temperature and pressure dependence of the rain-snow phase transition over land and ocean. Geophys. Res. Lett., 35, L12802, doi: 10.1029/2008GL033295.)

High resolution figure

surface water fluxes, with the goal to improve our understanding and thus modeling and prediction of atmospheric moist convection, precipitation processes, and land surface hydrology on a broad range of time scales. The diurnal cycle of warm-season precipitation over the U.S. and other parts of the world has been employed as a means to systematically examine precipitation characteristics (onset, diurnal timing, frequency, intensity, duration, amount, type, etc.) in data and models, thus allowing a diagnosis of deficiencies in weather and climate models.

The Water Cycle Program also interacts with other ESSL programs such as the Biogeoscience Program - as well as leverages other NSF, NASA, and NOAA-funded studies related to the water cycle. dData sets and model evaluation work produced under this project are helpful for improving the Community Climate System Model (CCSM) and other climate models.

Recent Accomplishments

Recent Water Cycle accomplishments include 1) quantifying the temperature and pressure dependence of the snow-rain phase transition (Figure); 2) determining water and energy budgets in hurricanes; 3) analysis of the hydrological effect of Mt. Pinatubo's volcanic eruption and its resultant implications for geo-engineering solutions to global warming; 4) creation of an updated, global data- set of continuous, monthly river outflow for community use in quantifying decadal and long-term changes in continental freshwater discharge; and 5) analyses of satellite-observed and model-simulated precipitation and other hydrologic fields. These studies have resulted in a number of refereed publications.

For example, the phase of precipitation is important for weather forecasts, land hydrology and remote sensing. To quantify the temperature and pressure dependence of snow frequency (F, in %) when precipitation occurs, we have analyzed 3-hourly weather reports of surface air temperature (T_s, °C) and pressure (P_s), and snow and rain occurrences from over 15,000 land stations and available ship observations from 1977 - 2007. It is found that the phase transition occurs over a fairly wide range of temperature from about -2°C to +4°C over (low-elevation) land and -3°C to +6°C over ocean. The F-T_s relationship can be represented by a hyperbolic tangent: $F(T_s) = a\,[\tanh(b\,(T_s - c)) - d]$, with the slope parameter b close to 0.7 over land and 0.4 over ocean. The pressure-dependence is only secondary and reflected in the parameters. Results show that snow occurs often (F > 50%) for T_s = 1.2°C over land and T_s = 1.9°C over ocean, and are non-negligible (F > 5%) for T_s = 3.8°C over land and T_s = 5.5°C over ocean. This "warm bias" results from the falling of snowflakes into warmer surface layers, which is especially true over ocean. The warm bias is higher when air pressure is below ~750 hPa because snow falls faster in thin air.

Other major findings from recent ESSL work include: a) changes related to human influences on climate since 1970 have increased sea-surface temperatures (SSTs) and water vapor, and this may have altered hurricanes and increased associated storm rainfalls, quantified to be 6-8% higher than the baseline b) major unintended adverse effects, such as reduced water resources and increased drought, may occur from proposed geo-engineering solutions to mitigate global warming through emulating volcanic eruptions by injecting large amounts of aerosols into the Stratosphere; c) continental freshwater discharge into global oceans shows a slight decrease from 1949-2004, in contrast to the notion that continental discharge has increased as the global hydrological cycle intensifies under global warming; and d). large increases in the discharge into the Arctic Ocean during 1949-2004 are not accompanied by increases in precipitation; instead, increased runoff resulting from melting of soil ice in Eurasia may be a significant contributor.

2009 and Beyond

Future plans call for further work to quantify characteristics of precipitation frequency and intensity using high-resolution satellite observations, to improve simulations of these two quantities in CAM by modifying the cumulus parameterizations, and to analyze more comprehensively ofthe potential impacts of global warming on atmospheric water vapor and snowpack over the Colorado headwater regions.

return to top

Parameterization

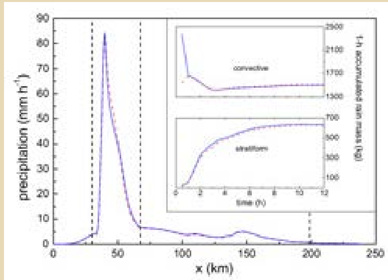


Figure: Spatial distribution of the steady-state surface precipitation for PRISTINE (red dashed lines) and POLLUTED (solid blue lines) simulations. Convective and stratiform region boundaries are shown as dashed vertical lines. Inserted figure shows time evolution of the area-integrated surface precipitation separated into convective and stratiform regions.

High resolution figure

Representation of cloud microphysical processes in models of various complexity (from small-scale to global) is a challenging aspect of numerical weather prediction and climate modeling. This is mostly because of the disparity between scales at which cloud microphysical processes operate (i.e., millimeters and centimeters) and scales resolved by models and observations. With the advent of convection-permitting numerical weather prediction using the Weather Research and Forecasting (WRF) model and application of the superparameterization approach to climate modeling representation of cloud microphysics emerges as the next “key problem”, similarly to the “convection parameterization problem” in the past. The superparameterization approach to climate modeling is the focus of the NSF's Science and Technology Center for Multiscale Modeling of Atmospheric Processes (CMMAP) at Colorado State University. Several NCAR scientists are members of the CMMAP team and are actively involved in the CMMAP research.

MMM scientists have developed a new comprehensive double-moment bulk-microphysics scheme to represent warm-rain and ice processes. These schemes are designed to include information about the atmospheric aerosols that affect cloud formation, the cloud condensation nuclei (CCN) and ice-forming nuclei (IN). Much of the research to improve cloud microphysical schemes is driven by suggested effects of CCN and IN on weather and climate. These are referred to as the indirect aerosol effects. Their uncertain role in climate and climate change was highlighted by the 2007 report of the Intergovernmental Panel on Climate Change. The warm-rain scheme is currently being applied in simulations of shallow convective cloud fields based on observations in BOMEX and RICO. The goal is to investigate indirect aerosol effects in shallow tropical convection. The warm-rain and ice scheme was applied in a study concerning effects of aerosols on precipitation from deep organized convection. In general, aerosol effects on deep convection are difficult to assess because of complex interactions between cloud microphysics and cloud dynamics. As a first step, a 2D kinematic (prescribed-flow) model mimicking a mature squall line was combined with the double-moment microphysics scheme and applied in a large set of sensitivity simulations. For each set of model parameters (such as environmental sounding, convective/mesoscale updraft strength, collision efficiencies, etc), a pair of simulations was performed featuring CCN characteristics of either pristine or polluted environment. In general, results in each pair differ insignificantly (see the figure). These results imply that CCN can affect precipitation from deep organized convection only through the microphysics-dynamics feedback (i.e., affecting the flow pattern), which can only be investigated in the dynamic cloud model.

Work is in progress to include the new scheme in WRF model and to apply it to several observationally based test cases.

return to top

Role of the oceans in climate

Overview

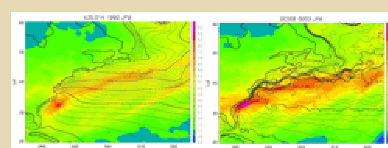


Figure 1. Winter season mean sea surface temperature (contours) and precipitation rate (colors) over the Northwest Atlantic in two CCSM coupled simulations. In the simulation depicted on the left, the 0.5° resolution CAM atmospheric model is coupled to the 1° resolution POP ocean model. In the simulation depicted on the right, the same 0.5° resolution CAM atmospheric model is coupled to the very high resolution 0.1° POP ocean model. As strong SST gradients in the Gulf Stream become realistically represented in the high resolution ocean model, the convergence of the low level atmospheric winds becomes stronger in a band parallel to the SST front, resulting in higher precipitation rates. This association of wind convergence and mesoscale SST gradients has only recently been observed in nature with the availability of high resolution scatterometer based wind products.

Covering 71% of the Earth, the oceans absorb the majority of the solar energy reaching the surface. The heat capacity of the upper three meters of the oceans exceeds that of the entire atmosphere, and the oceans contain approximately 50 times greater inventory of CO_2 than the atmosphere. The phase change from liquid to vapor by evaporation at the sea surface is the dominant source of moisture to the atmosphere, and the phase change from liquid to solid in the formation of sea ice has a strong effect on the reflectivity of the Earth's surface. Ocean currents, accomplish roughly equivalent energy transport from the tropics to polar latitudes as the atmosphere, and the meridional transports of sea water and sea ice close the global water cycle.. Ocean currents and turbulent mixing also transport nutrients from the deep ocean to the sunlit upper layers to support marine ecosystems. Through this capacity for storing and transporting energy, water, and radiatively and biologically active chemical species, the oceans act to moderate, modulate, and initiate climate variability and climate change. Instances of abrupt climate change observed in the paleo-climate record and in simulations of future climates with increasing greenhose gases arise from the interactions of sea ice, the hydrologic cycle and the ocean thermohaline circulation. A comprehensive understanding of, and the ability to predict, the behavior of the climate system must therefore be based on an understanding of the physical, chemical, and biological processes operating in the oceans and their interaction with other components of the Earth system.

Through research to develop an understanding of ocean processes, and using this understanding in improving their representation in ocean models,

High resolution figure

ESSL ocean scientists support a broad spectrum of ESSL scientific objectives. These include: prediction of the Earth's energy, water and biogeochemical cycles, and understanding natural and human influenced climate variability, including high impact variations such as sea level rise. In turn, the ESSL objective of understanding two-way scale interactions within the Earth system is central to improving our understanding of how thermodynamic processes such as sea-ice formation and ocean circulation features such as coastal upwelling zones, western boundary currents, and meso-scale eddies are affected by and affect the basin- to global-scale ocean circulation and the large-scale climate system.

Significant increases in computational resources together with improved physics and greater confidence in CCSM climate models at both modest and high resolution have allowed ocean model developments to be evaluated in fully coupled models for their effects on the climate system as a whole. In a number of cases, these coupled model results have been much more profound and widespread than anticipated from consideration of effects on the ocean in isolation. The key factor is for the ocean model changes to produce small, but persistent, changes in near surface ocean temperatures or sea-ice coverage, then for the coupled model to react to these signals in such a way as to amplify the changes.

Recent Accomplishments

A concerted effort was made move the parameterization of diapycnal mixing (the small scale three dimensional turbulence across surfaces of neutral density) from ad hoc prescriptions to a more physically based foundation. A wide range of processes not explicitly represented in the ocean general circulation model need to be considered as potential sources of energy for this turbulence. New parameterizations of the deep ocean mixing from breaking internal tides and tidal mixing in shallow seas have been guided by offline calculations with tide models, theoretical developments, and observations. Incorporation of tidal mixing in the shallow seas of the Indonesian Throughflow region was found to improve the simulation of SST in that region with a large consequent impact on precipitation in this important region for generating atmospheric variability. Microstructure measurements of ocean turbulence and theory have revealed a systematic latitudinal dependence of the interior diapycnal mixing resulting from breaking internal waves, with a maximum in subtropical latitudes, decreasing towards both the equator and polar regions. Incorporating the theoretically predicted latitudinal dependence in CCSM3.5 shows that the changes in the mean ocean state project onto longstanding precipitation biases. Gravity currents entrain and mix with overlying waters in their descent of the continental slope from deep water formation regions in marginal seas to the abyssal ocean. A parameterization of this process previously developed specifically for the outflow from the Mediterranean Sea was generalized and applied to the key deep water passages connecting the North Atlantic with the Greenland-Iceland-Norwegian Seas. A new parameterization of mixing by sub-mesoscale eddies, a process connecting the largely isopycnal mixing by mesoscale eddies, with the diapycnal cross-frontal mixing in the surface boundary layer was incorporated and shown to improve the representation of ocean ventilation processes. The ability to investigate the impacts of these changes in interior mixing have required an increase in vertical resolution such that the intended variations are not overwhelmed by implicit numerical mixing in the advective transport algorithm.

Corresponding changes toward more physically based representations of subgrid scale thermodynamic and radiative processes in the sea ice model have been made. These include the incorporation of a new radiative transfer scheme that makes use of inherent optical properties to define the scattering and absorption properties for snow, sea ice and included absorbers. An explicit melt pond parameterization has been incorporated which relates the pond evolution to the surface ice and snow melt water flux. Additionally, aerosol deposition and cycling within the sea ice component for black carbon and dust species is now included. Taken together, these improvements provide a more sophisticated and complete sea ice albedo treatment.

The improvements achieved in the representation of ocean transport processes in the most recent versions of CCSM have motivated the decision to carry out fully interactive carbon cycle experiments at higher horizontal and vertical resolution than was used in CCSM3. The computational burden of running the higher resolution carbon cycle model thousands of simulated years in order to bring it into equilibrium remains a significant roadblock however. Mathematical techniques based on Newton-Krylov non-linear equation solvers are being investigated to circumvent the need to carry out an explicit time-dependent integration of the model and obtain the equilibrium solution directly.

2009 and Beyond

Nearly all of the ocean model developments completed and underway have been evaluated in a coupled climate context, but typically individually. The effort over the next year will be to bring them together to more fully understand their interactions and collective impact on the climate system. Comparisons with ocean tracers, both observed and as simulated by very high resolution models, will provide the metrics for judging the impact of these parameterizations on ocean transport and ventilation. Diapycnal mixing occurs on scales of centimeters to meters and will remain unresolved, and require parameterization, in global ocean climate models for many generations to come. However, coupled climate simulations that do resolve ocean mesoscale variability, on scales of 10s to 100s of kilometers are now on the horizon. Early results from prototype integrations in this class, as illustrated in the accompanying figure, reveal intriguing new classes of ocean-atmosphere interaction. The emerging availability of high resolution remote sensing products for ocean winds, surface temperature, and surface currents will facilitate an assessment of the performance of CCSM in this resolution regime, and the application of CCSM to furthering our understanding of the processes and scale interactions connecting the ocean mesoscale to the global climate system.

return to top

Structure and evolution of clear and cloudy atmospheric boundary layers

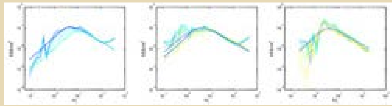


Figure: Spectra of vertical velocity multiplied by wavenumber and normalized by the convective velocity for 5, 6, and 12 August 1996 (top to bottom) versus wavenumber normalized by the CBL depth zi. Levels vary from ~0.25zi (dark blue) to ~0.75zi (yellow) every 30 m. Heavy smooth lines are von Kármán model spectra fitted to the lowest (dark blue) and highest (yellow) observed levels. The upturn at the right end of the spectra on 1 and 6 August is due to measurement noise. The dashed lines on 6 August are Kaimal model spectrum, which gives a more gradual transition between the low- and high-wavenumber spectral regions, fitted to the same levels. Although there is considerable day-to-day variability, generally, the von Kármán spectra better fit the data, which tend to have an even sharper transition between low and high wavenumbers than the von Kármán spectra; the 6 August case is an exception.

High resolution figure

Work has continued on analysis of the chemical behavior of dimethyl sulfide (DMS) and scalar variance budgets in the marine boundary layer (MBL) using DYCOMS-II data from the NCAR C-130 aircraft, in collaboration with Ian Faloona (University of California, Davis). The scope of the effort has expanded somewhat to also include analysis of DMS and SO2 data from the PAcific Sulfur Experiment (PASE) carried out in summer 2007, also flown on the C-130 aircraft. Thus far, the effort is mainly concentrated on documenting the overall structure of the MBL in the equatorial region where PASE was conducted. This effort will continue during FY2009.

This past year, a study of vertical velocity w spectra in the convective planetary boundary (CBL) has been carried out using Doppler lidar data collected during the Lidars in Flat Terrain (LIFT) experiment over flat farmland in central Illinois during summer 1996. This is a continuation of previous analyses that dealt with the 2-point turbulence statistics of w. The NOAA High Resolution Doppler Lidar (HRDL) was pointed straight up for over 100 hrs, providing 11 different cases of a midday convective boundary layer. This takes advantage of the lidar's capability to obtain range-resolved radial measurements, from which a two-dimensional field of w can be obtained by assuming that the field of turbulence is "frozen" as it advects past the lidar. Measurements of w were obtained from a height of z ? 390 m above the surface to near the CBL top with an unprecedented vertical resolution of 30 m. Considerable day-to-day variability was found in the spectral shape, as shown in the figure, and previous models of the w spectra were not particularly good at describing the observations. Some of this variability was found to be linked to mean CBL structure, including wind speed, shear across the CBL top, and processes at, and just above the capping inversion.

Work will continue over the next year on analysis and interpretation of profiles of higher-order moments of w, from LIFT, including variance, skewness and kurtosis, which will be compared with large-eddy simulation results.

return to top

Fine Mesh Land Model

The goal of the Fine-Mesh Land Model project was to develop and implement a framework for modeling land surface processes using NCAR community land models at scales several multiples finer than those of parent atmospheric models. The approach taken was to enhance and implement the fine-mesh model of Hahmann and Dickinson (2001) within the Community Atmosphere Model - Community Land Model (CAM - CLM) climate model.

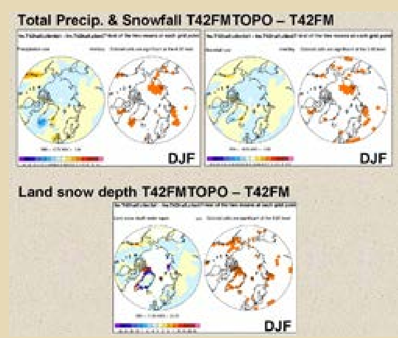


Figure 1: Effects of fine-mesh topography on large-scale circulation. The total precipitation and snow fall are impacted as is the snowpack structure.

High resolution figure

A paper summarizing the results from the fine-mesh modeling work within CAM/CLM has been written and submitted. Results from simulations with sub-grid topography showed significant changes to both the general circulation and the model surface hydrological fields compared with those where only subgrid land use and land cover was specified. The principal changes were an alteration of the Northern Hemisphere wintertime mid-latitude wave train in the North Pacific. A relative increase in the strength of the Aleutian low combined with changes land surface elevations result in widespread changes in the amount of total precipitation and partitioning between rain and snow over the parts of western Canada and Alaska. Effects in other complex regions appeared to be of lesser magnitudes. Changes in rain-snow partitioning also impart a lag-effect on the surface hydrology by altering the timing and location of snowmelt and runoff from cool season precipitation. Implementation of a precipitation disaggregation scheme into the fine-mesh model which stochastically determines the sub-grid area occurrence and intensity of precipitation based on the coarse grid model precipitation was also completed. Results from simulations including the subgrid precipitation aggregation show modest changes in the global circulation as well as the surface hydroclimate though regional changes were sometimes quite substantial. In the U.S. Great Plains there appears to be a distinct strengthening of the low-level moisture transport from the Gulf of Mexico occurring with a regional increase and redistribution of rainfall and surface evaporation.

return to top

NASA African Monsoon Multidisciplinary Analysis (NAMMA)

Figure: Lenticular wave cloud sampled on 13 December 2007 during ICE-L.

High resolution figure

We reported on our research last year as part of the NASA-sponsored African Monsoon Multidisciplinary Analyses (NAMMA) campaign. This project was a field research investigation conducted during August-September 2006 based in the Cape Verde Islands, 350 miles off the coast of Senegal in west Africa. We have made considerable progress on the analysis of these data. With Cynthia Twohy of Oregon State University, we have shown that the Saharan dust aerosols acquire a sulfate coating and act efficiently as cloud condensation nuclei. The net effect is that exceedingly high cloud-droplet concentrations are produced in the dust-perturbed clouds. Dr. Twohy has submitted an article to Nature Magazine, with us as coauthors.

We have further found that an appreciable portion of the cloud droplets are lofted high into the NAMMA clouds in vigorous convection. These freeze via spontaneous ice nucleation at temperatures near -40C, thereby producing high concentrations of radiatively reflective small ice particles. A paper reporting on these observations is in preparation.

In November and December 2007, we conducted the ICE-L (ice in clouds experiment- layer clouds). The primary goal of ICE-L was to show that under given conditions, direct ice nucleation measurement(s), or other specific measurable characteristics of the aerosol, can be used to predict the number of ice particles forming by nucleation mechanisms in selected clouds. The target clouds were primarily lenticular mountain-wave clouds. These clouds can act as a laboratory-type setting because they are relatively stationary, permitting repeated penetrations at multiple levels. Flying along or against the wind is laboratory-like in that distance along the wind corresponds to particle-growth times.

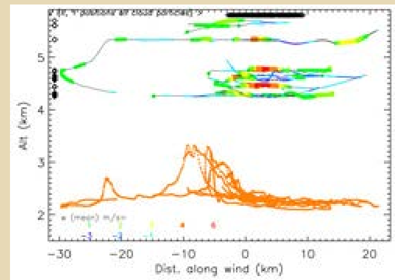


Figure: Horizontal section (altitude, distance along the wind) through wave cloud sampled on 11 December 2007. The mountain range below the aircraft is shown in orange coloring. The color-coding in the cloud-forming region refers to the air vertical velocity.

High resolution figure

We used the NCAR C-130 aircraft for ICE-L. A dozen or so university investigators, sponsored by NSF, participated in the experiment and many brought instruments that brought a new level of detail to how ice forms in clouds. We had eight probes to measure droplet and ice-particle-size distributions, three of which measured sub-50 micron particles with an open-path design to mitigate shattering which has contaminated earlier measurements of ice-particle concentrations. Incredibly interesting and valuable data were acquired with the onboard upward- and downward-viewing cloud radar (94 GHz) and upward-viewing lidar. We had two particulate mass spectrometers and a CVI to get at the composition of the ice nuclei, ice-nucleus measurements, two CCN spectrometers and a photometer to sense the volatility of the ice nuclei.

Nine flights were conducted in lenticular mountain wave clouds (see Figure 1a). Up to a dozen penetrations were made in individual wave clouds (Figure 1b). Our early analyses indicate that there is no mismatch between ice-nucleus concentrations and ice-crystal concentrations. Ice-nucleus and ice-crystal concentrations show very little dependence on temperature. This contrasts with parameterizations of ice-nucleus concentrations currently used in WRF and most cloud and mesoscale models that show that these concentrations increase strongly with temperature. We plan to parameterize the ICE-L results for incorporation into WRF.

return to top

Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) contributions

ESSL scientists are participating in the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS), a new ten-year land-atmosphere project of the International Geosphere-Biosphere Programme (IGBP). The goal of iLEAPS is to understand how interacting physical, chemical, and biological processes transport and transform energy and matter through the land-atmosphere interface. The project is designed to study interactions and feedbacks on scales from molecules to the entire globe, and from minutes to centuries, both past and future. The project brings together multi- and cross-disciplinary scientists to collaborate, distribute ideas and results rapidly, and increase scientific relations with developing countries. The iLEAPS International Project Office is based at the University of Helsinki in Finland and promotes international research projects studying essential phenomena related to global climate change.

In FY2008 ESSL scientists participated in the iLEAPS expert workshop on "The relevance of surface and boundary layer processes for the exchanges of reactive- and greenhouse gases" in Wageningen, Netherlands and the iLEAPS workshop on "Process-based description of trace gas emissions in land surface models" in Helsingborg, Sweden. ESSL scientists will continue to contribute to iLEAPS activities in FY09 and will propose the BEACHON project for sponsorship by iLEAPS. This work is funded by NSF/NCAR.

return to top

Texas air quality study

The Texas Air Quality Study (TEXAQS 2006) was a NOAA led field campaign out of Houston, Texas, that focused on providing a more complete understanding of the sources and processes responsible for photochemical pollution (ozone) and regional haze (aerosols) during the summer in Texas. Ozone and aerosols both play important roles in air quality and climate change as a result of their chemical and radiative properties. A significant fraction of ozone in the troposphere is produced photochemically from precursors that have both anthropogenic and natural sources. Major urban centers are a large source of these precursors, which results in elevated levels of ozone on local and regional scales from production and transport. These elevated levels can be a human health hazard in urban and surrounding areas and can impact ecosystems in both urban and rural areas. Enhanced aerosol production in urban areas can also impact human health and ecosystems. Exposure to high levels of aerosols can lead to respiratory problems for humans and can acidify ecosystems as they are removed by rain. On the NOAA P3 aircraft, ACD scientists measured PANs and collected whole air samples for analysis of non-methane hydrocarbons, halocarbons, alkyl nitrates, and oxygenated VOCs. One interesting result from the measurements made during TexAQS2006 is illustrated in Figure 1. One goal of the TexAQS 2006 campaign was aimed at investigating the changes in photochemical ozone production over Houston as a result of emission reductions implemented between 2000 (the first TexAQS campaign) and 2006. Of high concern were in 2000 the episodes of very efficient ozone production from highly reactive NMHC like ethene, propene, and butenes which are emitted from petrochemical facilities. The measurements made on this flight on October 6, 2007, show that this is still a problem. The plot shows 1-second time resolution measurements of PAN and APAN (both tracers of photochemical ozone production, along with ozone mixing ratios. APAN is a unique product from the oxidation of butadiene, an extremely reactive hydrocarbon used to make butyl rubber. PAN is being produced from many hydrocarbons which produce ozone in the troposphere. During the flight, four passes downwind of major butene emitters (blue dots on map, the size of the dots is proportional to the butene emission magnitude) were made. Ozone is enhanced by almost 80 ppb only 1.5 hours downwind of the source of emissions. Even though dilution sets in for passes #3 and #4 (spiral profile) further downwind ozone is still 60-70 ppb enhanced over the background. This is a very large ozone production rate and cases like this contribute significantly for the overall large ozone problem in the Houston area. The thick black arrow points out where additional ozone production was observed which does not involve butadiene as PAN and ozone are enhanced here but APAN is not. This illustrates the advantage of measuring several (in our case, 5) different PAN species quasi-simultaneously and how it allows us to identify specific hydrocarbon species as they contribute to the photochemical production of ozone.

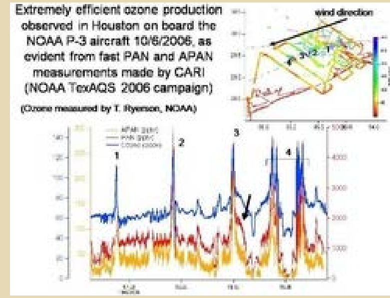


Figure 1. Rapid production of PANs and ozone downwind of a petrochemical facility emitting large quantities of 1-butene measured on the NOAA P3 during the TexAQS 2006 campaign.

High resolution figure

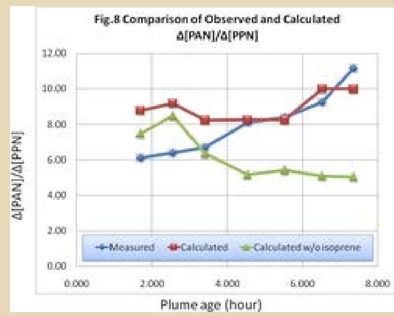


Figure 2: measured and calculated development of the PAN/PPN ratio as air is transported away from downtown Houston into the suburbs.

High resolution figure

Observed PAN/PPN ratios were also analyzed in air masses which were transported downwind of the city of Houston into the suburban areas. An increase of the [PAN]/[PPN] ratio was observed during transport of the Houston plume away from the city. PPN is more thermally stable than PAN which works to decrease this ratio if no more production of either of the species took place. However, the precursors for PPN generally react away faster with OH compared to the PAN precursors, shifting the ratio to increasing values while air masses are still production dominated. This generally faster depletion of PPN precursors alone was found to be inadequate to explain the overall observed increase. Our calculations show that isoprene emissions from the surrounding areas are a major source of PAN downwind of Houston and cause much of the observed increase of the [PAN]/[PPN] ratio (see Figure 2).

return to top

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ESSL LAR 2008: STRATEGIC GOAL #1, PRIORITY #2

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #1, Improve understanding of the atmosphere, the Earth system, and the Sun. This Strategic Goal encompasses four Strategic Priorities, each of which is dependent on the efforts and accomplishments of ESSL staff.

ESSL developed an action plan with seven priority themes which involve direct partnerships with the university community and contribute directly to the ESSL Strategic Vision and to several priority items of the NCAR Strategic Plan.

ESSL's seven priority themes:

1. Climate projection, with emphasis on short-term prediction.
2. Biosphere-Atmosphere-Hydrosphere interactions and specifically development of BEACHON Project (Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, Hydrology, Organics and Nitrogen).
3. Water system research, specifically the development of the Society, Water, Atmosphere and Natural Systems Project (SWANS).
4. An advanced Weather Research and Forecasting system, specifically the development of the Hurricane Intensity and Forecasts (HiFi) Project.
5. Space Weather, specifically the development of the Coronal Solar Magnetism Observatory Project (COSMO).
6. Chemical Weather, including interpretation of observed data gathered during the Megacity Impact on Regional and Global Environments (MIRAGE) campaign, and the development of a capability for chemical data monitoring and prediction.
7. Prediction across scales, specifically the development of an advanced next-generation, climate-weather modeling system and an integrated Earth system model of intermediate complexity.

Goal #1, Priority #2: Investigating the Interactions of the Atmosphere, the Broader Earth System and Human Society, is described as a combination of "...meteorology and climatology," which "were (previously) considered separate fields, largely because of disparate time and length scales. Today, the two fields are strongly coupled, not only because climate provides boundaries for investigating the weather, but also because localized events can influence larger climatological scales. The activities that NCAR scientists focused on this year ranged from collecting in situ data to better understand climate, weather and related phenomena, to developing and analyzing ways to better model natural processes and working with university partners to devise ways of tackling scientific questions."

This NCAR priority, driven by ESSL's themes 2, 3, 4, 6, & 7, is critical to achieving NCAR's first strategic goal.

The section below describes specific research conducted by ESSL staff under projects relevant to Priority 2. The major ESSL activities in this area are studies of the global and regional carbon, nitrogen, and water cycles and their coupling, feedbacks, and interactions. Additional major activities focus on climate change and variability, extreme weather events, and the impacts of climate, weather, and urbanization on society and ecosystems.

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11. Exploring the role of aerosols - ACD
12. Convection organization: Observational analysis and resolved simulations - MMM
13. Atmosphere/ocean interactions - MMM
14. Long-term climate change in the thermosphere - HAO
15. The impacts of climate and weather on society and ecosystems: Climate change - probabilistic climate change, and solar forcing of climate - CGD
16. Land-atmosphere coupling - MMM
17. Emission inventories and application - ACD
18. The impacts of climate and weather on society and ecosystems: Water cycle - CGD
19. Parameterization - MMM
20. Role of the oceans in climate - CGD
21. Structure and evolution of clear and cloudy atmospheric boundary layers - MMM
22. Fine mesh land model - TIIMES
23. NASA African Monsoon Multidisciplinary Analysis (NAMMA) - MMM
24. Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) contributions - ACD
25. Texas air quality study - ACD

Regional Carbon Cycle

TIIMES measurement and instrument development projects have advanced our understanding of regional carbon fluxes, particularly in the mountain west, and provided key NCAR contributions to the multi-agency North American Carbon Program (NACP). A central component of this effort is the Regional Atmospheric Continuous Carbon Dioxide Network in the Rocky Mountains (Rocky RACCOON).

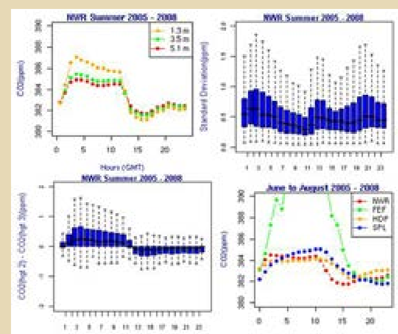


Figure 1: Summertime RACCOON data averaged over the months June-August. a) Calibrated CO_2 values from three heights at NWR b) Boxplot of the distribution of hourly standard deviations at NWR. c) Boxplot showing the distribution of 3.5 m to 5.1 m vertical gradients at NWR. d) Filtered diurnal cycles from four sites are generally representative of concentrations over large regions.

High resolution figure

In order to improve our understanding of regional carbon fluxes in the Rocky Mountain West, TIIMES scientists have developed and deployed autonomous, inexpensive, and robust CO_2 analyzers (AIRCOA) at six sites throughout Colorado, Utah, and Arizona over the past three years (http://raccoon.ucar.edu). Analysis of the diurnal cycles in CO_2 concentration and CO_2 variability at these sites provide insight as to when and under what conditions mountaintop CO_2 signals are regionally representative, as well as first-order constraints on boundary-layer heights and flux rates for use in evaluating model fidelity (Figure 1).

Comparisons between the RACCOON measurements and estimates of free-tropospheric background concentrations reveal regional-scale CO_2 flux signals that are generally consistent with one another and our expectation of peak CO_2 uptake in mountain forests during spring (Figure 2). Combining these differences with information on boundary-layer mixing can lead to quantitative estimates of monthly regional CO_2 fluxes. These data have also been used in the NOAA CarbonTracker flux estimation system as well as the GlobalView data product used by modeling groups around the world.

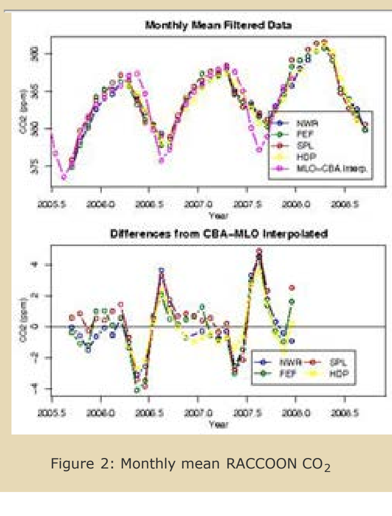


Figure 2: Monthly mean RACCOON CO_2

The RACCOON observations at Fraser Experimental Forest have occurred while the trees in the St. Louis creek drainage have experienced widespread mortality due to mountain pine bark beetle infestation. The CO_2 measurements at the base of this valley show large increases in CO_2 at night as the valley drainage flow pools respiration from a large area. This nocturnal build-up has decreased over the past three years (Figure 3), suggesting a decrease in ecosystem respiration in response to the insect outbreak. This decrease indicates that the reduction in autotrophic respiration is greater than any short-term increase in litter fall, and will be a valuable test of models predicting the impact of the recent outbreaks on regional scale carbon fluxes.

Future plans to address regional carbon fluxes include in depth analysis of ACME-07 and Rocky RACCOON data and synthesis with modeling efforts to:

1. define regional-scale monthly to interannual carbon fluxes for the U.S. Central

Rocky Mountains and Southwest,

2. assess key drivers of variability and trends including drought, fires, and insects, and
3. optimize community CO_2 observational efforts across the Mountain West.

return to top

concentrations at four sites and differences from marine boundary layer concentrations interpolated to the same latitude. The differences indicate strong CO_2 uptake during spring in the Central Rocky Mountains.

High resolution figure

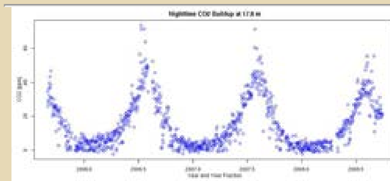


Figure 3: Nighttime valley CO_2 buildup measured at the Fraser Experimental Forest site. The decreasing trend indicates reduced ecosystem respiration following widespread beetle mortality.

High resolution figure

Landfall impacts of hurricanes

The 2005 Atlantic hurricane season is a vivid reminder of the economic and societal consequences of landfalling tropical cyclones. Improved forecasts of hurricane structure, intensity change, and time-extensions of skillful track prediction are vital for evacuation strategies. Progress requires solving difficult problems such as the inner-core hurricane dynamics and how it affects intensity, quantifying the net enthalpy flux from the ocean in high-wind-speed conditions, and incorporation of a variety of remotely sensed data into model initial conditions. The purpose of ESSL/MMM research in hurricane simulations is to create the next generation hurricane-prediction system, and a community hurricane-prediction model that can be used for process and predictability studies.

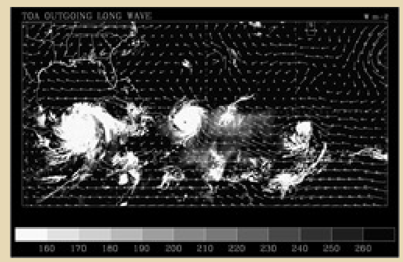


Figure: Snapshot of Outgoing Long wave Radiation (W/m2) and wind vectors at 700mb from the Nested Regional Climate Model. The figure shows two mature hurricanes in the Caribbean and the genesis of a tropical cyclone further east over the tropical North Atlantic Ocean.

High resolution figure

During the past year, analysis of the real-time forecasts for the 2007 North Atlantic hurricane season revealed that intensity prediction is currently limited by poor initialization of the hurricane vortex. Experimentation with the Ensemble Kalman Filter data assimilation technique shows this could be key in creating suitable initial conditions and improved intensity prediction. A breakthrough science project allowed a simulation of an idealized hurricane to be conducted at 62m grid spacing. At this resolution, the model was able to resolve turbulent eddies. The 1-minute mean wind field form this simulation showed lower maximum winds than a more coarse resolution simulation that was unable to resolve turbulence.

In a new application, WRF simulations of the major U.S. landfalling hurricanes of 2004 and 2005 were used as inputs into insurance-industry loss models to evaluate the potential utility of high-resolution winds for improving hazard assessment and loss estimation. The project revealed WRF can provide information on asymmetries and small-scale details of the wind field that are currently not included in most insurance loss models.

Nested Regional Climate Model simulations have been explored using a tropical-cyclone-detection algorithm. The model captured the general global and seasonal distributions of tropical cyclones but consistently overproduced the number of tropical cyclones. Two-way nesting down from 36km to 12km over the Atlantic region for the 2005 season improved both the number and spatial distribution. This dataset has been used to show the importance of the background flow in modulating easterly waves thereby creating favorable conditions for tropical cyclogenesis, and higher-resolution simulations of genesis have shown vortices merging during the period of genesis.

In the coming year, new ground will be broken with the Ensemble Kalman Filter technique by running this cycling assimilation system for an entire North Atlantic hurricane season to create initial conditions for high-resolution hurricane simulations. These simulations will make an important contribution to NOAA's Hurricane Forecast Improvement Project by providing a statistically significant comparison of the effect of high-resolution (~1km in the horizontal) on the accuracy of hurricane-intensity forecasts. Data from T-PARC will be analyzed and cycling assimilation will be run retrospectively for the period of the campaign. Finally, trends in hurricane activity in the North Atlantic, Caribbean and Gulf of Mexico regions will be examined through ensembles of high-resolution climate-change simulations using the Nested Regional Climate Model driven by boundary conditions from the Community Climate System Model. This ambitious project is providing for the first time, decadal climate simulations of hurricanes at a resolution sufficient to identify key intensity and structural details. It also provides a genuine test of the requirements for future supercomputing systems to enable decadal predictions of the regional detail required for planning and adaptation strategies. The work has strong community involvement and support, including financial support from the offshore oil industry.

return to top

Global and Regional Water Cycle

The Water Cycle Program has conducted research related to the Regional and Global water cycle since 2001. Using the diurnal cycle of precipitation as a focus, research has shown that current climate models do not accurately simulate the frequency, intensity, and timing of summer time convection over much of the globe, including continental regions, despite reasonable simulations of precipitation amount (see figure). This model deficiency greatly hampers climate models' ability to predict future changes in intense storms, flash floods, tornados, hurricanes, and other severe weather events that likely have the largest impact on the society under global warming. This model deficiency results from a variety of factors, including: 1) a lack of realistic representation of atmospheric convective inhibition processes, and 2) a poor representation of propagating systems of convection in the lee of major mountain ranges. This later deficiency is reflected in the high degree of uncertainty of current climate model runs in these regions.

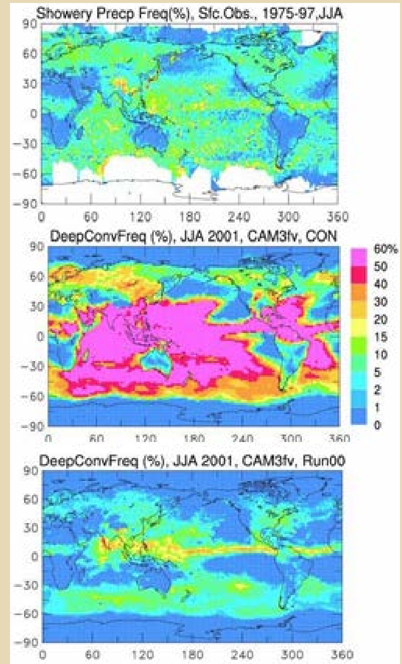


Figure 1: June-August moist convection frequency (in % of time) from surface observations (top), CAM3 with its standard convection scheme (middle) and a newly modified scheme (bottom) that significantly improves the simulated frequency of convection.

High resolution figure

The goals of the Water Cycle program are: 1) to reduce this uncertainty through focused research on the physical mechanisms leading to the onset of moist convection and the propagation of convective systems in the real world, 2) to test and improve new parameterizations of convection that improve simulations of these phenomena, 3) to improve our understanding of the coupling between the land surface, atmospheric boundary layer and convective parameterizations in climate models, and 4) to improve the representation of the cool season water cycle over complex terrain in climate models.

Current research has focused on the following areas supporting the goals mentioned above:

1. Further quantifying precipitation characteristics (frequency and intensity and their dependence on data resolution, temporal and spatial correlative structures, etc.) on global and large scales using high-resolution satellite data, and apply them to evaluate global models (Dai, Laing, Trier, Davis, Carbone, Trenberth, Wang).
2. Studying Upper Colorado Basin snowpack under projected climate change in the 21st century using high-resolution regional models (the Colorado Headwaters Project) (Rasmussen, Gochis, Chen, Liu, Ikeda, Arsenault, Houser, Liang, Dudhia, Yu, Tewari,Thompson).
3. Improving convective parameterizations in climate models for better simulations of the frequency, intensity, and diurnal timing of precipitation and the propagation of convective systems (Dai, Li, Neale, Liu, Moncrieff, Tulich, Grabowski, Davis, Rasmussen, Mapes, Neelin, Wu).
4. Conducting high resolution model simulations using boundary conditions with short waves removed. Investigate the role of the mountain-plains circulation in maintaining and initiating the propagating convection as well as other mechanisms (Trier, Wang, Tuttle, Carbone).
5. Percent of precipitation over the United States attributable to propagating convection. Twelve year radar dataset does not reveal a correlation of the intensity or phase of the propagating convection to ENSO (Tuttle, Carbone).
6. Diagnosing the water cycle in climate models and observations and in retrospective datasets (Dai and Trenberth).
7. Improving the hydrological cycle in CLM3 (Oleson and Lawrence).
8. Examine the role of the Great Plains nocturnal jet in modulating convection in CAM (Caron).
9. Examining the role of the land surface in modulating propagating convection (Chen, Tewari, LeMone).

Results to date show that short waves are not the dominant factor in initiating convection. Research is now focused on other mechanisms such as the mountain/plains diurnal circulation. Examination of the amount of precipitation attributed to propagating precipitation over the continental U.S. suggests that up to 70% of central U.S. precipitation is due to propagating systems. Research on the role of land surface impacts suggest that the land surface plays a secondary role in the formation and propagating of long-lived convective systems. Research related to the low-level jet over the central U.S. shows a strong coupling of the corridors of propagating convection to the low level jet. In support of improved simulation of these propagating systems in climate models, a new cross-NCAR convective parameterization scientific interest group has been formed and has been holding monthly meetings to discuss new work related to convection parameterization. The Colorado Headwaters project started, and was awarded 500,000 GAUs through the Accelerated Science Discovery competition.

The Water Cycle Program will focus on the following areas during the next few years:

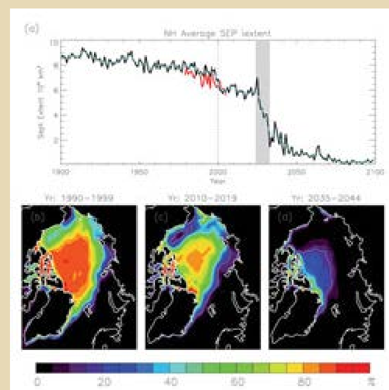
1. Continued emphasis on improving convective parameterizations in climate models, including the testing of various candidate schemes (including the new Moncreiff and Liu scheme developed under Water Cycle sponsorship) and testing different treatments of convective inhibition in models, with the aim to reduce the model bias related to precipitation frequency, intensity and diurnal cycle. The Convective Parameterization group will continue to meet and likely hold workshop.
2. Finalize work related to mechanisms that lead to the initiation of propagating systems.
3. Continue with Regional and Global Diagnostic studies of the water cycle.
4. Evaluate how to improve the coupling of land surface, boundary layer, and convective schemes in climate models.
5. Initiate and carry out the Colorado Headwaters cool season water cycle over complex terrain project.

return to top

The impacts of climate and weather on society and ecosystems: Polar climate

Overview

Over the past several decades, Arctic sea ice extent has been steadily shrinking. Due to the ice-albedo feedback, this reduction in ice cover has contributed to an observed amplification of Arctic warming relative to the rest of the world. Observed sea ice extent in September 2007 smashed the previous record low. Climate models project that sea ice decline will continue into the foreseeable future, with the possibility of summer ice-free conditions being reached later this century. Considerable effort is underway to examine these observed and projected changes in the sea ice system and the consequences of a seasonally ice-free Arctic ocean for the climate and ecological systems. An analysis of projected changes in the future ice cover suggests that gradual, linear changes are unlikely; rather, sea ice decline is likely to be punctuated by abrupt transitions such as that seen in 2007. Integrations with the Community Climate System Model (CCSM) exhibit abrupt reductions in the future summer sea ice cover, with the most extreme event going from 80% September ice coverage to 20% coverage in approximately 10 years (Figure 1). The mechanisms responsible for these transitions include: 1) an increased efficiency of open water production as the Arctic ice thins, 2) rapid increases in ocean heat transport that trigger the events, and 3) the surface albedo feedback, which accelerates the ice retreat. An analysis of additional models participating in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4) indicates that about 50% of them exhibit similar abrupt reductions in future Arctic summer ice cover for some future forcing scenarios, although the length and magnitude of the events vary. The presence of seasonally ice-free conditions has potential impacts on the Arctic and global systems and CCSM is being used to assess the impacts on global atmospheric circulation, the hydrological cycle as well as ocean and terrestrial conditions.



a) The time series of September Arctic ice extent from CCSM-3 (black), the CCSM-3 5-year running mean (blue) and the satellite observations (red), with the identified abrupt event shown by the grey shading. The sea ice conditions for the (b) 1990-1999 average, the (c) 2010-2019 average and the (d) 2035-2044 average are also shown and indicate the realistic present day ice cover simulated by CCSM-3 and the rapid decline that occurs by mid-century.

High resolution figure

Along with sea ice loss, there are strong indications that the permafrost is warming and thawing over large scales. Thawing of permafrost is likely to induce a number of feedbacks to the hydrologic and carbon cycles of the Arctic system. Of particular concern, especially from a global perspective, is how permafrost thaw will affect the carbon balance in the Arctic. The future carbon balance of the Arctic remains one of the largest uncertainties in climate change science.

Changing sea ice and permafrost conditions have important implications for the Arctic hydrological system change. Because of the proximity to deep water formation regions within the northern North Atlantic, this in turn can modify the global thermohaline circulation.

Finally, while changes in high northern latitudes are considerable, the Antarctic region generally remains quite stable. There are numerous and varied reasons for this different behavior in the southern high latitudes, including changes in the atmospheric circulation and ocean heat uptake that appear to mute an anthropogenic warming signal. However, the interactions and importance of these processes for the future Antarctic climate remain unclear.

Recent Accomplishments

In 2008, we made substantial progress on a variety of research topics, ranging from an evaluation of the role of external versus internal forcing of sea ice transitions, an assessment of the impact of sea-ice loss on polar bear habitat and on permafrost degradation. We also continue to evaluate the role of changes in freshwater forcing on the thermohaline circulation. We also made substantial progress improving the representation of polar processes in CCSM in preparation for CCSM4. For more information, see the following topics:

- Natural versus external forcing of rapid ice loss [M. Holland Profile]
- Polar bear habitat loss [M. Holland Profile]
- Accelerated terrestrial warming during rapid sea ice loss and permafrost degradation [C. Deser Profile] [M. Holland Profile] [D. Lawrence Profile]
- Role of atmospheric circulation in sea ice decline [C. Deser Profile] [H. Teng Profile]
- Impact of freshwater forcing on thermohaline circulation [G. Meehl Profile] [B. Otto-Bliesner Profile]
- Development and improvement of polar processes in CCSM4 [D. Lawrence]

2009 and Beyond

CCSM experiments exhibiting periods of abrupt sea ice loss and rapid permafrost thaw raise the question as to whether or not sea ice or permafrost loss exhibit characteristics of a so-called tipping point in the climate system. Experiments are underway to evaluate whether or not sea ice can thin to the point that its further loss is no longer dependent on further warming. Related work on the stability of seasonally ice free conditions is also in progress. Experiments are also planned to evaluate whether permafrost is sustainable or not once the ground has reached a thermal state in which talik, a perpetually unfrozen layer between seasonally frozen ground above and permafrost below, has formed.

Work is also underway to incorporate a dynamic wetland model that is capable of simulating the anticipated changes in wetland distribution associated with permafrost thaw induced soil subsidence. Additional efforts will focus on an integration of the CLM organic soil representation with the prognostic soil carbon calculated in the CLM carbon cycle model. We also intend to evaluate how a conversion of tundra to woody arctic shrubland will affect the carbon cycle and surface energy budgets, with an emphasis on the relative importance on these budgets.

Within the context of our longer term efforts to understand how and why permafrost degrades so rapidly in CCSM, we are conducting a series of prescribed snow experiments that will isolate how projected changes in snowfall, snow depth, and snow-season length affect the rate of soil temperature change in the model.

We also intend to continue to evaluate the climate response to Arctic sea ice loss, with a particular emphasis on the seasonal atmospheric, oceanic, and terrestrial response. The primary goal of this proposed project is to investigate the mechanisms underlying the seasonal response of the climate system to Arctic sea ice loss within the context of anthropogenic climate change. Additional studies on the marine ecosystem response to a changing sea ice melt season length are also planned.

The mechanisms involved in the relative stability of the Antarctic sea ice are also the subject of ongoing investigation. This includes studies on the influence of changing sea ice buoyancy forcing for ocean conditions and work that investigates the different sea ice behavior and feedbacks in the two hemispheres.

return to top

Megacities Impacts on Regional And Global Environments / Megacity Initiative: Local And Global Research Observatories (MIRAGE/MILAGRO)

MIRAGE is a NCAR Strategic Initiative designed to improve the understanding, numerical modeling, and predictability of the chemical and physical processes that occur when urban plumes are dispersed over larger geographic regions. Future urbanization of the global atmosphere could have wide-ranging consequences for human health and cultivated and natural ecosystems, visibility degradation, weather modification, changes in radiative forcing, and tropospheric oxidation (self-cleaning) capacity.

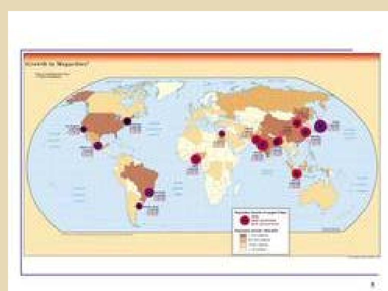


Figure 1. Population growth in megacities, defined as more than 10 million inhabitants, in 1950, 2000, and 2015. Colors within continents represent population growth during 1950-2000.

In the first phase of MIRAGE, NCAR organized and led a large field campaign to examine the atmosphere in and near Mexico City, with coordinated aircraft and ground-based measurements supported by extensive modeling and satellite observations. More than 400 researchers from 8 countries and 50 universities (35 U.S.), government labs, and other institutions participated in the intensive observational period during March 2006. Many others are collaborating in the ongoing analysis, interpretation, and modeling of the results.

ACD scientists plan to continue the analysis, interpretation, and modeling of

High resolution figure

the 2006 Mexico measurements, in collaboration with researchers from academia and government labs. This work is proceeding along three broad lines:

- Characterization of the atmosphere in Mexico City and surroundings, including better quantification of different sources (urban, industrial, biomass burning, long-range transport), prevailing chemical regimes (VOC and NOx limitations), and radiative impacts of various aerosols.
- Model evaluation and improvement, particularly for the state-of-the-art chemistry transport models WRF-Chem (regional) and CAM-Chem (global). The Mexico data base is being used extensively in this activity. Areas of critical uncertainty include the formation of secondary aerosols, budget and partitioning of nitrogen oxides, daytime and nighttime boundary layer processes, plume transport, and interactions with background air. We are also using detailed process models to examine some of the more problematic processes, including the SGMM model for the formation of organic aerosols, and the TUV model for radiative closure at visible and ultraviolet wavelengths.
- Coordination and synthesis of the community-wide effort in data analysis and modeling.

Concurrently, we are planning to extend the MIRAGE initiative to other megacities that are representative of specific environments and economic development. In view of rapid growth in China and India, we are focusing our next efforts on these regions (Figure 1). We have established a collaboration with the Shanghai Meteorological Bureau to implement the WRF-Chem model for their region and to participate with chemical instrumentation in ground-based field campaigns scheduled for September 2009 and (tentatively) May 2010. This will allow us to evaluate and improve models in a very different environment (relatively shallow PBL, humid-polluted, with large regional contributions) with different impacts on oxidant formation, aerosol composition and sizes, radiative budgets, and pollution-cloud interactions. ACD will bring to the field campaigns instruments to measure NOx, O3, VOCs, and spectral actinic fluxes, and will lead an intercomparison with instruments currently used by Chinese scientists, in order to help build capacity and enhance the quality of their long-term data collection. Longer-term plans include an aircraft campaign (likely with extensive ground-based components), carried out in India. This campaign would aim at investigating convectively influenced outflow of polluted air from a mega-city. Aspects of convective outflow are the processing of air masses in clouds, the modification of local convection and weather by the pollution emitted from the mega-city itself, and the convective lifting of the pollution into the upper troposphere with its implications for global transport of pollution and its impact on UT/LS chemistry. This work is funded by NSF/NCAR.

return to top

Biosphere-Atmosphere Exchange of Aerosols with Cloud, Carbon, and Hydrologic cycles including Organics and Nitrogen (BEACHON) program objectives and plans

The Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, H_2O, Organics & Nitrogen (BEACHON) project is a broadly collaborative and interdisciplinary research effort being developed by researchers at NCAR and the university community. BEACHON will improve predictability of earth system behavior over the time scale of months to a decade based on a better understanding of the coupling between water, energy and biogeochemical cycles in a multi-scale modeling framework. This will be accomplished through coordinated modeling, observations and process studies that explicitly address the coupled water, energy and biogeochemical cycles at multiple temporal and spatial scales. The main goal of the BEACHON project is to provide a detailed and quantitative characterization of biosphere-hydrosphere-atmosphere interactions and to use that characterization to improve regional and global models of the earth system. A major focus will be measurement and interpretation of surface fluxes of energy, aerosols, CO_2, water, and organic and nitrogen compounds. Investigations will also address other fundamental processes including atmospheric aerosol production and growth processes, oxidant and cloud processes; landscape heterogeneity impacts on hydrological and biogeochemical cycles; and the response of ecological, hydrological, and physiological processes to ecohydrological disturbances. BEACHON is focusing on water-limited ecosystems but will work with international programs, such as IGBB-iLEAPS (see www.ileaps.org), to compare and contrast over a large range of water availability.

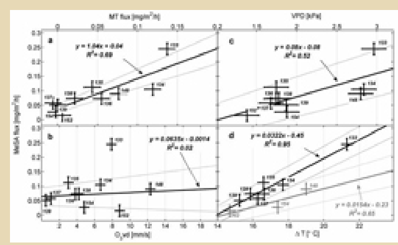


Figure 1: The figure illustrates BEACHON results from the 2007 CHATS study that are described in detail by Karl et al. Biogeosciences 2008. (a) MeSA flux plotted vs MT flux. (b) MeSA flux plotted vs O_3 deposition velocity (vd). (c) MeSA flux plotted vs VPD. (d) MeSA flux plotted versus ΔT before irrigation (black) and after irrigation (gray). Data point labels indicate Julian Day. Fitting equation and r^2 are shown for each x/y weighted fit. Dotted lines represent prediction bounds based on the standard deviation of the fitting parameters.

High resolution figure

ESSL scientists detected the first significant fluxes and concentrations of the signaling compound, methyl salicylate (MeSA), in a real forest atmosphere using micrometerological techniques in combination with highly sensitive mass spectrometry. These observations during the BEACHON CHATS study show that MeSA can make a major contribution to the total biogenic volatile organic compound (VOC) flux from a forest comes as a surprise. This finding may help to explain previous studies indicating that there is a *missing source* of biogenic VOCs. Due to the semivolatile nature of MeSA and similar plant hormones, these findings will influence future directions on biogenic VOC research in atmospheric sciences, for example the impact on secondary organic aerosol formation. The results also provide tangible proof that plant to plant communication occurs on the ecosystem level and connect two separate scientific communities on plant volatile research that have coevolved over the past years: One has historically focused on biogenic VOCs important for atmospheric chemistry (e.g. isoprene, monoterpenes); the second community has targeted the ecology of plant volatiles (e.g. floral scents). We expect this study will transform the research approaches of these separate scientific communities and result in more integrated and multi-disciplinary studies.

An initial BEACHON workshop was organized in FY08 for the purpose of developing a detailed implementation plan and was attended by more than 100 participants including more than 50 atmospheric scientists, ecologists and hydrologists from the university community. The workshop and following discussions defined four major scientific themes for the BEACHON project and identified NCAR and university leaders:

1. Biogenic aerosol, clouds, and water availability
2. Eco-hydrological disturbances: bark beetles and forest fires
3. Moisture and nutrient limitations of eco-hydrological processes
4. Landscape heterogeneity: topography and canopy structure

More than 50 scientists, including representatives of 12 universities, participated in the initial BEACHON study (July-September 2008) at the U.S. Forest Service Rocky Mountain Research Station MEF observatory (see www.tiimes.ucar.edu/beachon/srm/activities.html). Investigations focused on:

- The formation and growth of atmospheric nanoparticles
- Emissions and reactions of BVOCs and other important trace gases and oxidants
- The formation and hygroscopic properties of biogenic SOA and primary particles
- Terrestrial and canopy controls on the emission and deposition of water, nutrients and aerosols
- Characterize transport in canopy and from canopy to cloud
- Modeling of Aerosol-Cloud-Emissions Interactions

BEACHON FY09 objectives include the development of specific scientific and implementation plans for each of the four scientific themes. These efforts will include instrument and model (1D, LES and regional) development and application, long-term observations and intensive campaigns at BEACHON field sites, and process studies in NCAR and university laboratory facilities. FY09 activities will also include analysis of the CHATS and MEF-08 field study data. BEACHON instrument development will include airborne and tower flux measurements systems, Time-of-Flight Chemical Ionization Mass Spectrometry systems (TOF-CIMS), and aerosol measurement systems. Model development will include significant advances in land surface model parameterizations and implementation of improved biogenic emission, aerosol formation and growth, and cloud microphysics in the WRF regional model. Field observations will be used to characterize the processes controlling biosphere-atmosphere exchange and to evaluate model simulations of these processes. Laboratory studies will emphasize observations that will improve quantitative descriptions of atmospheric and ecological drivers (e.g., drought stress, insect infestation, climate driven ecosystem changes, solar radiation, and temperature) of biogeochemical cycling and their impact on atmospheric distributions of trace gases and aerosols.

return to top

Global biogeochemical cycles

As is clearly articulated in the Fourth Assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007), there is increasingly strong motivation to examine terrestrial and oceanic carbon fluxes on regional to continental scales, to understand the coupling of the carbon cycle to the climate system and to other biogeochemical cycles, to understand the processes responsible for present uptake of anthropogenic carbon, to predict future trends in these fluxes under various climate change scenarios, and to assess potential strategies for increasing carbon uptake and storage into the future. The challenges of scaling up from local measurements and scaling down from global constraints are being addressed in TIIMES through the development and application of advanced observational and modeling tools.

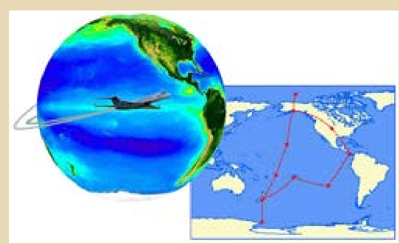


Figure 1: The project HIAPER Pole-to-Pole Observations of Atmospheric Tracers (HIPPO) will conduct five global loops over the next three years, profiling from the tropopause to the surface. Investigators from Harvard, NCAR, Scripps, and NOAA will measure CO_2, O_2, CH_4, CO, N_2O, H_2, SF_6, COS, CFCs, HCFCs, O_3, H_2O, black carbon, and selected hydrocarbons.

High resolution figure

As highlighted by the report of Stephens et al., (2007), there exists less than 100% uncertainty in localizing the terrestrial uptake of anthropogenic carbon to specific latitudinal zones and this uncertainty is directly linked to vertical transport biases in the coarse-resolution atmospheric transport models used in CO_2 inversion studies. Comprehensive measurements of atmospheric CO_2 and related tracers, particularly at altitude and in previously undersampled regions, are needed to challenge these models and improve our understanding of global carbon cycling. This is the aim of the project HIAPER Pole-to-Pole Observations of Atmospheric CO_2 and Related

Tracers (HIPPO), a Harvard-NCAR-Scripps-NOAA collaboration to measure cross sections of atmospheric concentrations approximately pole-to-pole, from the surface to the tropopause, five times during different seasons over the next three-years (see Figure 1).

A comprehensive suite of tracers of the carbon cycle and related species will be measured: CO_2, O_2:N_2 ratio, CH_4, CO, N_2O, $^{13}CO_2$:$^{12}CO_2$, H_2, SF_6, COS, CFCs, HFCs, HCFCs, black carbon, and selected hydrocarbons. HIPPO will transect the mid-Pacific ocean and return over the Eastern Pacific. The program will provide the first comprehensive, global survey of atmospheric trace gases, covering the full troposphere in all seasons and multiple years. HIPPO will quantify the sources of major carbon cycle and greenhouse gases by region at the global scale. Hypotheses to be tested include, as examples:

a. Northern mid-latitude terrestrial ecosystems are a major sink for CO_2

b. The Southern Ocean is a major sink for CO_2 and the driver for global seasonality of the O_2:N_2 ratio

c. Amazonia is a major source region for CH_4, CO, and N_2O

d. Upper tropospheric data can be used to challenge models used to derive inverse analysis of the global carbon cycle

TIIMES scientists are supporting several key systems on these flights, including the NCAR Airborne Oxygen instrument (AO2, see Figure 2) and the MEDUSA flask sampler. These systems flew during the START-08/pre-HIPPO campaign in April-June of 2008. In this campaign, AO2 made the first successful airborne measurements of oxygen variations. This vacuum-ultraviolet absorption instrument is based on an existing NCAR laboratory instrument, but has been designed specifically for airborne use to minimize motion and thermal sensitivity and with a pressure and flow controlled inlet system. AO2 has a precision of +/- 2 per meg on a 4-second measurement which is the equivalent to detecting the removal of one O_2 molecule from 2.5 million molecules of air. Such measurement are very useful in discriminating various influences on atmospheric CO_2 (see Figure 3). The flasks collected during this campaign are being analyzed at Scripps for O_2, Ar, and isotopes of CO_2. Both AO2 and MEDUSA are planned for long-term availability to community researchers.

Figure 2: The NCAR Airborne Oxygen Instrument (AO2) measures O_2 concentration (reported as O_2:N_2 ratio) using a vacuum-ultraviolet absorption technique. It consists of a pump module, a cylinder module, and an instrument module.

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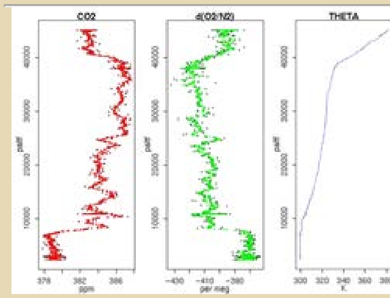


Figure 3: Measurements of atmospheric O_2 and CO_2, made by the AO2 instrument on the NCAR GV during the START-08/pre-HIPPO campaign, while descending from the stratosphere to the surface over Grand Forks, ND in the mid afternoon. Correlated O_2 and CO_2 variations reflect the influence of stratospheric air age across the tropopause, pollution and boundary-layer air plumes in the free troposphere, and photosynthetic CO_2 drawdown and O_2 enhancement in the boundary layer.

High resolution figure

Stephens et al., Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO_2, Science, 316, 22 June 2007.

return to top

Bioemissions and photochemical processing

Chemicals produced by the biosphere include volatile compounds that are emitted into the air where they can have a substantial impact on the chemistry of the atmosphere. These biogenic gases are dominated by volatile organic compounds (VOCs) both in total mass and number of compounds. The important role of biogenic VOCs in controlling global oxidant (e.g., OH and ozone) distributions has been demonstrated using global models while regional air quality models have shown that it is necessary to included biogenic VOC emissions in modeling efforts to develop regional ozone pollution control strategies. ACD and TIIMES scientists are investigating the processes controlling biogenic emissions and their role in tropospheric photochemistry and are developing numerical schemes for including this information in regional and global earth system models.

Observations of OH and other trace gases at rural and remote sites suggest that OH losses are considerably higher than what can be accounted for by the measured OH sinks. This may indicate that atmospheric chemistry models are missing some of the chemical species that are needed to accurately describe photochemical processing. In FY2008, ACD/TIIMES

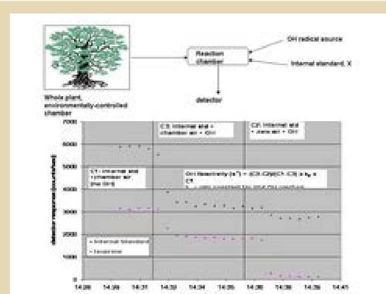


Figure 1 shows that isoprene comprised 85% of the OH reactivity (367 s-1) observed in chamber air surrounding an oak tree. Other reactants including CO, NOx and other VOC make up the balance. This suggests that this particular plant does not emit any OH reactive compounds that cannot be observed scientists collaborated with Prof. Yoshizumi Kajii's research group from Tokyo Metropolitan University to investigate OH lifetime and sinks associated with plants growing in NCAR foothills laboratory growth chamber and at the ESSL BEACHON research site in the Manitou Experimental Forest. Emissions and ambient concentrations of a wide range of compounds were measured to quantify their contributions to OH loss. The initial results suggest that observed compounds in the ambient air can account for some, but not all, of the missing OH sinks. The compounds emitted from enclosed vegetation can, at least in some cases, explain the observed OH reactivity (see Figure 1).

Tropical landscapes are thought to be responsible for about 80% of global biogenic VOC emissions and yet are among the least understood. Global chemistry and transport models often perform poorly when using the biogenic VOC emission rates recommended by current emission models. This could be due to uncertainties in emissions but could also be a result of inaccurate characterization of boundary layer meteorology and/or chemistry. ACD and TIIMES scientists participated in the January-March 2008 AMAZonian aerosol characterization experiment (AMAZE) in central Amazonia along with an international team of scientists that included Scot Martin (Harvard University), Jose Jimenez (U. Colorado) and Tony Prenni (Colorado State University). The NCAR scientists quantified the magnitude and variation of VOC, ozone and NOx fluxes and concentrations during the study and are using these observations to understand the processes controlling aerosol formation and growth in this region. ACD and TIIMES scientists also participated in the Oxidant and Particle Photochemical Processes (OP3, see http://badc.nerc.ac.uk/data/op3/) study in the south-east Asian tropical forests of Borneo. NCAR scientists measured biogenic VOC emissions using enclosures and tower based measurements.

by standard analytical techniques.

High resolution figure

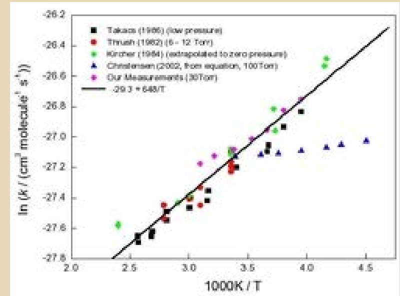


Figure 2. Arrhenius plot for the combination reaction of HO2 radicals. The natural logarithm of the rate coefficient is plotted against reciprocal temperature. Results of 5 studies pertaining to low pressures (P < 150 mbar) are shown.

High resolution figure

FY2009 work will continue laboratory and field investigations of factors affecting biogenic emissions and their impact on oxidants. This work was funded by NSF/NCAR and EPA.

Laboratory Kinetics Studies

ACD scientists have been studying the reaction kinetics and mechanisms of hydroperoxy radicals, HO2, using a number of complementary techniques. HO2 radicals are a member of the HOx family, which is comprised of OH and HO2. Hydroxyl radicals, OH, are responsible for the oxidation of many organic and inorganic pollutants which are emitted into the troposphere. Following a series of reactions, HO2 is usually produced, and then cycled back to OH by its reaction with nitric oxide, NO. However, measurements of radical concentrations in forested areas have shown unexpectedly high levels of OH, suggesting that some recycling of radicals is taking place. Normally this requires the presence of NO, but in clean areas other mechanisms may dominate.

The reactions of HO2 radicals with organic peroxy radicals are being investigated in the laboratory using a combination of techniques (infrared spectrometry, gas chromatography and high performance liquid chromatography). These reactions were initially thought to form solely organic hydroperoxides, reasonably stable compounds that terminate the oxidative chain reactions. However, in a 2004 study in collaboration with Fresno State University [Hasson et al., 2004] it was shown that OH radicals could be produced in substantial yield from the reaction of HO2 with acetyl peroxy radicals.

$$HO_2 + CH_3C(O)O_2 \rightarrow CH_3CO_2 + OH + O_2$$

The potential for recycling of HO2 to OH in these reactions may be able to explain apparently high levels of OH radicals in relatively clean, forested areas. A systematic study of the OH yields from reaction of HO2 with oxygenated peroxy radicals is currently underway.

In the lower stratosphere, OH and HO2 radicals play a large role in controlling the concentration of ozone.

$$OH + O_3 \rightarrow HO_2 + O_2$$
$$HO_2 + O_3 \rightarrow OH + 2O_2$$

These oxidation chains can be terminated via the self reaction of HO2 radicals, which forms hydrogen peroxide as a product.

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$$

The rate coefficient for this particular reaction depends on both the temperature and pressure, and water vapor concentration. Scientists in ACD have measured the variation of the rate coefficient with temperature at low pressure. The HO2 radicals are produced by a pulse of ultraviolet laser radiation, which dissociates chlorine gas; the chlorine atoms then initiate the chemistry which forms the HO2. The radicals are then detected using tunable diode laser spectroscopy. The technique allows the decay of the radicals to be followed in real time over a time span of tens of milliseconds, from which the rate coefficient can be determined.

There have been 4 previous determinations of the temperature dependence of the rate coefficient at low pressure.

Whereas 3 measurements in the 1980s (Thrush and Tyndall, 1982; Kircher and Sander, 1984; Takacs and Howard, 1986) showed a dependence on temperature, a more recent one (Christensen et al, 2002) suggested that the reaction rate is independent of temperature. However, the new measurements indicate an increase in the rate coefficient at low temperature, in agreement with the earlier studies. A stronger temperature dependence to this reaction reduces the concentration of HO2 radicals in the upper troposphere and lower stratosphere, and consequently reduces the amount of ozone depletion due to HOx radicals.

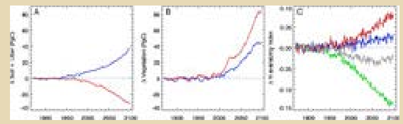
Laboratory studies of reaction kinetics and mechanisms will continue, with a focus on the formation mechanisms of organic nitrates. This work was funded by NSF/NCAR and NASA.

return to top

Ecosystem - biogeochemistry - climate interactions

Overview

As described by Friedlingstein et al. (2006), feedbacks between the climate and the carbon cycle have the potential to modify, perhaps enhance, climate change. In ESSL, we study these feedbacks to help understand projections of future climate. Our primary tool is CCSM, with the addition of parameterizations of terrestrial and marine biogeochemical cycles. The work happens within the context of the Biogeochemistry Working Group, whose overall goal is to improve our understanding of the interactions and feedbacks between the physical climate and biogeochemical systems under past, present and future climates.



Changes (due to multiple factors) in global total land carbon stocks for litter and soil organic matter (A), and vegetation (B), and in global mean nitrogen availability index (C). In all panels change due to climate change and anthropogenic mineral nitrogen deposition are shown in red and blue, respectively. In (C), change due to biogeochemical effects of increasing CO2 is shown in green, and all three effects at once in gray.

High resolution figure

Recent Accomplishments

CCSM scientists continued to develop models of the global carbon cycle, including oceanic and terrestrial ecosystems. Model experiments found that the coupling between the terrestrial carbon and nitrogen cycles significantly alters the carbon cycle-climate feedback. The nitrogen cycle leads to increased carbon storage on land under radiatively-forced climate change, and an overall negative climate-carbon cycle feedback. The primary mechanism responsible for increased land carbon storage is fertilization of plant growth by increased mineralization of nitrogen directly associated with increased decomposition of soil organic matter under a warming climate.

Additional analysis of these experiments has revealed deficiencies in the oceanic uptake of trace gases, including anthropogenic CO2 and CFCs, a class of purely anthropogenic chemicals that are well sampled in the ocean. In order to address this model bias, oceanic mixing parameterizations have been enhanced to include processes that were previously omitted. These efforts have significantly reduced the bias in CFC uptake and will presumably reduce the bias in anthropogenic CO2 uptake as well.mes more computational resource than the 2 degree run. The 0.5 degree version of the new CCSM 4 will be used to make the short-term climate projections for the next IPCC assessment.

2009 and Beyond

Continued development of the terrestrial carbon cycle model, including additional capabilities to simulate dynamic vegetation, anthropogenic land cover change, croplands, wildfire, and biogeochemical cycles is currently underway.

As the model matures, a primary scientific theme to examine will be natural and human-mediated changes in land cover and ecosystem functions and their effects on climate, water resources, and biogeochemistry.

return to top

Numerical simulation of turbulence

Large-Eddy Simulation (LES) has been widely used to examine turbulent processes in the PBL, however most LES applications have been limited to PBLs over horizontally uniform surfaces or idealized strip-like heterogeneous surfaces, which are uncommon in nature. The most logical way to expand our LES study for more complex and realistic PBLs is by nesting an LES code inside a regional mesoscale model. However, nesting a turbulence-resolving model (like LES) inside a turbulence-parameterizing model (like mesoscale or climate models) is difficult because at the nest boundaries the simulated flow fields change abruptly from non-turbulent to turbulent flows, or vice versa. We plan to explore the capability of nesting WRF-LES inside WRF-mesoscale domains.

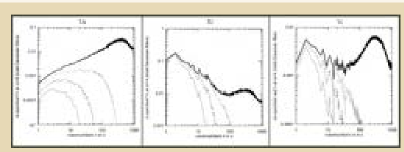


Figure: Spectra of (a) vertical velocity w and (b) total moisture q, and (c) co-spectrum of w and q. The solid curves are from the unfiltered field of the LES and other curves are from the filtered fields using three Gaussian filter widths.

High resolution figure

Another complex and important PBL regime is the one under cumulonimbi. We know precipitation can generate cold pools in the PBL due to evaporation, but how these cold pools affect turbulent transport in the PBL and how the change in the PBL affects the life cycle of deep convection remain uncertain. As part of the research funded by the new NSF Science and Technology Center for Multiscale Modeling for Atmospheric Processes (CMMAP), which is based at Colorado State University and led by Dave Randall, we began exploring the interaction between deep convection and the PBL. A benchmark LES of a tropical deep convection system (over a domain of about 205 km x 205 km x 27 km with a grid mesh of 100 m x 100 m in the horizontal and 50-150 m in the vertical) was performed by a CMMAP colleague (Marat Khairoutdinov at the Stony Brook University) in which deep and shallow convection, as well as energy-containing turbulent eddies are all resolved. A spectral analysis (Fig. 1) of the benchmark flow in the PBL shows that the vertical-velocity w variance peaks at the energy-containing turbulence scale (which is about 500 m, the average PBL depth), the moisture q variance peaks at the cloud-system cold-pool scale (on the order of 50 km), and the co-spectrum of w and q peaks at both scales. A systematic application of a low-pass filter separates the flow field into cloud-system scales and turbulence scales, and shows that about half of the moisture flux in the PBL is carried by turbulent motions smaller than 1-2 km and the other half by cloud-scale motions. The goal of this work is to find a way to represent the effects of turbulence inside a cloud-system-resolving model that has a grid mesh on the order of 1-2 km.

return to top

Exploring the role of aerosols

The effects of aerosols on climate represent the single largest source of uncertainty in our understanding of global warming. In order to reduce the uncertainty of the role of aerosols in climate and weather, ESSL scientists are conducting both experimental and modeling studies of aerosol formation, composition, and direct as well as indirect radiative forcing.

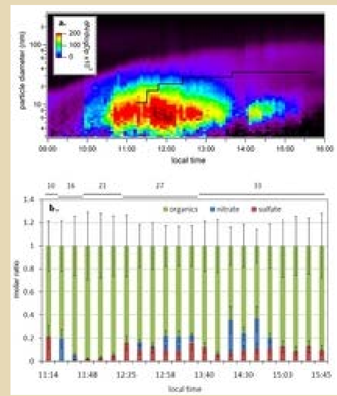


Figure 1. (a) Contour plot of the particle size distributions on 16 March 2006 in Tecamac, Mexico, during the MILAGRO campaign, showing a new particle formation event that started just before 10am local time. Also plotted in black is the particle diameter used for TDCIMS chemical composition measurements. (b) TDCIMS measurements of the ion molar ratio of sulfate, nitrate, and organics. Numbers at the top of the plot are the mass mean diameter of the analyzed aerosol.

High resolution figure

During 2008, ACD scientists collaborated with Peter McMurry (U. Minn.) to investigate the formation and growth of nanometer-sized particles in the atmosphere. These minute particles form from nucleation of low-volatility vapors, and grow by condensation by processes that are, as yet, not well understood. It's essential that we understand the processes by which particles form and grow in the atmosphere because nucleation is main global source of particle number, and subsequent condensational growth makes these particles important to the earth system by allowing them to be cloud condensation nuclei (CCN). Measurements performed at the ground site in Tecamac, Mexico, during the 2007 MILAGRO campaign suggest that current models that do not account for growth due to organic species most likely underpredict the growth of particles formed by nucleation, and thus underpredict the impact of new particle formation on climate. Figure 1 elucidates this point. The plot in Figure 1a shows a vigorous new particle formation event that occurred on March 16, 2007. The black trace on the plot shows the diameter analyzed using NCAR's Thermal Desorption Chemical Ionization Mass Spectrometer (TDCIMS), which can measure the chemical composition of size-selected particles as small as 8 nm. Figure 1b shows the results of TDCIMS measurements during the event with species broadly classified as sulfate, nitrate, and organics. The result is that about 84% of the detected ions are organic, comprising of organic acids, hydrocarbon-like species, and nitrogen-containing organic compounds. Particulate sulfate which arises from the condensation of sulfuric acid vapor constituted only 10% of the detected ions, and nitrate comprised 6%. Results such as those in Figure 1b suggest a prominent role of organic species in particle formation processes: unraveling the mechanism by which these organics create highly nonvolatile species through gas and particle phase chemistry is a major research goal in 2009.

During March - April 2008, ACD scientists led a field study to evaluate the chemical composition of the atmospheric aerosol, investigate primary biological particles in the atmosphere, and to explore relationships between the aerosols and clouds at a high altitude site. The Storm Peak Aerosol and Cloud Characterization Study (SPACCS) was funded in part by a unique two-year program, organized by scientists in ACD, to foster US/Nordic collaboration among early career scientists in the field of biogenic secondary organic aerosol.

Funded by: NSF, NOAA, USEPA, DOE, U. Nevada/DRI.

return to top

Convection organization: Observational analysis and resolved simulations

The propensity for deep, moist convection to organize and project onto larger spatial and temporal scales requires numerical simulations spanning convection-resolving scales to continental scales. Furthermore, simulation studies must be closely constrained by observational analysis of the organizing properties of convection. Prediction of tropical and warm-season higher-latitude convection, and the response of the synoptic-scale and planetary-scale flow is vital for increasing our ability to anticipate

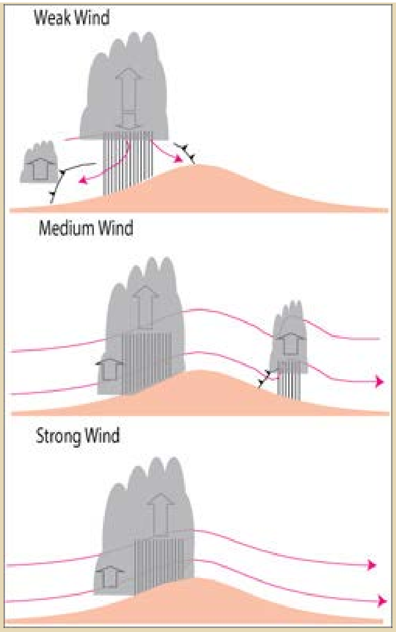


Figure: Schematic diagram of the along-ridge-average convective flow as a function of ambient wind speed. For weak wind, the solution is dominated by cold pools and there is no orgraphic rain in the steady-state solution; for moderate-to-strong wind, convective showers persist on the upwind side of the ridge with little net cold-air production since potentially cold rainy downdrafts must compete with advection of potentially warm environmental air. In the moderate-wind case, convective showers persist downwind on the "hydraulic-jump" feature know from past solutions of the dry orographic flow problem.

High resolution figure

significant weather events more than a day in advance. It is also vital for credible representations by models of regional climate.

Last year, simulations of convection episodes in E. Asia and the U.S. continued and simulations over Africa commenced. Initial results suggest that the Advance Research WRF was able to simulate the proper modes of African convection, though the latitude of maximum convective activity was biased southward during a 12-day simulation. Simulations of convection over North America, forced by only the mean diurnal cycle on the boundaries, showed a reasonable representation of a corridor of propagating convection with essentially no mesoscale perturbations in the initial state. An improved double-moment microphysics algorithm was tested in ARW and showed improved simulations of the trailing stratiform region of MCSs.

The Taiwan Island Mesoscale Rainfall Experiment (TIMREX) was conducted and obtained data on several cases of heavy coastal rainfall in Taiwan. Theoretical research on orographic rainfall showed a strong dependence of rainfall location on the impinging flow speed (FIG XX), but not on the nondimensional mountain height. Simulations of maritime convection in an idealized context showed the organized convection occurs over the gradient in sea-surface temperature, not where the temperature is greatest.

In the coming year, simulations of TIMREX cases will occur, focusing on mechanisms determining whether rainfall occurs on the coastal plain or over higher terrain. Analysis of TIMREX dropsonde and rawinsonde data will be performed to verify numerical simulations and enhance the thermodynamic interpretation of heavy rainfall cases. TIMREX work will also integrate the recent theoretical work on orographic rainfall. Simulations of convection episodes over North America and Africa will continue, emphasizing the diurnal cycle in the ARW model.

return to top

Atmosphere / ocean interactions

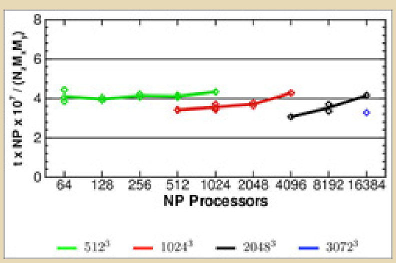


Figure: Scaling of parallel pseudospectral computational time per gridpoint for different combinations of problem size and 2-D domain decomposition for the Cray XT4. a) green lines and symbols problem size 5123; b) red lines and symbols 10243; c) black lines and symbols 20483; and d) blue symbol 30723. For a given number of total processors NP the symbols are varying vertical and horizontal decompositions, i.e., different combinations of processors in the x and y directions. Perfect scaling is represented by a level line across processors.

High resolution figure

Air-sea interaction occurs over a wide spectrum of scales ranging from millimeters (spray droplets and air bubbles) to hundreds of kilometers (synoptic-scale storms) and even larger (global climate). A goal of marine surface-layer research is to identify and quantify coupling mechanisms that connect the atmospheric and oceanic boundary layers (the ABL and OBL) and surface waves. Some of the specific problems of interest in the ABL include the effects of wave age, swell, surface roughness, and wind-wave misalignment. In the OBL, waves may induce mean currents and turbulence. Wave influences on the OBL are of particular importance under high-wind conditions. Turbulence-resolving simulations, and in particular large-eddy simulation (LES), with its ability to perform systematic process studies, play an important role in air-sea interaction research. LES has provided new insights into the couplings between imposed ocean waves and turbulence.

In the past year, MMM air-sea interaction research was directed towards developing LES models of the marine atmospheric and oceanic boundary layers applicable to high-wind regimes. For the atmospheric boundary layer MMM scientists began building an LES model to simulate turbulent flow over a general time-dependent moving wavy surface, i.e., over a spectrum of imposed surface waves. This algorithm is a generalization of the scheme used previously to simulate turbulent flow over 2-D waves. The wave field imposed at the lower boundary of the computational domain is constructed from a general set of plane waves; the wave heights can be chosen to match empirical spectra, e.g., the equilibrium Pierson-Moskowitz wave height spectrum, or can be smoothed wave-height measurements. The future turbulence simulations will be computationally intense as they require fine-mesh resolution and small time steps to resolve both small and large-scale surface waves. The basis of the wavy surface LES is a recently developed massively parallel algorithm. This parallel code, which utilizes a 2-D domain decomposition based on the Message Passing Interface, has been exercised on different machine architectures and can use as many as 16,384 processors (see Figure AA). The long term goal of the research is to utilize LES with resolved surface waves to help in the interpretation of observations collected in the High-Resolution Air-Sea Interaction (HRES) field campaign. Of particular interest is the pressure distribution over a spectrum of waves and the identification of the scales that support momentum transfer from the atmosphere to the ocean as a function of wind speed and wave age. HRES is sponsored by the Office of Naval Research and is tentatively planned for Spring 2010 off the California coast.

return to top

Long-term climate change in the thermosphere

Anthropogenic changes in "greenhouse gases" can increase temperature in the lower atmosphere due to their ability to absorb infrared radiation, but also affect the upper atmosphere through radiational cooling. Since the prediction by Roble and Dickinson [1989] that a consequence of increasing CO_2 levels would be to decrease the temperature of the upper atmosphere, NCAR researchers have been studying this effect and its consequences for the neutral density of the near-Earth space environment.

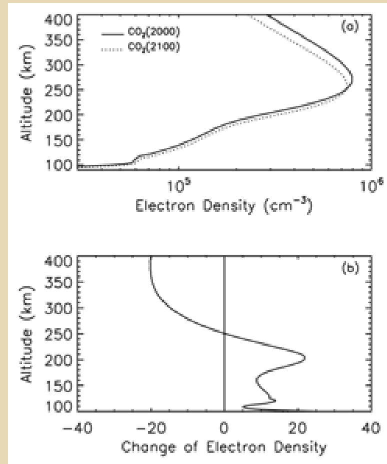


Figure 1: (a) Electron number density profiles for the base case and the doubled CO_2 case, under solar medium conditions ($F_{10.7} = \overline{F}_{10.7} = 150$). Solid line: base case; dotted line: doubled CO_2 case; (b) Percentage change of electron number density from the base case to the doubled CO_2 case, under solar medium conditions ($F_{10.7} = \overline{F}_{10.7} = 150$).

Qian, L., S. C. Solomon, R. G. Roble, and T. J. Kane (2008), Model simulations of global change in the ionosphere, *Geophys. Res. Lett.*, **35**, L07811, doi:10.1029/2007GL033156.

High resolution figure

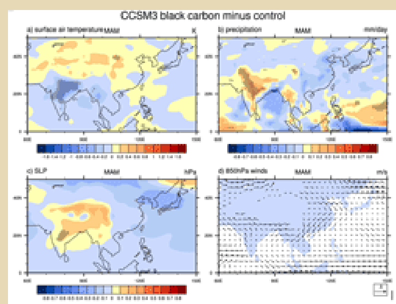
The thermosphere goes through natural, cyclical changes in density driven by the Sun's 11-year activity cycle, heating and expanding at solar maximum, cooling and contracting at solar minimum. Detection of the smaller and more gradual changes occurring due to increasing anthropogenic emissions in this context is therefore difficult, but during the last several years, three different groups have been able to measure thermospheric density changes by observing the effect of atmospheric drag on satellite orbits. These studies agreed that thermospheric density is systematically decreasing by several percent per decade near 400 km altitude, in general agreement with simulations conducted at the NCAR High Altitude Observatory using an extended and updated version of the Roble and Dickinson model. The modeled secular change under solar minimum and solar maximum conditions is variable, with larger trends at solar minimum and smaller change during solar maximum, and there is now observational support for these systematic differences.

A key question for thermosphere/ionosphere physics is how these changes in the thermosphere affect ionospheric densities and dynamics. Observations of secular trends in the E and F1 regions of the ionosphere indicate that electron densities have increased, and that the height of the E-region peak has decreased, during the past several decades. Detection of trends in the upper ionosphere through analysis of F2-layer parameters has been more complex and controversial. In order to facilitate observational detection of long-term trends in the ionosphere, simulations were performed by Qian et al. [2008] using CO_2 concentrations for the year 2000 and projected for the year 2100. Results show that increased CO_2 concentration increases electron density in the lower regions of the ionosphere, but decreases electron density in the upper ionosphere. The transition altitude occurs slightly below the F_2 peak altitude. The proximity of this peak to the transition altitude may explain why different analyses of long-term trends in F_2 peak density have shown both positive and negative trends.

return to top

The impacts of climate and weather on society and ecosystems: Climate change - probabilistic climate change, and solar forcing of climate

Overview



NCAR was one of the first centers to study anthropogenic climate change with global coupled climate models starting in the late-1970s. Consequently, the earliest climate change experiments done at that time were pioneer projects at a national and international level. Few groups were doing climate change modeling as it was considered to be a sidelight to other more highly regarded modeling problems. NCAR climate change modeling (funded by DOE and NSF) was prominent in the DOE State-of-the-Art climate change assessments in the late 1980s, and in the first IPCC assessment in 1990 and the 1992 IPCC update since only four groups in the world (including NCAR) had functioning global coupled climate models that were being used for climate change projections.

Since then, climate change modeling has become a very prominent activity at NCAR, most recently through the Community Climate System Model effort, and is now a headline activity for ESSL. As climate change modeling evolves to include more complexity, we are moving toward an earth system model-type activity. This crosses division boundaries in ESSL and requires close cooperation with the other science divisions since such earth system models will include not only the basic atmosphere-ocean-land surface-sea ice global coupled model, but also components of chemistry, aerosols, dynamic vegetation and carbon cycle.

Figure 1. Effects of BC aerosols during the pre-monsoon season of MAM on a) surface air temperature (°C), b) precipitation (mm day^{-1}), c) sea level pressure (SLP, hPa), and d) 850 hPa winds (scaling vector of 0.5 m sec^{-1} at lower right). Stippling indicates areas where the ensemble mean signal divided by the inter-ensemble standard deviation exceeds 1.0.

High resolution figure

Recent Accomplishments

CGD scientists and collaborators have been involved with research that has directly influenced and characterized national and international assessment activities. For example, there has been a growing awareness that anthropogenic black carbon aerosols, with their properties of both absorbing and reflecting solar radiation, may be contributing to significant climate change in the Indian monsoon region of south Asia. To address this problem, a six member ensemble of 20th century simulations with changes to only time-evolving global distributions of black carbon aerosols in a global coupled climate model was analyzed to study the effects of black carbon (BC) aerosols on the Indian monsoon. The BC aerosols act to increase lower tropospheric heating over south Asia and reduce the amount of solar radiation reaching the surface during the dry season. The increased meridional tropospheric temperature gradient in the pre-monsoon months of March-April-May, particularly between the elevated heat source of the Tibetan Plateau and areas to the south, contributes to enhanced precipitation over India in those months (Fig. 1). With the onset of the monsoon, the reduced surface temperatures in the Bay of Bengal, Arabian Sea, and over India that extend to the Himalayas act to reduce monsoon rainfall over India itself, with some small increases over the Tibetan Plateau (Fig. 2). During the summer monsoon season, the model experiments showed that BC aerosols have likely contributed to observed decreasing precipitation trends over parts of India, Bangladesh, Burma, and Thailand.

2009 and Beyond

Future research priorities in climate change modeling include further studies of extremes, studying decadal variability including understanding the relative contributions of inherent decadal variability and forced response in 20th century climate change, and mitigation scenario simulations of future climate change.

return to top

Land atmosphere coupling

Over the last forty years, atmospheric research has shown that land-atmosphere coupling is of critical importance for weather and climate prediction. Due to its diverse nature, a tall canopy's influence on turbulent exchange is extremely complex, e.g., because of their spatial distribution, seasonal variability, flexibility, porosity, etc. Within the layer of the atmosphere directly influenced by the canopy, turbulence varies dramatically depending on the detailed structure of the roughness elements and cannot be described by traditional similarity relationships. Where vegetation covers the surface, it becomes the important momentum sink and a key player in distributing sources and sinks of moisture, heat and trace atmospheric constituents. Parameterization of turbulent transport in and above tall canopies remains somewhat elusive but is essential for accurate weather and climate prediction. Large-eddy simulation (LES) is an important tool for studying the coupling between microscale and mesoscale motions. LES can also incorporate the influence of vegetation on momentum, energy, and scalars. Because observing three-dimensional and time-dependent fields of all quantities of interest is difficult, LES has become a direct link between currently observable quantities and larger-scale models which are forced to parameterize all of the turbulence.
LES needs to be validated and improved to deal with complex flows, especially for surface layers where dependence on the subfilter-scale (SFS) model increases. To address this issue, NCAR, in collaboration with several university groups, carried out three pioneering observational studies to improve subfilter-scale parameterizations over flat terrain with short sparse vegetation (Horizontal Array Turbulence Study, HATS, over the ocean (Ocean HATS; OHATS), and within and just above a tree canopy (Canopy HATS, http://www.eol.ucar.edu/rtf/projects/CHATS/isff/). These studies provide an observational basis for testing and improving closure approximations used in LES and they have substantially increased our confidence in parameterizations developed using LES as their basis.

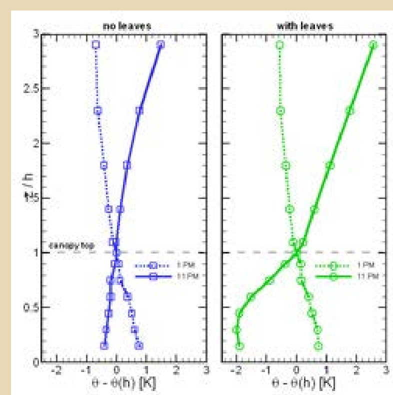


Figure: Spectra of vertical velocity multiplied by wavenumber and normalized by the convective velocity for 5, 6, and 12 August 1996 (top to bottom) versus wavenumber normalized by the CBL depth zi. Levels vary from ~0.25zi (dark blue) to ~0.75zi (yellow) every 30 m. Heavy smooth lines are von Kármán model spectra fitted to the lowest (dark blue) and highest (yellow) observed levels. The upturn at the right end of the spectra on 1 and 6 August is due to measurement noise. The dashed lines on 6 August are Kaimal model spectrum, which gives a more gradual transition between the low- and high-wavenumber spectral regions, fitted to the same levels. Although there is considerable day-to-day variability,

At this point, the character of within-canopy SFS motions is not known, nor the role that the eddies shed in the lee of the plant elements play, nor how these wake-scale motions affect scalar and momentum transport. CHATS has provided detailed measurements of SFS variables in a complex environment linking the biosphere, geosphere, and the atmosphere that will allow study of the fundamental interaction between vegetation and atmospheric turbulence, and validation of currently utilized SFS models and improvement of parameterizations representing this critical regime.

generally, the von Kármán spectra better fit the data, which tend to have an even sharper transition between low and high wavenumbers than the von Kármán spectra; the 6 August case is an exception.

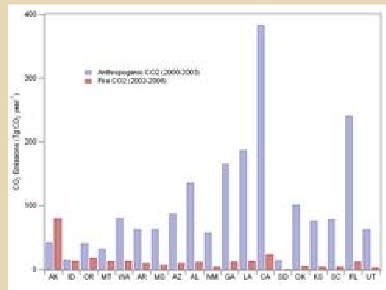
High resolution figure

Analysis currently underway includes: studying the impact of vegetation on sub-filter scale momentum/scalar fluxes and dissipation as a function of stability; establishing whether pressure correlates with canopy-scale coherent structures and evaluating the pressure destruction term in the scalar-flux equation; investigating heat storage within the canopy and the time-evolution and vertical variation of within-canopy stability; estimating horizontal length scales at the canopy-top using both helicopter and sonic-anemometer array data; studying canopy and stability influences on turbulent diffusion; and investigating sub-canopy processing and transport of biogenic reactive species (relate leaf-level to above-canopy fluxes); and exploring fine-scale turbulent coherent structures above the canopy using the Raman Eye-safe Aerosol Lidar (REAL) that was deployed in CHATS to delineate boundary-layer structure and motion. These studies will continue into the following year and beyond.

return to top

Emission inventories and application

Trace gas and aerosol emissions into the atmosphere are the major drivers of the chemical composition of the atmosphere. There is widespread concern about the effect of human activities on these emissions and their impact on atmospheric chemical composition. Changes in human activities are the underlying cause of the current increase in pollutant levels on regional and global scales. In some cases, changes in trace gas emissions are due to obvious pollutant sources including many technological sources. Other sources, including biomass burning and biogenic sources, have a natural component but are strongly influenced by humans. In order to understand these increases and to predict future changes, ACD/TIIMES scientists are quantifying emissions from various sources and improving our understanding of the natural and human influenced processes that control emissions.



This figure shows estimates of monthly, state-level total CO2 emissions and the contribution from fires (Wiedinmyer and Neff 2008).

High resolution figure

ACD/TIIMES scientists have completed a new version of the Model of Emissions of Gases and Aerosols from Nature (MEGAN), which is a modeling system for estimating the net emission of gases and aerosols from terrestrial ecosystems into the atmosphere. It is driven by landcover, weather, and atmospheric chemical composition. MEGAN is a global model with a base resolution of ~ 1 km. A stand-alone version of MEGAN is now available on the NCAR community data portal during the past year and has already been downloaded by > 100 users from more than 20 countries. MEGAN has also been incorporated as an on-line component of several regional and global models including MOZART, CCSM-CLM, GEOS-CHEM and WRF-CHEM. Continued development of MEGAN has resulted in a version that includes a detailed canopy environment model that will enable more realistic estimates of the response to landcover and climate change. MEGAN regional and global estimates of isoprene emissions are being evaluated by comparisons with satellite observations of HCHO which is a product of isoprene oxidation.

ACD/TIIMES scientists have also continued to improve a North American wildfire emission model and have used the model to forecast fire emission estimates for the NCAR MIRAGE field campaign. The model estimates daily emissions from fires for all of North America at a 1km resolution. More recently, emissions of mercury were included in the fire emissions model, and the first, state- and monthly resolved mercury emission estimates from fires have been produced. ACD/TIIMES scientists teamed with Jason Neff (U. Colorado) to quantify monthly, state-level CO2 emissions from fires and discuss the potential policy implications of these emissions (see figure).

FY2009 work will include continued improvements of MEGAN and the fire emissions model and enhanced support for the communities using these models. In addition, efforts will be focused on evaluating the model results and quantifying model uncertainties. The emission models will be used in regional chemical transport modeling studies to investigate the radiative impact of aerosols from fires and biogenic sources, interactions between direct particulate fire emissions and secondary organic aerosol formation, and mercury deposition. This work is funded by NSF/NCAR and EPA.

return to top

The impacts of climate and weather on society and ecosystems: Water cycle

Overview

As part of the Water Cycle Program, which involves scientists across ESSL and other national lab and university colleagues, various aspects of the water cycle have been examined in both in observations and climate models. The focus is on precipitation, atmospheric water vapor, and land

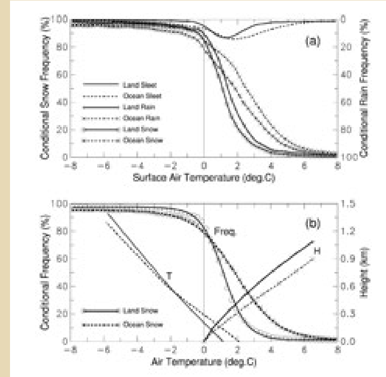


Figure 1. (a) Observed temperature-dependence of the conditional snow, rain, and sleet frequency (read on the right ordinate) during all seasons from 1977-2007 over global land (solid line) and ocean (dashed line). (b) The snow frequency over land (circles) and ocean (stars) from (a) overlaid by the fitted frequency (lines) using Eq.(1). Also shown in (b) is the mean temperature profiles (denoted by "T", right ordinate, which is the height above the surface) derived from the 6-hourly ERA-40 reanalysis [Uppala et al., 2005] from 1980-1989 by averaging over the land (solid line, slope=-5.1°C km^{-1} for the lowest 1km) and ocean (dashed line, slope=-6.6°C km^{-1}) areas where surface air temperature (T_s) is within the snow-rain transition range (-2°C to 4°C for land and -3°C to +6°C for ocean). The mean height of the freezing level as a function of T_s is also shown (denoted by "H", solid line=land, dashed=ocean). (Dai, A., 2008: Temperature and pressure dependence of the rain-snow phase transition over land and ocean. Geophys. Res. Lett., 35, L12802, doi: 10.1029/2008GL033295.)

High resolution figure

surface water fluxes, with the goal to improve our understanding and thus modeling and prediction of atmospheric moist convection, precipitation processes, and land surface hydrology on a broad range of time scales. The diurnal cycle of warm-season precipitation over the U.S. and other parts of the world has been employed as a means to systematically examine precipitation characteristics (onset, diurnal timing, frequency, intensity, duration, amount, type, etc.) in data and models, thus allowing a diagnosis of deficiencies in weather and climate models.

The Water Cycle Program also interacts with other ESSL programs such as the Biogeoscience Program - as well as leverages other NSF, NASA, and NOAA-funded studies related to the water cycle. dData sets and model evaluation work produced under this project are helpful for improving the Community Climate System Model (CCSM) and other climate models.

Recent Accomplishments

Recent Water Cycle accomplishments include 1) quantifying the temperature and pressure dependence of the snow-rain phase transition (Figure); 2) determining water and energy budgets in hurricanes; 3) analysis of the hydrological effect of Mt. Pinatubo's volcanic eruption and its resultant implications for geo-engineering solutions to global warming; 4) creation of an updated, global data- set of continuous, monthly river outflow for community use in quantifying decadal and long-term changes in continental freshwater discharge; and 5) analyses of satellite-observed and model-simulated precipitation and other hydrologic fields. These studies have resulted in a number of refereed publications.

For example, the phase of precipitation is important for weather forecasts, land hydrology and remote sensing. To quantify the temperature and pressure dependence of snow frequency (F, in %) when precipitation occurs, we have analyzed 3-hourly weather reports of surface air temperature (T_S, °C) and pressure (P_S), and snow and rain occurrences from over 15,000 land stations and available ship observations from 1977 - 2007. It is found that the phase transition occurs over a fairly wide range of temperature from about -2°C to +4°C over (low-elevation) land and -3°C to +6°C over ocean. The F-T_S relationship can be represented by a hyperbolic tangent: $F(T_S) = a [\tanh (b (T_S - c)) - d]$, with the slope parameter b close to 0.7 over land and 0.4 over ocean. The pressure-dependence is only secondary and reflected in the parameters. Results show that snow occurs often (F > 50%) for T_S = 1.2°C over land and T_S = 1.9°C over ocean, and are non-negligible (F > 5%) for T_S = 3.8°C over land and T_S = 5.5°C over ocean. This "warm bias" results from the falling of snowflakes into warmer surface layers, which is especially true over ocean. The warm bias is higher when air pressure is below ~750 hPa because snow falls faster in thin air.

Other major findings from recent ESSL work include: a) changes related to human influences on climate since 1970 have increased sea-surface temperatures (SSTs) and water vapor, and this may have altered hurricanes and increased associated storm rainfalls, quantified to be 6-8% higher than the baseline b) major unintended adverse effects, such as reduced water resources and increased drought, may occur from proposed geo-engineering solutions to mitigate global warming through emulating volcanic eruptions by injecting large amounts of aerosols into the Stratosphere; c) continental freshwater discharge into global oceans shows a slight decrease from 1949-2004, in contrast to the notion that continental discharge has increased as the global hydrological cycle intensifies under global warming; and d). large increases in the discharge into the Arctic Ocean during 1949-2004 are not accompanied by increases in precipitation; instead, increased runoff resulting from melting of soil ice in Eurasia may be a significant contributor.

2009 and Beyond

Future plans call for further work to quantify characteristics of precipitation frequency and intensity using high-resolution satellite observations, to improve simulations of these two quantities in CAM by modifying the cumulus parameterizations, and to analyze more comprehensively ofthe potential impacts of global warming on atmospheric water vapor and snowpack over the Colorado headwater regions.

return to top

Parameterization

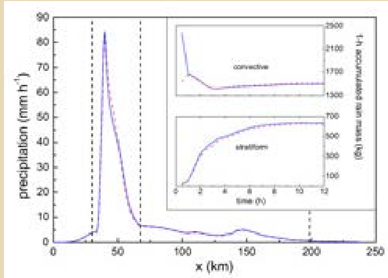


Figure: Spatial distribution of the steady-state surface precipitation for PRISTINE (red dashed lines) and POLLUTED (solid blue lines) simulations. Convective and stratiform region boundaries are shown as dashed vertical lines. Inserted figure shows time evolution of the area-integrated surface precipitation separated into convective and stratiform regions.

High resolution figure

Representation of cloud microphysical processes in models of various complexity (from small-scale to global) is a challenging aspect of numerical weather prediction and climate modeling. This is mostly because of the disparity between scales at which cloud microphysical processes operate (i.e., millimeters and centimeters) and scales resolved by models and observations. With the advent of convection-permitting numerical weather prediction using the Weather Research and Forecasting (WRF) model and application of the superparameterization approach to climate modeling representation of cloud microphysics emerges as the next "key problem", similarly to the "convection parameterization problem" in the past. The superparameterization approach to climate modeling is the focus of the NSF's Science and Technology Center for Multiscale Modeling of Atmospheric Processes (CMMAP) at Colorado State University. Several NCAR scientists are members of the CMMAP team and are actively involved in the CMMAP research.

MMM scientists have developed a new comprehensive double-moment bulk-microphysics scheme to represent warm-rain and ice processes. These schemes are designed to include information about the atmospheric aerosols that affect cloud formation, the cloud condensation nuclei (CCN) and ice-forming nuclei (IN). Much of the research to improve cloud microphysical schemes is driven by suggested effects of CCN and IN on weather and climate. These are referred to as the indirect aerosol effects. Their uncertain role in climate and climate change was highlighted by the 2007 report of the Intergovernmental Panel on Climate Change. The warm-rain scheme is currently being applied in simulations of shallow convective cloud fields based on observations in BOMEX and RICO. The goal is to investigate indirect aerosol effects in shallow tropical convection. The warm-rain and ice scheme was applied in a study concerning effects of aerosols on precipitation from deep organized convection. In general, aerosol effects on deep convection are difficult to assess because of complex interactions between cloud microphysics and cloud dynamics. As a first step, a 2D kinematic (prescribed-flow) model mimicking a mature squall line was combined with the double-moment microphysics scheme and applied in a large set of sensitivity simulations. For each set of model parameters (such as environmental sounding, convective/mesoscale updraft strength, collision efficiencies, etc), a pair of simulations was performed featuring CCN characteristics of either pristine or polluted environment. In general, results in each pair differ insignificantly (see the figure). These results imply that CCN can affect precipitation from deep organized convection only through the microphysics-dynamics feedback (i.e., affecting the flow pattern), which can only be investigated in the dynamic cloud model.

Work is in progress to include the new scheme in WRF model and to apply it to several observationally based test cases.

return to top

Role of the oceans in climate

Overview

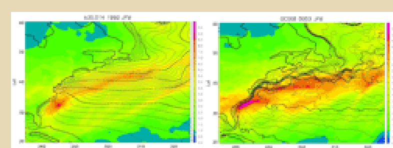


Figure 1. Winter season mean sea surface temperature (contours) and precipitation rate (colors) over the Northwest Atlantic in two CCSM coupled simulations. In the simulation depicted on the left, the 0.5° resolution CAM atmospheric model is coupled to the 1° resolution POP ocean model. In the simulation depicted on the right, the same 0.5° resolution CAM atmospheric model is coupled to the very high resolution 0.1° POP ocean model. As strong SST gradients in the Gulf Stream become realistically represented in the high resolution ocean model, the convergence of the low level atmospheric winds becomes stronger in a band parallel to the SST front, resulting in higher precipitation rates. This association of wind convergence and mesoscale SST gradients has only recently been observed in nature with the availability of high resolution scatterometer based wind products.

Covering 71% of the Earth, the oceans absorb the majority of the solar energy reaching the surface. The heat capacity of the upper three meters of the oceans exceeds that of the entire atmosphere, and the oceans contain approximately 50 times greater inventory of CO_2 than the atmosphere. The phase change from liquid to vapor by evaporation at the sea surface is the dominant source of moisture to the atmosphere, and the phase change from liquid to solid in the formation of sea ice has a strong effect on the reflectivity of the Earth's surface. Ocean currents, accomplish roughly equivalent energy transport from the tropics to polar latitudes as the atmosphere, and the meridional transports of sea water and sea ice close the global water cycle.. Ocean currents and turbulent mixing also transport nutrients from the deep ocean to the sunlit upper layers to support marine ecosystems. Through this capacity for storing and transporting energy, water, and radiatively and biologically active chemical species, the oceans act to moderate, modulate, and initiate climate variability and climate change. Instances of abrupt climate change observed in the paleo-climate record and in simulations of future climates with increasing greenhose gases arise from the interactions of sea ice, the hydrologic cycle and the ocean thermohaline circulation. A comprehensive understanding of, and the ability to predict, the behavior of the climate system must therefore be based on an understanding of the physical, chemical, and biological processes operating in the oceans and their interaction with other components of the Earth system.

Through research to develop an understanding of ocean processes, and using this understanding in improving their representation in ocean models,

High resolution figure

ESSL ocean scientists support a broad spectrum of ESSL scientific objectives. These include: prediction of the Earth's energy, water and biogeochemical cycles, and understanding natural and human influenced climate variability, including high impact variations such as sea level rise. In turn, the ESSL objective of understanding two-way scale interactions within the Earth system is central to improving our understanding of how thermodynamic processes such as sea-ice formation and ocean circulation features such as coastal upwelling zones, western boundary currents, and meso-scale eddies are affected by and affect the basin- to global-scale ocean circulation and the large-scale climate system.

Significant increases in computational resources together with improved physics and greater confidence in CCSM climate models at both modest and high resolution have allowed ocean model developments to be evaluated in fully coupled models for their effects on the climate system as a whole. In a number of cases, these coupled model results have been much more profound and widespread than anticipated from consideration of effects on the ocean in isolation. The key factor is for the ocean model changes to produce small, but persistent, changes in near surface ocean temperatures or sea-ice coverage, then for the coupled model to react to these signals in such a way as to amplify the changes.

Recent Accomplishments

A concerted effort was made move the parameterization of diapycnal mixing (the small scale three dimensional turbulence across surfaces of neutral density) from ad hoc prescriptions to a more physically based foundation. A wide range of processes not explicitly represented in the ocean general circulation model need to be considered as potential sources of energy for this turbulence. New parameterizations of the deep ocean mixing from breaking internal tides and tidal mixing in shallow seas have been guided by offline calculations with tide models, theoretical developments, and observations. Incorporation of tidal mixing in the shallow seas of the Indonesian Throughflow region was found to improve the simulation of SST in that region with a large consequent impact on precipitation in this important region for generating atmospheric variability. Microstructure measurements of ocean turbulence and theory have revealed a systematic latitudinal dependence of the interior diapycnal mixing resulting from breaking internal waves, with a maximum in subtropical latitudes, decreasing towards both the equator and polar regions. Incorporating the theoretically predicted latitudinal dependence in CCSM3.5 shows that the changes in the mean ocean state project onto longstanding precipitation biases. Gravity currents entrain and mix with overlying waters in their descent of the continental slope from deep water formation regions in marginal seas to the abyssal ocean. A parameterization of this process previously developed specifically for the outflow from the Mediterranean Sea was generalized and applied to the key deep water passages connecting the North Atlantic with the Greenland-Iceland-Norwegian Seas. A new parameterization of mixing by sub-mesoscale eddies, a process connecting the largely isopycnal mixing by mesoscale eddies, with the diapycnal cross-frontal mixing in the surface boundary layer was incorporated and shown to improve the representation of ocean ventilation processes. The ability to investigate the impacts of these changes in interior mixing have required an increase in vertical resolution such that the intended variations are not overwhelmed by implicit numerical mixing in the advective transport algorithm.

Corresponding changes toward more physically based representations of subgrid scale thermodynamic and radiative processes in the sea ice model have been made. These include the incorporation of a new radiative transfer scheme that makes use of inherent optical properties to define the scattering and absorption properties for snow, sea ice and included absorbers. An explicit melt pond parameterization has been incorporated which relates the pond evolution to the surface ice and snow melt water flux. Additionally, aerosol deposition and cycling within the sea ice component for black carbon and dust species is now included. Taken together, these improvements provide a more sophisticated and complete sea ice albedo treatment.

The improvements achieved in the representation of ocean transport processes in the most recent versions of CCSM have motivated the decision to carry out fully interactive carbon cycle experiments at higher horizontal and vertical resolution than was used in CCSM3. The computational burden of running the higher resolution carbon cycle model thousands of simulated years in order to bring it into equilibrium remains a significant roadblock however. Mathematical techniques based on Newton-Krylov non-linear equation solvers are being investigated to circumvent the need to carry out an explicit time-dependent integration of the model and obtain the equilibrium solution directly.

2009 and Beyond

Nearly all of the ocean model developments completed and underway have been evaluated in a coupled climate context, but typically individually. The effort over the next year will be to bring them together to more fully understand their interactions and collective impact on the climate system. Comparisons with ocean tracers, both observed and as simulated by very high resolution models, will provide the metrics for judging the impact of these parameterizations on ocean transport and ventilation. Diapycnal mixing occurs on scales of centimeters to meters and will remain unresolved, and require parameterization, in global ocean climate models for many generations to come. However, coupled climate simulations that do resolve ocean mesoscale variability, on scales of 10s to 100s of kilometers are now on the horizon. Early results from prototype integrations in this class, as illustrated in the accompanying figure, reveal intriguing new classes of ocean-atmosphere interaction. The emerging availability of high resolution remote sensing products for ocean winds, surface temperature, and surface currents will facilitate an assessment of the performance of CCSM in this resolution regime, and the application of CCSM to furthering our understanding of the processes and scale interactions connecting the ocean mesoscale to the global climate system.

return to top

Structure and evolution of clear and cloudy atmospheric boundary layers

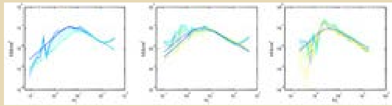


Figure: Spectra of vertical velocity multiplied by wavenumber and normalized by the convective velocity for 5, 6, and 12 August 1996 (top to bottom) versus wavenumber normalized by the CBL depth z_i. Levels vary from ~0.25z_i (dark blue) to ~0.75z_i (yellow) every 30 m. Heavy smooth lines are von Kármán model spectra fitted to the lowest (dark blue) and highest (yellow) observed levels. The upturn at the right end of the spectra on 1 and 6 August is due to measurement noise. The dashed lines on 6 August are Kaimal model spectrum, which gives a more gradual transition between the low- and high-wavenumber spectral regions, fitted to the same levels. Although there is considerable day-to-day variability, generally, the von Kármán spectra better fit the data, which tend to have an even sharper transition between low and high wavenumbers than the von Kármán spectra; the 6 August case is an exception.

High resolution figure

Work has continued on analysis of the chemical behavior of dimethyl sulfide (DMS) and scalar variance budgets in the marine boundary layer (MBL) using DYCOMS-II data from the NCAR C-130 aircraft, in collaboration with Ian Faloona (University of California, Davis). The scope of the effort has expanded somewhat to also include analysis of DMS and SO_2 data from the PAcific Sulfur Experiment (PASE) carried out in summer 2007, also flown on the C-130 aircraft. Thus far, the effort is mainly concentrated on documenting the overall structure of the MBL in the equatorial region where PASE was conducted. This effort will continue during FY2009.

This past year, a study of vertical velocity w spectra in the convective planetary boundary (CBL) has been carried out using Doppler lidar data collected during the Lidars in Flat Terrain (LIFT) experiment over flat farmland in central Illinois during summer 1996. This is a continuation of previous analyses that dealt with the 2-point turbulence statistics of w. The NOAA High Resolution Doppler Lidar (HRDL) was pointed straight up for over 100 hrs, providing 11 different cases of a midday convective boundary layer. This takes advantage of the lidar’s capability to obtain range-resolved radial measurements, from which a two-dimensional field of w can be obtained by assuming that the field of turbulence is “frozen” as it advects past the lidar. Measurements of w were obtained from a height of z ? 390 m above the surface to near the CBL top with an unprecedented vertical resolution of 30 m. Considerable day-to-day variability was found in the spectral shape, as shown in the figure, and previous models of the w spectra were not particularly good at describing the observations. Some of this variability was found to be linked to mean CBL structure, including wind speed, shear across the CBL top, and processes at, and just above the capping inversion.

Work will continue over the next year on analysis and interpretation of profiles of higher-order moments of w, from LIFT, including variance, skewness and kurtosis, which will be compared with large-eddy simulation results.

return to top

Fine Mesh Land Model

The goal of the Fine-Mesh Land Model project was to develop and implement a framework for modeling land surface processes using NCAR community land models at scales several multiples finer than those of parent atmospheric models. The approach taken was to enhance and implement the fine-mesh model of Hahmann and Dickinson (2001) within the Community Atmosphere Model - Community Land Model (CAM - CLM) climate model.

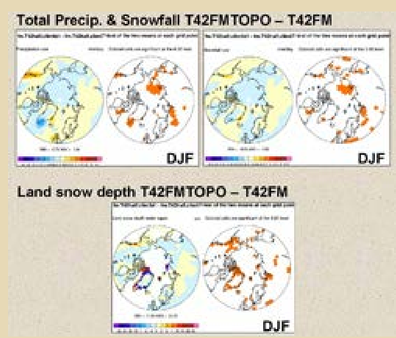


Figure 1: Effects of fine-mesh topography on large-scale circulation. The total precipitation and snow fall are impacted as is the snowpack structure.

High resolution figure

A paper summarizing the results from the fine-mesh modeling work within CAM/CLM has been written and submitted. Results from simulations with sub-grid topography showed significant changes to both the general circulation and the model surface hydrological fields compared with those where only subgrid land use and land cover was specified. The principal changes were an alteration of the Northern Hemisphere wintertime mid-latitude wave train in the North Pacific. A relative increase in the strength of the Aleutian low combined with changes land surface elevations result in widespread changes in the amount of total precipitation and partitioning between rain and snow over the parts of western Canada and Alaska. Effects in other complex regions appeared to be of lesser magnitudes. Changes in rain-snow partitioning also impart a lag-effect on the surface hydrology by altering the timing and location of snowmelt and runoff from cool season precipitation. Implementation of a precipitation disaggregation scheme into the fine-mesh model which stochastically determines the sub-grid area occurrence and intensity of precipitation based on the coarse grid model precipitation was also completed. Results from simulations including the subgrid precipitation aggregation show modest changes in the global circulation as well as the surface hydroclimate though regional changes were sometimes quite substantial. In the U.S. Great Plains there appears to be a distinct strengthening of the low-level moisture transport from the Gulf of Mexico occurring with a regional increase and redistribution of rainfall and surface evaporation.

return to top

NASA African Monsoon Multidisciplinary Analysis (NAMMA)

Figure: Lenticular wave cloud sampled on 13 December 2007 during ICE-L.

High resolution figure

We reported on our research last year as part of the NASA-sponsored African Monsoon Multidisciplinary Analyses (NAMMA) campaign. This project was a field research investigation conducted during August-September 2006 based in the Cape Verde Islands, 350 miles off the coast of Senegal in west Africa. We have made considerable progress on the analysis of these data. With Cynthia Twohy of Oregon State University, we have shown that the Saharan dust aerosols acquire a sulfate coating and act efficiently as cloud condensation nuclei. The net effect is that exceedingly high cloud-droplet concentrations are produced in the dust-perturbed clouds. Dr. Twohy has submitted an article to Nature Magazine, with us as coauthors.

We have further found that an appreciable portion of the cloud droplets are lofted high into the NAMMA clouds in vigorous convection. These freeze via spontaneous ice nucleation at temperatures near -40C, thereby producing high concentrations of radiatively reflective small ice particles. A paper reporting on these observations is in preparation.

In November and December 2007, we conducted the ICE-L (ice in clouds experiment- layer clouds). The primary goal of ICE-L was to show that under given conditions, direct ice nucleation measurement(s), or other specific measurable characteristics of the aerosol, can be used to predict the number of ice particles forming by nucleation mechanisms in selected clouds. The target clouds were primarily lenticular mountain-wave clouds. These clouds can act as a laboratory-type setting because they are relatively stationary, permitting repeated penetrations at multiple levels. Flying along or against the wind is laboratory-like in that distance along the wind corresponds to particle-growth times.

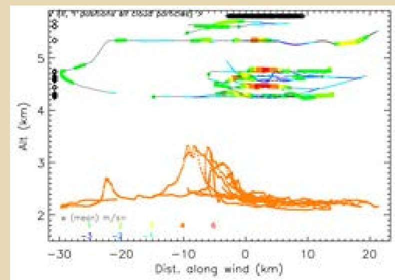


Figure: Horizontal section (altitude, distance along the wind) through wave cloud sampled on 11 December 2007. The mountain range below the aircraft is shown in orange coloring. The color-coding in the cloud-forming region refers to the air vertical velocity.

High resolution figure

We used the NCAR C-130 aircraft for ICE-L. A dozen or so university investigators, sponsored by NSF, participated in the experiment and many brought instruments that brought a new level of detail to how ice forms in clouds. We had eight probes to measure droplet and ice-particle-size distributions, three of which measured sub-50 micron particles with an open-path design to mitigate shattering which has contaminated earlier measurements of ice-particle concentrations. Incredibly interesting and valuable data were acquired with the onboard upward- and downward-viewing cloud radar (94 GHz) and upward-viewing lidar. We had two particulate mass spectrometers and a CVI to get at the composition of the ice nuclei, ice-nucleus measurements, two CCN spectrometers and a photometer to sense the volatility of the ice nuclei.

Nine flights were conducted in lenticular mountain wave clouds (see Figure 1a). Up to a dozen penetrations were made in individual wave clouds (Figure 1b). Our early analyses indicate that there is no mismatch between ice-nucleus concentrations and ice-crystal concentrations. Ice-nucleus and ice-crystal concentrations show very little dependence on temperature. This contrasts with parameterizations of ice-nucleus concentrations currently used in WRF and most cloud and mesoscale models that show that these concentrations increase strongly with temperature. We plan to parameterize the ICE-L results for incorporation into WRF.

return to top

Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) contributions

ESSL scientists are participating in the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS), a new ten-year land-atmosphere project of the International Geosphere-Biosphere Programme (IGBP). The goal of iLEAPS is to understand how interacting physical, chemical, and biological processes transport and transform energy and matter through the land-atmosphere interface. The project is designed to study interactions and feedbacks on scales from molecules to the entire globe, and from minutes to centuries, both past and future. The project brings together multi- and cross-disciplinary scientists to collaborate, distribute ideas and results rapidly, and increase scientific relations with developing countries. The iLEAPS International Project Office is based at the University of Helsinki in Finland and promotes international research projects studying essential phenomena related to global climate change.

In FY2008 ESSL scientists participated in the iLEAPS expert workshop on "The relevance of surface and boundary layer processes for the exchanges of reactive- and greenhouse gases" in Wageningen, Netherlands and the iLEAPS workshop on "Process-based description of trace gas emissions in land surface models" in Helsingborg, Sweden. ESSL scientists will continue to contribute to iLEAPS activities in FY09 and will propose the BEACHON project for sponsorship by iLEAPS. This work is funded by NSF/NCAR.

[return to top](#)

Texas air quality study

The Texas Air Quality Study (TEXAQS 2006) was a NOAA led field campaign out of Houston, Texas, that focused on providing a more complete understanding of the sources and processes responsible for photochemical pollution (ozone) and regional haze (aerosols) during the summer in Texas. Ozone and aerosols both play important roles in air quality and climate change as a result of their chemical and radiative properties. A significant fraction of ozone in the troposphere is produced photochemically from precursors that have both anthropogenic and natural sources. Major urban centers are a large source of these precursors, which results in elevated levels of ozone on local and regional scales from production and transport. These elevated levels can be a human health hazard in urban and surrounding areas and can impact ecosystems in both urban and rural areas. Enhanced aerosol production in urban areas can also impact human health and ecosystems. Exposure to high levels of aerosols can lead to respiratory problems for humans and can acidify ecosystems as they are removed by rain. On the NOAA P3 aircraft, ACD scientists measured PANs and collected whole air samples for analysis of non-methane hydrocarbons, halocarbons, alkyl nitrates, and oxygenated VOCs. One interesting result from the measurements made during TexAQS2006 is illustrated in Figure 1. One goal of the TexAQS 2006 campaign was aimed at investigating the changes in photochemical ozone production over Houston as a result of emission reductions implemented between 2000 (the first TexAQS campaign) and 2006. Of high concern were in 2000 the episodes of very efficient ozone production from highly reactive NMHC like ethene, propene, and butenes which are emitted from petrochemical facilities. The measurements made on this flight on October 6, 2007, show that this is still a problem. The plot shows 1-second time resolution measurements of PAN and APAN (both tracers of photochemical ozone production, along with ozone mixing ratios. APAN is a unique product from the oxidation of butadiene, an extremely reactive hydrocarbon used to make butyl rubber. PAN is being produced from many hydrocarbons which produce ozone in the troposphere. During the flight, four passes downwind of major butene emitters (blue dots on map, the size of the dots is proportional to the butene emission magnitude) were made. Ozone is enhanced by almost 80 ppb only 1.5 hours downwind of the source of emissions. Even though dilution sets in for passes #3 and #4 (spiral profile) further downwind ozone is still 60-70 ppb enhanced over the background. This is a very large ozone production rate and cases like this contribute significantly for the overall large ozone problem in the Houston area. The thick black arrow points out where additional ozone production was observed which does not involve butadiene as PAN and ozone are enhanced here but APAN is not. This illustrates the advantage of measuring several (in our case, 5) different PAN species quasi-simultaneously and how it allows us to identify specific hydrocarbon species as they contribute to the photochemical production of ozone.

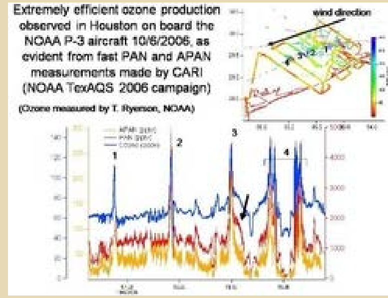


Figure 1. Rapid production of PANs and ozone downwind of a petrochemical facility emitting large quantities of 1-butene measured on the NOAA P3 during the TexAQS 2006 campaign.

[High resolution figure](#)

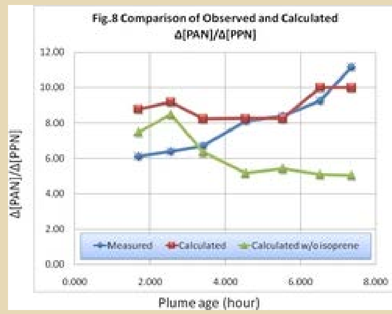


Figure 2: measured and calculated development of the PAN/PPN ratio as air is transported away from downtown Houston into the suburbs.

[High resolution figure](#)

Observed PAN/PPN ratios were also analyzed in air masses which were transported downwind of the city of Houston into the suburban areas. An increase of the [PAN]/[PPN] ratio was observed during transport of the Houston plume away from the city. PPN is more thermally stable than PAN which works to decrease this ratio if no more production of either of the species took place. However, the precursors for PPN generally react away faster with OH compared to the PAN precursors, shifting the ratio to increasing values while air masses are still production dominated. This generally faster depletion of PPN precursors alone was found to be inadequate to explain the overall observed increase. Our calculations show that isoprene emissions from the surrounding areas are a major source of PAN downwind of Houston and cause much of the observed increase of the [PAN]/[PPN] ratio (see Figure 2).

[return to top](#)

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ESSL LAR 2008: STRATEGIC GOAL #1, PRIORITY #3

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #1, Improve understanding of the atmosphere, the Earth system, and the Sun. This Strategic Goal encompasses four Strategic Priorities, each of which is dependent on the efforts and accomplishments of ESSL staff.

ESSL developed an action plan with seven priority themes which involve direct partnerships with the university community and contribute directly to the ESSL Strategic Vision and to several priority items of the NCAR Strategic Plan.

ESSL's seven priority themes:

1. Climate projection, with emphasis on short-term prediction.
2. Biosphere-Atmosphere-Hydrosphere interactions and specifically development of BEACHON Project (Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, Hydrology, Organics and Nitrogen).
3. Water system research, specifically the development of the Society, Water, Atmosphere and Natural Systems Project (SWANS).
4. An advanced Weather Research and Forecasting system, specifically the development of the Hurricane Intensity and Forecasts (HiFi) Project.
5. Space Weather, specifically the development of the Coronal Solar Magnetism Observatory Project (COSMO).
6. Chemical Weather, including interpretation of observed data gathered during the Megacity Impact on Regional and Global Environments (MIRAGE) campaign, and the development of a capability for chemical data monitoring and prediction.
7. Prediction across scales, specifically the development of an advanced next-generation, climate-weather modeling system and an integrated Earth system model of intermediate complexity.

Goal #1, Priority #3: Improving Prediction of Weather, Climate, and Other Atmospheric Phenomena, is described in the NCAR Strategic Plan as follows: "Understanding of the Earth system is a prerequisite to predicting its behavior, the latter being, however, of a more direct use to many components of society. In that context, for this priority, the key activities within NCAR's laboratories range from improving climate models, to exploring new approaches to prediction across scales, and global and local weather prediction."

This NCAR priority, driven by ESSL's themes 1, 3, 4 & 7, is critical to achieving NCAR's first strategic goal.

The section below describes specific research conducted by ESSL staff under projects relevant to Priority 3. The major ESSL activities in this area involve studies designed to improve prediction of weather, climate, and atmospheric chemistry. The activities center around the use and evaluation of the Weather Research and Forecasting/Advanced Research WRF (WRF/ARW) model, the Community Climate Systems Model (CCSM), and the Nested Regional Climate Model (NRCM).

Weather Research and Forecasting Model/Advanced Research WRF (WRF/ARW)

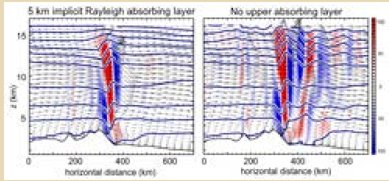


Figure: 30 h ARW forecast for mountain waves over the eastern slope of the Colorado Rockies on 05 December 2007 06 UTC. Updrafts and down drafts are depicted with red/blue shading and potential temperature is contoured with 10 K intervals. Left panel: forecast with 5 km implicit Rayleigh absorbing layer beneath the upper-domain boundary; Right panel: forecast with no upper absorbing layer.

High resolution figure

The overall goal of the WRF model project is to develop a next-generation mesoscale forecast model and data-assimilation system that will advance both the understanding and prediction of mesoscale weather and accelerate the transfer of research advances into operations. WRF has been developed as a collaborative effort among NCAR (ESSL, MMM Division), NOAA's National Centers for Environmental Prediction (NCEP) and Earth System Research Laboratory (ESRL), the Department of Defense's Air Force Weather Agency (AFWA) and Naval Research Laboratory (NRL), the Center for the Analysis and Prediction of Storms (CAPS) at the University of Oklahoma, and the Federal Aviation Administration (FAA), along with the participation of numerous university scientists. WRF is intended to improve the forecast accuracy of significant weather features across scales ranging from cloud to synoptic, with priority emphasis on horizontal grids of 1–10 kilometers. The model incorporates advanced numerics and data-assimilation techniques, a nesting capability supporting multiple and moving grids, and a range of physics options, particularly for treatment of convection and mesoscale precipitation systems. It is well-suited for a wide range of applications, from idealized simulations to operational forecasting, with the flexibility to accommodate a range of potential enhancements.

MMM scientists instigated the WRF endeavor a decade ago to promote closer ties between research- and operational-model development. Since then, WRF has matured to become the most popular mesoscale model in the world. MMM has led the development of the WRF software infrastructure and the Advanced Research WRF (ARW) dynamic core and maintains and supports the system for the research community. The WRF effort provides the primary facility for supporting the NCAR strategic priority of investigation of the dynamics and predictability of weather systems on time scales of 0–48 h. In addition, it furthers NCAR’s mission to provide and support state-of-the-art modeling systems for broad use in the research community.

Within MMM, project activities are distributed across three areas: 1) development and enhancement of WRF capabilities to meet the needs of MMM and community-research objectives; 2) research to advance the understanding and prediction of high-impact weather systems; and 3) model support to the research community. The effort is ongoing as the WRF system evolves to meet future requirements for advanced weather research and forecasting, while timelines attend deliverables in specific funded projects and in commitments to provide modeling capabilities for MMM and the research community.

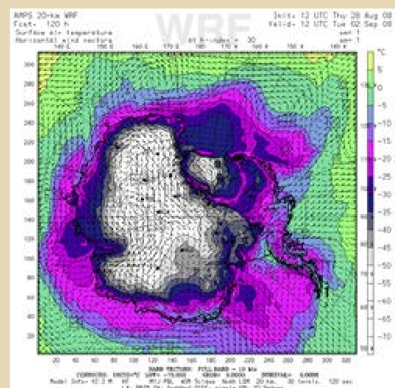


Figure: 120-hr forecast of surface temperature (°C) over Antarctica using Polar WRF. Surface winds full barb= 10 kts) also shown. Forecast initialized at 120 UTC 28 August 2008.

High resolution figure

During the past year, NCAR continued to develop new capabilities for the ARW and support it to the community. Over 2000 new users registered to download the code, bringing the total number of registered users to over 7,600. Over half of this total is non-US users, and 113 countries are represented. In June 2008 MMM organized and conducted the 9th Annual WRF Users’ Workshop, with over 225 participants attending from many different countries. MMM personnel also conducted three user tutorials on the ARW and WRF-VAR. Two ARW tutorials were in Boulder, with approximately 60 persons, while another was in Seoul, Korea. Operational forecasting with the ARW continued at NCEP and AFWA (worldwide regional theatres), as well as a number of international operational applications. MMM manages the WRF code repository, assists community researchers in development, coordinates additions to the repository, and oversees the code integration and testing for new releases. This past year, MMM released WRF Version 3.0 (April 2008). Key features of V3.0 included:

1. Global ARW;
2. Unified WRF and WRF-Var codes;
3. WRF-Chem;
4. New and modified microphysics and cumulus schemes;
5. Streamlined infrastructure and memory utilization;
6. New and modified land-surface and PBL schemes;
7. Upper-boundary gravity-wave-absorbing layer; and
8. Simple ocean mixed-layer model.

Improvements were made to the WPS (WRF Preprocessing System) and numerous bugfixes and enhanced support for a range of computing platforms were included.
As part of the ARW V3.0, a new technique has been developed and implemented to mitigate the artificial reflection of gravity-wave energy from the upper boundary of the model domain, which is well suited for

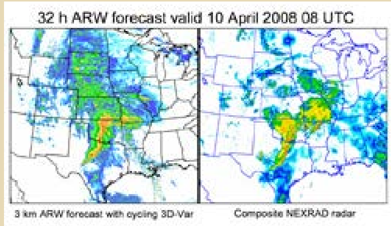


Figure: 32 h ARW forecast (left panel), valid 10 April 2008 08 UTC, for simulated radar reflectivity using cycling 3D_Var for model initialization in comparison with observed radar reflectivity (right panel).

High resolution figure

NWP applications. In this method, an implicit Rayleigh damping term is applied only to the vertical velocity in a split-explicit time integration, as a final adjustment at the end of each small (acoustic) time step. The adjustment is equivalent to including an implicit Rayleigh damping term in the vertical momentum equation together with an implicit vertical diffusion of w. This implicit damping for the vertical velocity is unconditionally stable and remains effective even for hydrostatic gravity waves. The good absorption characteristics of this absorbing layer across a wide range of horizontal scales is confirmed though analysis of the linear wave equations, simulations of idealized mountain-waves, and through NWP applications, as reflected by the simulation of mountain waves over the Colorado Rocky Mountains shown in Figure1.

MMM continued to apply the ARW in the Antarctic Mesoscale Prediction System (AMPS) for real-time NWP support for the United States Antarctic Program. Over the past year MMM personnel have incorporated WRF polar modifications developed with collaborator The Ohio State University into WRF V3.0. “Polar WRF” has been tested and found to be superior to regular WRF and to Polar MM5, and MMM has now switched to using the Polar WRF in its AMPS forecasts. The modifications include fractional sea-ice representation and changes to surface characteristics to better capture the conditions of ice sheets. Figure 2 presents an example of a 5-day forecast of surface temperature over Antarctica (20-km grid) using Polar WRF. Polar WRF 3.0.1 is now being implemented into the current version of AMPS. The AMPS group at NCAR has a plan to incorporate the ARW polar mods into the WRF repository, and thus to make Polar WRF available to the community in the next major release (Spring 2009).

MMM has continued to assess and enhance the accuracy of forecasting convective weather systems through real-time convection-resolving forecast experiments with WRF. In support of the NOAA Hazardous Weather Testbed (HWT) 2008 Spring Experiment , MMM ran daily, convection-permitting (3-km grid), real-time forecasts over the central US for the 10 April–6 June period. This year, for the first time, the runs were initialized using WRF-Var, a 3-dimensional variational data assimilation system, with the goal of evaluating the potential benefits of using WRF-Var for initializing the high-resolution ARW runs, as opposed to initializing from gridded operational analyses. To this end, a 9-km ARW run was initialized at 1200 UTC using the GFS, and then cycled every 3 h to produce initial conditions at 0000 UTC (interpolated from 9 km to 3 km). An example of an ARW forecast from this spring experiment is shown in Figure 3. One of the more significant factors in the new approach is that explicit precipitation from the 9-km cycled forecast is now included in the initialization, which was not possible in the “cold start” procedures used in prior years. For many of the cases, this explicit precipitation initialization improved the forecast over the first six hours, as the model did not have to spin up precipitation starting from 0000 UTC. However, the approach also contributed to a number of forecast failures, particularly when the 12-h forecast precipitation features from the 9-km grid did not sufficiently reflect the observed features. This revealed a significant weakness of 3DVAR cycling in the absence of assimilating radar data, which could not be incorporated this year due to time and computer resource constraints. These experiences with WRF-Var will help guide plans for next year’s real-time forecast exercise, in support of the VORTEX2 field program.

Last year’s goals for the ARW effort included assisting domestic and international users of the ARW, conducting the 9th WRF Users Workshop in June 2008 and tutorials in January and July 2008, and a major new release, V3.0. All of these were accomplished. In addition, Global ARW was not only tested, but also released in V3.0, and a new tech note for V3.0 was published. For better management of the WRF code, MMM finalized and published procedures for the administration of the repository and of releases. It also published information for code contributors. Plans for next year include a major release in Spring 2009, the 10th WRF Users’ Workshop, tutorials in Winter and Summer, and continued community support.

The WRF modeling system will continue to serve as a versatile scientific tool for the weather- and climate-research communities. It is a high-performance computational model that scales well from single-processor environments to massively parallel petascale applications. In addition to being a state-of–the-art weather prediction model, it has been adapted to atmospheric chemistry, air quality, and nested regional-climate applications. The successful migration of WRF into operational forecasting yields significant economic and societal benefits. Supporting WRF for widespread community use greatly leverages resources by allowing researchers access to a sophisticated atmospheric tool without a large resource investment, but with the opportunity to contribute to, and benefit from, the advancement of a common modeling system.

The WRF effort within MMM is supported by NCAR/NSF base funds through the MMM budget and USWRP resources, from the NSF Office of Polar Programs, and from outside-funded projects with AFWA, the FAA, and CWB and CAA (Taiwan).

return to top

Community Climate Systems Model: Advancing Climate Science

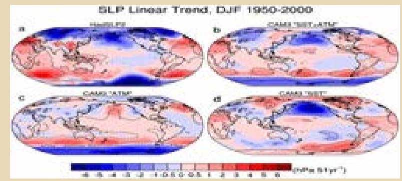
Overview

Each year much effort is devoted to further development of the Community Climate Systems Model (CCSM) and those efforts in and of themselves can lead to discoveries about the processes that contribute to climate and its fluctuations. Beyond this, even more is learned about the climate system by applying the CCSM to various outstanding problems concerning the character of the climate and the mechanisms that control its behavior. To this end, members in every section of CGD use the CCSM to investigate a broad range of issues. Below are examples that demonstrate the breadth of topics considered in FY2008.

Recent Accomplishments

CAM3

CAM3, the atmospheric component of CCSM, was been used to attribute the causes of observed atmospheric circulation trends during the second half of the 20th century, in particular the relative roles of direct atmospheric radiative forcing (due to observed changes in greenhouse gases, tropospheric and stratospheric ozone, sulfate and volcanic aerosols, and solar output) and observed sea surface temperature (SST) forcing. CAM3 realistically simulated the observed sea level pressure trends when both types of forcing were considered (upper panels of Fig. 1). Additional experiments showed that direct radiative forcing and observed SST forcing drive distinctive circulation responses that contribute about equally to the global pattern of observed circulation trends (lower panels of figure below). In particular, radiative forcing accounted for much of the observed sea level pressure trends in the high latitude southern hemisphere while SST forcing accounted for the observed sea level pressure trends over the north Pacific and tropics.

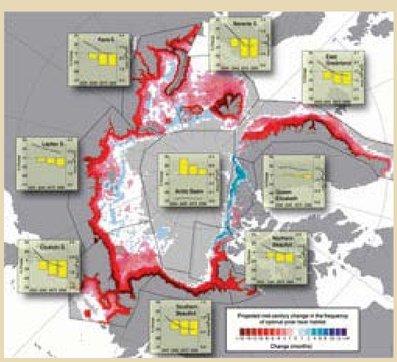


Linear trends (color shading; hPa per 51 yrs) of December-February SLP during 1950-2000 from observations (HadSLP2; upper left) and CAM3 model simulations forced with observed SSTs and atmospheric radiative changes (upper right), observed SSTs only (lower right) and atmospheric radiative changes only (lower left). Dashed contours indicate trends that are significantly different from zero at the 95% level.

High resolution figure

CCSM: Polar Regions

The CCSM project continued to take a lead on model developments for polar regions and on studies related to polar climate variability and change. This included the investigation of mechanisms leading to rapid summer Arctic ice loss in CCSM simulations, the potential that these represent "tipping point" or threshold behavior, and the effect that these events have on terrestrial warming and permafrost conditions. Studies using CCSM also assessed Arctic freshwater budget change, with indications that the Arctic hydrological cycle is and will continue to intensify in a warming climate. In related work, CCSM was used to assess the impact that large freshwater discharge has on thermohaline circulation change under present-day and Last Glacial Maximum climate states. Additionally, CCSM simulations were used to study ecosystem impacts in polar regions. Most notably, the CCSM project contributed to studies that resulted in the listing of the polar bear as a threatened species under the Endangered Species Act.



Projected changes (based on 10 IPCC AR-4 GCM models run with the SRES-A1B forcing scenario) in the spatial distribution and integrated annual area of optimal polar bear habitat. Base map shows the cumulative number of months per decade where optimal polar bear habitat was either lost (red) or gained (blue) from 2001-2010 to 2041-2050. Offshore gray shading denotes areas where optimal habitat was absent in both periods. Insets show the average annual cumulative area of optimal habitat (right y-axis, line plot) for four 10-year periods in the 21st century (x-axis midpoints), and their associated percent change in area (left y axis, histograms) relative to the first

Climate predictability

Past investigations of climate change often focused on century timescales, but nearer term changes are of equal interest to society and scientifically distinct in that the initial state of the system may influence its evolution. To estimate the predictability of climate on decadal time scales an ensemble of integrations was performed with CCSM in which the years 2000 to 2062 were simulated. Each realization was forced by the same SRES A1b sequence of climate forcings, but each had a different initial atmospheric state. Due to the chaotic nature of the climate system, the evolution of the state of all model components varied markedly from one realization to another, but there were indications of predictable phenomena in the experiment. For example, the ensemble mean of the Pacific Decadal Oscillation had a predictable signal for more than 40 years.

2009 and Beyond

Applications of CCSM will continue on a wide range of topics. Examples related to the investigations outlined above include:

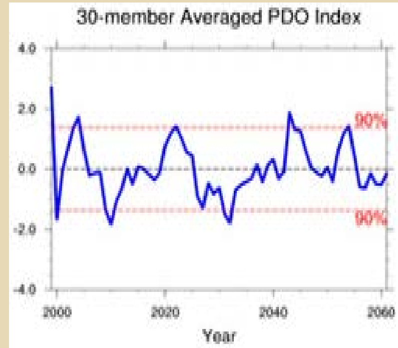
Attribution of atmosphric circulation: The work on attribution of atmospheric circulation trends with CAM will be continued in FY09 to include future climate states simulated by the CCSM model under the SRES A1B scenario. In addition to prescribing the full SST and atmospheric radiative forcings in CAM for the next 50-100 years, the forcings will also be decomposed into their natural and anthropogenic components for enhanced attribution.

Continuted terrestrial carbon cycle model development: There will be continued development of the terrestrial carbon cycle model, including additional capabilities to simulate dynamic vegetation, anthropogenic land decade (2001-2010).

High resolution figure

cover change, croplands, wildfire, and biogeochemical cycles. As the model matures, a primary scientific theme will be to examine natural and human-mediated changes in land cover and ecosystem functions and their effects on climate, water resources, and biogeochemistry.

Polar region model development: Numerous model improvements targeted at polar regions will be included in the next generation CCSM model. These include improved sea ice albedo parameterizations, permafrost dynamics, dynamic vegetation processes, and cloud microphysics, among others. This will allow for more reliable polar climate simulations. Additionally, it will enable new research on the role of these processes in climate variability and change. For example, the incorporation of black carbon cycling within the sea ice and terrestrial snow components will permit us to assess the role that increased soot deposition has played in the warming Arctic climate. In the longer-term, the incorporation of an ice sheet model within the CCSM system, which is currently underway through a collaborative effort with the Los Alamos National Laboratory, will allow improved simulations of sea level rise and the influence of ice sheet change on climate.



Evolution of an index of the Pacific Decadal Oscillation in the ensemble average of 30 integrations of CCSM3.0 each of which is driven by SRES A1b forcing.

High resolution figure

Predictability signatures: The ensemble of SRES A1b scenario integrations will be further expanded so that signatures of predictability can be detected with greater levels of significance. And the dynamical mechanisms and atmosphere-ocean interactions that contribute to the decadal predictability will be diagnosed and compared to existing theories of intrinsic modes of North Pacific variability. Moreover, studies of decadal predictability in other basins will be furthered.

return to top

U.S. Weather Research Program / Short Term Explicit Prediction Program (USWRP / STEP)

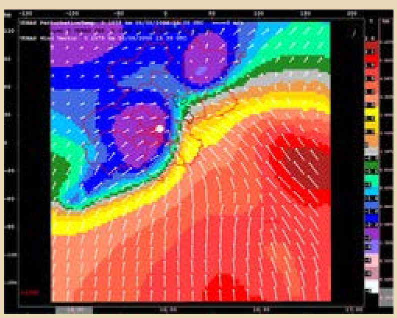


Figure: VDRAS real-time analysis of the perturbation temperature field and horizontal wind (vectors) at the altitude of 0.187 km for Aug. 8, 2008, the day of the Olympics opening ceremony was held in the Bird's Nest National Stadium (marked by the white dot). The black contours show the 30 dBZ reflectivity and the red lines show the Beijing districts. The convective cells are initiated in the region between two cold pools from previous convection. The cold pool southwest of the convective cells was a result of a storm that dissipated before reaching the stadium.

High resolution figure

The Short Term Explicit Prediction (STEP) Program (http://www.mmm.ucar.edu/STEP) is a multi-NCAR-Laboratory activity to improve the short-term forecasting of high-impact weather such as severe thunderstorms, winter storms, and hurricanes. Improving short-term forecasts of such weather can have significant societal and economic benefits, including: (1) reduced fatalities and injuries due to weather hazards; (2) reduced private, public, and industrial property damage; and (3) improved efficiency and savings for industry, transportation, and agriculture. The STEP Program is also being stimulated by the significant advancement in a number of fields that are required to make progress in this area. These include the ability to observe the four-dimensional structure of the atmosphere, the development of new data-assimilation techniques, such as 3DVar/4DVar and the Ensemble Kalman Filter (EnKF), and the continuing development of numerical-modeling systems, such as the Advanced Research/Weather Research and Forecasting model (WRF/ARW), which can be run at grid resolutions that properly represent the physical processes critical to the production of such hazardous weather. The program includes research into basic understanding of high-impact weather systems, development of forecast techniques, real-time testing of forecast systems, verification, and interaction with users. This collaborative effort incorporates national and international scientists, engineers, and operational personnel from universities, government institutions and the private sector.

The primary activity for STEP this year was the collaborative effort on an IHOP retrospective study. STEP scientists specializing in various topics, ranging from mesoscale observation analysis, automated nowcasting, high-resolution data assimilation, high-resolution WRF-ARW modeling, and convective precipitation verification, participated in the study. A workshop was conducted in July 2008 to report on progress for each project and to discuss future coordination and publication of the results. In order to better accomplish the STEP goal as stated in the STEP strategic plan, a process to redistribute the STEP funds for FY08 and 09 funding cycle was conducted. On the research level, a wide range of activities which are central to STEP research goals, and which involve MMM, RAL and EOL scientists have been ongoing over the past year(s). Within MMM, WRF/ARW development efforts continued to be a critical component of STEP, offering a range of new capabilities, from improved numerics and physics to new data-assimilation systems that can address the short-term forecast problem. The data-assimilation systems based on 3DVar, 4DVar, and EnKF techniques continued to be developed, and research on the inclusion of radar observations into these systems was emphasized for the STEP program.

Other than the variety of basic research and development, one of the major themes in STEP is to demonstrate high-resolution forecasting systems in real time. In collaboration with the Spring 2008 SPC/NSSL Hazardous Weather Testbed experiment, WRF/ARW was run at a 3-km horizontal grid resolution over the central U.S. to produce explicit 0-36 hour convective-weather forecasts. The WRF/ARW run was initialized by the 3DVAR data-assimilation system with a 9-km resolution. These forecasts were evaluated by forecasters and researchers from across the country, and exhibited noticeable improvements over past years, especially as regards the representation of convective precipitation. STEP's nowcasting system and the radar data assimilation system VDRAS were demonstrated in Beijing during the Olympics 2008 as part of the WMO sponsored Olympics forecasting demonstration project. VDRAS produced 3-km wind, temperature, and humidity analyses updated every 12 minutes. A number of STEP scientists participated in the planning and the actual execution of the Terrain-induced Monsoon Rainfall Experiment (TiMREX) which was conducted in southwest Taiwan.

In the coming year, the IHOP retrospective studies will be completed and a number of publications will be written to summarize the results. A workshop will be held in December to present findings from these studies. Comparisons will be made to evaluate strengths and weaknesses of each data assimilation, nowcasting, and forecasting systems and the impact of including radar in the assimilation. Efforts at developing new techniques for verifying high-resolution forecast guidance will be continued. Future development of verification will focus on this inter-comparison to understand the strengths and weaknesses of different approaches. Efforts on studies of convective weather dynamics based on observations and model results will also be continued.

return to top

Data assimilation / ensembles

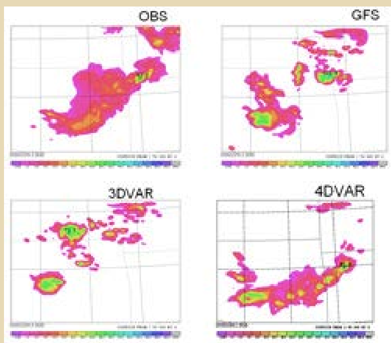


Figure: Six-hour forecasts of hourly precipitation from three experiments of a 4km WRF with different initial conditions for an IHOP case compared with Stage IV data (OBS). GFS: initialized by GFS analysis; 3DVAR: initialized by WRF 3DVAR with radar data; and 4DVAR: initialized by WRF 4DVAR with radar data.

High resolution figure

Data assimilation is the process of combining observations and a previous forecast to provide a gridded estimate of the atmospheric state at a certain time. These estimates can then be used as initial conditions for subsequent forecasts or as tools to analyze and understand the atmosphere. While much progress has been made at global scales, data assimilation for scales of less than a few hundred kilometers (the "mesoscale," where most severe and damaging weather occurs) remains a significant open problem in atmospheric science. Mesoscale data assimilation is especially challenging for two reasons. First, mesoscale motions are intimately coupled to complex physical processes such as those involving moisture, cloud and rain or interaction with the land or ocean surface. These processes are difficult to represent accurately in numerical models. They also lead to distinct and strongly nonlinear dynamics at the mesoscale, so that balances between mass and wind, which pertain at large scales in the atmosphere and underlie global data assimilation schemes, are questionable at the mesoscale. Second, observations that are plentiful (e.g., Doppler radar measurements of wind and reflectivity) involve only a subset of atmospheric variables, while observing platforms that measure all relevant variables (i.e., radiosondes) are sparse and resolve mesoscale motions poorly. To overcome these difficulties, there has been substantial effort within ESSL/MMM to advance mesoscale data assimilation.

A significant component of these efforts has been to build, and support for the community, a data assimilation facility for WRF based on variational assimilation techniques, known as WRF-Var. The WRF-Var system continues to be widely used in research at universities and as the basis for operational assimilation system development at the U.S. Air Force Weather Agency (AFWA) and several other operational centers internationally. WRF-Var has been extended from three to four dimensions (WRF 4D-Var) to meet the increasing demand for improving initial model states in multi-scale and time-dependent numerical simulations and forecasts. WRF 4D-Var uses the WRF model adjoint as a constraint to impose a dynamic balance on the assimilation. It has been demonstrated to evolve the background error covariance and produce the flow-dependent analysis increments. Recent experiments with Doppler-radar observations have shown the potential of WRF 4D-Var for high-resolution assimilation with explicit representation of moist convection (Fig. 1). These results illustrate clear advantages of 4D-Var over the existing 3D-Var for this problem.

ESSL/MMM also has a strong research program in the area of ensemble-based data assimilation. In collaboration with the Data Assimilation Research Section within CISL/IMAGe, an ensemble Kalman filter for WRF has been developed within the Data Assimilation Research Testbed; this assimilation system is known as WRF/DART. Assimilation of Doppler-radar observations is also an emphasis of WRF/DART research and multiple case studies using WSR-88D observations of severe convective storms have been completed. These case studies indicate an overall analysis quality comparable to or better than traditional dual-Doppler retrievals, besides providing gridded analysis of WRF's microphysical and thermodynamic variables. Several areas important for continued improvement of radar assimilation have also been identified. Most crucial are better representations of forecast-model errors in the assimilation process and the extension to larger domains to include multiple spatial scales, spanning both meso- and convective-scale motions.

return to top

THe Observing-system Research and Predictability EXperiment (THORPEX)

Figure 1

High resolution figure

THORPEX seeks to reduce and mitigate the effects of natural disasters on society by transforming timely and accurate weather forecasts into specific and definite information in support of decisions that produce the desired benefits.

One aspect of the TIIMES mission is to be the administrative home of programs that cut across the divisional and laboratory structure of NCAR. One such effort is THORPEX (The Observing-System Research and Predictability Experiment), which is a long-term effort within the World Meteorological Organization's World Weather Research Program (WMO/WWRP). The overarching goals of THORPEX are to accelerate both the forecast skill of high impact weather events on the 1 to 14-day time scale and utilization of forecast information. THORPEX research is meant to benefit society, the economy and the environment with one focus to mitigation of disasters in the developing world. While THORPEX was designed to concentrate on the 1 to 14-day time-scale, THORPEX is also developing collaborations with the World Climate Research Program for time-scales that fall between the time-scales of numerical weather prediction and climate projections. These time-scales include seasonal prediction and longer subseasonal time-scales, such as the Madden Julian Oscillations. The THORPEX and the WCRP collaboration includes research on topics of mutual interest (e.g., improving the characterization in numerical models of a variety of processes that include tropical convection, polar precipitation events and the triggering and enhancements of Rossby wave trains).

TIIMES has hosted both the US THORPEX Project and the co-chair of the North American THORPEX Regional Committee until 28 February 2008. David Parsons held both these posts. He is now on a Collaborative Visit to the WMO to become the Chief of the WWRP and Manager of the THORPEX International Project Office. The THORPEX research effort in the US already has significant participation within the university community and the effort has the potential to involve weather and climate researchers within ESSL at NCAR and the activities of CISL, RAL and SERE. One aspect of THORPEX is to move the user and research community from relying on deterministic forecasts to ensemble forecast systems that better represent the uncertainty in simulations of the non-linear, partly chaotic nature of the atmosphere. During the past year, NCAR CISL initiated an archive of the ensemble members of the ensemble global forecasts of the major operational forecast centers, which when fully operational will include ~256 ensemble members produced daily for forecast periods from 1 to 14-days. The archive includes the basic model derived parameters as well as derived parameters that are of interest to researchers. This ensemble archive is called TIGGE (THORPEX Interactive Grand Global Ensemble). TIGGE is well utilized by the research community as, for example, over hundred users have registered.

Figure 2

High resolution figure

Parsons was also the Principal Investigator for two major international field experiments with accompanying numerical modeling efforts called THORPEX Pacific Asian Regional Campaign (T-PARC) and CONCORDIASI until he took on the position of international oversight of THORPEX and the WWRP. The goals of T-PARC are to advance understanding and improve prediction of i) high impact weather over the western Pacific and east Asia with a focus tropical cyclones from genesis to extratropical transition (ET) or decay; ii) downstream high impact weather events over North America, the Arctic and Europe whose dynamical roots and forecast errors are over the western Pacific and east Asia. The tropical cyclone and ET phases of T-PARC took place from August to early October 2008. A winter phase planned for January to March 2009. T-PARC, and a collaborative Office of Naval Research project called TCS-08 (Tropical Cyclone Structure) experiment is one of the largest coordinated efforts of the international research and operational community to address tropical cyclones in the Pacific and their impacts on downstream flow.

The CONCORDIASI project has begun and will end in early October 2009. This program has multi-disciplinary goals, such as i) more accurate representation of the atmosphere over Antarctica through advancing satellite data assimilation for weather prediction and the climate record, ii) advancing prediction of precipitation events near Antarctica and the impact of these events on lower latitude circulations; iii) more accurate prediction of ozone concentrations through Lagrangian measurements of ozone depletion and the microphysics of stratospheric NAT clouds.

A new THORPEX effort that involves significant collaboration with the World Climate Research Program (WCRP) is called the Year of Tropical Convection (YOTC - see below).

Year of Tropical Convection (YOTC)

Mitch Moncrieff (MMM) and Duane Waliser (JPL-CalTech) are leading a major new international project described as follows. Incomplete knowledge and practical issues severely disadvantage the skill of numerical weather prediction models and climate models, for example, the

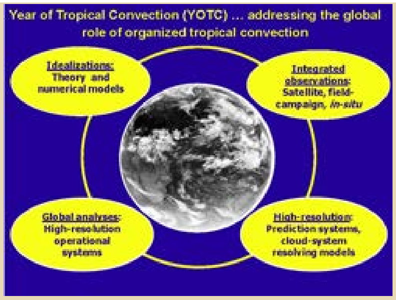


Figure 3: YOTC will improve the predictive skill of operational models by addressing convective organization on spatial scales up to global and time scales up to sub-seasonal (the intersection of weather and climate) using: i) global analyses from high-resolution operational systems; ii) high-resolution prediction systems and cloud-system resolving models; iii) integrated satellite, field-campaign and in situ observations; iv) theoretical and idealized models.

Reference: Waliser, D. E., and M.W. Moncrieff, 2007: Year of Tropical Convection: A joint WCRP-THORPEX Activity to Address the Challenge of Tropical Convection., GEWEX News, 17, 8-9.

High resolution figure

reliable representation of prominent tropical phenomena such as the InterTropical Convergence Zone (ITCZ), El Nino/Southern Oscillation (ENSO), monsoons and their active/break periods, the Madden-Julian Oscillation (MJO), tropical-subtropical transition, and easterly waves/ tropical cyclones Furthermore, tropical convection has long-range effects on stratospheric-tropospheric exchange, the large-scale circulation of the upper-atmosphere, and the variability of weather and climate around the world. Convective organization is involved at a basic level.

In order to address this major challenge, WCRP and WWRP-THORPEX proposed a year of coordinated observing, modeling, and forecasting, which led to the Year of Tropical Convection, YOTC. The focal theme of YOTC is the role of organized tropical convection at large scales. Together with accompanying research activities, the YOTC seeks to advance knowledge, diagnosis, modeling, parameterization, and prediction of multi-scale tropical convection and two-way interaction between the tropics and extra-tropics. The YOTC project will exploit the vast amounts of existing and emerging observations, the expanding computational resources, the new, high-resolution modeling frameworks, and theoretical insights (see Figure 3). This activity involves unprecedented collaboration between international programmatic activities, the operational prediction, research laboratory, and academic communities. Global databases of satellite data, in-situ data, and high-resolution model analysis and forecasts will be constructed. Emphasis is on timescales ranging from days-to-months; that is, the intersection of weather and climate.

The following objectives were achieved this year:

i. the ECMWF T799 (25 km) global analysis, forecast products, and special diagnostics being archived at ECMWF will be available to the community;

ii. the YOTC Science Plan was drafted;

iii. the YOTC Implementation Plan is in the first stage of development.

Started in May 2008, YOTC will contribute to the Asian Monsoon Year (AMY), the THORPEX Pacific Area Regional Campaign (TPARC), the United Nations Year of Planet Earth, and the International Polar Year. The scientific basis for YOTC is published in Moncrieff et al (2007), and a brief summary is published in Waliser and Moncrieff (2007).

return to top

Climate change and regional air quality implications

Globally, secondary organic aerosol (SOA) from biogenic precursors surpasses those from anthropogenic sources. These organic particles impact climate directly by scattering and absorbing of radiation, and indirectly through the modification of clouds and precipitation. These processes exert a substantial influence back upon the earth system through links to the terrestrial carbon and water cycles (e.g., precipitation regulates plant growth and thus emissions of organic compounds). Understanding the feedbacks between the atmosphere and terrestrial environment is key to estimating the impact of climate change on regional air quality.

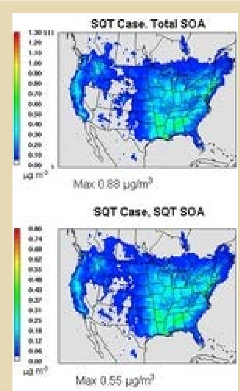


Figure 1: Simulated total secondary organic aerosol (SOA) (Top) and SOA from sesquiterpenes (Bottom) averaged for July 2001.

High resolution figure

In the past year, ACD scientists collaborated with Jack Chen, Jeremey Avise, and Brian Lamb (Wash. State U.), Cliff Mass (U. Washington), Donald McKenzie and Susan Fergusen (US Forest Service) to investigate the impact of future climate and land cover on regional air quality in the Pacific Northwest and North Central U.S. The results indicate that U.S. regional air quality (e.g., ozone and particles) will degrade even if U.S. anthropogenic emissions remain the same. The changes are due to a combination of pollutant transport from other countries (primarily China, Mexico and Canada), changes in wildfire emissions, and changes in biogenic emissions. The increased pollution transport is due to predicted increases in emissions in these countries. Wildfire activity is predicted to increase due to a warming and drying climate. Biogenic VOC emissions are expected to increase in response to higher temperatures. Land use change (i.e. tree plantations, agriculture, and urbanization) scenarios result in dramatic increases in some regions and decreases in other areas.

ACD scientists, collaborating with researchers from the University of Colorado, have also created a new emissions inventory of sesquiterpenes from vegetation using the Model of Emissions of Gases and Aerosols from Nature (MEGAN). These emissions were input to a regional chemical transport model so that the impact of these compounds on secondary organic aerosol (SOA) concentrations could be evaluated. The results, plotted in Figure 1, show that sesquiterpenes from vegetation roughly doubled the amount of SOA simulated when compared to simulations without sesquiterpenes; however, the model still underpredicted particulate organic matter when compared to observations.

Other modeling efforts in ACD have focused on investigating the role of dust aerosol in the heterogeneous removal of reactive nitrogen species in the vicinity of Mexico City. Changes in pollutant concentrations (i.e. nitric acid, nitrates) including the impact on ozone at the regional scale were quantified using WRF-chem model and observations from the MILAGRO field campaign. During the next year, modeling efforts relating to the roles of aerosol in coupling atmospheric chemistry with climate include work on characterizing carbonaceous aerosols observed in the Mexico City area in terms of their chemical composition, origin (i.e. anthropogenic, biogenic, biomass burning) and spatio-temporal variability. The predictions of these models will then be compared with measurements using the Aerosol Mass Spectrometer (AMS) at several sites from MILAGRO.

In order to improve on uncertainties relating to the indirect effects of aerosols on climate, ACD scientists have added a new aerosol scheme using a modal approach to the global models. Current evaluations of this scheme focus on evaluating warm cloud indirect effects, and on adding ice cloud formation to the models.

return to top

Model physics

Diffusion	Constant 3d Turbulent Kenetic Energy 3d Smagorinsky 2d Smagorinsky
Shortwave Radiation	Dudhia (MM5) Goddard CAM GFDL
Longwave Radiation	RRTM CAM GFDL
Surface Layer/Boundary Layer	Yonsei University PBL Mellow-Yamada-Janjic PBL ACM2 PBL MRF PBL
Land Surface	5-layer Thermal Diffusion Noah LSM RUC LSM Pleim-Xiu LSM
Cumulus Parameterization	Kain-Fritsch (new and old versions) Betts-Miller-Janjic Grell-Devenyi Grell-3
Microphysics	Kessler Lin et al. WRF Single Moment (WSM3, WSM5, WSM6) Eta (Ferrier) Thompson Goddard Morrison 2-moment

Figure: For Version 3.0, highlights of the new physics development included the ACM2 PBL, and PX LSM from scientists at the EPA (Environmental Protection Agency), the new Grell-3 cumulus scheme from NOAA/ESRL, the NASA Goddard microphysics scheme, and the Morrison 2-moment microphysics scheme.

High resolution figure

The Weather Research and Forecasting (WRF) Model is being used in an increasingly wider set of applications as computing power improves. WRF was developed as a community mesoscale model for numerical weather prediction, case studies, and idealized simulations, and as a tool for related applications such as air-quality research and forecasting. Some examples of newer applications that have resulted from improved computing resources are real-time cloud-resolving forecasting, including moving-nest hurricane forecasting, and nested regional-climate modeling. With these applications come new priorities in physics development to enable better hurricane and regional-climate modeling. These priorities fit with several of ESSL's priorities, including those of weather prediction and simulation across scales. Furthermore the aim of providing the university research community with a relevant up-to-date modeling system is met by continually updating the model to make use of the new capabilities in the current computing era, and improvements in model physics form one critical aspect of this development.

WRF already has a large set of physics options designed for its range of uses, from fast-physics packages for operational uses, to more complex packages for scientific studies. The table shown summarizes the current WRF physics options available to the ARW dynamical core as of its last release (Version 3.0) in April 2008. Version 3.0 also included a new global model capability, and extended the large-eddy simulation (LES) PBL capability to interact with land-surface fluxes.

Ongoing physics collaborations exist with NCEP, NASA Goddard, the EPA, NRL, NOAA/ESRL, the Pacific Northwest National Laboratory, Colorado State University, UCLA, the University of South Florida, University of New Mexico, and YonSei University (Seoul, Korea), as well as across the NCAR Divisions and Laboratories. Many of these reached fruition with more options for the WRF user community in the Version 3.0 release. Support for this work included NSF, KMA, AFWA, ARO, and the FAA.

Plans for FY09 include further collaboration with the CCSM modeling group to include some CCSM physics options and capabilities for regional-climate simulations. Also gravity-wave drag and spectral-nudging capabilities are being developed in addition to more physics options including sub-grid turbulence, radiation and microphysics development in a variety of collaborative projects.

return to top

Chemistry-climate coupling: Past and future

1. Lower stratospheric trends

In continuation of the work performed under FY2008, we have expanded our analysis of the lower stratospheric as simulated by CAM-chem (paper published in Journal of Geophysical Research, 2008). In this subsequent

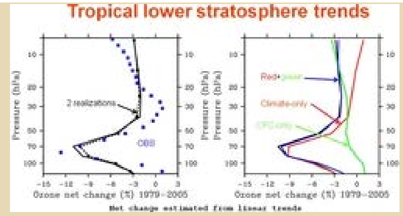


Figure 1.

High resolution figure

analysis, we focus on the understanding of the trend in the lower stratospheric tropical (20°S-20°N); using different simulations with different subsets of forcing agents we show that, based on this model, climate change (as identified here by changes in CO2 and sea-surface temperatures) is the largest contributor to the ozone trend in that region, much larger than the contribution of ozone-depleting substances; this work is submitted to Geophysical Research Letters. Additional studies will be performed during FY2009; in particular, focus will be given on changes in the width of the tropics and changes in tropospheric composition. This work was funded by DOE.

2. Impact of sectoral emission change

In support of the US Climate Change Science Program (DOE), we have performed and analyzed in collaboration with NASA-GISS and NOAA-GFDL a series of simulations where emissions from specific sectors (transportation for example) are reduced by 30% over a specific region. This is to identify the potential chemistry and climate impact regional pollution control measures; in particular, over the United States, transportation is the sector which has the largest impact. This work in submitted to Atmospheric Chemistry and Physics Discussions. This work was funded by DOE.

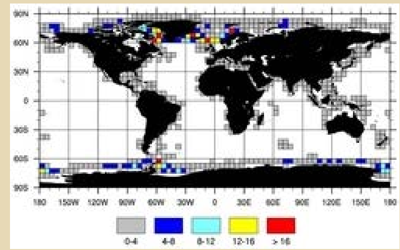


Figure 2. Geographical distribution (averaged over a 5° latitude-longitude grid) of the model-mean potential methane flux (in Tg(CH4)/year) at the bottom of the ocean based on the 100-yr temperature increase from each model.

High resolution figure

3. Methane clathrates

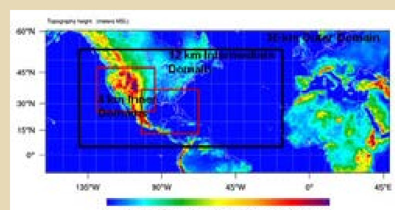
In continuation of the work performed under FY2008, we have furthered our investigation of the potential role for methane clathrates to act as a strong methane source during the 21st century. Using a combination of model simulations from IPCC AR4 and model results for under the seafloor methane destabilization, we show that it is unlikely that methane from clathrate destabilization will be a strong source of methane by the time CO2 as doubled over pre-industrial conditions (i.e. second half of 21st century). This work is in press in Geophysical Research Letters. This work was funded by DOE.

return to top

Prediction across scales

Overview

The Prediction Across Scales initiative is a collaborative effort between CGD and MMM to coordinate research and system development activities across weather and climate scales. Recent major advances in petascale computing coupled with rapid advances in scientific understanding are enabling progress in simulating a wide range of physical and dynamical phenomena with associated physical, biological and chemical feedbacks that collectively cross the traditional weather-climate divide. Such simulations and predictions are essential to a society that is becoming much more sophisticated in its requirements for weather, air quality and climate predictions and that is able to make useful economic and social use of such improvements. Moreover, fundamental barriers to advancing such prediction on time scales from days to years, as well as long-standing systematic errors in weather and climate models, are partly attributable to our limited understanding and capability to simulate the complex, multiscale interactions intrinsic to atmospheric and oceanic fluid motions. The scientific and societal questions and issues to be addressed are many. A limited sample includes better understanding of



Domain configuration for the latest NRCM runs. The outer domain will be coupled to CCSM-3 IPCC archived runs, while the intermediate and inner domains will use standard ARW coupling.

High resolution figure

- The water cycle and its predictability, particularly the limitations of available water and the impacts on food production;
- The limits of weather, air quality and climate predictability including the impacts of mega-cities and the stressed Earth's capacity to sustain quality of life;
- The interaction of hydrological, chemical and biogeochemical cycles and their feedback on weather/climate processes;
- The mechanisms by which solar variations influence the chemistry and dynamics of the upper atmosphere, and how these effects are manifested in the lower atmosphere;
- The interactions between climate change, ENSO and other natural modes of variability, including changes to the

behavior of phenomena like hurricanes; and

- The mechanisms of abrupt climate change and potential tipping points.

The enabling tool for much of this research will be a community Nested Regional Climate Model (NRCM). The result of this ambitious effort to combine high resolution regional atmosphere and ocean models with a state-of-the-science climate model will be fundamental progress on the understanding and prediction of regional climate variability and change. In particular, embedding Advanced Research WRF (ARW) and a Regional Ocean Model System (ROMS) within CCSM will allow scientists to resolve processes that occur at the regional scale, as well as the influence of those processes on the large-scale climate, thereby improving the fidelity of climate change simulations and their utility for local and regional planning.

Recent Accomplishments

As a first step toward the development of NRCM, NCAR and community scientists completed a 1995-2005 simulation of the tropical circulation with the NRCM configured in a channel mode at 36 km resolution using NCEP/NCAR reanalysis data on the poleward boundaries and specified surface conditions. A set of comparative simulations were also made using the atmospheric component of CCSM at T170 resolution configured in a similar channel mode with relaxation towards reanalysis in the polar regions. In addition, several high resolution two-way interactive simulations inside the channel model were completed, including high resolution nested domains over the Maritime Continent and the North Atlantic. These simulations utilized NCAR, NASA and DOE computing resources, and they are currently being analyzed by a number of NCAR and external scientists. The results will be featured in a special issue of Climate Dynamics in 2009.

In addition, progress was made over the past year nesting of ROMS within CCSM in two-way interactive mode. Initial experiments were conducted in the eastern Pacific Ocean with the goal of improving the poor performance of climate models in this region. This work will also provide a platform to include higher trophic level marine ecosystem models into CCSM.

2009 and Beyond

A new set of simulations began in FY2008 and will continue into FY2009 through the support of CISL. These experiments are designed to study the potential impacts of climate change on North Atlantic hurricane activity and on water resources over the intermountain West. They consist of a series of one-way nested simulations with interior ARW domains at ~4 km resolution over the intermountain West and the Gulf of Mexico. A coarser resolution (36 km) domain encompasses both regions, as does a higher resolution 12 km domain (Figure 1). The large-scale forcing data is provided from A1B and A2 scenario CCSM-3 T85 integrations using a time-slice approach, which will allow an examination of the fidelity of the simulation against current climate as well as project likely future changes in regional weather statistics. The results will be used to advise two communities on potential climate changes:

- vulnerable coastal communities and the offshore oil industry on potential changes in hurricane intensity and frequency in the Gulf of Mexico over approximately the next 50 years; and,
- a diverse group of stakeholders (government planners, water managers, terrestrial ecologists, etc.) on the changes in water resources in the western Intermountain states.

More generally, the experiments will:

- allow a further assessment of the skill of ARW for climate applications at high resolution over both tropical and extratropical domains, which is important for future model development as well as the ultimate NRCM goal of two-way nesting ARW within CCSM;
- draw into NRCM a much larger base of "earth system scientists", all of whom require climate data on scales of a few kilometers (or less); and,
- produce unique data sets of a climate change scenario that would be of immense interest to many stakeholders.

return to top

Climate and tropical cyclones

The impact of climate change on hurricanes has continued to be investigated and expanded to include the upscale influence of hurricanes on climate. An earlier study that showed a marked increase of 50% in the global proportion of the most intense hurricanes, which caused considerable controversy, has been validated by a new study using a completely independent data set. A further study has shown that the North Atlantic is now experiencing 2-3 times the proportion of category 5 hurricanes compared to previous activity. A major new modeling study with the NRCM to investigate future hurricane changes and variability has commenced with support from the Willis Research Network and the Research Partnership to Secure Energy for America. This includes NRCM projections at resolutions of 12 and 4 km, sufficient for the first time to resolve the intensity and structure of major hurricanes. A new study has provided a strong indication that hurricanes may have a substantial upscale role on climate through their

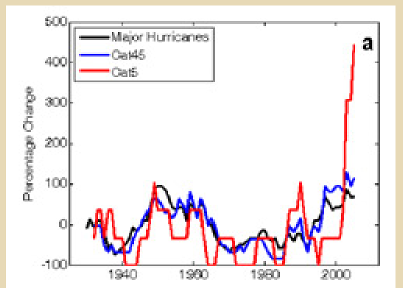


Figure: Variation in Major Hurricanes, Cat 4 and Cat 5 Hurricanes and Cat 5 Hurricanes for the North Atlantic as percentage change vertical and horizontal transports of energy.

return to top

from the long-term mean (smoothed by a running 5-y filter, showing the unprecedented recent increase in category 5 hurricanes.

High resolution figure

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ESSL LAR 2008: STRATEGIC GOAL #1, PRIORITY #3

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #1, Improve understanding of the atmosphere, the Earth system, and the Sun. This Strategic Goal encompasses four Strategic Priorities, each of which is dependent on the efforts and accomplishments of ESSL staff.

ESSL developed an action plan with seven priority themes which involve direct partnerships with the university community and contribute directly to the ESSL Strategic Vision and to several priority items of the NCAR Strategic Plan.

ESSL's seven priority themes:

1. Climate projection, with emphasis on short-term prediction.
2. Biosphere-Atmosphere-Hydrosphere interactions and specifically development of BEACHON Project (Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, Hydrology, Organics and Nitrogen).
3. Water system research, specifically the development of the Society, Water, Atmosphere and Natural Systems Project (SWANS).
4. An advanced Weather Research and Forecasting system, specifically the development of the Hurricane Intensity and Forecasts (HiFi) Project.
5. Space Weather, specifically the development of the Coronal Solar Magnetism Observatory Project (COSMO).
6. Chemical Weather, including interpretation of observed data gathered during the Megacity Impact on Regional and Global Environments (MIRAGE) campaign, and the development of a capability for chemical data monitoring and prediction.
7. Prediction across scales, specifically the development of an advanced next-generation, climate-weather modeling system and an integrated Earth system model of intermediate complexity.

Goal #1, Priority #3: Improving Prediction of Weather, Climate, and Other Atmospheric Phenomena, is described in the NCAR Strategic Plan as follows: "Understanding of the Earth system is a prerequisite to predicting its behavior, the latter being, however, of a more direct use to many components of society. In that context, for this priority, the key activities within NCAR's laboratories range from improving climate models, to exploring new approaches to prediction across scales, and global and local weather prediction."

This NCAR priority, driven by ESSL's themes 1, 3, 4 & 7, is critical to achieving NCAR's first strategic goal.

The section below describes specific research conducted by ESSL staff under projects relevant to Priority 3. The major ESSL activities in this area involve studies designed to improve prediction of weather, climate, and atmospheric chemistry. The activities center around the use and evaluation of the Weather Research and Forecasting/Advanced Research WRF (WRF/ARW) model, the Community Climate Systems Model (CCSM), and the Nested Regional Climate Model (NRCM).

Weather Research and Forecasting Model/Advanced Research WRF (WRF/ARW)

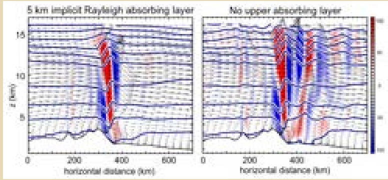


Figure: 30 h ARW forecast for mountain waves over the eastern slope of the Colorado Rockies on 05 December 2007 06 UTC. Updrafts and down drafts are depicted with red/blue shading and potential temperature is contoured with 10 K intervals. Left panel: forecast with 5 km implicit Rayleigh absorbing layer beneath the upper-domain boundary; Right panel: forecast with no upper absorbing layer.

High resolution figure

The overall goal of the WRF model project is to develop a next-generation mesoscale forecast model and data-assimilation system that will advance both the understanding and prediction of mesoscale weather and accelerate the transfer of research advances into operations. WRF has been developed as a collaborative effort among NCAR (ESSL, MMM Division), NOAA's National Centers for Environmental Prediction (NCEP) and Earth System Research Laboratory (ESRL), the Department of Defense's Air Force Weather Agency (AFWA) and Naval Research Laboratory (NRL), the Center for the Analysis and Prediction of Storms (CAPS) at the University of Oklahoma, and the Federal Aviation Administration (FAA), along with the participation of numerous university scientists. WRF is intended to improve the forecast accuracy of significant weather features across scales ranging from cloud to synoptic, with priority emphasis on horizontal grids of 1–10 kilometers. The model incorporates advanced numerics and data-assimilation techniques, a nesting capability supporting multiple and moving grids, and a range of physics options, particularly for treatment of convection and mesoscale precipitation systems. It is well-suited for a wide range of applications, from idealized simulations to operational forecasting, with the flexibility to accommodate a range of potential enhancements.

MMM scientists instigated the WRF endeavor a decade ago to promote closer ties between research- and operational-model development. Since then, WRF has matured to become the most popular mesoscale model in the world. MMM has led the development of the WRF software infrastructure and the Advanced Research WRF (ARW) dynamic core and maintains and supports the system for the research community. The WRF effort provides the primary facility for supporting the NCAR strategic priority of investigation of the dynamics and predictability of weather systems on time scales of 0–48 h. In addition, it furthers NCAR’s mission to provide and support state-of-the-art modeling systems for broad use in the research community.

Within MMM, project activities are distributed across three areas: 1) development and enhancement of WRF capabilities to meet the needs of MMM and community-research objectives; 2) research to advance the understanding and prediction of high-impact weather systems; and 3) model support to the research community. The effort is ongoing as the WRF system evolves to meet future requirements for advanced weather research and forecasting, while timelines attend deliverables in specific funded projects and in commitments to provide modeling capabilities for MMM and the research community.

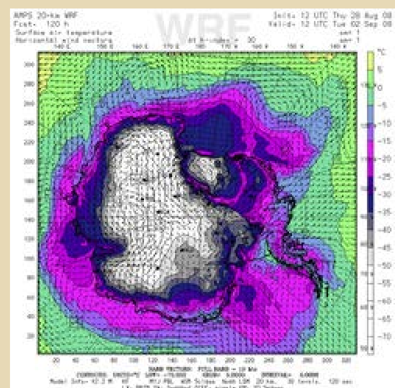


Figure: 120-hr forecast of surface temperature (°C) over Antarctica using Polar WRF. Surface winds full barb= 10 kts) also shown. Forecast initialized at 120 UTC 28 August 2008.

High resolution figure

During the past year, NCAR continued to develop new capabilities for the ARW and support it to the community. Over 2000 new users registered to download the code, bringing the total number of registered users to over 7,600. Over half of this total is non-US users, and 113 countries are represented. In June 2008 MMM organized and conducted the 9th Annual WRF Users’ Workshop, with over 225 participants attending from many different countries. MMM personnel also conducted three user tutorials on the ARW and WRF-VAR. Two ARW tutorials were in Boulder, with approximately 60 persons, while another was in Seoul, Korea. Operational forecasting with the ARW continued at NCEP and AFWA (worldwide regional theatres), as well as a number of international operational applications. MMM manages the WRF code repository, assists community researchers in development, coordinates additions to the repository, and oversees the code integration and testing for new releases. This past year, MMM released WRF Version 3.0 (April 2008). Key features of V3.0 included:

1. Global ARW;
2. Unified WRF and WRF-Var codes;
3. WRF-Chem;
4. New and modified microphysics and cumulus schemes;
5. Streamlined infrastructure and memory utilization;
6. New and modified land-surface and PBL schemes;
7. Upper-boundary gravity-wave-absorbing layer; and
8. Simple ocean mixed-layer model.

Improvements were made to the WPS (WRF Preprocessing System) and numerous bugfixes and enhanced support for a range of computing platforms were included.
As part of the ARW V3.0, a new technique has been developed and implemented to mitigate the artificial reflection of gravity-wave energy from the upper boundary of the model domain, which is well suited for

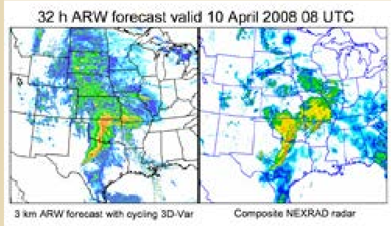


Figure: 32 h ARW forecast (left panel), valid 10 April 2008 08 UTC, for simulated radar reflectivity using cycling 3D_Var for model initialization in comparison with observed radar reflectivity (right panel).

High resolution figure

NWP applications. In this method, an implicit Rayleigh damping term is applied only to the vertical velocity in a split-explicit time integration, as a final adjustment at the end of each small (acoustic) time step. The adjustment is equivalent to including an implicit Rayleigh damping term in the vertical momentum equation together with an implicit vertical diffusion of w. This implicit damping for the vertical velocity is unconditionally stable and remains effective even for hydrostatic gravity waves. The good absorption characteristics of this absorbing layer across a wide range of horizontal scales is confirmed though analysis of the linear wave equations, simulations of idealized mountain-waves, and through NWP applications, as reflected by the simulation of mountain waves over the Colorado Rocky Mountains shown in Figure1.

MMM continued to apply the ARW in the Antarctic Mesoscale Prediction System (AMPS) for real-time NWP support for the United States Antarctic Program. Over the past year MMM personnel have incorporated WRF polar modifications developed with collaborator The Ohio State University into WRF V3.0. “Polar WRF” has been tested and found to be superior to regular WRF and to Polar MM5, and MMM has now switched to using the Polar WRF in its AMPS forecasts. The modifications include fractional sea-ice representation and changes to surface characteristics to better capture the conditions of ice sheets. Figure 2 presents an example of a 5-day forecast of surface temperature over Antarctica (20-km grid) using Polar WRF. Polar WRF 3.0.1 is now being implemented into the current version of AMPS. The AMPS group at NCAR has a plan to incorporate the ARW polar mods into the WRF repository, and thus to make Polar WRF available to the community in the next major release (Spring 2009).

MMM has continued to assess and enhance the accuracy of forecasting convective weather systems through real-time convection-resolving forecast experiments with WRF. In support of the NOAA Hazardous Weather Testbed (HWT) 2008 Spring Experiment , MMM ran daily, convection-permitting (3-km grid), real-time forecasts over the central US for the 10 April–6 June period. This year, for the first time, the runs were initialized using WRF-Var, a 3-dimensional variational data assimilation system, with the goal of evaluating the potential benefits of using WRF-Var for initializing the high-resolution ARW runs, as opposed to initializing from gridded operational analyses. To this end, a 9-km ARW run was initialized at 1200 UTC using the GFS, and then cycled every 3 h to produce initial conditions at 0000 UTC (interpolated from 9 km to 3 km). An example of an ARW forecast from this spring experiment is shown in Figure 3. One of the more significant factors in the new approach is that explicit precipitation from the 9-km cycled forecast is now included in the initialization, which was not possible in the “cold start” procedures used in prior years. For many of the cases, this explicit precipitation initialization improved the forecast over the first six hours, as the model did not have to spin up precipitation starting from 0000 UTC. However, the approach also contributed to a number of forecast failures, particularly when the 12-h forecast precipitation features from the 9-km grid did not sufficiently reflect the observed features. This revealed a significant weakness of 3DVAR cycling in the absence of assimilating radar data, which could not be incorporated this year due to time and computer resource constraints. These experiences with WRF-Var will help guide plans for next year’s real-time forecast exercise, in support of the VORTEX2 field program.

Last year’s goals for the ARW effort included assisting domestic and international users of the ARW, conducting the 9th WRF Users Workshop in June 2008 and tutorials in January and July 2008, and a major new release, V3.0. All of these were accomplished. In addition, Global ARW was not only tested, but also released in V3.0, and a new tech note for V3.0 was published. For better management of the WRF code, MMM finalized and published procedures for the administration of the repository and of releases. It also published information for code contributors. Plans for next year include a major release in Spring 2009, the 10th WRF Users’ Workshop, tutorials in Winter and Summer, and continued community support.

The WRF modeling system will continue to serve as a versatile scientific tool for the weather- and climate-research communities. It is a high-performance computational model that scales well from single-processor environments to massively parallel petascale applications. In addition to being a state-of–the-art weather prediction model, it has been adapted to atmospheric chemistry, air quality, and nested regional-climate applications. The successful migration of WRF into operational forecasting yields significant economic and societal benefits. Supporting WRF for widespread community use greatly leverages resources by allowing researchers access to a sophisticated atmospheric tool without a large resource investment, but with the opportunity to contribute to, and benefit from, the advancement of a common modeling system.

The WRF effort within MMM is supported by NCAR/NSF base funds through the MMM budget and USWRP resources, from the NSF Office of Polar Programs, and from outside-funded projects with AFWA, the FAA, and CWB and CAA (Taiwan).

return to top

Community Climate Systems Model: Advancing Climate Science

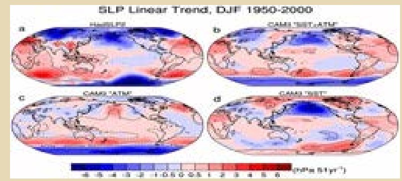
Overview

Each year much effort is devoted to further development of the Community Climate Systems Model (CCSM) and those efforts in and of themselves can lead to discoveries about the processes that contribute to climate and its fluctuations. Beyond this, even more is learned about the climate system by applying the CCSM to various outstanding problems concerning the character of the climate and the mechanisms that control its behavior. To this end, members in every section of CGD use the CCSM to investigate a broad range of issues. Below are examples that demonstrate the breadth of topics considered in FY2008.

Recent Accomplishments

CAM3

CAM3, the atmospheric component of CCSM, was been used to attribute the causes of observed atmospheric circulation trends during the second half of the 20th century, in particular the relative roles of direct atmospheric radiative forcing (due to observed changes in greenhouse gases, tropospheric and stratospheric ozone, sulfate and volcanic aerosols, and solar output) and observed sea surface temperature (SST) forcing. CAM3 realistically simulated the observed sea level pressure trends when both types of forcing were considered (upper panels of Fig. 1). Additional experiments showed that direct radiative forcing and observed SST forcing drive distinctive circulation responses that contribute about equally to the global pattern of observed circulation trends (lower panels of figure below). In particular, radiative forcing accounted for much of the observed sea level pressure trends in the high latitude southern hemisphere while SST forcing accounted for the observed sea level pressure trends over the north Pacific and tropics.

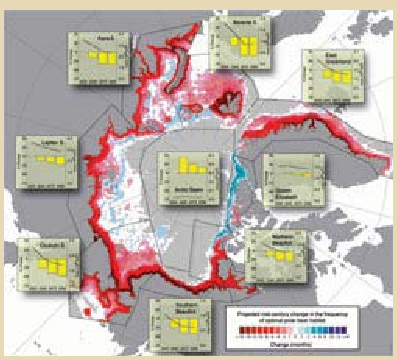


Linear trends (color shading; hPa per 51 yrs) of December-February SLP during 1950-2000 from observations (HadSLP2; upper left) and CAM3 model simulations forced with observed SSTs and atmospheric radiative changes (upper right), observed SSTs only (lower right) and atmospheric radiative changes only (lower left). Dashed contours indicate trends that are significantly different from zero at the 95% level.

High resolution figure

CCSM: Polar Regions

The CCSM project continued to take a lead on model developments for polar regions and on studies related to polar climate variability and change. This included the investigation of mechanisms leading to rapid summer Arctic ice loss in CCSM simulations, the potential that these represent "tipping point" or threshold behavior, and the effect that these events have on terrestrial warming and permafrost conditions. Studies using CCSM also assessed Arctic freshwater budget change, with indications that the Arctic hydrological cycle is and will continue to intensify in a warming climate. In related work, CCSM was used to assess the impact that large freshwater discharge has on thermohaline circulation change under present-day and Last Glacial Maximum climate states. Additionally, CCSM simulations were used to study ecosystem impacts in polar regions. Most notably, the CCSM project contributed to studies that resulted in the listing of the polar bear as a threatened species under the Endangered Species Act.



Projected changes (based on 10 IPCC AR-4 GCM models run with the SRES-A1B forcing scenario) in the spatial distribution and integrated annual area of optimal polar bear habitat. Base map shows the cumulative number of months per decade where optimal polar bear habitat was either lost (red) or gained (blue) from 2001-2010 to 2041-2050. Offshore gray shading denotes areas where optimal habitat was absent in both periods. Insets show the average annual cumulative area of optimal habitat (right y-axis, line plot) for four 10-year periods in the 21st century (x-axis midpoints), and their associated percent change in area (left y axis, histograms) relative to the first

Climate predictability

Past investigations of climate change often focused on century timescales, but nearer term changes are of equal interest to society and scientifically distinct in that the initial state of the system may influence its evolution. To estimate the predictability of climate on decadal time scales an ensemble of integrations was performed with CCSM in which the years 2000 to 2062 were simulated. Each realization was forced by the same SRES A1b sequence of climate forcings, but each had a different initial atmospheric state. Due to the chaotic nature of the climate system, the evolution of the state of all model components varied markedly from one realization to another, but there were indications of predictable phenomena in the experiment. For example, the ensemble mean of the Pacific Decadal Oscillation had a predictable signal for more than 40 years.

2009 and Beyond

Applications of CCSM will continue on a wide range of topics. Examples related to the investigations outlined above include:

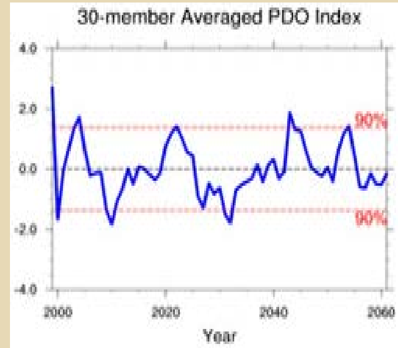
Attribution of atmosphric circulation: The work on attribution of atmospheric circulation trends with CAM will be continued in FY09 to include future climate states simulated by the CCSM model under the SRES A1B scenario. In addition to prescribing the full SST and atmospheric radiative forcings in CAM for the next 50-100 years, the forcings will also be decomposed into their natural and anthropogenic components for enhanced attribution.

Continuted terrestrial carbon cycle model development: There will be continued development of the terrestrial carbon cycle model, including additional capabilities to simulate dynamic vegetation, anthropogenic land decade (2001-2010).

High resolution figure

cover change, croplands, wildfire, and biogeochemical cycles. As the model matures, a primary scientific theme will be to examine natural and human-mediated changes in land cover and ecosystem functions and their effects on climate, water resources, and biogeochemistry.

Polar region model development: Numerous model improvements targeted at polar regions will be included in the next generation CCSM model. These include improved sea ice albedo parameterizations, permafrost dynamics, dynamic vegetation processes, and cloud microphysics, among others. This will allow for more reliable polar climate simulations. Additionally, it will enable new research on the role of these processes in climate variability and change. For example, the incorporation of black carbon cycling within the sea ice and terrestrial snow components will permit us to assess the role that increased soot deposition has played in the warming Arctic climate. In the longer-term, the incorporation of an ice sheet model within the CCSM system, which is currently underway through a collaborative effort with the Los Alamos National Laboratory, will allow improved simulations of sea level rise and the influence of ice sheet change on climate.



Evolution of an index of the Pacific Decadal Oscillation in the ensemble average of 30 integrations of CCSM3.0 each of which is driven by SRES A1b forcing.

High resolution figure

Predictability signatures: The ensemble of SRES A1b scenario integrations will be further expanded so that signatures of predictability can be detected with greater levels of significance. And the dynamical mechanisms and atmosphere-ocean interactions that contribute to the decadal predictability will be diagnosed and compared to existing theories of intrinsic modes of North Pacific variability. Moreover, studies of decadal predictability in other basins will be furthered.

return to top

U.S. Weather Research Program / Short Term Explicit Prediction Program (USWRP / STEP)

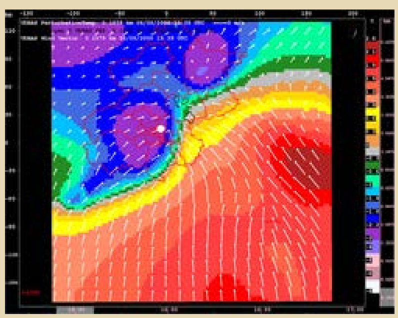


Figure: VDRAS real-time analysis of the perturbation temperature field and horizontal wind (vectors) at the altitude of 0.187 km for Aug. 8, 2008, the day of the Olympics opening ceremony was held in the Bird's Nest National Stadium (marked by the white dot). The black contours show the 30 dBZ reflectivity and the red lines show the Beijing districts. The convective cells are initiated in the region between two cold pools from previous convection. The cold pool southwest of the convective cells was a result of a storm that dissipated before reaching the stadium.

High resolution figure

The Short Term Explicit Prediction (STEP) Program (http://www.mmm.ucar.edu/STEP) is a multi-NCAR-Laboratory activity to improve the short-term forecasting of high-impact weather such as severe thunderstorms, winter storms, and hurricanes. Improving short-term forecasts of such weather can have significant societal and economic benefits, including: (1) reduced fatalities and injuries due to weather hazards; (2) reduced private, public, and industrial property damage; and (3) improved efficiency and savings for industry, transportation, and agriculture. The STEP Program is also being stimulated by the significant advancement in a number of fields that are required to make progress in this area. These include the ability to observe the four-dimensional structure of the atmosphere, the development of new data-assimilation techniques, such as 3DVar/4DVar and the Ensemble Kalman Filter (EnKF), and the continuing development of numerical-modeling systems, such as the Advanced Research/Weather Research and Forecasting model (WRF/ARW), which can be run at grid resolutions that properly represent the physical processes critical to the production of such hazardous weather. The program includes research into basic understanding of high-impact weather systems, development of forecast techniques, real-time testing of forecast systems, verification, and interaction with users. This collaborative effort incorporates national and international scientists, engineers, and operational personnel from universities, government institutions and the private sector.

The primary activity for STEP this year was the collaborative effort on an IHOP retrospective study. STEP scientists specializing in various topics, ranging from mesoscale observation analysis, automated nowcasting, high-resolution data assimilation, high-resolution WRF-ARW modeling, and convective precipitation verification, participated in the study. A workshop was conducted in July 2008 to report on progress for each project and to discuss future coordination and publication of the results. In order to better accomplish the STEP goal as stated in the STEP strategic plan, a process to redistribute the STEP funds for FY08 and 09 funding cycle was conducted. On the research level, a wide range of activities which are central to STEP research goals, and which involve MMM, RAL and EOL scientists have been ongoing over the past year(s). Within MMM, WRF/ARW development efforts continued to be a critical component of STEP, offering a range of new capabilities, from improved numerics and physics to new data-assimilation systems that can address the short-term forecast problem. The data-assimilation systems based on 3DVar, 4DVar, and EnKF techniques continued to be developed, and research on the inclusion of radar observations into these systems was emphasized for the STEP program.

Other than the variety of basic research and development, one of the major themes in STEP is to demonstrate high-resolution forecasting systems in real time. In collaboration with the Spring 2008 SPC/NSSL Hazardous Weather Testbed experiment, WRF/ARW was run at a 3-km horizontal grid resolution over the central U.S. to produce explicit 0-36 hour convective-weather forecasts. The WRF/ARW run was initialized by the 3DVAR data-assimilation system with a 9-km resolution. These forecasts were evaluated by forecasters and researchers from across the country, and exhibited noticeable improvements over past years, especially as regards the representation of convective precipitation. STEP's nowcasting system and the radar data assimilation system VDRAS were demonstrated in Beijing during the Olympics 2008 as part of the WMO sponsored Olympics forecasting demonstration project. VDRAS produced 3-km wind, temperature, and humidity analyses updated every 12 minutes. A number of STEP scientists participated in the planning and the actual execution of the Terrain-induced Monsoon Rainfall Experiment (TiMREX) which was conducted in southwest Taiwan.

In the coming year, the IHOP retrospective studies will be completed and a number of publications will be written to summarize the results. A workshop will be held in December to present findings from these studies. Comparisons will be made to evaluate strengths and weaknesses of each data assimilation, nowcasting, and forecasting systems and the impact of including radar in the assimilation. Efforts at developing new techniques for verifying high-resolution forecast guidance will be continued. Future development of verification will focus on this inter-comparison to understand the strengths and weaknesses of different approaches. Efforts on studies of convective weather dynamics based on observations and model results will also be continued.

return to top

Data assimilation / ensembles

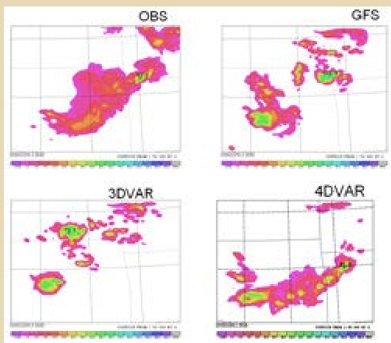


Figure: Six-hour forecasts of hourly precipitation from three experiments of a 4km WRF with different initial conditions for an IHOP case compared with Stage IV data (OBS). GFS: initialized by GFS analysis; 3DVAR: initialized by WRF 3DVAR with radar data; and 4DVAR: initialized by WRF 4DVAR with radar data.

High resolution figure

Data assimilation is the process of combining observations and a previous forecast to provide a gridded estimate of the atmospheric state at a certain time. These estimates can then be used as initial conditions for subsequent forecasts or as tools to analyze and understand the atmosphere. While much progress has been made at global scales, data assimilation for scales of less than a few hundred kilometers (the "mesoscale," where most severe and damaging weather occurs) remains a significant open problem in atmospheric science. Mesoscale data assimilation is especially challenging for two reasons. First, mesoscale motions are intimately coupled to complex physical processes such as those involving moisture, cloud and rain or interaction with the land or ocean surface. These processes are difficult to represent accurately in numerical models. They also lead to distinct and strongly nonlinear dynamics at the mesoscale, so that balances between mass and wind, which pertain at large scales in the atmosphere and underlie global data assimilation schemes, are questionable at the mesoscale. Second, observations that are plentiful (e.g., Doppler radar measurements of wind and reflectivity) involve only a subset of atmospheric variables, while observing platforms that measure all relevant variables (i.e., radiosondes) are sparse and resolve mesoscale motions poorly. To overcome these difficulties, there has been substantial effort within ESSL/MMM to advance mesoscale data assimilation.

A significant component of these efforts has been to build, and support for the community, a data assimilation facility for WRF based on variational assimilation techniques, known as WRF-Var. The WRF-Var system continues to be widely used in research at universities and as the basis for operational assimilation system development at the U.S. Air Force Weather Agency (AFWA) and several other operational centers internationally. WRF-Var has been extended from three to four dimensions (WRF 4D-Var) to meet the increasing demand for improving initial model states in multi-scale and time-dependent numerical simulations and forecasts. WRF 4D-Var uses the WRF model adjoint as a constraint to impose a dynamic balance on the assimilation. It has been demonstrated to evolve the background error covariance and produce the flow-dependent analysis increments. Recent experiments with Doppler-radar observations have shown the potential of WRF 4D-Var for high-resolution assimilation with explicit representation of moist convection (Fig. 1). These results illustrate clear advantages of 4D-Var over the existing 3D-Var for this problem.

ESSL/MMM also has a strong research program in the area of ensemble-based data assimilation. In collaboration with the Data Assimilation Research Section within CISL/IMAGe, an ensemble Kalman filter for WRF has been developed within the Data Assimilation Research Testbed; this assimilation system is known as WRF/DART. Assimilation of Doppler-radar observations is also an emphasis of WRF/DART research and multiple case studies using WSR-88D observations of severe convective storms have been completed. These case studies indicate an overall analysis quality comparable to or better than traditional dual-Doppler retrievals, besides providing gridded analysis of WRF’s microphysical and thermodynamic variables. Several areas important for continued improvement of radar assimilation have also been identified. Most crucial are better representations of forecast-model errors in the assimilation process and the extension to larger domains to include multiple spatial scales, spanning both meso- and convective-scale motions.

return to top

THe Observing-system Research and Predictability EXperiment (THORPEX)

Figure 1

High resolution figure

THORPEX seeks to reduce and mitigate the effects of natural disasters on society by transforming timely and accurate weather forecasts into specific and definite information in support of decisions that produce the desired benefits.

One aspect of the TIIMES mission is to be the administrative home of programs that cut across the divisional and laboratory structure of NCAR. One such effort is THORPEX (The Observing-System Research and Predictability Experiment), which is a long-term effort within the World Meteorological Organization's World Weather Research Program (WMO/WWRP). The overarching goals of THORPEX are to accelerate both the forecast skill of high impact weather events on the 1 to 14-day time scale and utilization of forecast information. THORPEX research is meant to benefit society, the economy and the environment with one focus to mitigation of disasters in the developing world. While THORPEX was designed to concentrate on the 1 to 14-day time-scale, THORPEX is also developing collaborations with the World Climate Research Program for time-scales that fall between the time-scales of numerical weather prediction and climate projections. These time-scales include seasonal prediction and longer subseasonal time-scales, such as the Madden Julian Oscillations. The THORPEX and the WCRP collaboration includes research on topics of mutual interest (e.g., improving the characterization in numerical models of a variety of processes that include tropical convection, polar precipitation events and the triggering and enhancements of Rossby wave trains).

TIIMES has hosted both the US THORPEX Project and the co-chair of the North American THORPEX Regional Committee until 28 February 2008. David Parsons held both these posts. He is now on a Collaborative Visit to the WMO to become the Chief of the WWRP and Manager of the THORPEX International Project Office. The THORPEX research effort in the US already has significant participation within the university community and the effort has the potential to involve weather and climate researchers within ESSL at NCAR and the activities of CISL, RAL and SERE. One aspect of THORPEX is to move the user and research community from relying on deterministic forecasts to ensemble forecast systems that better represent the uncertainty in simulations of the non-linear, partly chaotic nature of the atmosphere. During the past year, NCAR CISL initiated an archive of the ensemble members of the ensemble global forecasts of the major operational forecast centers, which when fully operational will include ~256 ensemble members produced daily for forecast periods from 1 to 14-days. The archive includes the basic model derived parameters as well as derived parameters that are of interest to researchers. This ensemble archive is called TIGGE (THORPEX Interactive Grand Global Ensemble). TIGGE is well utilized by the research community as, for example, over hundred users have registered.

Figure 2

High resolution figure

Parsons was also the Principal Investigator for two major international field experiments with accompanying numerical modeling efforts called THORPEX Pacific Asian Regional Campaign (T-PARC) and CONCORDIASI until he took on the position of international oversight of THORPEX and the WWRP. The goals of T-PARC are to advance understanding and improve prediction of i) high impact weather over the western Pacific and east Asia with a focus tropical cyclones from genesis to extratropical transition (ET) or decay; ii) downstream high impact weather events over North America, the Arctic and Europe whose dynamical roots and forecast errors are over the western Pacific and east Asia. The tropical cyclone and ET phases of T-PARC took place from August to early October 2008. A winter phase planned for January to March 2009. T-PARC, and a collaborative Office of Naval Research project called TCS-08 (Tropical Cyclone Structure) experiment is one of the largest coordinated efforts of the international research and operational community to address tropical cyclones in the Pacific and their impacts on downstream flow.

The CONCORDIASI project has begun and will end in early October 2009. This program has multi-disciplinary goals, such as i) more accurate representation of the atmosphere over Antarctica through advancing satellite data assimilation for weather prediction and the climate record, ii) advancing prediction of precipitation events near Antarctica and the impact of these events on lower latitude circulations; iii) more accurate prediction of ozone concentrations through Lagrangian measurements of ozone depletion and the microphysics of stratospheric NAT clouds.

A new THORPEX effort that involves significant collaboration with the World Climate Research Program (WCRP) is called the Year of Tropical Convection (YOTC - see below).

Year of Tropical Convection (YOTC)

Mitch Moncrieff (MMM) and Duane Waliser (JPL-CalTech) are leading a major new international project described as follows. Incomplete knowledge and practical issues severely disadvantage the skill of numerical weather prediction models and climate models, for example, the

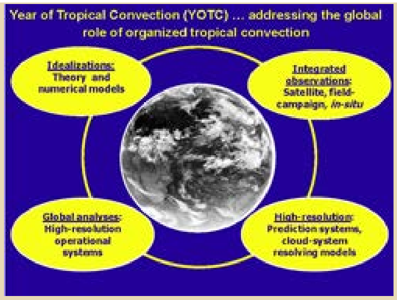


Figure 3: YOTC will improve the predictive skill of operational models by addressing convective organization on spatial scales up to global and time scales up to sub-seasonal (the intersection of weather and climate) using: i) global analyses from high-resolution operational systems; ii) high-resolution prediction systems and cloud-system resolving models; iii) integrated satellite, field-campaign and in situ observations; iv) theoretical and idealized models.

Reference: Waliser, D. E., and M.W. Moncrieff, 2007: Year of Tropical Convection: A joint WCRP-THORPEX Activity to Address the Challenge of Tropical Convection., GEWEX News, 17, 8-9.

High resolution figure

reliable representation of prominent tropical phenomena such as the InterTropical Convergence Zone (ITCZ), El Nino/Southern Oscillation (ENSO), monsoons and their active/break periods, the Madden-Julian Oscillation (MJO), tropical-subtropical transition, and easterly waves/ tropical cyclones Furthermore, tropical convection has long-range effects on stratospheric-tropospheric exchange, the large-scale circulation of the upper-atmosphere, and the variability of weather and climate around the world. Convective organization is involved at a basic level.

In order to address this major challenge, WCRP and WWRP-THORPEX proposed a year of coordinated observing, modeling, and forecasting, which led to the Year of Tropical Convection, YOTC. The focal theme of YOTC is the role of organized tropical convection at large scales. Together with accompanying research activities, the YOTC seeks to advance knowledge, diagnosis, modeling, parameterization, and prediction of multi-scale tropical convection and two-way interaction between the tropics and extra-tropics. The YOTC project will exploit the vast amounts of existing and emerging observations, the expanding computational resources, the new, high-resolution modeling frameworks, and theoretical insights (see Figure 3). This activity involves unprecedented collaboration between international programmatic activities, the operational prediction, research laboratory, and academic communities. Global databases of satellite data, in-situ data, and high-resolution model analysis and forecasts will be constructed. Emphasis is on timescales ranging from days-to-months; that is, the intersection of weather and climate.

The following objectives were achieved this year:

i. the ECMWF T799 (25 km) global analysis, forecast products, and special diagnostics being archived at ECMWF will be available to the community;

ii. the YOTC Science Plan was drafted;

iii. the YOTC Implementation Plan is in the first stage of development.

Started in May 2008, YOTC will contribute to the Asian Monsoon Year (AMY), the THORPEX Pacific Area Regional Campaign (TPARC), the United Nations Year of Planet Earth, and the International Polar Year. The scientific basis for YOTC is published in Moncrieff et al (2007), and a brief summary is published in Waliser and Moncrieff (2007).

return to top

Climate change and regional air quality implications

Globally, secondary organic aerosol (SOA) from biogenic precursors surpasses those from anthropogenic sources. These organic particles impact climate directly by scattering and absorbing of radiation, and indirectly through the modification of clouds and precipitation. These processes exert a substantial influence back upon the earth system through links to the terrestrial carbon and water cycles (e.g., precipitation regulates plant growth and thus emissions of organic compounds). Understanding the feedbacks between the atmosphere and terrestrial environment is key to estimating the impact of climate change on regional air quality.

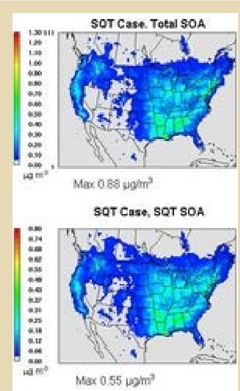


Figure 1: Simulated total secondary organic aerosol (SOA) (Top) and SOA from sesquiterpenes (Bottom) averaged for July 2001.

High resolution figure

In the past year, ACD scientists collaborated with Jack Chen, Jeremey Avise, and Brian Lamb (Wash. State U.), Cliff Mass (U. Washington), Donald McKenzie and Susan Fergusen (US Forest Service) to investigate the impact of future climate and land cover on regional air quality in the Pacific Northwest and North Central U.S. The results indicate that U.S. regional air quality (e.g., ozone and particles) will degrade even if U.S. anthropogenic emissions remain the same. The changes are due to a combination of pollutant transport from other countries (primarily China, Mexico and Canada), changes in wildfire emissions, and changes in biogenic emissions. The increased pollution transport is due to predicted increases in emissions in these countries. Wildfire activity is predicted to increase due to a warming and drying climate. Biogenic VOC emissions are expected to increase in response to higher temperatures. Land use change (i.e. tree plantations, agriculture, and urbanization) scenarios result in dramatic increases in some regions and decreases in other areas.

ACD scientists, collaborating with researchers from the University of Colorado, have also created a new emissions inventory of sesquiterpenes from vegetation using the Model of Emissions of Gases and Aerosols from Nature (MEGAN). These emissions were input to a regional chemical transport model so that the impact of these compounds on secondary organic aerosol (SOA) concentrations could be evaluated. The results, plotted in Figure 1, show that sesquiterpenes from vegetation roughly doubled the amount of SOA simulated when compared to simulations without sesquiterpenes; however, the model still underpredicted particulate organic matter when compared to observations.

Other modeling efforts in ACD have focused on investigating the role of dust aerosol in the heterogeneous removal of reactive nitrogen species in the vicinity of Mexico City. Changes in pollutant concentrations (i.e. nitric acid, nitrates) including the impact on ozone at the regional scale were quantified using WRF-chem model and observations from the MILAGRO field campaign. During the next year, modeling efforts relating to the roles of aerosol in coupling atmospheric chemistry with climate include work on characterizing carbonaceous aerosols observed in the Mexico City area in terms of their chemical composition, origin (i.e. anthropogenic, biogenic, biomass burning) and spatio-temporal variability. The predictions of these models will then be compared with measurements using the Aerosol Mass Spectrometer (AMS) at several sites from MILAGRO.

In order to improve on uncertainties relating to the indirect effects of aerosols on climate, ACD scientists have added a new aerosol scheme using a modal approach to the global models. Current evaluations of this scheme focus on evaluating warm cloud indirect effects, and on adding ice cloud formation to the models.

return to top

Model physics

Diffusion	Constant 3d Turbulent Kenetic Energy 3d Smagorinsky 2d Smagorinsky
Shortwave Radiation	Dudhia (MM5) Goddard CAM GFDL
Longwave Radiation	RRTM CAM GFDL
Surface Layer/Boundary Layer	Yonsei University PBL Mellow-Yamada-Janjic PBL ACM2 PBL MRF PBL
Land Surface	5-layer Thermal Diffusion Noah LSM RUC LSM Pleim-Xiu LSM
Cumulus Parameterization	Kain-Fritsch (new and old versions) Betts-Miller-Janjic Grell-Devenyi Grell-3
Microphysics	Kessler Lin et al. WRF Single Moment (WSM3, WSM5, WSM6) Eta (Ferrier) Thompson Goddard Morrison 2-moment

Figure: For Version 3.0, highlights of the new physics development included the ACM2 PBL, and PX LSM from scientists at the EPA (Environmental Protection Agency), the new Grell-3 cumulus scheme from NOAA/ESRL, the NASA Goddard microphysics scheme, and the Morrison 2-moment microphysics scheme.

High resolution figure

The Weather Research and Forecasting (WRF) Model is being used in an increasingly wider set of applications as computing power improves. WRF was developed as a community mesoscale model for numerical weather prediction, case studies, and idealized simulations, and as a tool for related applications such as air-quality research and forecasting. Some examples of newer applications that have resulted from improved computing resources are real-time cloud-resolving forecasting, including moving-nest hurricane forecasting, and nested regional-climate modeling. With these applications come new priorities in physics development to enable better hurricane and regional-climate modeling. These priorities fit with several of ESSL's priorities, including those of weather prediction and simulation across scales. Furthermore the aim of providing the university research community with a relevant up-to-date modeling system is met by continually updating the model to make use of the new capabilities in the current computing era, and improvements in model physics form one critical aspect of this development.

WRF already has a large set of physics options designed for its range of uses, from fast-physics packages for operational uses, to more complex packages for scientific studies. The table shown summarizes the current WRF physics options available to the ARW dynamical core as of its last release (Version 3.0) in April 2008. Version 3.0 also included a new global model capability, and extended the large-eddy simulation (LES) PBL capability to interact with land-surface fluxes.

Ongoing physics collaborations exist with NCEP, NASA Goddard, the EPA, NRL, NOAA/ESRL, the Pacific Northwest National Laboratory, Colorado State University, UCLA, the University of South Florida, University of New Mexico, and YonSei University (Seoul, Korea), as well as across the NCAR Divisions and Laboratories. Many of these reached fruition with more options for the WRF user community in the Version 3.0 release. Support for this work included NSF, KMA, AFWA, ARO, and the FAA.

Plans for FY09 include further collaboration with the CCSM modeling group to include some CCSM physics options and capabilities for regional-climate simulations. Also gravity-wave drag and spectral-nudging capabilities are being developed in addition to more physics options including sub-grid turbulence, radiation and microphysics development in a variety of collaborative projects.

return to top

Chemistry-climate coupling: Past and future

1. Lower stratospheric trends

In continuation of the work performed under FY2008, we have expanded our analysis of the lower stratospheric as simulated by CAM-chem (paper published in Journal of Geophysical Research, 2008). In this subsequent

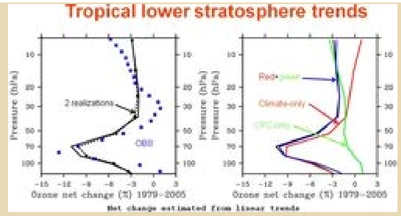


Figure 1.

High resolution figure

analysis, we focus on the understanding of the trend in the lower stratospheric tropical (20°S-20°N); using different simulations with different subsets of forcing agents we show that, based on this model, climate change (as identified here by changes in CO2 and sea-surface temperatures) is the largest contributor to the ozone trend in that region, much larger than the contribution of ozone-depleting substances; this work is submitted to Geophysical Research Letters. Additional studies will be performed during FY2009; in particular, focus will be given on changes in the width of the tropics and changes in tropospheric composition. This work was funded by DOE.

2. Impact of sectoral emission change

In support of the US Climate Change Science Program (DOE), we have performed and analyzed in collaboration with NASA-GISS and NOAA-GFDL a series of simulations where emissions from specific sectors (transportation for example) are reduced by 30% over a specific region. This is to identify the potential chemistry and climate impact regional pollution control measures; in particular, over the United States, transportation is the sector which has the largest impact. This work in submitted to Atmospheric Chemistry and Physics Discussions. This work was funded by DOE.

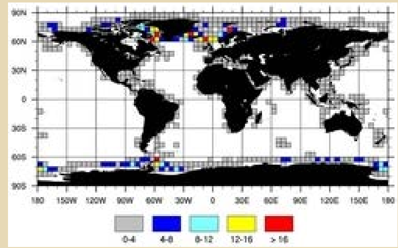


Figure 2. Geographical distribution (averaged over a 5° latitude-longitude grid) of the model-mean potential methane flux (in Tg(CH4)/year) at the bottom of the ocean based on the 100-yr temperature increase from each model.

High resolution figure

3. Methane clathrates

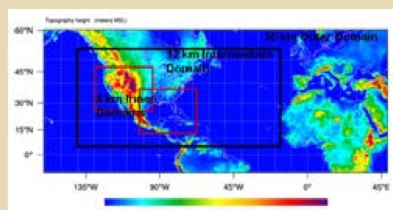
In continuation of the work performed under FY2008, we have furthered our investigation of the potential role for methane clathrates to act as a strong methane source during the 21st century. Using a combination of model simulations from IPCC AR4 and model results for under the seafloor methane destabilization, we show that it is unlikely that methane from clathrate destabilization will be a strong source of methane by the time CO2 as doubled over pre-industrial conditions (i.e. second half of 21st century). This work is in press in Geophysical Research Letters. This work was funded by DOE.

return to top

Prediction across scales

Overview

The Prediction Across Scales initiative is a collaborative effort between CGD and MMM to coordinate research and system development activities across weather and climate scales. Recent major advances in petascale computing coupled with rapid advances in scientific understanding are enabling progress in simulating a wide range of physical and dynamical phenomena with associated physical, biological and chemical feedbacks that collectively cross the traditional weather-climate divide. Such simulations and predictions are essential to a society that is becoming much more sophisticated in its requirements for weather, air quality and climate predictions and that is able to make useful economic and social use of such improvements. Moreover, fundamental barriers to advancing such prediction on time scales from days to years, as well as long-standing systematic errors in weather and climate models, are partly attributable to our limited understanding and capability to simulate the complex, multiscale interactions intrinsic to atmospheric and oceanic fluid motions. The scientific and societal questions and issues to be addressed are many. A limited sample includes better understanding of



Domain configuration for the latest NRCM runs. The outer domain will be coupled to CCSM-3 IPCC archived runs, while the intermediate and inner domains will use standard ARW coupling.

High resolution figure

- The water cycle and its predictability, particularly the limitations of available water and the impacts on food production;
- The limits of weather, air quality and climate predictability including the impacts of mega-cities and the stressed Earth's capacity to sustain quality of life;
- The interaction of hydrological, chemical and biogeochemical cycles and their feedback on weather/climate processes;
- The mechanisms by which solar variations influence the chemistry and dynamics of the upper atmosphere, and how these effects are manifested in the lower atmosphere;
- The interactions between climate change, ENSO and other natural modes of variability, including changes to the

behavior of phenomena like hurricanes; and

- The mechanisms of abrupt climate change and potential tipping points.

The enabling tool for much of this research will be a community Nested Regional Climate Model (NRCM). The result of this ambitious effort to combine high resolution regional atmosphere and ocean models with a state-of-the-science climate model will be fundamental progress on the understanding and prediction of regional climate variability and change. In particular, embedding Advanced Research WRF (ARW) and a Regional Ocean Model System (ROMS) within CCSM will allow scientists to resolve processes that occur at the regional scale, as well as the influence of those processes on the large-scale climate, thereby improving the fidelity of climate change simulations and their utility for local and regional planning.

Recent Accomplishments

As a first step toward the development of NRCM, NCAR and community scientists completed a 1995-2005 simulation of the tropical circulation with the NRCM configured in a channel mode at 36 km resolution using NCEP/NCAR reanalysis data on the poleward boundaries and specified surface conditions. A set of comparative simulations were also made using the atmospheric component of CCSM at T170 resolution configured in a similar channel mode with relaxation towards reanalysis in the polar regions. In addition, several high resolution two-way interactive simulations inside the channel model were completed, including high resolution nested domains over the Maritime Continent and the North Atlantic. These simulations utilized NCAR, NASA and DOE computing resources, and they are currently being analyzed by a number of NCAR and external scientists. The results will be featured in a special issue of Climate Dynamics in 2009.

In addition, progress was made over the past year nesting of ROMS within CCSM in two-way interactive mode. Initial experiments were conducted in the eastern Pacific Ocean with the goal of improving the poor performance of climate models in this region. This work will also provide a platform to include higher trophic level marine ecosystem models into CCSM.

2009 and Beyond

A new set of simulations began in FY2008 and will continue into FY2009 through the support of CISL. These experiments are designed to study the potential impacts of climate change on North Atlantic hurricane activity and on water resources over the intermountain West. They consist of a series of one-way nested simulations with interior ARW domains at ~4 km resolution over the intermountain West and the Gulf of Mexico. A coarser resolution (36 km) domain encompasses both regions, as does a higher resolution 12 km domain (Figure 1). The large-scale forcing data is provided from A1B and A2 scenario CCSM-3 T85 integrations using a time-slice approach, which will allow an examination of the fidelity of the simulation against current climate as well as project likely future changes in regional weather statistics. The results will be used to advise two communities on potential climate changes:

- vulnerable coastal communities and the offshore oil industry on potential changes in hurricane intensity and frequency in the Gulf of Mexico over approximately the next 50 years; and,
- a diverse group of stakeholders (government planners, water managers, terrestrial ecologists, etc.) on the changes in water resources in the western Intermountain states.

More generally, the experiments will:

- allow a further assessment of the skill of ARW for climate applications at high resolution over both tropical and extratropical domains, which is important for future model development as well as the ultimate NRCM goal of two-way nesting ARW within CCSM;
- draw into NRCM a much larger base of "earth system scientists", all of whom require climate data on scales of a few kilometers (or less); and,
- produce unique data sets of a climate change scenario that would be of immense interest to many stakeholders.

return to top

Climate and tropical cyclones

The impact of climate change on hurricanes has continued to be investigated and expanded to include the upscale influence of hurricanes on climate. An earlier study that showed a marked increase of 50% in the global proportion of the most intense hurricanes, which caused considerable controversy, has been validated by a new study using a completely independent data set. A further study has shown that the North Atlantic is now experiencing 2-3 times the proportion of category 5 hurricanes compared to previous activity. A major new modeling study with the NRCM to investigate future hurricane changes and variability has commenced with support from the Willis Research Network and the Research Partnership to Secure Energy for America. This includes NRCM projections at resolutions of 12 and 4 km, sufficient for the first time to resolve the intensity and structure of major hurricanes. A new study has provided a strong indication that hurricanes may have a substantial upscale role on climate through their

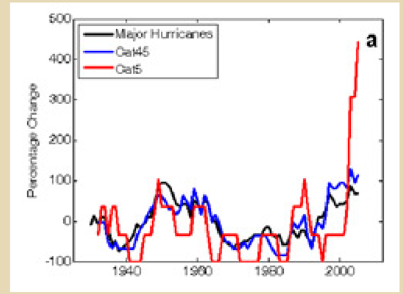


Figure: Variation in Major Hurricanes, Cat 4 and Cat 5 Hurricanes and Cat 5 Hurricanes for the North Atlantic as percentage change vertical and horizontal transports of energy.

return to top

from the long-term mean (smoothed by a running 5-y filter, showing the unprecedented recent increase in category 5 hurricanes.

High resolution figure

Strategic Goal #1, Priority #3

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

NCAR is sponsored by the National Science Foundation.

ESSL LAR 2008: STRATEGIC GOAL #1, PRIORITY #4

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #1, Improve understanding of the atmosphere, the Earth system, and the Sun. This Strategic Goal encompasses four Strategic Priorities, each of which is dependent on the efforts and accomplishments of ESSL staff.

ESSL developed an action plan with seven priority themes which involve direct partnerships with the university community and contribute directly to the ESSL Strategic Vision and to several priority items of the NCAR Strategic Plan.

ESSL's seven priority themes:

1. Climate projection, with emphasis on short-term prediction.
2. Biosphere-Atmosphere-Hydrosphere interactions and specifically development of BEACHON Project (Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, Hydrology, Organics and Nitrogen).
3. Water system research, specifically the development of the Society, Water, Atmosphere and Natural Systems Project (SWANS).
4. An advanced Weather Research and Forecasting system, specifically the development of the Hurricane Intensity and Forecasts (HiFi) Project.
5. Space Weather, specifically the development of the Coronal Solar Magnetism Observatory Project (COSMO).
6. Chemical Weather, including interpretation of observed data gathered during the Megacity Impact on Regional and Global Environments (MIRAGE) campaign, and the development of a capability for chemical data monitoring and prediction.
7. Prediction across scales, specifically the development of an advanced next-generation, climate-weather modeling system and an integrated Earth system model of intermediate complexity.

Goal #1, Priority #4: Developing Community Models, is described in the NCAR Strategic Plan as follows: "Developing numerical models and making them available to the scientific community is at the heart of NCAR's research and service to the community. Key activities in this priority are creating and adding to community models, research models, as well as progressing toward creation of an Earth system model."

This NCAR priority, driven by ESSL's themes 1, 4, 5, 6 & 7, is critical to achieving NCAR's first strategic goal.

The section below describes specific research conducted by ESSL staff under projects relevant to Priority 4. The major ESSL activities in this area are ongoing improvement and development efforts focused on the following numerical models: the Community Climate Systems Model (CCSM), the Weather Research and Forecasting model (WRF), Space Weather prediction models, the Nested Regional Climate Model (NRCM), and the Whole Atmosphere Community Climate Model (WACCM). Additional models included in these efforts are the Model for Ozone and Related chemical Tracers (MOZART), the Community Atmosphere Model with chemistry (CAM-Chem), upper atmosphere models, and carbon/nitrogen cycle models.

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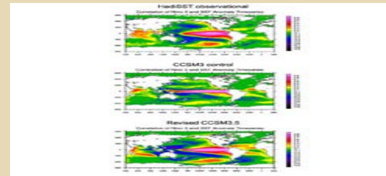
12. Analysis, Integration and Modeling of the Earth System (AIMES) - CGD
13. Master mechanism - ACD
14. Tropospheric Ultraviolet and Visible (TUV) - Radiation Model - ACD

Community Climate System Model: Development of Scientific Capabilities

Overview



The correlation of the Nino 3 and global sea surface temperature anomaly timeseries from a) HadiSST observations, b) CCSM 3 control, and c) CCSM 3.5 model.

High resolution figure

The development and continuous improvement of a comprehensive climate modeling system that is at the forefront of international efforts to understand and predict the behavior of the Earth's climate is a high priority of NCAR research. This includes the Community Climate System Model (CCSM) as well as its component models. The CCSM, run on some of the world's most powerful supercomputers, simulates the many interconnected events that drive Earth's climate. These include changes in the atmosphere and oceans, the ebb and flow of sea ice, and the subtle impacts of forests and rivers.

CCSM is unique among the most comprehensive of global climate models. Primarily supported by the National Science Foundation (NSF) and the Department of Energy (DOE), with additional support from the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), it belongs to the entire community of climate scientists, rather than to a single institution. Hundreds of specialists from across the United States and overseas collaborate on improvements to CCSM. The model's underlying computer code is freely available on the Web. As a result, scientists throughout the world can use CCSM for their climate experiments.

The CCSM project was started in 1994, although climate modeling at NCAR has a much longer history, stretching back to about 1980. The first version of CCSM was unveiled in 1998, and the most recent version, CCSM-3, was released in 2004. CCSM-3 represents a major advance over earlier versions of the model because it contains far more information about Earth's physical processes. For example, it tracks the flow of major rivers that empty into the oceans and it now resolves five different thickness categories of sea ice within each grid cell, such as the thickness and the melt rate. Moreover, the finer scale and lower viscosity of its ocean allows scientists to capture significantly greater detail about ocean currents and the mixing of salt and fresh water.

CCSM is constantly being updated and improved; CCSM4 is most likely to be released in 2009. In preparation, an interim version, CCSM3.5, was assembled in mid-2007, and is being evaluated from a number of perspectives, with carbon system spin-up a particular focus. In addition to remaining at the forefront of international modeling efforts, the scientific goals of the CCSM project are as follows:

- to use the modeling system to investigate and understand the mechanisms that lead to interdecadal, interannual, and seasonal variability in Earth's climate;
- to explore the history of Earth's climate through the application of versions of the CCSM suitable for paleoclimate simulations; and
- to apply this modeling system to estimate the likely future of Earth's environment in order to provide information required by governments in support of local, state, national, and international policy determination.

ESSL/CGD (in collaboration with scientific and software engineering partners from Universities, DOE, NASA) has been busy in developing component models, integrating those components as candidates considered for the next generation of the CCSM, and exploring these in a variety of ways for understanding the Earth System and climate change. One of the topics identified in last year�s report as a "Plan for 2008" was "a concerted effort to address systematic model biases in the tropics on seasonal and longer timescales." We describe one contribution to that effort here.

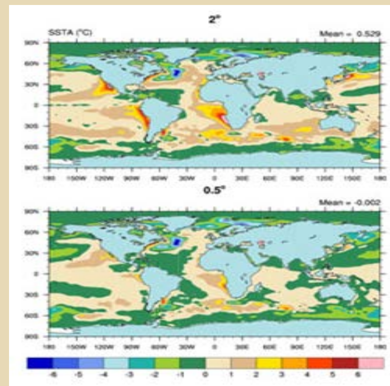
Recent Accomplishments

A significant reformulation of the parameterization of convection within Community Atmosphere Model (CAM) took place in 2007. The parameterized convection was made much more sensitive to the dilution of air as it ascends in the atmosphere. The convecting parcels were also made sensitive to the change in phase of condensate between liquid and ice, and momentum transports were included in the formulation. The result was a substantial improvement in many aspects of the atmospheric simulation when driven with observed sea surface temperatures, and in the coupled system. The changes were included in the CCSM 3.5, an interim version, which was finalized in October 2007. This uses the new finite volume dynamical core in the atmosphere component, the updated POP 2 code for the ocean component, the latest CICE 4 version for the sea ice component, and a much updated version of the land component compared to the CCSM 3. There have also been significant parameterization improvements in all the components. CLM 3.5 has a very much improved hydrology cycle compared to CLM 3, and the global partitioning of evapotranspiration is greatly improved using the CLM 3.5.

The most significant aspect of CCSM 3.5 is in its simulation of the El Nino - Southern Oscillation (ENSO) in the tropical Pacific Ocean. All previous versions of the CCSM, and most other climate models, had a peak in the ENSO frequency near two years, which is much shorter than in reality. This problem has now been corrected in CCSM 3.5, which shows a frequency peak between 3-6 years. In addition, the correlation between the Nino 3 SST timeseries and SST anomalies across the globe has also been substantially improved. Figure 1 shows this correlation from the HadiSST observational data set, the previous CCSM 3 control, and the new model version with the CAM 3.5. The improvement is quite remarkable, with the new model showing a correlation pattern that is very like the pattern from observations. The correlation is much broader in the eastern tropical Pacific, and the correlation patterns in the Pacific and other oceans are also much improved. We believe this is primarily due to the two modifications of the deep convection parameterization in the atmosphere, which include convective momentum transport and a dilute approximation to calculate CAPE.

Another accomplishment during FY 08 has been to run the first proof of concept short-term projection from 1980 to 2030. This run uses much finer horizontal resolution of 0.5 degree in the atmosphere and land components. The initial conditions for these components were interpolated from the January 1st 1980 fields from a 20th century run using 2 degree resolution in the atmosphere and land components. The two runs were integrated from 1980 to 2030 using observed carbon dioxide levels to 2000, and then the A1B future scenario. The largest improvement was in the sea surface temperature fields in the three major upwelling regions. The SST errors compared to observations in the two runs are shown in Figure 2. The SST errors are reduced by well over 50% off the west coasts of the USA and Peru, and by a smaller percentage off Namibia. This is a significant improvement, but the 0.5 degree run takes about 20 times more computational resource than the 2 degree run. The 0.5 degree version of the new CCSM 4 will be used to make the short-term climate projections for the next IPCC assessment.

During FY 2008, the major CSEG accomplishment has been to finalize and test the sequential, single-executable CCSM. The goal was to create a sequential system that contains backwards compatibility with the current concurrent system, provides "plug and play" capability of data and active components and produces the same climate as the current concurrent system. In addition, the CSEG has ported and tested the results from the CCSM 3.5 running on several new computer platforms across the USA.



The sea surface temperature errors compared to observations over 1985-2000 from the CCSM 3.5 using 2 degree and 0.5 degree resolutions in the atmosphere and land components.

High resolution figure

2009 and Beyond

2009 will be a very busy year for the CCSM project. The deadline for delivery of individual components of the next version, CCSM 4, is September 30, 2008. CCSM 4 then needs to be finalized, which requires acceptable 1870 Control and 20th century runs to have been made and positively analyzed. This usually takes several months to achieve, and will first be done using a resolution of 2 degrees in the atmosphere and land, and 1 degree in the ocean and sea ice. Then, an acceptable 0.5 degree version of the atmosphere and land components needs to be assembled to be used in the short-term simulations. Finally, a low resolution version of the CCSM 4 needs to be assembled for use in Paleoclimate studies.

return to top

Space weather: Model development and data analysis

Space weather research seeks to understand and work towards predictions of the physical conditions in the geospace environment, particularly when disturbed by energetic events occurring on the Sun. This is a multidisciplinary field of research which requires understanding of solar, solar wind, magnetospheric, and ionospheric physics. It covers a broad range of time scales, including solar cycle variations (years), recurrent solar wind streams (months), coronal mass ejection (CME) propagation and geomagnetic storms (days), flares and energetic particles (minutes). Understanding these phenomena is important for human spaceflight, satellite design, communication and navigation systems used by our increasingly technologically dependent society.

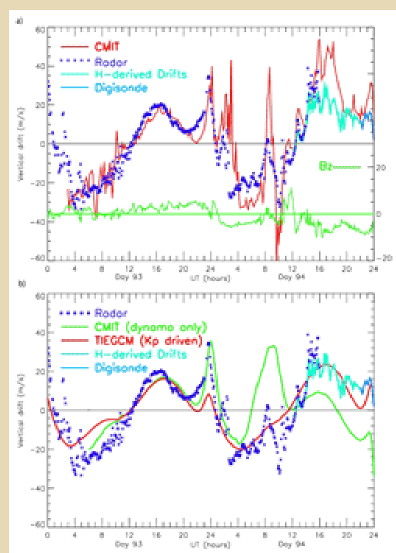


Figure 1: (a) Ion vertical drift velocities (m/s) at the F2 peak measured by the Jicamarca radar (blue crosses), inferred from ground-based magnetometer (light green line) data

HAO scientists continue to make substantial progress in modeling the many aspects of Space Weather. Coronal mass ejections are a main driver of significant space weather events. Using 3D MHD simulations Yuhong Fan and Sarah Gibson have been able to determine that both the precursor magnetic field configuration in the corona and the initiation mechanism play and an important role in determining the geoeffectiveness of a CME. In particular, they found that eruptions triggered by the torus instability or the kink instability can result in magnetic clouds which differ in their geoeffectiveness due to the different amount of rotation of the escaping flux rope that ultimately affects the orientation of the magnetic field impacting the Earth's magnetosphere. Mark Miesch and colleagues have completed initial development of a heliospheric model using the FLASH code produced by the University of Chicago. This model is currently capable of modeling the configuration of the plasma and magnetic fields into which a CME must propagate before reaching the Earth. AIM scientists led by Wenbin Wang used the CMIT 2.0 Model developed in collaboration with the Center for Integrated Space Weather Modeling (CISM) to study vertical drifts in the F region of the ionosphere. They found that the model does a good job of capturing the temporal variations of these drifts. Furthermore, they conclude that these variations were primarily driven by changes in the solar wind conditions. In collaboration with colleagues at Dartmouth College, AIM scientist Michael Wiltberger began the process of adding mass outflow from the ionosphere into magnetosphere in the Coupled Magnetosphere Ionosphere Thermosphere (CMIT) model. Initial results from these studies have shown that this outflow can have a significant impact on the evolution of the magnetosphere. In particular, simulations with large outflows have shown a multiple substorm sequence for steady IMF conditions which is not seen in simulations for similar conditions which do not include the outflow. Another major achievement of the AIM group, directed by Stan Solomon, in support of Space Weather modeling has been the release of the TIE-GCM, an essential component of CMIT, directly to the community under an open source licensing agreement. In addition, we are working closely with NASA's Community Coordinated Modeling Center (CCMC) to provide the space weather community with the ability to conduct runs on request of CMIT.

and determined from the F2 peak bottomside height changes from the Jicamarca digisonde (light blue line), and simulated by the CMIT model (red line) for the April 2-5, 2004 geomagnetic storm event. Also shown in the plot is the IMF Bz component (nT, green line). (b) Ion vertical drift velocities (m/s) caused by the neutral wind dynamo (dynamo only, green line), and those from the stand-alone TIEGCM (red line).

High resolution figure

Over the course of the next year simulations of CMEs will be conducted using vector magnetic field observations from the recently launched Hinode satellite as basis for determining the shearing and twisting motions driving specific events. These event studies will allow for a direct quantitative comparison of the simulation results with multi-wavelength coronal observations. The heliosphere model will be used to model the solar wind conditions observed during the Whole Heliosphere Interval. Work on this model will also include coupling it with CME eruption modeling to study the evolution of the magnetic field structure within and around the CME as it propagates to the Earth. Now that initial work on including mass outflow into CMIT has been completed we will focus on the extension of this work to incorporate the factors regulating the magnitude and location of the outflow into the model. Development of CMIT will also include efforts to improve the representation of the magnetic field in the inner magnetosphere by coupling it to a ring current model.

return to top

Nested regional climate modeling (NRCM)

Mesoscale processes can have a major impact on large-scale circulations. Yet climate models do not adequately represent this upscale influence of mesoscale processes. NCAR is addressing this challenge by developing a multi-scale modeling system to aid our understanding of climate processes, particularly at the regional scales important to society, and projecting how these may change in the future. A multi-scale modeling system is necessary not only to reduce these climate biases but also to:

(a) downscale climate variability and climate change to the regional scale for applications such as water resource management over, say, the Western US, and to determine the climatology of extreme events such as tropical cyclones.
(b) capture the upscale impacts of regional phenomena such as eastern boundary upwelling regimes or mesoscale convection.

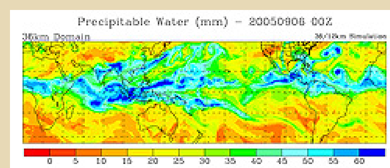


Figure: Precipitable water analysis for 2005 Sep 06, 00Z from the NRCM 10-y simulation of current tropical climate showing hurricanes in the North Atlantic.

High resolution figure

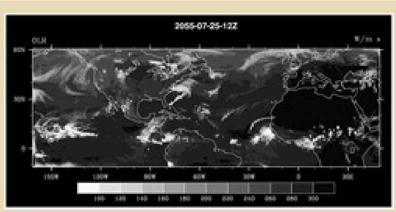


Figure: Outgoing long-wave radiation (Wm-2) for 2055 Jul 25, 12Z from the NRCM time-slice projection of future climate under A2 forcing scenario showing a tropical cyclone off the east coast of the US and a convective disturbance off the west coast of Africa.

High resolution figure

The Advanced Research WRF (ARW) and Community Climate System Model (CCSM) have been specifically proposed as candidates from which to develop a two-way coupled multi-scale modeling system. As a first step in this direction, a consortium of University, DOE and NCAR/MMM and CGD scientists engaged in developing the Nested Regional Climate Model (NRCM) from the ARW model. The NRCM has been configured to a tropical channel domain, driven by NCEP-NCAR reanalysis conditions at the north and south boundaries, to enable investigations of the simulation of tropical modes and their interaction with moist convection and to provide high-resolution winds for a study of eastern oceanic boundary issues. Figure 1 shows a snapshot of precipitable water over the tropical channel domain showing tropical cyclones over the North Atlantic. This work included a range of 1-way and 2-way nesting configurations aimed at gaining experience with such configurations and at enabling leading-edge research on the output. The experience with this phase of the program has been an excellent learning activity as well as providing improved understanding of the interactions between mesoscale processes, specifically moist convection, monsoons, and climate. The NRCM has also been instructive in providing a means of distinguishing processes that are, or may be adequately parameterized, from those that cannot and must be resolved in climate simulations.

Our main research goal in FY2008 was to perform a more detailed and extensive analysis of the tropical channel simulations to advance our understanding of tropical wave modes, and evaluate the model's skill in simulating various tropical phenomena using different levels of nesting. Building on strong collaborations between MMM and CGD, and between NCAR and a host of external investigators, significant progress has been made in several areas, with a few key examples highlighted below:

1) Analysis of tropical wave modes

A preliminary space-time spectral analysis of the outgoing long-wave radiation in FY2006 indicated that the tropical channel model is able to capture important wave-like modes corresponding to Kelvin waves and Madden-Julian Oscillation (MJO). In FY2007, a more detailed analysis of the Kelvin waves showed that their horizontal propagation speeds and vertical dynamical signals are reasonably well simulated, although the climatological variance of these waves is significantly under-predicted in the deep tropics (between 5S-5N). A similar under-prediction problem was found for the MJO, which also appears less well organized than the observed MJO.
To investigate the causes of this poor MJO representation, an additional analysis was performed of two simulations of an MJO event that occurred during May - June of 1997. Careful processing of the continuous run initialized on January 1, 1996, shows that no MJO events occurred during the May - June period. However, in a simulation initialized on May 1, 1997, the MJO event was successfully reproduced. These findings suggest that model biases built up in the continuous run have a significant negative impact on the simulation of MJO. Additional analyses are being performed to understand the separate influences of initial conditions, lateral boundary conditions, and model physics on the ability of the model to capture various tropical modes.

In FY08, space-time spectral filtering of the simulated OLR was used to isolate easterly waves and tropical-depression type disturbances, extending the Kelvin wave analysis of FY07. Results showed reasonable climatological variance of easterly waves in the Pacific basin, but a significant under-prediction of wave activity in the Atlantic. Presumably this bias stems from biases in the mean state, such as anomalously heavy rainfall over the Pacific and drier conditions over Africa. Given that a large fraction of tropical cyclones in the model are found to develop from easterly waves (as demonstrated through composite analyses), it would seem that the paucity of tropical cyclogenesis cases over the tropical Atlantic can be traced to deficiencies in the mean state.

2) Analysis of the East Asian monsoon

Comparison of the observed and simulated East Asian summer monsoon circulation and precipitation revealed a major weakness in the NRCM simulation. This problem was particularly significant during 1997 when the West Pacific Subtropical High in the simulation was displaced much further east and a low pressure center was generated near the South China Sea that created a northeasterly flow into central and southern China, as opposed to the southwesterly monsoonal flow that brings abundant moisture and precipitation. On the other hand, the simulation compared well with observations during the 1998 summer.

To investigate the reasons for the large difference in model skill from year to year, we performed several sensitivity experiments to isolate the impacts of model initialization, sea surface temperature (SST), lateral boundary conditions, and physics parameterizations. These experiments suggest that SST plays a dominant role in explaining the large difference between the simulations in 1997 and 1998, possibly due to the strong dynamical feedbacks between SST forced convective heating in the western Pacific and the large scale circulation. However, the erroneous circulation in 1997 was insensitive to the convective parameterizations used. In FY08, we conducted a series of 4-month sensitivity experiments for the 1997 East Asian monsoon. We found that the error in the simulation of East Asian monsoon was largely due to the lack of atmosphere-ocean interaction in the current NCRM simulation. Deep convection may be triggered too easily in the model because of the lack of air-sea coupling that should provide a negative feedback to modulate deep convection in areas with warm SST. The excessive convection also accounts for the significant over prediction in the number of tropical cyclones over the western Pacific Ocean. When daily SST together with a simplified diurnal SST model was implemented, the error in precipitation forecast was substantially reduced. This highlights the need to develop a full-coupled atmosphere-ocean regional climate model that is also fully coupled with the global climate model.

3) Analysis of tropical cyclones

NRCM simulations have been explored using a tropical cyclone detection algorithm. The model captured the general global and seasonal distributions of tropical cyclones but consistently overproduced the number of tropical cyclones. Two-way nesting down from 36km to 12km over the Atlantic region for the 2005 season improved both the number and spatial distribution. This dataset has also been used to show the importance of the background flow in modulating easterly waves thereby creating favorable conditions for tropical cyclogenesis, and higher resolution simulations of genesis has shown vortices merging during the period of genesis.

Plans for FY09 include a climate change experiment using NRCM over the North America region, which is currently underway, and represents the second stage of research and model development towards a multi-scale modeling system based on ARW and CCSM. Research is primarily aimed at water resource variations in the intermountain western region and tropical cyclone variations over the North Atlantic region. The period of particular interest is the next 50 years or so, when society will largely have to adapt to those climate changes that are inevitable. The large-scale forcing data is provided from CCSM3 T85 climate change integrations and a series of “time-slice” ensemble experiments are currently being generated for three ten-year periods: 1995-2005, 2020-2030, and 2045-2055. Figure 2 shows a snapshot of outgoing long-wave radiation from July 2055 showing a tropical cyclone off the east coast of the US and a disturbance off the west coast of Africa. This experiment provides a genuine test of the requirements for future supercomputing systems to enable decadal predictions of the regional detail required for planning and adaptation strategies.

Trends in hurricane activity in the North Atlantic, Caribbean and Gulf of Mexico regions will be examined. This ambitious project is providing for the first time, decadal climate simulations of hurricanes at a resolution sufficient to identify key intensity and structural details. Another key focus area will be trends in water resources over the Western U.S.

The NRCM effort represents a step towards a new global weather climate model, referred to here as the Earth System Model (ESM), at 'convection permitting' resolution. A new model is necessary to perform well on future computing platforms. The ESM is currently in its inception phase and it is anticipated a robust model is ten years away. Lessons learned from NRCM are directly relevant to the ESM effort and will steer its development.
NCAR plans that the NRCM will eventually be provided and maintained as a community resource for use by all the academic, government, and private sector communities. The NRCM project has strong community support and is funded largely by the offshore oil industry, the reinsurance industry and NSF, supported by the MMM and CGD divisions.

return to top

Weather Research Forecasting (WRF) Model

During the past year, NCAR continued to develop new capabilities for the Advanced Research WRF (ARW) and support it to the community. Over 2000 new users registered to download the code, bringing the total number of registered users to over 7,600. Over half of this total is non-US users, and 113 countries are represented. Figure 1 shows the numbers of registered WRF users and a breakdown by group.

Figure: WRF user registration and growth of registered users (as of Aug. 2008).

High resolution figure

In June 2008 MMM organized and conducted the 9th Annual WRF Users' Workshop, with over 225 participants attending from many different countries. MMM personnel also conducted three user tutorials on the ARW and WRF-VAR. The two ARW tutorials were held in Boulder with approximately 60 participants attending the first and 71 the second. The WRF-VAR tutorial, also in Boulder, attracted 52 participants. In addition, MMM division staff put on the 2nd East Asia Weather Research and Forecasting (WRF) Model Workshop and Tutorial at Seoul National University in Korea in April 2008. The workshop focused on recent WRF developments in data assimilation, global modeling, and regional climate modeling, applications to high-impact weather and climate, and real-time operations. The workshop and tutorial were conducted as part of the Korea Foundation for International Cooperation of Science and Technology (KICOS) Global Partnership Program, under the Korea Ministry of Science and Technology.

return to top

WACCM

The Whole-Atmosphere Community Climate Model (WACCM) is a comprehensive numerical model, spanning the range of altitude from the Earth's surface to the lower thermosphere. WACCM is built upon the numerical framework of NCAR's Community Climate System Model (CCSM), and is envisaged as a flexible modeling environment, whose domain and component modules can be configured according to the specific problem under study. WACCM incorporates physical and chemical processes required to investigate the coupling among atmospheric regions from the surface to ~140 km. The current version of WACCM (WACCM3) has fully interactive chemistry and dynamics, and can also be coupled to the ocean component of CCSM. Addition of upper thermospheric physics and chemistry is currently underway, and will allow the model to extend upward to about 500 km.

WACCM has contributed to the Chemistry-Climate Model evaluation (CCMval) effort, an international activity under the auspices of the Stratospheric Processes And their Role in Climate (SPARC), and to the most recent Ozone Assessment (2006) of the World Meteorological Organization. In addition, the following topics are currently under investigation using WACCM:

- the effects of solar variability in the middle atmosphere using time-slice simulations during solar minimum and maximum conditions with and without the quasibiennial oscillation in the Tropics;
- the role of parameterized gravity waves and their tropospheric sources in simulations of the whole atmosphere;
- the dynamical variability in the middle atmosphere, in collaboration with University colleagues and other modeling groups;
- the response of the Brewer-Dobson circulation to climate change;
- the validation of chemistry and the dynamics of WACCM against observations (satellite and ground-based);
- testing and application of a new version of the model that can be driven by assimilated meteorological data to study the exchange of mass and constituents in the upper troposphere/ lower stratosphere;

- atmospheric predictability in the whole atmosphere context;
- the application of a version of the model coupled to the CCSM ocean component to understand climate change, including dynamics, temperature and chemical composition, in the 20th century and predict changes in the 21st century.

Recently published papers on these and other subjects may be found in the WACCM website . During 2008-2009, major emphases of the WACCM project will include: the study of the effect of the middle atmosphere on tropospheric climate; extension of WACCM to 500 km with the addition of an electrodynamics model component; improvements to the parameterization of mesoscale gravity waves; elucidation of the factors that accelerate the Brewer-Dobson circulation in the context of global-warming; and comparison of WACCM tides and other fast wave motions with global satellite observations.

return to top

WACCM development and extension

The goal of the Whole Atmosphere Community Climate Model (WACCM) is to develop a model that extends from the Earth surface to the upper thermosphere, and self-consistently resolve the dynamical, chemical, radiative, and electrodynamical processes and the coupling between atmospheric regions. The current standard WACCM version (WACCM3) has an upper boundary in the lower thermosphere (~140 km).

In the previous year (FY07), we developed a WACCM extended (WACCM-X) to the upper thermosphere at pressure 3.4×10^{-7} Pa (~500 km), and implemented thermospheric physics modules, including major species diffusion, the constituent-dependent specific heats, gas constant, and mean molecular weight, and revised the treatment of the vertical diffusion equations for minor species and heat conduction equation. In FY08, we have built on the WACCM-X and further tested and validated the model. Major achievments include:

1. Full model-year runs of WACCM-X under solar maximum, medium, and minimum conditions. Monthly mean climatology of winds and temperature structures in the upper atmosphere show general agreement with empirical models (MSIS-00 and HWM) and the TIME-GCM.
2. The semi-annual variation of the O/N2 ratio in the upper thermosphere is reproduced by the model, including the magnitude of the variation and its dependence on the solar flux.
3. Tides from the model were compared with TIMED/SABER and TIDI obserbations. The seasonal variability of the migrating diurnal tide, with maximum at March equinox and secondary maximum at September equinox, are in good agreement with observations, though the tidal amplitude from the model is weaker. We also demonstrated that the model amplitude is in much better agreement with observations when the vertical resolution of the model is doubled.
4. The nonmigrating eastward wavenumber 3 component from the model, which is the second strongest diurnal tide in the lower thermosphere, shows excellent agreement with that derived from SABER and TIDI in both its amplitude and seasonal variability.
5. The thermospheric tides show strong short-term variability, which is likely due to penetration of the lower atmospheric perturbations and their interaction with tides.

We are currently merging WACCM-X with WACCM 3.5. A significant improvement in the new version is the gravity wave source specification based on actual sources of convection and frontogenesis. We will examine its impact on the thermosphere. We are currently working on the electrodynamics of the model ionosphere by implementing ambipolar diffusion and ExB drift in the WACCM.

return to top

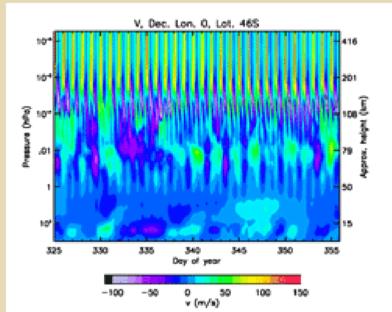
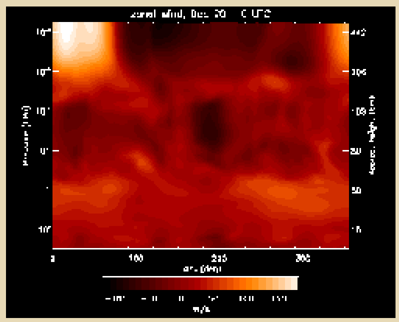


Figure 1: Meridional wind from the ground to the upper thermosphere from WACCM-X. At this southern mid-latitude (46S), variability associated with quasi-two-day waves, semi-diurnal tides, and diurnal tides are clearly seen in the mesosphere, lower thermosphere, and upper thermosphere, respectively. The model also produces short-term variability in tidal amplitude in the upper thermosphere.

High resolution figure



Movie 1: This animation shows the zonal wind from 20 to 29 December at 52N from a WACCM-X simulation. The output interval is 3 hours. From the simulation it is evident that planetary waves and migrating tides dominate below the mesosphere and in the upper thermosphere, respectively. In the mesosphere and lower thermopshere, the temporal and spatial scales are very complex with the presence of tides, planetary waves, resolved gravity waves, and probably the interaction of these waves.

Click to see movie

MOZART

The Model for Ozone and Related chemical Tracers (MOZART) is a global offline chemical transport model. Version 2 (MOZART-2) is available to the public through the NCAR Community Data Portal and has been downloaded by 110 users.

Two new versions, MOZART-3 and MOZART-4 have been recently completed and are actively used by ACD scientists. MOZART-3 is an extension of MOZART-2 into the stratosphere, with the addition of halogen chemistry and heterogeneous processes on polar stratospheric clouds (Kinnison et al., JGR, 2007). MOZART-4 has been updated over MOZART-2 to improve tropospheric chemistry simulations, with more detailed representation of hydrocarbons and tropospheric aerosols. Examples of some of the studies using MOZART-4 are shown under Strategic Priority 1 in Section 6 and Section 7.

The chemical schemes of MOZART-3 and MOZART-4 have been incorporated in the coupled chemistry-climate models WACCM and CAM-Chem.

MOZART-3 and MOZART-4 (source code and documentation) will be made available to the public on the NCAR CDP by the end of 2008.

return to top

Community Atmosphere Model combined with the MOZART chemical Mechanism (CAM CHEM)

CAM is the latest in a series of global atmosphere models developed at NCAR for the weather and climate research communities. CAM also serves as the atmospheric component of the Community Climate System Model (CCSM). The continued incorporation of interactive chemistry capability in the Community Atmosphere Model (CAM) has reached a fairly stable state and now encompasses a variety of options to accommodate the needs of the coupled climate model, including a full interaction with the cloud microphysics (to represent the indirect effect, through collaboration with CGD and MMM scientist); in particular, using the implemented MOZART framework, CAM-chem can now be configured to combine prognostic and diagnostic variables. As a result. aerosols can either be prescribed, simulated using simple input oxidant fields, or simulated using the full MOZART-4 aerosol parameterization, or a combination of both; this flexibility is important to understand the specific role (radiatively and through cloud-aerosol interaction). In addition, the flexibility enabled the quick implementation of the modal (3 and 7 modes) aerosol scheme developed by S. Ghan (PNNL).

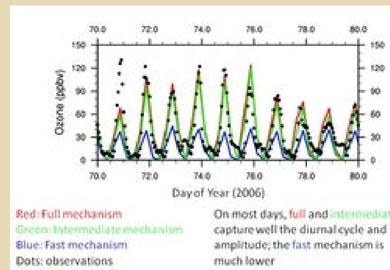


Figure 1. Comparison with surface observations in Mexico City (RAMA).

High resolution figure

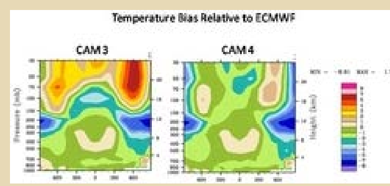


Figure 2.

High resolution figure

In addition, a version of CAM-chem with a representation of stratospheric chemistry was developed as a tool to represent ozone changes in the lower stratosphere; simulations over 1970-2005 indicate a very good comparison of ozone trends with respect to observations. This version will be used in 2009 for chemistry simulations in support of IPCC AR5.

For extended chemistry-climate studies, a number of different options exist for simulating aerosols and chemistry to facilitate using the model in the optimal configuration. In collaboration with scientists from Lawrence Livermore National Laboratory and University of California, Irvine, we have extensively tested 3 chemical mechanisms for tropospheric chemistry with increasing complexity of non-methane hydrocarbon (NMHC) representation; the overall goal is an understanding of how much chemistry is needed for specific applications (regional pollution chemistry or climate). In particular, comparison with the Mexico City (MIRAGE) campaign indicates (Figure 1) that an intermediate representation of NMHC is sufficient to represent ozone at the surface.

CAM-chem is now being merged with WACCM to allow for more flexibility in the model configuration and added ease of maintenance; indeed, this approach has eliminated code redundancy as much as possible. This merged code will now be the only version of CAM-chem or WACCM to be developed; this will allow for improvement from one science community to directly benefit the other one.

FY2009 plans include continued evaluation of the model performance under the different options described above. This work is funded by NSF/NCAR, NSF Biocomplexity, and DOE.

The computation of the radiative effects of the atmospheric composition is central to efforts to understand climate. A new radiative transfer model (RRTMG), developed by AER, Inc., has been incorporated into CAM/CCSM. The interface between the atmospheric specifications in CAM and the radiative solver has significantly improved user flexibility in testing new optics and testing radiative forcing due to changes in atmospheric composition as well the extensibility for new species. Microphysical specifications in CAM have been made consistent with optical parameterizations. Collaborators from LBL, UC Berkeley, PNNL, DRI, and AER have contributed optics, solvers, and validated the new package. This work is funded by DOE/SCIDAC.

FY2009 plans include efforts to study the new radiation budget of the climate system.

Microphysics parameterization for CAM

ACD and CGD scientists have been leading a collaborative development effort for a new microphysics parameterization for CAM. The goal of this effort is to develop an advanced microphysics package which can represent the size of cloud drops, and simulate how cloud drops are influenced by the distribution of aerosols. The ultimate goal is to quantify aerosol indirect effects in CAM and CCSM. This work dovetails with other studies in ACD, MMM and CGD of cloud microphysics, both in observations and in models. An important component of the broader activity is the development of better satellite data sets of cloud microphysical properties for comparing the CAM and WACCM simulations to observations. This work has recently been extended to treat the effects of ice clouds and ice cloud aerosol interactions.

return to top

Upper Atmosphere Community Models

HAO scientists have developed a suite of upper-atmospheric models, in collaboration with scientific visitors and scientists at universities, government labs, and other organizations. These models are made available for use by the community, typically through collaborations between HAO scientists and scientists in the community. A central model is the Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM) and simplified variants of it. The TIME-GCM simulates the three-dimensional, time-dependent global dynamics, chemistry, energetics, and electrodynamics of the mesosphere, thermosphere, and ionosphere, for given inputs representing solar, magnetospheric, and lower-atmospheric effects. Other HAO models with extensive use by the community are the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure for synthesizing high-latitude observations of ionospheric electric fields and currents, the Global-Scale Wave Model (GSWM) for calculating atmospheric tides and planetary waves from the ground through the thermosphere, and the GLOW model for calculating the effects of solar ultraviolet and X-rays as well as energetic particles. These models are used to understand the processes affecting the dynamical, electrodynamical, thermodynamical, and chemical conditions in the Earth's upper atmosphere, its response to the Sun's variable radiative, particulate and magnetic emissions, and its coupling to the lower atmosphere and the magnetosphere.

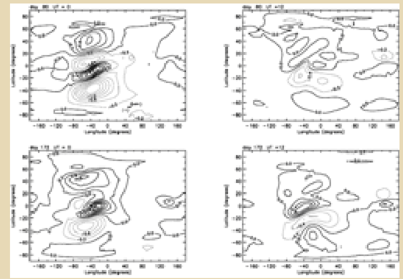


Figure 1: Simulated global change in foF2 (MHz) at day 80 (top) and day 172 (bottom) at 0 UT (left) and 12 UT (right) due to geomagnetic-field change between 1957 and 1997.

High resolution figure

The models have been upgraded through improvements to atmospheric tidal forcing, auroral precipitation, and coupling with magnetospheric electrodynamics. In collaboration with the University of Colorado, the Global Ionosphere Plasmasphere (GIP) model has been coupled with the TIE-GCM, to allow replacement of the TIE-GCM imposed upper boundary conditions on the ionosphere with a physical model. Model results have been provided to collaborators in the community. A documented version of the TIE-GCM, version 1.9, has been made public at http://www.hao.ucar.edu/modeling/tgcm/ . This work has been sponsored by NSF base support to NCAR, NSF Space Weather special funds, and NSF CEDAR special funds. It has also been supported by NASA and DOD programs.

Highlight: Modelling the effects of changes in the Earth�s magnetic field from 1957 to 1997 on the ionospheric hmF2 and foF2 parameters

Long-term trends in ionospheric electron density and peak height have been used to study global-change effects in the upper atmosphere. However, the ionosphere responds not only to increased atmospheric carbon dioxide, but also to slow variations of the Earth's magnetic field and to trends in geomagnetic activity. In order to quantify the importance of changes in the Earth's magnetic field, the NCAR TIE-GCM was used to model the ionosphere for the magnetic field as it existed in 1957 and 1997, taking into account self-consistently the changes in thermospheric winds due to changes in ionospheric drag. Substantial changes in the peak height, hmF2, (up to ±20 km) and critical frequency for radio-wave reflection, foF2, (up to ±0.5 MHz) are predicted over the Atlantic Ocean and South America. This would make up a significant contribution to observed long-term trends in these areas and therefore must be taken into account in their interpretation. Modeled trends of hmF2 and foF2 exhibit a strong seasonal and diurnal variation, highlighting the importance of separating data with respect to season and local time. Most of the modeled changes in hmF2 and foF2 can be related to changes in plasma transport up or down magnetic field lines driven by neutral winds, changes which are mostly caused by changes in the inclination of the field, though changes in declination and neutral wind also play a role. Changes in the vertical component of the electrodynamic drift velocity have relatively little effect (Figure 1).

This work was supported in part by NSF base funding. Graduate student visitor Ingrid Cnossen was supported by a Marie Curie fellowship of the European Union.

Reference: Cnossen, I., and A.D. Richmond (2008), Modelling the effects of changes in the Earth's magnetic field from 1957 to 1997 on the ionospheric hmF2 and foF2 parameters, *J. Atmos. Solar-Terr. Phys.*, 1512-1524.

Future Plans

For FY09, we plan to continue model upgrades, testing, and scientific analysis in collaboration with the community. Model developments will continue to be documented, and upgraded versions of the TIE-GCM source code will be made available at the www.hao.ucar.edu/modeling/tgcm web site. Results of scientific studies will be published. Particular foci will be testing and implementing the full electrodynamic coupling of the GIP plasmasphere model with the TIE-GCM, continuing to transfer and document process modules from the TIME-GCM to WACCM, and continuing to test and implement modules coupling the magnetosphere with the ionosphere and thermosphere.

return to top

Carbon / Nitrogen cycle modeling

Overview

ESSL scientists have recently completed a model development project to bring together parallel efforts in the climate modeling and ecological modeling communities, integrating a detailed treatment of the terrestrial carbon cycle with a state-of-the-art land surface model (the Community Land Model - CLM). The resulting model has now been tested and its performance documented in offline configurations. A critical application of the model has been to study the influence of carbon-nitrogen cycle coupling on present-day and potential future climate-carbon cycle feedbacks. Inclusion of the nitrogen cycle has the net effect of limiting atmospheric carbon dioxide uptake, with more carbon dioxide remaining in the atmosphere to play a role in climate forcing. Development and evaluation of the simulated terrestrial carbon cycle and climate-carbon cycle feedbacks continues.

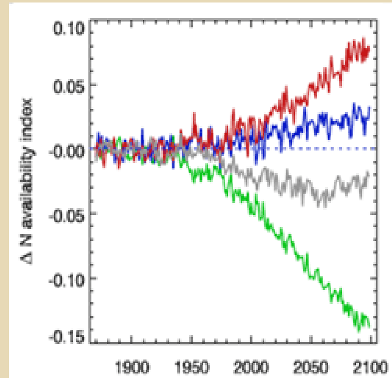


Figure 1. Results from Thornton et al. (in press), showing the changing climate and nitrogen deposition on nitrogen availability. The result is that the C-N model predicts a smaller land carbon sink over time as fossil fuel emissions of CO_2 increase, leading to a higher future concentration of atmospheric CO_2 .

High resolution figure

Recent Accomplishments

ESSL scientists participated in a project known as C-LAMP (Carbon LAnd Model intercomparison Project) to evaluate two different implementations of the terrestrial carbon cycle in the CLM. One model, CLM-CN, includes carbon-nitrogen interactions. A second model, CLM-CASA', simulates only the carbon cycle. The first paper describing the evaluation of the land model predictions against a broad database of observations (remotely sensed and in situ) of many different ecosystem states and fluxes has been submitted. Both models replicate key features of the terrestrial carbon cycle, but also have key deficiencies and model development continues.

Development of a fire module, coupling to the dynamic global vegetation model, implementation of land cover change, and a model of soil NO, N_2O and N_2 emissions adds to the functionality of the CLM.

2009 and Beyond

The work in FY 2009 continues to focus on the development and evaluation of the terrestrial carbon model in preparation for the release of CCSM 4.0. The primary scientific focus beyond the CCSM 4.0 release is to examine human and natural feedbacks and forcings in the earth system operating through the biogeochemical cycles.

return to top

Analysis, Integration and Modeling of the Earth System (AIMES)

Overview

ESSL is the home of the International Project Office (IPO) for the International Geosphere-Biosphere Programme's (IGBP) Earth System modeling project, Analysis, Integration and Modeling of the Earth System (AIMES). The AIMES project endeavors to extend Earth System modeling approaches to include dynamics of human activities alongside biogeochemical and biophysical processes of the coupled climate system. Modeling activities in AIMES include improving biophysical and biogeochemical components of global models and testing the sensitivity of tradeoffs in vulnerability and resilience in terms of economic and ecosystem consequences.

AIMES and the WCRP Working Group on Coupled Modeling (WGCM) have collaborated to develop a strategy for next generation climate simulations for the upcoming Fifth Assessment.

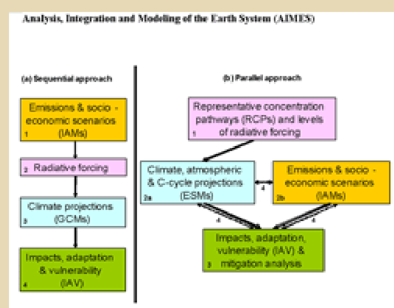


Figure 1. Approaches to the development of global scenarios from Moss et al., (2008): (a) previous *sequential* approach; (b) proposed *parallel* approach. Numbers indicate analytical steps (2a and 2b proceed concurrently). Solid arrows indicate transfers of information. Dotted arrows indicate integration of information..

Recent Accomplishments

Report of the IPCC (AR5). Climate modeling experiments for AR5 will include both long term (e.g., 2100 and beyond) and decadal prediction (Hibbard and Meehl 2007). In addition, AIMES also collaborates with the Integrated Assessment Modeling Consortium (IAMC) on the generation of scenarios for

AR5. This collaboration has led to close collaboration and improved understanding of the provenance of the radiative forcings provided by the integrated assessment community and the strengths and limitations of climate modeling between the two modeling communities. This collaboration has resulted in a proposed parallel process (Figure 1) where the climate, integrated assessment and impacts, adaptation and vulnerability communities work much more closely towards the development of new scenarios for possible assessment activities beyond AR5. To initialize the AR5 process, AIMES worked with the IAMC and WGCM on the development and harmonization of land use, land cover and emissions between the climate and integrated assessment models for the representive concentration pathways that will define the scenarios for AR5.

High resolution figure

Relevant activities in AIMES include the Coupled Carbon Cycle-Climate Model Intercomparison Project (C4MIP), where the magnitudes of terrestrial carbon uncertainties are still largely uncertain. C4MIP investigates model benchmark and evaluation exercises to explore mechanisms that influence the response of the terrestrial carbon cycle: (1) soil moisture and net primary production, particularly in the tropics, (2) effects of CO2 fertilisation, and (3) disturbance and land cover. A joint strategy of AIMES and the is to collaborate with the IPCC Working Groups to develop climate change stabilization experiments with coupled atmosphere/ocean general circulation models, Earth System and Integrated Assessment models. AIMES, on behalf of the IGBP is leading an applied Earth System Science initiative to foster collaboration and exchange of information between the scientific community and resource managers, policy and and assessment communities and development agencies. The International Nitrogen Initiative (INI), addresses end-to-end problem solving across scales (e.g., spatial, temporal, management) implementing process-based research through mitigation or management. In addition, AIMES sponsors the Global Emissions Inventory Activity (GEIA). AIMES is also working within the international community to develop an integrated synthesis of activities in the northern high latitudes to promote model development.

To date, AIMES has initiated a Young Scientist's Network (YSN) with topics including integrating indirect human activities (e.g., land use) with the Community Climate System Model (CCSM), Urbanization, biogeochemistry and the climate system, and land-use decision making for Earth system models. In 2008, NCAR hosted a YSN on Cultural Use and Impacts of Fire: Past, Present and Future.

The Integrated History of People and Earth (IHOPE) activity started in 2005 with a Dahlem conference on Collapse or Sustainability: an Integrated History and Future of People on Earth (Costanza et al., 2007, 2008). An overall conclusion from the Dahlem-IHOPE conference is that societies respond in various manners to environmental (e.g., climate) stress. Extreme drought, for instance, has triggered both social collapse and ingenious management of water through irrigation. AIMES is communicating with the Stockholm Resilience Centre (SRC) in Sweden to organize IHOPE-related activities targeting issues on historical, even decadal, timescales on the various ways of understanding the growth of environmental prediction and modeling, largely a 20th c. phenomenon (and, an understanding of IHOPE itself as a feature of modern "historiography"). AIMES and the SRC are discussing a series of meetings in 2009-2010, encompassing both the global south and the global north.

Sponsoring entities for workshops, symposia and colloquia include: NSF, NASA, EC-ACCENT (EU EC_FP6), IGBP, MPI (Germany), QUEST (UK), Arizona State University, University of Vermont, IHDP, the IAMC and WCRP.

return to top

Master mechanism

The NCAR Master Mechanism is an explicit and detailed gas phase chemical mechanism combined with a box model solver. User inputs include species of interest, emissions, temperature, dilution, and boundary layer height. Any input parameter may be constrained with respect to time. Photolysis rates are calculated using the TUV model included in the code package. The model is written in a mixture of F77 and Fortran90, and is managed using C-shell scripts.

ACD scientists continued the development of the Generator for Explicit Chemistry and Kinetics of Organics in the Atmosphere (GECKO-A), producing the only fully explicit mechanism for the gas-phase atmospheric oxidation of hydrocarbons. In collaboration with Bernard Aumont and Marie Camredon (U. Paris), ACD scientists have removed the 8-carbon limitation on hydrocarbon chain length, by assuming complete condensation to the aerosol phase for species with vapor pressures lower than 10^{-13}. For conditions relevant to Mexico City and chain lengths up to 10 carbons (the largest hydrocarbons for which observations are available), the gas phase mechanism consists of ca. 1.2×10^6 reactions among ca. 2×10^5 different chemical species. By allowing for gas-particle partitioning of these condensible compounds, they simulated the formation of secondary organic aerosols (SOA) in Mexico City for the conditions of the MIRAGE campaign. Results show significant SOA production for several days, although at rates slower than observed.

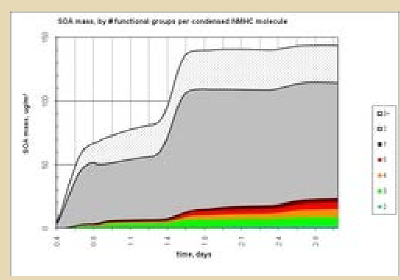


Figure 1: Evolution of secondary organic aerosols simulated with the Self-Generating Master Mechanism (SGMM) for Mexico City, April 2003. Color areas show multifunctional organics partitioned to the aerosol phase, while black & white areas show multifunctional organics remaining in the gas phase. [Lee-Taylor, J., S. Madronich, G. Tyndall, B. Aumont, and M. Camredon (2006), Explicit modeling of SOA precursors in Mexico City, Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract A23A-0935.]

High resolution figure

ACD scientists, together with researchers from Pacific Northwest National Labs and the U. of Washington used smog chamber measurements to show that hydrophobic aerosols play no role in SOA formation, contrary to previous theories. ACD scientists are also collaborating with PNNL researchers to provide input to a comprehensive, generalized inorganic-organic aerosol model.

FY 2009 work will continue development and evaluation of the GECKO-A mechanism generator, and perform further box model simulations for Mexico City to interpret results from the MIRAGE campaign.

This work is funded by NSF/NCAR and the DOE.

return to top

Tropospheric Ultraviolet and Visible (TUV) - Radiation Model

The Tropospheric Ultraviolet-Visible (TUV) radiation model calculates spectral irradiances and actinic fluxes, biologically active UV radiation at the surface, and photolysis coefficients (J values) for atmospheric chemistry use. TUV version 4.5 is available to the community through the NCAR/SCD Community Data Portal. ACD scientists have also made available global UV climatologies using TOMS v.8 ozone, specifically, maps of UV-A, UV-B, and several biologically weighted exposures (erythema, non-methane skin cancer, and vitamin D production). [Lee-Taylor, J. and S. Madronich, Climatology of UV-A, UV-B, and Erythemal Radiation at the Earth's Surface, 1979-2000, NCAR Technical Note TN-474-STR, August 2007.] An analytic formula for the UV Index in terms of the ozone column and sun angle allows efficient parameterization of UV effects of ozone changes.

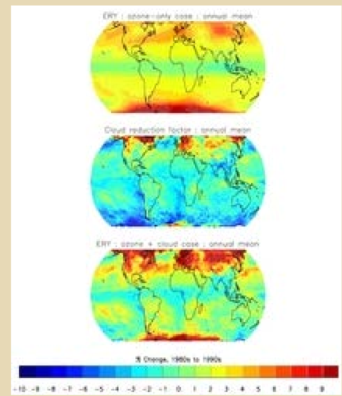


Figure 1: Change in annual mean sunburning (erythemal) UV radiation from the 80's (1979-1989) to the 90's (1990-2000). Top panel shows UV changes stemming from ozone changes only, middle panel for cloud changes only, and bottom panel from both ozone and cloud changes. [Lee-Taylor, J. and S. Madronich, Climatology of UV-A, UV-B, and Erythemal Radiation at the Earth's Surface, 1979-2000, NCAR Technical Note TN-474-STR, August 2007.]

High resolution figure

ACD scientists collaborated with university colleagues to apply the TUV model and UV climatologies to diverse problems including skin cancer incidence and plant-based methanogenesis. ACD scientists and university colleagues are also examining the UV radiation field during the MIRAGE-Mex field campaign. Mexico City's pollutants (ozone, sulfur dioxide, nitrogen dioxide, and aerosols) reduce the UV radiation field in the boundary layer by 10-20% and at the surface by 20-40%. Preliminary analyses suggest that aerosols are more absorbing at UV wavelengths than at visible wavelengths. The UV reductions slow photochemistry significantly, allowing for greater export of yet-unreacted pollutants.

This work is funded by NSF/NCAR.

return to top

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

NCAR is sponsored by the National Science Foundation.

ESSL LAR 2008: STRATEGIC GOAL #1, PRIORITY #4

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #1, Improve understanding of the atmosphere, the Earth system, and the Sun. This Strategic Goal encompasses four Strategic Priorities, each of which is dependent on the efforts and accomplishments of ESSL staff.

ESSL developed an action plan with seven priority themes which involve direct partnerships with the university community and contribute directly to the ESSL Strategic Vision and to several priority items of the NCAR Strategic Plan.

ESSL's seven priority themes:

1. Climate projection, with emphasis on short-term prediction.
2. Biosphere-Atmosphere-Hydrosphere interactions and specifically development of BEACHON Project (Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, Hydrology, Organics and Nitrogen).
3. Water system research, specifically the development of the Society, Water, Atmosphere and Natural Systems Project (SWANS).
4. An advanced Weather Research and Forecasting system, specifically the development of the Hurricane Intensity and Forecasts (HiFi) Project.
5. Space Weather, specifically the development of the Coronal Solar Magnetism Observatory Project (COSMO).
6. Chemical Weather, including interpretation of observed data gathered during the Megacity Impact on Regional and Global Environments (MIRAGE) campaign, and the development of a capability for chemical data monitoring and prediction.
7. Prediction across scales, specifically the development of an advanced next-generation, climate-weather modeling system and an integrated Earth system model of intermediate complexity.

Goal #1, Priority #4: Developing Community Models, is described in the NCAR Strategic Plan as follows: "Developing numerical models and making them available to the scientific community is at the heart of NCAR's research and service to the community. Key activities in this priority are creating and adding to community models, research models, as well as progressing toward creation of an Earth system model."

This NCAR priority, driven by ESSL's themes 1, 4, 5, 6 & 7, is critical to achieving NCAR's first strategic goal.

The section below describes specific research conducted by ESSL staff under projects relevant to Priority 4. The major ESSL activities in this area are ongoing improvement and development efforts focused on the following numerical models: the Community Climate Systems Model (CCSM), the Weather Research and Forecasting model (WRF), Space Weather prediction models, the Nested Regional Climate Model (NRCM), and the Whole Atmosphere Community Climate Model (WACCM). Additional models included in these efforts are the Model for Ozone and Related chemical Tracers (MOZART), the Community Atmosphere Model with chemistry (CAM-Chem), upper atmosphere models, and carbon/nitrogen cycle models.

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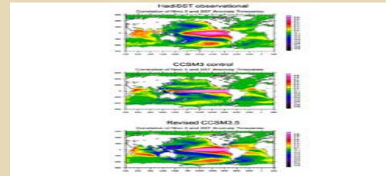
12. Analysis, Integration and Modeling of the Earth System (AIMES) - CGD
13. Master mechanism - ACD
14. Tropospheric Ultraviolet and Visible (TUV) - Radiation Model - ACD

Community Climate System Model: Development of Scientific Capabilities

Overview



The correlation of the Nino 3 and global sea surface temperature anomaly timeseries from a) HadiSST observations, b) CCSM 3 control, and c) CCSM 3.5 model.

High resolution figure

The development and continuous improvement of a comprehensive climate modeling system that is at the forefront of international efforts to understand and predict the behavior of the Earth's climate is a high priority of NCAR research. This includes the Community Climate System Model (CCSM) as well as its component models. The CCSM, run on some of the world's most powerful supercomputers, simulates the many interconnected events that drive Earth's climate. These include changes in the atmosphere and oceans, the ebb and flow of sea ice, and the subtle impacts of forests and rivers.

CCSM is unique among the most comprehensive of global climate models. Primarily supported by the National Science Foundation (NSF) and the Department of Energy (DOE), with additional support from the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), it belongs to the entire community of climate scientists, rather than to a single institution. Hundreds of specialists from across the United States and overseas collaborate on improvements to CCSM. The model's underlying computer code is freely available on the Web. As a result, scientists throughout the world can use CCSM for their climate experiments.

The CCSM project was started in 1994, although climate modeling at NCAR has a much longer history, stretching back to about 1980. The first version of CCSM was unveiled in 1998, and the most recent version, CCSM-3, was released in 2004. CCSM-3 represents a major advance over earlier versions of the model because it contains far more information about Earth's physical processes. For example, it tracks the flow of major rivers that empty into the oceans and it now resolves five different thickness categories of sea ice within each grid cell, such as the thickness and the melt rate. Moreover, the finer scale and lower viscosity of its ocean allows scientists to capture significantly greater detail about ocean currents and the mixing of salt and fresh water.

CCSM is constantly being updated and improved; CCSM4 is most likely to be released in 2009. In preparation, an interim version, CCSM3.5, was assembled in mid-2007, and is being evaluated from a number of perspectives, with carbon system spin-up a particular focus. In addition to remaining at the forefront of international modeling efforts, the scientific goals of the CCSM project are as follows:

- to use the modeling system to investigate and understand the mechanisms that lead to interdecadal, interannual, and seasonal variability in Earth's climate;
- to explore the history of Earth's climate through the application of versions of the CCSM suitable for paleoclimate simulations; and
- to apply this modeling system to estimate the likely future of Earth's environment in order to provide information required by governments in support of local, state, national, and international policy determination.

ESSL/CGD (in collaboration with scientific and software engineering partners from Universities, DOE, NASA) has been busy in developing component models, integrating those components as candidates considered for the next generation of the CCSM, and exploring these in a variety of ways for understanding the Earth System and climate change. One of the topics identified in last year�s report as a "Plan for 2008" was "a concerted effort to address systematic model biases in the tropics on seasonal and longer timescales." We describe one contribution to that effort here.

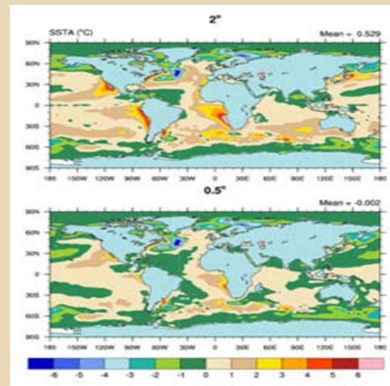
Recent Accomplishments

A significant reformulation of the parameterization of convection within Community Atmosphere Model (CAM) took place in 2007. The parameterized convection was made much more sensitive to the dilution of air as it ascends in the atmosphere. The convecting parcels were also made sensitive to the change in phase of condensate between liquid and ice, and momentum transports were included in the formulation. The result was a substantial improvement in many aspects of the atmospheric simulation when driven with observed sea surface temperatures, and in the coupled system. The changes were included in the CCSM 3.5, an interim version, which was finalized in October 2007. This uses the new finite volume dynamical core in the atmosphere component, the updated POP 2 code for the ocean component, the latest CICE 4 version for the sea ice component, and a much updated version of the land component compared to the CCSM 3. There have also been significant parameterization improvements in all the components. CLM 3.5 has a very much improved hydrology cycle compared to CLM 3, and the global partitioning of evapotranspiration is greatly improved using the CLM 3.5.

The most significant aspect of CCSM 3.5 is in its simulation of the El Nino - Southern Oscillation (ENSO) in the tropical Pacific Ocean. All previous versions of the CCSM, and most other climate models, had a peak in the ENSO frequency near two years, which is much shorter than in reality. This problem has now been corrected in CCSM 3.5, which shows a frequency peak between 3-6 years. In addition, the correlation between the Nino 3 SST timeseries and SST anomalies across the globe has also been substantially improved. Figure 1 shows this correlation from the HadiSST observational data set, the previous CCSM 3 control, and the new model version with the CAM 3.5. The improvement is quite remarkable, with the new model showing a correlation pattern that is very like the pattern from observations. The correlation is much broader in the eastern tropical Pacific, and the correlation patterns in the Pacific and other oceans are also much improved. We believe this is primarily due to the two modifications of the deep convection parameterization in the atmosphere, which include convective momentum transport and a dilute approximation to calculate CAPE.

Another accomplishment during FY 08 has been to run the first proof of concept short-term projection from 1980 to 2030. This run uses much finer horizontal resolution of 0.5 degree in the atmosphere and land components. The initial conditions for these components were interpolated from the January 1st 1980 fields from a 20th century run using 2 degree resolution in the atmosphere and land components. The two runs were integrated from 1980 to 2030 using observed carbon dioxide levels to 2000, and then the A1B future scenario. The largest improvement was in the sea surface temperature fields in the three major upwelling regions. The SST errors compared to observations in the two runs are shown in Figure 2. The SST errors are reduced by well over 50% off the west coasts of the USA and Peru, and by a smaller percentage off Namibia. This is a significant improvement, but the 0.5 degree run takes about 20 times more computational resource than the 2 degree run. The 0.5 degree version of the new CCSM 4 will be used to make the short-term climate projections for the next IPCC assessment.

During FY 2008, the major CSEG accomplishment has been to finalize and test the sequential, single-executable CCSM. The goal was to create a sequential system that contains backwards compatibility with the current concurrent system, provides "plug and play" capability of data and active components and produces the same climate as the current concurrent system. In addition, the CSEG has ported and tested the results from the CCSM 3.5 running on several new computer platforms across the USA.



The sea surface temperature errors compared to observations over 1985-2000 from the CCSM 3.5 using 2 degree and 0.5 degree resolutions in the atmosphere and land components.

High resolution figure

2009 and Beyond

2009 will be a very busy year for the CCSM project. The deadline for delivery of individual components of the next version, CCSM 4, is September 30, 2008. CCSM 4 then needs to be finalized, which requires acceptable 1870 Control and 20th century runs to have been made and positively analyzed. This usually takes several months to achieve, and will first be done using a resolution of 2 degrees in the atmosphere and land, and 1 degree in the ocean and sea ice. Then, an acceptable 0.5 degree version of the atmosphere and land components needs to be assembled to be used in the short-term simulations. Finally, a low resolution version of the CCSM 4 needs to be assembled for use in Paleoclimate studies.

return to top

Space weather: Model development and data analysis

Space weather research seeks to understand and work towards predictions of the physical conditions in the geospace environment, particularly when disturbed by energetic events occurring on the Sun. This is a multidisciplinary field of research which requires understanding of solar, solar wind, magnetospheric, and ionospheric physics. It covers a broad range of time scales, including solar cycle variations (years), recurrent solar wind streams (months), coronal mass ejection (CME) propagation and geomagnetic storms (days), flares and energetic particles (minutes). Understanding these phenomena is important for human spaceflight, satellite design, communication and navigation systems used by our increasingly technologically dependent society.

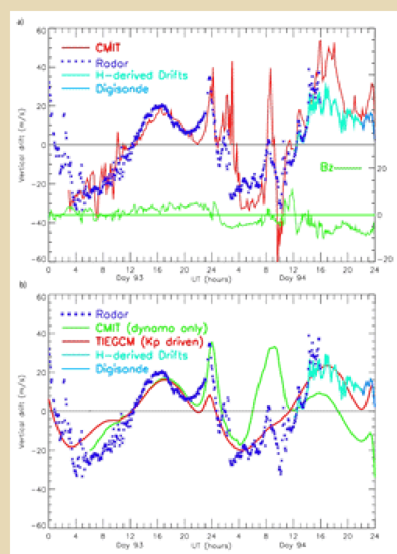


Figure 1: (a) Ion vertical drift velocities (m/s) at the F2 peak measured by the Jicamarca radar (blue crosses), inferred from ground-based magnetometer (light green line) data

HAO scientists continue to make substantial progress in modeling the many aspects of Space Weather. Coronal mass ejections are a main driver of significant space weather events. Using 3D MHD simulations Yuhong Fan and Sarah Gibson have been able to determine that both the precursor magnetic field configuration in the corona and the initiation mechanism play and an important role in determining the geoeffectiveness of a CME. In particular, they found that eruptions triggered by the torus instability or the kink instability can result in magnetic clouds which differ in their geoeffectiveness due to the different amount of rotation of the escaping flux rope that ultimately affects the orientation of the magnetic field impacting the Earth's magnetosphere. Mark Miesch and colleagues have completed initial development of a heliospheric model using the FLASH code produced by the University of Chicago. This model is currently capable of modeling the configuration of the plasma and magnetic fields into which a CME must propagate before reaching the Earth. AIM scientists led by Wenbin Wang used the CMIT 2.0 Model developed in collaboration with the Center for Integrated Space Weather Modeling (CISM) to study vertical drifts in the F region of the ionosphere. They found that the model does a good job of capturing the temporal variations of these drifts. Furthermore, they conclude that these variations were primarily driven by changes in the solar wind conditions. In collaboration with colleagues at Dartmouth College, AIM scientist Michael Wiltberger began the process of adding mass outflow from the ionosphere into magnetosphere in the Coupled Magnetosphere Ionosphere Thermosphere (CMIT) model. Initial results from these studies have shown that this outflow can have a significant impact on the evolution of the magnetosphere. In particular, simulations with large outflows have shown a multiple substorm sequence for steady IMF conditions which is not seen in simulations for similar conditions which do not include the outflow. Another major achievement of the AIM group, directed by Stan Solomon, in support of Space Weather modeling has been the release of the TIE-GCM, an essential component of CMIT, directly to the community under an open source licensing agreement. In addition, we are working closely with NASA's Community Coordinated Modeling Center (CCMC) to provide the space weather community with the ability to conduct runs on request of CMIT.

and determined from the F2 peak bottomside height changes from the Jicamarca digisonde (light blue line), and simulated by the CMIT model (red line) for the April 2-5, 2004 geomagnetic storm event. Also shown in the plot is the IMF Bz component (nT, green line). (b) Ion vertical drift velocities (m/s) caused by the neutral wind dynamo (dynamo only, green line), and those from the stand-alone TIEGCM (red line).

High resolution figure

Over the course of the next year simulations of CMEs will be conducted using vector magnetic field observations from the recently launched Hinode satellite as basis for determining the shearing and twisting motions driving specific events. These event studies will allow for a direct quantitative comparison of the simulation results with multi-wavelength coronal observations. The heliosphere model will be used to model the solar wind conditions observed during the Whole Heliosphere Interval. Work on this model will also include coupling it with CME eruption modeling to study the evolution of the magnetic field structure within and around the CME as it propagates to the Earth. Now that initial work on including mass outflow into CMIT has been completed we will focus on the extension of this work to incorporate the factors regulating the magnitude and location of the outflow into the model. Development of CMIT will also include efforts to improve the representation of the magnetic field in the inner magnetosphere by coupling it to a ring current model.

return to top

Nested regional climate modeling (NRCM)

Mesoscale processes can have a major impact on large-scale circulations. Yet climate models do not adequately represent this upscale influence of mesoscale processes. NCAR is addressing this challenge by developing a multi-scale modeling system to aid our understanding of climate processes, particularly at the regional scales important to society, and projecting how these may change in the future. A multi-scale modeling system is necessary not only to reduce these climate biases but also to:

(a) downscale climate variability and climate change to the regional scale for applications such as water resource management over, say, the Western US, and to determine the climatology of extreme events such as tropical cyclones.
(b) capture the upscale impacts of regional phenomena such as eastern boundary upwelling regimes or mesoscale convection.

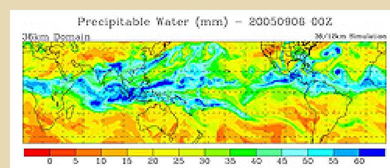


Figure: Precipitable water analysis for 2005 Sep 06, 00Z from the NRCM 10-y simulation of current tropical climate showing hurricanes in the North Atlantic.

High resolution figure

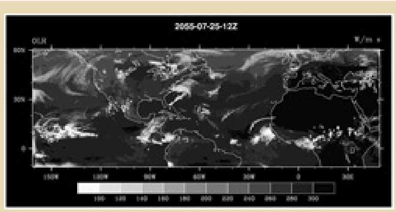


Figure: Outgoing long-wave radiation (Wm-2) for 2055 Jul 25, 12Z from the NRCM time-slice projection of future climate under A2 forcing scenario showing a tropical cyclone off the east coast of the US and a convective disturbance off the west coast of Africa.

High resolution figure

The Advanced Research WRF (ARW) and Community Climate System Model (CCSM) have been specifically proposed as candidates from which to develop a two-way coupled multi-scale modeling system. As a first step in this direction, a consortium of University, DOE and NCAR/MMM and CGD scientists engaged in developing the Nested Regional Climate Model (NRCM) from the ARW model. The NRCM has been configured to a tropical channel domain, driven by NCEP-NCAR reanalysis conditions at the north and south boundaries, to enable investigations of the simulation of tropical modes and their interaction with moist convection and to provide high-resolution winds for a study of eastern oceanic boundary issues. Figure 1 shows a snapshot of precipitable water over the tropical channel domain showing tropical cyclones over the North Atlantic. This work included a range of 1-way and 2-way nesting configurations aimed at gaining experience with such configurations and at enabling leading-edge research on the output. The experience with this phase of the program has been an excellent learning activity as well as providing improved understanding of the interactions between mesoscale processes, specifically moist convection, monsoons, and climate. The NRCM has also been instructive in providing a means of distinguishing processes that are, or may be adequately parameterized, from those that cannot and must be resolved in climate simulations.

Our main research goal in FY2008 was to perform a more detailed and extensive analysis of the tropical channel simulations to advance our understanding of tropical wave modes, and evaluate the model's skill in simulating various tropical phenomena using different levels of nesting. Building on strong collaborations between MMM and CGD, and between NCAR and a host of external investigators, significant progress has been made in several areas, with a few key examples highlighted below:

1) Analysis of tropical wave modes

A preliminary space-time spectral analysis of the outgoing long-wave radiation in FY2006 indicated that the tropical channel model is able to capture important wave-like modes corresponding to Kelvin waves and Madden-Julian Oscillation (MJO). In FY2007, a more detailed analysis of the Kelvin waves showed that their horizontal propagation speeds and vertical dynamical signals are reasonably well simulated, although the climatological variance of these waves is significantly under-predicted in the deep tropics (between 5S-5N). A similar under-prediction problem was found for the MJO, which also appears less well organized than the observed MJO.
To investigate the causes of this poor MJO representation, an additional analysis was performed of two simulations of an MJO event that occurred during May - June of 1997. Careful processing of the continuous run initialized on January 1, 1996, shows that no MJO events occurred during the May - June period. However, in a simulation initialized on May 1, 1997, the MJO event was successfully reproduced. These findings suggest that model biases built up in the continuous run have a significant negative impact on the simulation of MJO. Additional analyses are being performed to understand the separate influences of initial conditions, lateral boundary conditions, and model physics on the ability of the model to capture various tropical modes.

In FY08, space-time spectral filtering of the simulated OLR was used to isolate easterly waves and tropical-depression type disturbances, extending the Kelvin wave analysis of FY07. Results showed reasonable climatological variance of easterly waves in the Pacific basin, but a significant under-prediction of wave activity in the Atlantic. Presumably this bias stems from biases in the mean state, such as anomalously heavy rainfall over the Pacific and drier conditions over Africa. Given that a large fraction of tropical cyclones in the model are found to develop from easterly waves (as demonstrated through composite analyses), it would seem that the paucity of tropical cyclogenesis cases over the tropical Atlantic can be traced to deficiencies in the mean state.

2) Analysis of the East Asian monsoon

Comparison of the observed and simulated East Asian summer monsoon circulation and precipitation revealed a major weakness in the NRCM simulation. This problem was particularly significant during 1997 when the West Pacific Subtropical High in the simulation was displaced much further east and a low pressure center was generated near the South China Sea that created a northeasterly flow into central and southern China, as opposed to the southwesterly monsoonal flow that brings abundant moisture and precipitation. On the other hand, the simulation compared well with observations during the 1998 summer.

To investigate the reasons for the large difference in model skill from year to year, we performed several sensitivity experiments to isolate the impacts of model initialization, sea surface temperature (SST), lateral boundary conditions, and physics parameterizations. These experiments suggest that SST plays a dominant role in explaining the large difference between the simulations in 1997 and 1998, possibly due to the strong dynamical feedbacks between SST forced convective heating in the western Pacific and the large scale circulation. However, the erroneous circulation in 1997 was insensitive to the convective parameterizations used. In FY08, we conducted a series of 4-month sensitivity experiments for the 1997 East Asian monsoon. We found that the error in the simulation of East Asian monsoon was largely due to the lack of atmosphere-ocean interaction in the current NCRM simulation. Deep convection may be triggered too easily in the model because of the lack of air-sea coupling that should provide a negative feedback to modulate deep convection in areas with warm SST. The excessive convection also accounts for the significant over prediction in the number of tropical cyclones over the western Pacific Ocean. When daily SST together with a simplified diurnal SST model was implemented, the error in precipitation forecast was substantially reduced. This highlights the need to develop a full-coupled atmosphere-ocean regional climate model that is also fully coupled with the global climate model.

3) Analysis of tropical cyclones

NRCM simulations have been explored using a tropical cyclone detection algorithm. The model captured the general global and seasonal distributions of tropical cyclones but consistently overproduced the number of tropical cyclones. Two-way nesting down from 36km to 12km over the Atlantic region for the 2005 season improved both the number and spatial distribution. This dataset has also been used to show the importance of the background flow in modulating easterly waves thereby creating favorable conditions for tropical cyclogenesis, and higher resolution simulations of genesis has shown vortices merging during the period of genesis.

Plans for FY09 include a climate change experiment using NRCM over the North America region, which is currently underway, and represents the second stage of research and model development towards a multi-scale modeling system based on ARW and CCSM. Research is primarily aimed at water resource variations in the intermountain western region and tropical cyclone variations over the North Atlantic region. The period of particular interest is the next 50 years or so, when society will largely have to adapt to those climate changes that are inevitable. The large-scale forcing data is provided from CCSM3 T85 climate change integrations and a series of “time-slice” ensemble experiments are currently being generated for three ten-year periods: 1995-2005, 2020-2030, and 2045-2055. Figure 2 shows a snapshot of outgoing long-wave radiation from July 2055 showing a tropical cyclone off the east coast of the US and a disturbance off the west coast of Africa. This experiment provides a genuine test of the requirements for future supercomputing systems to enable decadal predictions of the regional detail required for planning and adaptation strategies.

Trends in hurricane activity in the North Atlantic, Caribbean and Gulf of Mexico regions will be examined. This ambitious project is providing for the first time, decadal climate simulations of hurricanes at a resolution sufficient to identify key intensity and structural details. Another key focus area will be trends in water resources over the Western U.S.

The NRCM effort represents a step towards a new global weather climate model, referred to here as the Earth System Model (ESM), at 'convection permitting' resolution. A new model is necessary to perform well on future computing platforms. The ESM is currently in its inception phase and it is anticipated a robust model is ten years away. Lessons learned from NRCM are directly relevant to the ESM effort and will steer its development.
NCAR plans that the NRCM will eventually be provided and maintained as a community resource for use by all the academic, government, and private sector communities. The NRCM project has strong community support and is funded largely by the offshore oil industry, the reinsurance industry and NSF, supported by the MMM and CGD divisions.

return to top

Weather Research Forecasting (WRF) Model

During the past year, NCAR continued to develop new capabilities for the Advanced Research WRF (ARW) and support it to the community. Over 2000 new users registered to download the code, bringing the total number of registered users to over 7,600. Over half of this total is non-US users, and 113 countries are represented. Figure 1 shows the numbers of registered WRF users and a breakdown by group.

Figure: WRF user registration and growth of registered users (as of Aug. 2008).

High resolution figure

In June 2008 MMM organized and conducted the 9th Annual WRF Users' Workshop, with over 225 participants attending from many different countries. MMM personnel also conducted three user tutorials on the ARW and WRF-VAR. The two ARW tutorials were held in Boulder with approximately 60 participants attending the first and 71 the second. The WRF-VAR tutorial, also in Boulder, attracted 52 participants. In addition, MMM division staff put on the 2nd East Asia Weather Research and Forecasting (WRF) Model Workshop and Tutorial at Seoul National University in Korea in April 2008. The workshop focused on recent WRF developments in data assimilation, global modeling, and regional climate modeling, applications to high-impact weather and climate, and real-time operations. The workshop and tutorial were conducted as part of the Korea Foundation for International Cooperation of Science and Technology (KICOS) Global Partnership Program, under the Korea Ministry of Science and Technology.

return to top

WACCM

The Whole-Atmosphere Community Climate Model (WACCM) is a comprehensive numerical model, spanning the range of altitude from the Earth's surface to the lower thermosphere. WACCM is built upon the numerical framework of NCAR's Community Climate System Model (CCSM), and is envisaged as a flexible modeling environment, whose domain and component modules can be configured according to the specific problem under study. WACCM incorporates physical and chemical processes required to investigate the coupling among atmospheric regions from the surface to ~140 km. The current version of WACCM (WACCM3) has fully interactive chemistry and dynamics, and can also be coupled to the ocean component of CCSM. Addition of upper thermospheric physics and chemistry is currently underway, and will allow the model to extend upward to about 500 km.

WACCM has contributed to the Chemistry-Climate Model evaluation (CCMval) effort, an international activity under the auspices of the Stratospheric Processes And their Role in Climate (SPARC), and to the most recent Ozone Assessment (2006) of the World Meteorological Organization. In addition, the following topics are currently under investigation using WACCM:

- the effects of solar variability in the middle atmosphere using time-slice simulations during solar minimum and maximum conditions with and without the quasibiennial oscillation in the Tropics;
- the role of parameterized gravity waves and their tropospheric sources in simulations of the whole atmosphere;
- the dynamical variability in the middle atmosphere, in collaboration with University colleagues and other modeling groups;
- the response of the Brewer-Dobson circulation to climate change;
- the validation of chemistry and the dynamics of WACCM against observations (satellite and ground-based);
- testing and application of a new version of the model that can be driven by assimilated meteorological data to study the exchange of mass and constituents in the upper troposphere/ lower stratosphere;

- atmospheric predictability in the whole atmosphere context;
- the application of a version of the model coupled to the CCSM ocean component to understand climate change, including dynamics, temperature and chemical composition, in the 20th century and predict changes in the 21st century.

Recently published papers on these and other subjects may be found in the WACCM website . During 2008-2009, major emphases of the WACCM project will include: the study of the effect of the middle atmosphere on tropospheric climate; extension of WACCM to 500 km with the addition of an electrodynamics model component; improvements to the parameterization of mesoscale gravity waves; elucidation of the factors that accelerate the Brewer-Dobson circulation in the context of global-warming; and comparison of WACCM tides and other fast wave motions with global satellite observations.

return to top

WACCM development and extension

The goal of the Whole Atmosphere Community Climate Model (WACCM) is to develop a model that extends from the Earth surface to the upper thermosphere, and self-consistently resolve the dynamical, chemical, radiative, and electrodynamical processes and the coupling between atmospheric regions. The current standard WACCM version (WACCM3) has an upper boundary in the lower thermosphere (~140 km).

In the previous year (FY07), we developed a WACCM extended (WACCM-X) to the upper thermosphere at pressure 3.4x10^{-7} Pa (~500 km), and implemented thermospheric physics modules, including major species diffusion, the constituent-dependent specific heats, gas constant, and mean molecular weight, and revised the treatment of the vertical diffusion equations for minor species and heat conduction equation. In FY08, we have built on the WACCM-X and further tested and validated the model. Major achievments include:

1. Full model-year runs of WACCM-X under solar maximum, medium, and minimum conditions. Monthly mean climatology of winds and temperature structures in the upper atmosphere show general agreement with empirical models (MSIS-00 and HWM) and the TIME-GCM.
2. The semi-annual variation of the O/N2 ratio in the upper thermosphere is reproduced by the model, including the magnitude of the variation and its dependence on the solar flux.
3. Tides from the model were compared with TIMED/SABER and TIDI obserbations. The seasonal variability of the migrating diurnal tide, with maximum at March equinox and secondary maximum at September equinox, are in good agreement with observations, though the tidal amplitude from the model is weaker. We also demonstrated that the model amplitude is in much better agreement with observations when the vertical resolution of the model is doubled.
4. The nonmigrating eastward wavenumber 3 component from the model, which is the second strongest diurnal tide in the lower thermosphere, shows excellent agreement with that derived from SABER and TIDI in both its amplitude and seasonal variability.
5. The thermospheric tides show strong short-term variability, which is likely due to penetration of the lower atmospheric perturbations and their interaction with tides.

We are currently merging WACCM-X with WACCM 3.5. A significant improvement in the new version is the gravity wave source specification based on actual sources of convection and frontogenesis. We will examine its impact on the thermosphere. We are currently working on the electrodynamics of the model ionosphere by implementing ambipolar diffusion and ExB drift in the WACCM.

return to top

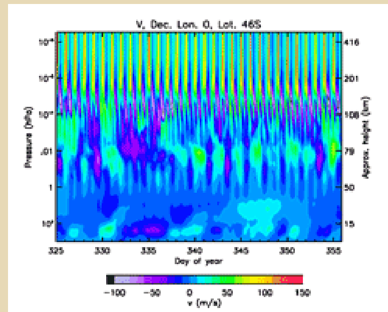
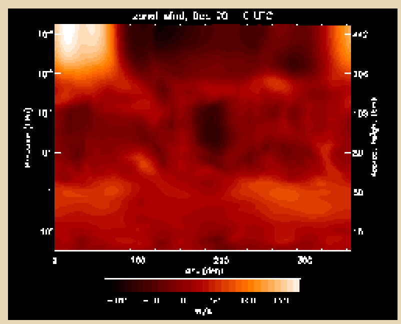


Figure 1: Meridional wind from the ground to the upper thermosphere from WACCM-X. At this southern mid-latitude (46S), variability associated with quasi-two-day waves, semi-diurnal tides, and diurnal tides are clearly seen in the mesosphere, lower thermosphere, and upper thermosphere, respectively. The model also produces short-term variability in tidal amplitude in the upper thermosphere.

High resolution figure



Movie 1: This animation shows the zonal wind from 20 to 29 December at 52N from a WACCM-X simulation. The output interval is 3 hours. From the simulation it is evident that planetary waves and migrating tides dominate below the mesosphere and in the upper thermosphere, respectively. In the mesosphere and lower thermopshere, the temporal and spatial scales are very complex with the presence of tides, planetary waves, resolved gravity waves, and probably the interaction of these waves.

Click to see movie

MOZART

The Model for Ozone and Related chemical Tracers (MOZART) is a global offline chemical transport model. Version 2 (MOZART-2) is available to the public through the NCAR Community Data Portal and has been downloaded by 110 users.

Two new versions, MOZART-3 and MOZART-4 have been recently completed and are actively used by ACD scientists. MOZART-3 is an extension of MOZART-2 into the stratosphere, with the addition of halogen chemistry and heterogeneous processes on polar stratospheric clouds (Kinnison et al., JGR, 2007). MOZART-4 has been updated over MOZART-2 to improve tropospheric chemistry simulations, with more detailed representation of hydrocarbons and tropospheric aerosols. Examples of some of the studies using MOZART-4 are shown under Strategic Priority 1 in Section 6 and Section 7.

The chemical schemes of MOZART-3 and MOZART-4 have been incorporated in the coupled chemistry-climate models WACCM and CAM-Chem.

MOZART-3 and MOZART-4 (source code and documentation) will be made available to the public on the NCAR CDP by the end of 2008.

return to top

Community Atmosphere Model combined with the MOZART chemical Mechanism (CAM CHEM)

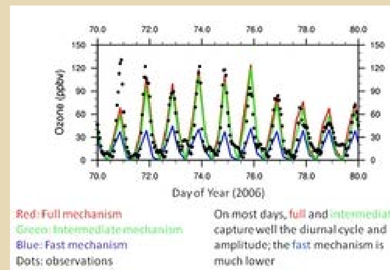


Figure 1. Comparison with surface observations in Mexico City (RAMA).

High resolution figure

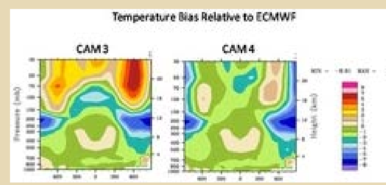


Figure 2.

High resolution figure

CAM is the latest in a series of global atmosphere models developed at NCAR for the weather and climate research communities. CAM also serves as the atmospheric component of the Community Climate System Model (CCSM). The continued incorporation of interactive chemistry capability in the Community Atmosphere Model (CAM) has reached a fairly stable state and now encompasses a variety of options to accommodate the needs of the coupled climate model, including a full interaction with the cloud microphysics (to represent the indirect effect, through collaboration with CGD and MMM scientist); in particular, using the implemented MOZART framework, CAM-chem can now be configured to combine prognostic and diagnostic variables. As a result. aerosols can either be prescribed, simulated using simple input oxidant fields, or simulated using the full MOZART-4 aerosol parameterization, or a combination of both; this flexibility is important to understand the specific role (radiatively and through cloud-aerosol interaction). In addition, the flexibility enabled the quick implementation of the modal (3 and 7 modes) aerosol scheme developed by S. Ghan (PNNL).

In addition, a version of CAM-chem with a representation of stratospheric chemistry was developed as a tool to represent ozone changes in the lower stratosphere; simulations over 1970-2005 indicate a very good comparison of ozone trends with respect to observations. This version will be used in 2009 for chemistry simulations in support of IPCC AR5.

For extended chemistry-climate studies, a number of different options exist for simulating aerosols and chemistry to facilitate using the model in the optimal configuration. In collaboration with scientists from Lawrence Livermore National Laboratory and University of California, Irvine, we have extensively tested 3 chemical mechanisms for tropospheric chemistry with increasing complexity of non-methane hydrocarbon (NMHC) representation; the overall goal is an understanding of how much chemistry is needed for specific applications (regional pollution chemistry or climate). In particular, comparison with the Mexico City (MIRAGE) campaign indicates (Figure 1) that an intermediate representation of NMHC is sufficient to represent ozone at the surface.

CAM-chem is now being merged with WACCM to allow for more flexibility in the model configuration and added ease of maintenance; indeed, this approach has eliminated code redundancy as much as possible. This merged code will now be the only version of CAM-chem or WACCM to be developed; this will allow for improvement from one science community to directly benefit the other one.

FY2009 plans include continued evaluation of the model performance under the different options described above. This work is funded by NSF/NCAR, NSF Biocomplexity, and DOE.

The computation of the radiative effects of the atmospheric composition is central to efforts to understand climate. A new radiative transfer model (RRTMG), developed by AER, Inc., has been incorporated into CAM/CCSM. The interface between the atmospheric specifications in CAM and the radiative solver has significantly improved user flexibility in testing new optics and testing radiative forcing due to changes in atmospheric composition as well the extensibility for new species. Microphysical specifications in CAM have been made consistent with optical parameterizations. Collaborators from LBL, UC Berkeley, PNNL, DRI, and AER have contributed optics, solvers, and validated the new package. This work is funded by DOE/SCIDAC.

FY2009 plans include efforts to study the new radiation budget of the climate system.

Microphysics parameterization for CAM

ACD and CGD scientists have been leading a collaborative development effort for a new microphysics parameterization for CAM. The goal of this effort is to develop an advanced microphysics package which can represent the size of cloud drops, and simulate how cloud drops are influenced by the distribution of aerosols. The ultimate goal is to quantify aerosol indirect effects in CAM and CCSM. This work dovetails with other studies in ACD, MMM and CGD of cloud microphysics, both in observations and in models. An important component of the broader activity is the development of better satellite data sets of cloud microphysical properties for comparing the CAM and WACCM simulations to observations. This work has recently been extended to treat the effects of ice clouds and ice cloud aerosol interactions.

return to top

Upper Atmosphere Community Models

HAO scientists have developed a suite of upper-atmospheric models, in collaboration with scientific visitors and scientists at universities, government labs, and other organizations. These models are made available for use by the community, typically through collaborations between HAO scientists and scientists in the community. A central model is the Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM) and simplified variants of it. The TIME-GCM simulates the three-dimensional, time-dependent global dynamics, chemistry, energetics, and electrodynamics of the mesosphere, thermosphere, and ionosphere, for given inputs representing solar, magnetospheric, and lower-atmospheric effects. Other HAO models with extensive use by the community are the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure for synthesizing high-latitude observations of ionospheric electric fields and currents, the Global-Scale Wave Model (GSWM) for calculating atmospheric tides and planetary waves from the ground through the thermosphere, and the GLOW model for calculating the effects of solar ultraviolet and X-rays as well as energetic particles. These models are used to understand the processes affecting the dynamical, electrodynamical, thermodynamical, and chemical conditions in the Earth's upper atmosphere, its response to the Sun's variable radiative, particulate and magnetic emissions, and its coupling to the lower atmosphere and the magnetosphere.

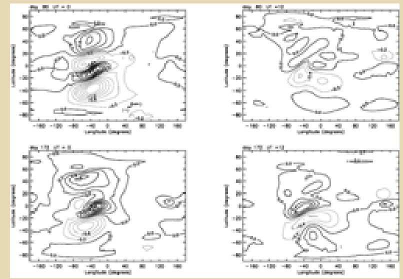


Figure 1: Simulated global change in foF2 (MHz) at day 80 (top) and day 172 (bottom) at 0 UT (left) and 12 UT (right) due to geomagnetic-field change between 1957 and 1997.

High resolution figure

The models have been upgraded through improvements to atmospheric tidal forcing, auroral precipitation, and coupling with magnetospheric electrodynamics. In collaboration with the University of Colorado, the Global Ionosphere Plasmasphere (GIP) model has been coupled with the TIE-GCM, to allow replacement of the TIE-GCM imposed upper boundary conditions on the ionosphere with a physical model. Model results have been provided to collaborators in the community. A documented version of the TIE-GCM, version 1.9, has been made public at http://www.hao.ucar.edu/modeling/tgcm/ . This work has been sponsored by NSF base support to NCAR, NSF Space Weather special funds, and NSF CEDAR special funds. It has also been supported by NASA and DOD programs.

Highlight: Modelling the effects of changes in the Earth�s magnetic field from 1957 to 1997 on the ionospheric hmF2 and foF2 parameters

Long-term trends in ionospheric electron density and peak height have been used to study global-change effects in the upper atmosphere. However, the ionosphere responds not only to increased atmospheric carbon dioxide, but also to slow variations of the Earth's magnetic field and to trends in geomagnetic activity. In order to quantify the importance of changes in the Earth's magnetic field, the NCAR TIE-GCM was used to model the ionosphere for the magnetic field as it existed in 1957 and 1997, taking into account self-consistently the changes in thermospheric winds due to changes in ionospheric drag. Substantial changes in the peak height, hmF2, (up to ±20 km) and critical frequency for radio-wave reflection, foF2, (up to ±0.5 MHz) are predicted over the Atlantic Ocean and South America. This would make up a significant contribution to observed long-term trends in these areas and therefore must be taken into account in their interpretation. Modeled trends of hmF2 and foF2 exhibit a strong seasonal and diurnal variation, highlighting the importance of separating data with respect to season and local time. Most of the modeled changes in hmF2 and foF2 can be related to changes in plasma transport up or down magnetic field lines driven by neutral winds, changes which are mostly caused by changes in the inclination of the field, though changes in declination and neutral wind also play a role. Changes in the vertical component of the electrodynamic drift velocity have relatively little effect (Figure 1).

This work was supported in part by NSF base funding. Graduate student visitor Ingrid Cnossen was supported by a Marie Curie fellowship of the European Union.

Reference: Cnossen, I., and A.D. Richmond (2008), Modelling the effects of changes in the Earth's magnetic field from 1957 to 1997 on the ionospheric hmF2 and foF2 parameters, *J. Atmos. Solar-Terr. Phys.*, 1512-1524.

Future Plans

For FY09, we plan to continue model upgrades, testing, and scientific analysis in collaboration with the community. Model developments will continue to be documented, and upgraded versions of the TIE-GCM source code will be made available at the www.hao.ucar.edu/modeling/tgcm web site. Results of scientific studies will be published. Particular foci will be testing and implementing the full electrodynamic coupling of the GIP plasmasphere model with the TIE-GCM, continuing to transfer and document process modules from the TIME-GCM to WACCM, and continuing to test and implement modules coupling the magnetosphere with the ionosphere and thermosphere.

return to top

Carbon / Nitrogen cycle modeling

Overview

ESSL scientists have recently completed a model development project to bring together parallel efforts in the climate modeling and ecological modeling communities, integrating a detailed treatment of the terrestrial carbon cycle with a state-of-the-art land surface model (the Community Land Model - CLM). The resulting model has now been tested and its performance documented in offline configurations. A critical application of the model has been to study the influence of carbon-nitrogen cycle coupling on present-day and potential future climate-carbon cycle feedbacks. Inclusion of the nitrogen cycle has the net effect of limiting atmospheric carbon dioxide uptake, with more carbon dioxide remaining in the atmosphere to play a role in climate forcing. Development and evaluation of the simulated terrestrial carbon cycle and climate-carbon cycle feedbacks continues.

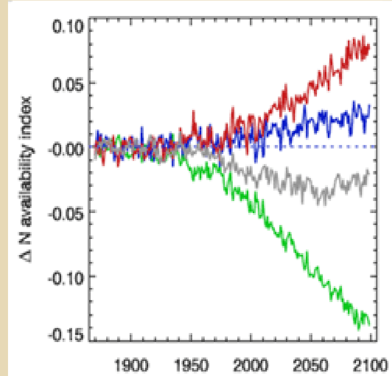


Figure 1. Results from Thornton et al. (in press), showing the changing climate and nitrogen deposition on nitrogen availability. The result is that the C-N model predicts a smaller land carbon sink over time as fossil fuel emissions of CO_2 increase, leading to a higher future concentration of atmospheric CO_2 .

High resolution figure

Recent Accomplishments

ESSL scientists participated in a project known as C-LAMP (Carbon LAnd Model intercomparison Project) to evaluate two different implementations of the terrestrial carbon cycle in the CLM. One model, CLM-CN, includes carbon-nitrogen interactions. A second model, CLM-CASA', simulates only the carbon cycle. The first paper describing the evaluation of the land model predictions against a broad database of observations (remotely sensed and in situ) of many different ecosystem states and fluxes has been submitted. Both models replicate key features of the terrestrial carbon cycle, but also have key deficiencies and model development continues.

Development of a fire module, coupling to the dynamic global vegetation model, implementation of land cover change, and a model of soil NO, N_2O and N_2 emissions adds to the functionality of the CLM.

2009 and Beyond

The work in FY 2009 continues to focus on the development and evaluation of the terrestrial carbon model in preparation for the release of CCSM 4.0. The primary scientific focus beyond the CCSM 4.0 release is to examine human and natural feedbacks and forcings in the earth system operating through the biogeochemical cycles.

return to top

Analysis, Integration and Modeling of the Earth System (AIMES)

Overview

ESSL is the home of the International Project Office (IPO) for the International Geosphere-Biosphere Programme's (IGBP) Earth System modeling project, Analysis, Integration and Modeling of the Earth System (AIMES). The AIMES project endeavors to extend Earth System modeling approaches to include dynamics of human activities alongside biogeochemical and biophysical processes of the coupled climate system. Modeling activities in AIMES include improving biophysical and biogeochemical components of global models and testing the sensitivity of tradeoffs in vulnerability and resilience in terms of economic and ecosystem consequences.

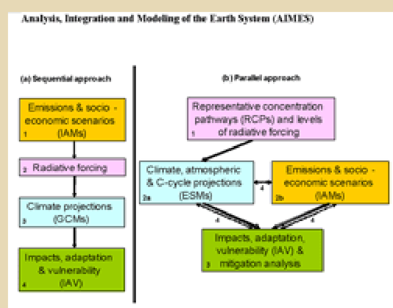


Figure 1. Approaches to the development of global scenarios from Moss et al., (2008): (a) previous *sequential* approach; (b) proposed *parallel* approach. Numbers indicate analytical steps (2a and 2b proceed concurrently). Solid arrows indicate transfers of information. Dotted arrows indicate integration of information..

AIMES and the WCRP Working Group on Coupled Modeling (WGCM) have collaborated to develop a strategy for next generation climate simulations for the upcoming Fifth Assessment.

Recent Accomplishments

Report of the IPCC (AR5). Climate modeling experiments for AR5 will include both long term (e.g., 2100 and beyond) and decadal prediction (Hibbard and Meehl 2007). In addition, AIMES also collaborates with the Integrated Assessment Modeling Consortium (IAMC) on the generation of scenarios for

AR5. This collaboration has led to close collaboration and improved understanding of the provenance of the radiative forcings provided by the integrated assessment community and the strengths and limitations of climate modeling between the two modeling communities. This collaboration has resulted in a proposed parallel process (Figure 1) where the climate, integrated assessment and impacts, adaptation and vulnerability communities work much more closely towards the development of new scenarios for possible assessment activities beyond AR5. To initialize the AR5 process, AIMES worked with the IAMC and WGCM on the development and harmonization of land use, land cover and emissions between the climate and integrated assessment models for the representive concentration pathways that will define the scenarios for AR5.

High resolution figure

Relevant activities in AIMES include the Coupled Carbon Cycle-Climate Model Intercomparison Project (C4MIP), where the magnitudes of terrestrial carbon uncertainties are still largely uncertain. C4MIP investigates model benchmark and evaluation exercises to explore mechanisms that influence the response of the terrestrial carbon cycle: (1) soil moisture and net primary production, particularly in the tropics, (2) effects of CO2 fertilisation, and (3) disturbance and land cover. A joint strategy of AIMES and the is to collaborate with the IPCC Working Groups to develop climate change stabilization experiments with coupled atmosphere/ocean general circulation models, Earth System and Integrated Assessment models. AIMES, on behalf of the IGBP is leading an applied Earth System Science initiative to foster collaboration and exchange of information between the scientific community and resource managers, policy and and assessment communities and development agencies. The International Nitrogen Initiative (INI), addresses end-to-end problem solving across scales (e.g., spatial, temporal, management) implementing process-based research through mitigation or management. In addition, AIMES sponsors the Global Emissions Inventory Activity (GEIA). AIMES is also working within the international community to develop an integrated synthesis of activities in the northern high latitudes to promote model development.

To date, AIMES has initiated a Young Scientist's Network (YSN) with topics including integrating indirect human activities (e.g., land use) with the Community Climate System Model (CCSM), Urbanization, biogeochemistry and the climate system, and land-use decision making for Earth system models. In 2008, NCAR hosted a YSN on Cultural Use and Impacts of Fire: Past, Present and Future.

The Integrated History of People and Earth (IHOPE) activity started in 2005 with a Dahlem conference on Collapse or Sustainability: an Integrated History and Future of People on Earth (Costanza et al., 2007, 2008). An overall conclusion from the Dahlem-IHOPE conference is that societies respond in various manners to environmental (e.g., climate) stress. Extreme drought, for instance, has triggered both social collapse and ingenious management of water through irrigation. AIMES is communicating with the Stockholm Resilience Centre (SRC) in Sweden to organize IHOPE-related activities targeting issues on historical, even decadal, timescales on the various ways of understanding the growth of environmental prediction and modeling, largely a 20th c. phenomenon (and, an understanding of IHOPE itself as a feature of modern "historiography"). AIMES and the SRC are discussing a series of meetings in 2009-2010, encompassing both the global south and the global north.

Sponsoring entities for workshops, symposia and colloquia include: NSF, NASA, EC-ACCENT (EU EC_FP6), IGBP, MPI (Germany), QUEST (UK), Arizona State University, University of Vermont, IHDP, the IAMC and WCRP.

return to top

Master mechanism

The NCAR Master Mechanism is an explicit and detailed gas phase chemical mechanism combined with a box model solver. User inputs include species of interest, emissions, temperature, dilution, and boundary layer height. Any input parameter may be constrained with respect to time. Photolysis rates are calculated using the TUV model included in the code package. The model is written in a mixture of F77 and Fortran90, and is managed using C-shell scripts.

ACD scientists continued the development of the Generator for Explicit Chemistry and Kinetics of Organics in the Atmosphere (GECKO-A), producing the only fully explicit mechanism for the gas-phase atmospheric oxidation of hydrocarbons. In collaboration with Bernard Aumont and Marie Camredon (U. Paris), ACD scientists have removed the 8-carbon limitation on hydrocarbon chain length, by assuming complete condensation to the aerosol phase for species with vapor pressures lower than 10^{-13}. For conditions relevant to Mexico City and chain lengths up to 10 carbons (the largest hydrocarbons for which observations are available), the gas phase mechanism consists of ca. 1.2×10^6 reactions among ca. 2×10^5 different chemical species. By allowing for gas-particle partitioning of these condensible compounds, they simulated the formation of secondary organic aerosols (SOA) in Mexico City for the conditions of the MIRAGE campaign. Results show significant SOA production for several days, although at rates slower than observed.

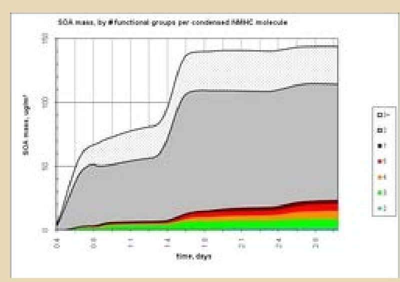


Figure 1: Evolution of secondary organic aerosols simulated with the Self-Generating Master Mechanism (SGMM) for Mexico City, April 2003. Color areas show multifunctional organics partitioned to the aerosol phase, while black & white areas show multifunctional organics remaining in the gas phase. [Lee-Taylor, J., S. Madronich, G. Tyndall, B. Aumont, and M. Camredon (2006), Explicit modeling of SOA precursors in Mexico City, Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract A23A-0935.]

High resolution figure

ACD scientists, together with researchers from Pacific Northwest National Labs and the U. of Washington used smog chamber measurements to show that hydrophobic aerosols play no role in SOA formation, contrary to previous theories. ACD scientists are also collaborating with PNNL researchers to provide input to a comprehensive, generalized inorganic-organic aerosol model.

FY 2009 work will continue development and evaluation of the GECKO-A mechanism generator, and perform further box model simulations for Mexico City to interpret results from the MIRAGE campaign.

This work is funded by NSF/NCAR and the DOE.

return to top

Tropospheric Ultraviolet and Visible (TUV) - Radiation Model

The Tropospheric Ultraviolet-Visible (TUV) radiation model calculates spectral irradiances and actinic fluxes, biologically active UV radiation at the surface, and photolysis coefficients (J values) for atmospheric chemistry use. TUV version 4.5 is available to the community through the NCAR/SCD Community Data Portal. ACD scientists have also made available global UV climatologies using TOMS v.8 ozone, specifically, maps of UV-A, UV-B, and several biologically weighted exposures (erythema, non-methane skin cancer, and vitamin D production). [Lee-Taylor, J. and S. Madronich, Climatology of UV-A, UV-B, and Erythemal Radiation at the Earth's Surface, 1979-2000, NCAR Technical Note TN-474-STR, August 2007.] An analytic formula for the UV Index in terms of the ozone column and sun angle allows efficient parameterization of UV effects of ozone changes.

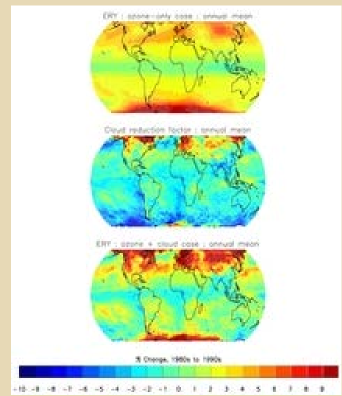


Figure 1: Change in annual mean sunburning (erythemal) UV radiation from the 80's (1979-1989) to the 90's (1990-2000). Top panel shows UV changes stemming from ozone changes only, middle panel for cloud changes only, and bottom panel from both ozone and cloud changes. [Lee-Taylor, J. and S. Madronich, Climatology of UV-A, UV-B, and Erythemal Radiation at the Earth's Surface, 1979-2000, NCAR Technical Note TN-474-STR, August 2007.]

High resolution figure

ACD scientists collaborated with university colleagues to apply the TUV model and UV climatologies to diverse problems including skin cancer incidence and plant-based methanogenesis. ACD scientists and university colleagues are also examining the UV radiation field during the MIRAGE-Mex field campaign. Mexico City's pollutants (ozone, sulfur dioxide, nitrogen dioxide, and aerosols) reduce the UV radiation field in the boundary layer by 10-20% and at the surface by 20-40%. Preliminary analyses suggest that aerosols are more absorbing at UV wavelengths than at visible wavelengths. The UV reductions slow photochemistry significantly, allowing for greater export of yet-unreacted pollutants.

This work is funded by NSF/NCAR.

return to top

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ESSL LAR 2008: STRATEGIC GOAL #5, PRIORITY #1

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #5, to "Provide world-class ground, airborne, and space-borne observational facilities and services." This Strategic Goal includes three Strategic Priorities, two of which are closely tied to work by ESSL staff

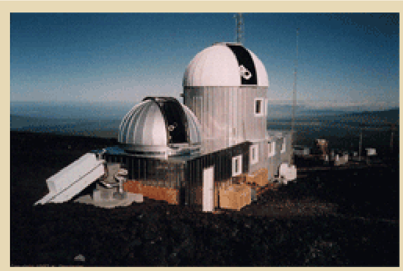
Goal #5, Priority #1: Enabling Innovative Field Experiments and Measurement Campaigns, is described as follows in the NCAR Strategic Plan: "The accuracy, robustness, and performance of weather, climate, and chemistry models depend on sound theory and accurate measurements. NCAR leadership in the area of field program planning and implementation provides a critical service to the community, and we are proud of our achievements in this area....Maintaining flexibility and responsiveness, NCAR serves as the coordination point for scientific field campaigns, offering services ranging from advice and consultation during the initial stages of planning to field design and project implementation plans, tailored and specialized logistics support, the fielding, operation, and maintenance of scientific instrumentation, real-time data communication, organizational and operational management, and the coordination of educational activities."

Significant efforts by scientists and staff of the Earth and Sun Systems Laboratory (ESSL) are focused on addressing this Priority in order to provide the observations necessary for improved understanding of the Earth and Sun Systems.

The section below describes specific research conducted by ESSL staff under projects relevant to Goal #5, Strategic Priority #1. The major ESSL activities in this area are the Mauna Loa Solar Observatory facility, development and improvement of community chemistry instruments, virtual observatories and data services, and planning for START08 and DC3 field campaigns that will utilize HIAPER.

Mauna Loa Solar Observatory Facility

The Mauna Loa Solar Observatory (MLSO) is a facility of the National Center for Atmospheric Research (NCAR) and operated by the High Altitude Observatory (HAO). It provides observations of the Sun's atmosphere in support of the solar and space physics goal of understanding the Sun's continuous release of plasma and energy into interplanetary space and its impact at Earth. HAO is committed to providing the community with critically important, high-quality solar observations. MLSO was constructed in 1965 and is located at 11,200 feet on the northern flank of Mauna Loa on the island of Hawaii. The site was chosen for its ideal sky conditions (e.g. dark skies, low water vapor, few cloudy days) that allow observations of the corona and chromosphere, on average, about 345 days per year. The nominal observing schedule is 9 hours per day weather permitting.



The Mauna Loa Solar Observatory

Current Instrumentation

MLSO began operation in December 1965. HAO operates 4 instruments at MLSO:

1. MK4 K-Coronameter
2. Polarimeter for Inner Coronal Studies (PICS)
3. Chromospheric He-I Imaging Photometer (CHIP)
4. Precision Solar Photometric Telescope (PSPT)

Scientific Usefulness

Ground-based observations, such as those from Mauna Loa, are cost-effective and can be maintained for decades at a very modest price. They are often unique and enhance the value of space-based missions.

HAO continues to provide new data products to the community utilizing new space-based observations. New products in 2008 include: 1) STEREO/MK4 and LASCO/EIT/MK4 daily composite images (shown above), 2) added full resolution images of realtime MLSO data, 3) full resolution jpegs (in addition to low res.) of MK4 archived images. In addition, MLSO has recently joined the Big Bear Global Hα Network and will begin providing Hα observations directly through this global network before the end of 2008.

MLSO Data Usage

All data are provided on the MLSO web site: http://www.mlso.ucar.edu

MLSO provides the public with the largest quantity of solar data from a single ground-based observatory and is the largest provider of observations of any HAO facility. The data are widely used, and usage has increased dramatically over the last 5 years. User statistics are provided:

296 registered users (17 new users in the last 2 months)

28 U.S. and 29 intl. universities, 17 U.S. and 41 intl. labs and observatories

2.8 million web page hits/year

Serves 321 GBytes / year

555 verified publications

Future Plans and Prioritizations

HAO staff have established a preliminary prioritization of current and future instrumentation and data products as those deemed to be most effective at meeting HAO coronal science goals and providing breakthrough observations over the coming decade:

1. COronal Multi-Channel Polarimeter (CoMP) / COSMO coronal magnetic field measurements
2. Prominence Magnetometer (ProMag) prominence magnetic fields
3. MK4 replacement Koronagraph (low corona; polarization brightness)

Status:

CoMP records the full Stokes (I,Q,U,V) of the forbidden FeXIII lines at 1074.7 nm and 1079.8 nm and the He-I line at 1083.0 nm. CoMP can determine the coronal magnetic field plane-of-sky (POS) direction and line-of-sight (LOS) strength. The LOS plasma motions are determined from the wings of the intensity line and the POS density is determined from the line ratios. CoMP was initially installed and tested at The NSO Sac Peak Observatory. It is currently being refitted and redeployed to Hawaii (Haleakala Observatory) by early 2009. The CoMP data pipeline has been deemed a top priority in order to serve CoMP data products using the MLSO data infrastructure shortly after first light. CoMP is the prototype instrument for a 1.4 meter coronagraph (COSMO) to measure coronal magnetic fields at significantly better temporal and spatial scales. For more information on CoMP and COSMO see : http://cosmo.ucar.edu

The Prominence Magnetometer (ProMag) is a spectro-polarimeter designed to simultaneously observe in the Helium D3 line at 587.6 nm and He-I at 1083.0 nm in order to determine the magnetic field in prominences via the Hanle effect. Fabrication is being completed at HAO with the hope of deploying ProMag at Sacramento Peak Observatory by the end of 2008. For more information see:
http://www.hao.ucar.edu/projects/csac/prototypes.php

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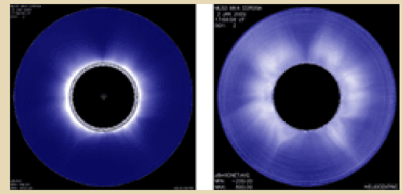

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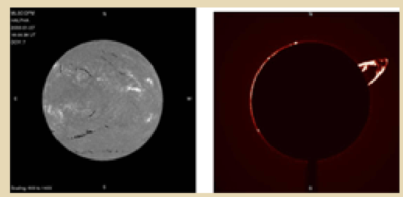
High resolution figure



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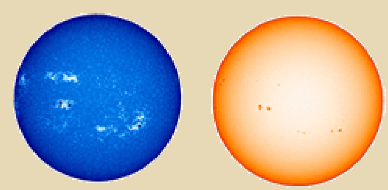

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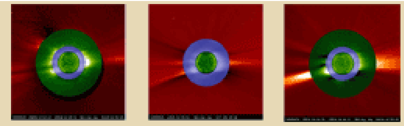

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return to top

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Figure 1. The CARI Fast-O_3 and CO instrument combined in one aircraft rack, ready to be installed on the NCAR/NSF GV aircraft in support of the START-08 mission.

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CARI supported four field campaigns in FY2008, two of which were multi-intensive campaigns spanning the spring and summer of 2008. Water vapor and Fast-Ozone measurements were provided for the Pacific Sulfur Experiment (PASE) flown on the C-130; CO, Fast-Ozone, and water vapor measurements were made during ICE-L also flown on the C-130.

NO, NOy, Fast-Ozone, CO, and Water vapor were measured during the START-08 project on the GV; and our four channel NO/NO_2/NOy/Ozone instrument was flown on the NASA DC-8 aircraft during the NASA-led ARCTAS campaign. Please see the ESSL Laboratory Research Catalog for details on these campaigns.

In addition, the upload and testing was completed for the VOCALS campaign, to be flown on the C-130 during October and November 2008. Further improvements to the airborne CO_2 instrument electronics and data acquisition system were implemented in preparation for VOCALS. Improved noise specifications and reliability of operation were observed.

CARI participated in a project to characterize the accuracy and precision of several NCAR humidity sensors and our commercial humidity calibration system. CARI participated in the European intercomparison experiment, AquaVit, in October, 2007 at the AIDA chamber of the Forschung Zentrum Karlsruhe, Germany (http://imk-aida.fzk.de/campaigns/RH01/Water-Intercomparison-www.htm). This project was conducted in collaboration with the Technical University of Wiesbaden, and has resulted in a diploma thesis for our student visitor, Dennis Kraemer. The CARI group provided the technical and educational oversight and mentoring, TIIMES provided visitor funds, and EOL provided the hygrometric equipment and calibration systems.

FY2009 work will include data workup and submission for the missions listed above, data analysis for these projects, continued data analysis from TexAQS2006, MIRAGE, and INTEX-B as well as post-mission calibration efforts for each instrument. Results from TexAQS 2006, MIRAGE, PACDEX, and an instrument paper were presented at the 2007 AGU Fall meeting. Instruments will be reconfigured, calibrated, and prepared for four field deployments during FY2009.

This work is funded by NSF/NCAR with supplemental funding from NASA for ARCTAS.

return to top

Informatics: Virtual Observatories and Data Services

The National Center for Atmospheric Research Earth and Sun Systems High Altitude Observatory (NCAR/ESSL/HAO), the NCAR Computational Information Systems Laboratory Scientific Computing Division (NCAR/CISL/SCD), and McGuinness Associates have completed a collaborative NSF-funded project called the Virtual Solar Terrestrial Observatory (VSTO). The VSTO is in production and provides a distributed, scalable education and research environment for searching, integrating, and analyzing observational, experimental and model databases in the fields of solar, solar-terrestrial and space physics (SSTSP). VSTO comprises a semantically-enabled data framework which provides virtual access to specific SSTSP data, model, tool and material archives containing items from a variety of space- and ground-based instruments and experiments, as well as individual and community modeling and software efforts bridging research and educational use. The VSTO is a fully functional production system addressing a substantial need within several major SSTSP communities, allowing science projects to advance more rapidly. The overall goal is to integrate a balance of data/model holdings, portals and client software, to the underlying semantically rich, ontology-enabled (a machine readable specification of concepts and relations that hold among them)framework, to provide the environment that researchers can use without undue effort as if all the materials were available on their local computers and in a language that is consistent with their field of expertise. The VSTO ontology version 1.0 has been published and is being used by other groups.

Figure 1:

High resolution figure

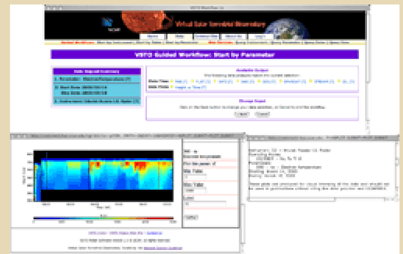

Figure 2:

High resolution figure

Figure 3: X High resolution figure

High resolution figure

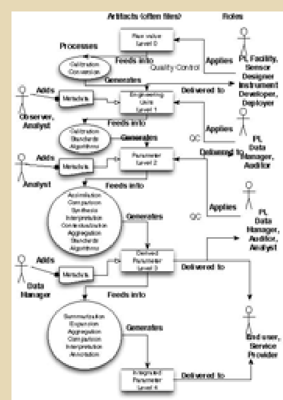

Figure 4: Z High resolution figure

High resolution figure

VSTO's success has been in unifying (via abstraction of the common concepts) the query workflow across very distinct science disciplines and data-types, decreasing input requirements for query (in one case reducing the number of selections from eight to three), generating only syntactically correct queries (which was not always insurable in previous implementations without semantics), providing semantic query support (by using background ontologies and a reasoner, only exposing coherent queries), and semantic integration (in the past users had to remember and maintain codes to account for numerous different ways to combine and plot the data) via understanding of coordinate systems, relationships, data synthesis, transformations, etc. Lastly, we have found a broader range of potential users (PhD scientists, students, professional research associates and those from outside the fields) are able to access data via VSTO.

The VSTO framework is being utilized (without changes in the basic structure but with suitable population of the ontology for the application area) in scientific data integration projects ranging from solid-earth, atmosphere and ocean applications. The upper panel of the figure shows a high-level schematic of the VSTO framework indicating the input ontologies, semantic filters and the reasoning engine which lead to the primary selection via choices of instrument, parameter and date-time supplemented by ancillary metadata (such as the long time records that are common in SSTSP). Users can access and query data using a web portal and machine-to-machine access is provided via semantic web services.

The VSTO work is being extended at present with research into knowledge provenance. The Semantic Provenance Capture in Data Ingest Systems (SPCDIS) completed its first year. When science data and information (often in the form of graphical images) are made available to an end-user (Fig. 1), it often happens after a number of data filtration and processing steps. As a consequence, any important metadata and/or documentation that may be needed to answer questions about the provenance may not have been generated, saved, propagated or be in a form or location that can be utilized (at all, or without significant effort or expertise). Virtual Observatories are particularly prone to this information gap. Thus, this project traces the entire pipeline and accounts for all roles, processes and metadata as they relate to use cases, which require provenance. This year we engaged data providers, instrument and algorithm developers from HAO and the community in general. We analyzed and documented the data ingest pipeline for our instrument suite operating at the Mauna Loa Solar Observatory to identify and extract the needed provenance and annotation requirements. We have compiled a set of use cases to ground our developments. As a concrete demonstration we have implemented the first set of provenance collection and utilized existing tools for provenance search and browsing to provide end-users with a capability that they can provide feedback upon (which, to date, is very positive).

SPCDIS is an NSF/OCI/SDCI funded project.

return to top

Planning of DC3 Field Program

The Deep Convective Clouds and Chemistry (DC3) Field Experiment will characterize the effect of midlatitude, continental convection on the transport and transformation of ozone and its precursors. Along with measurements of hydrogen oxide radicals, their precursors, and nitrogen oxides in both the inflow and outflow regions of deep convection, measurements of cloud microphysical properties, storm kinematics, and lightning discharges will be conducted. These measurements are planned for three locales in the United States, northeast Colorado, central Oklahoma, and northern Alabama, during May and June 2011 where remote continental regions can be contrasted to anthropogenically-influenced regions.

Figure 1: The nation's most advanced high-altitude research aircraft, the NCAR Gulfstream V (or G-V, formerly referred to as HIAPER), will be used to collect data for the DC3 Field Experiment.

High resolution figure

The Scientific Plan Overview (SPO) and Experimental Design Overview (EDO) documents have been drafted. In doing so, the primary goals of DC3 have been refined to the following:

1. Quantify and characterize the convection and convective transport of fresh emissions, including water, to the upper troposphere within the first few hours of active convection, investigating storm dynamics and physics, lightning and production of nitrogen oxides from lightning, cloud hydrometeor effects on wet deposition of species, surface emission variability, and chemistry in the anvil.
2. Quantify the changes in chemistry and composition after active convection, focusing on 12-48 hours after convection and the seasonal transition of the chemical composition of the UT.

Ancillary goals of DC3 are to investigate the influence of aerosols on droplet/storm formation, secondary aerosol formation, and transport of halogens.

The experimental design includes basing the aircraft in either central Oklahoma or Kansas so that the two aircraft can easily ferry to Colorado, Oklahoma or Alabama. Details of the flight plans have been developed for the HIAPER G-V aircraft, which will fly in the anvil of the storms measuring storm-processed characteristics of the storm, and for the low altitude aircraft (either the NSF C-130 or the NASA DC-8), which will measure characteristics of the inflow both below cloud and in the mid-troposphere. The DC3 science team would also welcome the proposed storm-penetrating aircraft (A-10 Warthog) if it is available when DC3 occurs. Ground-based radar and lightning mapping arrays will support the aircraft measurements by sampling kinematic, microphysical, and electrical characteristics of the storms sampled. The DC3 experiment will benefit from both satellite and numerical modeling analysis. Satellite data provide the context of the environment in which the storms form and have been used to show regions of high nitrogen dioxide (NO_2), a molecule that is a product of lightning discharges, near thunderstorm activity. Numerical modeling can provide both forecasts of where convection will be occurring and analysis of what processes contribute significantly to the observed constituent concentrations. WRF-Chem simulations of isolated storms, squall lines, and air mass storms are being conducted to examine the convective transport of chemical constituents in aiding the planning of the experiment.

Additional information on DC3 may be found at http://utls.tiimes.ucar.edu/Science/dc3.shtml

FY2009 work will be to submit the SPO and EDO documents to NSF and NASA and to continue planning DC3 by developing needed instruments for the HIAPER aircraft and analyzing WRF-Chem model results of typical storms in the three study regions. The planned DC3 experiment will be presented at the annual AMS meeting. This planning work is funded by NSF-NCAR.

return to top

Planning of START-08 Field Campaign

Figure 1: START-08 / Pre-HIPPO flight tracks for the 18 flights during April-June 2008

High resolution figure

Stratosphere-Troposphere Analyses of Regional Transport 2008 (START-08) experiment was successfully conducted during April-June 2008. This experiment was designed to map out the major transport pathways between the upper troposphere and the lower stratosphere (UTLS) to improve the trace gas climatology of this region in its range of dynamical variability. A large suite of trace gas measurements was made in the tropopause region using the NSF-NCAR research aircraft Gulfstream V (GV), operated from the NCAR/EOL Research Aviation Facility at Broomfield, Colorado. START08 shared the payload and flight operations with the test flights of the HIPAER Pole-to-Pole Observation of Atmosphere Tracers (pre-HIPPO) experiment. A total of 18 flights and 123 GV hours was flow within 6 flight weeks that covered Spring (April 15-May 15) and Summer (June 16-28) seasons. The flights covered an extensive latitude-longitude range of the North America (Figure 1). The measurements targeted a set of meteorological conditions that result in intrusions of stratospheric air into troposphere during the tropopause fold, and the intrusions of tropospheric air into stratosphere between the double tropopause, and sampled the regions of well-defined and disrupted tropopause. The tracers and tracer correlations from the measurements will provide a set of *finger prints* relating the meteorological fields and the UTLS chemical distribution.

Analyzing the data and reporting the scientific findings from the experiment in publications and conferences will be the team's main task during FY2009. The analyses will also result in papers quantifying the transport effect of specific types of tropospheric weather system the experiment targeted. These transport processes modify the distribution of radiatively sensitive chemical species, hence feed back to the climate system. In addition, the new observations on GV from the START-08 experiment will result in a set of diagnostics for the chemistry-climate models. As part of the international effort of process oriented chemistry-climate model validation (CCMVal), the group will work on applying the diagnostics to a set of CCMs, including NCAR model WACCM, and to evaluate how well the transport and mixing in the UTLS region is represented in the models.

The experiment is planned and led by NCAR UTLS initiative and is a collaborative effort within NCAR and with external community. NCAR participants include scientists from ACD, MMM, EOL, facilitated through TIIMES. The external collaborators include University of Miami, Texas A&M University, Harvard University, University of Colorado, and NOAA. ESSL scientists played important role in providing and operating community instruments including Fast Ozone (ACD), NO-NOy (ACD), Airborne Oxygen (TIIMES), VUV CO and TDL water vapor. The complexity of the chemical measurements implemented on the GV is a significant enhancement of the platform's payload capability.

return to top

BEACHON - SRM Manitou Experimental Forest SuperSite

BEACHON Manitou Experimental Forest Observatory

The BEACHON project has enabled long-term measurements in the southern Rocky Mountains that enhance existing NSF and U.S. Forest Service supported facilities in this region. This includes deploying instruments at NSF sponsored and university managed long-term sites in Wyoming, Colorado and New Mexico. In addition, the BEACHON project is collaborating with the U.S. Forest Service to develop an atmospheric and ecohydrological observatory within the U.S. Forest Service Rocky Mountain Research Station Manitou Experimental Forest (MEF, http://www.fs.fed.us/rm/landscapes/Locations/Manitou/Manitou.shtml) that will be central to the success of BEACHON. The experiments planned for MEF have requirements (e.g., terrain, vegetation cover, security, power availability, access, ability to conduct manipulative experiments) that exceed what is available at any existing site within this region. The BEACHON science team is working with the U.S. Forest Service to develop a research facility at MEF that will meet the requirements of planned BEACHON studies. The MEF site is ideal for biological, biogeochemical, micrometeorological and canopy-atmosphere exchange studies related to BEACHON and we expect this site to attract future NCAR and university-led experiments. The enthusiasm of the U.S. research community for conducting research at this field site was demonstrated by the more than 50 scientists, including representatives of 12 universities, who participated in an initial FY08 study at the MEF observatory. Long-term measurements at the site will characterize clouds (e.g. dual K-band radars, video dendrometer), soils (moisture, infiltration, hydraulic properties), turbulence (vertical array of sonic anemometers), canopy physiology (CO_2, water and energy fluxes), trace gases (ozone, NO, NO_2, NOy, speciated VOC, SO_2, CO) and aerosols (size, numbers, chemical composition).

Figure 1: The figure shows the above-canopy walk-up tower and mobile laboratories deployed at the BEACHON MEF observatory.

High resolution figure

BEACHON Airborne Flux Facilities and Tower Flux Networks

Regional characterization of trace gas and aerosol fluxes is currently limited by a lack of facilities for measuring these fluxes across different landscapes. BEACHON will enable these observations through the development of airborne systems and tower networks. Airborne trace gas and aerosol flux facilities will be developed in collaboration with university investigators. A heli-borne eddy covariance flux system for VOC, ozone and particles will be developed in collaboration with Roni Avissar (Duke University) as an extension of the Duke HOP helicopter flux platform (hop.pratt.duke.edu). A Disjunct Eddy Accumulation flux system for VOC has been developed for the Purdue ALAR flux aircraft (www.chem.purdue.edu/shepson/alar.html) in collaboration with Paul Shepson and BEACHON will support the operation of this system for community field studies. BEACHON scientists are also working with University of Wyoming investigators to develop plans to add trace gas and aerosol flux measurement capabilities to the NSF supported Wyoming King Air. BEACHON will extend the long-term carbon, water and energy fluxes that are made at existing networks (www.fluxnet.ornl.gov) by supporting the development and operation of trace gas and particle flux measurement systems. FY09 tower based activities will focus on a VOC measurement network using the relaxed eddy accumulation approach.

return to top

Strategic Goal #5, Priority #1

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ESSL LAR 2008: STRATEGIC GOAL #5, PRIORITY #1

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #5, to "Provide world-class ground, airborne, and space-borne observational facilities and services." This Strategic Goal includes three Strategic Priorities, two of which are closely tied to work by ESSL staff

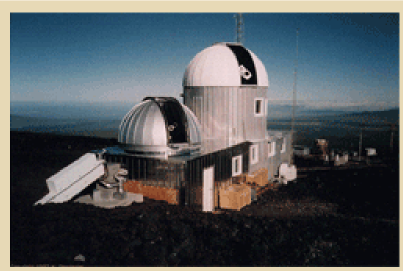
Goal #5, Priority #1: Enabling Innovative Field Experiments and Measurement Campaigns, is described as follows in the NCAR Strategic Plan: "The accuracy, robustness, and performance of weather, climate, and chemistry models depend on sound theory and accurate measurements. NCAR leadership in the area of field program planning and implementation provides a critical service to the community, and we are proud of our achievements in this area....Maintaining flexibility and responsiveness, NCAR serves as the coordination point for scientific field campaigns, offering services ranging from advice and consultation during the initial stages of planning to field design and project implementation plans, tailored and specialized logistics support, the fielding, operation, and maintenance of scientific instrumentation, real-time data communication, organizational and operational management, and the coordination of educational activities."

Significant efforts by scientists and staff of the Earth and Sun Systems Laboratory (ESSL) are focused on addressing this Priority in order to provide the observations necessary for improved understanding of the Earth and Sun Systems.

The section below describes specific research conducted by ESSL staff under projects relevant to Goal #5, Strategic Priority #1. The major ESSL activities in this area are the Mauna Loa Solar Observatory facility, development and improvement of community chemistry instruments, virtual observatories and data services, and planning for START08 and DC3 field campaigns that will utilize HIAPER.

Mauna Loa Solar Observatory Facility

The Mauna Loa Solar Observatory (MLSO) is a facility of the National Center for Atmospheric Research (NCAR) and operated by the High Altitude Observatory (HAO). It provides observations of the Sun's atmosphere in support of the solar and space physics goal of understanding the Sun's continuous release of plasma and energy into interplanetary space and its impact at Earth. HAO is committed to providing the community with critically important, high-quality solar observations. MLSO was constructed in 1965 and is located at 11,200 feet on the northern flank of Mauna Loa on the island of Hawaii. The site was chosen for its ideal sky conditions (e.g. dark skies, low water vapor, few cloudy days) that allow observations of the corona and chromosphere, on average, about 345 days per year. The nominal observing schedule is 9 hours per day weather permitting.



The Mauna Loa Solar Observatory

Current Instrumentation

MLSO began operation in December 1965. HAO operates 4 instruments at MLSO:

1. MK4 K-Coronameter
2. Polarimeter for Inner Coronal Studies (PICS)
3. Chromospheric He-I Imaging Photometer (CHIP)
4. Precision Solar Photometric Telescope (PSPT)

Scientific Usefulness

Ground-based observations, such as those from Mauna Loa, are cost-effective and can be maintained for decades at a very modest price. They are often unique and enhance the value of space-based missions.

HAO continues to provide new data products to the community utilizing new space-based observations. New products in 2008 include: 1) STEREO/MK4 and LASCO/EIT/MK4 daily composite images (shown above), 2) added full resolution images of realtime MLSO data, 3) full resolution jpegs (in addition to low res.) of MK4 archived images. In addition, MLSO has recently joined the Big Bear Global Hα Network and will begin providing Hα observations directly through this global network before the end of 2008.

MLSO Data Usage

All data are provided on the MLSO web site: http://www.mlso.ucar.edu

MLSO provides the public with the largest quantity of solar data from a single ground-based observatory and is the largest provider of observations of any HAO facility. The data are widely used, and usage has increased dramatically over the last 5 years. User statistics are provided:

296 registered users (17 new users in the last 2 months)

28 U.S. and 29 intl. universities, 17 U.S. and 41 intl. labs and observatories

2.8 million web page hits/year

Serves 321 GBytes / year

555 verified publications

Future Plans and Prioritizations

HAO staff have established a preliminary prioritization of current and future instrumentation and data products as those deemed to be most effective at meeting HAO coronal science goals and providing breakthrough observations over the coming decade:

1. COronal Multi-Channel Polarimeter (CoMP) / COSMO coronal magnetic field measurements
2. Prominence Magnetometer (ProMag) prominence magnetic fields
3. MK4 replacement Koronagraph (low corona; polarization brightness)

Status:

CoMP records the full Stokes (I,Q,U,V) of the forbidden FeXIII lines at 1074.7 nm and 1079.8 nm and the He-I line at 1083.0 nm. CoMP can determine the coronal magnetic field plane-of-sky (POS) direction and line-of-sight (LOS) strength. The LOS plasma motions are determined from the wings of the intensity line and the POS density is determined from the line ratios. CoMP was initially installed and tested at The NSO Sac Peak Observatory. It is currently being refitted and redeployed to Hawaii (Haleakala Observatory) by early 2009. The CoMP data pipeline has been deemed a top priority in order to serve CoMP data products using the MLSO data infrastructure shortly after first light. CoMP is the prototype instrument for a 1.4 meter coronagraph (COSMO) to measure coronal magnetic fields at significantly better temporal and spatial scales. For more information on CoMP and COSMO see : http://cosmo.ucar.edu

The Prominence Magnetometer (ProMag) is a spectro-polarimeter designed to simultaneously observe in the Helium D3 line at 587.6 nm and He-I at 1083.0 nm in order to determine the magnetic field in prominences via the Hanle effect. Fabrication is being completed at HAO with the hope of deploying ProMag at Sacramento Peak Observatory by the end of 2008. For more information see: http://www.hao.ucar.edu/projects/csac/prototypes.php

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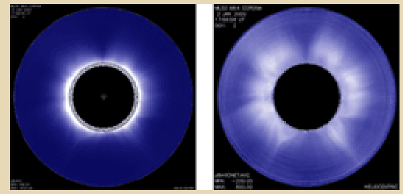

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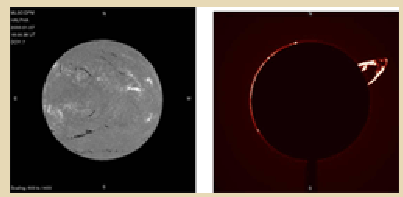

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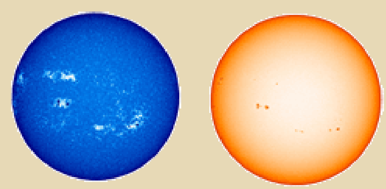

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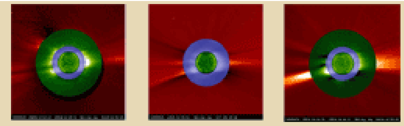

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return to top

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High resolution figure

CARI supported four field campaigns in FY2008, two of which were multi-intensive campaigns spanning the spring and summer of 2008. Water vapor and Fast-Ozone measurements were provided for the Pacific Sulfur Experiment (PASE) flown on the C-130; CO, Fast-Ozone, and water vapor measurements were made during ICE-L also flown on the C-130.

NO, NOy, Fast-Ozone, CO, and Water vapor were measured during the START-08 project on the GV; and our four channel NO/NO_2/NOy/Ozone instrument was flown on the NASA DC-8 aircraft during the NASA-led ARCTAS campaign. Please see the ESSL Laboratory Research Catalog for details on these campaigns.

In addition, the upload and testing was completed for the VOCALS campaign, to be flown on the C-130 during October and November 2008. Further improvements to the airborne CO_2 instrument electronics and data acquisition system were implemented in preparation for VOCALS. Improved noise specifications and reliability of operation were observed.

CARI participated in a project to characterize the accuracy and precision of several NCAR humidity sensors and our commercial humidity calibration system. CARI participated in the European intercomparison experiment, AquaVit, in October, 2007 at the AIDA chamber of the Forschung Zentrum Karlsruhe, Germany (http://imk-aida.fzk.de/campaigns/RH01/Water-Intercomparison-www.htm). This project was conducted in collaboration with the Technical University of Wiesbaden, and has resulted in a diploma thesis for our student visitor, Dennis Kraemer. The CARI group provided the technical and educational oversight and mentoring, TIIMES provided visitor funds, and EOL provided the hygrometric equipment and calibration systems.

FY2009 work will include data workup and submission for the missions listed above, data analysis for these projects, continued data analysis from TexAQS2006, MIRAGE, and INTEX-B as well as post-mission calibration efforts for each instrument. Results from TexAQS 2006, MIRAGE, PACDEX, and an instrument paper were presented at the 2007 AGU Fall meeting. Instruments will be reconfigured, calibrated, and prepared for four field deployments during FY2009.

This work is funded by NSF/NCAR with supplemental funding from NASA for ARCTAS.

return to top

Informatics: Virtual Observatories and Data Services

The National Center for Atmospheric Research Earth and Sun Systems High Altitude Observatory (NCAR/ESSL/HAO), the NCAR Computational Information Systems Laboratory Scientific Computing Division (NCAR/CISL/SCD), and McGuinness Associates have completed a collaborative NSF-funded project called the Virtual Solar Terrestrial Observatory (VSTO). The VSTO is in production and provides a distributed, scalable education and research environment for searching, integrating, and analyzing observational, experimental and model databases in the fields of solar, solar-terrestrial and space physics (SSTSP). VSTO comprises a semantically-enabled data framework which provides virtual access to specific SSTSP data, model, tool and material archives containing items from a variety of space- and ground-based instruments and experiments, as well as individual and community modeling and software efforts bridging research and educational use. The VSTO is a fully functional production system addressing a substantial need within several major SSTSP communities, allowing science projects to advance more rapidly. The overall goal is to integrate a balance of data/model holdings, portals and client software, to the underlying semantically rich, ontology-enabled (a machine readable specification of concepts and relations that hold among them)framework, to provide the environment that researchers can use without undue effort as if all the materials were available on their local computers and in a language that is consistent with their field of expertise. The VSTO ontology version 1.0 has been published and is being used by other groups.

VSTO's success has been in unifying (via abstraction of the common concepts) the query workflow across very distinct science disciplines and data-types, decreasing input requirements for query (in one case reducing the number of selections from eight to three), generating only syntactically correct queries (which was not always insurable in previous implementations without semantics), providing semantic query support (by using background ontologies and a reasoner, only exposing coherent queries), and semantic integration (in the past users had to remember and maintain codes to account for numerous different ways to combine and plot the data) via understanding of coordinate systems, relationships, data synthesis, transformations, etc. Lastly, we have found a broader range of potential users (PhD scientists, students, professional research associates and those from outside the fields) are able to access data via VSTO.

The VSTO framework is being utilized (without changes in the basic structure but with suitable population of the ontology for the application area) in scientific data integration projects ranging from solid-earth, atmosphere and ocean applications. The upper panel of the figure shows a high-level schematic of the VSTO framework indicating the input ontologies, semantic filters and the reasoning engine which lead to the primary selection via choices of instrument, parameter and date-time supplemented by ancillary metadata (such as the long time records that are common in SSTSP). Users can access and query data using a web portal and machine-to-machine access is provided via semantic web services.

The VSTO work is being extended at present with research into knowledge provenance. The Semantic Provenance Capture in Data Ingest Systems (SPCDIS) completed its first year. When science data and information (often in the form of graphical images) are made available to an end-user (Fig. 1), it often happens after a number of data filtration and processing steps. As a consequence, any important metadata and/or documentation that may be needed to answer questions about the provenance may not have been generated, saved, propagated or be in a form or location that can be utilized (at all, or without significant effort or expertise). Virtual Observatories are particularly prone to this information gap. Thus, this project traces the entire pipeline and accounts for all roles, processes and metadata as they relate to use cases, which require provenance. This year we engaged data providers, instrument and algorithm developers from HAO and the community in general. We analyzed and documented the data ingest pipeline for our instrument suite operating at the Mauna Loa Solar Observatory to identify and extract the needed provenance and annotation requirements. We have compiled a set of use cases to ground our developments. As a concrete demonstration we have implemented the first set of provenance collection and utilized existing tools for provenance search and browsing to provide end-users with a capability that they can provide feedback upon (which, to date, is very positive).

Figure 1:

High resolution figure

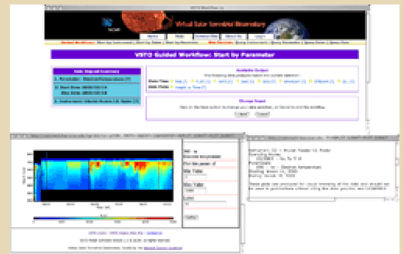

Figure 2:

High resolution figure

Figure 3: X High resolution figure

High resolution figure

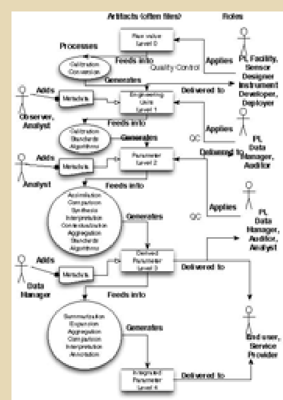

Figure 4: Z High resolution figure

High resolution figure

SPCDIS is an NSF/OCI/SDCI funded project.

return to top

Planning of DC3 Field Program

Figure 1: The nation's most advanced high-altitude research aircraft, the NCAR Gulfstream V (or G-V, formerly referred to as HIAPER), will be used to collect data for the DC3 Field Experiment.

High resolution figure

The Deep Convective Clouds and Chemistry (DC3) Field Experiment will characterize the effect of midlatitude, continental convection on the transport and transformation of ozone and its precursors. Along with measurements of hydrogen oxide radicals, their precursors, and nitrogen oxides in both the inflow and outflow regions of deep convection, measurements of cloud microphysical properties, storm kinematics, and lightning discharges will be conducted. These measurements are planned for three locales in the United States, northeast Colorado, central Oklahoma, and northern Alabama, during May and June 2011 where remote continental regions can be contrasted to anthropogenically-influenced regions.

The Scientific Plan Overview (SPO) and Experimental Design Overview (EDO) documents have been drafted. In doing so, the primary goals of DC3 have been refined to the following:

1. Quantify and characterize the convection and convective transport of fresh emissions, including water, to the upper troposphere within the first few hours of active convection, investigating storm dynamics and physics, lightning and production of nitrogen oxides from lightning, cloud hydrometeor effects on wet deposition of species, surface emission variability, and chemistry in the anvil.
2. Quantify the changes in chemistry and composition after active convection, focusing on 12-48 hours after convection and the seasonal transition of the chemical composition of the UT.

Ancillary goals of DC3 are to investigate the influence of aerosols on droplet/storm formation, secondary aerosol formation, and transport of halogens.

The experimental design includes basing the aircraft in either central Oklahoma or Kansas so that the two aircraft can easily ferry to Colorado, Oklahoma or Alabama. Details of the flight plans have been developed for the HIAPER G-V aircraft, which will fly in the anvil of the storms measuring storm-processed characteristics of the storm, and for the low altitude aircraft (either the NSF C-130 or the NASA DC-8), which will measure characteristics of the inflow both below cloud and in the mid-troposphere. The DC3 science team would also welcome the proposed storm-penetrating aircraft (A-10 Warthog) if it is available when DC3 occurs. Ground-based radar and lightning mapping arrays will support the aircraft measurements by sampling kinematic, microphysical, and electrical characteristics of the storms sampled. The DC3 experiment will benefit from both satellite and numerical modeling analysis. Satellite data provide the context of the environment in which the storms form and have been used to show regions of high nitrogen dioxide (NO_2), a molecule that is a product of lightning discharges, near thunderstorm activity. Numerical modeling can provide both forecasts of where convection will be occurring and analysis of what processes contribute significantly to the observed constituent concentrations. WRF-Chem simulations of isolated storms, squall lines, and air mass storms are being conducted to examine the convective transport of chemical constituents in aiding the planning of the experiment.

Additional information on DC3 may be found at http://utls.tiimes.ucar.edu/Science/dc3.shtml

FY2009 work will be to submit the SPO and EDO documents to NSF and NASA and to continue planning DC3 by developing needed instruments for the HIAPER aircraft and analyzing WRF-Chem model results of typical storms in the three study regions. The planned DC3 experiment will be presented at the annual AMS meeting. This planning work is funded by NSF-NCAR.

return to top

Planning of START-08 Field Campaign

Figure 1: START-08 / Pre-HIPPO flight tracks for the 18 flights during April-June 2008

High resolution figure

Stratosphere-Troposphere Analyses of Regional Transport 2008 (START-08) experiment was successfully conducted during April-June 2008. This experiment was designed to map out the major transport pathways between the upper troposphere and the lower stratosphere (UTLS) to improve the trace gas climatology of this region in its range of dynamical variability. A large suite of trace gas measurements was made in the tropopause region using the NSF-NCAR research aircraft Gulfstream V (GV), operated from the NCAR/EOL Research Aviation Facility at Broomfield, Colorado. START08 shared the payload and flight operations with the test flights of the HIPAER Pole-to-Pole Observation of Atmosphere Tracers (pre-HIPPO) experiment. A total of 18 flights and 123 GV hours was flow within 6 flight weeks that covered Spring (April 15-May 15) and Summer (June 16-28) seasons. The flights covered an extensive latitude-longitude range of the North America (Figure 1). The measurements targeted a set of meteorological conditions that result in intrusions of stratospheric air into troposphere during the tropopause fold, and the intrusions of tropospheric air into stratosphere between the double tropopause, and sampled the regions of well-defined and disrupted tropopause. The tracers and tracer correlations from the measurements will provide a set of *finger prints* relating the meteorological fields and the UTLS chemical distribution.

Analyzing the data and reporting the scientific findings from the experiment in publications and conferences will be the team's main task during FY2009. The analyses will also result in papers quantifying the transport effect of specific types of tropospheric weather system the experiment targeted. These transport processes modify the distribution of radiatively sensitive chemical species, hence feed back to the climate system. In addition, the new observations on GV from the START-08 experiment will result in a set of diagnostics for the chemistry-climate models. As part of the international effort of process oriented chemistry-climate model validation (CCMVal), the group will work on applying the diagnostics to a set of CCMs, including NCAR model WACCM, and to evaluate how well the transport and mixing in the UTLS region is represented in the models.

The experiment is planned and led by NCAR UTLS initiative and is a collaborative effort within NCAR and with external community. NCAR participants include scientists from ACD, MMM, EOL, facilitated through TIIMES. The external collaborators include University of Miami, Texas A&M University, Harvard University, University of Colorado, and NOAA. ESSL scientists played important role in providing and operating community instruments including Fast Ozone (ACD), NO-NOy (ACD), Airborne Oxygen (TIIMES), VUV CO and TDL water vapor. The complexity of the chemical measurements implemented on the GV is a significant enhancement of the platform's payload capability.

return to top

BEACHON - SRM Manitou Experimental Forest SuperSite

BEACHON Manitou Experimental Forest Observatory

The BEACHON project has enabled long-term measurements in the southern Rocky Mountains that enhance existing NSF and U.S. Forest Service supported facilities in this region. This includes deploying instruments at NSF sponsored and university managed long-term sites in Wyoming, Colorado and New Mexico. In addition, the BEACHON project is collaborating with the U.S. Forest Service to develop an atmospheric and ecohydrological observatory within the U.S. Forest Service Rocky Mountain Research Station Manitou Experimental Forest (MEF, http://www.fs.fed.us/rm/landscapes/Locations/Manitou/Manitou.shtml) that will be central to the success of BEACHON. The experiments planned for MEF have requirements (e.g., terrain, vegetation cover, security, power availability, access, ability to conduct manipulative experiments) that exceed what is available at any existing site within this region. The BEACHON science team is working with the U.S. Forest Service to develop a research facility at MEF that will meet the requirements of planned BEACHON studies. The MEF site is ideal for biological, biogeochemical, micrometeorological and canopy-atmosphere exchange studies related to BEACHON and we expect this site to attract future NCAR and university-led experiments. The enthusiasm of the U.S. research community for conducting research at this field site was demonstrated by the more than 50 scientists, including representatives of 12 universities, who participated in an initial FY08 study at the MEF observatory. Long-term measurements at the site will characterize clouds (e.g. dual K-band radars, video dendrometer), soils (moisture, infiltration, hydraulic properties), turbulence (vertical array of sonic anemometers), canopy physiology (CO_2, water and energy fluxes), trace gases (ozone, NO, NO_2, NOy, speciated VOC, SO_2, CO) and aerosols (size, numbers, chemical composition).

Figure 1: The figure shows the above-canopy walk-up tower and mobile laboratories deployed at the BEACHON MEF observatory.

High resolution figure

BEACHON Airborne Flux Facilities and Tower Flux Networks

Regional characterization of trace gas and aerosol fluxes is currently limited by a lack of facilities for measuring these fluxes across different landscapes. BEACHON will enable these observations through the development of airborne systems and tower networks. Airborne trace gas and aerosol flux facilities will be developed in collaboration with university investigators. A heli-borne eddy covariance flux system for VOC, ozone and particles will be developed in collaboration with Roni Avissar (Duke University) as an extension of the Duke HOP helicopter flux platform (hop.pratt.duke.edu). A Disjunct Eddy Accumulation flux system for VOC has been developed for the Purdue ALAR flux aircraft (www.chem.purdue.edu/shepson/alar.html) in collaboration with Paul Shepson and BEACHON will support the operation of this system for community field studies. BEACHON scientists are also working with University of Wyoming investigators to develop plans to add trace gas and aerosol flux measurement capabilities to the NSF supported Wyoming King Air. BEACHON will extend the long-term carbon, water and energy fluxes that are made at existing networks (www.fluxnet.ornl.gov) by supporting the development and operation of trace gas and particle flux measurement systems. FY09 tower based activities will focus on a VOC measurement network using the relaxed eddy accumulation approach.

return to top

Strategic Goal #5, Priority #1

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

NCAR is sponsored by the National Science Foundation.

ESSL LAR 2008: STRATEGIC GOAL #5, PRIORITY #2

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #5, to "Provide world-class ground, airborne, and space-borne observational facilities and services." This Strategic Goal includes three Strategic Priorities, two of which are closely tied to work by ESSL staff.

Goal #5, Priority #2, Developing new instrumentation, is described in the NCAR Strategic Plan as follows: "Advances in research on weather, climate, the water cycle, chemistry and dynamics of the upper troposphere/lower stratosphere, space weather and solar physics, and biogeosciences all require capabilities that stretch beyond those provided by (NCAR's) current suite of airborne and ground-based instruments. NCAR is tasked with developing a new generation of robust, inexpensive, easily deployable, and versatile instrument systems to address the university community's need for these instruments, which facilitate their research efforts. Our extensive and talented scientific and engineering staff continually creates and test new instrumentation for studying the links between atmospheric composition and the biogeosciences, with systems for quantifying the surface-atmosphere exchange of gases and aerosols on whole-plant, whole-canopy, and regional scales using mobile laboratories and research aircraft."

Significant efforts by scientists and staff of the Earth and Sun Systems Laboratory (ESSL) are focused on addressing this Priority in order to provide the observations necessary for improved understanding of the Earth and Sun Systems.

The section below describes specific research conducted by ESSL staff under projects relevant to Goal #5, Priority # 2. The major ESSL activities in this area include development of chemical instruments for HIAPER, development of a Coronal Solar Magnetism Observatory (COSMO) and instruments for the Solar Dynamics Observatory, continued use and evaluation of satellite measurements from the HIRDLS and MOPITT instruments, development of airborne and ground-based chemical and meteorological instrumentation, and development of a Satellite Observation Simulator and Assimilation System (SOSAS).

Development of a COronal Solar Magnetism Observatory (COSMO)

Driven by society's need to understand the origins of space weather, NCAR scientists at the High Altitude Observatory, along with colleagues at the University of Hawaii and the University of Michigan, plan to build the Coronal Solar Magnetism Observatory (COSMO). The facility will take continuous synoptic measurements of the entire corona in order to understand solar eruptive events that drive space weather and to investigate long-term and solar-cycle phenomena. The primary instrument will consist of a 1.5-m coronagraph with two detector systems: a narrow-band filter polarimeter and a spectropolarimeter. Supporting instruments are

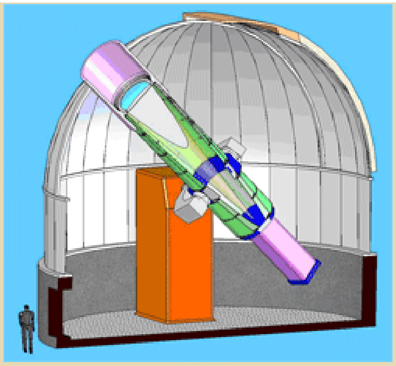


Figure 1: Concept drawing of the COSMO 1.5-meter coronagraph and dome. The telescope is a simple tube structure on an equatorial mount. The diameter of the dome is 12.2 meters.

High resolution figure

a white-light coronagraph to record the evolution of the electron scattered corona (K-corona) and a chromosphere and prominence magnetometer. This new facility will replace the current NCAR Mauna Loa Solar Observatory which has been collecting synoptic coronal data for over 40 years in support of the solar and heliospheric community.

In order to demonstrate the feasibility of measuring coronal magnetic fields, prototype instruments have been developed over the past 5 years at NCAR and the University of Hawaii. The Coronal Multi-channel Polarimeter (CoMP) instrument is a prototype of the COSMO coronal magnetometer which was built at NCAR/HAO. Last year, the CoMP enabled a scientific breakthrough by imaging, for the first time, Alfven waves in the solar corona. These waves were found in observations of the Doppler-shift of coronal plasma in the Fe XIII emission line at 1074.7 nm. These waves are important in that they transport energy from the turbulent photosphere out into the solar corona, and could explain why the solar corona is heated to a temperature of 1 million degrees. In 2008, we exploited the fact that the speed of propagation of these waves depends on the magnetic field of the corona. This allows us to use the wave speed measurements from CoMP to determine the strength of the coronal field. This effort is part of an exciting new field called Coronal Seismology.

In 2009, we will move CoMP from the NSO Sacramento Peak Observatory in New Mexico to the University of Hawaii's Mees Observatory atop Haleakala in Maui. This will allow us to obtain coronal observations under excellent sky conditions and fully exploit the scientific potential of the CoMP instrument.

Planning for COSMO has been assisted by a Scientific Advisory Panel of community members who have set the scientific requirements for the facility. Operation of the facility will continue to be guided by the Scientific Advisory Panel which will insure that the facility will continue to meet the needs of the solar and heliospheric community which it serves. The development of the CoMP instrument was supported by the NSF through the NCAR Strategic Initiative Fund and HAO base funds.

return to top

High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) instrumentation

PI: Andrew Weinheimer (UCAR/NCAR) - completed FY2008

NO-NOy Instrument **- Two-channel instrument for the in situ measurement of NO (nitric oxide) and NOy (total reactive nitrogen).**

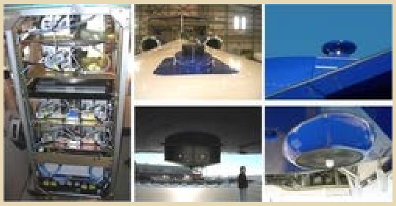


Figure 1. HARP rack installed on the NSF HIAPER GV aircraft, irradiance and actinic flux zenith and nadir optics.

High resolution figure

The CARI two-channel chemiluminescence instrument is capable of 1-sec in situ measurements of NO and NOy. The instrument was completed and certified for the GV early in FY2008, and was flown successfully on the NCAR/NSF GV aircraft during the START08 mission in April/May and June/July of 2008. The instrument worked very well and we collected a complete data set during the START08 mission, which will contribute to the characterization of stratosphere-troposphere exchange processes in mid-latitudes. Plans for FY2009 include some re-design of the inlet to optimize pressure control and minimize wall losses of nitric acid. This inlet design will also support the needs of the GA Tech CIMS HAIS instrument, which the CARI group expects to receive during FY2009. Some software changes and reprogramming are also planned to make the software more stable while communicating with GV the aircraft data systems. See the CARI group report for details on the NO/NOy instrument.

PI: Teresa Campos (UCAR/NCAR) - completed in FY2008

Fast Ozone Instrument **- Quantification of ozone mixing ratios at 5 Hz using the method of chemiluminescent reaction of ozone with nitric oxide.**

The Fast-Ozone instrument was completed and certified to fly on the GV in early FY2008. The instrument was then flown on the START08 mission, together with the NO/NOy instrument. Both systems used an integrated pumping system and shared the data system which was redeveloped to accommodate both instruments to save space and weight when deployed together on the GV. Laboratory tests as well as analysis of flight data confirmed that the time resolution of the fast-Ozone instrument is indeed 5 Hz or better. A complete data set was collected during the START08 mission and the ozone data compared extremely well with two additional ozone sensors flown during START08 and operated by NOAA.

PI: Eric Apel (UCAR/NCAR) - estimated completion: FY2009

Trace Organic Gas Analyzer (TOGA) **- In situ measurements of oxygenated volatile organic compounds (OVOCs), non-methane hydrocarbons (NMHCs), and halocarbons.**

The Trace Organic Gas Analyzer (TOGA) will be completed in FY 09. It will have the unique capability of simultaneously measuring, with one instrument, a suite of organic compounds that play important functions in many areas of atmospheric chemistry. Several of the compounds are precursors or intermediates in atmospheric oxidation sequences. Others are indicators or tracers of different anthropogenic and biogenic processes. The compounds that TOGA will measure consist of a series of hydrocarbons, oxygenated compounds, halocarbons (including HCFCs and CFCs), and a few nitrogen and sulfur containing compounds. These species are identified in the HIAPER Advisory Committee Report as high priority. A prototype of this instrument was flown successfully on the NASA DC-8 aircraft during the ARCTAS mission in March/April and June/July of 2008. Excellent data was collected during ARCTAS including quite possibly the first accurate data of acetaldehyde in clean air masses.

PI: Rick Shetter (UCAR/NCAR) Estimated Final Acceptance: FY2009

HIAPER Atmospheric Radiation Package (HARP) **- Spectrally resolved actinic flux and stabilized platform irradiance measurements.**

Rick Shetter and his Atmospheric Radiation Investigations and Measurements (ARIM) team, in collaboration with Peter Pilewskie and Bruce Kindel of the University of Colorado, Manfred Wendisch of the Leibniz-Institute for Tropospheric Research, Rainer Schmitt of Metcon, Inc and Dieter Schell of Enviscope GmbH, Germany, developed the HIAPER Airborne Radiation Package (HARP), a comprehensive atmospheric radiation suite to measure in situ actinic flux and irradiance. The ARIM group developed the actinic flux package using a CAFS detection and was responsible for building the spectrometer computer systems, creating the data acquisition and control software, coordinating the assembly of the racks, equipment, input optics and stabilized platforms, and leading the integration and flight management of the instrumentation.

The irradiance measurements rely on horizontal stabilization to determine layer properties, such as reflectance, transmittance and absorbance. Thus, the HARP irradiance package is mounted on zenith and nadir stabilized platforms to account for aircraft attitude changes. The platform was tested during the HIAPER Aircraft Instrumentation Solicitation Experimental Flight Test - 2008 (HEFT-08). The stabilized platform performed well and responded precisely to positional commands. However, the navigation signals used to determine aircraft attitude were inaccurate due to signal timing delays and noise on the signal line. To eliminate these external errors, the HARP system has been upgraded to receive direct GPS antenna signals. Final testing and delivery of the HARP instrumentation is forthcoming.

return to top

Analysis of data from Hinode and STEREO

During FY2008 the Joint Japan/US/UK Hinode mission entered its second year of operation. Many new science results continue to pour from the analysis of Hinode data. HAO/ESSL/NCAR hosted the Second Hinode Science Meeting in Boulder the week of 28 September 2008, with an international participation of about 200 scientists. The theme of this meeting, "Beyond Discovery, Toward Understanding", emphasized detailed quantitative analysis and the integration of numerical models with observations. The Hinode team at HAO has contributed many new science developments over the past year, some of which are highlighted in this document under "Profiles in Science and Technology." Furthermore, HAO scientists were involved in many articles in the Special Issue of Science Magazine (7 December 2007) devoted to new results from Hinode. The Hinode mission has provided an avenue for many HAO scientists to open new scientific collaborations, including advising and collaborating with PhD students from other institutions.

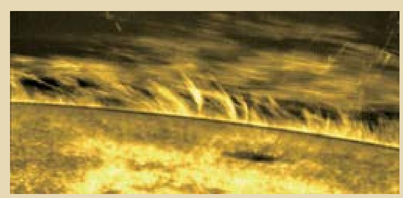


Figure 1: Fine structure of the solar chromosphere and a solar prominence are clearly visible in this image taken by Hinode. Time sequences of imaging data have revealed the presence of MHD waves in the upper atmosphere that may be the elusive source of heating the outer solar atmosphere and acceleration of the solar wind. This image is taken from an article by Okamaoto, et al. in the special Hinode issue of Science, 7 December 2008, p 1577.

High resolution figure

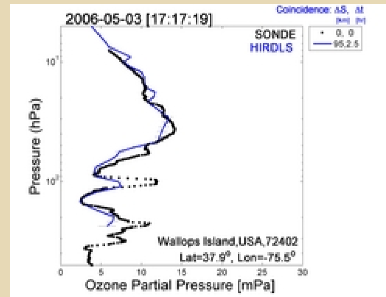
HAO continues to contribute to mission operations and community access to Hinode data. Systematic data reduction of the now almost 2 years of Hinode science data from the Spectro-Polarimeter (SP) onboard Hinode is being carried out at NCAR. The complex analysis procedure for SP data was developed at HAO initially under the NCAR Strategic Initiative "Community Spectro-Polarimetric Analysis Center" (CSAC). Refinement and updates to this reduction software are ongoing as a contribution of HAO to the Hinode program. These fully calibrated "Level 1" SP data are then made available to the community via the internet. Through CSAC, HAO is also providing the SP "Level 2" data: a detailed analysis of the polarization spectra to provide maps of the magnetic field vector in the solar atmosphere. Bulk processing of SP Level 2 data began at HAO in FY2008, and is now being made available to the community. HAO scientists participated in Hinode mission operations that require them to travel to Japan to prepare the science operations plans.

HAO scientists, in collaboration with many other scientists worldwide, continue to use the Hinode observations in innovative ways. One such example is the high resolution Hinode image shown in Figure 1 that reveals the ultra-fine structure of the upper layers of the solar atmosphere (the chromosphere). Sequences of such images have led to new understanding regarding the dynamics of the solar atmosphere, how it is linked to the dynamics of the magnetic field below, and how waves propagating through this region might be the elusive source of the heating of the solar corona and acceleration of the solar wind.

[return to top](#)

HIRDLS

The High Resolution Dynamics Limb Sounder (HIRDLS) is a 21 channel infrared limb scanning radiometer, jointly developed by ACD, the University of Colorado, and the Physics Department of Oxford University. It is designed to make observations of temperature, ozone, water vapor and 8 other trace species, as well as PSC's, aerosols and cirrus clouds, from the upper troposphere to the mesosphere, with higher vertical resolution than has previously been available from space observations. NASA funded the U.S. share of the HIRDLS development. When HIRDLS was launched on the Aura spacecraft in July 2004, a thin plastic film from inside HIRDLS came loose and obstructed most of the instrument's aperture, limiting the view to the atmosphere to a small fraction of the width of the optical beam. As described previously, the HIRDLS team, led by John Gille, the U.S. PI, and John Barnett (Oxford), the U.K. PI, showed that there was useful information in the signals. This required the development of 4 major adaptations and corrections to the measured signals. The first, revising the calibration, was described earlier.



Figures 1 and 2. Comparisons of HIRDLS V4 ozone retrievals with ozone sonde data at the locations and dates indicated. Separation of the sonde and HIRDLS retrievals is 95 km and 2.5 hours for the May profile, and 238 km and 0 hours for the April profile. The HIRDLS retrievals (blue) pick up the fine vertical features seen by the sondes (black dots).

[High resolution figure](#)

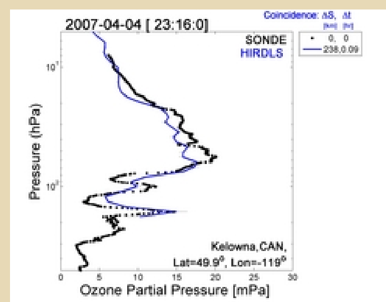


Figure 2.

[High resolution figure](#)

The next steps were to correct the measured signals to make them as close as possible to the expected radiances. The major efforts this year were to complete the algorithms to remove the spurious oscillations (due to mechanical oscillations of the plastic), and to recalculate the pointing. In addition, critical improvements were made in the corrections for the partial viewing area, and the estimation and removal of the signal coming from the obstruction.

A key method for determining these corrections is to have the spacecraft pitch by ~5°, so that HIRDLS looks above the atmosphere and measures signals only from the plastic film. This year the ACD HIRDLS team coordinated 2 of these pitch maneuvers. The initial development of these algorithms was described previously, but work continued, especially to improve the estimate of the reduced viewing area, and to refine subtraction of the signal from the plastic film. The latter is the biggest difficulty at this time. Updated calibration coefficients, radiance sample geo-location, and improved cloud location had been incorporated in the operational processing code. The resulting processor version was run on all the observations to produce a data set designated internally version 2.04.09. These data include global profiles of temperature, ozone, nitric acid and aerosol/cirrus; it was released to the community as Version 3 (V3) data. These were publicly released at the beginning of the reporting period.

Subsequent improvements have resulted in a new processor, v2.04.19, and a new V4 data set that was released near the close of the reporting period. These data include profiles of CFC 11, CFC12, and aerosol extinction, as well as temperature and ozone that have improved accuracy and fewer data spikes. The HIRDLS temperatures are now in within 0.5K of U.K. Meteorological Office high-resolution radiosonde data for 9 widely distributed stations, and for all data available from January 2005 until August 2007, while continuing the 1 km vertical resolution obtained previously. HIRDLS temperature retrievals show the same very good agreement with high resolution radiosondes as the earlier version, shown in the last Annual Report. V4 ozone retrievals also show very good agreement with sonde data, and the ability to see small scale structure, as illustrated in Figures 1 and 2.

The NCAR HIRDLS team hosted members of the core Oxford team for a 2 day meeting in January to discuss data improvements and future plans. This was followed by an open meeting with community members to discuss and encourage the scientific applications of HIRDLS data. The team also presented their status and plans to a review team from NASA, and attended similar core team and open science meetings in Oxford in June.

After an increasing number of spikes in the chopper motor current beginning in January, the chopper ceased operating on 17 March. Considerable effort has gone into diagnosing the problem, and attempting to restart the chopper, so far without success.

In the next year the correction algorithms will be refined to allow the recovery of additional species such as water vapor and methane. Emphasis will be on improved estimation of the partial view area and especially of the signal from the plastic, including allowances for the variation of the latter with time. In parallel, emphasis will be placed on the use of the released data for scientific studies, especially of UT/LS processes and strat-trop exchange, but broadening to many other areas (See Goal 1).

return to top

Measurements of Pollution in the Troposphere (MOPITT)

MOPITT Operational Production of Carbon Monoxide Data

The daily operational processing of Measurement Of Pollution In The Troposphere (MOPITT) instrument raw counts into the final retrieved geophysical products, delivery of products to NASA for free public access, and user education and support, constitutes a major service to the scientific community. MOPITT is also unique in providing the community with the longest continuous validated global CO data product. Scientific results have been presented worldwide at numerous scientific meetings and show a documented strong presence on the Internet. MOPITT data distribution, publications, literature citations, and conference presentations are all showing strong upward trends, indicating mounting demand and scientific interest.

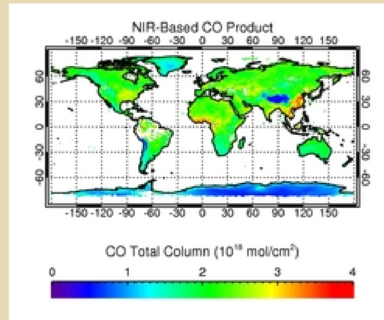


Figure 1. Monthly mean MOPITT CO total column results for March, 2006 based solely on near-infrared observations.

High resolution figure

Development of new data processing software for the next product release, 'Version 4,' has just been completed. Major features of the new retrieval algorithm include: (1) a new forward model with improved description of the MOPITT gas correlation cells and applicability to a wider range of CO mixing ratios; (2) a new description of the retrieval a priori surface emissivity; (3) a new seasonally and geographically variable CO retrieval a priori; and (4) the use of an assumed log-normal variability for CO volume mixing ratio. The new product also includes more extensive diagnostics, including the retrieval averaging kernels.

Activities during FY08

Algorithm Development and Product Evaluation

The development of a substantially improved retrieval algorithm for processing the next major MOPITT data product ('Version 4') was recently finalized. Associated activities completed in FY08 included (1) enhancement of the operational radiative transfer model to reflect actual in-orbit instrumental parameters and to better handle extremely polluted atmospheres and (2) determination of appropriate radiance bias correction factors. Product evaluation activities included analysis of V4 results at validation sites where aircraft in-situ profiles and surface measurements are available throughout the mission (since 2000). Overall, validation results indicate very small retrieval biases at all levels and demonstrate significantly weaker long-term drift than was observed in the current MOPITT Version 3 Product.

Long-term goals for the MOPITT Team include the incorporation of MOPITT's near-infrared measurements (i.e., 'solar channels') to provide additional information with respect to the CO total column measurement. Neither the current MOPITT Version 3 product nor the upcoming Version 4 products exploit these measurements because of challenges in understanding apparent instrument noise specific to these channels. During FY08, however, MOPITT retrievals based on these measurements were demonstrated for the first time, and clearly indicate the promise of combined thermal-infrared/near-infrared (TIR/NIR) CO retrievals for future products. Figure 1 presents global monthly-mean CO total column retrievals based solely on MOPITT NIR measurements during March, 2006. Regions of biomass burning in Equatorial Africa as well as anthropogenic emissions in China (principally from fossil fuel burning) are both clearly evident in the figure. Compared to current retrievals based purely on TIR measurements, the new NIR retrieval product is more sensitive to CO in the boundary layer and therefore should be much more capable of identifying sources at the surface.

Reference: "CO retrievals based on MOPITT near-infrared observations," by M. N. Deeter, D. P. Edwards, J. C. Gille, and James R. Drummond, *submitted to J. Geophys. Res.*

Field Campaign Support

The NCAR MOPITT Team produced and provided near real-time imagery and CO data products to support the ARCTAS (Arctic Research of the Composition of the Troposphere from Aircraft and Satellites) field campaign during Spring and Summer phases in FY08. Analyses of these data are ongoing.

Plans for FY09

Production and Release of V4

Operational processing of the MOPITT Version 4 product will begin in early FY09. The acquisition of new linux servers should allow processing of the entire MOPITT mission within several months, however the prerequisite task of porting all of the associated software to the new hardware may itself take several months. This process has begun. In preparation for the release of the new product, a new User's Guide is being drafted. Also, as the official release date approaches (possibly around the end of 2008), the new product will be publicized within the community. This effort will include a presentation at the Fall AGU meeting.

Version 5 Development

As operational processing of the Version 4 product becomes routine, initial steps to define and develop the Version 5 product will begin. While preliminary, current objectives for V5 development include the incorporation of MOPITT's solar channels and an evaluation of alternative sources for meteorological data.

Continued Analysis of Operational MOPITT Products

The MOPITT Science Team will continue to evaluate operational products both in the context of traditional validation (e.g., using available in-situ data from aircraft and ground-based spectroscopic measurements) and in comparison to models.

return to top

Atmospheric chemistry instrumentation

ACD scientists are involved in ongoing efforts to develop, improve, operate, and maintain a number of instruments designed to measure trace gases, radicals, optical properties, and aerosols in the atmosphere.

CARI Instrumentation

Aside from the community chemistry instruments and HIAPER instruments the CARI Group maintains and continued to improve a four channel chemiluminescence (CL) instrument for the simultaneous measurement of NO, NO2, NOy, and Ozone with a time resolution of 1 second or better. This instrument can be configured to fly on a variety of aircraft such as the NCAR C-130, the NASA WB-57, the NASA DC-8, and others. It can be flown unattended or with an operator and was deployed successfully during the NASA led ARCTAS experiment in 2008. CARI also maintains a compact chemical ionization mass spectrometer (PAN-CIGARette, Figure 1) which measures PAN at up to 4 Hz frequency or a number of different PAN species at 0.5Hz or better depending on number of species. We are planning to add this instrument to the pool of community instruments maintained by CARI . The PAN CIGARette would then become requestable for use on the NCAR/NSF aircraft. Both the four channel CL and the PAN CIGARette will be deployed during the OASIS field mission planned for early 2009 in Barrow, AK.

Figure 1. The new, compact PAN-CIGARette instrument was used for fast (1-2 sec), continuous measurements of PAN and related species on the C-130 for the MIRAGE and INTEX-B programs.

High resolution figure

Ultrafine Aerosols

During 2008 the Ultrafine Aerosols group developed new instruments to study the formation of atmospheric aerosols and their impacts on climate. An ion trap mass spectrometer was built by visiting German Research Foundation postdoc Andreas Held and interfaced with a redesigned electrostatic nanoparticle sampler for measuring nanoparticle chemical composition by the thermal desorption chemical ionization mass spectrometry (TDCIMS). Dr. Held also completed the design of a conditional sampling inlet which works with the TDCIMS to obtain size-resolved nanoparticle chemical flux. This instrument was deployed at Marshall Field Site and at the BEACHON Southern Rocky Mountain experimental site in 2008. Work continued on developing a scanning mobility particle sizer for the GV aircraft. Design of the instrument is nearing completion with the goal of flight testing the system in 2009. Finally, a hygroscopicity and volatility tandem differential mobility analyzer was designed and assembled that can measure size-resolved aerosol hygroscopic growth factors at 90% RH at user selectable residence times of 1, 2, 5 and 28 s as well as size-resolved aerosol volatility at user selectable temperatures from room temperature to 300 °C and at user selectable residence times of 0.8 and 10.5 s. This instrument operates autonomously and will be used in the 2009 OASIS field study in Barrow, AK.

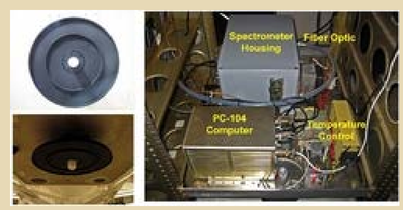


Figure 2. Zenith and nadir optics and instrument rack on the NASA DC-8 aircraft during ARCTAS.

High resolution figure

Photochemical Oxidation and Products

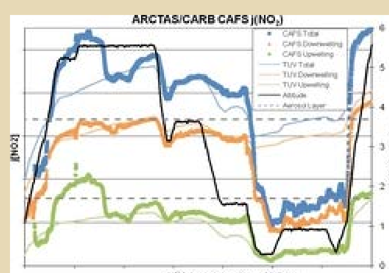


Figure 3. CAFS measured and TUV (clear sky) modeled j(NO2) during the ARCTAS/CARB deployment. The measurement/model differences are due to clouds and aerosol

In the Photochemical Oxidation and Products Group (POP), instrumentation for the measurement of HOx has been present in ACD since the late 1980s when an improved chemical amplifier was developed and deployed during MLOPEX II (1991-1992) (Cantrell et al., 1984; Cantrell et al., 1996). This instrument provided valuable information in this ground-based study. Follow-on studies saw further improvements. The presence of the NCAR chemical amplifier was instrumental in assessing the status of HOx measurements during the PRICE-I campaign in southern Germany. While useful, the chemical amplifier has a number of limitations. After MLOPEX II, Fred Eisele moved from the Georgia Institute of Technology bringing his mass spectrometric-based method for measurement of tropospheric OH and sulfuric acid (H2SO4) (Eisele et al., 1996). This enhancement to the measurement capability at NCAR also offered the opportunity to develop a new technique for quantification of peroxy radicals (HO2 and RO2). In addition, through internal and external support, the previous ground-based instrumentation was improved to allow deployment aboard aircraft platforms (Mauldin et al., 2001). Improvements continue with the development of smaller, lighter single channel OH and HO2 instruments, which were deployed during the recent NASA-sponsored ARCTAS campaign (spring & summer 2008). Currently, instrumentation for deployment on the NSF Gulfstream-V aircraft is under development, and University of Colorado graduate student, Josh McGrath, is developing a new tool to measure the reactivity of OH in the ambient troposphere. In the past, mass spectrometric-based instrumentation was used to measure DMSO and DMSO2 (DMS oxidation products, Nowak et al., 2002), HNO3 (Zondlo et al., 2003), and NH3.

layers.

High resolution figure

Atmospheric Radiation Investigations and Measurements

The Atmospheric Radiation Investigations and Measurements (ARIM) group maintains Charged-coupled device Actinic Flux Spectroradiometers (CAFS) and Scanning Actinic Flux Spectroradiometers (SAFS) to measure up and down-welling wavelength dependent actinic flux in the UV and visible wavelengths. The measurements are based on a 2π steradian hemispherical zenith and nadir optical collectors coupled with UV enhanced fiber optic bundles to small, lightweight, monolithic CCD monochromators and double monochromator with photomultiplier tube detection, respectively. The instruments have an excellent record of performance on the NCAR HIAPER GV and C-130, the NASA DC-8, WB-57 and P-3B, the NOAA WP-3D and at numerous ground stations.

The ARIM optical calibration facility is equipped with precision radiometric power supplies and multiple NIST traceable 1000W quartz tungsten halogen lamps to determine the spectral response of each instrument. Secondary lamp standards are applied in the field. Mercury line calibrations are also performed to track the wavelength accuracy.

ARCTAS

The 2008 ARCTAS (funded by NASA) mission investigated the transport and transformation of gases and aerosols affecting the Arctic. The winter phase was based in Fairbanks, AK, and explored the transport of pollution across the Arctic, with a focus on arctic haze, tropospheric ozone and surface deposited black carbon. The summer phase was based in Cold Lake, Alberta, and concentrated on the contribution of boreal fires to the atmospheric composition and climate of the Arctic region.

CAFS instruments were deployed on the NASA DC-8 aircraft for the full campaign to provide photolysis frequencies for the critical chemical constituents of the arctic. In particular, the photolysis contributes to the study of the evolution of pollution plumes and the tropospheric oxidant chemistry. Several factors specific to the arctic affected the actinic flux. The scattering in arctic haze tends to increase the flux while absorption in boreal fire emissions decreases the flux. Surface deposited black carbon also decreases the flux by reducing the surface albedo. Thus, the in situ measurements were critical to assessing the local radiation field.

Prior to the summer phase in Cold Lake, Alberta, the California Air Resources Board funded a series of flights based from the NASA Palmdale facility to study the dynamics of the transport of Asian pollution into California, local anthropogenic pollution and greenhouse gas emissions. Again, the actinic flux measurements were critical to understand the local chemistry and evolution of the emissions.

The extensive California wildfires were also studied. The actinic flux was often dramatically reduced within the fire plumes, slowing the photolysis chemistry.

The CAFS instruments were redesigned for DC-8 installation, including new instrument housings, PC-104 computers and electronics, and upgrades to the data acquisition and control software. Data coverage was near 100% for the entire mission.

return to top

Community Spectro-Polarimetric Analysis Center (CSAC)

The Community Spectro-Polarimetric Analysis Center (CSAC) Strategic Initiative was conceived to strengthen HAO's position in the rapidly growing spectro-polarimetry community and also to transfer its 30+ years of heritage and leadership in the field to the broader community. CSAC is providing support for a host of new instruments for measuring vector magnetic fields in a range of solar atmospheric layers. Its most significant contribution to the broader community is the development and distribution of a modular suite of "standardized" (numerically robust, accessible, well-documented, and portable) computer analysis and data visualization codes that will be applicable to past and future spectro-polarimetric instrumentation.

During FY08 CSAC implemented the MERLIN (Milne-Eddington gRid Inversion Network) code as the workhorse analysis tool for data from the SOT/SP instrument on board of the Japan/US/UK Hinode spacecraft. These data receive the highest visibility and usage in the solar community. MERLIN output for SOT/SP is now being released through the CSAC web client. In FY2008 CSAC also begun standardizing the next-generation analysis tool LILIA (LTE Inversion based on the Lorien Iterative Algorithm) which will allows users to derive more detailed information about physical conditions in three dimensions within the Sun's magnetic photosphere by utilizing a more realistic atmospheric model.

In addition, work has begun on development of CAZAM (CSAC AZimuth AMbiguity utility), to visualize the vector magnetic field information produced by these codes. Current User Group: The CSAC user group currently consists of researchers from twenty institutes across the world.

return to top

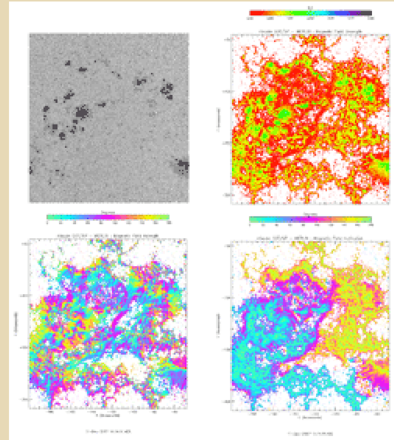


Figure 1: Results from a MERLIN inversion of Hinode data obtained on 11 December 2007 are shown. The continuum intensity showing the sunspots is at upper left. This active region shows a channel of (upper right)horizontal (inclination &126;90° lower right) magnetic flux running from lower left to upper right, corresponding to a filament in the chromosphere above. The fields are oriented roughly along the channel (field azimuth, lower left). These data suggest that the flux forming the filament results from the emergence of a rope of magnetic flux.

High resolution figure

Instrument and experimental meteorology

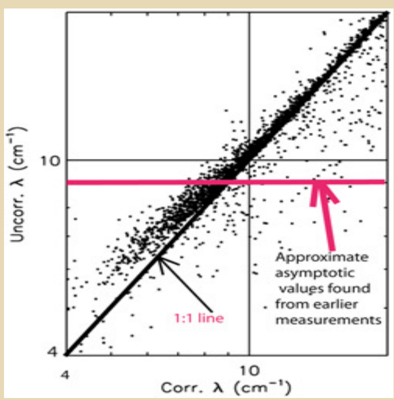


Figure: Effect of shattering of large ice on the slopes of particle size distributions derived in ice cloud layers from several field programs. The uncorrected slopes have been shown to level off at about 9 cm-1 from many field programs (y axis). By removing shattering events from particle interarrival times, corrected values of the slopes have been obtained (x axis). It is noted that in fact the slopes continue to diminish (x axis) to as low as 4 cm-1. This shows that physical processes such as collisional breakup of large aggregates as has been theorized based on the earlier measurements is not a valid explanation for the earlier results but that shattering of large ice is.

High resolution figure

A central issue in the cloud physics community is the recognition that after three decades of measurements of particle size distributions we are not yet able to accurately measure the concentrations of ice crystals in clouds. The cause of these overestimates is shattering of large particles that impact the leading edge of the probes, with the resulting fragments passing through the probe's inlets and being sensed as real particles. Overestimates of ice concentrations lead to smaller, more slowly falling crystals that do not sublimate readily in climate models in the middle troposphere through to the lower stratosphere and in these models ice-cloud albedos are significantly overestimated. This can result in major errors in the earth's net radiation budget that requires other non-physical model changes to correct.

In an to attempt to rectify deficiencies in the measurement of ice crystal concentrations, we wrote an article this year that has pointed to errors in past interpretations of ice-particle-growth processes as a result of the shattering issue. Measurements of particle-size distributions (PSD) over more than two decades have shown that the slopes of exponential functions used to represent ice PSD's in deep stratiform cloud layers reach a lower limit and then remain there. By correcting ice PSD for shattering based on measurements of particle interarrival times, this article shows that the reason why this lower limit was reached was due to shattering. Large particles impacting the leading edges of 2D imaging probes shattered, producing small particles. Broad size distributions, therefore, produced anomalous (shattered) numbers of small ones, maintaining the slopes at this lower limit. By removing the artifacts, this lower limit disappears (see figure).

Our efforts to understand and characterize ice PSD's have extended to particles 50 microns and below, an area particularly troublesome to measure. We have acquired a new type of probe that has been designed to reduce known problems with the earlier probes. The small ice detector (SID-2) probe, an open path instrument that sizes in the range 1 to 60 microns, flew on the NCAR C130 aircraft during the Ice in Clouds Experiment (ICE-L [layer]) in November and December 2007. The ICE-L research flights included repeated penetrations through mountain-induced lenticular clouds. Three other probes that were designed to remove the shattering problem were deployed in the experiment. We have developed new knowledge on the presence and amount of small ice particles in clouds from these measurements.

return to top

Development of Instrumentation for the Solar Dynamics Observatory (SDO)

The Helioseismic and Magnetic Imager (HMI) is one of the primary instruments to be flown on board NASA's Solar Dynamics Observatory spacecraft which will launch in June 2009 or January 2010. The HMI will record images of the Sun with 4096 by 4096 pixel detectors in wavelengths around the Fe spectrum line at 617.3 nm in various polarization states. These will allow us to construct images of the velocity and magnetic field over the entire solar surface with a spatial resolution of 2 arcseconds at a cadence of 90 seconds. The instrument development is led by researchers at Stanford University and the instrument is being constructed at Lockheed Martin. The construction phase was completed in 2008 and the instrument is now undergoing final testing at NASA's Goddard Space Flight Facility. Our role at HAO is to assist with the calibration of the instrument and to develop tools to convert the observations into physical parameters, such as the magnetic field strength and orientation. One challenging aspect will be to analyze the enormous volume of data in real time. In 2008, we completed the development of a computer code VFISV (Very Fast Inversion of the Stokes Vector) which can determine magnetic field parameters from polarization measurements significantly faster than any previous code. This code is now being incorporated into the HMI processing pipeline and is available for use by the community through the NCAR sponsored Community Spectro-Polarimetric Analysis Center (CSAC).

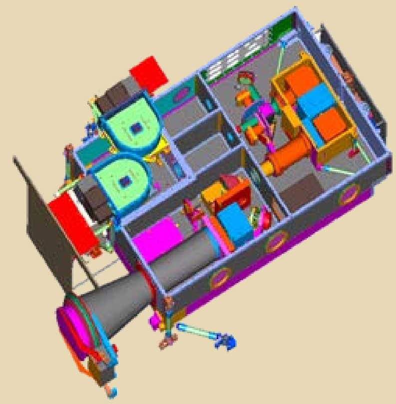


Figure 1: Engineering drawing of the HMI Instrument. Light enters through the primary lens at the lower left and is images on the CCD cameras (light green, upper left). Click high resolution image for image with part names.

High resolution figure

return to top

Fundamental Physics of Radiative Processes

Almost everything we know about the Sun comes from our interpretation of its radiative output. The study of the intensity and polarization of the radiation that we receive from solar regions allows us to infer the thermo-dynamical and magnetic properties of the emitting plasma, if we are able to formulate adequate models of the origin and transport of polarized radiation in the solar atmosphere. In the deeper and denser layers of the visible atmosphere (photosphere), plasma collisions typically ensure that, at each point in the plasma, the ratio of radiation emissivity to absorptivity (source function) is only determined by the local thermal properties of the plasma (local thermodynamic equilibrium, or LTE). Under these special conditions, the mechanisms for the production and transport of polarized radiation are very well understood, and reliable models have been available for at least half a century.

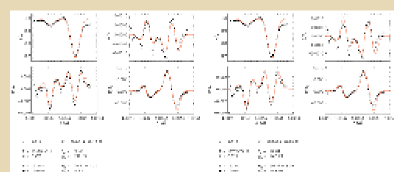


Figure 1: Convective patterns in a simulation of solar convection. Shown are (a) the radial velocity (b) the radial vorticity, (c) the horizontal divergence and (d) the temperature perturbation near the outer surface.

High resolution figure

As we move outward in the solar atmosphere (chromosphere and corona), the plasma density rapidly decreases, while at the same time the radiation becomes increasingly anisotropic. Both conditions determine significant departures from LTE, as the atomic equilibrium is now driven mainly by optical pumping by the underlying photospheric radiation. These are also the regions of the solar atmosphere where the topology of the magnetic fields that permeate the heliosphere - finally interacting with the Earth's magnetosphere - takes shape. So the development of adequate models of polarized radiative transfer in these regions, in order to determine the correct magnetic boundary conditions of the heliosphere, is of primary importance for our understanding of solar drivers of Space Weather.

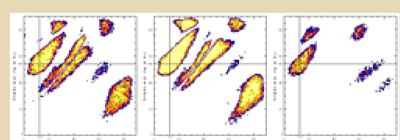


Figure 1: The ProMag Calibration linear solver uses a 4-point calibration sequence of the form $\alpha_P(i) = (i - 1)\delta_P$ and $\alpha_R(i) = (i = 1, 2, 3, 4)$, where α_P and α_R are the positions of the calibration polarizer and retarder, repectively. The figure shows contour plots of the calibration success rate (above 90%) on the (δ_P, δ_R) plane, for the three wavelengths of operation of ProMag (left to right: 587.6 nm, 635.3 nm 1083.0 nm). We see that, for ProMag�s specific design, there is a restricted set of optimal step pairs that maximize the success rate of the calibration

FY08 achievements

1. R. Casini and M. Landi Degl'Innocenti and M. Landolfi (both of the Observatorio Atrofisico di Arcetri, Italy) resumed work on the derivation of a higher-order master equation for the description of atom+radiation evolution, based on a Feynman-diagram approach. The goal is to arrive at a self-consistent treatment of partial redistribution of photon frequency in the polarized scattering of radiation from complex atoms. This is a much needed advancement in order to achieve a full understanding of the many enigmatic polarization signatures observed in the

procedure.

High resolution figure

solar spectrum. Progress in this long-term effort had come to a halt when Casini and collaborators were confronted with problems of non-conservation of probability in the atomic system. A delicate point in the derivation of the formalism is in the handling of the (unknown) initial conditions. In the past, this has been dealt with by resorting to heuristic arguments. This recent work has shown instead that it is possible to remove all references to the initial conditions in a systematic way. In the process, new terms appear in the formalism, which had not been considered before. Casini and co-workers have also initiated a systematic study of the implications of partial resummation of self-energy diagrams, through Dyson's equation, for the non-unitarity of the S-matrix in this type of radiation problems. The goal is to see if weak non-unitarity can be tolerated without compromising the correct physical picture of coherent radiation scattering.

2. Casini worked on the creation of a calibration package for the Prominence Magnetometer (ProMag). A linear solver was built that can work on a restricted set of configurations of the calibration optics, optimized for the specific optical characteristics of ProMag's polarimeter. Numerical tests have shown that the linear solver gives stable, reproducible results in the determination of the polarimeter matrix. This linear approach is going to be much faster than typical non-linear optimization schemes applied to a redundant set of calibration configurations. The code has also been tested during the laboratory characterization of ProMag, and it has been instrumental to identify design and assembly issues with the polarimeter. Because of the ensuing delay in the field deployment of ProMag at the NSO Evans Coronal Facility, unfortunately the code has not yet been tested on real solar data from that telescope.

*FY09 plans**

1. To progress on the theory of the polarized line formation in the presence of coherent scattering (partial redistribution in frequency), by evaluating the newly found terms, and by assessing the significance of the identified problems of non-unitarity of the S-matrix for the description of radiation processes in a dressed atom.
2. To devise plasma diagnostic techniques exploiting the polarization effects of micro-turbulent electric fields on hydrogen lines (e.g., the role of electric-induced dichroism in optically thick plasmas), and to apply them to the joint determination of vector magnetic fields and plasma density in solar regions. (Collaborators: Rafael Manso Sainz, Arturo Lopez Ariste. Instituto de Astrofisica de Canarias.)
3. To start the rewriting of the HANLE codes for scattering polarization in the chromosphere and corona to modern software standards, within the effort of the NCAR-funded Community Spectro-polarimetric Analysis Center (CSAC) strategic initiative.

return to top

Virtual remote sensing facility

ACRESP activities build on our current satellite missions and our expertise and leadership in satellite remote sensing science, Earth System modeling, and data assimilation. Recent advances in tropospheric remote sensing have opened the way for measuring, monitoring, and understanding processes that lead to atmospheric pollution. As part of an integrated observing strategy, satellite measurements provide a context for localized observations and help to extend these observations to continental and global scales. The challenge for future space-borne missions will be directly accessing the local scale and facilitating the use of remotely sensed information for improving local- and regional-scale air quality (AQ) forecasts. Achieving this goal will provide important societal dividends for public health, for policy applications related to managing national AQ, and for assessing the impact of daily human activity on the distributions of important trace gases and aerosols and their short-timescale variability - known as "chemical weather" - as well as on climate.

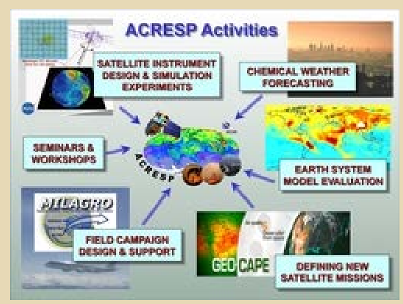


Figure 1. ACRESP Activities are grouped in two main areas: Satellite instrument design and future mission planning for atmospheric composition and air quality, and chemical weather forecasting, satellite data assimilation and field campaign support.

High resolution figure

Satellite Instrument Design:

If a satellite mission related to atmospheric composition and air quality is to become a reality within the next decade, the atmospheric chemistry community will need to establish clear scientific motivation for the new measurements. For this, there is considerable interest in using chemical observing system simulation experiment (OSSE) studies to help define quantitative measurement requirements for satellite missions and to evaluate the expected performance of proposed observing strategies. These experiments will hopefully provide a practical way of defining a traceability matrix to map science requirements through measurement requirements onto instrument requirements.

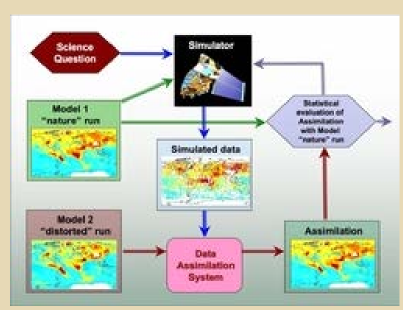


Figure 2. The OSSE framework comprises the following key elements: (1) a science-driven

OSSEs must be driven by well-defined scientific questions and the experiment formulation constructed accordingly. We have completed an example OSSE motivated by the desire to measure the distribution and time evolution of carbon monoxide in the lower-most troposphere for air quality applications using candidate satellite multispectral measurements in the thermal and near infrared.

Future Satellite Missions:

The ACRESP group is involved in the planning of The Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission that has been recommended for launch in the 2013-2016 time frame by the National Research Council. The mission's purpose is to gather science that identifies human versus natural sources of aerosols and ozone precursors, tracks air pollution transport, and studies the dynamics of coastal ecosystems, river plumes and tidal fronts. Continuous observation from GEO-CAPE's geostationary platform will allow for more adequate monitoring of population exposure and the ability to relate pollutant concentrations to their sources or transport, thereby providing data to improve air quality forecasts.

ACRESP is a partner on a carbon monoxide instrument, the Compact Imaging Spectroradiometer (CISR), that builds on MOPITT experience and that has been specifically designed for geostationary deployment. CISR is candidate technology for GEO-CAPE and is currently under development as part of the NASA Instrument Incubator Program (IIP).

A longer-term goal of the ACRESP OSSE activity is to develop a community facility at NCAR. This would be used by researchers from the universities and agency centers for building and testing instrument simulators as part of the proposal and design of the next generation of satellite instruments.

Air Quality "Chemical Weather" Forecasting:

The Chemical Weather: Local, regional, and global distributions of important trace gases and aerosols and their variation on time scales of minutes to hours to days, particularly in light of their various impacts, such as on human health, ecosystems, the meteorological weather, and climate. (Lawrence et al., Environ. Chem. 2005, 2, 6-8, doi:10.1071/EN05014)

The ACRESP Program is developing an air quality "chemical weather" forecasting capability based on existing satellite observations. Chemical weather is a priority research theme for ESSL. The characterization of global and regional scale air quality involves field campaigns, chemical transport modeling, and remote sensing. The goal is a scientific and observing framework analogous to that used for weather forecasting with a model assimilation of observations from satellite, aircraft and surface platforms to derive a 4-dimensional view (3 spatial plus temporal) of the physical state of the atmosphere.

This analysis will be used in air quality basic research: the quantification of emissions of ozone and aerosol precursors and the examination of the long-range transport of pollutants extending from regional to global scales. The general tools and methodologies developed will also be used for studies examining the connections between climate change and regional air quality, and the roles of anthropogenic and natural processes in changing atmospheric composition. The predictive capability will provide a powerful tool to support field campaign activities such as those involving HAIPER chemical instrumentation. There also exists the possibility of demonstrating schemes for future operational applications elsewhere in the community related to air quality management and health advisories.

Increasingly, there is interest in accessing finer spatial scales to quantify both the wider impact of local pollution sources such as wildfires and mega-cities and assessing the contribution of transported pollution. We are conducting a chemical weather case study for the MIRAGE and INTEX-B spring 2006 period. This involves global model simulations using analyzed meteorology and the best possible chemical sources with fire emissions based on satellite fire products. A nested regional model simulation concentrating on Mexico and parts of the INTEX-B Pacific region are also being performed using WRF-Chem.

One of the open questions in AQ policy management is to what degree Asian industrialization and the associated transpacific transport of pollution could hinder improvements in AQ in the US from domestic emission controls. We have used the data set collected during the April/May 2006 phase of INTEX-B to look into the impacts of the long-range transport of pollutants across the Pacific on the U.S. West Coast. The study used global model simulations with altered Asian emission scenarios as boundary conditions for WRF-Chem simulations to examine the changes in concentration fields in both the global and the regional model. In another study, we focused on a direct application to AQ and quantified the impact of the fires in California in fall 2007 on regional air quality and especially on surface ozone by analyzing surface observations of ozone concentrations together with model simulations. It was found that the frequency of violations in the public health standards nearly tripled because of the fires.

requirement for a chemical species observation, (2) a satellite instrument simulator and observing strategy that might be capable of making a useful measurement, (3) a simulated data retrieval of the species with "nature" defined by an appropriate chemical transport Model 1, (4) a forecast of the species distribution using an assimilation of the retrieval in the "distorted" model 2, and (5) a quantitative assessment of the value of the measurement.

High resolution figure

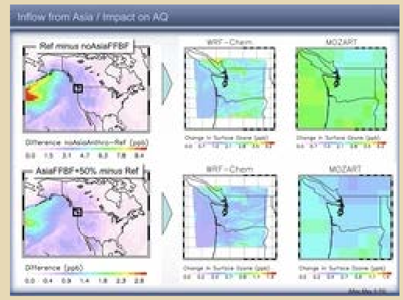


Figure 3. WRF-Chem and MOZART simulated change in surface ozone (Maximum change for May 3-10) over Washington State with changes in Asian emissions.

High resolution figure

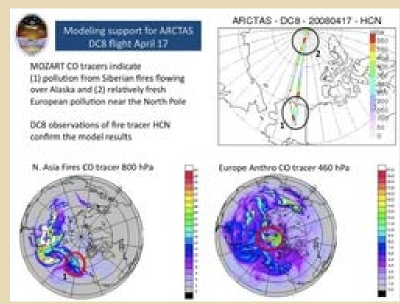


Figure 4. An example of the success of the ARCTAS chemical forecasts in predicting pollution plumes subsequently confirmed by aircraft measurements.

High resolution figure

Assimilation of available satellite data sets such as Terra/Aqua/MODIS aerosol optical depth, ENVISAT/SCIAMACHY and Aura/OMI NO2, OMI O3 tropospheric column, and Terra/MOPITT, Aura/TES, and METOP/IASI CO and O3 are being explored. This exercise will impose constraints on the modeled chemical fields and can be evaluated by compaing with actual field measurements. We have been working on a pre-cursor study with idealized satellite retrievals to examine the benefits and shortcomings in the assimilation of chemically active species. Largest improvements in predicting surface ozone were found when O3 or also NO2 fields throughout the atmosphere are available with high temporal resolution (3hrs) and for the online inversion of NO emission. However, the latter had the tendency for increasing biases in outflow regions. Work is ongoing on the assimilation of concentrations fields on a daily basis.

These projects involve the collaborative efforts between ACD and the DART initiative in IMAGe. We will also aim to foster collaboration with other efforts in the development of chemical weather forecast capability both within U.S. Universities, NOAA and NASA, and internationally, particularly with the GEMS project (http://www.ecmwf.int/research/EU_projects/GEMS/) in Europe.

Field Campaign Support and Data Analysis:

ACRESP supported the NASA Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) field campaign with a combination of model simulations and satellite observations. Measurements were made from the NASA DC8 aircraft in the Spring and Summer of 2008, and were coordinated with several other field experiments as part of the International Polar Year (IPY). The Spring Phase of ARCTAS was April 1-19, based in Fairbanks, AK, and the Summer Phase was in Cold Lake, Alberta, June 26-July 14. In addition, several DC8 flights were made from Palmdale, CA, June 18-24, in coordination with the California Air Resources Board (CARB).

Retrievals of carbon monoxide (CO) from observations by Terra/MOPITT were produced in near-real-time. Chemical forecasts were produced using Ensemble Kalman Filter Data Assimilation of meteorological observations, MOPITT CO, and MODIS aerosol optical depth (AOD) with the NCAR Community Atmosphere Model with Chemistry (CAM-Chem). The data assimilation was performed in the Data Assimilation Research Testbed (DART) framework. Forecasts were also run with MOZART-4 driven by NCEP/GFS meteorology. The satellite retrievals and chemical forecasts were used to assist in the planning of the DC8 flights during the campaign by identifying features of interest for the aircraft to sample, such as pollution plumes from fires in Siberia and Canada.

Analysis of the ARCTAS measurements will continue in the coming year using a combination of satellite and model simulations. The assimilation of MOPITT CO and MODIS AOD in CAM-Chem/DART will be refined and evaluated with the aircraft observations, and, in turn, used to assist in the interpretation of the observations. Discrepancies between the model and observations will be used to improve the model and the emissions used to drive the model.

return to top

Analysis of data from TIMED and COSMIC

HAO conducts data analysis activities for several space-based observing missions, and uses the results to validate and improve models of the upper atmosphere and magnetosphere. One of the most important new activities is analysis of ionospheric results from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) mission, also known as FORMOSAT-3, which is a partnership between the U.S. and Taiwan and is managed by the University Corporation for Atmospheric Research.

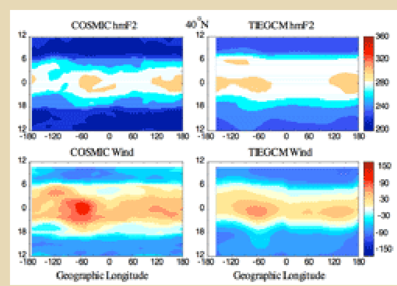


Figure 1: Comparison of longitudinal variations of the F_2 layer peak height in km (top) and magnetic meridional winds in m/s, positive equatorward (bottom), as a function of local time at 40° N during winter. Left: measurements by the COSMIC mission. Right: model results from the NCAR TIE-GCM.

High resolution figure

HAO scientists and colleagues at National Central University in Taiwan have conducted several studies using data from COSMIC in the past year. Initial work during the first year of the mission focused on data validation and climatology, but during the second year, with the constellation fully deployed and dispersed, it has been possible to explore ionospheric phenomena, and to measure other quantities such as thermospheric neutral winds near 250 km altitude. This is done by measuring the effect of winds on the height of the maximum of the main ionospheric layer, the F2 peak. A study by Luan and Solomon [2008] compared peak heights and inferred meridional winds measured by COSMIC to simulations by the NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM), demonstrating the longitudinal variation of the wind pattern, controlled by the declination of the geomagnetic field (figure 1).

Work by Burns et al. [2008] revealed the global connections of a once-forgotten feature of the southern ionosphere, the tendency of the late evening ionosphere to increase its density over mid-day levels during summer originally observed by the Halley Bay ionosonde and hence called the Weddell Sea anomaly. With global measurements by COSMIC (figure 2), this feature is seen to be a large region near the Antarctic peninsula, and its formation appears to be connected to the better-known equatorial ionization anomaly. Thermosphere-ionosphere models cannot yet reproduce this feature, even with magnetospheric coupling, so what it is telling us about

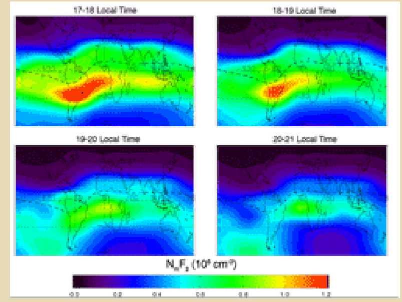


Figure 2: Development of the Weddell Sea ionization anomaly during southern hemisphere summer as seen in these constant-local-time plots of COSMIC data. The peak density of the F_2 region of the ionosphere exhibits a possible connection to the equatorial ionization anomaly.

High resolution figure

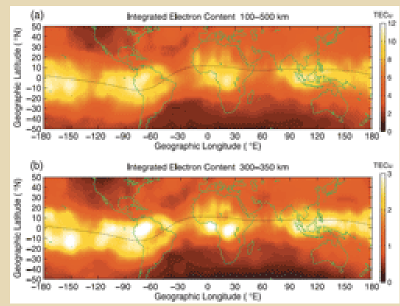


Figure 3: Ionospheric electron content integrated between (a) 100-500 km altitude range and (b) 300-350 km altitude range of the COSMIC electron density observation at 2000-2200 local time during September equinox, 2006. 1 TECu = 10^{12} electrons/cm^2.

High resolution figure

the extended nature of the ionosphere-plasmasphere interaction remains a curious challenge for ionospheric physics.

COSMIC data also have a key function in mapping the longitudinal variation of the equatorial ionization anomaly, which is thought to be influenced by the eastward propagating zonal wavenumber-3 diurnal tide that is excited by latent heat release in the tropical troposphere [Hagan et al., 2007]. Work by Lin et al. [2007] in collaboration with NCAR scientists examined the structure of this effect using COSMIC data during September equinox. The global three-dimensional ionospheric electron density shows a prominent four-peaked wave-like longitudinal enhancement, and the vertical electron density structures reveal that the feature exists mainly above 250 km altitude (figure 3).

References

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return to top

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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ESSL LAR 2008: STRATEGIC GOAL #5, PRIORITY #2

Earth and Sun Systems Laboratory endeavors are central to NCAR's Strategic Goal #5, to "Provide world-class ground, airborne, and space-borne observational facilities and services." This Strategic Goal includes three Strategic Priorities, two of which are closely tied to work by ESSL staff.

Goal #5, Priority #2, Developing new instrumentation, is described in the NCAR Strategic Plan as follows: "Advances in research on weather, climate, the water cycle, chemistry and dynamics of the upper troposphere/lower stratosphere, space weather and solar physics, and biogeosciences all require capabilities that stretch beyond those provided by (NCAR's) current suite of airborne and ground-based instruments. NCAR is tasked with developing a new generation of robust, inexpensive, easily deployable, and versatile instrument systems to address the university community's need for these instruments, which facilitate their research efforts. Our extensive and talented scientific and engineering staff continually creates and test new instrumentation for studying the links between atmospheric composition and the biogeosciences, with systems for quantifying the surface-atmosphere exchange of gases and aerosols on whole-plant, whole-canopy, and regional scales using mobile laboratories and research aircraft."

Significant efforts by scientists and staff of the Earth and Sun Systems Laboratory (ESSL) are focused on addressing this Priority in order to provide the observations necessary for improved understanding of the Earth and Sun Systems.

The section below describes specific research conducted by ESSL staff under projects relevant to Goal #5, Priority # 2. The major ESSL activities in this area include development of chemical instruments for HIAPER, development of a Coronal Solar Magnetism Observatory (COSMO) and instruments for the Solar Dynamics Observatory, continued use and evaluation of satellite measurements from the HIRDLS and MOPITT instruments, development of airborne and ground-based chemical and meteorological instrumentation, and development of a Satellite Observation Simulator and Assimilation System (SOSAS).

Development of a COronal Solar Magnetism Observatory (COSMO)

Driven by society's need to understand the origins of space weather, NCAR scientists at the High Altitude Observatory, along with colleagues at the University of Hawaii and the University of Michigan, plan to build the Coronal Solar Magnetism Observatory (COSMO). The facility will take continuous synoptic measurements of the entire corona in order to understand solar eruptive events that drive space weather and to investigate long-term and solar-cycle phenomena. The primary instrument will consist of a 1.5-m coronagraph with two detector systems: a narrow-band filter polarimeter and a spectropolarimeter. Supporting instruments are

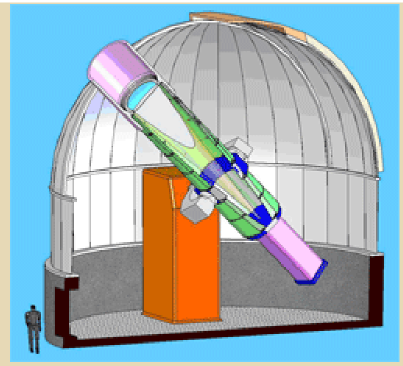


Figure 1: Concept drawing of the COSMO 1.5-meter coronagraph and dome. The telescope is a simple tube structure on an equatorial mount. The diameter of the dome is 12.2 meters.

High resolution figure

a white-light coronagraph to record the evolution of the electron scattered corona (K-corona) and a chromosphere and prominence magnetometer. This new facility will replace the current NCAR Mauna Loa Solar Observatory which has been collecting synoptic coronal data for over 40 years in support of the solar and heliospheric community.

In order to demonstrate the feasibility of measuring coronal magnetic fields, prototype instruments have been developed over the past 5 years at NCAR and the University of Hawaii. The Coronal Multi-channel Polarimeter (CoMP) instrument is a prototype of the COSMO coronal magnetometer which was built at NCAR/HAO. Last year, the CoMP enabled a scientific breakthrough by imaging, for the first time, Alfven waves in the solar corona. These waves were found in observations of the Doppler-shift of coronal plasma in the Fe XIII emission line at 1074.7 nm. These waves are important in that they transport energy from the turbulent photosphere out into the solar corona, and could explain why the solar corona is heated to a temperature of 1 million degrees. In 2008, we exploited the fact that the speed of propagation of these waves depends on the magnetic field of the corona. This allows us to use the wave speed measurements from CoMP to determine the strength of the coronal field. This effort is part of an exciting new field called Coronal Seismology.

In 2009, we will move CoMP from the NSO Sacramento Peak Observatory in New Mexico to the University of Hawaii's Mees Observatory atop Haleakala in Maui. This will allow us to obtain coronal observations under excellent sky conditions and fully exploit the scientific potential of the CoMP instrument.

Planning for COSMO has been assisted by a Scientific Advisory Panel of community members who have set the scientific requirements for the facility. Operation of the facility will continue to be guided by the Scientific Advisory Panel which will insure that the facility will continue to meet the needs of the solar and heliospheric community which it serves. The development of the CoMP instrument was supported by the NSF through the NCAR Strategic Initiative Fund and HAO base funds.

return to top

High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) instrumentation

PI: Andrew Weinheimer (UCAR/NCAR) - completed FY2008

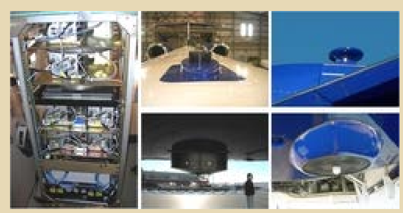


Figure 1. HARP rack installed on the NSF HIAPER GV aircraft, irradiance and actinic flux zenith and nadir optics.

High resolution figure

NO-NOy Instrument **- Two-channel instrument for the in situ measurement of NO (nitric oxide) and NOy (total reactive nitrogen).**

The CARI two-channel chemiluminescence instrument is capable of 1-sec in situ measurements of NO and NOy. The instrument was completed and certified for the GV early in FY2008, and was flown successfully on the NCAR/NSF GV aircraft during the START08 mission in April/May and June/July of 2008. The instrument worked very well and we collected a complete data set during the START08 mission, which will contribute to the characterization of stratosphere-troposphere exchange processes in mid-latitudes. Plans for FY2009 include some re-design of the inlet to optimize pressure control and minimize wall losses of nitric acid. This inlet design will also support the needs of the GA Tech CIMS HAIS instrument, which the CARI group expects to receive during FY2009. Some software changes and reprogramming are also planned to make the software more stable while communicating with GV the aircraft data systems. See the CARI group report for details on the NO/NOy instrument.

PI: Teresa Campos (UCAR/NCAR) - completed in FY2008

Fast Ozone Instrument **- Quantification of ozone mixing ratios at 5 Hz using the method of chemiluminescent reaction of ozone with nitric oxide.**

The Fast-Ozone instrument was completed and certified to fly on the GV in early FY2008. The instrument was then flown on the START08 mission, together with the NO/NOy instrument. Both systems used an integrated pumping system and shared the data system which was redeveloped to accommodate both instruments to save space and weight when deployed together on the GV. Laboratory tests as well as analysis of flight data confirmed that the time resolution of the fast-Ozone instrument is indeed 5 Hz or better. A complete data set was collected during the START08 mission and the ozone data compared extremely well with two additional ozone sensors flown during START08 and operated by NOAA.

PI: Eric Apel (UCAR/NCAR) - estimated completion: FY2009

Trace Organic Gas Analyzer (TOGA) **- In situ measurements of oxygenated volatile organic compounds (OVOCs), non-methane hydrocarbons (NMHCs), and halocarbons.**

The Trace Organic Gas Analyzer (TOGA) will be completed in FY 09. It will have the unique capability of simultaneously measuring, with one instrument, a suite of organic compounds that play important functions in many areas of atmospheric chemistry. Several of the compounds are precursors or intermediates in atmospheric oxidation sequences. Others are indicators or tracers of different anthropogenic and biogenic processes. The compounds that TOGA will measure consist of a series of hydrocarbons, oxygenated compounds, halocarbons (including HCFCs and CFCs), and a few nitrogen and sulfur containing compounds. These species are identified in the HIAPER Advisory Committee Report as high priority. A prototype of this instrument was flown successfully on the NASA DC-8 aircraft during the ARCTAS mission in March/April and June/July of 2008. Excellent data was collected during ARCTAS including quite possibly the first accurate data of acetaldehyde in clean air masses.

PI: Rick Shetter (UCAR/NCAR) Estimated Final Acceptance: FY2009

HIAPER Atmospheric Radiation Package (HARP) **- Spectrally resolved actinic flux and stabilized platform irradiance measurements.**

Rick Shetter and his Atmospheric Radiation Investigations and Measurements (ARIM) team, in collaboration with Peter Pilewskie and Bruce Kindel of the University of Colorado, Manfred Wendisch of the Leibniz-Institute for Tropospheric Research, Rainer Schmitt of Metcon, Inc and Dieter Schell of Enviscope GmbH, Germany, developed the HIAPER Airborne Radiation Package (HARP), a comprehensive atmospheric radiation suite to measure in situ actinic flux and irradiance. The ARIM group developed the actinic flux package using a CAFS detection and was responsible for building the spectrometer computer systems, creating the data acquisition and control software, coordinating the assembly of the racks, equipment, input optics and stabilized platforms, and leading the integration and flight management of the instrumentation.

The irradiance measurements rely on horizontal stabilization to determine layer properties, such as reflectance, transmittance and absorbance. Thus, the HARP irradiance package is mounted on zenith and nadir stabilized platforms to account for aircraft attitude changes. The platform was tested during the HIAPER Aircraft Instrumentation Solicitation Experimental Flight Test - 2008 (HEFT-08). The stabilized platform performed well and responded precisely to positional commands. However, the navigation signals used to determine aircraft attitude were inaccurate due to signal timing delays and noise on the signal line. To eliminate these external errors, the HARP system has been upgraded to receive direct GPS antenna signals. Final testing and delivery of the HARP instrumentation is forthcoming.

return to top

Analysis of data from Hinode and STEREO

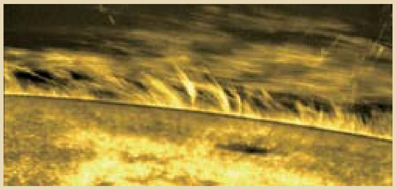


Figure 1: Fine structure of the solar chromosphere and a solar prominence are clearly visible in this image taken by Hinode. Time sequences of imaging data have revealed the presence of MHD waves in the upper atmosphere that may be the elusive source of heating the outer solar atmosphere and acceleration of the solar wind. This image is taken from an article by Okamaoto, et al. in the special Hinode issue of Science, 7 December 2008, p 1577.

High resolution figure

During FY2008 the Joint Japan/US/UK Hinode mission entered its second year of operation. Many new science results continue to pour from the analysis of Hinode data. HAO/ESSL/NCAR hosted the Second Hinode Science Meeting in Boulder the week of 28 September 2008, with an international participation of about 200 scientists. The theme of this meeting, "Beyond Discovery, Toward Understanding", emphasized detailed quantitative analysis and the integration of numerical models with observations. The Hinode team at HAO has contributed many new science developments over the past year, some of which are highlighted in this document under "Profiles in Science and Technology." Furthermore, HAO scientists were involved in many articles in the Special Issue of Science Magazine (7 December 2007) devoted to new results from Hinode. The Hinode mission has provided an avenue for many HAO scientists to open new scientific collaborations, including advising and collaborating with PhD students from other institutions.

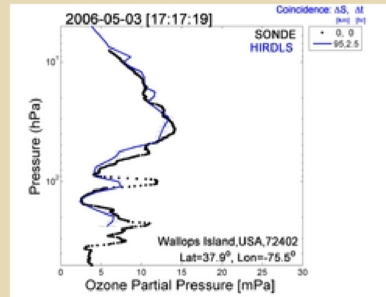
HAO continues to contribute to mission operations and community access to Hinode data. Systematic data reduction of the now almost 2 years of Hinode science data from the Spectro-Polarimeter (SP) onboard Hinode is being carried out at NCAR. The complex analysis procedure for SP data was developed at HAO initially under the NCAR Strategic Initiative "Community Spectro-Polarimetric Analysis Center" (CSAC). Refinement and updates to this reduction software are ongoing as a contribution of HAO to the Hinode program. These fully calibrated "Level 1" SP data are then made available to the community via the internet. Through CSAC, HAO is also providing the SP "Level 2" data: a detailed analysis of the polarization spectra to provide maps of the magnetic field vector in the solar atmosphere. Bulk processing of SP Level 2 data began at HAO in FY2008, and is now being made available to the community. HAO scientists participated in Hinode mission operations that require them to travel to Japan to prepare the science operations plans.

HAO scientists, in collaboration with many other scientists worldwide, continue to use the Hinode observations in innovative ways. One such example is the high resolution Hinode image shown in Figure 1 that reveals the ultra-fine structure of the upper layers of the solar atmosphere (the chromosphere). Sequences of such images have led to new understanding regarding the dynamics of the solar atmosphere, how it is linked to the dynamics of the magnetic field below, and how waves propagating through this region might be the elusive source of the heating of the solar corona and acceleration of the solar wind.

return to top

HIRDLS

The High Resolution Dynamics Limb Sounder (HIRDLS) is a 21 channel infrared limb scanning radiometer, jointly developed by ACD, the University of Colorado, and the Physics Department of Oxford University. It is designed to make observations of temperature, ozone, water vapor and 8 other trace species, as well as PSC's, aerosols and cirrus clouds, from the upper troposphere to the mesosphere, with higher vertical resolution than has previously been available from space observations. NASA funded the U.S. share of the HIRDLS development. When HIRDLS was launched on the Aura spacecraft in July 2004, a thin plastic film from inside HIRDLS came loose and obstructed most of the instrument's aperture, limiting the view to the atmosphere to a small fraction of the width of the optical beam. As described previously, the HIRDLS team, led by John Gille, the U.S. PI, and John Barnett (Oxford), the U.K. PI, showed that there was useful information in the signals. This required the development of 4 major adaptations and corrections to the measured signals. The first, revising the calibration, was described earlier.



Figures 1 and 2. Comparisons of HIRDLS V4 ozone retrievals with ozone sonde data at the locations and dates indicated. Separation of the sonde and HIRDLS retrievals is 95 km and 2.5 hours for the May profile, and 238 km and 0 hours for the April profile. The HIRDLS retrievals (blue) pick up the fine vertical features seen by the sondes (black dots).

High resolution figure

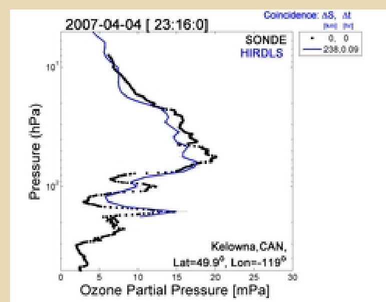


Figure 2.

High resolution figure

The next steps were to correct the measured signals to make them as close as possible to the expected radiances. The major efforts this year were to complete the algorithms to remove the spurious oscillations (due to mechanical oscillations of the plastic), and to recalculate the pointing. In addition, critical improvements were made in the corrections for the partial viewing area, and the estimation and removal of the signal coming from the obstruction.

A key method for determining these corrections is to have the spacecraft pitch by ~5°, so that HIRDLS looks above the atmosphere and measures signals only from the plastic film. This year the ACD HIRDLS team coordinated 2 of these pitch maneuvers. The initial development of these algorithms was described previously, but work continued, especially to improve the estimate of the reduced viewing area, and to refine subtraction of the signal from the plastic film. The latter is the biggest difficulty at this time. Updated calibration coefficients, radiance sample geo-location, and improved cloud location had been incorporated in the operational processing code. The resulting processor version was run on all the observations to produce a data set designated internally version 2.04.09. These data include global profiles of temperature, ozone, nitric acid and aerosol/cirrus; it was released to the community as Version 3 (V3) data. These were publicly released at the beginning of the reporting period.

Subsequent improvements have resulted in a new processor, v2.04.19, and a new V4 data set that was released near the close of the reporting period. These data include profiles of CFC 11, CFC12, and aerosol extinction, as well as temperature and ozone that have improved accuracy and fewer data spikes. The HIRDLS temperatures are now in within 0.5K of U.K. Meteorological Office high-resolution radiosonde data for 9 widely distributed stations, and for all data available from January 2005 until August 2007, while continuing the 1 km vertical resolution obtained previously. HIRDLS temperature retrievals show the same very good agreement with high resolution radiosondes as the earlier version, shown in the last Annual Report. V4 ozone retrievals also show very good agreement with sonde data, and the ability to see small scale structure, as illustrated in Figures 1 and 2.

The NCAR HIRDLS team hosted members of the core Oxford team for a 2 day meeting in January to discuss data improvements and future plans. This was followed by an open meeting with community members to discuss and encourage the scientific applications of HIRDLS data. The team also presented their status and plans to a review team from NASA, and attended similar core team and open science meetings in Oxford in June.

After an increasing number of spikes in the chopper motor current beginning in January, the chopper ceased operating on 17 March. Considerable effort has gone into diagnosing the problem, and attempting to restart the chopper, so far without success.

In the next year the correction algorithms will be refined to allow the recovery of additional species such as water vapor and methane. Emphasis will be on improved estimation of the partial view area and especially of the signal from the plastic, including allowances for the variation of the latter with time. In parallel, emphasis will be placed on the use of the released data for scientific studies, especially of UT/LS processes and strat-trop exchange, but broadening to many other areas (See Goal 1).

return to top

Measurements of Pollution in the Troposphere (MOPITT)

MOPITT Operational Production of Carbon Monoxide Data

The daily operational processing of Measurement Of Pollution In The Troposphere (MOPITT) instrument raw counts into the final retrieved geophysical products, delivery of products to NASA for free public access, and user education and support, constitutes a major service to the scientific community. MOPITT is also unique in providing the community with the longest continuous validated global CO data product. Scientific results have been presented worldwide at numerous scientific meetings and show a documented strong presence on the Internet. MOPITT data distribution, publications, literature citations, and conference presentations are all showing strong upward trends, indicating mounting demand and scientific interest.

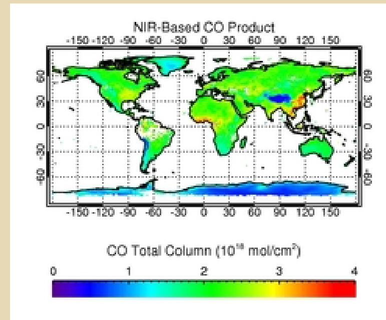


Figure 1. Monthly mean MOPITT CO total column results for March, 2006 based solely on near-infrared observations.

High resolution figure

Development of new data processing software for the next product release, 'Version 4,' has just been completed. Major features of the new retrieval algorithm include: (1) a new forward model with improved description of the MOPITT gas correlation cells and applicability to a wider range of CO mixing ratios; (2) a new description of the retrieval a priori surface emissivity; (3) a new seasonally and geographically variable CO retrieval a priori; and (4) the use of an assumed log-normal variability for CO volume mixing ratio. The new product also includes more extensive diagnostics, including the retrieval averaging kernels.

Activities during FY08

Algorithm Development and Product Evaluation

The development of a substantially improved retrieval algorithm for processing the next major MOPITT data product ('Version 4') was recently finalized. Associated activities completed in FY08 included (1) enhancement of the operational radiative transfer model to reflect actual in-orbit instrumental parameters and to better handle extremely polluted atmospheres and (2) determination of appropriate radiance bias correction factors. Product evaluation activities included analysis of V4 results at validation sites where aircraft in-situ profiles and surface measurements are available throughout the mission (since 2000). Overall, validation results indicate very small retrieval biases at all levels and demonstrate significantly weaker long-term drift than was observed in the current MOPITT Version 3 Product.

Long-term goals for the MOPITT Team include the incorporation of MOPITT's near-infrared measurements (i.e., 'solar channels') to provide additional information with respect to the CO total column measurement. Neither the current MOPITT Version 3 product nor the upcoming Version 4 products exploit these measurements because of challenges in understanding apparent instrument noise specific to these channels. During FY08, however, MOPITT retrievals based on these measurements were demonstrated for the first time, and clearly indicate the promise of combined thermal-infrared/near-infrared (TIR/NIR) CO retrievals for future products. Figure 1 presents global monthly-mean CO total column retrievals based solely on MOPITT NIR measurements during March, 2006. Regions of biomass burning in Equatorial Africa as well as anthropogenic emissions in China (principally from fossil fuel burning) are both clearly evident in the figure. Compared to current retrievals based purely on TIR measurements, the new NIR retrieval product is more sensitive to CO in the boundary layer and therefore should be much more capable of identifying sources at the surface.

Reference: "CO retrievals based on MOPITT near-infrared observations," by M. N. Deeter, D. P. Edwards, J. C. Gille, and James R. Drummond, *submitted to J. Geophys. Res.*

Field Campaign Support

The NCAR MOPITT Team produced and provided near real-time imagery and CO data products to support the ARCTAS (Arctic Research of the Composition of the Troposphere from Aircraft and Satellites) field campaign during Spring and Summer phases in FY08. Analyses of these data are ongoing.

Plans for FY09

Production and Release of V4

Operational processing of the MOPITT Version 4 product will begin in early FY09. The acquisition of new linux servers should allow processing of the entire MOPITT mission within several months, however the prerequisite task of porting all of the associated software to the new hardware may itself take several months. This process has begun. In preparation for the release of the new product, a new User's Guide is being drafted. Also, as the official release date approaches (possibly around the end of 2008), the new product will be publicized within the community. This effort will include a presentation at the Fall AGU meeting.

Version 5 Development

As operational processing of the Version 4 product becomes routine, initial steps to define and develop the Version 5 product will begin. While preliminary, current objectives for V5 development include the incorporation of MOPITT's solar channels and an evaluation of alternative sources for meteorological data.

Continued Analysis of Operational MOPITT Products

The MOPITT Science Team will continue to evaluate operational products both in the context of traditional validation (e.g., using available in-situ data from aircraft and ground-based spectroscopic measurements) and in comparison to models.

return to top

Atmospheric chemistry instrumentation

ACD scientists are involved in ongoing efforts to develop, improve, operate, and maintain a number of instruments designed to measure trace gases, radicals, optical properties, and aerosols in the atmosphere.

CARI Instrumentation

Aside from the community chemistry instruments and HIAPER instruments the CARI Group maintains and continued to improve a four channel chemiluminescence (CL) instrument for the simultaneous measurement of NO, NO2, NOy, and Ozone with a time resolution of 1 second or better. This instrument can be configured to fly on a variety of aircraft such as the NCAR C-130, the NASA WB-57, the NASA DC-8, and others. It can be flown unattended or with an operator and was deployed successfully during the NASA led ARCTAS experiment in 2008. CARI also maintains a compact chemical ionization mass spectrometer (PAN-CIGARette, Figure 1) which measures PAN at up to 4 Hz frequency or a number of different PAN species at 0.5Hz or better depending on number of species. We are planning to add this instrument to the pool of community instruments maintained by CARI . The PAN CIGARette would then become requestable for use on the NCAR/NSF aircraft. Both the four channel CL and the PAN CIGARette will be deployed during the OASIS field mission planned for early 2009 in Barrow, AK.

Figure 1. The new, compact PAN-CIGARette instrument was used for fast (1-2 sec), continuous measurements of PAN and related species on the C-130 for the MIRAGE and INTEX-B programs.

High resolution figure

Ultrafine Aerosols

During 2008 the Ultrafine Aerosols group developed new instruments to study the formation of atmospheric aerosols and their impacts on climate. An ion trap mass spectrometer was built by visiting German Research Foundation postdoc Andreas Held and interfaced with a redesigned electrostatic nanoparticle sampler for measuring nanoparticle chemical composition by the thermal desorption chemical ionization mass spectrometry (TDCIMS). Dr. Held also completed the design of a conditional sampling inlet which works with the TDCIMS to obtain size-resolved nanoparticle chemical flux. This instrument was deployed at Marshall Field Site and at the BEACHON Southern Rocky Mountain experimental site in 2008. Work continued on developing a scanning mobility particle sizer for the GV aircraft. Design of the instrument is nearing completion with the goal of flight testing the system in 2009. Finally, a hygroscopicity and volatility tandem differential mobility analyzer was designed and assembled that can measure size-resolved aerosol hygroscopic growth factors at 90% RH at user selectable residence times of 1, 2, 5 and 28 s as well as size-resolved aerosol volatility at user selectable temperatures from room temperature to 300 °C and at user selectable residence times of 0.8 and 10.5 s. This instrument operates autonomously and will be used in the 2009 OASIS field study in Barrow, AK.

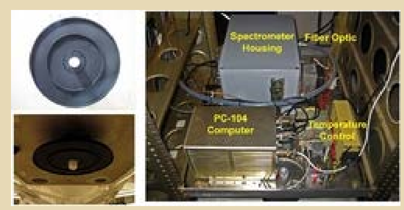


Figure 2. Zenith and nadir optics and instrument rack on the NASA DC-8 aircraft during ARCTAS.

High resolution figure

Photochemical Oxidation and Products

In the Photochemical Oxidation and Products Group (POP), instrumentation for the measurement of HOx has been present in ACD since the late 1980s when an improved chemical amplifier was developed and deployed during MLOPEX II (1991-1992) (Cantrell et al., 1984; Cantrell et al., 1996). This

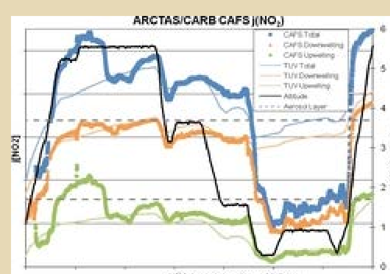


Figure 3. CAFS measured and TUV (clear sky) modeled j(NO2) during the ARCTAS/CARB deployment. The measurement/model differences are due to clouds and aerosol

instrument provided valuable information in this ground-based study. Follow-on studies saw further improvements. The presence of the NCAR chemical amplifier was instrumental in assessing the status of HOx measurements during the PRICE-I campaign in southern Germany. While useful, the chemical amplifier has a number of limitations. After MLOPEX II, Fred Eisele moved from the Georgia Institute of Technology bringing his mass spectrometric-based method for measurement of tropospheric OH and sulfuric acid (H2SO4) (Eisele et al., 1996). This enhancement to the measurement capability at NCAR also offered the opportunity to develop a new technique for quantification of peroxy radicals (HO2 and RO2). In addition, through internal and external support, the previous ground-based instrumentation was improved to allow deployment aboard aircraft platforms (Mauldin et al., 2001). Improvements continue with the development of smaller, lighter single channel OH and HO2 instruments, which were deployed during the recent NASA-sponsored ARCTAS campaign (spring & summer 2008). Currently, instrumentation for deployment on the NSF Gulfstream-V aircraft is under development, and University of Colorado graduate student, Josh McGrath, is developing a new tool to measure the reactivity of OH in the ambient troposphere. In the past, mass spectrometric-based instrumentation was used to measure DMSO and DMSO2 (DMS oxidation products, Nowak et al., 2002), HNO3 (Zondlo et al., 2003), and NH3.

layers.

High resolution figure

Atmospheric Radiation Investigations and Measurements

The Atmospheric Radiation Investigations and Measurements (ARIM) group maintains Charged-coupled device Actinic Flux Spectroradiometers (CAFS) and Scanning Actinic Flux Spectroradiometers (SAFS) to measure up and down-welling wavelength dependent actinic flux in the UV and visible wavelengths. The measurements are based on a 2π steradian hemispherical zenith and nadir optical collectors coupled with UV enhanced fiber optic bundles to small, lightweight, monolithic CCD monochromators and double monochromator with photomultiplier tube detection, respectively. The instruments have an excellent record of performance on the NCAR HIAPER GV and C-130, the NASA DC-8, WB-57 and P-3B, the NOAA WP-3D and at numerous ground stations.

The ARIM optical calibration facility is equipped with precision radiometric power supplies and multiple NIST traceable 1000W quartz tungsten halogen lamps to determine the spectral response of each instrument. Secondary lamp standards are applied in the field. Mercury line calibrations are also performed to track the wavelength accuracy.

ARCTAS

The 2008 ARCTAS (funded by NASA) mission investigated the transport and transformation of gases and aerosols affecting the Arctic. The winter phase was based in Fairbanks, AK, and explored the transport of pollution across the Arctic, with a focus on arctic haze, tropospheric ozone and surface deposited black carbon. The summer phase was based in Cold Lake, Alberta, and concentrated on the contribution of boreal fires to the atmospheric composition and climate of the Arctic region.

CAFS instruments were deployed on the NASA DC-8 aircraft for the full campaign to provide photolysis frequencies for the critical chemical constituents of the arctic. In particular, the photolysis contributes to the study of the evolution of pollution plumes and the tropospheric oxidant chemistry. Several factors specific to the arctic affected the actinic flux. The scattering in arctic haze tends to increase the flux while absorption in boreal fire emissions decreases the flux. Surface deposited black carbon also decreases the flux by reducing the surface albedo. Thus, the in situ measurements were critical to assessing the local radiation field.

Prior to the summer phase in Cold Lake, Alberta, the California Air Resources Board funded a series of flights based from the NASA Palmdale facility to study the dynamics of the transport of Asian pollution into California, local anthropogenic pollution and greenhouse gas emissions. Again, the actinic flux measurements were critical to understand the local chemistry and evolution of the emissions.

The extensive California wildfires were also studied. The actinic flux was often dramatically reduced within the fire plumes, slowing the photolysis chemistry.

The CAFS instruments were redesigned for DC-8 installation, including new instrument housings, PC-104 computers and electronics, and upgrades to the data acquisition and control software. Data coverage was near 100% for the entire mission.

return to top

Community Spectro-Polarimetric Analysis Center (CSAC)

The Community Spectro-Polarimetric Analysis Center (CSAC) Strategic Initiative was conceived to strengthen HAO's position in the rapidly growing spectro-polarimetry community and also to transfer its 30+ years of heritage and leadership in the field to the broader community. CSAC is providing support for a host of new instruments for measuring vector magnetic fields in a range of solar atmospheric layers. Its most significant contribution to the broader community is the development and distribution of a modular suite of "standardized" (numerically robust, accessible, well-documented, and portable) computer analysis and data visualization codes that will be applicable to past and future spectro-polarimetric

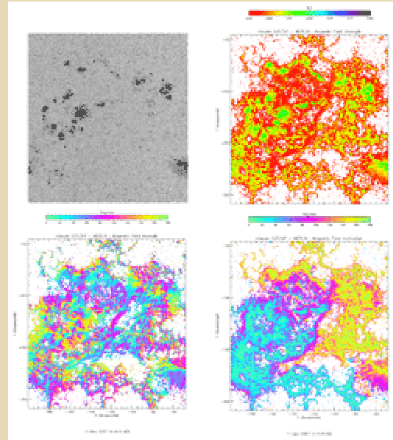


Figure 1: Results from a MERLIN inversion of Hinode data obtained on 11 December 2007 are shown. The continuum intensity showing the sunspots is at upper left. This active region shows a channel of (upper right)horizontal (inclination &126;90° lower right) magnetic flux running from lower left to upper right, corresponding to a filament in the chromosphere above. The fields are oriented roughly along the channel (field azimuth, lower left). These data suggest that the flux forming the filament results from the emergence of a rope of magnetic flux.

High resolution figure

instrumentation.

During FY08 CSAC implemented the MERLIN (Milne-Eddington gRid Inversion Network) code as the workhorse analysis tool for data from the SOT/SP instrument on board of the Japan/US/UK Hinode spacecraft. These data receive the highest visibility and usage in the solar community. MERLIN output for SOT/SP is now being released through the CSAC web client. In FY2008 CSAC also begun standardizing the next-generation analysis tool LILIA (LTE Inversion based on the Lorien Iterative Algorithm) which will allows users to derive more detailed information about physical conditions in three dimensions within the Sun's magnetic photosphere by utilizing a more realistic atmospheric model.

In addition, work has begun on development of CAZAM (CSAC AZimuth AMbiguity utility), to visualize the vector magnetic field information produced by these codes. Current User Group: The CSAC user group currently consists of researchers from twenty institutes across the world.

return to top

Instrument and experimental meteorology

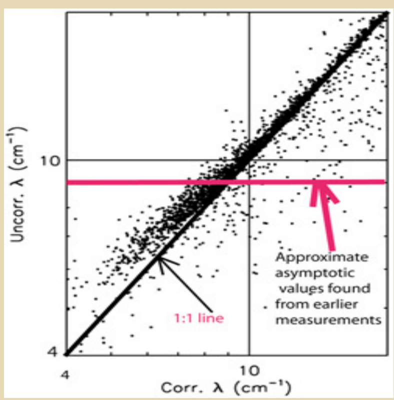


Figure: Effect of shattering of large ice on the slopes of particle size distributions derived in ice cloud layers from several field programs. The uncorrected slopes have been shown to level off at about 9 cm-1 from many field programs (y axis). By removing shattering events from particle interarrival times, corrected values of the slopes have been obtained (x axis). It is noted that in fact the slopes continue to diminish (x axis) to as low as 4 cm-1. This shows that physical processes such as collisional breakup of large aggregates as has been theorized based on the earlier measurements is not a valid explanation for the earlier results but that shattering of large ice is.

High resolution figure

A central issue in the cloud physics community is the recognition that after three decades of measurements of particle size distributions we are not yet able to accurately measure the concentrations of ice crystals in clouds. The cause of these overestimates is shattering of large particles that impact the leading edge of the probes, with the resulting fragments passing through the probe’s inlets and being sensed as real particles. Overestimates of ice concentrations lead to smaller, more slowly falling crystals that do not sublimate readily in climate models in the middle troposphere through to the lower stratosphere and in these models ice-cloud albedos are significantly overestimated. This can result in major errors in the earth’s net radiation budget that requires other non-physical model changes to correct.

In an to attempt to rectify deficiencies in the measurement of ice crystal concentrations, we wrote an article this year that has pointed to errors in past interpretations of ice-particle-growth processes as a result of the shattering issue. Measurements of particle-size distributions (PSD) over more than two decades have shown that the slopes of exponential functions used to represent ice PSD’s in deep stratiform cloud layers reach a lower limit and then remain there. By correcting ice PSD for shattering based on measurements of particle interarrival times, this article shows that the reason why this lower limit was reached was due to shattering. Large particles impacting the leading edges of 2D imaging probes shattered, producing small particles. Broad size distributions, therefore, produced anomalous (shattered) numbers of small ones, maintaining the slopes at this lower limit. By removing the artifacts, this lower limit disappears (see figure).

Our efforts to understand and characterize ice PSD’s have extended to particles 50 microns and below, an area particularly troublesome to measure. We have acquired a new type of probe that has been designed to reduce known problems with the earlier probes. The small ice detector (SID-2) probe, an open path instrument that sizes in the range 1 to 60 microns, flew on the NCAR C130 aircraft during the Ice in Clouds Experiment (ICE-L [layer]) in November and December 2007. The ICE-L research flights included repeated penetrations through mountain-induced lenticular clouds. Three other probes that were designed to remove the shattering problem were deployed in the experiment. We have developed new knowledge on the presence and amount of small ice particles in clouds from these measurements.

return to top

Development of Instrumentation for the Solar Dynamics Observatory (SDO)

The Helioseismic and Magnetic Imager (HMI) is one of the primary instruments to be flown on board NASA's Solar Dynamics Observatory spacecraft which will launch in June 2009 or January 2010. The HMI will record images of the Sun with 4096 by 4096 pixel detectors in wavelengths around the Fe spectrum line at 617.3 nm in various polarization states. These will allow us to construct images of the velocity and magnetic field over the entire solar surface with a spatial resolution of 2 arcseconds at a cadence of 90 seconds. The instrument development is led by researchers at Stanford University and the instrument is being constructed at Lockheed Martin. The construction phase was completed in 2008 and the instrument is now undergoing final testing at NASA's Goddard Space Flight Facility. Our role at HAO is to assist with the calibration of the instrument and to develop tools to convert the observations into physical parameters, such as the magnetic field strength and orientation. One challenging aspect will be to analyze the enormous volume of data in real time. In 2008, we completed the development of a computer code VFISV (Very Fast Inversion of the Stokes Vector) which can determine magnetic field parameters from polarization measurements significantly faster than any previous code. This code is now being incorporated into the HMI processing pipeline and is available for use by the community through the NCAR sponsored Community Spectro-Polarimetric Analysis Center (CSAC).

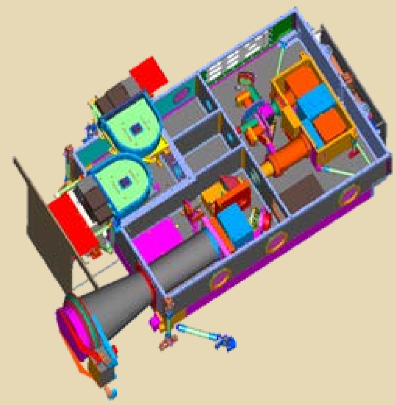


Figure 1: Engineering drawing of the HMI Instrument. Light enters through the primary lens at the lower left and is images on the CCD cameras (light green, upper left). Click high resolution image for image with part names.

High resolution figure

return to top

Fundamental Physics of Radiative Processes

Almost everything we know about the Sun comes from our interpretation of its radiative output. The study of the intensity and polarization of the radiation that we receive from solar regions allows us to infer the thermo-dynamical and magnetic properties of the emitting plasma, if we are able to formulate adequate models of the origin and transport of polarized radiation in the solar atmosphere. In the deeper and denser layers of the visible atmosphere (photosphere), plasma collisions typically ensure that, at each point in the plasma, the ratio of radiation emissivity to absorptivity (source function) is only determined by the local thermal properties of the plasma (local thermodynamic equilibrium, or LTE). Under these special conditions, the mechanisms for the production and transport of polarized radiation are very well understood, and reliable models have been available for at least half a century.

As we move outward in the solar atmosphere (chromosphere and corona), the plasma density rapidly decreases, while at the same time the radiation becomes increasingly anisotropic. Both conditions determine significant departures from LTE, as the atomic equilibrium is now driven mainly by optical pumping by the underlying photospheric radiation. These are also the regions of the solar atmosphere where the topology of the magnetic fields that permeate the heliosphere - finally interacting with the Earth's magnetosphere - takes shape. So the development of adequate models of polarized radiative transfer in these regions, in order to determine the correct magnetic boundary conditions of the heliosphere, is of primary importance for our understanding of solar drivers of Space Weather.

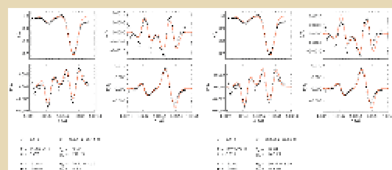


Figure 1: Convective patterns in a simulation of solar convection. Shown are (a) the radial velocity (b) the radial vorticity, (c) the horizontal divergence and (d) the temperature perturbation near the outer surface.

High resolution figure

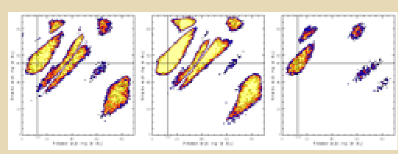


Figure 1: The ProMag Calibration linear solver uses a 4-point calibration sequence of the form $\alpha_P(i) = (i - 1)\delta_P$ and $\alpha_R(i) = (i = 1, 2, 3, 4)$, where α_P and α_R are the positions of the calibration polarizer and retarder, repectively. The figure shows contour plots of the calibration success rate (above 90%) on the (δ_P, δ_R) plane, for the three wavelengths of operation of ProMag (left to right: 587.6 nm, 635.3 nm 1083.0 nm). We see that, for ProMags�s specific design, there is a restricted set of optimal step pairs that maximize the success rate of the calibration

FY08 achievements

1. R. Casini and M. Landi Degl'Innocenti and M. Landolfi (both of the Observatorio Atrofisico di Arcetri, Italy) resumed work on the derivation of a higher-order master equation for the description of atom+radiation evolution, based on a Feynman-diagram approach. The goal is to arrive at a self-consistent treatment of partial redistribution of photon frequency in the polarized scattering of radiation from complex atoms. This is a much needed advancement in order to achieve a full understanding of the many enigmatic polarization signatures observed in the

procedure.

High resolution figure

solar spectrum. Progress in this long-term effort had come to a halt when Casini and collaborators were confronted with problems of non-conservation of probability in the atomic system. A delicate point in the derivation of the formalism is in the handling of the (unknown) initial conditions. In the past, this has been dealt with by resorting to heuristic arguments. This recent work has shown instead that it is possible to remove all references to the initial conditions in a systematic way. In the process, new terms appear in the formalism, which had not been considered before. Casini and co-workers have also initiated a systematic study of the implications of partial resummation of self-energy diagrams, through Dyson's equation, for the non-unitarity of the S-matrix in this type of radiation problems. The goal is to see if weak non-unitarity can be tolerated without compromising the correct physical picture of coherent radiation scattering.

2. Casini worked on the creation of a calibration package for the Prominence Magnetometer (ProMag). A linear solver was built that can work on a restricted set of configurations of the calibration optics, optimized for the specific optical characteristics of ProMag's polarimeter. Numerical tests have shown that the linear solver gives stable, reproducible results in the determination of the polarimeter matrix. This linear approach is going to be much faster than typical non-linear optimization schemes applied to a redundant set of calibration configurations. The code has also been tested during the laboratory characterization of ProMag, and it has been instrumental to identify design and assembly issues with the polarimeter. Because of the ensuing delay in the field deployment of ProMag at the NSO Evans Coronal Facility, unfortunately the code has not yet been tested on real solar data from that telescope.

FY09 plans*

1. To progress on the theory of the polarized line formation in the presence of coherent scattering (partial redistribution in frequency), by evaluating the newly found terms, and by assessing the significance of the identified problems of non-unitarity of the S-matrix for the description of radiation processes in a dressed atom.
2. To devise plasma diagnostic techniques exploiting the polarization effects of micro-turbulent electric fields on hydrogen lines (e.g., the role of electric-induced dichroism in optically thick plasmas), and to apply them to the joint determination of vector magnetic fields and plasma density in solar regions. (Collaborators: Rafael Manso Sainz, Arturo Lopez Ariste. Instituto de Astrofisica de Canarias.)
3. To start the rewriting of the HANLE codes for scattering polarization in the chromosphere and corona to modern software standards, within the effort of the NCAR-funded Community Spectro-polarimetric Analysis Center (CSAC) strategic initiative.

return to top

Virtual remote sensing facility

ACRESP activities build on our current satellite missions and our expertise and leadership in satellite remote sensing science, Earth System modeling, and data assimilation. Recent advances in tropospheric remote sensing have opened the way for measuring, monitoring, and understanding processes that lead to atmospheric pollution. As part of an integrated observing strategy, satellite measurements provide a context for localized observations and help to extend these observations to continental and global scales. The challenge for future space-borne missions will be directly accessing the local scale and facilitating the use of remotely sensed information for improving local- and regional-scale air quality (AQ) forecasts. Achieving this goal will provide important societal dividends for public health, for policy applications related to managing national AQ, and for assessing the impact of daily human activity on the distributions of important trace gases and aerosols and their short-timescale variability - known as "chemical weather" - as well as on climate.

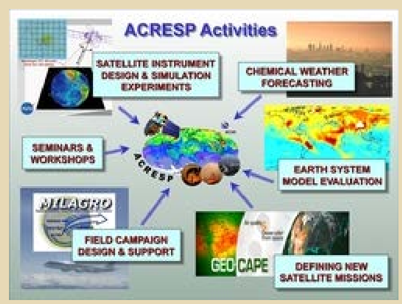


Figure 1. ACRESP Activities are grouped in two main areas: Satellite instrument design and future mission planning for atmospheric composition and air quality, and chemical weather forecasting, satellite data assimilation and field campaign support.

High resolution figure

Satellite Instrument Design:

If a satellite mission related to atmospheric composition and air quality is to become a reality within the next decade, the atmospheric chemistry community will need to establish clear scientific motivation for the new measurements. For this, there is considerable interest in using chemical observing system simulation experiment (OSSE) studies to help define quantitative measurement requirements for satellite missions and to evaluate the expected performance of proposed observing strategies. These experiments will hopefully provide a practical way of defining a traceability matrix to map science requirements through measurement requirements onto instrument requirements.

OSSEs must be driven by well-defined scientific questions and the experiment formulation constructed accordingly. We have completed an example OSSE motivated by the desire to measure the distribution and time evolution of carbon monoxide in the lower-most troposphere for air quality applications using candidate satellite multispectral measurements in the

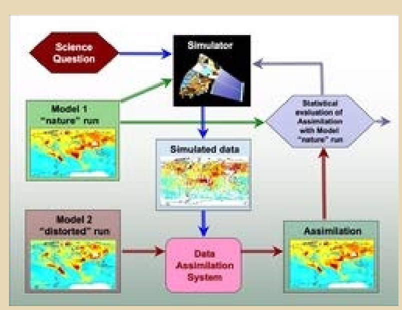


Figure 2. The OSSE framework comprises the following key elements: (1) a science-driven

thermal and near infrared.

Future Satellite Missions:

The ACRESP group is involved in the planning of The Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission that has been recommended for launch in the 2013-2016 time frame by the National Research Council. The mission's purpose is to gather science that identifies human versus natural sources of aerosols and ozone precursors, tracks air pollution transport, and studies the dynamics of coastal ecosystems, river plumes and tidal fronts. Continuous observation from GEO-CAPE's geostationary platform will allow for more adequate monitoring of population exposure and the ability to relate pollutant concentrations to their sources or transport, thereby providing data to improve air quality forecasts.

ACRESP is a partner on a carbon monoxide instrument, the Compact Imaging Spectroradiometer (CISR), that builds on MOPITT experience and that has been specifically designed for geostationary deployment. CISR is candidate technology for GEO-CAPE and is currently under development as part of the NASA Instrument Incubator Program (IIP).

A longer-term goal of the ACRESP OSSE activity is to develop a community facility at NCAR. This would be used by researchers from the universities and agency centers for building and testing instrument simulators as part of the proposal and design of the next generation of satellite instruments.

Air Quality "Chemical Weather" Forecasting:

The Chemical Weather: Local, regional, and global distributions of important trace gases and aerosols and their variation on time scales of minutes to hours to days, particularly in light of their various impacts, such as on human health, ecosystems, the meteorological weather, and climate. (Lawrence et al., Environ. Chem. 2005, 2, 6-8, doi:10.1071/EN05014)

The ACRESP Program is developing an air quality "chemical weather" forecasting capability based on existing satellite observations. Chemical weather is a priority research theme for ESSL. The characterization of global and regional scale air quality involves field campaigns, chemical transport modeling, and remote sensing. The goal is a scientific and observing framework analogous to that used for weather forecasting with a model assimilation of observations from satellite, aircraft and surface platforms to derive a 4-dimensional view (3 spatial plus temporal) of the physical state of the atmosphere.

This analysis will be used in air quality basic research: the quantification of emissions of ozone and aerosol precursors and the examination of the long-range transport of pollutants extending from regional to global scales. The general tools and methodologies developed will also be used for studies examining the connections between climate change and regional air quality, and the roles of anthropogenic and natural processes in changing atmospheric composition. The predictive capability will provide a powerful tool to support field campaign activities such as those involving HAIPER chemical instrumentation. There also exists the possibility of demonstrating schemes for future operational applications elsewhere in the community related to air quality management and health advisories.

requirement for a chemical species observation, (2) a satellite instrument simulator and observing strategy that might be capable of making a useful measurement, (3) a simulated data retrieval of the species with "nature" defined by an appropriate chemical transport Model 1, (4) a forecast of the species distribution using an assimilation of the retrieval in the "distorted" model 2, and (5) a quantitative assessment of the value of the measurement.

High resolution figure

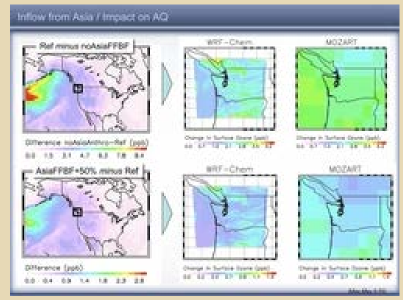


Figure 3. WRF-Chem and MOZART simulated change in surface ozone (Maximum change for May 3-10) over Washington State with changes in Asian emissions.

High resolution figure

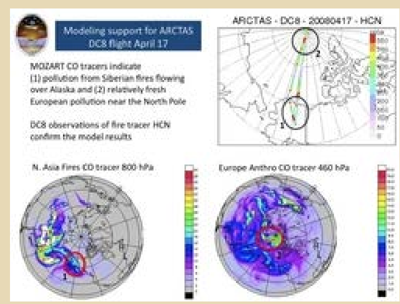


Figure 4. An example of the success of the ARCTAS chemical forecasts in predicting pollution plumes subsequently confirmed by aircraft measurements.

High resolution figure

Increasingly, there is interest in accessing finer spatial scales to quantify both the wider impact of local pollution sources such as wildfires and mega-cities and assessing the contribution of transported pollution. We are conducting a chemical weather case study for the MIRAGE and INTEX-B spring 2006 period. This involves global model simulations using analyzed meteorology and the best possible chemical sources with fire emissions based on satellite fire products. A nested regional model simulation concentrating on Mexico and parts of the INTEX-B Pacific region are also being performed using WRF-Chem.

One of the open questions in AQ policy management is to what degree Asian industrialization and the associated transpacific transport of pollution could hinder improvements in AQ in the US from domestic emission controls. We have used the data set collected during the April/May 2006 phase of INTEX-B to look into the impacts of the long-range transport of pollutants across the Pacific on the U.S. West Coast. The study used global model simulations with altered Asian emission scenarios as boundary conditions for WRF-Chem simulations to examine the changes in concentration fields in both the global and the regional model. In another study, we focused on a direct application to AQ and quantified the impact of the fires in California in fall 2007 on regional air quality and especially on surface ozone by analyzing surface observations of ozone concentrations together with model simulations. It was found that the frequency of violations in the public health standards nearly tripled because of the fires.

Assimilation of available satellite data sets such as Terra/Aqua/MODIS aerosol optical depth, ENVISAT/SCIAMACHY and Aura/OMI NO2, OMI O3 tropospheric column, and Terra/MOPITT, Aura/TES, and METOP/IASI CO and O3 are being explored. This exercise will impose constraints on the modeled chemical fields and can be evaluated by compaing with actual field measurements. We have been working on a pre-cursor study with idealized satellite retrievals to examine the benefits and shortcomings in the assimilation of chemically active species. Largest improvements in predicting surface ozone were found when O3 or also NO2 fields throughout the atmosphere are available with high temporal resolution (3hrs) and for the online inversion of NO emission. However, the latter had the tendency for increasing biases in outflow regions. Work is ongoing on the assimilation of concentrations fields on a daily basis.

These projects involve the collaborative efforts between ACD and the DART initiative in IMAGe. We will also aim to foster collaboration with other efforts in the development of chemical weather forecast capability both within U.S. Universities, NOAA and NASA, and internationally, particularly with the GEMS project (http://www.ecmwf.int/research/EU_projects/GEMS/) in Europe.

Field Campaign Support and Data Analysis:

ACRESP supported the NASA Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) field campaign with a combination of model simulations and satellite observations. Measurements were made from the NASA DC8 aircraft in the Spring and Summer of 2008, and were coordinated with several other field experiments as part of the International Polar Year (IPY). The Spring Phase of ARCTAS was April 1-19, based in Fairbanks, AK, and the Summer Phase was in Cold Lake, Alberta, June 26-July 14. In addition, several DC8 flights were made from Palmdale, CA, June 18-24, in coordination with the California Air Resources Board (CARB).

Retrievals of carbon monoxide (CO) from observations by Terra/MOPITT were produced in near-real-time. Chemical forecasts were produced using Ensemble Kalman Filter Data Assimilation of meteorological observations, MOPITT CO, and MODIS aerosol optical depth (AOD) with the NCAR Community Atmosphere Model with Chemistry (CAM-Chem). The data assimilation was performed in the Data Assimilation Research Testbed (DART) framework. Forecasts were also run with MOZART-4 driven by NCEP/GFS meteorology. The satellite retrievals and chemical forecasts were used to assist in the planning of the DC8 flights during the campaign by identifying features of interest for the aircraft to sample, such as pollution plumes from fires in Siberia and Canada.

Analysis of the ARCTAS measurements will continue in the coming year using a combination of satellite and model simulations. The assimilation of MOPITT CO and MODIS AOD in CAM-Chem/DART will be refined and evaluated with the aircraft observations, and, in turn, used to assist in the interpretation of the observations. Discrepancies between the model and observations will be used to improve the model and the emissions used to drive the model.

return to top

Analysis of data from TIMED and COSMIC

HAO conducts data analysis activities for several space-based observing missions, and uses the results to validate and improve models of the upper atmosphere and magnetosphere. One of the most important new activities is analysis of ionospheric results from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) mission, also known as FORMOSAT-3, which is a partnership between the U.S. and Taiwan and is managed by the University Corporation for Atmospheric Research.

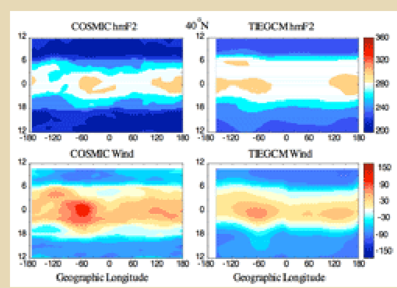


Figure 1: Comparison of longitudinal variations of the F_2 layer peak height in km (top) and magnetic meridional winds in m/s, positive equatorward (bottom), as a function of local time at 40° N during winter. Left: measurements by the COSMIC mission. Right: model results from the NCAR TIE-GCM.

High resolution figure

HAO scientists and colleagues at National Central University in Taiwan have conducted several studies using data from COSMIC in the past year. Initial work during the first year of the mission focused on data validation and climatology, but during the second year, with the constellation fully deployed and dispersed, it has been possible to explore ionospheric phenomena, and to measure other quantities such as thermospheric neutral winds near 250 km altitude. This is done by measuring the effect of winds on the height of the maximum of the main ionospheric layer, the F2 peak. A study by Luan and Solomon [2008] compared peak heights and inferred meridional winds measured by COSMIC to simulations by the NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM), demonstrating the longitudinal variation of the wind pattern, controlled by the declination of the geomagnetic field (figure 1).

Work by Burns et al. [2008] revealed the global connections of a once-forgotten feature of the southern ionosphere, the tendency of the late evening ionosphere to increase its density over mid-day levels during summer originally observed by the Halley Bay ionosonde and hence called the Weddell Sea anomaly. With global measurements by COSMIC (figure 2), this feature is seen to be a large region near the Antarctic peninsula, and its formation appears to be connected to the better-known equatorial ionization anomaly. Thermosphere-ionosphere models cannot yet reproduce this feature, even with magnetospheric coupling, so what it is telling us about the extended nature of the ionosphere-plasmasphere interaction remains a curious challenge for ionospheric physics.

COSMIC data also have a key function in mapping the longitudinal variation of the equatorial ionization anomaly, which is thought to be influenced by the eastward propagating zonal wavenumber-3 diurnal tide that is excited by latent heat release in the tropical troposphere [Hagan et al., 2007]. Work by Lin et al. [2007] in collaboration with NCAR scientists examined the structure of this effect using COSMIC data during September equinox. The global three-dimensional ionospheric electron density shows a prominent four-peaked wave-like longitudinal enhancement, and the vertical electron density structures reveal that the feature exists mainly above 250 km altitude (figure 3).

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Luan, X., and S. C. Solomon (2008), Meridional winds derived from COSMIC radio occultation measurements in winter, *J. Geophys. Res.*, **113**, A08302, doi:10.1029/2008JA013089.

return to top

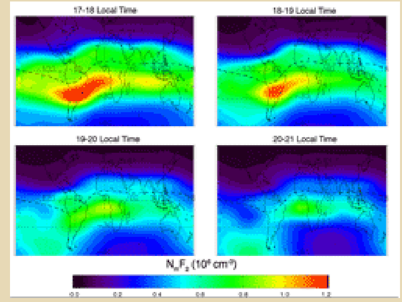

Figure 2: Development of the Weddell Sea ionization anomaly during southern hemisphere summer as seen in these constant-local-time plots of COSMIC data. The peak density of the F_2 region of the ionosphere exhibits a possible connection to the equatorial ionization anomaly.

High resolution figure

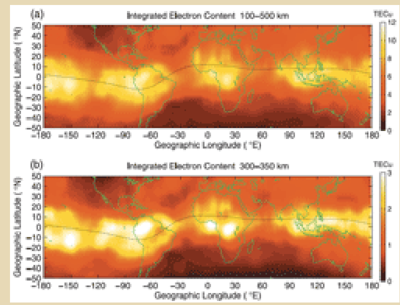

Figure 3: Ionospheric electron content integrated between (a) 100-500 km altitude range and (b) 300-350 km altitude range of the COSMIC electron density observation at 2000-2200 local time during September equinox, 2006. 1 TECu = 10^{12} electrons/cm^2.

High resolution figure

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- Cantrell, Christopher (Chris)
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- Deeter, Merritt
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- Emmons, Louisa
- Flocke, Frank
- Francis, Gene
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- Garcia, Rolando
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- Gille, John
- Greenberg, Jim
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- Hall, Samuel
- Hall, William (Bill)
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- Hannigan, James
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- Hartsough, Craig
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- Tang, Yongxin
- Tie, Xuexi
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- Tilmes, Simone
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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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Table of Contents

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BEACHON: **B**io-hydro-atmosphere interactions of **E**nergy, **A**erosols, **C**arbon, **H**2O, **O**rganics & **N**itrogen

BGS: BioGeoSciences

GW: Gravity Waves

Incubator: Ideas being developed

THORPEX: THe Observing-System Research and Predictability EXperiment

UTLS: Upper Troposphere and Lower Stratosphere

WS: Water Systems

WCI: Weather-Climate Interface

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DAVID AHIJEVYCH

2008 Publications

Parker, M. D., D. A. Ahijevych, 2007: Convective episodes in the east-central United States. Mon. Wea. Rev., 135, 3707-3727, doi: 10.1175/2007MWR2098.1.2

ABSTRACT

Nine years of composited radar data are investigated to assess the presence of organized convective episodes in the east-central United States. In the eastern United States, the afternoon maximum in thunderstorms is ubiquitous over land. However, after removing this principal diurnal peak from the radar data, the presence and motion of organized convective systems becomes apparent in both temporally averaged fields and in the statistics of convective episodes identified by an objective algorithm. Convective echoes are diurnally maximized over the Appalachian chain, and are repeatedly observed to move toward the east. Partly as a result of this, the daily maximum in storms is delayed over the Piedmont and coastal plain relative to the Appalachian Mountains and the Atlantic coast. During the 9 yr studied, the objective algorithm identified 2128 total convective episodes (236 yr-1), with several recurring behaviors. Many systems developed over the elevated terrain during the afternoon and moved eastward, often to the coastline and even offshore. In addition, numerous systems formed to the west of the Appalachian Mountains and moved into and across the eastern U.S. study domain. In particular, many nocturnal convective systems from the central United States entered the western side of the study domain, frequently arriving at the eastern mountains around the next day�s afternoon maximum in storm frequency. A fraction of such well-timed systems succeeded in crossing the Appalachians and continuing across the Piedmont and coastal plain. Convective episodes were most frequent during the high-instability, low-shear months of summer, which dominate the year-round statistics. Even so, an important result is that the episodes still occurred almost exclusively in above-average vertical wind shear. Despite the overall dominance of the diurnal cycle, the data show that adequate shear in the region frequently leads to long-lived convective episodes with mesoscale organization.

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Table of Contents

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CGD 2008 PROFILES IN SCIENCE: DR. CASPAR AMMANN

Summary of achievements

Caspar Ammann

Caspar Ammann's research centers around the high-resolution climate of past centuries and millennia and how this information can help to understand what elements of future climate might be predictable as well as what potential environmental and ecological impacts are to be anticipated given various story lines of climate change scenarios.

Better natural climate forcing datasets are necessary for more realistic simulations of past centuries and millennia and for a quantitatively more thorough assessment of the cause of natural variability. The significantly increased number of ice core records from the polar ice sheets offer the opportunity of more thorough statistical description of the volcanic forcing, going from a single series to a description where every eruption is provided with a probability of that event having happened in the first place and where the magnitude can be described by a distribution. Such a probabilistic formulation of the forcings is scientifically consistent with the underlying goal of quantifying the link between the forcing and climate.

Climate model studies that investigate the effects of externally forced climate are being performed. Process studies of the effects of low and high latitude volcanic eruptions as well as simulations of solar irradiance/activity changes offer insight into the models ensemble response of the climate system. In collaboration with Post-Doc David Schneider, these simulations are also serving an interdisciplinary Arctic research collaborative that attempts to synthesize the climate record gained primarily from high-resolution lake records. Collaborations across ESSL are used to identify what model configurations are necessary to capture the necessary processes. Using a suite of simulations with increasing model complexity from the standard CCSM towards a more complete representation of the climate system of WACCM (vertical extent, coupled chemistry), climate response to the repeated solar cycle and to the injection of volcanic aerosol are investigated. Other simulations with the coupled CCSM-3 investigate the cause of global patterns of climate during Medieval times as well as the transition into the Little Ice Age. No coupled GCM has so far reproduced the full structure of climate anomalies that can be found in the proxy record. In collaboration with Nicholas Graham (HRC & Scripps) and a team led by Kim Cobb (Georgia Tech), simulations are being performed that focus on the tropical circulation and its possible response to radiative forcing through mid-latitude teleconnections.

Extending the instrumental record through the development of improved high resolution climate reconstructions is crucial if we are to understand the role of forced changes in climate at regional scales. A fundamental problem in identifying what part of climate variability is externally forced arises from the large uncertainty in existing reconstruction methods and series. Caspar's collaborations with a multi-institution team of paleoclimatologists and statisticians is developing a new way of reconstructing climate using Bayesian Hierarchical Models as the framework (http://www.cgd.ucar.edu/ccr/ammann/CMG/). This allows for a more complete exploitation of the available climate record through inclusion of records with extremely different characteristics as well as explicit physical constraints. Addtionally, the community program of the Paleoclimate Reconstruction (PR) Challenge (http://www.pages.unibe.ch/science/prchallenge/index.html) is setup to test the accuracy of regional reconstructions and to guide the paleo reconstruction communities in developing more adequate forward models for their proxies. Using climate model output, a systematic intercomparison of the existing reconstruction approaches is performed and a double-blind setup will allow the community to identify where the next efforts need to be put in.

Publications

C.M. Ammann and E. Wahl, 2007: The importance of the geophysical context in statistical evaluations of climate reconstruction procedures. Climate Change, 85, 71-88 doi:10.1007/s10584-007-9276-x.

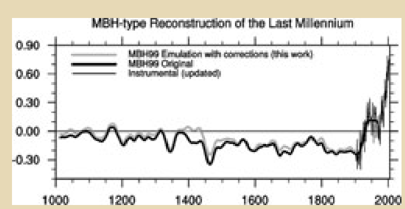


Figure 1.

Abstract: A portion of the debate about climate reconstructions of the past millennium, and in particular about the well-known Mann-Bradley-Hughes ("MBH" 1998, 1999) reconstructions, has become disconnected from the goal of understanding natural climate variability. Here, we reflect on what can be learned from recent scientific exchanges and identify important challenges that remain to be addressed openly and productively by the community. One challenge arises from the real, underlying trend in temperatures during the instrumental period. This trend can affect regression-based reconstruction performance in cases where the calibration period does not appropriately cover the range of conditions encountered during the reconstruction. However, because it is tied to a unique spatial pattern driven by change in radiative balance, the trend cannot simply be

removed in the method of climate field reconstruction used by MBH on the statistical argument of preserving degrees of freedom. More appropriately, the influence from the trend can be taken into account in some methods of significance testing. We illustrate these considerations as they apply to the MBH reconstruction and show that it remains robust back to AD 1450, and given other empirical information also back to AD 1000. However, there is now a need to move beyond hemispheric average temperatures and to focus instead on resolving climate variability at the socially more relevant regional scale.

High resolution figure

Figure caption: Correction of MBH99: our emulation of the real world proxy-based MBH99 reconstruction containing full-period proxy PC-centering corrections and omission of the Gaspe-series during 1400-1449 (*solid grey line*) is compared to the original MBH99 reconstruction (*solid black line*).

E. Wahl and C.M. Ammann, 2007: Robustness of the Mann, Bradley, Hughes reconstruction of Northern Hemisphere surface temperatures: Examination of criticisms based on the nature and processing of proxy climate evidence. Climate Change, doi:10.1007/s10584-006-9105-7.

Abstract: The Mann et al. (1998) Northern Hemisphere annual temperature reconstruction over 1400-1980 is examined in light of recent criticisms concerning the nature and processing of included climate proxy data. A systematic sequence of analyses is presented that examine issues concerning the proxy evidence, utilizing both indirect analyses via exclusion of proxies and processing steps subject to criticism, and direct analyses of principal component (PC) processing methods in question. Altogether new reconstructions over 1400-1980 are developed in both the indirect and direct analyses, which demonstrate that the Mann et al. reconstruction is robust against the proxy-based criticisms addressed. In particular, reconstructed hemispheric temperatures are demonstrated to be largely unaffected by the use or non-use of PCs to summarize proxy evidence from the data-rich North American region. When proxy PCs are employed, neither the time period used to "center" the data before PC calculation nor the way the PC calculations are performed significantly affects the results, as long as the full extent of the climate information actually in the proxy data is represented by the PC time series. Clear convergence of the resulting climate reconstructions is a strong indicator for achieving this criterion. Also, recent "corrections" to the Mann et al. reconstruction that suggest 15th century temperatures could have been as high as those of the late-20th century are shown to be without statistical and climatological merit. Our examination does suggest that a slight modification to the original Mann et al. reconstruction is justifiable for the first half of the 15th century (~+0.05�), which leaves entirely unaltered the primary conclusion of Mann et al. (as well as many other reconstructions) that both the 20th century upward trend and high late-20th century hemispheric surface temperatures are anomalous over at least the last 600 years. Our results are also used to evaluate the separate criticism of reduced amplitude in the Mann et al. reconstructions over significant portions of 1400-1900, in relation to some other climate reconstructions and model-based examinations. We find that, from the perspective of the proxy data themselves, such losses probably exist, but they may be smaller than those reported in other recent work.

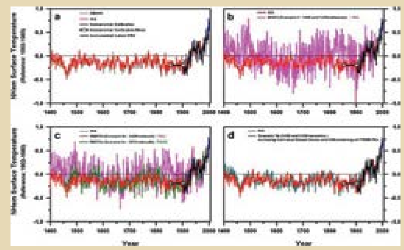


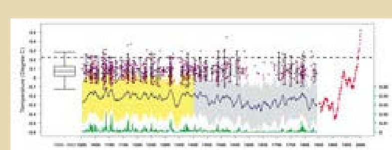
Figure 2.

High resolution figure

Figure caption: Summary of results. Panel (a) compares the Wahl-Ammann (WA) emulation of the MBH reconstruction (red) with the original (grey). Panel (b) compares the WA reconstruction (red) with an emulation of the MM03 *Energy and Environment* reconstruction (pink). The MM03 emulation for 1400-1449 uses the MBH 1400 proxy network as adjusted by MM03; the MM03 emulation for 1450-1980 uses the MBH 1450 proxy network as adjusted by MM03. Panel (c) compares the WA reconstruction (red) with emulations of the MM05b *Energy and Environment* reconstruction. The emulations directly exclude the bristlecone/foxtail pine records from calculation of PC summaries of N. American tree ring data (which are indirectly excluded by MM05a/b, cf. "Results" in text). The MM05b emulation using the 1400 proxy network is continued through 1980 (pink), as is the MM05b emulation using the 1450 proxy network (green). Panel (d) compares the WA reconstruction (red) with a reconstruction based on exclusion of the Gaspe record over 1400-1449 and use of the MM centering convention for forming PC summaries of North American tree ring data (dark magenta). Pink-coded reconstructions show validation failure according to critieria described in Section 2.3. Zero reference level in each panel is mean value for 1902-1980 instrumental data. Instrumental data in all panels are indicated as follows. Instrumental data used in calibration and verification are shown in black: annual data for full Northern Hemisphere grid over 1902-1993, and the mean of the spatially-restricted Northern Hemisphere grid over 1854-1901 (Jones and Briffa, 1992, updated). Instrumental data for 1902-2005 from Jones and Moberg (2003, updated) are also plotted, in dark blue.

D. Nychka and C. Ammann, 2007: The 'hockey stick' and the 1990s: a statistical perspective on reconstructing hemispheric temperatures. Tellus, doi:10.1111/j.1600-0870.2007.00270.x.

Introduction: The short instrumental record of about 100-150 yr forces us to use proxy indicators to study climate over long timescales. The climate information in these indirect data is embedded in considerable noise, and the past temperature reconstructions are therefore full of uncertainty, which blurs the understanding of the temperature evolution. To date, the characterization and quantification of uncertainty have not been a high priority in reconstruction procedures. Here we propose a new statistical methodology to explicitly account for three types of uncertainties in the reconstruction process. Via ensemble reconstruction, we



directly obtain the distribution of decadal maximum as well as annual maximum. Our method is an integration of linear regression, bootstrapping and cross-validation techniques, and it (1) accounts for the effects of temporal correlation of temperature; (2) identifies the variability of the estimated statistical model and (3) adjusts the effects of potential overfitting. We apply our method to the Northern Hemisphere (NH) average temperature reconstruction. Our results indicate that the recent decadal temperature increase is rapidly overwhelming previous maxima, even with uncertainty taken into account, and the last decade is highly likely to be the warmest in the last millennium.

Figure 3.

High resolution figure

Figure caption: Summary of 1000 temperature ensembles: the decadal average of mean temperature over the 1000 ensembles (blue curve) with its 95% confidence region (yellow and grey band); decadal maxima from 1000 individual ensembles (purple dots) and the chance of each year corresponding to the decadal maximum (green curve scaled by the green label); the upper bound of the 95% confidence interval of the decadal maxima (dashed line) and decadal instrumental temperatures (red asterisks). The small box plots overlapped with purple dots show the distribution of decadal maxima in small groups with each group containing about 20 yr, and the leftmost big box plot shows the distribution of all the decadal maxima. The decadal average of mean temperature before 1400 (the blue curve embedded in the yellow band) and its 95% confidence region (yellow band) can be compared to the corresponding section of Fig. 3(a) in MBH99.

Mann, M.E., S. Rutherford, E. Wahl, and C. Ammann, 2007: Robustness of proxy-based climate field reconstruction methods Journal of Geophysical Research, 112, doi:10.1029/2006JD008272.

Abstract: Smerdon and Kaplan (hereafter SK07) have independently identified a technical issue in the original Mann et al. (2005, hereafter MRWA05) procedure that was first identified and brought to our attention by F. Zwiers and T. Lee (2006, personal communication) and since corrected (Mann et al. 2007). As we discuss below, this has no significant consequences for the results or conclusions of MRWA05 or related studies. In more recent work, Mann et al. (2007) recover the results and conclusions of MRWA05 using an implementation of the "regularized expectation maximization (RegEM)" procedure that does not suffer from the technical issue SK07 note.

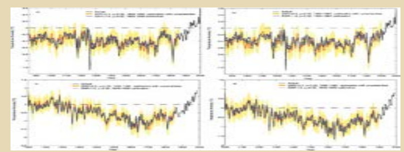


Figure 4

High resolution figure

Figure caption: Comparison of NH mean reconstructions using both NCAR CSM 1.4 and GKSS "Erik" simulations, based on network A, "red" proxy noise with ρ = 0.32, and two different SNR levels (0.4 and 1.0) (Table 1, experiments p-s for NCAR; experiments t-w for GKSS). (a) NCAR long (1856-1980) calibration, (b) NCAR short (1900-1980) calibration, (c) GKSS long (1856-1980) calibration, and (d) GKSS short (1900-1980) calibration. Uncertainties diagnosed from experiment s for NCAR and experiment w for GKSS.

Mann, M. E., S. Rutherford, E. Wahl, and C. Ammann, 2007: Comments on "Testing the Fidelity of Methods Used in Proxy-Based Reconstructions of Past Climate": The role of the standardization interval - Reply. Journal of Climate, doi:10.1175/2007JCLI1894.1

Abstract: We present results from continued investigations into the fidelity of covariance-based climate field reconstruction (CFR) approaches used in proxy-based climate reconstruction. Our experiments employ synthetic "pseudoproxy" data derived from simulations of forced climate changes over the past millennium. Using networks of these pseudoproxy data, we investigate the sensitivity of CFR performance to signal-to-noise ratios, the noise spectrum, the spatial sampling of pseudoproxy locations, the statistical representation of predictors used, and the diagnostic used to quantify reconstruction skill. Our results reinforce previous conclusions that CFR methods, correctly implemented and applied to suitable networks of proxy data, should yield reliable reconstructions of past climate histories within estimated uncertainties. Our results also demonstrate the deleterious impact of a linear detrending procedure performed recently in certain CFR studies and illustrate flaws in some previously proposed metrics of reconstruction skill.

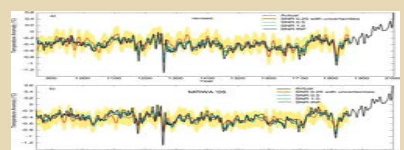


Figure 5.

High resolution figure

Figure caption: Reconstruction of Northern Hemisphere mean temperature based on the RegEM CFR approach applied using "pseudoproxy" networks diagnosed from simulation of the National Center for Atmospheric Research (NCAR) Climate System Model (CSM) 1.4 simulation as in MRWA05. An 1856-1980 calibration interval is used. (a) Employing TTLS for regularization as in Mann et al. (2007), with both simulated target climate and pseudoproxy-reconstructed time series standardized over 1856-1980. (b) Results from MRWA05 (correct areal weighting has been used, as discussed in the text). Self-consistent uncertainties in the reconstructions are estimated from the unresolved residual variance during an 1856-1899 "validation" interval, based on a short (1900-1980) calibration. Actual model NH series is shown for comparison (black). All series are decadally smoothed as in MRWA05.

Jones P.D. and 29 colleagues: High-resolution paleoclimatology of the last millennium: a review of current status and future prospects. The Holocene.

Abstract: This review of late-Holocene palaeoclimatology represents the results from a PAGES/CLIVAR Intersection Panel meeting that took place in June 2006. The review is in three parts: the principal high-resolution proxy disciplines (trees, corals, ice cores and documentary evidence), emphasizing current issues in their use for climate reconstruction; the various approaches that have been adopted to combine multiple climate proxy records to provide estimates of past annual-to-decadal timescale Northern Hemisphere surface temperatures and other climate variables, such as large-scale circulation indices; and the forcing histories used in climate model simulations of the past millennium. We discuss the need to develop a framework through which current and new approaches to interpreting these proxy data may be rigorously assessed using pseudo-proxies derived from climate model runs, where the 'answer' is known. The article concludes with a list of recommendations.

First, more raw proxy data are required from the diverse disciplines and from more locations, as well as replication, for all proxy sources, of the basic raw measurements to improve absolute dating, and to better distinguish the proxy climate signal from noise. Second, more effort is required to improve the understanding of what individual proxies respond to, supported by more site measurements and process studies. These activities should also be mindful of the correlation structure of instrumental data, indicating which adjacent proxy records ought to be in agreement and which not. Third, large-scale climate reconstructions should be attempted using a wide variety of techniques, emphasizing those for which quantified errors can be estimated at specified timescales. Fourth, a greater use of climate model simulations is needed to guide the choice of reconstruction techniques (the pseudo-proxy concept) and possibly help determine where, given limited resources, future sampling should be concentrated.

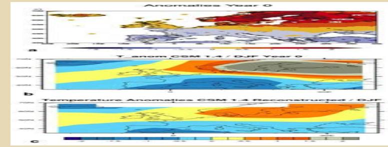


Figure 6.

High resolution figure

Figure caption: Example of field reconstruction performance: composite winter temperature anomalies for Europe after 15 tropical volcanic events over the past 500 years (cf. Fischer et al., 2007). (a) Anomalies reconstructed from intrumental, documentary, and proxy records using a truncated-EOF method (multivariate PC regression, Luterbacher et al., 2004). (b) Anomalies from NCAR-CSM model (Ammann et al., 2007) over same period. (c) Pseudo-proxy reconstructed anomalies in same model context as (b), using the Wahl and Ammann (2007) emulation of the MBH98 truncated-EOF inverse regression method.

Batista D., P. Naveau, C. Ammann, and C. Jegat: Extracting common pulse-like forcing factors in multivariate climatic time series. Nonlin. Processes Geophys., in prep.

Abstract: To understand the full range of natural climate variability, it is important to attribute past climate variations to particular forcing factors. In this paper, our main focus is to introduce an automatic procedure to estimate the impact of strong but short-lived perturbations from large explosive volcanic eruptions on climate. An extraction algorithm that handles multivariate time series with a common but unknown forcing is presented. This statistical procedure is based on a multivariate multi-state space model and it can provide an accurate estimator of the timing and duration of the climate response to an eruption from a set of different climatic time series. It not only allows for a more objective estimation of its associated peak amplitude and the subsequent time evolution of the signal, but at the same time it provides a measure of confidence through the posterior probability for each pulse-like event. The flexibility, robustness and limitations of our approach are discussed by applying our method to simulated and real multivariate time series.

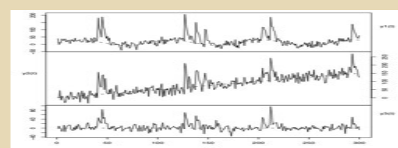


Figure 7.

High resolution figure

Figure caption: Three simulated time series with different trends and the common pulse-like time series displayed in Figure 2.

Gao C., A. Robock, and C. Ammann, 2008: Volcanic forcing of climate over the past 1500 years: An improved ice-core-based index for climate models. J. Geophys. Res., in press.

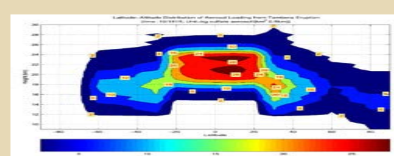


Figure 8.

High resolution figure

Abstract: Understanding natural causes of climate change is vital to evaluate the relative impacts of human pollution and land surface modification on climate. We have investigated one of the most important natural causes of climate change, volcanic eruptions, by using 54 ice core records from both the Arctic and Antarctica. Our recently collected suite of ice core data, more than double the number of cores ever used before, reduces errors inherent in reconstructions based on a single or small number of cores, which enables us to obtain much higher accuracy in both detection of events and quantification of the radiative effects. We extracted volcanic deposition signals from each ice core record by applying a high-pass LOESS filter to the time series and examining peaks that exceed twice the 31-year running median absolute deviation. We then studied the spatial pattern of volcanic sulfate deposition on Greenland and Antarctica, and combined this knowledge with a new understanding of stratospheric transport of volcanic aerosols to produce a forcing data set as a function of month, latitude, and altitude for the past 1500 years. We estimated the uncertainties associated with the choice of volcanic signal extraction criteria, ice-core sulfate deposition to stratospheric loading calibration factor, and the season for the eruptions without a recorded month. We forced an energy

balance climate model with this new volcanic forcing data set, together with solar and anthropogenic forcing, to simulate the large scale temperature response. The results agree well with instrumental observations for the past 150 years and with proxy records for the entire period. Through better characterization of the natural causes of climate change, this new data set will lead to improved prediction of anthropogenic impacts on climate. The new data set of stratospheric sulfate injections from volcanic eruptions for the past 1500 years, as a function of latitude, altitude, and month, is available for download in a format suitable for forcing general circulation models of the climate system.

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PHOTOCHEMICAL OXIDATION AND PRODUCTS (POP)

Group Members

Chris Cantrell (Group Leader)
Lee Mauldin
Rebecca Anderson
Ed Kosciuch
Fred Eisele

Figure 1. View of HOx instrumentation in the cabin of the NASA DC-8 as configured during ARCTAS (2008).

High resolution figure

Figure 2. Inlet configuration for HOx instrumentation on the NASA DC-8 during ARCTAS (2008). The top inlet is for peroxy radicals, and the bottom one is for OH and sulfuric acid. The small stainless tubes provide air inlets that are used to generate ions that are exposed to the sampled air.

High resolution figure

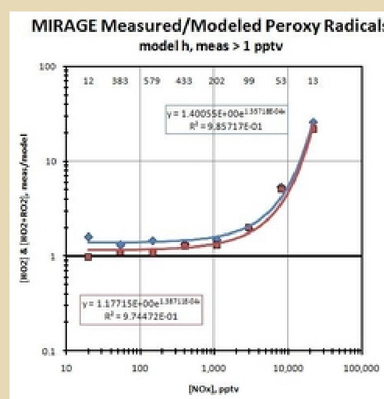

Figure 3. Ratio of measurement to constrained model calculation for HO2 and HO2+RO2 versus observed NOx during

Development and Deployment of HOx Instrumentation in ACD

Instrumentation for the measurement of HOx has been present in ACD since the late 1980s when an improved chemical amplifier was developed and deployed during MLOPEX II (1991-1992) (Cantrell et al., 1984; Cantrell et al., 1996). This instrument provided valuable information in this ground-based study. Follow-on studies saw further improvements. The presence of the NCAR chemical amplifier was instrumental in assessing the status of HOx measurements during the PRICE-I campaign in southern Germany. While useful, the chemical amplifier has a number of limitations. After MLOPEX II, Fred Eisele moved from the Georgia Institute of Technology bringing his mass spectrometric-based method for measurement of tropospheric OH and sulfuric acid (H_2SO_4) (Eisele et al., 1996). This enhancement to the measurement capability at NCAR also offered the opportunity to develop a new technique for quantification of peroxy radicals (HO_2 and RO_2). In addition, through internal and external support, the previous ground-based instrumentation was improved to allow deployment aboard aircraft platforms (Mauldin et al., 2001). Improvements continue with the development of smaller, lighter single channel OH and HO_2 instruments, which were deployed during the recent NASA-sponsored ARCTAS campaign (spring & summer 2008). Currently, instrumentation for deployment on the NSF Gulfstream-V aircraft is under development, and University of Colorado graduate student, Josh McGrath, is developing a new tool to measure the reactivity of OH in the ambient troposphere. In the past, mass spectrometric-based instrumentation was used to measure DMSO and $DMSO_2$ (DMS oxidation products, Nowak et al., 2002), HNO_3 (Zondlo et al., 2003), and NH_3.

A timeline for HOx instrumentation development in POP is shown in Table 1.

Table 1. Timeline of HOx instrumentation development in ACD over the past two decades.

Date	OH, H_2SO_4	HO_2, HO_2+RO_2	OH Reactivity
1988-1991		Chemical amplifier	
1993-1996	SICIMS (ground-based)	Dual Channel CA	
1996-1998	SICIMS (aircraft)	PeRCIMS (laboratory)	
2000		PeRCIMS (aircraft)	
2005	SICIMS (aircraft single channel)		
2007			SICIMS with flow reactor
2008		PeRCIMS (aircraft single channel)	Improved flow reactor
2009	SICIMS for HIAPER	PeRCIMS for HIAPER	

These development events also include multiple field deployments (some 30 over this period). Often field deployment needs drive the instrument improvement activities. Significant outside funding helped in many of these development activities.

MIRAGE/MILAGRO.

High resolution figure

These measurement capabilities allow us to address the following scientific questions:

1. What are the photochemical production rates of ozone under various conditions?
2. What are the rates of oxidation of various emitted species under various conditions? What is the nature of unidentified reactants? What is the nature of unidentified oxidants?
3. How does sulfuric acid contribute to aerosol formation and growth?
4. What are the oxidation products of DMS and what is their distribution?
5. How does ammonia contribute to aerosol formation and growth?
6. How do radical concentrations depend on the controlling variables (NOx, j-values, VOCs)?
7. What is the oxidizing capacity of the troposphere and how is it changing with human and natural events?
8. How does deep convection influence the photochemistry in the upper troposphere?
9. What do free radical measurements tell us about our understanding of tropospheric hydrocarbon oxidation chemistry?

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Eisele F. L., and D. J. TANNER, Ion-assisted tropospheric OH measurements, *J. Geophys. Res.*, D5, 9295-9308, 1991.

Mauldin, R.L. III, F. L. Eisele, C. A. Cantrell, E. Kosciuch, B.A. Ridley, B. Lefer, D. J. Tanner, J. B. Nowak, G. Chen, L. Wang, and D. Davis, Measurements of OH aboard the NASA P-3 during PEM-Tropics B, *J. Geophys. Res.*, 106, 32657-32666, 2001.

Nowak, J. B., L.G. Huey, F.L. Eisele, D.J. Tanner , R.L. Mauldin III, C. Cantrell , E. Kosciuch , and D.D. Davis, Chemical Ionization Mass Spectrometry Technique for the Detection of Dimethylsufoxide and Ammonia, *J. Geophys. Res.*, 107(D18), doi:10.1029/2001JD001058, 2002.

Zondlo, M. A., R. L. Mauldin, E. Kosciuch, C. A. Cantrell, and F. L. Eisele, Development and characterization of an airborne-based instrument used to measure nitric acid during the NASA Transport and Chemical Evolution over the Pacific field experiment, *J. Geophys. Res.*, 108(D20), 8793, doi:10.1029/2002JD003234, 2003.

Research Activities of the Atmospheric Radical Studies Project in the POP Section

Staff members: Chris Cantrell, Becky Anderson

The Atmospheric Radical Studies project develops and deploys instrumentation for the quantification of tropospheric peroxy radicals in order to better understand the details of the photochemical oxidation of emitted species and concomitant formation of secondary products such as ozone. Today, our primary tool is the Chemical Ionization Mass Spectrometer combined with inlet chemical conversion. This instrument has collected data in a variety of studies over the past decade. The earlier version of the technique allowed only measurement of the sum of HO2 and RO2. Most recently, we have extended the method to measurement of HO2 only and HO2+RO2. This improvement allows more direct tests of our understanding of tropospheric oxidation chemistry, and also the ability to directly compare with other HO2 measurement approaches (e.g. FAGE).

Briefly our peroxy radical measurements are based on the reactions in ambient air with added nitric oxide and sulfur dioxide. These reactions convert HO2 and/or RO2 into gas-phase sulfuric acid. Conditions within the instrument inlet are adjusted so that in one mode HO2+RO2 is measured (i.e. essentially all peroxy radicals form sulfuric acid), while in the other mode only HO2 is measured (i.e. only HO2 forms sulfuric acid; RO2 radicals form an unmeasured product). We quantify the sensitivity and selectivity of the two measurement modes using a portable calibration system developed in our laboratory.

Over the past few years, we have deployed this system in the MIRAGE/MILAGRO campaign (2006), INTEX-B (2006), PASE (2007), and most recently in ARCTAS (2008). These datasets combined with comprehensive measurements of complementary variables have provided results in a wide array of oxidation conditions leading to important tests of our current understanding. Analysis and publication of the results of these studies continues.

An example result from MIRAGE/MILAGRO is the comparison of observed peroxy radical concentrations and those calculated with a constrained box model versus the observed concentration of NOx (Figure 3). As can be seen, at lower levels of NOx, the measurements and calculations agree reasonably well, but at very high NOx levels (> 1000 pptv) the measurements are consistently and significantly above the model. We are exploring reasons for these differences. If the measurements are correct, it could have profound impacts on the ability of photochemical models to predict ozone and other species.

ACD Research Catalog

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

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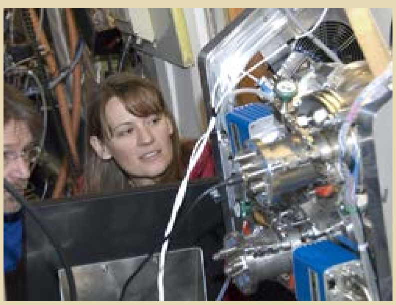
Research Focus & Field Programs FY08:



Chris Cantrell and Becky Anderson of the National Center for Atmospheric Research, Boulder, Colo., assess an instrument's operation on NASA's DC-8 aircraft during preparations for the ARCTAS field campaign. Credit: NASA

High resolution figure

I am working on the HOx/RO2 instrument for the NCAR-NSF GV (HIAPER) through the Upper Troposphere-Lower Stratosphere (UTLS) TIIMES initiative for the upcoming Deep Convective Clouds & Chemistry Experiment (DC3) Field experiment for the last year. During this time, work on the instrument design has been discussed, and a number of pumps and other components have been selected and ordered, and I participated in ARCTAS, which our group used as a testbed for high altitude HOx observations.

We deployed our previous instrumentation in the Megacities Impact on Regional & Global Environment (MIRAGE), the Intercontinental Chemical Transport Experiment (INTEX-B) campaigns and the Pacific Atmospheric Sulfur Experiment (PASE) field sudies and are now analyzing the data. The current system was deployed on the NASA DC-8 during Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS), and many components of this system will serve as components of our final HOx HIAPER instruments.

The Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) field campaign is poised to help scientists identify how air pollution contributes to climate changes in the Arctic. During the spring deployment, which took place in April in Fairbanks, Alaska, scientists gathered information about the effects of Arctic haze, stratosphere-troposphere exchange, and sunrise photochemistry (chemical reactions that occur when sunlight returns to the Arctic in spring). During the summer deployments in July & July in Palmdale, California, and in Cold Lake, Alberta, the team investigatee how emissions from northern wildfires affect the Arctic's atmosphere.

ARCTAS: Measuring the Arctic's Haze and Smoke: NCAR
NASA Launches Airborne Study of Arctic Atmosphere, Air Pollution: NASA

Community Service FY08:

- K-12 Activity: Science Presentations and demonstrations designed to interest elementary age girls in the sciences, Boulder, CO USA

Scientific Talks FY08:

- Measurements of HOx, RO2 and H2SO4 by Chemical Ionization Mass Spectrometry (Juelich, Germany)

Publications FY08:

Shon, Z. H., S. Madronich, S.-K. Song, F. M. Flocke, D. J. Knapp, R. S. Anderson, R. E. Shetter, C. A. Cantrell, S. R. Hall, 2008: Characteristics of the NO-NO2-O3 system in different chemical regimes during the MIRAGE-Mex field campaign. *Atmos. Chem. Phys. Discuss.*, 8, 2275-2309.4

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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COMMUNITY AIRBORNE RESEARCH INSTRUMENTATION (CARI)

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David Knapp
Deedee Montzka
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Andy Weinheimer
Wengang Zheng

Figure 1. The new two-channel NO-NOy instrument.

High resolution figure

Overview

The CARI group maintains, develops and deploys a number of aircraft trace gas instruments, including instrumentation which can be requested via the NSF/LAOF process, NSF/NCAR GV (HIAPER) instruments (two of those are part of the HAIS suite), and other atmospheric chemistry instruments. These instruments are:

CO	Two vacuum fluorescence instruments (Aerolaser, one certified for GV)
CO_2	Two infrared absorption carbon dioxide instruments (Li-Cor, one certified for GV)
H_2O	Two TDL infrared absorption open-path water vapor instruments (MayComm Instruments, one certified for GV)
Fast-O_3	NO chemiluminescence instrument (home built and certified for GV - HAIS)
NO/NOy	Compact 2-channel chemiluminescence instrument / photolytic conversion /gold catalytic conversion (home built and certified for GV)
NOx/NOy/O_3	4-channel chemiluminescence instrument / photolytic conversion /gold catalytic conversion (home built for various aircraft, not certified for GV)
PANs	Thermal dissociation Chemical Ionization Mass Spectrometer (built in collaboration with Georgia Tech)
VOC	TOGA fast GC-MS instrument measuring a variety of VOC (alkanes, alkenes, oxygeneates, aromatics, and others, about 40 compounds total) on a 2-min time scale (home built for GV - HAIS)

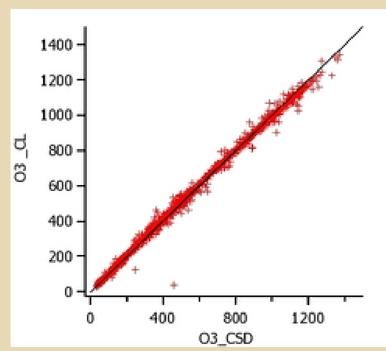

Figure 2. Comparison of the CARI fast-O3 HAIS instrument (O3_CL) with the NOAA UV absorption instrument (O3_CSD). The black line is a 1:1 line.

High resolution figure

The group expects to take responsibility for one or more of the HAIS instruments after they have been delivered to EOL. One of these instruments is the CIMS instrument, developed and built by GA Tech, which will measure HNO_3, HNO_4, and SO_2.

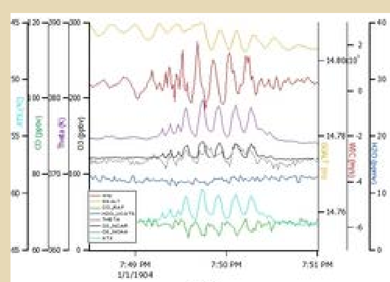

Figure 3. Gravity wave activity observed during START08. The black line shows ozone mixing ratio observed with the CARI fast-O3 HAIS instrument demonstrating its superior sensitivity and time resolution.

Summary of Goals and Activities for FY 2008

Field Experiments and instrument preparation/improvements

CARI participated in four major aircraft field experiments and an international laboratory study in the last year. The Pacific Sulfur Experiment (PASE) in Sept/Oct 2007 (funded by NSF), the Ice in Clouds Experiment (ICE-L) in November/December 2007 (funded by NSF), the Stratosphere-Troposphere Analyses of Regional Transport 2008 (START-08) mission in April/June of 2008 (funded by NSF), the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) mission in March/April and June/July 2008 (funded by NASA and NSF) and the VAMOS Ocean-Cloud-Atmosphere-Land Study – Regional Experiment (VOCALS-REx) experiment in October/November 2008 using the C-130 (funded by NSF). In October of 2007, CARI participated in the international water vapor intercomparison (AquaVit) in Germany (funded by the German BMBF and the EU with a contribution from NSF).

High resolution figure

Two of these missions (ARCTAS and START08) were multi-intensive missions which spanned the entire spring and summer of 2008. In addition, the START08 payload had never been flown before. Due to this heavy field load, CARI had to focus most of it's efforts on post-mission instrument testing and data QA/QD which is still ongoing. All missions went well and complete data sets were collected. We expect to meet all deadlines for data submission later this fall and early next year. In addition, CARI is preparing a number of instruments for the OASIS field mission, which will start in February of 2009.

START-08

Our new two-channel NO-NOy instrument was deployed on the GV for START08. Developed initially with Director's Opportunity Funds and completed with an EOL/TDF award, the instrument was finalized and certified just prior to installation on the GV in February 2008. NO and NOy were successfully measured on all 18 of the START08 research flights (April – June) focused on the chemical and transport properties of the extratropical upper troposphere and lower stratosphere (UTLS).

In the UTLS region, NO_x (=NO + NO_2) is mostly in the form of NO and is formed in situ by lightning, emitted in situ by aircraft, and may be transported to the UTLS from the boundary layer by convection. NO_y is a very useful tracer throughout the troposphere and especially across and above the tropopause. In the lower stratosphere O_3 and NO_y exhibit compact positive correlations that depend on latitude and season. Perturbations to the usual relationship can provide key information on tropospheric to stratospheric transport processes. In the troposphere, NO_y is good marker for identifying reasonably rapid (hours to several days) convective or frontal system transport of surface emissions to the middle and upper troposphere.

In START08, many interesting features were observed. On 20080506 (RF08) moderately elevated (1-2 ppbv) NO levels were observed in a widespread convective outflow over East Texas and Louisiana. On 20080430 (RF05), we sampled a large biomass-burning plume over Louisiana as well as numerous aircraft exhaust plumes encountered while transecting flight corridors on the return home. Additional, more localized, convective outflows, were sampled on (a) 20080616 (RF13) over Louisiana, where lightning-produced NO reached 3.5 ppbv, and (b) 20080618 (RF14) over the Dakotas and southern Manitoba, with NO levels up to 6 ppbv. The next-to-last flight of the project on 20080626 (RF17) included a successful comparison flight with our own instrumentation on the DC-8 (for ARCTAS), along with sampling of DC-8 exhaust. The comparison flight will aid in our evaluation of the performance of this new instrument, and the sampling of convective outflow was conducted as a precursor to the DC3 project and will aid in the design of that study.

The new HAIS fast-Ozone instrument also flew its maiden voyage during START08. The instrument was carefully characterized before START08 and its data system was integrated with the NO/NOy instrument which culminated in a Diploma Thesis by our student visitor Marcel Foeckler. The promised time resolution of 5Hz for the fast-Ozone instrument was characterized and verified in flight. The instrument also compared very favorably with the NOAA ozone UV absorption instrument, which was also flown on START08 (see figure 2). The excellent time resolution of the fast-Ozone HAIS instrument is demonstrated in figure 3 where gravity wave activity with a ~2km length was observed during one of the flights.

ARCTAS

Two phases of ARCTAS, which was flown aboard the NASA DC-8, were completed. Volatile organic compounds (VOCs) were measured with the Trace Organic Gas Analyzer (TOGA). NO, NO_2, NOy and Ozone were measured with our 4-channel chemiluminescence instrument. The spring ARCTAS deployment targeted anthropogenic pollution including arctic haze, stratosphere-troposphere exchange, and sunrise photochemistry which involves halogen (Cl and Br) radicals. A number of key measurements were made by TOGA which will lead to a better understanding of arctic halogen chemistry. NO, NO_2, NOy, and O_3 were measured on 9 flights during the spring phase in April. This phase was based in Fairbanks with an emphasis on Arctic haze and the accompanying mix of pollutant gas phase species that accumulate in the Arctic region over the winter and become subject to photochemical processing with the return of sunlight in the spring. In addition, several ozone depletion events were observed during which ozone fell to sub-ppbv levels, likely due to halogen chemistry not yet completely understood. A key aspect of the ARCTAS campaign was validation of satellite measurements, especially those of BrO, thought to be related to ozone depletion events. A curious lack of correlation was found between satellite-derived BrO and in situ measurements of BrO and depleted O_3 on the DC-8. This topic remains an area of intense interest in post-mission analysis. TOGA measured the first low-ppt mixing ratios of acetaldehyde ever recorded on board an aircraft, a compound which in the past could not be measured accurately in clean environments because of inlet artifacts.

The second, summertime ARCTAS intensive started with 4 June flights over and near California focused on air pollution from sources within California, as well as the inflow of pollutants from Asia and Mexico, so that California Air Resources Board can achieve a better understanding of the state's pollution sources and determine optimal control strategies. The second phase continued with a July deployment to Cold Lake, Alberta, with an excursion to Thule, Greenland that was aimed at sampling boreal forest fires and determining the impact of these fires on the Arctic region. Nature was cooperative, providing numerous fire sources, including not only those local to the Canadian region, but plumes arriving from Siberia as well as from the intense fire activity in California. We have numerous fire cases for analysis. Especially interesting is the interaction of the fires with convection, both with fires influencing convection and with the convection determining the transport of the fire emissions. TOGA measured a number of key compounds which will help in tracking and characterizing the biomass burning plumes. TOGA measurements will be combined with whole air sample analyses from the University of California, Irvine to obtain an overall understanding of the distribution of non-methane hydrocarbons (NMHCs), oxygenated volatile organic compounds (OVOCs), halogenated compounds and acetonitrile in the arctic.

ICE-L

The Ice in Clouds Experiment sampled Lee wave clouds from the NSF/NCAR C-130 in November and December, 2007, to gain insight into the poorly understood processes of ice initiation and secondary ice multiplication. The CARI group supported this experiment with measurements of in situ water vapor and ozone, CO and CO2 air mass tracers.

Water Vapor Intercomparison

The CARI and EOL/RAF airborne water vapor instruments participated in an international intercomparison of water vapor and total water sensors interfaced to the Forschung Zentrum Karlsruhe AIDA chamber during the Aqua Validation and Instrument Tests. Static and dynamic calibration streams were generated and sampled by over 20 instruments during the two week experiment in October, 2007.

Mega-cities

Along with Daniel Riemer at the University of Miami, we are conducting preliminary experiments aimed at characterizing the emissions profiles from mega-cities (over 10 million in population) and emerging megacities. The protocol calls for measuring a suite of VOCs, ozone, NOx, and filter to obtain baseline emissions data from cities in different stages of development and to lay the groundwork for future large scale studies.

Cities targeted for study include Mumbai, India, Lagos, Nigeria, and Dubai, U.A.E. The cities were chosen for the following reasons:

- Location, current population, and estimated population growth rate
- Scarcity or absence of measurement data for: CO2 and methane (including their isotopic signatures), CO, NO/NOy, VOCs, ozone, organic aerosols, and black carbon aerosol combined with expected differences in emissions patterns based on stages of economic development and patterns of energy use
- Potential impacts to the local, regional, and global atmosphere now and in the future

No megacities were chosen in the United States or Europe because of previous, ongoing, or planned research initiatives for those areas. This past year we studied Mumbai, India in the dry season. Initial results indicate similarities to Mexico City for the ozone and NOx diurnal profiles and also indicate that ozone is much higher than previously believed.

HAIS

The HAIS Trace Organic Gas Analyzer (TOGA) instrument is being developed to measure, with high accuracy and precision, a suite of atmospherically relevant organic compounds (process intermediaries, oxidation products, and tracers of anthropogenic and biogenic activity) throughout the troposphere including the UT/LS region. The NASA ARCTAS experiment, conducted on the DC-8, provided an invaluable test bed for the HAIS TOGA instrument development as a HAIS prototype instrument was successfully flown and excellent data coverage was obtained. This helped in finalizing the design of specific components needed for the operation of the instrument at high altitudes. The design is very nearly complete and construction is on-going. The instrument will be completed in August of 2009.

Plans for FY 2009

Instrumentation Research and Development

For information about current instrument development done by the CARI group please also refer to the ESSL laboratory annual report sections on Community Chemistry Instruments, Atmospheric Chemistry Instrumentation and HIAPER instruments. Please also refer to the following paragraph which describes the specific tasks related to preparing our instruments for participation in the FY2008 field programs that requested CARI instruments.

Both HAIS instruments, the Fast-O_3 and the TOGA VOC analyzer are slated for completion during FY2008. The NO-NOy and the Fast-O_3 instruments will be reconfigured and flown on HEFT and START-08. The first deployment for the HAIS-TOGA instrument will likely take place in FY2009.

We are planning to integrate instrument control and data acquisition functions of the Fast-O_3, NO-NOy and CO instruments. Furthermore, we are planning to share some components (such as pumps, pressure control and gases) between all three or pairs of these instruments in order to save weight and rack space on the GV if they are requested together as part of a chemistry or tracer package, which we expect to happen frequently (see START-08).

We are also planning to improve instrument control and electronics in our CO_2 instruments and enable raw data acquisition which we expect to significantly improve the data quality and lower the detection limit.

Modifications to the PAN-CIGARetteCI CIMS instrument will begin in FY2008 which are directed to certification for use on the GV. The GARette is already much more compact than the first generation PAN-CIMS instrument and only requires one side of a standard double rack or one GV rack space and weighs just over 200 lbs.

French student Marc Garofalo in our group is taking the lead on developing an automated canister sampling system which will be used by the CARI group. This system will allow for the unattended operation and analysis of up to 16 canister samples. The system is being designed to have ultra-high sensitivity which will allow for the collection of very small samples. This system will be valuable for both ground based studies, such as the Megacity project, and aircraft based studies and also will highly valuable for collaborative studies with the ACD Biogeochemistry group.

Field campaigns

In FY2009, CARI will participate in one aircraft campaign and one large ground based field deployment. The VAMOS Ocean-Cloud-Atmosphere-Land Study - Regional Experiment (VOCALS-REx) experiment in October/November using the C-130 and the OASIS campaign in Barrow, AK in February, March and April of 2009 (the CARI efforts of both campaigns are primarily funded by NSF with some other national and international funding supporting our collaborators).

VOCALS-REx is an international field experiment designed to better understand physical and chemical processes central to the climate system of the Southeast Pacific (SEP) region. VOCALS-REx will focus on interactions between clouds, aerosols, marine boundary layer (MBL) processes, upper ocean dynamics and thermodynamics, coastal currents and upwelling, large-scale subsidence, and regional diurnal circulations, to the west of the Andes mountain range. Among expected outcomes are improved model simulations of the coupled climate system in both the SEP and over the wider tropics and subtropics. CARI will provide water vapor, CO, CO2, and ozone measurements to this project. The measurements will provide valuable tracer information for identifying sources of aerosols and gases in air masses transported off-shore from the South American continent contributing to the cloud chemistry and dynamics aspects of the experiment.

The international OASIS (Ocean Atmosphere Snow Sea-Ice) field campaign will take place in Barrow, Alaska in the Spring of 2009. CARI will provide measurements of NO, NO_2, NOy, Ozone, PANs, VOC (TOGA), and, potentially, CO. The study is a large undertaking, led by Purdue University. It is aimed at investigating the unique chemistry in the arctic boundary layer, including sources and sinks of halogens, halogen radical species and HOx, sources and sinks of VOC, and exchange processes between the atmosphere , the ocean and the snowpack. NCAR's contribution, in collaboration with colleagues from Georgia Tech and UC Davis, will provide first measurements of the most important radical species along with other key compounds in the arctic.

Data Analysis and interpretation

Work on field campaign data will continue including data quality control and archiving, data analysis and interpretation and presentation of results, with emphasis on the publication of MIRAGE, INTEX, and PASE results as well as ARCTAS and START08.

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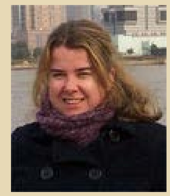
CGD 2008 PROFILES IN SCIENCE: JULIE ARBLASTER

Summary of achievements



Julie Arblaster

Julie Arblaster has concentrated on the analysis of twentieth century climate model experiments in order to understand the climate response to various external forcings. Black carbon aerosols, which have been accumulating over Asia in recent decades, were found to lead to increased warming in the lower troposphere over the Asian monsoon region and an enhancement of pre-monsoon rainfall. In accordance with that observed, a cold-event response to solar maximum, the peak of solar forcing from the Sun that occurs on an approximate 11-year cycle, was found in two NCAR climate models. Using these same models, temperature extremes over the United States were attributed for the first time to anthropogenic forcing using specialised runs where the models were forced with anthropogenic and natural forcings separately. Future research will investigate the ability of climate models to simulate observed changes in extremes at the regional scale, emerging signals of climate change in the first half of the 21st Century and additional experiments aimed at understanding the response of the climate system to variations in solar forcing.

Publications

Meehl, G.A., J.M. Arblaster, and W.D. Collins, 2008: Effects of Black Carbon Aerosols on the Indian Monsoon. Journal of Climate, 21, 2869-2882.

Abstract: A six-member ensemble of twentieth-century simulations with changes to only time-evolving global distributions of black carbon aerosols in a global coupled climate model is analyzed to study the effects of black carbon (BC) aerosols on the Indian monsoon. The BC aerosols act to increase lower-tropospheric heating over South Asia and reduce the amount of solar radiation reaching the surface during the dry season, as noted in previous studies. The increased meridional tropospheric temperature gradient in the premonsoon months of March-April-May (MAM), particularly between the elevated heat source of the Tibetan Plateau and areas to the south, contributes to enhanced precipitation over India in those months. With the onset of the monsoon, the reduced surface temperatures in the Bay of Bengal, Arabian Sea, and over India that extend to the Himalayas act to reduce monsoon rainfall over India itself, with some small increases over the Tibetan Plateau. Precipitation over China generally decreases due to the BC aerosol effects. There is a weakened latitudinal SST gradient resulting from BC aerosols in the model simulations as seen in the observations, and this is present in the multiple-forcings experiments with the Community Climate System Model, version 3 (CCSM3), which includes natural and anthropogenic forcings (including BC aerosols). The BC aerosols and consequent weakened latitudinal SST gradient in those experiments are associated with increased precipitation during MAM in northern India and over the Tibetan Plateau, with some decreased precipitation over southwest India, the Bay of Bengal, Burma, Thailand, and Malaysia, as seen in observations. During the summer monsoon season, the model experiments show that BC aerosols have likely contributed to observed decreasing precipitation trends over parts of India, Bangladesh, Burma, and Thailand. Analysis of single ensemble members from the multiple-forcings experiment suggests that the observed increasing precipitation trends over southern China appear to be associated with natural variability connected to surface temperature changes in the northwest Pacific.

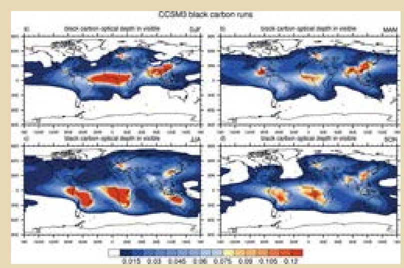


Figure 1.

High resolution figure

Figure caption: Distributions of black carbon optical depth for 1999 by season: (a) DJF, (b) MAM, (c) JJA, and (d) September-November (SON). This pattern was scaled back in time based on globally averaged human population.

Meehl, G.A., J.M. Arblaster, G. Branstator, and H. van Loon, 2008: A Coupled Air-Sea Response Mechanism to Solar Forcing in the Pacific Region. Climate Change, Journal of Climate, 21, 2883-2897.

Abstract: The 11-yr solar cycle [decadal solar oscillation (DSO)] at its peaks strengthens the climatological precipitation maxima in the tropical Pacific during northern winter. Results from two global coupled climate model ensemble simulations of twentieth-century climate that include anthropogenic (greenhouse gases, ozone, and sulfate aerosols, as well as black carbon aerosols in one of the

models) and natural (volcano and solar) forcings agree with observations in the Pacific region, though the amplitude of the response in the models is about half the magnitude of the observations. These models have poorly resolved stratospheres and no 11-yr ozone variations, so the mechanism depends almost entirely on the increased solar forcing at peaks in the DSO acting on the ocean surface in clear sky areas of the equatorial and subtropical Pacific. Mainly due to geometrical considerations and cloud feedbacks, this solar forcing can be nearly an order of magnitude greater in those regions than the globally averaged solar forcing. The mechanism involves the increased solar forcing at the surface being manifested by increased latent heat flux and evaporation. The resulting moisture is carried to the convergence zones by the trade winds, thereby strengthening the intertropical convergence zone (ITCZ) and the South Pacific convergence zone (SPCZ). Once these precipitation regimes begin to intensify, an amplifying set of coupled feedbacks similar to that in cold events (or La Niña events) occurs. There is a strengthening of the trades and greater upwelling of colder water that extends the equatorial cold tongue farther west and reduces precipitation across the equatorial Pacific, while increasing precipitation even more in the ITCZ and SPCZ. Experiments with the atmosphere component from one of the coupled models are performed in which heating anomalies similar to those observed during DSO peaks are specified in the tropical Pacific. The result is an anomalous Rossby wave response in the atmosphere and consequent positive sea level pressure (SLP) anomalies in the North Pacific extending to western North America. These patterns match features that occur during DSO peak years in observations and the coupled models.

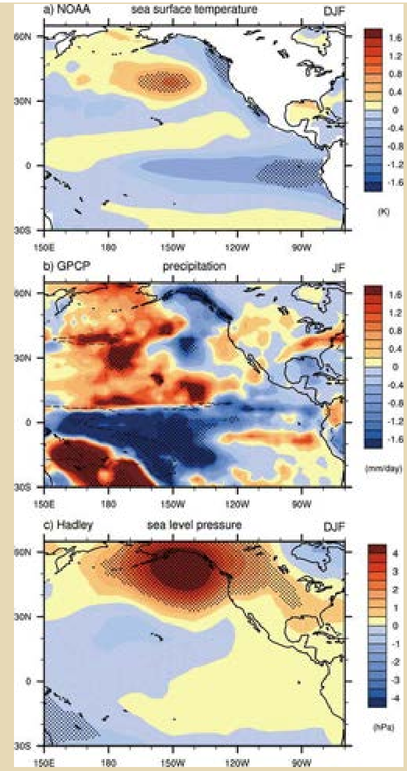


Figure 2.

High resolution figure

Figure caption: (a) The average anomalies of SST (°C) in the 11 solar peak years for DJF computed relative to all other years—1883, 1893, 1905, 1917, 1928, 1937, 1947, 1957, 1968, 1979, and 1989—from the NOAA ERSST dataset (available online at http://www.cdc.noaa.gov/cdc/data.noaa.ersst.html). (b) The average tropical rainfall anomalies (mm day-1) for January-February (GPCP gridded precipitation dataset) in the solar peaks in 1979, 1989, and 2000, in comparison to all other years. Dashed line is the 6 mm day-1 contour from the long-term mean climatology. (c) As in (a) but for the average anomalies of SLP (hPa) (Hadley Centre SLP dataset); shading indicates significance at or above the 95% level, indicating the relative magnitude of the anomalies compared to the noise. For further details regarding observed data sources, see van Loon et al. (2007).

Meehl, G. A., J. M. Arblaster, and C. Tebaldi (2007), Contributions of natural and anthropogenic forcing to changes in temperature extremes over the United States. Geophys. Res. Lett., 34, L19709, doi:10.1029/2007GL030948.

Abstract: Observations averaged over the U.S. for the second half of the 20th century have shown a decrease of frost days, an increase in growing season length, an increase in the number of warm nights, and an increase in heat wave intensity. For the first three, a nine member multi-model ensemble shows similar changes over the U.S. in 20th century experiments that combine anthropogenic and natural forcings, though the relative contributions of each are unclear. Here we show results from two global coupled climate models run with anthropogenic and natural forcings separately. Averaged over the continental U.S., they show that the observed changes in the four temperature extremes are accounted for with anthropogenic forcings, but not with natural forcings (even though there are some differences in the details of the forcings). This indicates that most of the changes in temperature extremes over the U.S. are likely due to human activity.

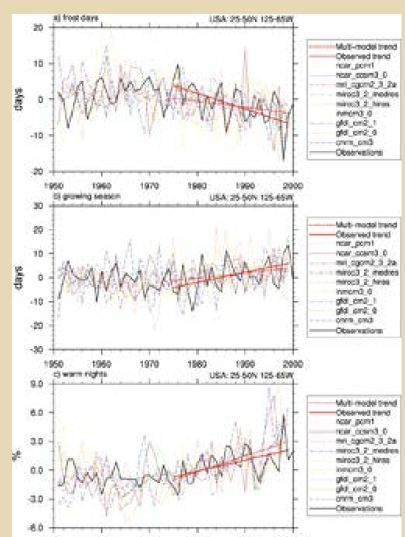


Figure 3.

High resolution figure

Figure caption: Three temperature-related extremes indices available for nine models in the WCRP CMIP3 multi-model dataset at PCMDI averaged for the continental U.S., annual means, anomalies from 1951-99. The models are interpolated to the HadEX grid and only grid points with valid observations are included in the area-weighted average: (a) frost days (in days), (b) growing season length (in days), and (c) warm nights (in %).

CGD Research Catalog

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

NCAR is sponsored by the National Science Foundation.

CHEMICAL REMOTE SENSING

Group Members

David Edwards (Group Leader)
Louisa Emmons
Merritt Deeter
Helen Worden
Gabi Pfister
Ave Arellano
Dallas Masters
Simone Tilmes

Research Activities

ACRESP activities build on our current satellite missions and our expertise and leadership in satellite remote sensing science, Earth System modeling, and data assimilation. Recent advances in tropospheric remote sensing have opened the way for measuring, monitoring, and understanding processes that lead to atmospheric pollution. As part of an integrated observing strategy, satellite measurements provide a context for localized observations and help to extend these observations to continental and global scales. The challenge for future space-borne missions will be directly accessing the local scale and facilitating the use of remotely sensed information for improving local- and regional-scale air quality (AQ) forecasts. Achieving this goal will provide important societal dividends for public health, for policy applications related to managing national AQ, and for assessing the impact of daily human activity on the distributions of important trace gases and aerosols and their short-timescale variability - known as "chemical weather" - as well as on climate.

Figure 1. Research activities are grouped in two main areas: Satellite instrument design and future mission planning for atmospheric composition and air quality, and chemical weather forecasting, satellite data assimilation and field campaign support.

High resolution figure

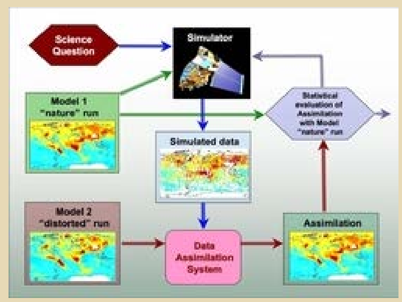

Figure 2. The OSSE framework comprises the following key elements: (1) a science-driven requirement for a chemical species observation, (2) a satellite instrument simulator and observing strategy that might be capable of making a useful measurement, (3) a simulated data retrieval of the species with "nature" defined by an appropriate chemical transport Model 1, (4) a forecast of the species distribution using an assimilation of the retrieval in the "distorted" model 2, and (5) a quantitative assessment of the value of the measurement.

High resolution figure

Satellite Instrument Design:

If a satellite mission related to atmospheric composition and air quality is to become a reality within the next decade, the atmospheric chemistry community will need to establish clear scientific motivation for the new measurements. For this, there is considerable interest in using chemical observing system simulation experiment (OSSE) studies to help define quantitative measurement requirements for satellite missions and to evaluate the expected performance of proposed observing strategies. These experiments will hopefully provide a practical way of defining a traceability matrix to map science requirements through measurement requirements onto instrument requirements.

OSSEs must be driven by well-defined scientific questions and the experiment formulation constructed accordingly. We have completed an example OSSE motivated by the desire to measure the distribution and time evolution of carbon monoxide in the lower-most troposphere for air quality applications using candidate satellite multispectral measurements in the thermal and near infrared.

Future Satellite Missions:

The ACRESP group is involved in the planning of The Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission that has been recommended for launch in the 2013-2016 time frame by the National Research Council. The mission's purpose is to gather science that identifies human versus natural sources of aerosols and ozone precursors, tracks air pollution transport, and studies the dynamics of coastal ecosystems, river plumes and tidal fronts. Continuous observation from GEO-CAPE's geostationary platform will allow for more adequate monitoring of population exposure and the ability to relate pollutant concentrations to their sources or transport, thereby providing data to improve air quality forecasts.

ACRESP is a partner on a carbon monoxide instrument, the Compact Imaging

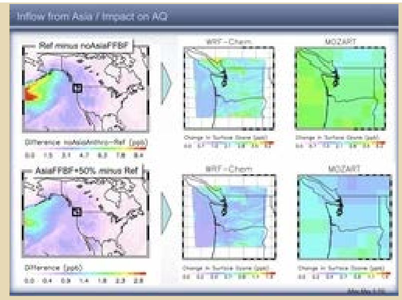

Figure 3. WRF-Chem and MOZART simulated change in surface ozone (Maximum change for May 3-10) over Washington State with changes in Asian emissions.

High resolution figure

Spectroradiometer (CISR), that builds on MOPITT experience and that has been specifically designed for geostationary deployment. CISR is candidate technology for GEO-CAPE and is currently under development as part of the NASA Instrument Incubator Program (IIP).

A longer-term goal of the ACRESP OSSE activity is to develop a community facility at NCAR. This would be used by researchers from the universities and agency centers for building and testing instrument simulators as part of the proposal and design of the next generation of satellite instruments.

Air Quality "Chemical Weather" Forecasting:

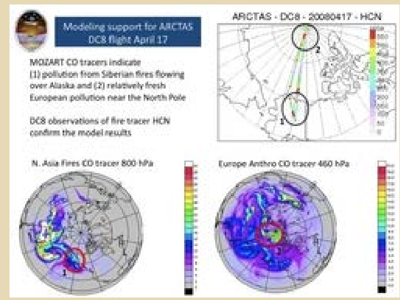

Figure 4. An example of the success of the ARCTAS chemical forecasts in predicting pollution plumes subsequently confirmed by aircraft measurements.

High resolution figure

The Chemical Weather: Local, regional, and global distributions of important trace gases and aerosols and their variation on time scales of minutes to hours to days, particularly in light of their various impacts, such as on human health, ecosystems, the meteorological weather, and climate. (Lawrence et al., Environ. Chem. 2005, 2, 6-8, doi:10.1071/EN05014)

The ACRESP Program is developing an air quality "chemical weather" forecasting capability based on existing satellite observations. Chemical weather is a priority research theme for ESSL. The characterization of global and regional scale air quality involves field campaigns, chemical transport modeling, and remote sensing. The goal is a scientific and observing framework analogous to that used for weather forecasting with a model assimilation of observations from satellite, aircraft and surface platforms to derive a 4-dimensional view (3 spatial plus temporal) of the physical state of the atmosphere.

This analysis will be used in air quality basic research: the quantification of emissions of ozone and aerosol precursors and the examination of the long-range transport of pollutants extending from regional to global scales. The general tools and methodologies developed will also be used for studies examining the connections between climate change and regional air quality, and the roles of anthropogenic and natural processes in changing atmospheric composition. The predictive capability will provide a powerful tool to support field campaign activities such as those involving HAIPER chemical instrumentation. There also exists the possibility of demonstrating schemes for future operational applications elsewhere in the community related to air quality management and health advisories.

Increasingly, there is interest in accessing finer spatial scales to quantify both the wider impact of local pollution sources such as wildfires and mega-cities and assessing the contribution of transported pollution. We are conducting a chemical weather case study for the MIRAGE and INTEX-B spring 2006 period. This involves global model simulations using analyzed meteorology and the best possible chemical sources with fire emissions based on satellite fire products. A nested regional model simulation concentrating on Mexico and parts of the INTEX-B Pacific region are also being performed using WRF-Chem.

One of the open questions in AQ policy management is to what degree Asian industrialization and the associated transpacific transport of pollution could hinder improvements in AQ in the US from domestic emission controls. We have used the data set collected during the April/May 2006 phase of INTEX-B to look into the impacts of the long-range transport of pollutants across the Pacific on the U.S. West Coast. The study used global model simulations with altered Asian emission scenarios as boundary conditions for WRF-Chem simulations to examine the changes in concentration fields in both the global and the regional model. In another study, we focused on a direct application to AQ and quantified the impact of the fires in California in fall 2007 on regional air quality and especially on surface ozone by analyzing surface observations of ozone concentrations together with model simulations. It was found that the frequency of violations in the public health standards nearly tripled because of the fires.

Assimilation of available satellite data sets such as Terra/Aqua/MODIS aerosol optical depth, ENVISAT/SCIAMACHY and Aura/OMI NO2, OMI O3 tropospheric column, and Terra/MOPITT, Aura/TES, and METOP/IASI CO and O3 are being explored. This exercise will impose constraints on the modeled chemical fields and can be evaluated by compaing with actual field measurements. We have been working on a pre-cursor study with idealized satellite retrievals to examine the benefits and shortcomings in the assimilation of chemically active species. Largest improvements in predicting surface ozone were found when O3 or also NO2 fields throughout the atmosphere are available with high temporal resolution (3hrs) and for the online inversion of NO emission. However, the latter had the tendency for increasing biases in outflow regions. Work is ongoing on the assimilation of concentrations fields on a daily basis.

These projects involve the collaborative efforts between ACD and the DART initiative in IMAGe. We will also aim to foster collaboration with other efforts in the development of chemical weather forecast capability both within U.S. Universities, NOAA and NASA, and internationally, particularly with the GEMS project (http://www.ecmwf.int/research/EU_projects/GEMS/) in Europe.

Field Campaign Support and Data Analysis:

ACRESP supported the NASA Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) field campaign with a combination of model simulations and satellite observations. Measurements were made from the NASA DC8 aircraft in the Spring and Summer of 2008, and were coordinated with several other field experiments as part of the International Polar Year (IPY). The Spring Phase of ARCTAS was April 1-19, based in Fairbanks, AK, and the Summer Phase was in Cold Lake, Alberta, June 26-July 14. In addition, several DC8 flights were made from Palmdale, CA, June 18-24, in coordination with the California Air Resources Board (CARB).

Retrievals of carbon monoxide (CO) from observations by Terra/MOPITT were produced in near-real-time. Chemical forecasts were produced using Ensemble Kalman Filter Data Assimilation of meteorological observations, MOPITT CO, and MODIS aerosol optical depth (AOD) with the NCAR Community Atmosphere Model with Chemistry (CAM-Chem). The data assimilation was performed in the Data Assimilation Research Testbed (DART) framework. Forecasts were also run with MOZART-4 driven by NCEP/GFS meteorology. The satellite retrievals and chemical forecasts were used to assist in the planning of the DC8 flights during the campaign by identifying features of interest for the aircraft to sample, such as pollution plumes from fires in Siberia and Canada.

Analysis of the ARCTAS measurements will continue in the coming year using a combination of satellite and model simulations. The assimilation of MOPITT CO and MODIS AOD in CAM-Chem/DART will be refined and evaluated with the aircraft observations, and, in turn, used to assist in the interpretation of the observations. Discrepancies between the model and observations will be used to improve the model and the emissions used to drive the model.

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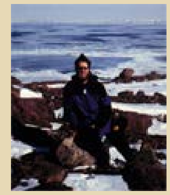
CGD 2008 PROFILES IN SCIENCE: DR. DAVID BAILEY

Summary of achievements



David Bailey

In my position as CCSM Polar Climate Working Group (PCWG) and sea ice model liaison, I am responsible for supporting the scientific projects of interest to the PCWG, generating sea ice diagnostic plots for simulations for the general CCSM community, aiding new users of CCSM with experimental setup and design, and ongoing maintenance and development of the Community Ice CodE (CICE), the sea ice component of the CCSM. Some recent examples of PCWG projects that I've been involved in are: providing sea ice concentration from IPCC 21st century projections for use in polar bear habitat prediction models; performing ensemble experiments using the CCSM to investigate possible sea ice response under idealized greenhouse gas commitment scenarios and predictability of September sea ice extent. Earlier this year I had participated in a workshop sponsored by NSF Arctic System Science (ARCSS) with particular focus on the 2007 September ice minimum. I was an active participant in the working group on predictability of the sea ice, which eventually led to an open community September sea ice outlook. I have also been involved with 20th century hindcast runs using the CCSM as a basis for short-term prediction studies. I am currently testing and developing new parameterizations in the sea ice for melt ponds, shortwave radiation, and aerosol deposition on sea ice. I am also peripherally involved in the grand challenge project to run the CCSM at very high resolution.

Publications

Holland, M.M., C.M. Bitz, B. Tremblay, D.A. Bailey, 2008: The role of natural versus forced change in future rapid summer Arctic ice loss, AGU Monograph on "Arctic Sea Ice Decline", in press.

Abstract: Climate model simulations from the Community Climate System Model (CCSM3) suggest that Arctic sea ice could undergo rapid September ice retreat in the 21st century. A previous study indicated that this results from a thinning of sea ice to more vulnerable conditions, a "kick" in the form of pulse-like increases in ocean heat transport and positive feedbacks that accelerate the retreat. Here we further examine the factors affecting these events, including the role of natural versus forced change and the possibility of threshold-like behavior in the simulated sea ice cover. We find little indication that a critical sea ice state is reached that then leads to rapid ice loss. Instead our results suggest that the rapid ice loss events result from anthropogenic change reinforced by growing intrinsic variability. The natural variability in summer ice extent increases in the 21st century due to the thinning ice cover. As the ice thins, large regions can easily melt out resulting in considerable ice extent variations. The important role of natural variability in the simulated rapid ice loss is such that we find little capability for predicting these events based on a knowledge of prior ice and ocean conditions. This is supported by results from sensitivity simulations initialized several years prior to an event, which exhibit little predictive skill.

Figure caption: Timeseries of September ice extent for the (a) Run 1 ensemble member and (b-f) sensitivity runs listed in Table 2. The 5-year running mean smoothed ice extent from Run 1 is shown in red in all of the panels. Abrupt events are indicated by the grey shading.

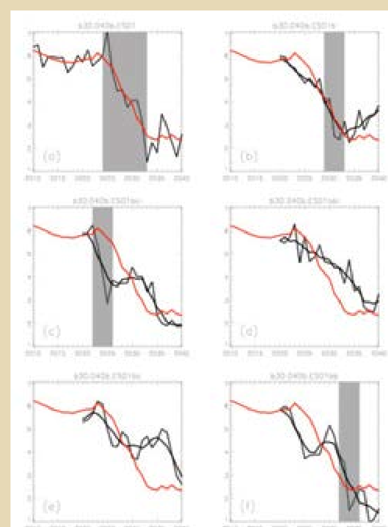


Figure 1.

High resolution figure

Durner, G.M., D.C. Douglas, R.M. Nielsen, S.C. Amstrup, T.L McDonald I. Stirling, M. Mauritzen, E.W. Born, O. Wiig, E. DeWeaver, M.C. Serreze S.E. Belikov, M.M. Holland, J. Maslanik, J. Aars, D.A. Bailey, and A.E. Derocher, 2008: Predicting 21st Century Polar Bear Habitat Distribution from Global Climate Models, Ecological Monographs, in press.

Abstract: Projections of polar bear (*Ursus maritimus*) sea ice habitat distribution in the polar basin during the 21st century were developed to understand the consequences of anticipated sea ice reductions on polar bear populations. We used

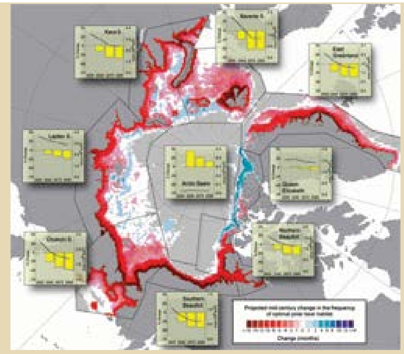


Figure 2.

High resolution figure

location data from satellite-collared polar bears and environmental data (e.g., bathymetry, distance to coastlines, and sea ice) collected from 1985-1995 to build Resource Selection Functions (RSF). RSFs described habitats polar bears preferred in summer, autumn, winter and spring. When applied to independent data from 1996-2006, the RSFs consistently identified habitats most frequently used by polar bears. We applied the RSFs to monthly maps of 21st century sea ice concentration projected by 10 general circulation models (GCMs) used in the Intergovernmental Panel of Climate Change Fourth Assessment Report, under the A1B greenhouse-gas forcing scenario. Despite variation in their projections, all GCMs indicated habitat losses in the polar basin during the 21st century. Losses in the highest-valued RSF habitat (optimal habitat) were greatest in the southern seas of the polar basin, especially the Chukchi and Barents seas, and least along the Arctic Ocean shores of Banks Island to northern Greenland. Average loss of optimal polar bear habitat was greatest during summer; from an observed 1.0 million km^2 in 1985-1995 (baseline) to a projected multi-model average of 0.32 million km^2 in 2090-2099 (-68% change). Projected winter losses of polar bear habitat were less; from 1.7 million km^2 in 1985-1995 to 1.4 million km^2 in 2090-2099 (-17% change). Habitat losses based on GCM multi-model averages may be conservative; simulated rates of habitat loss during 1985-2006 from many GCMs were less than observed rates of loss. Although a reduction in the total amount of optimal habitat will likely reduce polar bear populations, exact relationships between habitat losses and population demographics remain unknown. Density and energetic effects may become important as polar bears make long distance annual migrations from traditional winter ranges to remnant high-latitude summer sea ice. These impacts will likely affect specific sex and age groups differently and may ultimately preclude bears from seasonally returning to their traditional ranges.

Figure caption: Projected changes (based on 10 IPCC AR-4 GCM models run with the SRES-A1B forcing scenario) in the spatial distribution and integrated annual area of optimal polar bear habitat. Base map shows the cumulative number of months per decade where optimal polar bear habitat was either lost (red) or gained (blue) from 2001-2010 to 2041-2050. Offshore gray shading denotes areas whre optimal habitat was absent in both periods. Insets show the average annual (∑ 12 months) cumulative area of optimal habitat (right y-axis, line plot) for four 10-year periods in the 21st century (x-axis midpoints), and their associated percent change in area (left y-axis, histograms) relative to the first decade (2001-2010).

CGD Research Catalog

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AARON BANSEMER

2008 Publications

Field, P. R., A. J. Heymsfield, A. Bansemer, C. H. Twohy, 2008: Determination of the combined ventilation factor and capacitance for ice crystal aggregates from airborne observations in a tropical anvil cloud. J. Atmos. Sci., 65, 376-391, doi: 10.1175/2007JAS2391.1.

Abstract

The ventilation factor and capacitance used in numerical models to represent ice crystal aggregates directly affects the growth rate of the ice crystal aggregates, and consequently the sink of atmospheric water vapor. Currently, numerical models that prognose ice water content (IWC) and water vapor mixing ratio represent the capacitance and ventilation factor of precipitation-sized particles with simplified geometries, such as hexagonal plates. The geometries of actual precipitation-sized particles are often more complex, and a test of the values being employed is needed. Aircraft observations obtained during a Lagrangian spiral descent through the sublimation zone of a tropical anvil cloud have been used to determine an estimate of combined dimensionless capacitance and ventilation factor for the nonpristine geometries exhibited by ice crystal aggregates. By combining measurements of bulk ice water content, the particle size distribution, and environmental subsaturation, the change in ice water content was modeled throughout the spiral descent and compared with observations of the change in ice water content. Uncertainties resulting from potential systematic biases in the measurements and parameterizations used in the analysis were investigated with sensitivity tests. Most of the uncertainty was related to an assumed maximum potential bias in the measurement of IWC of ±45%. The resulting combined ventilation factor and dimensionless capacitance value was 1.3 (with a range of 0.6–1.9, defined by 68% of sensitivity test trials) for a particle size–weighted mean value of (Sc)1/3(Re)1/2 = 14.9 ± 1.7, where Sc is the Schmidt number and Re is the Reynolds number. Results from commonly adopted combinations of ventilation factor relations and capacitances are compared with the observations presented here, and, finally, surrogate dimensionless capacitances are suggested that when combined with commonly used ventilation factor relations are consistent with the results presented herein.

Heymsfield, A. J., A. Bansemer, S. Matrosov, L. Tian, 2008: The 94-GHz radar dim band: Relevance to ice cloud properties and cloudsat. Geophys. Res. Lett., 35, L03802, doi: 10.1029/2007GL03136.

Abstract

Details of the microphysics are shown to be responsible for a region of ice cloud which, when probed from above, has decreasing radar reflectivity (Z e) downwards at 94 GHz but increasing Z e at 9.7 GHz. This 94-GHz radar dim band is found to be due to the combination of ice particle aggregation and non-Rayleigh scattering effects. Observations and model calculations indicate that it occurs when the particle size distribution (PSD) broadens such that its slope, as derived from fitted PSD, decreases below about 15 cm-1, or equivalently, to a median volume diameter exceeding 0.25 cm. Dimming occurs at temperatures (T) primarily between -5 and 0°C but can occur at -30°C or below in convectively-generated ice clouds (anvils). The dimming effect may produce an appreciable low bias in the ice water content (IWC) retrieved from Z e measured by CloudSat's 94-GHz radar. Methods to estimate the IWC in the dim band are proposed.

Field, P. R., A. J. Heymsfield, A. Bansemer, 2007: Snow size distribution parameterization for midlatitude and tropical ice clouds. J. Atmos. Sci., 64, 4346-4365, doi: 10.1175/2007JAs2344.1testing.

Abstract

Many microphysical process rates involving snow are proportional to moments of the snow particle size distribution (PSD), and in this study a moment estimation parameterization applicable to both midlatitude and tropical ice clouds is proposed. To this end aircraft snow PSD data were analyzed from tropical anvils [Tropical Rainfall Measuring Mission/Kwajelein Experiment (TRMM/KWAJEX), Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE)] and midlatitude stratiform cloud [First International Satellite Cloud Climatology Project Research Experiment (FIRE), Atmospheric Radiation Measurement Program (ARM)]. For half of the dataset, moments of the PSDs are computed and a parameterization is generated for estimating other PSD moments when the second moment (proportional to the ice water content when particle mass is proportional to size squared) and temperature are known. Subsequently the parameterization was tested with the other half of the dataset to facilitate an independent comparison. The parameterization for estimating moments can be applied to midlatitude or tropical clouds without requiring prior knowledge of the regime of interest. Rescaling of the tropical and midlatitude size distributions is presented along with fits to allow the user to recreate realistic PSDs given estimates of ice water content and temperature. The effects of using different time averaging were investigated and were found not to be adverse. Finally, the merits of a single-moment snow microphysics versus multimoment representations are

discussed, and speculation on the physical differences between the rescaled size distributions from the Tropics and midlatitudes is presented.

Delanoe, J., A. Protat, D. Bouniol, A. J. Heymsfield, A. Bansemer, P. Brown, 2007: The characterization of ice cloud properties from Doppler radar measurements. J. Appl. Meteor. Climat., 46, 1682-1698, doi: 10.1175/JAM2543.1.

Abstract

The paper describes an original method that is complementary to the radar–lidar algorithm method to characterize ice cloud properties. The method makes use of two measurements from a Doppler cloud radar (35 or 95 GHz), namely, the radar reflectivity and the Doppler velocity, to recover the effective radius of crystals, the terminal fall velocity of hydrometeors, the ice water content, and the visible extinction from which the optical depth can be estimated. This radar method relies on the concept of scaling the ice particle size distribution. An error analysis using an extensive in situ airborne microphysical database shows that the expected errors on ice water content and extinction are around 30%–40% and 60%, respectively, including both a calibration error and a bias on the terminal fall velocity of the particles, which all translate into errors in the retrieval of the density–diameter and area–diameter relationships. Comparisons with the radar–lidar method in areas sampled by the two instruments also demonstrate the accuracy of this new method for retrieval of the cloud properties, with a roughly unbiased estimate of all cloud properties with respect to the radar–lidar method. This method is being systematically applied to the cloud radar measurements collected over the three-instrumented sites of the European Cloudnet project to validate the representation of ice clouds in numerical weather prediction models and to build a cloud climatology.

MMM Research Catalog

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Scientific Talks FY08:

- Convective Anvil Microphysical Observations in ACTIVE (Manchester, GBR, January 2008)
- Initial Experiences with the SID-2H (Broomfield, CO, May 2008)

Publications FY08: (abstracts)

Twohy, C., S. M. Kreidenweis, T. Eidhammer, E. V. Browell, A. J. Heymsfield, A. Bansemer, B. E. Anderson, G. Chen, S. Ismail, P. J. Demott, S. C. Van Den Heever, 2008: Saharan dust particles nucleate droplets in eastern Atlantic clouds. *Geophys. Res. Lett.*. (Submitted)

Heymsfield, A. J., P. Field, A. Bansemer, 2008: Explaining the lower limit to slopes of ice particle size distributions. *J. Atmos. Sci.*. (In Press)

Field, P. R., A. J. Heymsfield, A. Bansemer, C. H. Twohy, 2008: Determination of the combined ventilation factor and capacitance for ice crystal aggregates from airborne observations in a tropical anvil cloud. *J. Atmos. Sci.*, **65**, 376-391, doi: 10.1175/2007JAS2391.1.

Heymsfield, A. J., A. Bansemer, S. Matrosov, L. Tian, 2008: The 94-GHz radar dim band: Relevance to ice cloud properties and cloudsat. *Geophys. Res. Lett.*, **35**, L03802, doi: 10.1029/2007GL03136.

Field, P. R., A. J. Heymsfield, A. Bansemer, 2007: Snow size distribution parameterization for midlatitude and tropical ice clouds. *J. Atmos. Sci.*, **64**, 4346-4365, doi: 10.1175/2007JAs2344.1testing.

Delanoe, J., A. Protat, D. Bouniol, A. J. Heymsfield, A. Bansemer, P. Brown, 2007: The characterization of ice cloud properties from Doppler radar measurements. *J. Appl. Meteor. Climat.*, **46**, 1682-1698, doi: 10.1175/JAM2543.1.

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DALE BARKER

2008 Publications

Xiao, Q., E. Lim, D.-J. Won, J. Sun, W.-C. Lee, M.-S. Lee, W.-J. Lee, J.-Y. Cho, Y.-H. Kuo, D. M. Barker, D.-K. Lee, H. S. Lee, 2008: Doppler radar data assimilation in KMA's operational forecasting. Bull. Amer. Meteor. Soc., 89, 39-43, doi: 10.1175/BAMS-89-1-39.

Abstract

During 2001–03, the Mesoscale and Microscale Meteorology Division (MMM) at the National Center for Atmospheric Research (NCAR) partnered with the Korean Meteorological Administration (KMA) and Seoul National University (SNU) to use Doppler radar data in the MM5 with the Weather Research and Forecasting (WRF) 3-dimensional variational (3D-Var) data-assimilation system. After case studies and one-month comparison experiments with and without radar data assimilation in 2004, the system proceeded to semioperational testing in 2005 and was implemented for full operational production in 2006. The case studies showed benefits of radar data assimilation, and further tests indicated that Doppler radar data assimilation in WRF 3D-Var performed > robustly and improved rainfall forecasting.

The procedure for KMA Doppler radar data assimilation is rather sophisticated: it includes data preprocessing (quality control, error statistics, and formatting), assimilation with WRF 3D-Var, and analysis update cycling. The algorithms for direct assimilations of radial velocity and reflectivity are advanced and innovative. The transfer of the developed system from research mode at NCAR to operational mode at KMA has been very smooth and successful. With great efforts from all parties, KMA is running the advanced system operationally and benefiting Korea. The WRF 3D-Var Doppler radar data-assimilation system now resides in both NCAR and KMA and serves as a very useful tool for research.

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ULTRAFINE AEROSOLS

Group Members

Kelley Barsanti
Hans Friedli
James Pankow
James Smith (Group Leader)

Research Activities

The UA group conducts measurements to understand how particles form and grow in the atmosphere to be important participants in atmospheric chemistry and climate. Ultrafine aerosols are particles with diameters smaller than 100 nm. They can be formed in the atmosphere over spatial scales of hundreds of kilometers by a process known as nucleation. Measurements by the UA group and its collaborators, performed in atmospheric environments as diverse as Mexico City and the boreal forests in central Finland, confirm that new particle formation from nucleation occurs frequently and often is the fundamental process that controls particle number. Understanding and modeling the nucleation process and the mechanisms by which newly formed particles grow to become cloud condensation nuclei (CCN) are essential for reducing uncertainties in the roles that aerosols play in climate.

The research activities of the UA group during the past year have addressed three fundamental questions:

1. Can we develop new measurements for characterizing ultrafine aerosol physico-chemical properties and their impacts on climate?
2. How do newly formed aerosols grow to become important participants in chemistry/climate?
3. What are the impacts of biogenic emissions on secondary organic aerosol formation and growth?

As Table 1 shows, these activities address the ESSL strategic scientific priorities of investigating the interaction of the atmosphere with the broader Earth system and improving prediction of weather, climate, and other atmospheric phenomena.

Table 1. Summary of UA group research activities as they relate to ESSL 2008 strategic priorities.

UA Group Activity	Interaction of atmosphere with broader Earth system	Improving prediction of weather, climate, and other phenomena
Develop new measurements for characterizing ultrafine aerosol physico-chemical properties and their impacts on climate.	Better measurements of the physico-chemical properties of aerosols are needed to understand and model the impacts of aerosols on air quality and climate.	Better measurements of the physico-chemical properties of aerosols are needed to understand how aerosols form, grow, and impact climate through direct and indirect radiative effects as well as by the modification of clouds and precipitation.
Investigate how newly formed particles grow to become important participants in chemistry and climate.	New particle formation is the main global source of particle number, and subsequent condensational growth makes these particles important to the earth system by allowing them to become cloud condensation nuclei (CCN).	Understanding and modeling particle formation and growth will allow better predictions of the impact of this process on direct radiative scatter, cloud formation, and precipitation.

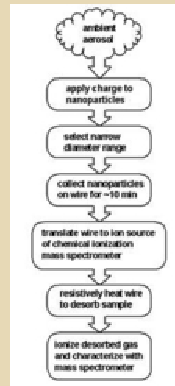

Figure 1. Flow diagram of TDCIMS particle collection and analysis.

High resolution figure

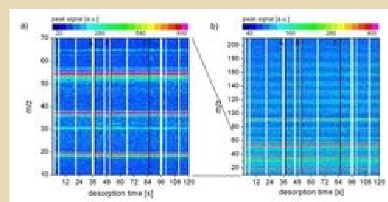

Figure 2. Ion trap TDCIMS positive ion spectra from 30 nm diameter ambient aerosol collected at the Marshall Field Site. The vertical lines marked "A," "B," and "C" indicated times at which the filament temperature of the TDCIMS was increased stepwise. (a) Close-up of the full spectrum, which is shown in (b), showing horizontal "stripes" corresponding to the main water peaks (19, 37, 55) and ammonium (18).

High resolution figure

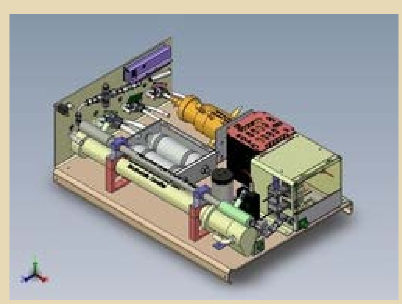

Figure 3. Assembly drawing of the GV Scanning Mobility Particle Sizer, which will fit on a standard aircraft rack.

High resolution figure

Investigate secondary organic aerosol (SOA) formation from biogenic emissions.	The interactions between anthropogenic oxidants and emissions and biogenic trace gases are poorly understood, and may be important in gas-phase chemistry and particle formation and growth.	SOA formation from biogenic emissionss surpasses that from anthropogenic precursors and can modify cloud properties. Cloud formation/precipitation can cause feedbacks on emissions and particle formation and growth, due to their influence on biogenic processes.

1.Developing new measurements for characterizing ultrafine aerosol physico-chemical properties and their impacts on climate

a.The chemical composition of atmospheric nanoparticles

The ability to characterize the molecular constituents in atmospheric nanoparticles, which is the subset of ultrafine particles whose diameters are smaller than 50 nm, is one of the greatest challenges in aerosol science. This is because these measurements require the characterization of highly non-volatile compounds, which are generally not amenable to study. In addition, rapid timescales for the growth of nanoparticles require measurements to be made at temporal resolutions as small as 10 minutes. The size of these nanoparticles conspires against such efforts, since many existing instruments require micrograms of aerosol and thus require collection times of at least 3 hours. Because of this there is still much that is not known about the species contribute to the formation and growth of particles in the atmosphere. Without this knowledge, we cannot adequately predict the impacts of aerosols in chemistry and climate. Meeting these challenges is of fundamental importance not only to the atmospheric sciences, but also to various engineering applications relating to the development of new materials and the control of particulate contaminates in microelectronics and nano-machine technologies.

To address the need for measuring the chemical composition of atmospheric nanoparticles, the UA group has teamed with Peter McMurry at the University of Minnesota to develop the Thermal Desorption Chemical Ionization Mass Spectrometer (TDCIMS). The TDCIMS is an instrument that is capable of measuring the molecular composition of particles as small as 4 nm (typically 8 nm in ambient air). It accomplishes this with a sensitivity that makes it possible to measure the molecular composition of nanoparticles at ambient concentrations in the atmosphere. Figure 1 shows a flow chart that describes TDCIMS operation. Aerosols are first charged, then size resolved and collected by electrostatic deposition onto a platinum (Pt) filament. The collection time varies with particle size and concentration, but usually ranges from 5 – 15 min. Then the filament is slid into the ionization region of an Atmospheric Pressure Chemical Ionization Mass Spectrometer (APCIMS), where it is resistively heated to evaporate the particles. The desorbed molecules are ionized by proton and electron transfer with protonated water clusters or oxygen anion/water clusters. Ions are then transferred to a triple quadrupole mass spectrometer for mass analysis.

During 2008, development efforts with the TDCIMS have focused on quantifying its sensitivity to various organic acids and amines. A manuscript summarizing the response to organic acids was published in the past year . Our studies show that the instrument sensitivity is relatively constant for most compounds that are ionized by our chemical ionization reagents (that is, for those species for which the proton or electron transfer process is exothermic).

During 2008, the UA group has developed other new instruments to study the formation of atmospheric aerosols and their impacts on climate. An ion trap mass spectrometer was built by visiting German Research Foundation postdoc Andreas Held and interfaced with a redesigned electrostatic nanoparticle sampler for measuring nanoparticle chemical composition using TDCIMS. Figure 2 shows results using this new instrument from a recent study of the formation and deposition of ultrafine aerosols at NCAR's Marshall Field Site. A manuscript describing this new instrument is in review . Dr. Held also completed the design of a conditional sampling inlet which works with the TDCIMS to obtain size-resolved nanoparticle chemical flux. This instrument was deployed at Marshall Field Site and at the BEACHON Southern Rocky Mountain experimental site in 2008. The latter measurements were performed by Washington State University graduate student Rasa Grivicke, who will also analyze the data.

b.Other instrument development activities

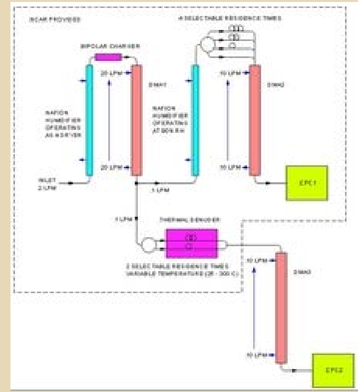

Figure 4. A schematic of the Hygroscopicity and Volatility Tandem Differential Mobility Analyzer being assembled at NCAR in collaboration with the University of Toronto.

High resolution figure

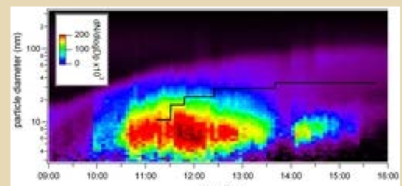

Figure 5. Contour plot of the particle size distribution on 16 March 2006 in Tecamac, Mexico, during the MILAGRO campaign, show a new particle formation "tomato" event that started just before 10am local time. Also plotted in black is the particle diameter used for TDCIMS chemical composition measurements.

High resolution figure

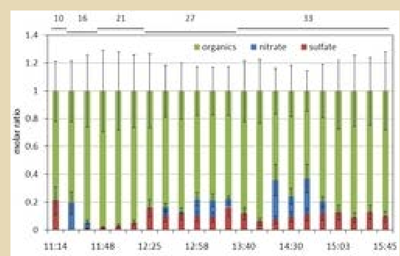

Figure 6. TDCIMS measurements of the molar ratio of sulfate, nitrate, and organics during 16 March 2006 event. Index above plot indicates the mass-weighted geometric mean diameter, in nanometers, of measured particles.

High resolution figure

Figure 7. Main 30 m tower surrounded by Ponderosa pine at the Manitou Experimental Forest Observatory.

High resolution figure

Work continued on developing a scanning mobility particle sizer for the GV aircraft. Design of the instrument is nearing completion with the goal of flight testing the system in 2009. Figure 3 shows an assembly drawing of this instrument, which features two differential mobility analyzers that allow the measurement of size distributions from 3 to 500 nm at atmospheric pressure, or 7 to 300 nm at the maximum flight altitude of 51000 feet.

A hygroscopicity and volatility tandem differential mobility analyzer was designed and assembled in 2008 that can measure size-resolved aerosol hygroscopic growth factors at 90% RH at user selectable residence times of 1, 2, 5 and 28 s, as well as size-resolved aerosol volatility at user selectable temperatures from room temperature to 300 °C and at user selectable residence times of 0.8 and 10.5 s. This instrument operates autonomously and will be used in the 2009 OASIS field study in Barrow, AK. Those measurements will be conducted in collaboration with Dr. Jon Abbatt's research group from the University of Toronto. A schematic of this instrument is shown in Figure 4.

2.Studying the growth of particles formed by nucleation

a.TDCIMS measurements from the MILAGRO field study in Tecamac, Mexico

There are presently huge uncertainties in predictions of the role of aerosols in climate, especially as related to cloud formation and precipitation . The use of global models to assess these impacts is at its infancy, yet one such study suggests that new particle formation can contribute up to 40% of the cloud condensation nuclei (CCN) at the boundary layer, and 90% in the remote troposphere . Field observations of new particle formation and, most importantly, the subsequent growth are needed to support such model developments.

During 2008 the UA group has continued work on the analysis of TDCIMS data acquired during the March 2006 MILAGRO campaign, in which TDCIMS measurements and particle size distributions were acquired at the ground-based "T1" site in Tecamac, Mexico . The particle formation events observed in Tecamac were unlike any they had seen. New particle formation was so vigorous that sub-10 nm particles were constantly being formed even as the particles were growing rapidly by condensation of low-volatility vapors. This phenomenon, looks like a tomato when plotted as a time series of particle size distribution, so we refer to these as "tomato events." Figure 5 shows one such tomato event that occurred on 16 March 2006. The shape of this size distribution made it particularly challenging to calculate the growth rates, since the peak of the distribution of the growing nanoparticles was obscured by the new sub-10 nm particles that were simultaneously being formed. A new technique, developed by UMN graduate student Kenjiro Iida , allowed the accurate determination of the growth rate during these tomato events that employed an additional measurement, the fraction of ambient nanoparticles that were charged. The result was a growth rate for the 16 March event of 22 nm hr-1, among the highest growth rates reported anywhere.

During the 16 March event, the TDCIMS was tuned to measure the composition of particles in the size range from 10 – 35 nm, depicted by the black line plotted over the size distribution in Figure 5. The result, shown in Figure 6, is that about 84% of the detected ions are organic, comprised of organic acids, hydrocarbon-like species, and nitrogen-containing organic compounds. Particulate sulfate which arises from the condensation of sulfuric acid vapor constituted only 10% of the detected ions, and nitrate comprised 6%. Measurements of gaseous sulfuric acid, performed by Greg Huey's research group at the Georgia Institute of Technology, showed that sulfuric acid levels were insufficient to account for the observed growth rate of 22 nm hr-1. The calculated growth rates based on these measurements of sulfuric acid, in which we assume that every sulfuric acid molecule that collides with a particle sticks to the particle and becomes particulate sulfate, amounted to 10% of the observed growth rate. This result that sulfuric acid contributes to 10% of particulate mass, based only on measurements of particle growth rate and sulfuric acid vapor concentration, is the exact same conclusion that one might draw from TDCIMS measurements if the detected ions correspond to the actual species present in particles. This latter issue, the extent to which detected ions correspond to the species in the particles, is the primary focus of current laboratory development with the TDCIMS.

The consequence of this research is that current models that are able to predict the growth of particles on that day would account for the 10% contribution of sulfuric acid to growth rates but entirely miss the 90% contribution of the organics. The result is that these models underestimate the impact of new particle formation on cloud processes. In addition, the prominence of the organic compounds in these particles highlights the need to understand the processes by which organic compounds transform into compounds with extremely low volatilities.

A manuscript on the TDCIMS measurements at the Tecamac site during MILAGRO is also being prepared on the observations of particulate amines. This is an important result as it provides additional support to the notion that amines could be stabilizing ambient nanoparticles through acid-base heterogeneous chemistry. Amines were also observed in Finnish boreal forest aerosols during the EUCAARI-07 campaign.

b.Thermodynamic modeling of organic salt formation as a mechanism for nanoparticle growth.

Based on our observations from Mexico City and Finland, we postulate that amines could be an important atmospheric base in ambient aerosol. Thermodynamic modeling of the organic acid/amine system is being performed to study the potential importance of this heterogeneous chemistry. The current modeling work focuses on two aspects of organic salt formation by organic acids and amines: 1) the relative importance of amines as a base in organic salt formation, as compared to the more commonly considered base, ammonia; and 2) the volatility of organic salts formed from organic acids and amines, particularly when curvature corrections are considered. Preliminary results suggest that amines are an important base, and may contribute significantly to ambient aerosol when their concentrations are within an order of magnitude (or more) of ammonia concentrations. A manuscript describing these studies is currently in preparation.

3.The impacts of biogenic emissions on aerosol formation and growth

During 2008 the UA group continued its close collaboration with the BAI group in order to assess the impact of biogenic emissions on aerosol formation and growth. Globally, secondary organic aerosol (SOA) formed from biogenic emissions surpasses those from anthropogenic precursors . These organic particles have important impacts on climate through their direct interactions with radiation, as well as their ability to modulate cloud condensation nuclei numbers and thus cloud properties and precipitation. These processes exert a substantial influence back upon the Earth system through links to the terrestrial carbon and water cycles (e.g., precipitation regulates plant growth and thus emissions of organic compounds).

To this end, the UA group has performed measurements on aerosol formation from the ozonolysis of Ponderosa pine emissions in their 10 m3 bioaerosol chamber. This work was conducted in the summer 2008 by ASP postdoc Kelley Barsanti along with visiting professor Dr. Rob Griffin and graduate student Meredith Cleveland from the University of New Hampshire. The experiments successfully demonstrated new particle formation from these reactions, which occurred at ambient concentrations. Data analysis is currently underway, and more experiments are planned for the Fall.

Another activity of the UA group in 2008 was to help establish the Manitou Experimental Forest Observatory (MEF) near Woodland Park, CO (Figure 7). The site was developed in close collaboration with several NCAR and university scientists associated with the TIIMES BEACHON project. The site will be used for long-term and intensive measurement campaigns to understand and quantify the role of biogenic aerosol in the complex interactions of the biological, physical and chemical components of the Earth system that regulate and link the terrestrial biogeochemical and water cycles in the southern Rocky Mountains.

To inaugurate the site, during 21 July - 19 September 2008 the UA group coordinated and participated in the TIIMES BEACHON Southern Rocky Mountains 2008 Study. The research objectives for the study included understanding and quantifying the formation of new particles in this setting, and determining the mechanism by which these particles grow to become important participants in atmospheric chemistry and climate. During this study we performed several measurements on new particle formation and nanoparticle composition, including the first measurements of 20 nm nanoparticle chemical flux using conditional sampling with the TDCIMS (see Sec. 1a).

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MARY BARTH

2008 Publications

Kim, D., C. Wang, A. M. L. Ekman, M. C. Barth, P. J. Rasch, 2008: Distribution and direct radiative forcing of carbonaceous and sulfate aerosols in an interactive size-resolving aerosol-climate model. J. Geophys. Res., 113, D16309, doi: 10.1029/2007JD009756.

Abstract

A multimode, two-moment aerosol model has been incorporated in the NCAR CAM3 to develop an interactive aerosol–climate model and to study the impact of anthropogenic aerosols on the global climate system. Currently, seven aerosol modes, namely three for external sulfate and one each for external black carbon (BC), external organic carbon (OC), sulfate/BC mixture (MBS; with BC core coated by sulfate shell), and sulfate/OC mixture (MOS; a uniform mixture of OC and sulfate) are included in the model. Both mass and number concentrations of each aerosol mode, as well as the mass of carbonaceous species in the mixed modes, are predicted by the model so that the chemical, physical, and radiative processes of various aerosols can be formulated depending on aerosol's size, chemical composition, and mixing state. Comparisons of modeled surface and vertical aerosol concentrations, as well as the optical depth of aerosols with available observations and previous model estimates, are in general agreement. However, some discrepancies do exist, likely caused by the coarse model resolution or the constant rates of anthropogenic emissions used to test the model. Comparing to the widely used mass-only method with prescribed geometric size of particles (one-moment scheme), the use of prognostic size distributions of aerosols based on a two-moment scheme in our model leads to a significant reduction in optical depth and thus the radiative forcing at the top of the atmosphere (TOA) of particularly external sulfate aerosols. The inclusion of two types of mixed aerosols alters the mass partitioning of carbonaceous and sulfate aerosol constituents: about 35.5%, 48.5%, and 32.2% of BC, OC, and sulfate mass, respectively, are found in the mixed aerosols. This also brings in competing effects in aerosol radiative forcing including a reduction in atmospheric abundance of BC and OC due to the shorter lifetime of internal mixtures (cooling), a mass loss of external sulfate to mixtures (warming), and an enhancement in atmospheric heating per BC mass due to the stronger absorption extinction of the MBS than external BC (warming). The combined result of including a prognostic size distribution and the mixed aerosols in the model is a much smaller total negative TOA forcing (-0.12 W m-2) of all carbonaceous and sulfate aerosol compounds compared to the cases using one-moment scheme either excluding or including internal mixtures (-0.42 and -0.71 W m-2, respectively). In addition, the global mean all-sky TOA direct forcing of aerosols is significantly more positive than the clear-sky value due to the existence of low clouds beneath the absorbing (external BC and MBS) aerosol layer, particularly over a dark surface. An emission reduction of about 44% for BC and 38% of primary OC is found to effectively change the TOA radiative forcing of the entire aerosol family by -0.14 W m-2 for clear-sky and -0.29 W m-2 for all-sky.

Barthe, C., M. C. Barth, 2008: Evaluation of a new lightning-produced NOx parameterization for cloud resolving models and its associated uncertainties. Atmos. Chem. Phys., 8, 4691-4710.

Abstract

A new parameterization of the lightning-produced NOx has been developed for cloud-resolving models. This parameterization is based on the unique characteristics of identifying which convective cells are capable of producing lightning based on a vertical velocity threshold and estimating the lightning flash rate in each convective cell from the non-precipitation and precipitation ice mass flux product. Further, the source location is filamentary instead of volumetric as in most previous parameterizations.

This parameterization has been tested on the 10 July 1996 Stratospheric-Tropospheric Experiment: Radiation, Aerosols and Ozone (STERAO) storm. Comparisons of the simulated flash rate and NO mixing ratio (control experiment) with observations at different locations and stages of the storm show good agreement. An individual flash produces on average 121±41 moles of NO (7.3±2.5×1025 molecules NO) for the simulated high cloud base, high shear storm that is dominated by intra-cloud flash activity. Sensitivity tests have been performed to study the impact of the flash rate, the cloud-to-ground flash ratio, the flash length, the spatial distribution of the NO molecules, and the production rate per flash on the NO concentration and distribution. Results show a strong impact from the flash rate, the spatial placement of the lightning-NOx source and the number of moles produced per flash. On the other hand, the simulations show almost no impact from the different cloud-to-ground (CG) ratios and the lightning-NOx production rates per CG flash used as input to the model.

Kim, S.-W., C.-H. Moeng, J. C. Weil, M. C. Barth, 2007: Comment on "Fumigation of pollutants in and above the entrainment zone into a growing convective boundary layer: A large-eddy simulation". Atmos. Environ., 41, 7679-7682, doi: 10.1016/j.atmosenv.2007.07.017.

MMM Research Catalog

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MARY BARTH

General Information

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Vita

Research Focus FY08:

Dr. Barth's research focuses on how clouds affect atmospheric chemistry and on how chemistry can affect cloud properties. This research is done using numerical models for different spatial scales.

Most of her recent research has focused on thunderstorms and chemistry. Dr. Barth is conducting numerical simulations with the Weather Research and Forecasting model coupled with gas and aqueous-phase chemistry to elucidate the processes that control the distribution of chemical species in thunderstorms. Further, she is a Principal Investigator of the Deep Convective Clouds and Chemistry (DC3) field experiment that seeks to characterize the effect of midlatitude, continental convection on the transport and transformation of atmospheric constituents.

Dr. Barth is also examining the influence of boundary layer processes on chemical reaction rates. To do this, Dr. Barth has coupled lumped hydrocarbon chemistry with a large eddy simulation. These studies have been extended to cloud-topped boundary layers so that effects of buoyancy, of aqueous chemistry, and of scattering of solar radiation on chemical species redistribution can be assessed.

Community Service FY08:

- 2007-2008: Co-chair of the International Programme Committee for the 10th International Global Atmospheric Chemistry Conference
- 2006–2008: Secretary of the AGU Atmospheric Sciences Section (Atmos. Chem.)
- SOARS Scientific Mentor

Scientific Talks FY08:

- Relevance of- and challenges in the representation of surface and boundary layer processes in mesoscale chemistry transport models, Expert Workshop on the Relevance of Surface and Boundary Layer Processes for the Exchanges of Reactive- and Greenhouse Gases (Wageningen, Netherlands, 10/2007)
- Current and Future Aerosol Studies Using WRF-Chem (Davis, CA USA, 12/2007)
- On the Use of Ice Mass Fluxes to Estimate Total Lightning in Cloud Resolving Models (San Francisco, CA USA, 12/2007)
- Advances in Cloud Chemsitry (New Orleans, LA USA, 01/2008)
- Effect of Deep Convection on Chemical Species Transport in the Central US (Cancun, MEX, 07/2008)
- Convective Scale Transport of CO and O3 During a 5-day Period over the Southern United States (Annecy, FRA, 09/2008)

Publications FY08: (abstracts)

Barthe, C., W. Deierling, M. C. Barth, 2008: The estimation of total lightning from various thundercloud parameters: A cloud-resolving model study. *J. Atmos. Sci.*. (Submitted)

Kim, D., C. Wang, A. M. L. Ekman, M. C. Barth, P. J. Rasch, 2008: Distribution and direct radiative forcing of carbonaceous and sulfate aerosols in an interactive size-resolving aerosol-climate model. *J. Geophys. Res.*, **113**, D16309, doi:

10.1029/2007JD009756.

Barthe, C., M. C. Barth, 2008: Evaluation of a new lightning-produced NOx parameterization for cloud resolving models and its associated uncertainties. *Atmos. Chem. Phys.*, **8**, 4691-4710.

Kim, S.-W., C.-H. Moeng, J. C. Weil, M. C. Barth, 2007: Comment on "Fumigation of pollutants in and above the entrainment zone into a growing convective boundary layer: A large-eddy simulation". *Atmos. Environ.*, **41**, 7679-7682, doi: 10.1016/j.atmosenv.2007.07.017.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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BHATTACHARYYA, RAMIT

Spontaneous formations of current sheets and break up of magnetic flux surfaces

According to Parker [1, 2], magnetic tangential discontinuities are inevitable in three dimensional magnetized plasmas of physical importance. The physics compelling this is the preservation of topology by the ideal plasma (perfectly conducting) as it dynamically relaxes to an equilibrium state. For most initial states in 3D, the preservation of topology will force the plasma to shear discontinuously and form tangential discontinuities in the process. The significance of this fundamental process can be found by noting that according to Ampere's law, discontinuous magnetic fields generate current sheets. In real plasma, resistivity is very small but non-zero and is a dominant effect at the small scales. The current sheets formed in such plasmas then do not collapse to zero thickness but are dissipated resistively to heat the solar atmosphere.

In collaboration with B. C. Low (HAO) and Piotr Smolarkiewicz (MMM), the current sheet formation in a three dimensional incompressible viscous magnetofluid under the condition of perfect electrical conductivity is studied through numerical simulations. A novel feature of these calculations is the description of untwisted magnetic fields in terms of flux surfaces of known geometrical properties. As the viscous plasma evolves in time, different sections of the same flux surface or the same section of the different flux surfaces with opposing magnetic fields may press into each other and generate current sheets in the process.

The key to this numerical experiment is the preservation of magnetic topology in the limit of zero resistive dissipation which relates to the numerical accuracy of the code in representing the ideal induction equation. For our calculations we are using the EULAG modeling system (see Prusa, Smolarkiewicz & Wyszogrodzki [3], for a recent review) customized for the problem at hand.

The first set of simulations, with static flow and cylindrically-shaped flux surfaces as initial state in a triply periodic Cartesian domain has already been completed. The results show all the leading signs of current sheet formation. Figure 1 represents a set of cylindrical flux surfaces with length in z-direction. With time, as the flow builds up, different sections of these surfaces interact with each other and undulate. For these particular calculations, viscosity is small but finite and physical electrical resistivity is zero. From 96 time units (seconds) onwards, numerical resistive dissipation sets in the system and the flux surfaces start to decay. Figure 2 represents the time evolution of a transverse cut of these surfaces as they undulate in time. The future direction for this work is to include boundary conditions related to the solar corona, as well as compressible flow. A fundamental problem of interest for future study is to address the formation of these discontinuities in finite time as described in the work of Grauer and Marliani [4].

[1] E. N. Parker 1994, Spontaneous current sheets in magnetic fields, Oxford University Press
[2] E. N. Parker 2007, Conversations on electric and magnetic fields in the cosmos, Princeton University Press
[3] Prusa, Smolarkiewicz and Wyszogrodzki 2008, Computers & Fluids 37, 1193-1207
[4] R. Grauer & C. Marliani 2000, PRL 84, 4850

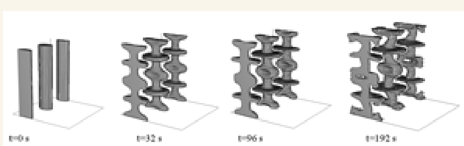

Figure 1 caption: *Temporal evolution of a given set of flux surface*

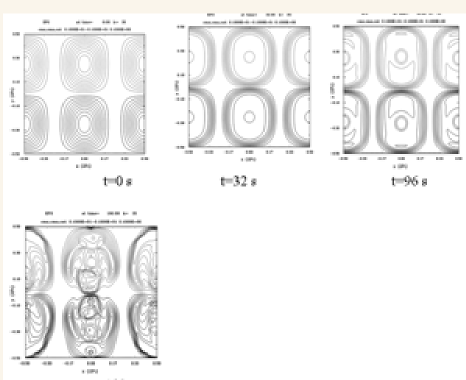

Figure 2 caption: *Time evolution of a transverse cut along the cylinder axis for the flux surfaces of Fig. 1. The observed necking and breaking of flux surfaces as the numerical dissipation sets in, is the omnipresent sign for the formation of current sheets during the evolution. Calculations are also done with different viscosity values. The results are essentially the same with effects of numerical resistive dissipation being pronounced at later times.*

HAO Research Catalog

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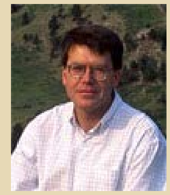
CGD 2008 PROFILES IN SCIENCE: DR. GORDON BONAN

Summary of achievements

Gordon Bonan's research examines land-atmosphere interactions, especially the ecological, hydrological, and biogeochemical processes by which terrestrial ecosystems affect climate. He studies natural and human changes in land cover and ecosystems functions and their effects on climate, water resources, and biogeochemistry. He develops and uses climate, hydrological, and ecosystem models to study the influence of the biosphere on climate. Publications for 2008 highlight the role of forests as forcings and feedbacks in the climate system, the development of urban land cover parameterizations for climate models, improvements to the hydrologic cycle in the Community Land Model (CLM3.5), and the importance of accurate representation of snow and Arctic vegetation for climate simulation.



Gordon Bonan

Publications

G.B. Bonan. 2008: Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. Science, 320:1444-1449, doi:10.1126/science.1155121.

Abstract: The world's forests influence climate through physical, chemical, and biological processes that affect planetary energetics, the hydrologic cycle, and atmospheric composition. These complex and nonlinear forest-atmosphere interactions can dampen or amplify anthropogenic climate change. Tropical, temperate, and boreal reforestation and afforestation attenuate global warming through carbon sequestration. Biogeophysical feedbacks can enhance or diminish this negative climate forcing. Tropical forests mitigate warming through evaporative cooling, but the low albedo of boreal forests is a positive climate forcing. The evaporative effect of temperate forests is unclear. The net climate forcing from these and other processes is not known. Forests are under tremendous pressure from global change. Interdisciplinary science that integrates knowledge of the many interacting climate services of forests with the impacts of global change is necessary to identify and understand as yet unexplored feedbacks in the Earth system and the potential of forests to mitigate climate change.

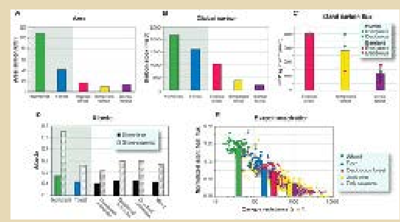


Figure 1.

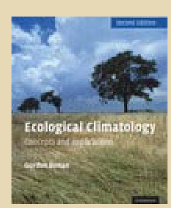
High resolution figure

Figure caption: Biogeochemical (carbon) and biogeophysical (albedo and evapotranspiration) processes by which terrestrial ecosystems affect climate (SOM). (A and B) Geographic extent and total (plant and soil) carbon stock of nonforest (green) and forest (blue) biomes (2). Individual forest biomes are also shown and sum to the forest total. (C) Net ecosystem production (NEP) for tropical, temperate, and boreal forest (47). Individual symbols shown mean NEP for humid evergreen tropical forest, three types of temperate forest, and three types of boreal forest. Vertical bars show NEP averaged across forest types. (D) Satellite-derived direct-beam albedo for snow-covered and snow-free nonforest (green) and forest (blue) biomes (48). Also shown are individual forest biomes. (E) Evapotranspiration normalized by its equilibrium rate in relation to canopy resistance for wheat, corn, temperate deciduous forest, boreal jack pine conifer forest, and oak savanna (49, 50). Shown are individual data points and the mean for each vegetation type.

Bonan, G.B. 2008. Ecological Climatology: Concepts and Applications. 2nd edition. Cambridge University Press, Cambridge. 568 pages.

Descption: This book introduces an interdisciplinary framework to understand the interaction between terrestrial ecosystems and climate change. It reviews basic meteorological, hydrological and ecological concepts to examine the physical, chemical and biological processes by which terrestrial ecosystems affect and are affected by climate. The textbook is written for advanced undergraduate and graduate students studying ecology, environmental science, atmospheric science and geography. The central argument is that terrestrial ecosystems become important determinants of climate through their cycling of energy, water, chemical elements and trace gases. This coupling between climate and vegetation is explored at spatial scales from plant cells to global vegetation geography and at

Figure 2. Ecological Climatology.



timescales of near instantaneous to millennia. The text also considers how human alterations to land become important for climate change. This restructured edition, with updated science and references, chapter summaries and review questions, and over 400 illustrations, including many in colour, serves as an essential student guide.

Oleson, K.W., G.B. Bonan, J. Feddema, M. Vertenstein, and C.S.B. Grimmond, 2008: An urban parameterization for a global climate model. 1. Formulation and evaluation for two cities. J. Appl. Meteorol. Clim., 47, 1038-1060, doi:10.1175/2007JAMC1597.1.

Abstract: Urbanization, the expansion of built-up areas, is an important yet less studied aspect of land use/cover change in climate science. To date, most global climate models used to evaluate effects of land use/cover change on climate do not include an urban parameterization. Here, we describe the formulation and evaluation of a parameterization of urban areas that is incorporated into the Community Land Model, the land surface component of the Community Climate System Model. The model is designed to be simple enough to be compatible with structural and computational constraints of a land surface model coupled to a global climate model, yet complex enough to explore physically-based processes known to be important in determining urban climatology. The city representation is based upon the 'urban canyon' concept which consists of roofs, sunlit and shaded walls, and canyon floor. The canyon floor is divided into pervious (e.g., residential lawns, parks) and impervious (e.g., roads, parking lots, sidewalks) fractions. Trapping of longwave radiation by canyon surfaces and solar radiation absorption and reflection is determined by accounting for multiple reflections. Separate energy balances and surface temperatures are determined for each canyon facet. A one-dimensional heat conduction equation is solved numerically for a ten-layer column to determine conduction fluxes into and out of canyon surfaces. Model performance is evaluated against measured fluxes and temperatures from two urban sites. Results indicate the model does a reasonable job of simulating the energy balance of cities.

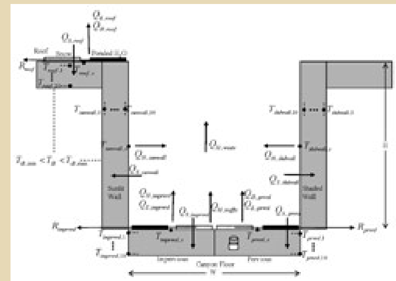


Figure 3.

High resolution figure

Figure caption: Schematic overview of the modeled urban land-unit. The canyon consists of roof, sunlit and shaded walls of height *H*, and a canyon floor of width *W* divided into pervious and impervious fractions. For each of these surfaces, temperatures (T), sensible (Q_H), latent (Q_E), and storage (Q_S) heat fluxes are simulated. Temperatures for each urban surface u include surface temperature ($T_{u,s}$) and internal temperatures for 10 layers ($T_{u,1\ldots10}$). An internal building temperature (T_{iB}) is simulated that can be held at prescribed comfort levels, $T_{iB,min}$ and $T_{iB,\ max}$, thereby simulating heating and/or air conditioning. Hydrology on the roof and canyon floor is simulated, walls are hydrologically inactive. Snowpacks can form on the active surfaces. A certain amount of liquid water is allowed to pond on these surfaces which supports evaporation. Snow melt water or water in excess of the maximum ponding depth runs off (R_{roof}, $R_{imprvrd}$, R_{prvrd}). The pervious canyon floor has a soil moisture store to support evaporation. Anthropogenic fluxes from traffic ($Q_{H,traffic}$) or other sources such as heating and/or air conditioning waste heat ($Q_{H,waste}$) can be accommodated. Incident, reflected, and net solar and longwave radiation are calculated for each individual surface but are not shown for clarity.

Support: This research was supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402, the National Science Foundation grants ATM-0107404 and ATM-0413540, the National Center for Atmospheric Research Water Cycle Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives, and the University of Kansas, Center for Research.

Oleson, K.W., G.B. Bonan, J. Feddema, and M. Vertenstein, 2008: An urban parameterization for a global climate model. 2. Sensitivity to input parameters and the simulated urban heat island in offline simulations. J. Appl. Meteorol. Clim., 47, 1061-1076, doi:10.1175/2007JAMC1598.1.

Abstract: In a companion paper (Oleson et al. 2007), we presented a formulation and evaluation of an urban parameterization designed to represent the urban energy balance in the Community Land Model. Here we test the robustness of the model through sensitivity studies and evaluate the model's ability to simulate urban heat islands in different environments. Findings show that heat storage and sensible heat flux are most sensitive to uncertainties in the input parameters within the atmospheric and surface conditions considered here. The sensitivity studies suggest that attention should be paid to not only accurately characterizing the structure of the urban area (e.g., height to width ratio), but also to the input data reflecting the thermal admittance properties of each of the city surfaces. Simulations of the urban heat island show that the urban model is able to capture typical observed characteristics of urban climates qualitatively. In particular, the model produces a significant heat island that increases with height to width ratio. In urban areas, daily minimum temperatures increase more than daily maximum temperatures resulting in a reduced diurnal temperature range compared to equivalent rural environments. The magnitude and timing of the heat island vary tremendously depending on the prevailing meteorological conditions and the

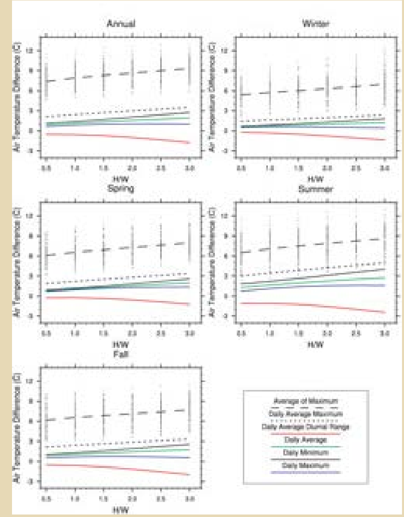


Figure 4.

High resolution figure

characteristics of surrounding rural environments. The model also correctly increases the Bowen ratio and canopy air temperatures of urban systems as impervious fraction increases. In general, these findings are in agreement with those observed for real urban ecosystems. Thus, the model appears to be a useful tool for examining the nature of the urban climate within the framework of global climate models.

Figure caption: Annual and seasonal (winter-DJF, spring-MAM, summer-JJA, fall-SON) characteristics of urban and rural air temperature differences. Urban and rural air temperatures, T_{urban} and T_{rural}, are from hourly data as described in the text. The lines indicate air temperature differences averaged over all grid cells. The daily maximum (blue line) is $T_{urban, max}$ - $T_{rural, max}$ (with overbar) where $T_{urban, max}$ and $T_{rural, max}$ are the maximum urban and rural air temperature in a given day, and the overbar represents the average over the number of days in a given season. Similarly, the daily minimum (solid black line) is $T_{urban, min}$ - $T_{rural, min}$ (with overbar). The daily average (green line) is $T_{urban, avg}$ - $T_{rural, avg}$ (with overbar) where $T_{urban, avg}$ and $T_{rural, avg}$ are the daily average of the hourly urban and rural air temperatures. The daily average diurnal range (red line) is ($T_{urban, max}$ - $T_{urban, min}$) - ($T_{rural, max}$ - $T_{rural, min}$) (with overbar). The dots represent the maximum T_{urban} - T_{rural}at each grid cell for a given height to width ratio, while the long dashed line (average of maximum) represents the average of these at each height to width ratio.

Support: This research was supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402, the National Science Foundation grants ATM-0107404 and ATM-0413540, the National Center for Atmospheric Research Water Cycle Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives, and the University of Kansas, Center for Research.

Cook, B.I., G.B. Bonan, S. Levis, and H.E. Epstein. 2008: The thermoinsulation effect of snow cover within a climate model. Climate Dynamics, 31:107-124, doi:10.1007/s00382-007-0341-y.

Abstract: We use a state of the art climate model (CAM3-CLM3) to investigate the sensitivity of surface climate and land surface processes to treatments of snow thermal conductivity. In the first set of experiments, the thermal conductivity of snow at each grid cell is set to that of the underlying soil (SC-SOIL), effectively eliminating any insulation effect. This scenario is compared against a control run (CTRL), where snow thermal conductivity is determined as a prognostic function of snow density. In the second set of experiments, high (SC-HI) and low (SC-LO) thermal conductivity values for snow are prescribed, based on upper and lower observed limits. These two scenarios are used to envelop model sensitivity to the range of realistic observed thermal conductivities. In both sets of experiments, the high conductivity/low insulation cases show increased heat exchange, with anomalous heat fluxes from the soil to the atmosphere during the winter and from the atmosphere to the soil during the summer. The increase in surface heat exchange leads to soil cooling of up to 20 K in the winter, anomalies that persist (though damped) into the summer season. The heat exchange also drives an asymmetric seasonal response in near-surface air temperatures, with boreal winter anomalies of +6 K and boreal summer anomalies of -2 K. On an annual basis there is a net loss of heat from the soil and increases in ground ice, leading to reductions in infiltration, evapotranspiration, and photosynthesis. Our results show land surface processes and the surface climate within CAM3-CLM3 are sensitive to the treatment of snow thermal conductivity.

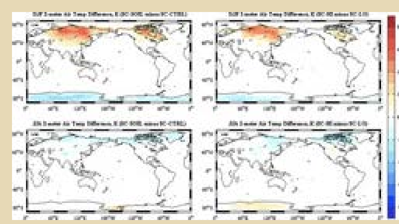


Figure 5.

High resolution figure

Figure caption: Differences in 2-meter air temperature (degrees C) for SC-SOIL minus CTRL and SC-HI minus SC-LO, for seasons DJF and JJA. Top row shows results from boreal winter (DJF) comparison, bottom row shows results from boreal summer (JJA) comparison.

Stockli, R., D. M. Lawrence, G. Y. Niu, K. W. Oleson, P. E. Thornton, Z. L. Yang, G. B. Bonan, A. S. Denning, and S. W. Running. 2008. Use of FLUXNET in the community land model development. Journal of Geophysical Research-

Biogeosciences, doi:10.1029/2007JG000562.

Abstract: The Community Land Model version 3 (CLM3.0) simulates land-atmosphere exchanges in response to climatic forcings. CLM3.0 has known biases in the surface energy partitioning as a result of deficiencies in its hydrological and biophysical parameterizations. Such models, however, need to be robust for multidecadal global climate simulations. FLUXNET now provides an extensive data source of carbon, water and energy exchanges for investigating land processes, and it encompasses a global range of ecosystem-climate interactions. Data from 15 FLUXNET sites are used to identify and improve model deficiencies. Including a prognostic aquifer, a bare soil evaporation resistance formulation and numerous other changes in the model result in a significantly improved soil hydrology and energy partitioning. Terrestrial water storage increased by up to 300 mm in warm climates and decreased in cold climates. Nitrogen control of photosynthesis is revealed as another missing process in the model. These improvements increase the correlation coefficient of hourly and monthly latent heat fluxes from a range of 0.5-0.6 to the range of 0.7-0.9. RMSE of the simulated sensible heat fluxes decrease by 20-50%. Primary production is overestimated during the wet season in mediterranean and tropical ecosystems. This might be related to missing carbon-nitrogen dynamics as well as to site-specific parameters. The new model (CLM3.5) with an improved terrestrial water cycle should lead to more realistic land-atmosphere exchanges in coupled simulations. FLUXNET is found to be a valuable tool to develop and validate land surface models prior to their application in computationally expensive global simulations.

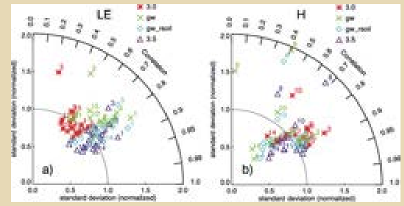


Figure 6.

High resolution figure

Figure caption: Performance of four model versions at 15 FLUXNET towers (numbers 1-15). Statistics in the Taylor diagram are derived from hourly simulated and observed LE and H fluxes. Legend: CLM3.0: red asterisks; CLMgw: green crosses; CLMgw_rsoil: cyan diamonds; CLM3.5: violet triangles. In CLM3.0 H is off-scale for the two tropical sites 8 and 9 (and therefore not shown).

Support: We acknowledge the NASA Energy and Water Cycle Study (NEWS) grant NNG06CG42G as the main funding source of this study.

Oleson, K. W., et al., 2008: Improvements to the Community Land Model and their impact on the hydrological cycle. J. Geophys. Res., 113, G01021, doi:10.1029/2007JG000563.

Abstract: The Community Land Model version 3 (CLM3) is the land component of the Community Climate System Model (CCSM). CLM3 has energy and water biases resulting from deficiencies in some of its canopy and soil parameterizations related to hydrological processes. Recent research by the community that utilizes CLM3 and the family of CCSM models has indicated several promising approaches to alleviating these biases. This paper describes the implementation of a selected set of these parameterizations and their effects on the simulated hydrological cycle. The modifications consist of surface data sets based on Moderate Resolution Imaging Spectroradiometer products, new parameterizations for canopy integration, canopy interception, frozen soil, soil water availability, and soil evaporation, a TOPMODEL-based model for surface and subsurface runoff, a groundwater model for determining water table depth, and the introduction of a factor to simulate nitrogen limitation on plant productivity. The results from a set of offline simulations were compared with observed data for runoff, river discharge, soil moisture, and total water storage to assess the performance of the new model (referred to as CLM3.5). CLM3.5 exhibits significant improvements in its partitioning of global evapotranspiration (ET) which result in wetter soils, less plant water stress, increased transpiration and photosynthesis, and an improved annual cycle of total water storage. Phase and amplitude of the runoff annual cycle is generally improved. Dramatic improvements in vegetation biogeography result when CLM3.5 is coupled to a dynamic global vegetation model. Lower than observed soil moisture variability in the rooting zone is noted as a remaining deficiency.

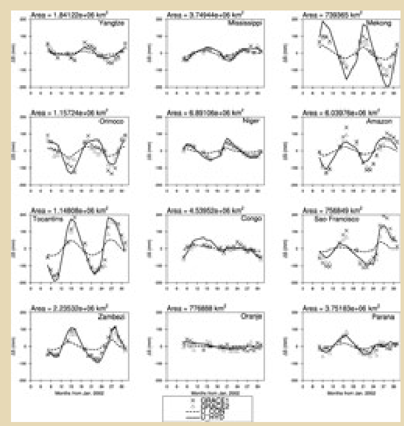


Figure 7.

High resolution figure

Figure caption: Total water storage anomalies (mm) for U_HYD (CLM3.5) and U_CON (CLM3.0) compared to two sources of GRACE data (GRACE1 [Seo and Wilson, 2005] and GRACE2 [Chen et al., 2005]). Model total water storage anomalies are calculated from the sum of snow water, canopy water, total column soil water, and aquifer water. GRACE data were interpolated to the model resolution.

Support: This work was supported by the NCAR Water Cycles Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives.

B. I. Cook, G. B. Bonan, S. Levis, and H. Epstein. 2008: Rapid vegetation responses and feedbacks amplify climate model response to snow cover changes. Climate Dynamics, 30:391-406, doi:10.1007/s00382-007-0296-z.

Abstract: We investigate the response of a climate system model to two different methods for estimating snow cover fraction. In the control case, snow cover fraction changes gradually with snow depth; in the alternative scenarios (one with prescribed vegetation and one with dynamic vegetation), snow cover fraction initially increases with snow depth almost twice as fast as the control method. In cases where the vegetation was fixed (prescribed), the choice of snow cover parameterization resulted in a limited model response. Increased albedo associated with the high snow caused some moderate localized cooling (3-5°C), mostly at very high latitudes (>70°N) and during the spring season. During the other seasons, however, the cooling was not very extensive. With dynamic vegetation the change is much more dramatic. The initial increases in snow cover fraction with the new parameterization lead to a large-scale southward retreat of boreal vegetation, widespread cooling, and persistent snow cover over much of the boreal region during the boreal summer. Large cold anomalies of up to 15°C cover much of northern Eurasia and North America and the cooling is geographically extensive in the northern hemisphere extratropics, especially during the spring and summer seasons. This study demonstrates the potential for dynamic vegetation within climate models to be quite sensitive to modest forcing. This highlights the importance of dynamic vegetation, both as an amplifier of feedbacks in the climate system and as an essential consideration when implementing adjustments to existing model parameters and algorithms.

Figure caption: Difference in 2-m air temperature for all four seasons between the dynamic vegetation case and control run (DV-Y97 minus CTRL). Insignificant differences have been masked out.

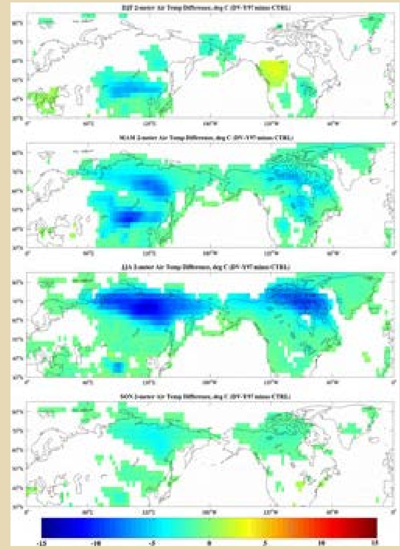


Figure 8.

High resolution figure

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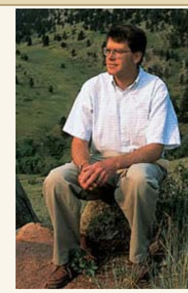
GORDON BONAN

General Information



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Research Focus FY08:

Gordon Bonan's research examines land-atmosphere interactions, especially the ecological, hydrological, and biogeochemical processes by which terrestrial ecosystems affect climate. He studies natural and human changes in land cover and ecosystems functions and their effects on climate, water resources, and biogeochemistry. He develops and uses climate, hydrological, and ecosystem models to study the influence of the biosphere on climate. Publications for 2008 highlight the role of forests as forcings and feedbacks in the climate system, the development of urban land cover parameterizations for climate models, improvements to the hydrologic cycle in the Community Land Model (CLM3.5), and the importance of accurate representation of snow and Arctic vegetation for climate simulation.

Award:

- Co-Recipient: 2008 CCSM Distinguished Achievement Award

Community Service FY08:

- Editorial Board: Global Change Biology
- Search Committee, Atmosphere-Biosphere Interactions faculty hire, AGU-AMS

Scientific Talks FY08:

- Advances in land-climate interactions for earth system models: The Community Land Model (CLM) experience (Vienna, AUT, 04/2008)
- Carbon-nitrogen coupling regulates climate-carbon feedback (Vienna, AUT, 04/2008)
- Contrasting impacts of deforestation in temperate and boreal regions from global and mesoscale simulations (Santa Barbara, CA USA, 01/2008)
- Earth system modeling - land forcings and feedbacks (Boulder, CO USA, 10/2007)
- Revisiting the meteorologically utopian city in a changing climate (Berkeley, CA USA, 11/2007)
- The importance of land cover change in simulating future climates (Boulder, CO USA, 10/2007)

Publications FY08 (abstracts):

Bonan, G., 2008: Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science*, **320**, 1444-1449.

Stockli, R., D. M. Lawrence, G.-Y. Niu, K. W. Oleson, P. Thornton, Z.-L. Yang, G. Bonan, A. Denning, S. Running, 2008: Use of FLUXNET in the community land model development. *J. Geophys. Res.*, **113**, G01025, doi: 10.1029/2007JG000562.

Cook, B., G. Bonan, S. Levis, H. Epstein, 2008: The thermoinsulation effect of snow cover within a climate model. *Clim. Dyn.*, **31**, 107-124.

Oleson, K. W., G.-Y. Niu, Z.-L. Yang, D. M. Lawrence, P. Thornton, P. Lawrence, R. Stockli, R. Dickinson, G. Bonan, S. Levis, A. Dai, T. Qian, 2008: Improvements to the community land model and their impact on the hydrological cycle. *J. Geophys. Res.*, **113**, G01021, doi: 10.1029/2007JG000563.

Oleson, K. W., G. B. Bonan, J. Feddema, M. Vertenstein, C. S. B. Gimmond, 2008: An urban parameterization for a global climate model. Part I. Formulation and evaluation for two cities. *J. Appl. Meteor. Climat.*, **47**, 1038-1060, doi: 10.1175/2007JAMC1597.1.

Oleson, K. W., G. B. Bonan, J. Feddema, M. Vertenstein, 2008: An urban parameterization for a global climate model. Part II. Sensitivity to input parameters and the simulated urban heat island in offline simulations. *J. Appl. Meteor. Climat.*, **47**, 1061-1076, doi: 10.1175/2007JAMC1598.1.

Cook, B. I., G. B. Bonan, S. Levis, H. E. Epstein, 2008: Rapid vegetation responses and feedbacks amplify climate model response to snow cover changes. *Clim. Dyn.*, **30**, 391-406, doi: 10.1007/s00382-007-0296-z.

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Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. ESTHER BRADY

Summary of achievements

Esther Brady's efforts in FY2008 have been focused in the area of the ocean's response to glacial/interglacial climate change using CCSM3. This year's PAGES publication with Bette Otto-Bliesner is an intercomparison of PMIP2 (Paleoclimate Modelling Intercomparison Project 2) climate model simulations of the Last Glacial Maximum at 21,000 years before present to proxy climate records of deep ocean thermohaline composition and sea ice extent in order to evaluate the capability of climate models to produce climate conditions different than today's. Further work with Bette Otto-Bliesner and other PMIP2 collaborators compares the simulated tropical sea surface temperature response at LGM to the MARGO SST proxy reconstructions. Results suggests that as a group the models produce a range of glacial cooling that is comparable to the magnitude of cooling suggested by the proxy reconstructions. However, the models fail to capture the greater spatial heterogeneity in the pattern of cooling found in the reconstructions.

With Bette Otto-Bliesner, Esther has investigated the ocean sensitivity and response to large magnitude freshwater events using the CCSM3 simulation of the Last Glacial Maximum as a base state. This suite of sensitivity experiments to idealized meltwater events will address some of the uncertainties in the proxy record of climate change associated with large meltwater events during the last deglaciation.

Esther Brady in FY2008 worked with Bette Otto-Bliesner and Zhengyu Liu (Univ. of Wisconsin /Madison) to setup and begin analyzing the simulation of Transient Climate Evolution over the last 21,000 years (TraCE-21), an INCITE project at NCCS/ORNL, using the T31x3 configuration of the CCSM3 with the Dynamic Global Vegetation Model. Preliminary results were presented in a poster at the Breckenridge June CCSM meeting comparing the glacial/interglacial rates of ocean ventilation as estimated from the first 5000 years of the TraCE-21 experiment (including spin up) and the multi-millennial Transient Mid-Holocene CCSM3 simulation (from 6000 to 3600 years before present).

Publications

Otto-Bliesner, B.L., and E.C. Brady, 2008: PMIP2 Climate Model-Proxy Data Intercomparisons for LGM. PAGES Newsletter, 16, 18-20.

Abstract: PMIP initially focused on two periods, the Last Glacial Maximum (LGM; ca. 21 cal kyr BP) and the mid-Holocene (MH; ca. 6 cal kyr BP). The experiments were designed to examine the climate response to Milankovitch orbital forcings for the MH and the presence of large ice sheets and low greenhouse gas (GHG) concentrations for the LGM. Seventeen modeling groups participated in simulations of these time periods with atmosphere-only models (PMIP1), and twelve groups in the second phase of the project (PMIP2) using ocean-atmosphere or ocean-atmosphere-vegetation models. With the incorporation of coupled atmosphere-ocean-sea ice models into PMIP2, new comparisons to proxy data can now be used in evaluating the capabilities of current climate models to simulate climate conditions different than present. Here, we describe two such com-parisons of the PMIP2 LGM simulations to glacial proxy data: deep-ocean temperatures and salinities in the Atlantic Ocean, and sea ice extent around Antarctica.

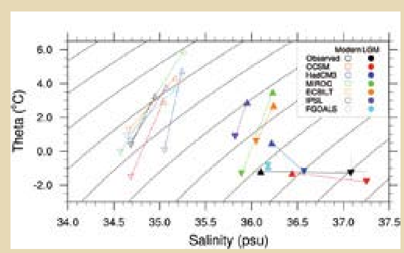

Figure 1.

High resolution figure

Figure caption: Theta (potential temperature) and salinity for modern (open symbols) and LGM (filled symbols) estimated from data (black symbols with error bars) at ODP sites (Adkins et al., Science, 2002) and predicted by PMIP2 models. Site 981 ((Δ)) is located in the North Atlantic (Feni Drift, 55°N, 15°W, 2184 m). Site 1093 ( ) is located in the South Atlantic (Shona Rise, 50°S, 6°E, 3626 m). Only CCSM included a 1 psu adjustment of ocean salinity at initialization to account for fresh water frozen into LGM ice sheets; predicted salinities for the other models have been adjusted to allow comparison.

Hu, A., B.L. Otto-Bliesner, G.A. Meehl, W. Han, C. Morrill, E.C. Brady, and B. Briegleb, 2008: Response of Thermohaline Circulation to Freshwater Forcing under Present-Day and LGM Conditions. J. Climate, 21, 2239-2258.

Abstract: Responses of the thermohaline circulation (THC) to freshwater forcing (hosing) in the subpolar North Atlantic Ocean under present-day and the last glacial maximum (LGM) conditions are investigated using the National Center for Atmospheric Research Community Climate System Model versions 2 and 3. Three sets of simulations are analyzed, with each set including a control run and a freshwater hosing run. The first two sets are under present-day conditions with an

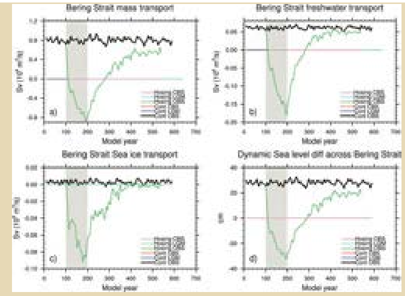

Figure 2.

High resolution figure

open and closed Bering Strait. The third one is under LGM conditions, which has a closed Bering Strait. Results show that the THC nearly collapses in all three hosing runs when the freshwater forcing is turned on. The full recovery of the THC, however, is at least a century earlier in the open Bering Strait run than the closed Bering Strait and LGM runs. This is because the excessive freshwater is diverged almost equally toward north and south from the subpolar North Atlantic when the Bering Strait is open. A significant portion of the freshwater flowing northward into the Arctic exits into the North Pacific via a reversed Bering Strait Throughflow, which accelerates the THC recovery. When the Bering Strait is closed, this Arctic to Pacific transport is absent and freshwater can only be removed through the southern end of the North Atlantic. Together with the surface freshwater excess due to precipitation, evaporation, river runoff, and melting ice in the closed Bering Strait experiments after the hosing, the removal of the excessive freshwater takes longer, and this slows the recovery of the THC. Although the background conditions are quite different between the present-day closed Bering Strait run and the LGM run, the THC responds to the freshwater forcing added in the North Atlantic in a very similar manner.

Figure caption: (a) The 13-yr low-pass-filtered Bering Strait mass, (b) freshwater, (c) ice transports, and (d) the dynamic sea level difference across the Bering Strait from the west side (Alaska side) to the east side (Siberian side). The unit for the transports is Sv and the unit for the dynamic sea level difference is cm. The shading indicates the 100-yr hosing period.

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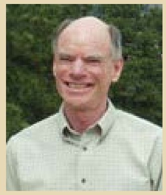
CGD 2008 PROFILES IN SCIENCE: DR. GRANT BRANSTATOR

Summary of achievements



Grant Branstator

Effort during the past year has been primarily devoted to three topics, each concerned with dynamical mechanisms that affect climate fluctuations. In the first project, undertaken jointly with Andrey Gritsun (RAS) and Andrew Majda (NYU), a generalization of the fluctuation-dissipation theorem (FDT) was used to construct response operators for systematic study of the impact of heating on climate statistics. Whereas the conventional FDT leads to operators that give accurate estimates of the response of mean state fields, the generalization produces operators that estimate the response of functionals of state. The resulting operators made it possible to answer optimum forcing/response questions, including finding the most effective means of altering the North Atlantic storm track through tropical heating. In the second project, carried out in collaboration with Jeffrey Yin, the influence of slow circulation fluctuations on the likelihood of exteme wind events in a control integration of CCSM was investigated. To accomplish this a framework was developed for distinguishing two separate effects. One of these is the simple additive effective in which the distribution of possible wind values is shifted by the low-frequency state. The other is a multiplicative effect in which the shape of the distribution is affected. It turns out that in the CCSM simulation the importance of these two effects varies greatly with geographical position. Similar characteristics were found for extreme events in nature. In the third project, completed with Frank Selten (KNMI), two commonly offered explanations for why the regional structure of climate trends might be expected to match the structure of intrinsic modes of variability were tested. This was done by analyzing a large ensemble of climate scenario experiments that had been carried out with CCSM. The ensemble mean circulation trend in this ensemble has the same structure as the model atmosphere's leading mode of variability, namely the Circumglobal Waveguide Pattern. Data analysis and experiments with the stochastically driven linearized equations of motion indicate that linear mechanisms are sufficient to understand most facets of system behavior; the nonlinear concept of regimes, or preferred states, which is the other prominently proposed explanation, does not appear to have much bearing on the GCM's solutions.

Publications

Yin, J. and G. Branstator, 2008: Variations of the Influence of Low Frequency Variability on Lower Tropospheric Extreme Westerly Wind Events. J. Clim, 21,4779-4798.

Abstract: A conceptual framework is developed for quantifying the relationship between low frequency variability and extreme events. In this framework, variability is decomposed into low frequency and synoptic components using complementary 10-day low pass and high pass filters, and a distinction is made between two ways that low frequency variability influences extremes: the additive effect, which neglects the dependence of synoptic variability on the low frequency state, and the multiplicative effect, which is due to the dependence of synoptic variability on the low frequency state. The influence of various factors on the relationship between low frequency variability and extreme events is decomposed and quantified by generating a series of simple synthetic data sets based on different assumptions about low frequency and synoptic variability and their relationship.

These techniques are used to study the relationship between low frequency variability and extreme westerly wind events in three data sets, a 1158-year GCM simulation and two reanalysis data sets, with similar results for all three. Geographical variations in the low frequency-extreme relationship are only partially explained by geographical variations in the low frequency to synoptic variance ratio; the non-Gaussianity of low frequency and synoptic variability and relationship between synoptic variance and the low frequency state are also found to be important. The simple synthetic data sets that include these factors provide good estimates of the magnitude and probability of extremes. Implications for predictability and applications to more complex low frequency-extreme relationships are discussed.

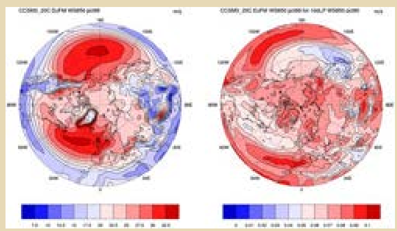


Figure 1.

High resolution figure

Figure caption: Statistics of DJFM 850 hPa zonal winds in CCSM3 control experiment. a) Value of the 99th percentile. b) Fraction of days that exceed the 99th percentile when low-pass values exceed their 90th percentile value.

Meehl, G.A., J.M. Arblaster, G. Branstator, and H. van Loon, 2008: A Coupled Air-Sea Response Mechanism to Solar

Forcing in the Pacific Region. Climate Change, Journal of Climate, 21, 2883-2897.

Abstract: The 11-yr solar cycle [decadal solar oscillation (DSO)] at its peaks strengthens the climatological precipitation maxima in the tropical Pacific during northern winter. Results from two global coupled climate model ensemble simulations of twentieth-century climate that include anthropogenic (greenhouse gases, ozone, and sulfate aerosols, as well as black carbon aerosols in one of the models) and natural (volcano and solar) forcings agree with observations in the Pacific region, though the amplitude of the response in the models is about half the magnitude of the observations. These models have poorly resolved stratospheres and no 11-yr ozone variations, so the mechanism depends almost entirely on the increased solar forcing at peaks in the DSO acting on the ocean surface in clear sky areas of the equatorial and subtropical Pacific. Mainly due to geometrical considerations and cloud feedbacks, this solar forcing can be nearly an order of magnitude greater in those regions than the globally averaged solar forcing. The mechanism involves the increased solar forcing at the surface being manifested by increased latent heat flux and evaporation. The resulting moisture is carried to the convergence zones by the trade winds, thereby strengthening the intertropical convergence zone (ITCZ) and the South Pacific convergence zone (SPCZ). Once these precipitation regimes begin to intensify, an amplifying set of coupled feedbacks similar to that in cold events (or La Niña events) occurs. There is a strengthening of the trades and greater upwelling of colder water that extends the equatorial cold tongue farther west and reduces precipitation across the equatorial Pacific, while increasing precipitation even more in the ITCZ and SPCZ. Experiments with the atmosphere component from one of the coupled models are performed in which heating anomalies similar to those observed during DSO peaks are specified in the tropical Pacific. The result is an anomalous Rossby wave response in the atmosphere and consequent positive sea level pressure (SLP) anomalies in the North Pacific extending to western North America. These patterns match features that occur during DSO peak years in observations and the coupled models.

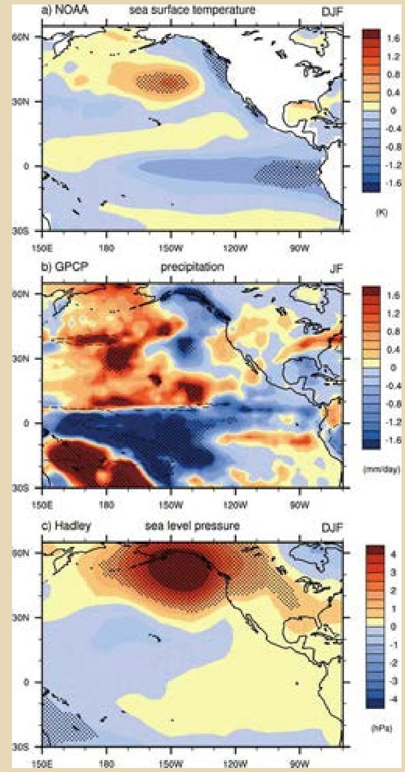


Figure 2.

[High resolution figure]

Figure caption: (a) The average anomalies of SST (°C) in the 11 solar peak years for DJF computed relative to all other years-1883, 1893, 1905, 1917, 1928, 1937, 1947, 1957, 1968, 1979, and 1989—from the NOAA ERSST dataset (available online at http://www.cdc.noaa.gov/cdc/data.noaa.ersst.html). (b) The average tropical rainfall anomalies (mm day-1) for January-February (GPCP gridded precipitation dataset) in the solar peaks in 1979, 1989, and 2000, in comparison to all other years. Dashed line is the 6 mm day-1 contour from the long-term mean climatology. (c) As in (a) but for the average anomalies of SLP (hPa) (Hadley Centre SLP dataset); shading indicates significance at or above the 95% level, indicating the relative magnitude of the anomalies compared to the noise. For further details regarding observed data sources, see van Loon et al. (2007).

Franzke, C., A.J. Majda, and G. Branstator, 2007: The Origin of Nonlinear Signatures of Planetary Wave Dynamics: Mean Phase Space Tendencies and Contributions from Non-Gaussianity. J. Atmos. Sci., 64, 3987-4003.

Abstract: Mean phase space tendencies are investigated to systematically identify the origin of nonlinear signatures and the dynamical significance of small deviations from Gaussianity of planetary low-frequency waves. A general framework for the systematic investigation of mean phase space tendencies in complex geophysical systems is derived. In the special case of purely Gaussian statistics, this theory predicts that the interactions among the planetary waves themselves are the source of the nonlinear signatures in phase space, whereas the unresolved waves contribute only an amplitude-independent forcing, and cannot contribute to any nonlinear signature.

The predictions of the general framework are studied for a simple stochastic climate model. This toy model has statistics that are very close to being Gaussian and a strong nonlinear signature in the form of a double swirl in the mean phase space tendencies of its low-frequency variables, much like recently identified signatures of nonlinear planetary wave dynamics in prototype and comprehensive atmospheric general circulation models (GCMs). As predicted by the general framework for the Gaussian case, the double swirl results from nonlinear interactions of the low-frequency variables. Mean phase space tendencies in a reduced space of a prototype atmospheric GCM are also investigated. Analysis of the dynamics producing nonlinear signatures in these mean tendencies shows a complex interplay between waves resolved in the subspace and unresolved waves. The interactions among the resolved planetary waves themselves do not produce the nonlinear signature. It is the interaction with the unresolved waves that is responsible for the nonlinear dynamics. Comparing this result with the predictions of the general framework for the Gaussian case shows that the impact of the unresolved waves is due to their small deviations from

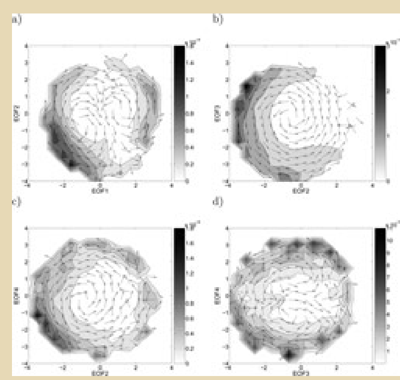


Figure 3.

[High resolution figure]

Gaussianity. This suggests that the observed deviations from Gaussianity, even though small, are dynamically relevant.

Figure caption: Mean phase space tendencies of total energy norm EOFs of QGT21L3. Shading indicates the magnitude in 1 std dev s^{-1}. Arrows are normalized to a unit magnitude. Only those tendencies are displayed with more than 100 contributions in the corresponding box.

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JAMES BRESCH

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Vita

Research Focus FY08:

James Bresch's work involves testing, development, and research on the numerical prediction of mesocale weather systems using the MM5 and WRF models with particular emphasis on real-time forecasts, convective and PBL-scheme behavior.

James Bresch Research Catalog

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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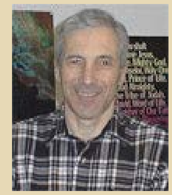
CGD 2008 PROFILES IN SCIENCE: MR. BRUCE BRIEGLEB

Summary of achievements



Bruce Briegleb

As part of the ocean thermohaline circulation, deep water forms in polar regions. While the convective formation processes for these cold, dense waters can be represented reasonably well in global ocean models, in general z-coordinate ocean models are unable to represent the deep penetration of these waters due to coarseness of the horizontal grid, along with the stair-step bottom topography which promotes excessive entrainment of ambient waters. To address this deficiency, I have been working to implement a new ocean parameterization, termed the overflow parameterization, into the ocean component of Community Climate System Model. This new parameterization attempts to represent the subgrid-scale, bottom topographic dense waters that are thought to be the main source of the deep waters. These dense deep waters hug the bottom topography and overflow sills or flow through narrow canyons from polar shelves or shallower polar basins into the abyssal ocean. We have found a workable method to put this parameterization into the POP2 ocean model, and are presently testing the parameterization for a realistically forced ocean. If the results look promising, we will attempt to include this parameterization into CCSM4.

This work was done under the direction of Dr. Gokhan Danabasoglu and Dr. Bill Large of NCAR.

FY2008 work was supported by NSF Grant OCE-0336834 for the Climate Process Team on Gravity Current Entrainment. The computational resources were partially provided by the Scientific Computing Division of the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation.

Publications

Hu, A., B.L. Otto-Bliesner, G.A. Meehl, W. Han, C. Morrill, E.C. Brady, and B. Briegleb, 2008: Response of Thermohaline Circulation to Freshwater Forcing under Present-Day and LGM Conditions. J. Climate, 21, 2239-2258.

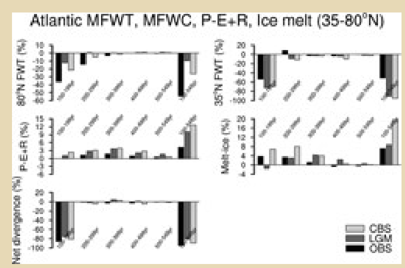


Figure 1.

High resolution figure

Abstract: Responses of the thermohaline circulation (THC) to freshwater forcing (hosing) in the subpolar North Atlantic Ocean under present-day and the last glacial maximum (LGM) conditions are investigated using the National Center for Atmospheric Research Community Climate System Model versions 2 and 3. Three sets of simulations are analyzed, with each set including a control run and a freshwater hosing run. The first two sets are under present-day conditions with an open and closed Bering Strait. The third one is under LGM conditions, which has a closed Bering Strait. Results show that the THC nearly collapses in all three hosing runs when the freshwater forcing is turned on. The full recovery of the THC, however, is at least a century earlier in the open Bering Strait run than the closed Bering Strait and LGM runs. This is because the excessive freshwater is diverged almost equally toward north and south from the subpolar North Atlantic when the Bering Strait is open. A significant portion of the freshwater flowing northward into the Arctic exits into the North Pacific via a reversed Bering Strait Throughflow, which accelerates the THC recovery. When the Bering Strait is closed, this Arctic to Pacific transport is absent and freshwater can only be removed through the southern end of the North Atlantic. Together with the surface freshwater excess due to precipitation, evaporation, river runoff, and melting ice in the closed Bering Strait experiments after the hosing, the removal of the excessive freshwater takes longer, and this slows the recovery of the THC. Although the background conditions are quite different between the present-day closed Bering Strait run and the LGM run, the THC responds to the freshwater forcing added in the North Atlantic in a very similar manner.

Figure caption: The anomalous meridional freshwater transport at 80°N, 35°N; the surface freshwater input anomaly from precipitation, evaporation, and river runoff (P _ E R); the melt-ice flux anomaly; and the net freshwater divergence in the region of the North Atlantic between 35° and 80°N in the three hosing runs. Values shown in these figures are the percentage of the total freshwater anomaly added into the subpolar North Atlantic during the 100-yr hosing period. The bars show the anomalous freshwater transport (or input) in the given period in the figures. Bars from darker to lighter color represent the OBS, LGM, and CBS cases, respectively. Negative (positive) values are freshwater being transported out (added into) the Atlantic between 35° and 80°N.

Legg, S., B. Briegleb, Y. Chang, E. P. Chassignet, G. Danabasoglu, T. Ezer, A. L. Gordon, S. Griffies, R. Hallberg, L. Jackson, W. Large, T. M. Ozgokmen, H. Peters, J. Price, U. Riemenschneider, W. Wu, X. Xu, and J. Yang, 2008: Improving oceanic overflow representation in climate models: The Gravity Current Entrainment Climate Process Team. BAMS, in press.

Abstract: Oceanic overflows are bottom-trapped density currents originating in semi-enclosed basins such as the Nordic seas, or on continental shelves such as the Antarctic shelf. Overflows are the source of most of the abyssal waters, and so play an important role in the large-scale ocean circulation, forming a component of the sinking branch of the thermohaline circulation. As they descend the continental slope, overflows mix vigorously with the surrounding oceanic waters, changing their density and transport significantly. These mixing processes occur on spatial scales well below the resolution of ocean climate models, with the result that deep waters and deep western boundary currents are simulated poorly. The Gravity Current Entrainment Climate Process Team was established by US CLIVAR to accelerate the development and implementation of improved representations of overflows within large-scale climate models, bringing together climate model developers with those conducting observational, numerical and laboratory process studies of overflows. Here the organization of the Climate Process Team is described and a few of the successes and lessons learned during this collaboration are highlighted, with some emphasis on the well-observed Mediterranean overflow. The Climate Process Team has developed several different overflow parameterizations, which are examined in a hierarchy of ocean models, from comparatively well-resolved regional models to the largest-scale global climate models.

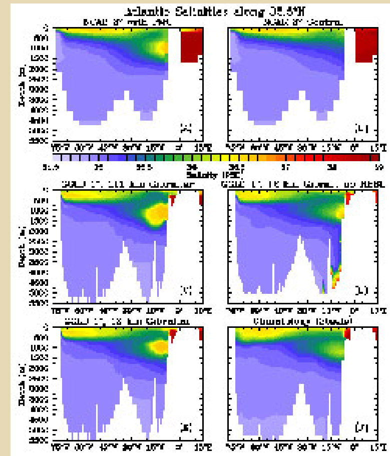


Figure 2.

High resolution figure

Figure caption: Salinity cross-sections in the Atlantic Ocean at the latitude of the Strait of Gibraltar. The top two panels compare the results after 30 years with the NCAR ocean-only simulations with the parameterized Mediterranean outflow (PMO) and a control experiment in which the Strait of Gibraltar is blocked. These simulations use the nominal 3-degree resolution version of the model. The improvements due to the PMO are obvious: The Mediterranean Salt Tongue is completely missing in the control integration, but clearly present in the PMO simulation. The next 3 panels show the results after 5 years in GFDL's 1-degree isopycnal coordinate model, GOLD, with Gibraltar open at 111 km (1 grid point) width, with Gibraltar restricted to 12 km but without the Hallberg Bottom Boundary Layer (HBBL) parameterization, and finally with both Turner-Ellison (TE) parameterization and HBBL parameterizations activated. With the inclusion of the HBBL parameterization in GOLD, the outflow plume now has a salinity, density, and volume much closer to that seen in observations. The final panel shows the salinity in the Steele ocean climatology; the data processing behind this climatology includes enough temporal and spatial smoothing that the "climatological" salinity of the plume is lower by several tenths of a PSU compared with raw profiles, but it should be reflective of the depth and extent of the plume.

CGD Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. FRANK BRYAN

Summary of achievements

My research concerns the role of the ocean in the climate system, with a particular focus on ocean transport processes and their role in determining the distributions of water masses and their tracer signatures. Over the past year I have been engaged in carrying out several high resolution (nominally 10 km) global ocean simulations specifically designed to investigate the role of ocean mesoscale eddies in tracer transport. The integrations are ongoing, and analyses will begin in the next year.

Frank Bryan

Publications

Bryan, F.O., 2008: Introduction: Ocean modeling Eddy or not. In: Eddy-Resolving Ocean Modelling. Geophysical Monograph Series, Volume 177, M.W. Hecht and H. Hasumi (Eds). AGU, Washington, D.C., 1-3.

Goes, M., I. Wainer, P. R. Gent, and F. O. Bryan, 2008: Changes in subduction in the South Atlantic Ocean during the 21st century in the CCSM3. Geophys. Res. Lett., 35, L06701, doi:10.1029/2007GL032762.

Abstract: The Community Climate System Model version 3 is used to analyse changes in water mass subduction rates in the South Atlantic Ocean over the 21st century. The model results are first compared to observations over 1950-2000, and shown to be rather good. The subduction rates do not change significantly over the 21st century, but the densities at which water masses form become significantly lighter. The strong westerly winds in this region do not change much, which suggests small changes to the rate at which the Atlantic sector of the Southern Ocean takes up heat and carbon dioxide over the 21st century.

Figure caption: Plot of zonal average salinity and density contours in the South Atlantic Ocean: a) Levitus observations, b) CCSM3 ensemble average <1950-1999>, and c) CCSM3 ensemble average <2080-2099>.

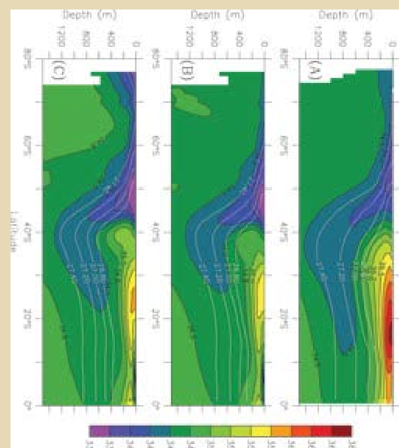

Figure 1.

High resolution figure

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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DONALD LENSCHOW

2008 Publications

Gao, Z., D. H. Lenschow, R. Horton, M. Zhou, J. Wen, 2008: Comparison of two soil temperature algorithms for a bare ground site on the Loess plateau in China. J. Geophys. Res. - Atmos., 113, D18105, doi: 10.1029/2008JD010285.

Abstract

Two thermal transfer algorithms for soil are used to investigate the diurnal vertical temperature variation in the common case of a vertically heterogeneous thermal diffusivity and the considerable liquid water flux which generally exists in soil when surface evaporation is large. One algorithm assumes that soil is vertically homogenous and takes into account only thermal conduction, and the other, developed in our recent study, considers the vertical heterogeneity of thermal diffusivity in soil and couples thermal conduction and convection (e.g., heat transfer by water flux). Theoretically the two methods are identical for vertically homogenous dry soil. On the basis of soil temperature data collected at a bare soil site over the Loess Plateau of China during the period from DOYs 197 to 241, 2005, we found that the new algorithm gives a realistic estimate of soil temperature while the previous one, on average, overestimates either the diurnal amplitude by 0.95 K or the phase shift by 0.207 rad (i.e., 47.44 min) at the soil depth of 0.10 m. Using the new algorithm and measurements of soil temperature, we determine the soil thermal diffusivity and a variable that represents the sum of the vertical gradient of soil thermal diffusivity and water flux density at three levels within the first 0.40 m of the soil surface. We also simulate the soil temperature for the depths of 0.20 m and 0.40 m, and the results are in satisfactory agreement with direct measurements. The main contribution here is to provide analytic insight into the role of heterogeneity and some simple formulae as tools for interpretation of the role of heterogeneity in observed diurnal temperature variations.

Lenschow, D. H., V. Savic-Jovcic, B. Stevens, 2007: Divergence and vorticity from aircraft air motion measurements. J. Atmos. Ocean. Technol., 24, 2062-2072, doi: 10.1175/2007JTECHA940.1.

ABSTRACT

This paper considers the accuracy of divergence estimates obtained from aircraft measurements of the horizontal velocity field and points out an error that appears in these estimates that has heretofore not been addressed. A procedure for eliminating this error is presented. The divergence and vorticity are estimated from the coefficients of a least squares fit to a wind field obtained from the Second Dynamics and Chemistry of Marine Stratocumulus (DYCOMS-II) circular flight legs. These estimates are compared with estimates from numerical models and satellites and with airplane estimates based on tracer budgets and the temporal changes in cloud-top height. The estimates are consistent with expectations and estimates using other methods, albeit somewhat high. Furthermore, significant differences occur among the cases, likely due to the large differences in the techniques. The results indicate that the wind field technique is a viable approach for estimating mesoscale divergence if the wind measurements are accurate. The largest source of wind field systematic error may be the result of flow distortion effects on the air velocity measurement and limitations of in-flight calibrations. Because of flow distortion, the only way the current systems can be calibrated is by flight maneuvers, which assume a steady-state homogeneous nonturbulent atmosphere. Analysis of the errors in this technique suggests that wind field measurements with minimal systematic errors should provide estimates of divergence with much greater accuracy than is now possible with other existing methods.

Rauber, R. M., B. Stevens, H. T. Ochs III, C. Knight, B. A. Albrecht, A. M. Blyth, C. W. Fairall, J. B. Jensen, S. G. Lasher-Trapp, O. L. Mayol-Bracero, G. Vali, J. R. Anderson, B. A. Baker, A. R. Bandy, F. Burnet, J.-L. Brenguier, W. A. Brewer, P. R. A. Brown, P. Chuang, W. R. Cotton, L. Di Girolamo, B. Geert, H. Gerber, S. Goeke, L. Gomes, B. G. Heikes, J. G. Hudson, P. Kollias, R. P. Lawson, P. Jonas, S. K. Krueger, D. H. Lenschow, L. Nuijens, D. W. O'Sullivan, R. A. Rilling, D. C. Rogers, A. P. Siebesma, E. Snodgrass, J. L. Stith, D. C. Thornton, S. Tucker, C. H. Twohy, P. Zuidema, 2007: Rain in (shallow) cumulus over the ocean - the RICO campaign. Bull. Amer. Meteor. Soc., 88, 1912-1928, doi: 10.1175/BAMS-88-12-1912.

Lenschow, D. H., J. Sun, 2007: The spectral composition of fluxes and variances over land and sea out to the mesoscale. Bound.-Layer Meteor., 125, 63-84, doi: 10.1007/s10546-007-9191-8.

Abstract

We discuss the accuracy requirements for measuring mesoscale (roughly horizontal scales > 10 km or 5 to 10 times the planetary boundary-layer (PBL) depth) fluxes in the convective PBL, and the ability of current research aircraft to achieve this

accuracy. We conclude that aircraft equipped with inertial nagivation systems capable of < 3 km hr-1 navigational accuracy are able to resolve mesoscale fluctuations in velocity, and thus variances and fluxes on the mesoscale. We then discuss measurements of velocity and scalar spectra, and cospectra of vertical velocity with horizontal velocity components and scalars, obtained from long flight legs with the National Center for Atmospheric Research Electra aircraft over the boreal forest of Canada in summer during the BOreal Ecosystem-Atmosphere Study (BOREAS), over the tropical Pacific Ocean from the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE), and over the East China Sea during wintertime cold-air outbreaks from the Air Mass Transformation Experiment (AMTEX). Each of these studies has somewhat different forcings and boundary conditions, so we can compare their consequences on the spectra and cospectra. On average, we found no significant scalar or momentum fluxes for horizontal scales > 10 km. We also develop a simple model based on observed thermal structure to explain the phase angle between vertical velocity and the along-wind horizontal velocity as a function of height, which shows good agreement with the observed phase angle in AMTEX.

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DON LENSCHOW

General Information

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Research Focus FY08:

Dr. Lenschow conducts research on both the clear and cloud-capped planetary boundary layer. He has devoted considerable effort to collecting and analyzing turbulence data from both airborne and ground-based field deployments. An example is the Dynamics and Chemistry of the Marine Stratocumulus (DYCOMS-II), conducted off the California coast in July 2001, where this picture caught him deep in thought planning a mission on the NCAR C-130 aircraft

Community Service FY08:

- Editorial Board Member: Boundary-Layer Meteorology
- Editorial Board Member: Journal of Atmospheric Chemistry
- Thesis Committee: Robert Tardif, University of Colorado

Scientific Talks FY08:

- The Planetary Boundary Layer: What We Know Now and Where to Go Next (Stockholm, SWE, 06/2008)
- A Simple Model for Vertical Transport of Reactive Species in the Convective Atmospheric Boundary Layer (Wangingen, NLD, 10/2007)
- Marine Boundary Layer Dynamics (Boulder, CO USA, 02/2008)
- Instrumental Limitations on Air Motion Measurements on the Larger Scales (Broomfield, CO USA, 04/2008)
- The Planetary Boundary Layer: What We Know Now and Where to Go Next (Roskilde, DNK, 06/2008)
- Fluxes in the Planetary Boundary Layer (Ward, CO USA, 07/2008)

Publications FY08 (abstracts):

Heus, T., C. Freek, H. J. Jonker, H. E. Van den Akker, D. H. Lenschow, 2008: Observational validation of the compensating mass flux through the shell around cumulus clouds. *Quart. J. Roy. Meteor. Soc.*. (Submitted)

Gao, Z., D. H. Lenschow, R. Horton, M. Zhou, J. Wen, 2008: Comparison of two soil temperature algorithms for a bare ground site on the Loess plateau in China. *J. Geophys. Res. - Atmos.*, **113**, D18105, doi: 10.1029/2008JD010285, 2008.

Patton, E. G., T. Horst, D. H. Lenschow, P. P. Sullivan, S. P. Oncley, S. P. Burns, A. B. Guenther, T. Karl, S. D. Mayor, S. M. Spuler, J. Sun, A. A. Turnipseed, E. Allwine, S. Edburg, B. Lamb, R. Avissar, H. Holder, R. Calhoun, J. Kleissl, W. Massman, K. Tha Paw U, J. Weil, L. Rizzo, A. Held, 2008: The Canopy Horizontal Array Turbulence Study (CHATS). , Stockholm, SE, AMS, American Meteorological Society, 18A.1.

Lenschow, D. H., V. Savic-Jovcic, B. Stevens, 2007: Divergence and vorticity from aircraft air motion measurements. *J. Atmos. Ocean. Technol.*, **24**, 2062-2072, doi: 10.1175/2007JTECHA940.1.

Rauber, R. M., B. Stevens, H. T. Ochs III, C. Knight, B. A. Albrecht, A. M. Blyth, C. W. Fairall, J. B. Jensen, S. G. Lasher-Trapp, O. L. Mayol-Bracero, G. Vali, J. R. Anderson, B. A. Baker, A. R. Bandy, F. Burnet, J.-L. Brenguier, W. A. Brewer, P. R. A. Brown, P. Chuang, W. R. Cotton, L. Di Girolamo, B. Geert, H. Gerber, S. Goeke, L. Gomes, B. G. Heikes, J. G. Hudson, P. Kollias, R. P. Lawson, P. Jonas, S. K. Krueger, D. H. Lenschow, L. Nuijens, D. W. O'Sullivan, R. A. Rilling, D. C. Rogers, A. P. Siebesma, E. Snodgrass, J. L. Stith, D. C. Thornton, S. Tucker, C. H. Twohy, P. Zuidema, 2007: Rain in (shallow) cumulus over the ocean -

the RICO campaign. *Bull. Amer. Meteor. Soc.*, **88**, 1912-1928, doi: 10.1175/BAMS-88-12-1912.

Lenschow, D. H., J. Sun, 2007: The spectral composition of fluxes and variances over land and sea out to the mesoscale. *Bound.-Layer Meteor.*, **125**, 63-84, doi: 10.1007/s10546-007-9191-8.

Don Lenschow Research Catalog

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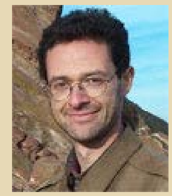
CGD 2008 PROFILES IN SCIENCE: DR. SAMUEL LEVIS

Summary of achievements

Sam Levis continues to work with, develop, and support the Community Land Model (CLM). Regarding model development, Sam upgraded CLM's CN module (Peter Thornton's Carbon-Nitrogen cycling model) to Dynamic Global Vegetation Model (dgvm) status. This means that CN can now simulate the movement of plant types across model grid cells (the way that the CLM-dgvm could before), instead of using satellite derived plant type distributions. Furthermore, Sam introduced to CN the "agro" part of the IBIS dgvm. As a result, now CLM-CN can simulate life cycles for maize, wheat, and soybean that respond to environmental conditions. Preliminary results suggest that such life cycles look more realistic than the simulated phenology of CLM-CN's generic crop. Regarding support, Sam continues to respond to hundreds of community (NCAR and external) requests per year regarding the CLM. This year for the first time Sam gave talks about Global Warming to high school students and to the Colorado Public Utilities Commission. Sam also spoke to a USDA panel visiting NCAR about recent advances in the CLM.



Samuel Levis

Publications

Cook, B.I., G.B. Bonan, S. Levis, and H.E. Epstein. 2008: The thermoinsulation effect of snow cover within a climate model. Climate Dynamics, 31:107-124, doi:10.1007/s00382-007-0341-y.

Abstract: We use a state of the art climate model (CAM3-CLM3) to investigate the sensitivity of surface climate and land surface processes to treatments of snow thermal conductivity. In the first set of experiments, the thermal conductivity of snow at each grid cell is set to that of the underlying soil (SC-SOIL), effectively eliminating any insulation effect. This scenario is compared against a control run (CTRL), where snow thermal conductivity is determined as a prognostic function of snow density. In the second set of experiments, high (SC-HI) and low (SC-LO) thermal conductivity values for snow are prescribed, based on upper and lower observed limits. These two scenarios are used to envelop model sensitivity to the range of realistic observed thermal conductivities. In both sets of experiments, the high conductivity/low insulation cases show increased heat exchange, with anomalous heat fluxes from the soil to the atmosphere during the winter and from the atmosphere to the soil during the summer. The increase in surface heat exchange leads to soil cooling of up to 20 K in the winter, anomalies that persist (though damped) into the summer season. The heat exchange also drives an asymmetric seasonal response in near-surface air temperatures, with boreal winter anomalies of +6 K and boreal summer anomalies of -2 K. On an annual basis there is a net loss of heat from the soil and increases in ground ice, leading to reductions in infiltration, evapotranspiration, and photosynthesis. Our results show land surface processes and the surface climate within CAM3-CLM3 are sensitive to the treatment of snow thermal conductivity.

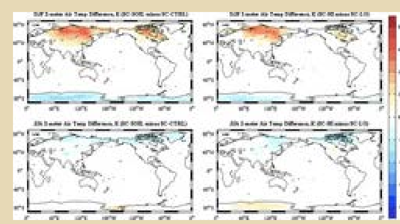


Figure 1.

High resolution figure

Figure caption: Differences in 2-meter air temperature (degrees C) for SC-SOIL minus CTRL and SC-HI minus SC-LO, for seasons DJF and JJA. Top row shows results from boreal winter (DJF) comparison, bottom row shows results from boreal summer (JJA) comparison.

Oleson, K. W., et al., 2008: Improvements to the Community Land Model and their impact on the hydrological cycle. J. Geophys. Res., 113, G01021, doi:10.1029/2007JG000563.

Abstract: The Community Land Model version 3 (CLM3) is the land component of the Community Climate System Model (CCSM). CLM3 has energy and water biases resulting from deficiencies in some of its canopy and soil parameterizations related to hydrological processes. Recent research by the community that utilizes CLM3 and the family of CCSM models has indicated several promising approaches to alleviating these biases. This paper describes the implementation of a selected set of these parameterizations and their effects on the simulated hydrological cycle. The modifications consist of surface data sets based on Moderate Resolution Imaging Spectroradiometer products, new parameterizations for canopy integration, canopy interception, frozen soil, soil water availability, and soil

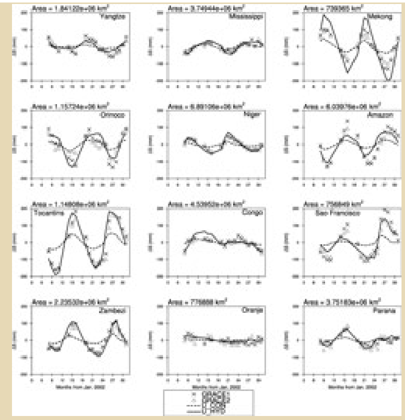


Figure 2.

High resolution figure

evaporation, a TOPMODEL-based model for surface and subsurface runoff, a groundwater model for determining water table depth, and the introduction of a factor to simulate nitrogen limitation on plant productivity. The results from a set of offline simulations were compared with observed data for runoff, river discharge, soil moisture, and total water storage to assess the performance of the new model (referred to as CLM3.5). CLM3.5 exhibits significant improvements in its partitioning of global evapotranspiration (ET) which result in wetter soils, less plant water stress, increased transpiration and photosynthesis, and an improved annual cycle of total water storage. Phase and amplitude of the runoff annual cycle is generally improved. Dramatic improvements in vegetation biogeography result when CLM3.5 is coupled to a dynamic global vegetation model. Lower than observed soil moisture variability in the rooting zone is noted as a remaining deficiency.

Figure caption: Total water storage anomalies (mm) for U_HYD (CLM3.5) and U_CON (CLM3.0) compared to two sources of GRACE data (GRACE1 [Seo and Wilson, 2005] and GRACE2 [Chen et al., 2005]). Model total water storage anomalies are calculated from the sum of snow water, canopy water, total column soil water, and aquifer water. GRACE data were interpolated to the model resolution.

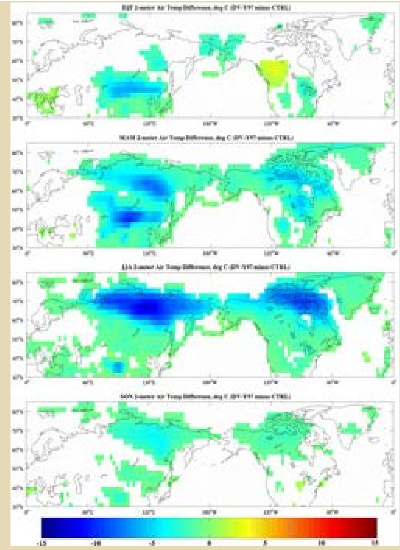
Support: This work was supported by the NCAR Water Cycles Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives.

Notaro, M., Y. Wang, Z. Liu, R. Gallimore, and S. Levis, 2008: Combined statistical and dynamical assessment of simulated vegetation-rainfall during the mid-Holocene. Global Change Biology, 14, 347-368, doi:10.1111/j.1365-2486.2007.01495.x.

Abstract: A negative feedback of vegetation cover on subsequent annual precipitation is simulated for the mid-Holocene over North Africa using a fully coupled general circulation model with dynamic vegetation, FOAM-LPJ (Fast Ocean Atmosphere Model-Lund Potsdam Jena Model). By computing a vegetation feedback parameter based on lagged autocovariances, the simulated impact of North African vegetation on precipitation is statistically quantified. The feedback is also dynamically assessed through initial value ensemble experiments, in which North African grass cover is initially reduced and the climatic response analyzed. The statistical and dynamical assessments of the negative vegetation feedback agree in sign and relative magnitude for FOAM-LPJ. The negative feedback on annual precipitation largely results from a competition between bare soil evaporation and plant transpiration, with increases in the former outweighing reductions in the latter given reduced grass cover. This negative feedback weakens and eventually reverses sign over time during a transient simulation from the mid-Holocene to present. A similar, but weaker, negative feedback is identified in Community Climate System Model Version 2 (CCSM2) over North Africa for the mid-Holocene.

B. I. Cook, G. B. Bonan, S. Levis, and H. Epstein. 2008: Rapid vegetation responses and feedbacks amplify climate model response to snow cover changes. Climate Dynamics, 30:391-406, doi:10.1007/s00382-007-0296-z.

Abstract: We investigate the response of a climate system model to two different methods for estimating snow cover fraction. In the control case, snow cover fraction changes gradually with snow depth; in the alternative scenarios (one with prescribed vegetation and one with dynamic vegetation), snow cover fraction initially increases with snow depth almost twice as fast as the control method. In cases where the vegetation was fixed (prescribed), the choice of snow cover parameterization resulted in a limited model response. Increased albedo associated with the high snow caused some moderate localized cooling (3-5°C), mostly at very high latitudes (>70°N) and during the spring season. During the other seasons, however, the cooling was not very extensive. With dynamic vegetation the change is much more dramatic. The initial increases in snow cover fraction with the new parameterization lead to a large-scale southward retreat of boreal vegetation, widespread cooling, and persistent snow cover over much of the boreal region during the boreal summer. Large cold anomalies of up to 15°C cover much of northern Eurasia and North America and the cooling is geographically extensive in the northern hemisphere extratropics, especially during the spring and summer seasons. This study demonstrates the potential for dynamic vegetation within climate models to be quite sensitive to modest forcing. This highlights the importance of dynamic vegetation, both as an amplifier of feedbacks



in the climate system and as an essential consideration when implementing adjustments to existing model parameters and algorithms.

Figure caption: Difference in 2-m air temperature for all four seasons between the dynamic vegetation case and control run (DV-Y97 minus CTRL). Insignificant differences have been masked out.

Figure 3.

High resolution figure

Sacks, W.J., B. I. Cook, N. Buenning, S. Levis, and J. H. Helkowski, 2008: Effects of global irrigation on the near-surface climate. Clim. Dyn., doi:10.1007/s00382-008-0445-z.

Abstract: Irrigation delivers about 2,600 km3 of water to the land surface each year, or about 2% of annual precipitation over land. We investigated how this redistribution of water affects the global climate, focusing on its effects on near-surface temperatures. Using the Community Atmosphere Model (CAM) coupled to the Community Land Model (CLM), we compared global simulations with and without irrigation. To approximate actual irrigation amounts and locations as closely as possible, we used national-level census data of agricultural water withdrawals, disaggregated with maps of croplands, areas equipped for irrigation, and climatic water deficits. We further investigated the sensitivity of our results to the timing and spatial extent of irrigation. We found that irrigation alters climate significantly in some regions, but has a negligible effect on global-average near-surface temperatures. Irrigation cooled the northern mid-latitudes; the central and southeast United States, portions of southeast China and portions of southern and southeast Asia cooled by *0.5 K averaged over the year. Much of northern Canada, on the other hand, warmed by *1 K. The cooling effect of irrigation seemed to be dominated by indirect effects like an increase in cloud cover, rather than by direct evaporative cooling. The regional effects of irrigation were as large as those seen in previous studies of land cover change, showing that changes in land management can be as important as changes in land cover in terms of their climatic effects. Our results were sensitive to the area of irrigation, but were insensitive to the details of irrigation timing and delivery.

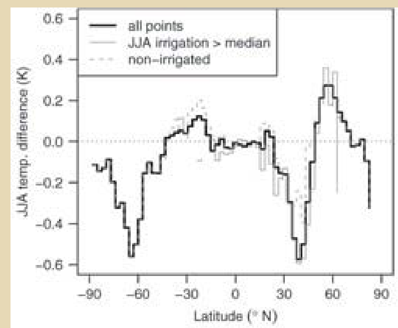


Figure 4.

High resolution figure

Figure caption: Zonal averages over land of the difference in JJA 2-m air temperature between the irrigated and non-irrigated coupled model runs (K). The three lines show averages for all land points (*dark line*), averages for only those points with JJA irrigation greater than median JJA irrigation (where the median includes only irrigated points; *light line*), and averages for only those land points that are never irrigated (*dashed line*). The similarity of the three sets of averages, especially in the northrn mid-latitudes, sugges that much of the cooling effect of irrigation is due to non-local processes.

CGD Research Catalog

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SAMUEL LEVIS

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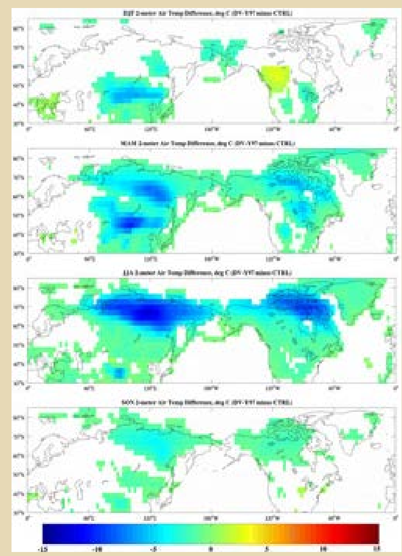
Research Focus FY08:

Sam Levis continues to work with, develop, and support the Community Land Model (CLM). Regarding model development, Sam upgraded CLM's CN module (Peter Thornton's Carbon-Nitrogen cycling model) to Dynamic Global Vegetation Model (dgvm) status. This means that CN can now simulate the movement of plant types across model grid cells (the way that the CLM-dgvm could before), instead of using satellite derived plant type distributions. Furthermore, Sam introduced to CN the "agro" part of the IBIS dgvm. As a result, now CLM-CN can simulate life cycles for maize, wheat, and soybean that respond to environmental conditions. Preliminary results suggest that such life cycles look more realistic than the simulated phenology of CLM-CN's generic crop. Regarding support, Sam continues to respond to hundreds of community (NCAR and external) requests per year regarding the CLM. This year for the first time Sam gave talks about Global Warming to high school students and to the Colorado Public Utilities Commission. Sam also spoke to a USDA panel visiting NCAR about recent advances in the CLM.



Difference in 2-m air temperature for all four seasons between the dynamic vegetation case and control run (DV-Y97 minus CTRL). Insignificant differences have been masked out.

High resolution figure

Community Service FY08:

- Guest Editor: Journal of Hydrology

Scientific Talks FY08:

- Vegetation modeling in the Community Land Model (Boulder, CO February 2008)

Publications FY08 (abstracts):

Cook, B., G. Bonan, S. Levis, H. Epstein, 2008: The thermoinsulation effect of snow cover within a climate model. *Clim. Dyn.*, **31**, 107-124.

Wang, Y., M. Notaro, Z. Liu, R. Gallimore, S. Levis, J. Kutzbach, 2008: Detecting vegetation-precipitation feedbacks in mid-Holocene North Africa from two climate models. *Clim. Past*, **4**, 59-67.

Sacks, W., B. Cook, N. Buenning, S. Levis, J. Helkowski, 2008: Effects of global irrigation on the near-surface climate. *Clim. Dyn.*, doi: 10.1007/s00382-008-0445-z.

Oleson, K. W., G.-Y. Niu, Z.-L. Yang, D. M. Lawrence, P. Thornton, P. Lawrence, R. Stockli, R. Dickinson, G. Bonan, S. Levis, A. Dai, T. Qian, 2008: Improvements to the community land model and their impact on the hydrological cycle. *J. Geophys. Res.*, **113**, G01021, doi: 10.1029/2007JG000563.

Cook, B. I., G. B. Bonan, S. Levis, H. E. Epstein, 2008: Rapid vegetation responses and feedbacks amplify climate model response to snow cover changes. *Clim. Dyn.*, **30**, 391-406, doi: 10.1007/s00382-007-0296-z.

Notaro, M., Y. Wang, Z. Liu, R. Gallimore, S. Levis, 2008: Combined statistical and dynamical assessment of simulated vegetation-rainfall interactions in North Africa during the mid-Holocene. *Global Change Biology*, **14**, 347-368, doi: 10.1111/j.1365-24866.2007.001495.x.

Samuel Levis Research Catalog

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Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. KEITH LINDSAY

Keith Lindsay

Publications

Boyd, P. W., S. C. Doney, R. Strzepek, J. Dusenberry, and K. Lindsay, 2008: Climate-mediated changes to mixed-layer properties in the Southern Ocean: assessing the phytoplankton response. Biogeosciences, 5, 847-864.

Abstract: Concurrent changes in ocean chemical and physical properties influence phytoplankton dynamics via alterations in carbonate chemistry, nutrient and trace metal inventories and upper ocean light environment. Using a fully coupled, global carbon-climate model (Climate System Model 1.4-carbon), we quantify anthropogenic climate change relative to the background natural interannual variability for the Southern Ocean over the period 2000 and 2100. Model results are interpreted using our understanding of the environmental control of phytoplankton growth rates - leading to two major findings. Firstly, comparison with results from phytoplankton perturbation experiments, in which environmental properties have been altered for key species (e. g., bloom formers), indicates that the predicted rates of change in oceanic properties over the next few decades are too subtle to be represented experimentally at present. Secondly, the rate of secular climate change will not exceed background natural variability, on seasonal to interannual time-scales, for at least several decades - which may not provide the prevailing conditions of change, i.e. constancy, needed for phytoplankton adaptation. Taken together, the relatively subtle environmental changes, due to climate change, may result in adaptation by resident phytoplankton, but not for several decades due to the confounding effects of climate variability. This presents major challenges for the detection and attribution of climate change effects on Southern Ocean phytoplankton. We advocate the development of multi-faceted tests/metrics that will reflect the relative plasticity of different phytoplankton functional groups and/or species to respond to changing ocean conditions.

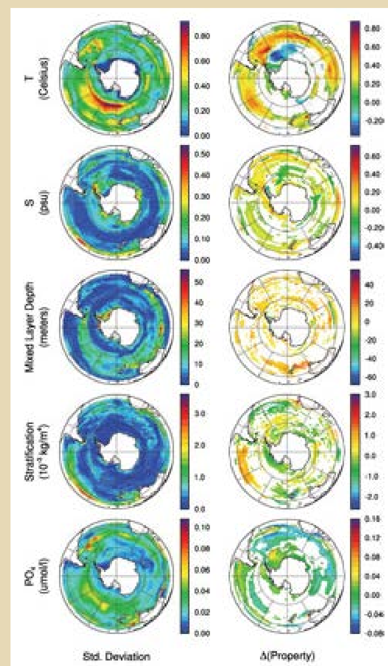

Figure 1.

High resolution figure

Figure caption: Spatial maps of S. Ocean interannual variability and anthropogenic climate response from the CSM1.4-carbon transient IPCC SRES A2 simulation. The left column shows the natural interannual variability, expressed as the standard deviation of the annual means from a 10 year segment of the control simulation; the right column shows the climate response expressed as the temporal difference over a 20 year time period, the average of model years 2020-2029 minus the average of model years 2000-2009. Each row displays a separate surface water physical or chemical property (temperature, salinity, mixed layer depth, density stratification, phosphate, dissolved iron, &3961;CO_2, incident photosythetically available radiation, upwelling, and ice fraction). Regions where the absolute value of the temporal difference is less than one standard error of the difference between the means are masked out.

Levine, N. M., S. C. Doney, R. Wanninkhof, K. Lindsay, and I. Fung, 2008: Impact of ocean carbon system variability on the detection of temporal increases in anthropogenic CO_2. Journal of Geophysical Research-Oceans, doi:10.1029/2007JC004153.

Abstract: Estimates of temporal trends in oceanic anthropogenic carbon dioxide (CO_2) rely on the ability of empirical methods to remove the large natural variability of the ocean carbon system. A coupled carbon-climate model is used to evaluate these empirical methods. Both the ΔC* and multiple linear regression (MLR) techniques reproduce the predicted increase in dissolved inorganic carbon for the majority of the ocean and have similar average percent errors for decadal differences (24.1% and 25.5%, respectively). However, this study identifies several regions where these methods may introduce errors. Of particular note are mode and deep water formation regions, where changes in air-sea disequilibrium and structure in the MLR residuals introduce errors. These results have significant implications for decadal repeat hydrography programs, indicating the need for subannual sampling in certain regions of the oceans in order to better constrain the natural variability in the system and to robustly estimate the intrusion of anthropogenic CO_2.

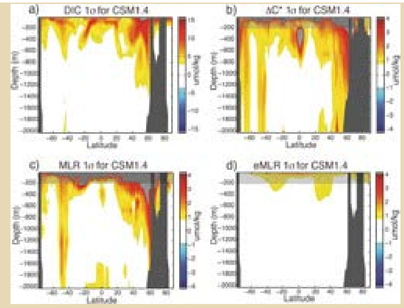

Figure 2.

High resolution figure

Figure caption: Depth profiles of CSM1.4 model output along the A16 transect showing RMS variability (1&3963;) for (a) model dissolved inorganic carbon (DIC) output, (b) ΔC*, (c) multiple linear regression (MLR), and (d) extended multiple linear regression (eMLR) calculated using years 101-450 of the 1000 year control run. ΔC* is calculated in isopycnal space and projected back into depth space. Note the difference in scale in model DIC output.

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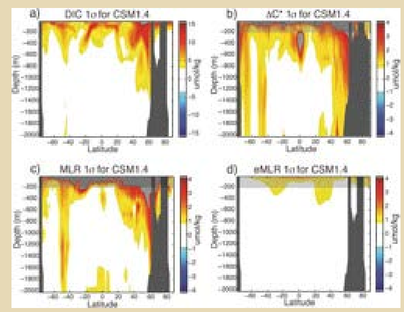
Research Focus FY08:

My research concerns the global carbon cycle, particularly in the ocean and how the oceanic carbon cycle couples to the terrestrial carbon cycle via concentrations of atmospheric of CO2. The research is conducted with global coupled climate models that have parameterizations of biogeochemical cycles incorporated into them, primarily done with other members of the Biogeochemistry Working Group of CCSM, of which I am the community liaison.



Depth profiles of CSM1.4 model output along the A16 transect showing RMS variability (1&3963;) for (a) model dissolved inorganic carbon (DIC) output, (b) ΔC*, (c) multiple linear regression (MLR), and (d) extended multiple linear regression (eMLR) calculated using years 101-450 of the 1000 year control run. ΔC* is calculated in isopycnal space and projected back into depth space. Note the difference in scale in model DIC output.

High resolution figure

Publications FY08 (abstracts):

Boyd, P. W., S. C. Doney, R. Strzepek, J. Dusenberry, and K. Lindsay, 2008: Climate-mediated changes to mixed-layer properties in the Southern Ocean: assessing the phytoplankton response. Biogeosciences, 5, 847-864.

Levine, N. M., S. C. Doney, R. Wanninkhof, K. Lindsay, and I. Fung, 2008: Impact of ocean carbon system variability on the detection of temporal increases in anthropogenic CO2. Journal of Geophysical Research-Oceans, doi:10.1029/2007JC004153.

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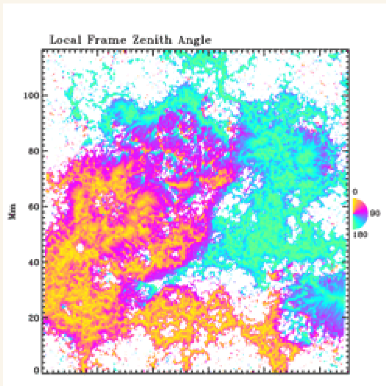
LITES, BRUCE

Emergence of Flux Ropes into the Solar Atmosphere



Hinode measurements give us the first observations of the evolution of the magnetic field vector in active regions over extended periods of time. By observing the development of active regions such as this one studied in detail during December 2007, B. Lites and his Hinode collaborators have found an instance of the apparent emergence of a twisted flux system into the solar atmosphere (see Figure) that leads to the formation of a filament in the solar corona above. The field has the tell-tale concave-upward geometry at the intersection of positive (orange) and negative (green) flux, with the horizontal field (purple) oriented parallel to the line bisecting the two polarities. Furthermore, near the center of this image, there exists a segment of horizontal field isolated from surrounding stronger opposite polarity flux. This occurrence suggests that the field emerged from the interior in a twisted state, and does not arise from local shear flow in the photosphere followed by reconnection in the upper atmosphere as has been postulated for the formation of solar filaments. These observations, and others that have been published recently by Hinode collaborators, are shedding new light on the formation of solar filaments and prominences, thereby enhancing our understanding of the processes leading to the eruption of filaments and coronal mass ejections.

Figure caption: *The color scale of this image indicates the angle of the magnetic field vector in the solar photospheric layers of an active region as measured by the Hinode Spectro-Polarimeter. Fields pointing upward (downward) are indicated by yellow (green), and horizontal fields are purple, as indicated by the color wheel at right (inclination angles in degrees). This active region contains an extended channel of relatively weak, horizontal magnetic fields extending from lower left toward upper right. The geometry of the magnetic field and its evolution strongly suggests the emergence of a flux rope into the solar atmosphere, and the subsequent formation of a filament in the chromosphere and corona.*

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CHANGHAI LIU

2008 Publications

Liu, C.-H., Q. Xiao, B. Wang, 2008: An ensemble-based four-dimensional variational data assimilation scheme: Part I: Technical formulation and preliminary test. Mon. Wea. Rev., 136, 3363-3373, doi: 10.1175/2008MWR2312.1.

ABSTRACT

Applying a flow-dependent background error covariance (matrix) in variational data assimilation has been a topic of interest among researchers in recent years. In this paper, an ensemble-based four-dimensional variational (En4DVAR) algorithm, designed by the authors, is presented that uses a flow-dependent background error covariance matrix constructed by ensemble forecasts and performs 4DVAR optimization to produce a balanced analysis. A great advantage of this En4DVAR design over standard 4DVAR methods is that the tangent linear and adjoint models can be avoided in its formulation and implementation. In addition, it can be easily incorporated into variational data assimilation systems that are already in use at operational centers and among the research community.

A one-dimensional shallow water model was used for preliminary tests of the En4DVAR scheme. Compared with standard 4DVAR, the En4DVAR converges well and can produce results that are as good as those with 4DVAR but with far less computation cost in its minimization. In addition, a comparison of the results from En4DVAR with those from other data assimilation schemes [e.g., 3DVAR and ensemble Kalman filter (EnKF)] is made. The results show that the En4DVAR yields an analysis that is comparable to the widely used variational or ensemble data assimilation schemes and can be a promising approach for real-time applications.

In addition, experiments were carried out to test the sensitivities of EnKF and En4DVAR, whose background error covariance is estimated from the same ensemble forecasts. The experiments indicated that En4DVAR obtained reasonably sound analysis even with larger observation error, higher observation frequency, and more unbalanced background field.

Liu, C.-H., M. W. Moncrieff, J. D. Tuttle, 2008: A note on propagating rainfall episodes over the Bay of Bengal. Quart. J. Roy. Meteor. Soc., 134, 787-792.

Abstract

An observational analysis of precipitation episodes over the Bay of Bengal and the adjacent coastal region is conducted using the TRMM Real-Time Multi-Satellite Precipitation Analysis (MPA-RT) products for three warm seasons (i.e. May to September for 2002-2004). Time-distance diagrams (Hovmüller diagrams) of rainfall episodes reveal frequent travelling precipitation episodes having lifetimes greatly exceeding those of individual convective systems. The majority of the episodes translate southward and many do not appear to have a steering level (i.e. they propagate in a hydraulic-like manner), unlike those previously documented over midlatitude and tropical continents which usually have a steering level. On average, the coherent systems have a latitudinal span of 5 degrees and a 1-day duration and a meridional propagation speed of 8 m s-1, approximately. The episodes mostly initiate over the coastal land around midday and offshore around midnight.

Das, S., R. Ashrit, M. W. Moncrieff, M. Dasgupta, J. Dudhia, C. Liu, S. R. Kalsi, 2007: Simulation of intense organized convective precipitation observed during the Arabian Sea Monsoon Experiment (ARMEX). J. Geophys. Res. - Atmos., 112, D20117, doi: 10.1029/2006JD007627.

Abstract

We examine a deep precipitating system that formed over the west coast of India during 26–28 June 2002 producing heavy rainfall of 2–61 cm day-1. The system developed into a well-marked low pressure area due to interaction between an eastward moving westerly trough and a westward moving monsoon low. We used the PSU/NCAR Mesoscale Model (MM5) to make 10-day interactively nested simulations at 90, 30, and 10 km grid-resolutions. We used observations from a special data set collected during an Arabian Sea Monsoon Experiment (ARMEX) conducted June–August, 2002. Nudging the observations produced a balanced atmosphere which, in turn, matched the location of vortex with cloud clusters observed from satellite. The simulated rainfall corresponded well with observations. We then use the simulated fields as forcing and boundary conditions for MM5 run in cloud-system resolving mode at 2 km grid-resolution to detail cloud-clusters embedded within the monsoon disturbance. We examined the sensitivity to different physical parameterizations and also the effect of continuous nudging four dimensional data assimilation (FDDA) on the rainfall forecasts. While the simulation of the convective event improved with certain combinations of physical parameterizations, the rainfall was not forecasted at the correct location, no matter which parameterization was used, unless continuous FDDA was performed in all domains throughout the integrations. Finally, cloud-cluster properties of the cloud-

system resolving simulations were compared with observations.

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Research Focus FY08:

Colorado Headwaters Program

(Liu, Kyoko, Rasmussen, Moncrieff ...)

The Colorado Headwaters Program is a key project of NCAR's Water System Program in this fiscal year. Its major objective is to assess the projected Upper Colorado Snowpack and Runoff by global climate models using a very high resolution regional climate model. We started from the present-day cold season simulations in this region to evaluate the sensitivity of the simulated snowfall and snowpack to both the horizontal and vertical grid spacings as well as the various physical parameterizations. We have performed a series of 2~30-km resolution experiments over two multi-day periods (i.e., November 19 -- December 8, 2002; February 1--16, 2008) with the WRF model. North American Regional Reanalysis (NARR) data are used to provide the initial and boundary conditions in our simulations. The Snow Telemetry network (SNOTEL) and PRISM observations are used to evaluate the simulated snowfall. The preliminary analysis indicates that 1) the high-resolution simulations with 2~4-km grid spacing can well capture the heavy snowfall episodes during the two periods; 2) the simulated snowfall has little dependence on the choice of the PBL and land-surface schemes, but shows considerable sensitivity to the choice of microphysics parameterizations; and 3) the model performance gradually degrades when the grid spacing is coarser and coarser.

Cloud-resolving simulations of convective cloud systems in TOGA COARE

(C.-H. Liu)

The WRF model was configured to run the three-dimensional cloud-resolving simulations of convective cloud systems during the 4-month intensive observing period of Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE). We started with a small computational domain which was only 64 km by 64 km so that our simulation results can be compared with previous CRM simulations which used the same domain size. Preliminary evaluation showed that the model well replicated the observed precipitation evolution. Our CGD collaborators will use the model data for momentum transport parameterization studies. We are going to repeat the simulation with a domain large enough to accommodate mesoscale convective systems.

Evaluation and improvement of YSU and MYJ PBL schemes in modeling the diurnal variation of summertime precipitation

(Y.-H. Yang, C.-H. Liu, J. Dudhia, M. Moncrieff, F. Chen)

We are performing hierarchical modeling of diurnal evolution of PBL and convective development with the WRF model. The numerical model is forced by specified diurnally-varying surface fluxes derived from an idealization of the observations made during the Tropical Rainfall Measuring Mission, Large Scale Biosphere-Atmosphere (TRMM-LBA) mission. The unique aspects in our approach are the employment of large-eddy simulations as a benchmark and the highly idealized experimental design that is much easier to isolate the errors associated with the tested physical parameterization than the real-data simulation approach. Three sets of diurnal three-dimensional simulations were completed, including 1) 50-m grid-spacing large-eddy simulations in which the PBL scheme is not required, 2) 1~4-km-resolution cloud-resolving simulations with the YSU scheme, and 3) 1~4-km-resolution cloud-resolving simulations with the MYJ scheme. The two PBL schemes are evaluated by comparing large-eddy simulation results against cloud-resolving simulation results. Preliminary results showed that the YSU (MYJ) scheme tends to overpredict (underpredict) the vertical mixing and thus the PBL development. Detailed evaluation is still under way.

Diurnal variations of summertime precipitation over the Tibetan Plateau in

relation to orographically-induced regional circulations
(X.-D. Liu, A.-J. Bai, C.-H. Liu)

The diurnal variation patterns of summertime precipitation over the Tibetan Plateau were first investigated using the TRMM multi-satellite precipitation analysis product for five summer seasons (i.e., June through August for 2002-2006). Both hourly precipitation amount and frequency exhibit pronounced daily variability with the strongest signal over the central Plateau. Overall, a late-afternoon-evening maximum and a morning minimum are dominant, similar to the diurnal phasing documented in other continental regions. An exception is the prevalent nocturnal maximum around the Plateau periphery.

Using six-hourly NCEP FNL data, we then examined the diurnal variability in the atmospheric circulation and thermodynamics in this region. The results show that the Plateau heats (cools) the overlying atmosphere during daytime (nighttime) more than the surrounding areas, and as a consequence, a relatively stronger confluent circulation in this region occurs during daytime than during nighttime, consistent with the diurnal rainfall cycles therein. This study further demonstrates the importance of the Tibetan Plateau in regulating regional circulation and precipitation.

Community Service FY08:

- Graduate Advisor: Aijuan Bai, Institute of Earth Environment, Xian, China
- Graduate Advisor: Xianfang Ma, Institute of Earth Environment, Xian, China

Scientific Talks FY08:

- Preliminary Results of Multi-day Snowfall Simulations over the Colorado Headwaters Region (Boulder, CO, March 2008)
- Assessment of Snowfall, Snowpack and Runoff over Colorado's Headwater Region Using a High Resolution Regional Climate Model (Xian, China, August 2008)

Publications FY08 (abstracts):

Ikeda, K., R. M. Rasmussen, C.-H. Liu, G. Thompson, L. Xue, 2008: Investigation of the dependence of squall line structure and dynamics on microphysical parameterization. *15th Intl. Conf. on Clouds and Precipitation*, Cancun, MX, International Association of Meteorology and Atmospheric Science.

Liu, C.-H., Q. Xiao, B. Wang, 2008: An ensemble-based four-dimensional variational data assimilation scheme: Part I: Technical formulation and preliminary test. *Mon. Wea. Rev.*, **136**, 3363-3373, doi: 10.1175/2008MWR2312.1.

Liu, C.-H., M. Moncrieff, 2008: Explicitly simulated tropical convection over idealized warm pools. *J. Geophys. Res.*. (Submitted)

Liu, C.-H., M. W. Moncrieff, J. D. Tuttle, 2008: A note on propagating rainfall episodes over the Bay of Bengal. *Quart. J. Roy. Meteor. Soc.*, **134**, 787-792.

Das, S., R. Ashrit, M. W. Moncrieff, M. Dasgupta, J. Dudhia, C. Liu, S. R. Kalsi, 2007: Simulation of intense organized convective precipitation observed during the Arabian Sea Monsoon Experiment (ARMEX). *J. Geophys. Res. - Atmos.*, **112**, D20117, doi: 10.1029/2006JD007627.

Bai, A.-J., C.-H. Liu, and X.-D. Liu, 2008: The diurnal variation of warm-season precipitation over the Tibetan Plateau and its neighboring regions revealed by TRMM Multi-satellite Precipitation Analysis. *J. Geophys*. (Chinese), submitted.

Liu, X.-D., A.-J. Bai, and C.-H. Liu, 2008: Diurnal variations of summertime precipitation over the Tibetan Plateau and their relationship with orographically-induced atmospheric circulations. *Quart. Roy. Meteor. Soc.*, submitted.

Ma, X.-F., C.-H. Liu, X.-D. Liu, R. Rasmussen, D.-H. Fu, and U. Blahak, 2008: A numerical study of aerosol concentration on a midlatitude mesoscale convective system. *J. Applied Meteorology* (Chinese). in press.

Fu, D.-H., X.-L. Guo, and C.-H. Liu, 2008: Characteristics of precipitation and cloud microphysics of monsoon convective systems over the South China Sea. *J. Geophys Res.*, submitted.

Changhai Liu Research Catalog

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Hanli Liu Research Catalog

Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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Gravity Waves

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Research Focus FY08:

Gravity waves play an important role in the coupling of various atmospheric regions. Therefore, the study of gravity waves is a focal point of lower, middle, and upper atmospheric research, being of strong inter-disciplinary interest.

Outstanding Questions and Problems: There are outstanding questions in the gravity wave excitation mechanism, source distribution and variability, wave impact in the lower, middle and upper atmosphere, and parameterization of wave source and impact in global scale models. Flow over topography has been a classical example of gravity wave excitation and has been extensively studied. However, surface drag from orographic wave parameterizations in general circulation models is still problematic and hinders our ability to correctly resolve planetary waves in whole-atmosphere models.

Mesoscale modeling of gravity waves using realistic orography and weather condition and observations from campaign studies of orographic waves should be used to improve the quantification of the process. Gravity waves generated from realistic convective systems and from spontaneous adjustment due to geostrophic imbalance, as well as from complex interactions of these systems are still poorly understood and not well quantified. Petascale computing capabilities afforded by the upcoming NCAR Supercomputing Center will make possible high-resolution simulations of such systems, which will help to improve understanding of the gravity waves generated.

The gravity waves affect atmospheric processes in the lower, middle and upper atmosphere. The transport and deposition of momentum can affect the middle and upper atmosphere circulation, and wave breaking can generate turbulence that can affect aviation, constituents mixing, specifically mass exchange between upper troposphere/ lower stratosphere and mesosphere/lower thermosphere, as well as heating and cooling in the upper atmosphere. Gravity waves may also affect space weather by seeding ionospheric irregularities.

The NCAR - University Opportunity: The vast spatial and temporal existence of gravity waves has important implications for the atmospheric dynamics and thermal/compositional structure from mesoscales to global scales. The multiscale nature of the gravity waves poses a stiff challenge to the physical understanding and quantification of these waves in both observations and numerical models. Integrated mesoscale modeling of these processes, extending from the wave sources to the impact region, is needed to address these problems. The integrated model can also support observational campaign studies of gravity waves as well as the validation of gravity wave parameterization. Such efforts will promote collaboration across the ESSL scientific divisions and between NCAR and the university community.

Satellite observations can provide valuable information on the global distribution and variability of gravity waves. The Constellation Observing System for Meteorology Ionosphere & Climate (COSMIC) radio occultation measurement is being used to derive the gravity wave variance and its global distribution and temporal variation. New algorithms will be explored to infer more specific gravity wave characteristics from COSMIC measurements. Data assimilation techniques will be tested to quantify global gravity wave impact by combining satellite observations of temperature, wind and the Whole-Atmosphere Community Climate Model (WACCM) simulations.

Community Service FY08:

- Associate Editor Journal of Geop0hysical Research - Space Physics
- CEDAR Science Steering Committee
- Graduate Research Advisor & Thesis Member: Chihoko Yamashita, University of Colorado, Boulder

Scientific Talks FY08:

- Gravity waves from the Nest Regional Climate Model (Anhui, CHN, 08/2008)
- Troposphere-thermosphere coupling by nonmigrating tides (Montreal, CAN, 07/2008)
- The quasi-biennial, annual, and semi-annual oscillations in the migrating diurnal tide (Montreal, CAN, 07/2008)
- Dynamical variability during 2006 SSW (Midway, UT USA, 06/2008)
- Atmospheric gravity waves: Apply classroom physics to research (Midway, UT USA, 06/2008)
- Gravity waves from the Nest Regional Climate Model (invited) (Crete, GRC, 05/2008)
- Neutral and plasma variability in the F region from the dissipation of gravity waves from convection (Crete, GRC, 05/2008)
- Modeling the ring structures in the OH airglow layer from gravity waves excited by convection near Fort Collins, Colorado (Crete, GRC, 05/2008)
- Simulations of the midnight temperature maximum with the NCAR TIME-GCM (Crete, GRC, 05/2008)
- Thermospheric structures and variabilities from the NCAR Whole Atmosphere Community Climate Model (WACCM) (New Orleans, LA USA, 01/2008)
- Assessment of the non-hydrostatic effect in general circulation models (GCMs) (San Francisco, CA USA, 12/2007)
- Analysis of mid-latitude neutral wind in the lower thermosphere: Comparison of Fall and Spring equinoxes (San Francisco, CA USA, 12/2007)
- Interannual variability in the effects of energetic particle precipitation (EPP) on the stratosphere (San Francisco, CA USA, 12/2007)
- On the existence and excitation of eastward propagating quasi-two day waves in the MLT (San Francisco, CA USA, 12/2007)
- Seasonal variations of mesospheric Fe layers at Rothera and comparison to the South Pole (San Francisco, CA USA, 12/2007)
- Whole Atmosphere Community Climate Model (WACCM): Recent development and research at HAO (Washington, DC USA, 11/2007)
- Sun-Earth coupling by energetic particles (Kyoto, JPN, 10/2007)
- Wind balance in the mesosphere and lower thermosphere (Kyoto, JPN, 10/2007)

Publications FY08:

Deng, Y., A. D. Richmond, A. J. Ridley, and H.-L. Liu, Assessment of the non-hydrostatic effect on the upper atmosphere using a general circulation model (GCM), Geophys. Res. Lett., 35, L01104, doi:10.1029/2007GL032182, 2008.

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Liu, H.-L., T. Li, C.-Y. She, J. Oberheide, Q. Wu, M. E. Hagan, J. Xu, R. G. Roble, M. G. Mlynczak, J. M. Russell III, Comparative study of short term tidal variability, J. Geophys. Res., 112, doi:10.1029/2007JD008542, 2007.

Xu, J., A. K. Smith, W. Yuan, H.-L. Liu, Q. Wu, M. G. Mlynczak, and J. M. Russell III, The global structure and long term variations of zonal mean temperature observed by TIMED/SABER, J. Geophys. Res., 112, 10.1029/2007JD008546, 2007.

Liu, H.-L., On the large wind shear and fast meridional transport above the mesopause, Geophys. Res. Lett., 34, L08815, doi:10.1029/2006GL028789, 2007.

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Li, T., C.-Y. She, S. E. Palo, Q. Wu, H.-L. Liu, and M. L. Salby, Coordinated Lidar and TIMED observations of the quasi-two-day wave during August 2002-2004 and possible quasi-biennial oscillation influence, Adv. Space Res., 41, 1462-1470, 2008.

Liu, H.-L., Spectral Properties of one-dimensional diffusive systems subject to stochastic forcing, J. Atmos. Sci., 64, 579-593, 2007.

Hanli Liu Research Catalog

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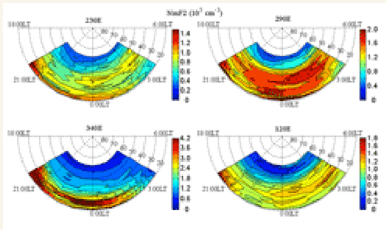
LUAN, XIAOLI

Mid-latitude nighttime enhancement in F-region electron density from global COSMIC measurements under solar minimum winter condition



In collaboration with colleagues in HAO (Wenbin Wang, Alan Burns, and Jiuhou Lei), Xiaoli Luan carried out an analysis on the global geographic morphology of the ionospheric electron density enhancement during the night-time and was aimed to discussion the mechanisms that involved. The global observation of electron density profiles from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) provide a good opportunity to do this analysis over the whole globe as well as over wide altitudinal band. The Figure presents the peak electron density (NmF_2) of the ionospheric F2-layer during the night-time at different longitudinal regions. From the COSMIC observation, both the peak electron density of the F2-layer and the way of its enhancements during the night-time are found to be distinctly different among the majority of the longitudes (~45-245°E), the Atlantic Ocean sector, the eastern part of the North American sectors. Several mechanisms can cause these longitudinal variations, including the separation between the geographic and geomagnetic axes, the difference of the magnetic field intensity at different longitudes and also the longitudinal variation of the magnetic meridional winds.

Figure caption: *F_2-layer peak density (NmF_2) during night at different longitudinal sectors: North America (230°E and 290°E), North Atlantic Ocean (340°E) and East Asia (120°E). Note different contour scales in each longitudinal sector.*

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Luan, X., W. Wang, A. Burns, S. C. Solomon, and J. Lei, 2008: "Midlatitude nighttime enhancement in F region electron density from global COSMIC measurements under solar minimum winter condition", *J. Geophys. Res.*, **113**, A09319, doi:10.1029/2008JA013063.

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Research Focus FY08:

Graduate Advisor: Changhai Liu

Colorado Headwaters Program

(Collaborators: Changhai Liu, Mitch Moncrieff, Roy Rasmussen, Xianfan Ma, Aijuan Bai, John Tuttle & others)

The Colorado Headwaters Program is a key project of NCAR's Water System Program in this fiscal year. Its major objective is to assess the projected Upper Colorado Snowpack and Runoff by global climate models using a very high resolution regional climate model. We started from the present-day cold season simulations in this region to evaluate the sensitivity of the simulated snowfall and snowpack to both the horizontal and vertical grid spacings as well as the various physical parameterizations. We have performed a series of 2~30-km resolution experiments over two multi-day periods (i.e., November 19 - December 8, 2002; February 1 - 16, 2008) with the WRF model. North American Regional Reanalysis (NARR) data are used to provide the initial and boundary conditions in our simulations. The Snow Telemetry network (SNOTEL) and PRISM observations are used to evaluate the simulated snowfall.

The preliminary analysis indicates that

1) the high-resolution simulations with 2~4-km grid spacing can well capture the heavy snowfall episodes during the two periods;

2) the simulated snowfall has little dependence on the choice of the PBL and land-surface schemes, but shows considerable sensitivity to the choice of microphysics parameterizations; and

3) the model performance gradually degrades when the grid spacing is coarser and coarser.

Publications FY08:

Xiao, Q., Y.-H. Kuo, Z. Ma, W. Huang, X.-Y. Huang, X. Zhang, D. M. Barker, J. Michalakes, 2008: Development of the WRF adjoint modeling system and its application to the investigation of the May 2004 McMurdo Antarctica severe wind event. *Mon. Wea. Rev.*, **136**, 3696-3713, doi: 10.1175/2008MWR2235.1.1

Huang, X.-Y., Q. Xiao, D. M. Barker, X. Zhang, J. Michalakes, W. Huang, T. Henderson, J. Bray, Y. Chen, Z. Ma, J. Dudhia, Y.-R. Guo, X. Zhang, D.-J. Won, H.-C. Lin, Y.-H. Kuo, 2008: Four-dimensional variational data assimilation for WRF: Formulation and preliminary results. *Mon. Wea. Rev.*. (Submitted)3

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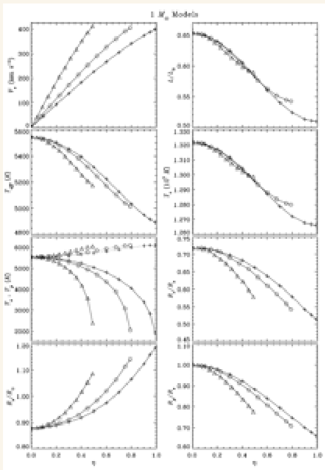
MACGREGOR, KEITH

Structural Models for Young, Differentially Rotating, Solar-type Stars



Rapid rotation can profoundly affect the structure of stars, changing basic stellar properties like the radiative luminosity and effective temperature and causing the photospheric shape to deviate from sphericity. Recent interferometric studies of rapidly rotating intermediate mass stars have provided the first direct observations of these effects, revealing several such objects to have significantly flattened shapes with surface brightness distributions indicative of substantial temperature differences between the polar and equatorial regions of the photosphere. HAO researchers have developed a method for computing models of chemically homogeneous, uniformly and differentially rotating stars that represent fully consistent solutions to the equations governing the stellar structure and gravitational potential. A reformulation of the so-called self-consistent field (SCF) method, this new approach yields two-dimensional, axisymmetric, equilibrium configurations for conservative rotation laws, that is, internal angular velocity distributions with the property that the associated centrifugal acceleration can be derived from a potential. In a conservatively rotating star, the angular velocity depends only on the perpendicular distance from the axis of rotation.

During the past year, HAO scientists Keith MacGregor and Travis Metcalfe, together with SOARS summer student Marques Cameron (Norfolk State University), have constructed a new grid of models for differentially rotating stars with masses between 1 and 2 solar masses. The rotation of these models is like that of the Sun, with the angular velocity variation such that the stellar equator rotates more rapidly than the poles. Specifically, for the assumed rotation law, the ratio of the equatorial angular velocity to the polar angular velocity is (1 + α2), where alpha is a prescribed constant. The accompanying figure depicts some of the properties of 1 solar mass models, obtained for alpha = 0 (crosses), 0.5 (circles), and 1 (triangles). The panels show the equatorial rotation speed (V_e), the radiative luminosity (L), the average surface temperature (T_{eff}), the temperature at the center of the star (T_c), the surface temperatures at the equator and pole (T_e [solid line], T_p [dotted line]), the radius of the convection zone base (R_c), and the equatorial and polar radii (R_e, R_p), all as functions of the dimensionless polar angular velocity (η). Increasingly rapid rotation produces flattened, oblate models with larger equatorial radii and smaller polar radii. Rotationally induced modifications of the thermodynamic conditions in the deep interior lead to reductions in both the stellar luminosity and surface temperature, with hotter poles and substantially cooler equatorial regions. Observations of solar-type stars indicate that in its youth, the Sun could have rotated significantly more rapidly than it does presently. If so, these results may have implications for both the "faint early Sun paradox" and the evolution of the solar abundances of some light metallic elements.

In other work carried out during the last year, MacGregor, Metcalfe, Steve Jackson, and Andy Skumanich collaborated with Daniel Reese (University of Sheffield) to investigate how rotation modifies stellar acoustic oscillation modes, and with Jason Aufdenberg (Embry-Riddle Aeronautical University) to compute detailed model atmospheres for rapidly rotating stars, for comparison with interferometric and spectroscopic observations. Efforts over the next year will center on the development of an SCF-like method applicable to non-conservatively rotating stars and the extension of the structural modeling code to include evolutionary effects.

Figure caption: *Physical properties of rotating, 1 solar mass stellar structural models, as described in the text. The results depicted in each panel pertain to uniform rotation (crosses), and to two cases of solar-like differential rotation (circles, triangles) in which the stellar equator rotates more rapidly than the poles.*

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BIOSPHERE-ATMOSPHERE INTERACTIONS (BAI)

Group Members

Alex Guenther (Group Leader)
Tiffany Duhl
Jim Greenberg
Peter Harley
Irina Herdlinger
Thomas Karl
Saewung Kim
Monica Madronich
Andrew Turnipseed
Christine Wiedinmyer

The research of the BAI group is designed to advance understanding of global biosphere - atmosphere interactions and to predict the response of the earth system to future perturbations. This is being accomplished through multidisciplinary field, laboratory and modeling studies of the processes controlling these interactions on various scales (e.g., leaf to canopy to landscape to global).

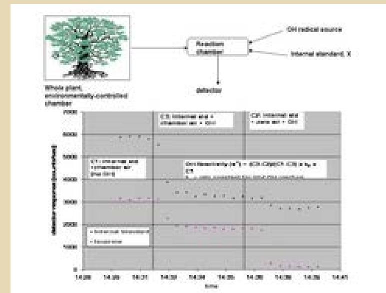

Figure 1 shows that isoprene comprised 85% of the OH reactivity (367 s-1) observed in chamber air surrounding an oak tree. Other reactants including CO, NOx and other VOC make up the balance. This suggests that this particular plant does not emit any OH reactive compounds that cannot be observed by standard analytical techniques.

High resolution figure

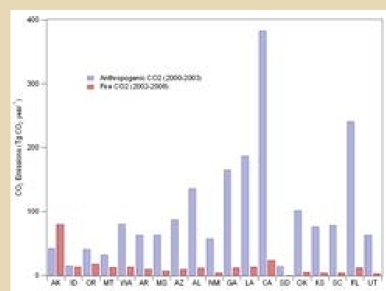

Figure 2 shows estimates of monthly, state-level total CO2 emissions and the contribution from fires (Wiedinmyer and Neff 2008).

High resolution figure

Bioemissions and photochemical processing

Chemicals produced by the biosphere include volatile compounds that are emitted into the air where they can have a substantial impact on the chemistry of the atmosphere. These biogenic gases are dominated by volatile organic compounds (VOCs) both in total mass and number of compounds. The important role of biogenic VOCs in controlling global oxidant (e.g., OH and ozone) distributions has been demonstrated using global models while regional air quality models have shown that it is necessary to included biogenic VOC emissions in modeling efforts to develop regional ozone pollution control strategies. ACD and TIIMES scientists are investigating the processes controlling biogenic emissions and their role in tropospheric photochemistry and are developing numerical schemes for including this information in regional and global earth system models.

Observations of OH and other trace gases at rural and remote sites suggest that OH losses are considerably higher than what can be accounted for by the measured OH sinks. This may indicate that atmospheric chemistry models are missing some of the chemical species that are needed to accurately describe photochemical processing. In FY2008, ACD/TIIMES scientists collaborated with Prof. Yoshizumi Kajii's research group from Tokyo Metropolitan University to investigate OH lifetime and sinks associated with plants growing in NCAR foothills laboratory growth chamber and at the ESSL BEACHON research site in the Manitou Experimental Forest. Emissions and ambient concentrations of a wide range of compounds were measured to quantify their contributions to OH loss. The initial results suggest that observed compounds in the ambient air can account for some, but not all, of the missing OH sinks. The compounds emitted from enclosed vegetation can, at least in some cases, explain the observed OH reactivity (see Figure 1).

Tropical landscapes are thought to be responsible for about 80% of global biogenic VOC emissions and yet are among the least understood. Global chemistry and transport models often perform poorly when using the biogenic VOC emission rates recommended by current emission models. This could be due to uncertainties in emissions but could also be a result of inaccurate characterization of boundary layer meteorology and/or chemistry. ACD and TIIMES scientists participated in the January-March 2008 AMAZonian aerosol characterization experiment (AMAZE) in central Amazonia along with an international team of scientists that included Scot Martin (Harvard University), Jose Jimenez (U. Colorado) and Tony Prenni (Colorado State University). The NCAR scientists quantified the magnitude and variation of VOC, ozone and NOx fluxes and concentrations during the study and are using these observations to understand the processes controlling aerosol formation and growth in this region. ACD and TIIMES scientists also participated in the Oxidant and Particle Photochemical Processes (OP3, see http://badc.nerc.ac.uk/data/op3/) study in the south-east Asian tropical forests of Borneo. NCAR scientists measured biogenic VOC emissions using enclosures and tower based measurements.

FY2009 work will continue laboratory and field investigations of factors affecting biogenic emissions and their impact on oxidants. This work was funded by NSF/NCAR and EPA.

Emission inventories and application

Trace gas and aerosol emissions into the atmosphere are the major drivers of the chemical composition of the atmosphere. There is widespread concern about the effect of human activities on these emissions and their impact on atmospheric chemical composition. Changes in human activities are the underlying cause of the current increase in pollutant levels on regional and global scales. In some cases, changes in trace gas emissions are due to obvious pollutant sources including many technological sources. Other sources, including biomass burning and biogenic sources, have a natural component but are strongly influenced by humans. In order to understand these increases and to predict future changes, ACD/TIIMES scientists are quantifying emissions from various sources and improving our understanding of the natural and human influenced processes that control emissions.

ACD/TIIMES scientists have completed a new version of the Model of Emissions of Gases and Aerosols from Nature (MEGAN), which is a modeling system for estimating the net emission of gases and aerosols from terrestrial ecosystems into the atmosphere. It is driven by land cover, weather, and atmospheric chemical composition. MEGAN is a global model with a base resolution of ~ 1 km. A stand-alone version of MEGAN is now available on the NCAR community data portal during the past year and has already been downloaded by > 100 users from more than 20 countries. MEGAN has also been incorporated as an on-line component of several regional and global models including MOZART, CCSM-CLM, GEOS-CHEM and WRF-CHEM. Continued development of MEGAN has resulted in a version that includes a detailed canopy environment model that will enable more realistic estimates of the response to land cover and climate change. MEGAN regional and global estimates of isoprene emissions are being evaluated by comparisons with satellite observations of HCHO which is a product of isoprene oxidation.

ACD/TIIMES scientists have also continued to improve a North American wildfire emission model and have used the model to forecast fire emission estimates for the NCAR MIRAGE field campaign. The model estimates daily emissions from fires for all of North America at a 1km resolution. More recently, emissions of mercury were included in the fire emissions model, and the first, state- and monthly resolved mercury emission estimates from fires have been produced. ACD/TIIMES scientists teamed with Jason Neff (U. Colorado) to quantify monthly, state-level CO_2 emissions from fires and discuss the potential policy implications of these emissions (see Figure 2).

FY2009 work will include continued improvements of MEGAN and the fire emissions model and enhanced support for the communities using these models. In addition, efforts will be focused on evaluating the model results and quantifying model uncertainties. The emission models will be used in regional chemical transport modeling studies to investigate the radiative impact of aerosols from fires and biogenic sources, interactions between direct particulate fire emissions and secondary organic aerosol formation, and mercury deposition. This work is funded by NSF/NCAR and EPA.

Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) contributions

ESSL scientists are participating in the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS), a new ten-year land-atmosphere project of the International Geosphere-Biosphere Programme (IGBP). The goal of iLEAPS is to understand how interacting physical, chemical, and biological processes transport and transform energy and matter through the land-atmosphere interface. The project is designed to study interactions and feedbacks on scales from molecules to the entire globe, and from minutes to centuries, both past and future. The project brings together multi- and cross-disciplinary scientists to collaborate, distribute ideas and results rapidly, and increase scientific relations with developing countries. The iLEAPS International Project Office is based at the University of Helsinki in Finland and promotes international research projects studying essential phenomena related to global climate change.

In FY2008 ESSL scientists participated in the iLEAPS expert workshop on "The relevance of surface and boundary layer processes for the exchanges of reactive- and greenhouse gases" in Wageningen, Netherlands and the iLEAPS workshop on "Process-based description of trace gas emissions in land surface models" in Helsingborg, Sweden. ESSL scientists will continue to contribute to iLEAPS activities in FY09 and will propose the BEACHON project for sponsorship by iLEAPS. This work is funded by NSF/NCAR.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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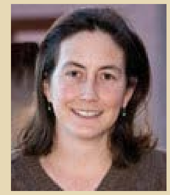
CGD 2008 PROFILES IN SCIENCE: DR. NATALIE MAHOWALD



Natalie Mahowald

Publications

Winckler, G., R. F. Anderson, M. Q. Fleisher, D. McGee, and N. Mahowald, 2008: Covariant Glacial-Interglacial Dust Fluxes in the Equatorial Pacific and Antarctica. Science, 320, 93-96, doi: 10.1126/science.1150595.

Abstract: Dust plays a critical role in Earth's climate system and serves as a natural source of iron and other micronutrients to remote regions of the ocean. We have generated records of dust deposition over the past 500,000 years at three sites spanning the breadth of the equatorial Pacific Ocean. Equatorial Pacific dust fluxes are highly correlated with global ice volume and with dust fluxes to Antarctica, which suggests that dust generation in interhemispheric source regions exhibited a common response to climate change over late-Pleistocene glacial cycles. Our results provide quantitative constraints on the variability of aeolian iron supply to the equatorial Pacific Ocean and, more generally, on the potential contribution of dust to past climate change and to related changes in biogeochemical cycles.

Figure caption: Correlation of ^{232}Th fluxes (red, reverse scale) with global ice volume, as traced by the oxygen isotopic composition of foraminifera (black), for (A) ODP site 806C and RC17-177 in the western equatorial Pacific [Th isotope data from (34); planktonic δ^{18}O from (35)]; (B) TTN013-PC72 in the central equatorial Pacific [Th isotope data from (17) and from this study; benthic δ18O from (15)], (C) ODP site 849 from the eastern equatorial Pacific [Th isotope data from this study; benthic δ^{18}O from (33)]. ^{232}Th fluxes are highest at maximum glacial conditions (as indicated by maximum {delta}^{18}O) and lowest at minimal ice coverage. The limited resolution of the records does not allow us to decipher a lead-lag relationship between dust flux and ice volume change at terminations.

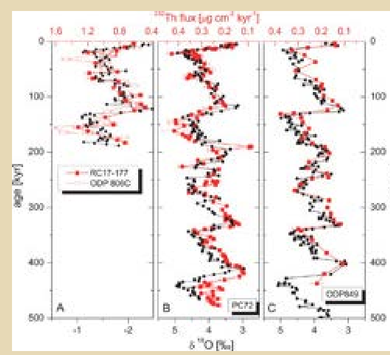


Figure 1.

High resolution figure

Wagener, T., C. Guieu, R. Losno, S. Bonnet, and N. Mahowald, 2008: Revisiting atmospheric dust export to the Southern Hemisphere ocean: Biogeochemical implications. Global Biogeochem. Cycles, 22, GB2006, doi:10.1029/2007GB002984.

Abstract: Aerosol concentrations in the Southern Hemisphere are largely undersampled. This study presents a chemical and physical description of dust particles collected on board research vessels in the southeast Pacific (SEPS) and the Southern Ocean (SOKS). Concentrations of dust were 6.1 ± 2.4 ng m^{-3} for SEPS and 13.0 ± 6.3 ng m^{-3} for SOKS. Dust fluxes, derived from those concentrations, were 9.9 ± 3.7 μg m^{-2} d^{-1} for SEPS and 38 ± 14 μg m^{-2} d^{-1} for SOKS and are shown to be representative of actual fluxes in those areas. Dust and iron deposition are up to 2 orders of magnitude lower than former predictions. A map of dust deposition on the Southern Hemisphere is proposed by

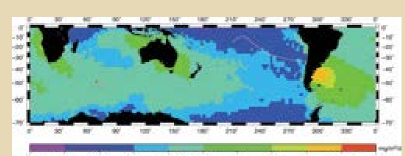


Figure 2.

High resolution figure

incorporating those in situ measurements into a dust model. This study confirms that dust deposition is not the dominant source of iron to the large high-nutrient low-chlorophyll Southern Ocean.

Figure caption: Average dust deposition between April 2004 and March 2005 over the Southern Hemisphere. Estimated from Lm and modified to fit the surface concentrations measured during the cruise. The cruise tracks are in gray.

Wong, S., A. E. Dessler, N. M. Mahowald, P. R. Colarco, and A. da Silva, 2008: Long-term variability in Saharan dust transport and its link to North Atlantic sea surface temperature. Geophys. Res. Lett., 35, L07812, doi:10.1029/2007GL032297.

Abstract: An understanding of the atmospheric distribution of Saharan dust is crucial for understanding many Earth-system processes. We demonstrate here a model simulation indicating that the August-September dust amount in the Tropical Atlantic is linked to the basin-wide North Atlantic sea surface temperature (SST). The increasing SSTs from 1979 to 2005 are associated with a strengthening cyclonic anomaly at 700 hPa in the tropical East Atlantic, reducing Saharan dust outflow into the Tropical Atlantic at latitudes between 10°-20°N. A decreasing dust amount over the same region is also observed by the Advanced Very High Resolution Radiometer. Given the previously observed anti-correlation between dust and tropical cyclone (TC) activity, the long-term variation of North Atlantic SST can then directly influence TC activity by changing a TC's maximum potential intensity and indirectly by modulating the transport of the dust-laden Saharan Air Layer.

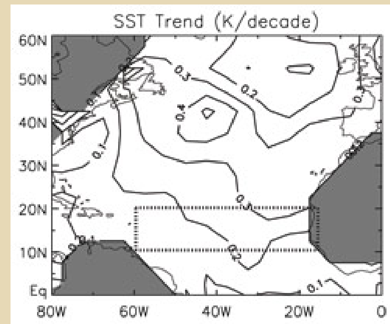


Figure caption: Linear trend in Kaplan North Atlantic SST (K/decade) in August-September for 1979-2005. The contour interval is 0.1, and the shaded area indicates the area with missing data.

Figure 3.

High resolution figure

Nevison, C. D., N. M. Mahowald, S. C. Doney, I. D. Lima, G. R. van der Werf, J. T. Randerson, D. F. Baker, P. Kasibhatla, and G. A. McKinley, 2008: Contribution of ocean, fossil fuel, land biosphere, and biomass burning carbon fluxes to seasonal and interannual variability in atmospheric CO_2. J. Geophys. Res., 113, G01010, doi:10.1029/2007JG000408.

Abstract: Seasonal and interannual variability in atmospheric carbon dioxide (CO_2) concentrations was simulated using fluxes from fossil fuel, ocean and terrestrial biogeochemical models, and a tracer transport model with time-varying winds. The atmospheric CO_2 variability resulting from these surface fluxes was compared to observations from 89 GLOBALVIEW monitoring stations. At northern hemisphere stations, the model simulations captured most of the observed seasonal cycle in atmospheric CO_2, with the land tracer accounting for the majority of the signal. The ocean tracer was 3-6 months out of phase with the observed cycle at these stations and had a seasonal amplitude only ~10% on average of observed. Model and observed interannual CO_2 growth anomalies were only moderately well correlated in the northern hemisphere (R ~ 0.4-0.8), and more poorly correlated in the southern hemisphere (R < 0.6). Land dominated the interannual variability (IAV) in the northern hemisphere, and biomass burning in particular accounted for much of the strong positive CO_2 growth anomaly observed during the 1997-1998 El Niño event. The signals in atmospheric CO_2 from the terrestrial biosphere extended throughout the southern hemisphere, but oceanic fluxes also exerted a strong influence there, accounting for roughly half of the IAV at many extratropical stations. However, the modeled ocean tracer was generally uncorrelated with observations in either hemisphere from 1979-2004, except during the weak El Niño/post-Pinatubo period of the early 1990s. During that time, model results suggested that the ocean may have accounted for 20-25% of the observed slowdown in the atmospheric CO_2 growth rate.

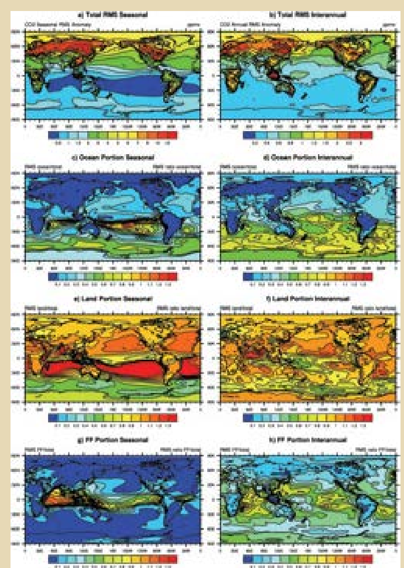


Figure caption: Absolute RMS variability (in ppmv) from 1997 to 2004 of best-case total CO_2. (a) Seasonal, (b) interannual (note different color bar scale). Portional contribution to RMS seasonal variability: (c) best-case WHOI ocean, (e) GFED land, (g) fossil fuel. Portional contribution to RMS interannual variability (d) best-case WHOI ocean, (f) GFED land, (h) fossil fuel. Note that portional RMS variabilities of ocean, land, and fossil fuel add up to >1 when cancellation among component tracers occurs in the summing of total CO_2.

Figure 4.

High resolution figure

Luo, C., N. Mahowald, T. Bond, P. Y. Chuang, P. Artaxo, R. Siefert, Y. Chen, and J. Schauer, 2008: Combustion iron distribution and deposition, Global Biogeochem. Cycles, 22, GB1012, doi:10.1029/2007GB002964.

Abstract: Iron is hypothesized to be an important micronutrient for ocean biota, thus modulating carbon dioxide uptake by the ocean biological pump. Studies have assumed that atmospheric deposition of iron to the open ocean is predominantly from mineral aerosols. For the first time we model the source, transport, and deposition of iron from combustion sources. Iron is produced in small quantities during fossil fuel burning, incinerator use, and biomass burning. The sources of combustion iron are concentrated in the industrialized regions and biomass burning regions, largely in the tropics. Model results suggest that combustion iron can represent up to 50% of the total iron deposited, but over open ocean regions it is usually less than 5% of the total iron, with the highest values (<30%) close to the East Asian continent in the North Pacific. For ocean biogeochemistry the bioavailability of the iron is important, and this is often estimated by the fraction which is soluble (Fe(II)). Previous studies have argued that atmospheric processing of the relatively insoluble Fe(III) occurs to make it more soluble (Fe(II)). Modeled estimates of soluble iron amounts based solely on atmospheric processing as simulated here cannot match the variability in daily averaged in situ concentration measurements in Korea, which is located close to both combustion and dust sources. The best match to the observations is that there are substantial direct emissions of soluble iron from combustion processes. If we assume observed soluble Fe/black carbon ratios in Korea are representative of the whole globe, we obtain the result that deposition of soluble iron from combustion contributes 20-100% of the soluble iron deposition over many ocean regions. This implies that more work should be done refining the emissions and deposition of combustion sources of soluble iron globally.

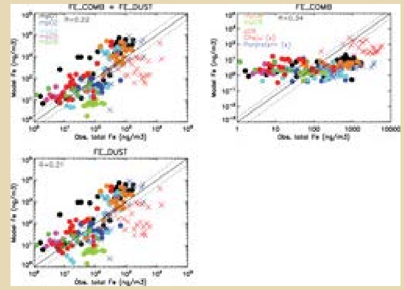


Figure 5.

High resolution figure

Figure caption: Comparisons of total iron concentrations for the different model cases for the cruises shown in Figure 2, FE_COMB + FE_DUST (a); FE_COMB (b); FE_DUST (c).

Thornton, P. E., J.-F. Lamarque, N. A. Rosenbloom, and N. M. Mahowald, 2007: Influence of carbon-nitrogen cycle coupling on land model response to CO_2 fertilization and climate variability. Global Biogeochem. Cycles, 21, GB4018, doi:10.1029/2006GB002868.

Abstract: Nutrient cycling affects carbon uptake by the terrestrial biosphere and imposes controls on carbon cycle response to variation in temperature and precipitation, but nutrient cycling is ignored in most global coupled models of the carbon cycle and climate system. We demonstrate here that the inclusion of nutrient cycle dynamics, specifically the close coupling between carbon and nitrogen cycles, in a terrestrial biogeochemistry component of a global coupled climate system model leads to fundamentally altered behavior for several of the most critical feedback mechanisms operating between the land biosphere and the global climate system. Carbon-nitrogen cycle coupling reduces the simulated global terrestrial carbon uptake response to increasing atmospheric CO_2 concentration by 74%, relative to a carbon-only counterpart model. Global integrated responses of net land carbon exchange to variation in temperature and precipitation are significantly damped by carbon-nitrogen cycle coupling. The carbon cycle responses to temperature and precipitation variation are reduced in magnitude as atmospheric CO_2 concentration rises for the coupled carbon-nitrogen model, but increase in magnitude for the carbon-only counterpart. Our results suggest that previous carbon-only treatments of climate-carbon cycle coupling likely overestimate the terrestrial biosphere's capacity to ameliorate atmospheric CO_2 increases through direct fertilization. The next generation of coupled climate-biogeochemistry model projections for future atmospheric CO_2 concentration and climate change should include explicit, prognostic treatment of terrestrial carbon-nitrogen cycle coupling.

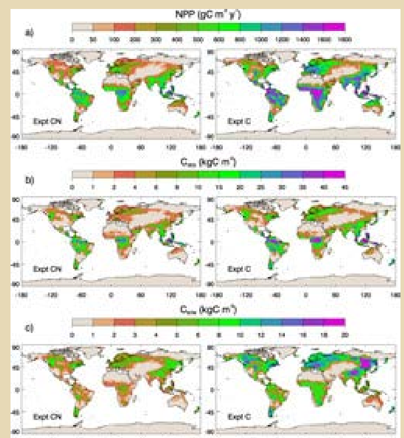


Figure 6.

High resolution figure

Figure caption: Example annual mean flux and state variables from final 25 a of control simulations for C-N (Experiment CN) and carbon-only (Experiment C) model configurations. (a) Net primary production (NPP). (b) Total vegetation carbon (C_{veg}). (c) Total soil organic matter carbon (C_{SOM}).

Winckler, G., R. F. Anderson, M. Q. Fleisher, D. McGee, and N. Mahowald, 2008: Half a million years of coherent dust flux variations in the tropical Pacific and Antarctica. Geochimica et Cosmochimica Acta, 72, A1026-A1026.

Abstract: Dust plays a critical role in Earth's climate system and serves as a natural source of iron and other micronutrients to remote regions of the ocean. We have generated records of dust deposition over the past 500,000 years at three sites spanning the breadth of the equatorial Pacific Ocean. Equatorial Pacific dust fluxes are highly correlated with global ice volume and with dust fluxes to Antarctica, which suggests that dust generation in interhemispheric source regions exhibited a common response to climate change over late-Pleistocene glacial cycles. Our results provide quantitative constraints on the variability of aeolian iron supply to the equatorial Pacific Ocean and, more generally, on the potential contribution of dust to past climate change and to related changes in biogeochemical cycles.

Nevison, C. D., N. M. Mahowald, S. C. Doney, I. D. Lima, and N. Cassar, 2008: Impact of variable air-sea O-2 and CO_2 fluxes on atmospheric potential oxygen (APO) and land-ocean carbon sink partitioning. Biogeosciences, 5, 875-889.

Abstract: A three dimensional, time-evolving field of atmospheric potential oxygen (APO similar to O-2/N-2+CO_2) was estimated using surface O-2, N-2 and CO_2 fluxes from the WHOI ocean ecosystem model to force the MATCH atmospheric transport model. Land and fossil carbon fluxes were also run in MATCH and translated into O-2 tracers using assumed O-2: CO_2 stoichiometries. The modeled seasonal cycles in APO agree well with the observed cycles at 13 global monitoring stations, with agreement helped by including oceanic CO_2 in the APO calculation. The modeled latitudinal gradient in APO is strongly influenced by seasonal rectifier effects in atmospheric transport. An analysis of the APO-vs.-CO_2 mass-balance method for partitioning land and ocean carbon sinks was performed in the controlled context of the MATCH simulation, in which the true surface carbon and oxygen fluxes were known exactly. This analysis suggests uncertainty of up to +/- 0.2 PgC in the inferred sinks due to variability associated with sparse atmospheric sampling. It also shows that interannual variability in oceanic O-2 fluxes can cause large errors in the sink partitioning when the method is applied over short timescales. However, when decadal or longer averages are used, the variability in the oceanic O-2 flux is relatively small, allowing carbon sinks to be partitioned to within a standard deviation of 0.1 Pg C/yr of the true values, provided one has an accurate estimate of long-term mean O-2 outgassing.

Neff, J. C., A. P. Ballantyne, G. L. Farmer, N. M. Mahowald, J. L. Conroy, C. C. Landry, J. T. Overpeck, T. H. Painter, C. R. Lawrence, and R. L. Reynolds, 2008: Increasing eolian dust deposition in the western United States linked to human activity. Nature Geoscience, 3, 189-195.

Abstract: Mineral aerosols from dust are an important influence on climate and on marine and terrestrial biogeochemical cycles. These aerosols are generated from wind erosion of surface soils. The amount of dust emission can therefore be affected by human activities that alter surface sediments. However, changes in regional- and global-scale dust fluxes following the rapid expansion of human populations and settlements over the past two centuries are not well understood. Here we determine the accumulation rates and geochemical properties of alpine lake sediments from the western interior United States for the past 5,000 years. We find that dust load levels increased by 500% above the late Holocene average following the increased western settlement of the United States during the nineteenth century. We suggest that the increased dust deposition is caused by the expansion of livestock grazing in the early twentieth century. The larger dust flux, which persists into the early twenty-first century, results in a more than fivefold increase in inputs of K, Mg, Ca, N and P to the alpine ecosystems, with implications for surface-water alkalinity, aquatic productivity and terrestrial nutrient cycling.

Evan, A. T., A. K. Heidinger, R. Bennartz, V. Bennington, N. M. Mahowald, H. Corrada-Bravo, c. S. Velden, G. Myhre, and J. P. Kossin, 2008: Ocean temperature forcing by aerosols across the Atlantic tropical cyclone development region. Geochemistry Geophysics Geosystems, 9, Q05V04, doi:10.1029/2007GC001774.

Abstract: Recent work has shown a statistical climatological link between African dust outbreaks and North Atlantic tropical cyclone frequency and intensity. However, a definite causal link between year-to-year changes in African dust and Atlantic tropical cyclones has yet to be proven. Here we show that variability in Atlantic dust cover is linked to changes in tropical cyclone activity through the aerosols' surface radiative forcing, which has a net cooling effect on tropical Atlantic Ocean temperatures. In this manuscript we describe a new methodology for incorporating more than 25 years of satellite observations of aerosols into a simple model that estimates the aerosol direct effect and its impact on tropical eastern Atlantic Ocean temperatures. The output from our model suggests that African dust outbreaks play a nonnegligible role in the evolution of eastern Atlantic Ocean temperatures. Using the strong relationship between temperatures in the so-called main development region and the seasonal power dissipation index (PDI), we estimate that about one third of the increase in PDI over the last 25 years can be attributed to decreases in dust loadings over the same period. Our results imply that efforts aimed at attributing causality to past variability of, or at predicting future changes in, North Atlantic tropical cyclone activity must consider the important radiative influence of African dust.

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Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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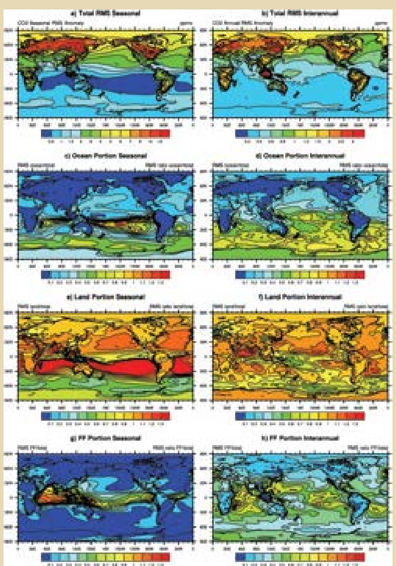
Research Focus FY08:



Absolute RMS variability (in ppmv) from 1997 to 2004 of best-case total CO_2. (a) Seasonal, (b) interannual (note different color bar scale). Portional contribution to RMS seasonal variability: (c) best-case WHOI ocean, (e) GFED land, (g) fossil fuel. Portional contribution to RMS interannual variability (d) best-case WHOI ocean, (f) GFED land, (h) fossil fuel. Note that portional RMS variabilities of ocean, land, and fossil fuel add up to >1 when cancellation among component tracers occurs in the summing of total CO_2.

High resolution figure

My research group is focused understanding on global and regional scale atmospheric transport of biogeochemically important species such as desert dust. We are interested in how humans are perturbing the natural environment, especially through perturbations to aerosols. We look at these issues through a combination of 3-dimensional global transport and climate models, as well as analysis of satellite and in situ data.

Abstract from one of my publications this year:
J. Geophy. Res., *Contribution of ocean, fossil fuel, land biosphere, and biomass burning carbon fluxes to seasonal and interannual variability in atmospheric CO2.*

Seasonal and interannual variability in atmospheric carbon dioxide (CO_2) concentrations was simulated using fluxes from fossil fuel, ocean and terrestrial biogeochemical models, and a tracer transport model with time-varying winds. The atmospheric CO_2 variability resulting from these surface fluxes was compared to observations from 89 GLOBALVIEW monitoring stations. At northern hemisphere stations, the model simulations captured most of the observed seasonal cycle in atmospheric CO_2, with the land tracer accounting for the majority of the signal. The ocean tracer was 3-6 months out of phase with the observed cycle at these stations and had a seasonal amplitude only ~10% on average of observed. Model and observed interannual CO_2 growth anomalies were only moderately well correlated in the northern hemisphere ($R \sim 0.4$-0.8), and more poorly correlated in the southern hemisphere ($R < 0.6$). Land dominated the interannual variability (IAV) in the northern hemisphere, and biomass burning in particular accounted for much of the strong positive CO_2 growth anomaly observed during the 1997-1998 El Niño event. The signals in atmospheric CO_2 from the terrestrial biosphere extended throughout the southern hemisphere, but oceanic fluxes also exerted a strong influence there, accounting for roughly half of the IAV at many extratropical stations. However, the modeled ocean tracer was generally uncorrelated with observations in either hemisphere from 1979-2004, except during the weak El Niño/post-Pinatubo period of the early 1990s. During that time, model results suggested that the ocean may have accounted for 20-25% of the observed slowdown in the atmospheric CO_2 growth rate.

Publications FY08 (abstracts):

Thornton, P. E., J.-F. Lamarque, N. A. Rosenbloom, N. M. Mahowald, 2007: Influence of carbon-nitrogen cycle coupling on land model response to CO_2 fertilization and climate variability. *Global Biogeochemical Cycles*, **21**, GB4018, doi: 10.1029/2006GB002868.

Winckler, G., R. F. Anderson, M. Q. Fleisher, D. McGee, and N. Mahowald, 2008: Covariant Glacial-Interglacial Dust Fluxes in the Equatorial Pacific and Antarctica. Science, 320, 93-96, doi: 10.1126/science.1150595.

Wagener, T., C. Guieu, R. Losno, S. Bonnet, and N. Mahowald, 2008: Revisiting atmospheric dust export to the Southern Hemisphere ocean: Biogeochemical implications. Global Biogeochem. Cycles, 22, GB2006, doi:10.1029/2007GB002984.

Wong, S., A. E. Dessler, N. M. Mahowald, P. R. Colarco, and A. da Silva, 2008: Long-term variability in Saharan dust transport and its link to North Atlantic sea surface temperature. Geophys. Res. Lett., 35, L07812, doi:10.1029/2007GL032297.

Nevison, C. D., N. M. Mahowald, S. C. Doney, I. D. Lima, G. R. van der Werf, J. T. Randerson, D. F. Baker, P. Kasibhatla, and G. A. McKinley, 2008: Contribution of ocean, fossil fuel, land biosphere, and biomass burning carbon fluxes to seasonal and interannual variability in atmospheric CO2. J. Geophys. Res., 113, G01010, doi:10.1029/2007JG000408.

Luo, C., N. Mahowald, T. Bond, P. Y. Chuang, P. Artaxo, R. Siefert, Y. Chen, and J. Schauer, 2008: Combustion iron distribution and deposition, Global Biogeochem. Cycles, 22, GB1012, doi:10.1029/2007GB002964.

Winckler, G., R. F. Anderson, M. Q. Fleisher, D. McGee, and N. Mahowald, 2008: Half a million years of coherent dust flux variations in the tropical Pacific and Antarctica. Geochimica et Cosmochimica Acta, 72, A1026-A1026.

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Neff, J. C., A. P. Ballantyne, G. L. Farmer, N. M. Mahowald, J. L. Conroy, C. C. Landry, J. T. Overpeck, T. H. Painter, C. R. Lawrence, and R. L. Reynolds, 2008: Increasing eolian dust deposition in the western United States linked to human activity. Nature Geoscience, 3, 189-195.

Evan, A. T., A. K. Heidinger, R. Bennartz, V. Bennington, N. M. Mahowald, H. Corrada-Bravo, c. S. Velden, G. Myhre, and J. P. Kossin, 2008: Ocean temperature forcing by aerosols across the Atlantic tropical cyclone development region. Geochemistry Geophysics Geosystems, 9, Q05V04, doi:10.1029/2007GC001774.

Natalie M. Mahowald Research

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Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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MIDDLE/UPPER ATMOSPHERE AND WACCM GROUP

Group Members

Anne Smith (Group Leader)
Rolando Garcia (Group Leader)
Dan Marsh
Doug Kinnison
Simone Tilmes
Aimee Merkel
Francis Vitt

Middle Atmosphere

ACD scientists have worked with data from the TIMED (Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics) satellite to investigate the dynamics and chemistry of the middle atmosphere. Much of this research has been done in collaboration with US and international colleagues.

The diurnal tide gives large amplitude variations over 24-hours of temperature and winds in the mesosphere. ACD scientists have worked on the characterization of variations in the tidal amplitudes and phases using temperature and wind data from TIMED and ground-based radar. The results indicate that there are large variations of tidal amplitude on semi-annual and annual timescales. The tide at the equator also varies on a multi-year timescale in concert with the quasi-biennial oscillation in equatorial lower stratospheric winds. This study will continue, using small differences in the tides to derive the eddy diffusion rate in the mesosphere.

Up to now, the chemistry of the mesosphere has been poorly constrained by observations. This is beginning to change, and analysis by ACD scientists is contributing. A new measurement from the SABER instrument on TIMED gives the distribution of atomic hydrogen. These global, multi-year measurements show a drop in the hydrogen in the summer mesosphere that is inconsistent with transport. However, a closer look indicates that this drop is consistent with the vertical redistribution of hydrogen due to the freezing of water in polar mesospheric clouds and subsequent vertical displacement and sublimation of the ice particles.

Ozone observations by SABER also reveal some unusual aspects. At the location of the ozone secondary maximum near 95 km, SABER observations show occasional very high mixing ratios of over 20 ppmv, and as high as 50 ppmv, during night. Analysis indicates that these are associated with unusually large amplitudes of the diurnal tide. The large tide leads to low nighttime temperatures at 95 km at the equator; the low temperatures affect the photochemistry of ozone in such a way that the ozone is high. The magnitude and occurrence of the high ozone fit well with current understanding of ozone photochemistry.

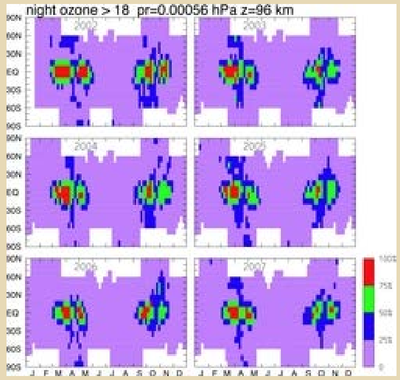

Figure 1: Latitude and day distribution of the incidence of ozone mixing ratio over 18 ppm at about 96 km (near the mesopause). The observations are from TIMED/SABER, nighttime only. The high ozone occurs near the equator during equinoxes, which is when the diurnal tide has its largest amplitude. At this altitude, the tidal phase is such that the coldest temperatures occur during the night. With colder temperature, the ozone production rate is faster and the loss rate is slower so the overall amount increases.

High resolution figure

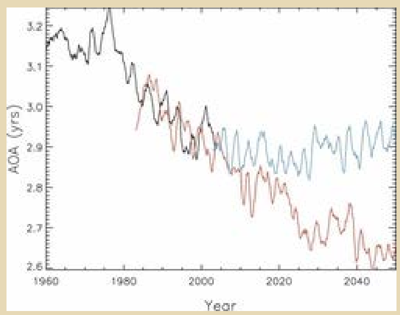

Figure 2: Evolution of the age of air near 10 hPa averaged over +/-22° for three-member ensemble simulations (i.e., three integrations of WACCM) of the climate of the twentieth century (black curve); the climate of the twenty-first century under increasing loading of greenhouse gases (red); and the climate of the twenty-first century with greenhouse gases held constant at 1995 values (blue). The decreasing age of air is an indication that the circulation is faster.

High resolution figure

WACCM

ACD work using the WACCM model involves an extensive set of collaborators from other ESSL divisions and externally from US and international institutions.

The model was used for a global simulation of dust particles from meteors hitting the Earth's atmosphere. The simulations show that the summer high-latitude mesosphere is relatively depleted in these particles due to large scale upwelling. The number of particles may still be sufficient to supply the necessary condensation nuclei to account for the formation of polar mesospheric clouds.

Another set of simulations used WACCM to assess the impact of the insertion of sulfur into the stratosphere: one of several suggested "geo-engineering" activities to counteract the predicted climate change from greenhouse gases. The sulfur would form particles that absorb and reflect sunlight, thereby reducing the solar heating at the Earth's surface in a manner similar to large volcanic eruptions. As shown by the WACCM simulations, the sulfate particles do delay the warming at the surface compared to other simulations without the injected sulfur. However, the sulfur would also accelerate the ozone loss that occurs in late winter over Antarctica and would increase the ozone loss over the northern polar region.

According to WACCM simulations, a regional nuclear conflict could also have severe consequences for stratospheric ozone. In this case, the primary effect would be the heating of the lower stratosphere due to thick and persistent smoke. The heating leads to photochemical loss of ozone. A conflict involving 100 bombs could lead to ozone losses of 20% globally, with predictions of more than 50% at high latitudes.

WACCM also predicts that the rising concentrations of greenhouse gases will lead to an acceleration of the Brewer–Dobson circulation. The circulation strengthens as a result of increased wave driving in the subtropical lower stratosphere, which in turn occurs because of enhanced propagation and dissipation of waves in this region. Enhanced wave propagation is due to changes in tropospheric and lower-stratospheric zonal-mean winds, which become more westerly. Ultimately, these trends follow from changes in the zonal-mean temperature distribution caused by the greenhouse effect. The circulation in the middle and upper stratosphere also accelerates as a result of filtering of parameterized gravity waves by stronger subtropical westerly winds.

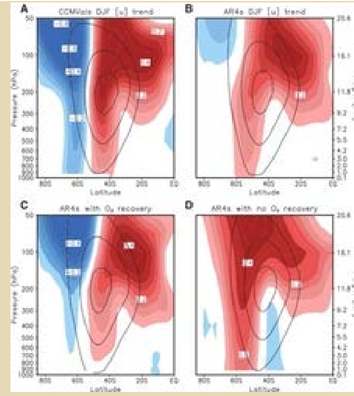

Figure 3: Trends in December-to-February zonal-mean zonal wind. The multimodel mean trends between 2001 and 2050 are shown for four groups of models. A) CCMVal models, which include interactive stratospheric chemistry. B) AR4 models, most of which have a model top below the stratopause and only about half of which specify recovering ozone for the future. C) a subset of the AR4 models with prescribed ozone recovery. D) AR4 models with no ozone recovery. Shading and contour intervals are 0.05 ms-1 decade-1. Deceleration and acceleration are indicated with blue and red colors, respectively, and trends weaker than 0.05 ms-1 decade-1 are omitted. Superimposed black solid lines are DJF zonal-mean zonal wind averaged from 2001 to 2010, with a contour interval of 10 ms-1, starting at 10 ms-1. EQ, equator. Note that AR4 models with prescribed ozone recovery (panel C) perform better, as compared to CCMVal models, than those without (panel D), but still do not reproduce the full extent of the prediction.

High resolution figure

Ozone recovery and climate

A study using WACCM and other models with interactive chemistry looked at the predictions for climate change in the Southern Hemisphere. In particular, the study addressed the predictions for winds in the SH middle and high latitudes. There is a clear difference in the climate predictions of models that do not include interactive stratospheric chemistry and those that do. The difference can be traced to the simulation of the ozone hole. When interactive chemistry is not included, winds continue to accelerate in a manner consistent with observations in recent years. However, in model simulations with interactive chemistry and a full stratosphere, the Antarctic ozone hole recovers during the 21st century due to the predicted drop in halogens in the stratosphere. This changes the thermal structure since ozone is an important radiative gas. With ozone recovery, polar temperatures warm and winds decelerate such that the overall prediction for the climate in the southern high latitudes is significantly different.

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HIGH RESOLUTION DYNAMICS LIMB SOUNDER (HIRDLS)

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Barb Tunison
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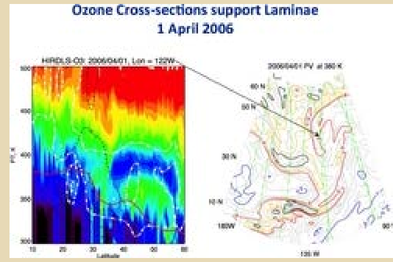
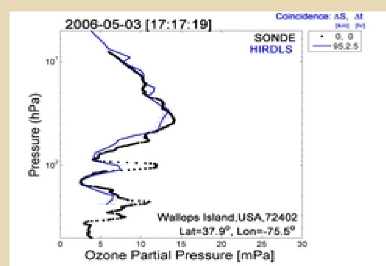


Figure. 1. a. Cross-section of ozone as a function of latitude and potential temperature along a HIRDLS scan track at 122°W (Eastern Pacific). Blue indicates mixing ratios ≤ 0.3 ppmv, green is near 0.8 ppmv, and red approaches 1.8 ppmv. Broken white lines indicate contours of potential vorticity (PV) at 6 and 10 PVU, the red line is the tropopause location, both from the Goddard Modeling and Assimilation Office (GMAO) Earth Observing System (GEOS5.1) data, which is also the source of the dashed lines indicating contours of zonal wind.
b. Plot of GEOS 5.1 PV on the 380K surface from 90-180°W, and 10-70°N on 1 April 2006. Contours highlighted in color are 2 PVU (blue), 6 PVU (red) 8 PVU (yellow) and 10PVU (black). Green dash-dot lines show the HIRDLS scan tracks this day. The tracks through 122° W can be seen.

High resolution figure



Figures 2 and 3. Comparisons of HIRDLS V4 ozone retrievals with ozone sonde data at the locations and dates indicated. Separation of the sonde and HIRDLS retrievals is 95 km and 2.5 hours for the May profile, and 238 km and 0 hours for the April profile. The HIRDLS retrievals (blue) pick up the fine vertical features seen by the sondes (black dots).

High resolution figure

Research Activities

The High Resolution Dynamics Limb Sounder (HIRDLS) is a 21 channel infrared limb scanning radiometer, jointly developed by ACD, the University of Colorado, and the Physics Department of Oxford University. It is designed to make observations of temperature, ozone, water vapor, and 8 other trace species, as well as PSC's, aerosols and cirrus clouds, from the upper troposphere to the mesosphere, with higher vertical resolution than has previously been available from space observations. HIRDLS was launched on the Aura spacecraft in July 2004. Despite an obstruction that limited the view to the atmosphere to a small fraction of the width of the optical beam, HIRDLS scientists demonstrated that there is recoverable atmospheric information in the signals, and worked hard to develop algorithms to correct for the effects of the obstruction, as discussed below.

As a result of these efforts, Version 4 of the data, providing high resolution retrievals of temperature, ozone, nitric acid, CFC 11, CFC 12, aerosol extinction plus cloud top location and types was made available to the community. Five papers describing the validation of V3 data were published. V4 data has improved cloud detection, leading to more reliable ozone data in the UTLS region. In addition, the mean accuracy of the temperature and ozone data has improved.

An example of what can be seen is shown in Figure 1, which shows a latitude-potential temperature cross-section along a HIRDLS scan track near 122°W on 1 April 2006. This shows a region of low ozone at 380K in mid latitudes, originally from low latitudes that has been injected across the tropopause, but here has been separated by atmospheric motions, believed to be related to baroclinic waves in the troposphere. Here it remains as a thin layer that is associated with a potential vorticity (PV) contour of 6 10-6 m2/s K/kg, (6 PVU) as shown in the PV map on the 380K surface in Figure 2. Following this air mass shows that the low ozone air remains close to the 6PVU contour for several days, before the PV contour relaxes to a lower altitude, leaving the air to mix with its surroundings.

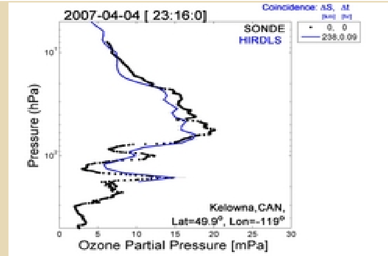


Figure 3.

High resolution figure

This can only be seen because of the high vertical resolution of the HIRDLS data.

Summarizing the accomplishments, the radiance correction algorithms were improved, adding the CFC's and aerosol extinction to be retrieved, as well as improving the accuracy and usefulness of temperature and ozone. A study of gravity waves was published, and several talks on UT/LS processes and strat-top exchange were presented. An anomaly with the HIRDLS chopper prevented participation in START08, or the ARCTAS field experiment.

The plans for FY09 call for increased emphasis on the application of these unique, high resolution data to a range of scientific applications, as well as continuation of work to further refine the correction and retrieval algorithms to retrieve additional species, and extend the altitude range of the results.

This work was supported by NASA and the NSF.

HIRDLS Recovery

When HIRDLS was launched on the Aura spacecraft in July 2004, a thin plastic film from inside HIRDLS came loose and obstructed most of the instrument's aperture, limiting the view to the atmosphere to a small fraction of the width of the optical beam. As described previously, the HIRDLS team, led by John Gille, the U.S. PI, and John Barnett (Oxford), the U.K. PI, showed that there was useful information in the signals. This required the development of 4 major adaptations and corrections to the measured signals. The first, revising the calibration, was described earlier.

The next steps were to correct the measured signals to make them as close as possible to the expected radiances. The major efforts this year were to complete the algorithms to remove the spurious oscillations (due to mechanical oscillations of the plastic), and to recalculate the pointing. In addition, critical improvements were made in the corrections for the partial viewing area, and the estimation and removal of the signal coming from the obstruction.

A key method for determining these corrections is to have the spacecraft pitch by ~5°, so that HIRDLS looks above the atmosphere and measures signals only from the plastic film. This year the ACD HIRDLS team coordinated 2 of these pitch maneuvers. The initial development of these algorithms was described previously, but work continued, especially to improve the estimate of the reduced viewing area, and to refine subtraction of the signal from the plastic film. The latter is the biggest difficulty at this time. Updated calibration coefficients, radiance sample geo-location, and improved cloud location had been incorporated in the operational processing code. The resulting processor version was run on all the observations to produce a data set designated internally version 2.04.09. These data include global profiles of temperature, ozone, nitric acid and aerosol/cirrus; it was released to the community as Version 3 (V3) data. These were publicly released at the beginning of the reporting period.

Subsequent improvements have resulted in a new processor, v2.04.19, and a new V4 data set that was released near the close of the reporting period. These data include profiles of CFC 11, CFC12, and aerosol extinction, as well as temperature and ozone that have improved accuracy and fewer data spikes. The HIRDLS temperatures are now in within 0.5K of U.K. Meteorological Office high-resolution radiosonde data for 9 widely distributed stations, and for all data available from January 2005 until August 2007, while continuing the 1 km vertical resolution obtained previously. HIRDLS temperature retrievals show the same very good agreement with high resolution radiosondes as the earlier version, shown in the last Annual Report. V4 ozone retrievals also show very good agreement with sonde data, and the ability to see small scale structure, as illustrated in the Figures 2 and 3.

The NCAR HIRDLS team hosted members of the core Oxford team for a 2 day meeting in January to discuss data improvements and future plans. This was followed by an open meeting with community members to discuss and encourage the scientific applications of HIRDLS data. The team also presented their status and plans to a review team from NASA, and attended similar core team and open science meetings in Oxford in June.

After an increasing number of spikes in the chopper motor current beginning in January, the chopper ceased operating on 17 March. Considerable effort has gone into diagnosing the problem, and attempting to restart the chopper, so far without success.

In the next year the correction algorithms will be refined to allow the recovery of additional species such as water vapor and methane. Emphasis will be on improved estimation of the partial view area and especially of the signal from the plastic, including allowances for the variation of the latter with time. In parallel, emphasis will be placed on the use of the released data for scientific studies, especially of UT/LS processes and strat-trop exchange, but broadening to many other areas (See Goal 1).

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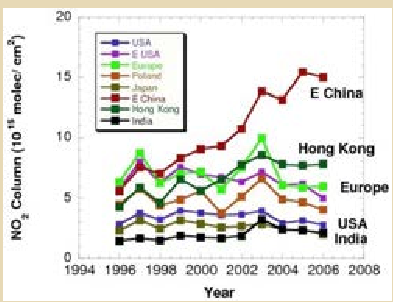

Regional NO2 Trends from satellite-based instruments (GOME and SCIAMACHY)

High resolution figure

Satellite Data Analysis (SDA) Group

The Satellite Data Analysis Group in ACD focuses on studies of global scale chemical behavior using satellite measurements, meteorological data sets and model simulations. Recent work has focused on understanding the chemical and dynamical behavior of the tropopause region, and its long-term variability, to help quantify processes which contribute to coupling in the upper troposphere lower stratosphere (UTLS).

High Resolution Dynamics Limb Sounder (HIRDLS)

The High Resolution Dynamics Limb Sounder (HIRDLS) is a 21 channel infrared limb scanning radiometer, jointly developed by ACD, the University of Colorado, and the Physics Department of Oxford University. It is designed to make observations of temperature, ozone, water vapor, and 8 other trace species, as well as PSC's, aerosols and cirrus clouds, from the upper troposphere to the mesosphere, with higher vertical resolution than has previously been available from space observations. HIRDLS was launched on the Aura spacecraft in July 2004. Despite an obstruction that limited the view to the atmosphere to a small fraction of the width of the optical beam, HIRDLS scientists demonstrated that there is recoverable atmospheric information in the signals, and worked hard to develop algorithms to correct for the effects of the obstruction...more

Community Service FY08:

- Chair: AURA Cloud Working Group (NASA)

Scientific Talks FY08:

- Aerosol indirect effects as a function of cloud top pressure (Lille, FRA, 10/2007)
- PACDEX from a satellite perspective (San Francisco, CA USA, 12/2007)
- HIRDLS observations of subvisible cirrus (Pasadena, CA USA, 12/2007)
- Cirrus clouds near the mid-latitude tropopause (Boulder, CO USA, 01/2008)
- A-train observations of cloud structures (Ft. Lauderdale, FL USA, 05/2008)
- HIRDLS observations of cirrus near the tropopause (Ft. Lauderdale, FL USA, 05/2008)
- Cloud and aerosol detection (Oxford, GBR, 06/2008)

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Steve Massie Research Catalog

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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MEASUREMENTS OF POLLUTION IN THE TROPOSPHERE

Group Members

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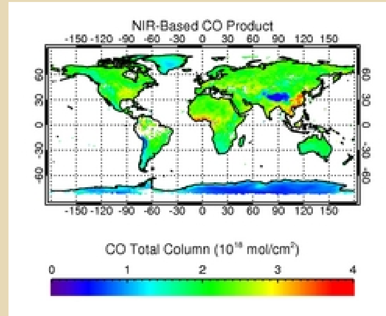

Figure 1. Monthly mean MOPITT CO total column results for March, 2006 based solely on near-infrared observations.

High resolution figure

MOPITT Operational Production of Carbon Monoxide Data

The daily operational processing of Measurement Of Pollution In The Troposphere (MOPITT) instrument raw counts into the final retrieved geophysical products, delivery of products to NASA for free public access, and user education and support, constitutes a major service to the scientific community. MOPITT is also unique in providing the community with the longest continuous validated global CO data product. Scientific results have been presented worldwide at numerous scientific meetings and show a documented strong presence on the Internet. MOPITT data distribution, publications, literature citations, and conference presentations are all showing strong upward trends, indicating mounting demand and scientific interest.

Development of new data processing software for the next product release, 'Version 4,' has just been completed. Major features of the new retrieval algorithm include: (1) a new forward model with improved description of the MOPITT gas correlation cells and applicability to a wider range of CO mixing ratios; (2) a new description of the retrieval a priori surface emissivity; (3) a new seasonally and geographically variable CO retrieval a priori; and (4) the use of an assumed log-normal variability for CO volume mixing ratio. The new product also includes more extensive diagnostics, including the retrieval averaging kernels.

Activities during FY08

Algorithm Development and Product Evaluation

The development of a substantially improved retrieval algorithm for processing the next major MOPITT data product ('Version 4') was recently finalized. Associated activities completed in FY08 included (1) enhancement of the operational radiative transfer model to reflect actual in-orbit instrumental parameters and to better handle extremely polluted atmospheres and (2) determination of appropriate radiance bias correction factors. Product evaluation activities included analysis of V4 results at validation sites where aircraft in-situ profiles and surface measurements are available throughout the mission (since 2000). Overall, validation results indicate very small retrieval biases at all levels and demonstrate significantly weaker long-term drift than was observed in the current MOPITT Version 3 Product.

Long-term goals for the MOPITT Team include the incorporation of MOPITT's near-infrared measurements (i.e., 'solar channels') to provide additional information with respect to the CO total column measurement. Neither the current MOPITT Version 3 product nor the upcoming Version 4 products exploit these measurements because of challenges in understanding apparent instrument noise specific to these channels. During FY08, however, MOPITT retrievals based on these measurements were demonstrated for the first time, and clearly indicate the promise of combined thermal-infrared/near-infrared (TIR/NIR) CO retrievals for future products. Figure 1 presents global monthly-mean CO total column retrievals based solely on MOPITT NIR measurements during March, 2006. Regions of biomass burning in Equatorial Africa as well as anthropogenic emissions in China (principally from fossil fuel burning) are both clearly evident in the figure. Compared to current retrievals based purely on TIR measurements, the new NIR retrieval product is more sensitive to CO in the boundary layer and therefore should be much more capable of identifying sources at the surface.

Reference: "CO retrievals based on MOPITT near-infrared observations," by M. N. Deeter, D. P. Edwards, J. C. Gille, and James R. Drummond, *submitted to J. Geophys. Res.*

Field Campaign Support

The NCAR MOPITT Team produced and provided near real-time imagery and CO data products to support the ARCTAS (Arctic Research of the Composition of the Troposphere from Aircraft and Satellites) field campaign during Spring and Summer phases in FY08. Analyses of these data are ongoing.

Plans for FY09

Production and Release of V4

Operational processing of the MOPITT Version 4 product will begin in early FY09. The acquisition of new linux servers should allow processing of the entire MOPITT mission within several months, however the prerequisite task of porting all of the associated software to the new hardware may itself take several months. This process has begun. In preparation for the release of the new product, a new User's Guide is being drafted. Also, as the official release date approaches (possibly around the end of 2008), the new product will be publicized within the community. This effort will include a presentation at the Fall AGU meeting.

Version 5 Development

As operational processing of the Version 4 product becomes routine, initial steps to define and develop the Version 5 product will begin. While preliminary, current objectives for V5 development include the incorporation of MOPITT's solar channels and an evaluation of alternative sources for meteorological data.

Continued Analysis of Operational MOPITT Products

The MOPITT Science Team will continue to evaluate operational products both in the context of traditional validation (e.g., using available in-situ data from aircraft and ground-based spectroscopic measurements) and in comparison to models.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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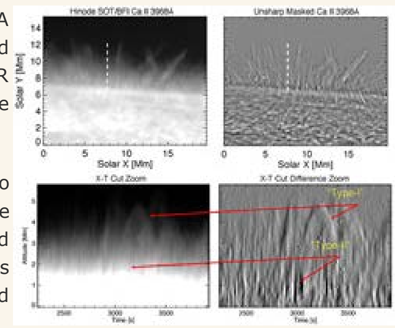
MCINTOSH, SCOTT

Structure of the Limb Chromosphere and Transition Region

Scott McIntosh In collaboration with Bart De Pontieu [Lockheed Martin Solar and Astrophysics Laboratory]

Additional Sources of Funding: NASA ROSES-2007 HGI grant NNX08AL22G; ROSES-2007 Living With A Star TR&T grant NNX08AH45G to BDP and SWM; NSF ATM-0541567; NASA ROSES-2005 NNG06GC89G



Using joint observations from the Solar Optical Telescope (SOT) on the NASA/JAXA Hinode spacecraft, images of UV continuum emission from the Transition Region and Coronal Explorer (TRACE) and UV spectroscopic observations from the SUMER instrument on the Solar and Heliospheric Observatory (SOHO), we are exploring the structure of the chromosphere and transition region at the solar limb.

Previous observations have shown that the chromospheric limb consists of at least two types of fundamental structure, known as spicules. "Type I" spicules live predominantly in closed magnetic field regions, have lifetimes of 3-7 minutes, and span out from the granular magnetic network into the cell interiors. "Type II" spicules live in the magnetic core of the granular network, have 10-100 second lifetimes and are normally oriented to the limb.

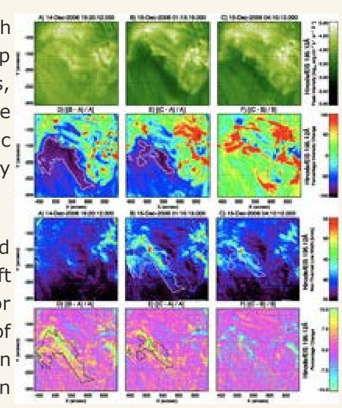
While Type-I spicules are relatively well understood, their more dynamic cousins are a not. While both of these structures have been shown to carry Alfvén waves, the latter is likely to be an important component in the process that heats the chromosphere, corona and can drive the solar wind. The new observations will provide information to understand their role at the lower boundary of the heliospheric plasma.

Figure caption: *Hinode/SOT observations of the chromosphere at the limb, seen in the raw (top left panel) and after the application of an unsharp masking to the image. Studying the evolution of material along a normal path (shown as white dashed line in the top two panels) via the space-t diagrams shown in the two lower panels we see two prevalent structures, the parabolic temporal trajectories typical of "Type I" spicules and the sharp linear features of "Type II" spicules.*

Spectroscopic Investigation of Transient Coronal Holes

Scott McIntosh

Additional Sources of Funding: NASA ROSES-2007 HGI grant NNX08AL22G.



We have investigated the occurrence of a coronal dimming using a combination of high resolution spectro-polarimetric, spectral and broadband images which span from the deep photosphere into the corona. These observations reinforce the belief that coronal dimmings, or transient coronal holes as they are also known, are locations of open magnetic flux in the corona resulting from the launch of a Coronal Mass Ejection (CME). As open magnetic regions, they must act just as coronal holes and be sources of the fast solar wind, but only temporarily.

This behavior is exemplified by the temporal evolution of several EUV emission lines observed by the Extreme-ultraviolet Imaging Spectrometer (EIS) on the NASA/JAXA Hinode spacecraft which demonstrate large plasma outflow (~40km/s) in the region and the dynamic behavior of non-thermal line widths. The latter is consistent with the dynamic growth and decay of sub-resolution Alfvénic motions in the plasma as it opens and eventually closes. Based on recent investigations these Alfvén waves are a likely driver of the fast solar wind in the open portion of the outer corona.

This work has posed an inescapable question - what impact does this source of fast wind have on the propagation and in-flight characteristics of the CME that initiates the coronal dimming in the first place?

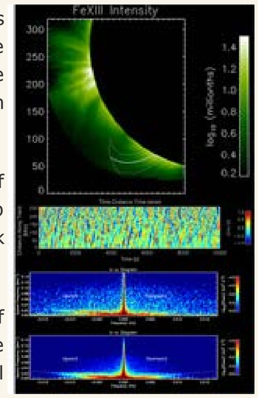
Figure caption: *Hinode/EIS observations of the corona before (left column), and after (center and right columns) the launch of a coronal mass ejection (CME). Shown in rows of the figure from top to bottom are the line intensity, intensity difference, non-*

thermal spectroscopic line width and their difference. The contoured region shows a reduction in intensity of 75% over the course of the event.

Time-Distance Seismology of the Solar Corona

Steven Tomczyk & Scott W. McIntosh

Additional Sources of Funding: NASA ROSES-2007 LWS TR&T grant NNX08AU30G.



The unique spectral imaging capability of HAO's Coronal Mutli-channel Polarimeter (CoMP) allows us to perform time-distance seismology of the solar corona. We have exploited the ubiquity of the Alfvénic motions observed in the corona to construct the first k-omega diagram of the region. These k-omega diagrams, and related diagnostics, have allowed us to refine the analysis presented in Tomczyk et al. (2007, Science, 317, 1192).

This new analysis has considerably improved the correspondence between the determined angle of wave propagation and the spectro-polarimetrically measured magnetic azimuth. The relationship between wave propagation angle and magnetic azimuth will be essential to resolve the Van Vleck ambiguity in the spectro-polarimetric measurements.

Using the k-&;omega diagrams we are able to measure both the phase speed and the amount of pro-grade (upward) and retro-grade (downward) Alfvén wave power in the corona. Measuring the spatial variation in the mixture of upward and downward waves is critical in identifying the physical process, or processes responsible for heating the solar corona and driving the solar wind.

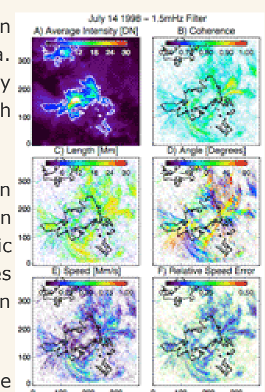
The observed contrast in the upward/downward wave motions is consistent with a picture of the corona where the low-frequency magneto-convection driven Alfvénic motions suffer significant dissipation along the magnetic structures along which they propagate, possibly as a result of turbulent interference processes.

Figure caption: *HAO/CoMP observations of the solar corona (top). Extracting a wave path from the Doppler velocity measurements (solid line) we can construct a time series of the plasma motion along the path (second row); the inclined striping of the wave motions indicates the phase speed. A two-dimensional Fourier spectrum of the time series yields the k-omega diagram of the waves on the path (third row) and that for all the paths found in a surrounding region (fourth row). In both cases we see that the waves present are non-dispersive and have equal phase speeds (inclination), but a different degree of power in each direction.*

Tracking MHD Waves in the Solar Corona

Scott W. McIntosh & Steve Tomczyk In collaboration with Bart De Pontieu [Lockheed Martin Solar and Astrophysics Laboratory, Palo Alto, CA]

Additional Sources of Funding: NASA ROSES-2007 HGI grant NNX08AL22G; ROSES-2007 Living With A Star TR&T grant NNX08AH45G to BDP and SWM; NSF ATM-0541567; NASA ROSES-2005 NNG06GC89G.



We have considered the problem of automatically (and robustly) isolating and extracting information about the propagating waves and oscillations observed in EUV image sequences of the solar corona. Such an approach is essential for near real-time application to the large data flow (~1Tb/day) likely from the Atmospheric Imaging Array (AIA) on the Solar Dynamics Observatory (SDO) that will launch in 2009.

Using a simple coherence / travel-time based approach detects and provides a wealth of information on transverse and longitudinal wave phenomena in the test sequences provided by the Transition Region and Coronal Explorer (TRACE). The results of the search are "pruned" (based on diagnostic errors) to minimize false-detections such that the remainder provides robust measurements of waves in the solar corona, with the calculated propagation speed allowing automated distinction between the various wave modes observed.

The automated approach taken has verified the results of several investigations reported in the literature while finding considerably more sources of oscillation, across a broad range of frequencies, to explore in the future. Perhaps the most intriguing of the new findings is the potential connection of oscillations in the corona to low-frequency (~1.5 mHz) internal gravity waves which propagate horizontally in a considerably lower region of the atmosphere.

Figure caption: *Results of the coronal wave detection algorithm for the 1.5mHz filtered timeseries for the 14 July 1998 dataset from TRACE. For context we show a TRACE 171Å intensity image of the corona (panel A), the weighted signal coherence (panel*

B), coherent length of the wave detected (panel C), wave propagation angle (panel D), wave phase speed (panel E), and relative error of the computed wave phase speed (panel F).

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- CGD - The Climate and Global Dynamics Division
- HAO - The High Altitude Observatory
- MMM - The Mesoscale and Microscale Meteorology
- TIIMES - The Institute for Integrative and Multidisciplinary Earth Studies

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HAO: Research summary and graphics
MMM: Publication abstracts and graphics
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GEORGE BRYAN

2008 Publications

Bryan, G. H., R. Rotunno, 2008: Gravity currents in a deep anelastic atmosphere. J. Atmos. Sci., 65, 536-556, doi: 10.1175/2007JAS2443.1.

ABSTRACT

This study presents analytic results for steady gravity currents in a channel using the deep anelastic equations. Results are cast in terms of a nondimensional parameter H/H0 that relates the channel depth H to a scale depth H0 (the depth at which density goes to zero in an isentropic atmosphere). The classic results based on the incompressible equations correspond to H/H0 = 0. For cold gravity currents (at the bottom of a channel), assuming energy-conserving flow, the nondimensional current depth h/H is much smaller, and nondimensional propagation speed C/(gH)1/2 is slightly smaller as H/H0 increases. For flows with energy dissipation, C/(gH)1/2 decreases as H/H0 increases, even for fixed h/H. The authors conclude that as H/H0 increases the normalized hydrostatic pressure rise in the cold pool increases near the bottom of the channel, whereas drag decreases near the top of the channel; these changes require gravity currents to propagate slower for steady flow to be maintained. From these results, the authors find that steady cold pools have a likely maximum depth of 4 km in the atmosphere (in the absence of shear). For warm gravity currents (at the top of a channel), h/H is slightly larger and C/(gH)1/2 is much larger as H/H0 increases. The authors also conduct two-dimensional numerical simulations of "lock-exchange flow" to provide an independent evaluation of the analytic results. For cold gravity currents the simulations support the analytic results. However, for warm gravity currents the simulations show unsteady behavior that cannot be captured by the analytic theory and which appears to have no analog in incompressible flow.

Kirshbaum, D. J., R. Rotunno, G. H. Bryan, 2007: The spacing of orographic rainbands triggered by small-scale topography. J. Atmos. Sci., 64, 4222-4245, doi: 10.1175/2007JAS2335.1.

ABSTRACT

A combination of idealized numerical simulations and analytical theory is used to investigate the spacing between convective orographic rainbands over the Coastal Range of western Oregon. The simulations, which are idealized from an observed banded precipitation event over the Coastal Range, indicate that the atmospheric response to conditionally unstable flow over the mountain ridge depends strongly on the subridge-scale topographic forcing on the windward side of the ridge. When this small-scale terrain contains only a single scale (?) of terrain variability, the band spacing is identical to ?, but when a spectrum of terrain scales are simultaneously present, the band spacing ranges between 5 and 10 km, a value that is consistent with observations. Based on the simulations, an inviscid linear model is developed to provide a physical basis for understanding the scale selection of the rainbands. This analytical model, which captures the transition from lee waves upstream of the orographic cloud to moist convection within it, reveals that the spacing of orographic rainbands depends on both the projection of lee-wave energy onto the unstable cap cloud and the growth rate of unstable perturbations within the cloud. The linear model is used in tandem with numerical simulations to determine the sensitivity of the band spacing to a number of environmental and terrain-related parameters.

Knievel, J. C., G. H. Bryan, J. P. Hacker, 2007: Explicit numerical diffusion in the WRF model. Mon. Wea. Rev., 135, 3808-3824, doi: 10.1175/2007MWR2100.1.

ABSTRACT

Diffusion that is implicit in the odd-ordered advection schemes in early versions of the Advanced Research core of the Weather Research and Forecasting (WRF) model is sometimes insufficient to remove noise from kinematical fields. The problem is worst when grid-relative wind speeds are low and when stratification is nearly neutral or unstable, such as in weakly forced daytime boundary layers, where noise can grow until it competes with the physical phenomena being simulated. One solution to this problem is an explicit, sixth-order numerical diffusion scheme that preserves the WRF model's high effective resolution and uses a flux limiter to ensure monotonicity. The scheme, and how it was added to the WRF model, are explained. The scheme is then demonstrated in an idealized framework and in simulations of salt breezes and lake breezes in northwestern Utah.

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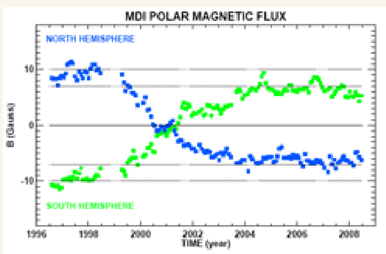
BURKEPILE, JOAN

Solar cycle 23: Is this a different kind of solar minimum?

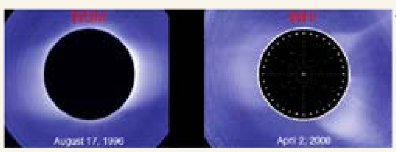
J. Burkepile, G. de Toma & S. Gibson in collaboration with the WHI team

Solar cycle 23 has been a weaker magnetic cycle than cycles 21 and 22. The lower rate of sunspot emergence combined with a slower meridional flow at the surface resulted into a slow polar reversal and a longer than average cycle. We are now observing the slow decline of the cycle into its minimum phase.

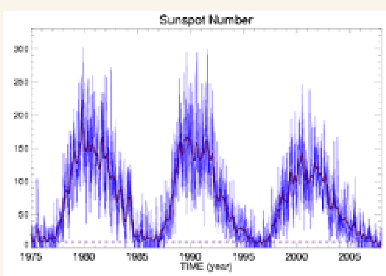
At present, the total magnetic flux on the Sun, the Sunspot Number and various solar acitvity indices, like F10.7, are comparable to the values observed during the previous solar minima, indicating we are in the minimum phase but have we reached the absolute minimum in magnetic activity? There were a few new-cycle spots on the Sun between January 2007 and September 2008 but the new cycle activity has been sparse and weak and we still have not seen the rise of cycle 24. This makes cycle 23 a long cycle of 12 years or more.



This solar minimum differs from the two previous ones in many ways. In particular, the polar fields are the weakest ever observed, about 30-40% less than in cycle 22 and 21. The weak poles combined with the presence of some old cycle activity at low latitudes give a more complex morphology to the solar corona which at present does not resemble a simple dipole. Furthermore, the polar coronal holes are smaller than in 1996 and there are several low-latitude coronal holes of significant size which are important sources of fast solar wind at the Earth.



The global magnetic field of the Sun now differs significantly from the one observed in 1996 when the open magnetic flux was originating mostly from the polar coronal holes and their equatorward extensions. The observed coronal morphology and variability in the solar wind are consistent with the complex, tilted shape of the heliospheric current sheet that is still observed in September 2008 vs. the simplest, flat current sheet observed in 1996 during the last minimum.

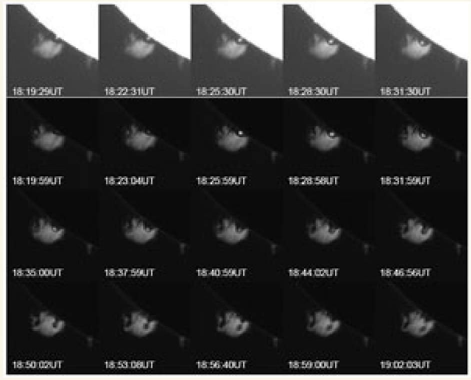


The differences between the minima in 1996 and 2008 have significant implications for the geospace and show that solar minima can differ in many ways even if the sunspot activity level is the same. To understand these differences during quiet times is one of the main goals of the WHI campaign.

Rise of a Dark Bubble Through a Quiescent Prominence

G. de Toma, R. Casini, J. Burkepile, & B.C. Low

On November 8, 2007, we observed an unusual and dynamic event in a solar quiescent prominence which provides new insights into the physical nature of prominences. A large scale, well-formed dark "bubble" with a bright core rose vertically through a prominence on the SE limb without causing it to erupt. This event was observed in Hα and He I 1083nm with the instruments of the Mauna Loa Solar Observatory. The dark bubble had a size of over ~40 arcsec and moved upward from the prominence base, at an average speed of about 12 km/s forming a bright compression front as it traversed the prominence. A compact bright core developed inside the bubble and accelerated from 12 km/s to about 20 km/s leaving a thin trail of material behind. Finally, the bubble assumed a "keyhole" shape before fading. A second elongated, dark bubble was also seen to rise at the north edge of the prominence almost



simultaneously to the first one. These structures moved through the prominence without disrupting it. A similar event, although with a much fainter core, was observed on April 6, 2008. These observations indicate that similar disturbances do occur occasionally in prominences without changing them significantly and opens questions on the nature and stability of prominences. We interpret the bubbles as well organized, closed magnetic structures where the strong magnetic pressure makes up for the weak plasma pressure. In this scenario, the bubbles are low density regions, with a dense core of compressed plasma, which become unstable and rise buoyantly through the prominence.

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SEAN BURNS

2008 Publications

Yi, C., D. E. Anderson, A. A. Turnipseed, S. P. Burns, J. P. Sparks, D. I. Stannard, R. K. Monson, 2008: The contribution of advective fluxes to net ecosystem exchange in a high-elevation, subalpine forest. Ecological Applications, 18, 1379-1390.

Abstract

The eddy covariance technique, which is used in the determination of net ecosystem CO2 exchange (NEE), is subject to significant errors when advection that carries CO2 in the mean flow is ignored. We measured horizontal and vertical advective CO2 fluxes at the Niwot Ridge AmeriFlux site (Colorado, USA) using a measurement approach consisting of multiple towers. We observed relatively high rates of both horizontal (Fhadv) and vertical (Fvadv) advective fluxes at low surface friction velocities (u*) which were associated with downslope katabatic flows. We observed that Fhadv was confined to a relatively thin layer (0–6 m thick) of subcanopy air that flowed beneath the eddy covariance sensors principally at night, carrying with it respired CO2 from the soil and lower parts of the canopy. The observed Fvadv came from above the canopy and was presumably due to the convergence of drainage flows at the tower site. The magnitudes of both Fhadv and Fvadv were similar, of opposite sign, and increased with decreasing u*, meaning that they most affected estimates of the total CO2 flux on calm nights with low wind speeds. The mathematical sign, temporal variation and dependence on u* of both Fhadv and Fvadv were determined by the unique terrain of the Niwot Ridge site. Therefore, the patterns we observed may not be broadly applicable to other sites. We evaluated the influence of advection on the cumulative annual and monthly estimates of the total CO2 flux (Fc), which is often used as an estimate of NEE, over six years using the dependence of Fhadv and Fvadv on u*. When the sum of Fhadv and Fvadv was used to correct monthly Fc, we observed values that were different from the monthly Fc calculated using the traditional u*-filter correction by -16 to 20 g C·m-2·mo-1; the mean percentage difference in monthly Fc for these two methods over the six-year period was 10%. When the sum of Fhadv and Fvadv was used to correct annual Fc, we observed a 65% difference compared to the traditional u*-filter approach. Thus, the errors to the local CO2 budget, when Fhadv and Fvadv are ignored, can become large when compounded in cumulative fashion over long time intervals. We conclude that the “micrometeorological” (using observations of Fhadv and Fvadv) and “biological” (using the u* filter and temperature vs. Fc relationship) corrections differ on the basis of fundamental mechanistic grounds. The micrometeorological correction is based on aerodynamic mechanisms and shows no correlation to drivers of biological activity. Conversely, the biological correction is based on climatic responses of organisms and has no physical connection to aerodynamic processes. In those cases where they impose corrections of similar magnitude on the cumulative Fc sum, the result is due to a serendipitous similarity in scale but has no clear mechanistic explanation.

Zobitz, J. M., S. P. Burns, M. Reichstein, D. R. Bowling, 2008: Partitioning net ecosystem carbon exchange and the carbon isotopic disequilibriumm in a subalpine forest. Global Change Biology, 14, 1785-1800, doi: 10.1111/j.1365-2486.2008.01609.x.

Abstract

We investigate the utility of an improved isotopic method to partition the net ecosystem exchange of CO2 (F) into net photosynthesis (FA) and nonfoliar respiration (FR). Measurements of F and the carbon isotopic content in air at a high-elevation coniferous forest (the Niwot Ridge AmeriFlux site) were used to partition F into FA and FR. Isotopically partitioned fluxes were then compared with an independent flux partitioning method that estimated gross photosynthesis (GEE) and total ecosystem respiration (TER) based on statistical regressions of night-time F and air temperature. We compared the estimates of FA and FR with expected canopy physiological relationships with light (photosynthetically active radiation) and air temperature. Estimates of FA and GEE were dependent on light as expected, and TER, but not FR, exhibited the expected dependence on temperature. Estimates of the isotopic disequilibrium D, or the difference between the isotopic signatures of net photosynthesis (dA, mean value -24.6‰) and ecosystem respiration (dR, mean value -25.1‰) were generally positive (dA>dR). The sign of D observed here is inconsistent with many other studies. The key parameters of the improved isotopic flux partitioning method presented here are ecosystem scale mesophyll conductance (gm) and maximal vegetative stomatal conductance (gcmax). The sensitivity analyses of FA, FR, and D to gcmax indicated a critical value of gcmax (0.15 mol m-2 s-1) above which estimates of FA and FR became larger in magnitude relative to GEE and TER. The value of D decreased with increasing values of gm and gcmax, but was still positive across all values of gm and gcmax. We conclude that the characterization of canopy-scale mesophyll and stomatal conductances are important for further progress with the isotope partitioning method, and to confirm our anomalous isotopic disequilibrium findings.

Schaeffer, S. M., D. E. Anderson, S. P. Burns, R. K. Monson, J. Sun, D. R. Bowling, 2007: Canopy structure and atmospheric flows in relation to the dell3C of respired CO2 in a subalpine coniferous forest. Agric. For. Meteorol., 148, 592-605, doi: 10.1016/j.agrformet.2007.11.003.

Abstract

Stable isotopes provide insight into ecosystem carbon cycling, plant physiological processes, atmospheric boundary-layer dynamics, and are useful for the integration of processes over multiple scales. Of particular interest is the carbon isotope content (d13C) of nocturnal ecosystem-respired CO2 (dR). Recent advances in technology have made it possible to continuously examine the variation in dR within a forest canopy over relatively long time-scales (months–years). We used tunable diode laser spectroscopy to examine dR at within- and below-canopy spatial locations in a Colorado subalpine forest (the Niwot Ridge AmeriFlux site). We found a systematic pattern of increased dR within the forest canopy (dR-c) compared to that near the ground (dR-g). Values of dR-c were weakly correlated with the previous day's mean maximum daytime vapor pressure deficit (VPD). Conversely, there was a negative but still weak correlation between dR-g and time-lagged (0–5 days) daily mean soil moisture. The topography and presence of sustained nightly drainage flows at the Niwot Ridge forest site suggests that, on nights with stable atmospheric conditions, there is little mixing of air near the ground with that in the canopy. Atmospheric stability was assessed using thresholds of friction velocity, stability above the canopy, and bulk Richardson number within the canopy. When we selectively calculated dR-g and dR-c by removing time periods when ground and canopy air were well mixed, we found stronger correlations between dR-c and VPD, and dR-g and soil moisture. This suggests that there may be fundamental differences in the environmental controls on dR at sub-canopy spatial scales. These results may help explain the wide variance observed in the correlation of dR with different environmental parameters in other studies.

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Research Focus FY08:

CHATS Array, picture by Sean Burns. High resolution figure

I continued analysis of 2004 "Carbon in the Mountains" Experiment (CME04) and Canopy Horizontal Array Turbulence Study field experiment (CHATS) data as part of my involvement in the Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, H2O, Organics & Nitrogen (BEACHON) project.

Atmospheric Boundary Layer Page - Jielun Sun & Sean Burns

Publications FY08 (abstracts):

Burns, S. P., A. Delany, J. Sun, B. B. Stephens, S. P. Oncley, G. D. Maclean, S. R. Semmer, J. Schroter, J. Ruppert, 2008: An evaluation of calibration techniques for in-situ carbon dioxide measurements using a programmable portable trace-gas measuring system. *J. Atmos. Ocean. Technol.*, doi: 10.1175/2008JTECHA1080.1. (In Press)

Xiao, J., Q. Zhuang, D. D. Baldocchi, B. E. Law, A. D. Richardson, J. Chen, R. Oren, G. Starr, A. Noormets, S. Ma, S. B. Verma, S. Wharton, S. C. Wofsy, P. V. Bolstad, S. P. Burns, D. R. Cook, P. S. Curtis, B. G. Drake, M. Falk, M. L. Fischer, D. R. Foster, L. Gu, J. L. Hadley, D. Y. Hollinger, G. G. Katul, M. Litvak, T. A. Martin, R. Matamala, S. McNulty, T. P. Meyers, R. K. Monson, J. W. Munger, W. C. Oechel, K. T. Paw U, H. P. Schmid, R. L. Scott, G. Sun, A. E. Suyker, M. S. Torn, 2008: Estimation of net ecosystem carbon exchange for the conterminous United States by combining MODIS and ameriflux data. *Agric. For. Meteorol.*, doi: 10.1016/j.agrformet.2008.06.015. (In Press)

Oncley, S. P., K. Schwenz, S. P. Burns, J. Sun, R. K. Monson, 2008: A cable-borne tram for atmospheric measurements along transects. *J. Atmos. Ocean. Technol.*, doi: 10.1175/2008JTECHA1158.1. (In Press)

Yi, C., D. E. Anderson, A. A. Turnipseed, S. P. Burns, J. P. Sparks, D. I. Stannard, R. K. Monson, 2008: The contribution of advective fluxes to net ecosystem exchange in a high-elevation, subalpine forest. *Ecological Applications*, **18**, 1379-1390.

Bowling, D. R., W. J. Massman, S. M. Schaeffer, S. P. Burns, R. K. Monson, M. W. Williams, 2008: Biological and physical influences on the carbon isotope content of CO2 in a subalpine forest snowpack, Niwot Ridge, Colorado. *Biogeochemistry*, doi: 10.1007/s10533-008-9233-4. (Accepted)

Patton, E. G., T. Horst, D. H. Lenschow, P. P. Sullivan, S. P. Oncley, S. P. Burns, A. B. Guenther, T. Karl, S. D. Mayor, S. M. Spuler, J. Sun, A. A. Turnipseed, E. Allwine, S. Edburg, B. Lamb, R. Avissar, H. Holder, R. Calhoun, J. Kleissl, W. Massman, K. Tha Paw U, J. Weil, L. Rizzo, A. Held, 2008: The Canopy Horizontal Array Turbulence Study (CHATS). , Stockholm, SE, AMS, American Meteorological Society, 18A.1.

Zobitz, J. M., S. P. Burns, M. Reichstein, D. R. Bowling, 2008: Partitioning net ecosystem carbon exchange and the carbon isotopic disequilibriumm in a subalpine forest. *Global Change Biology*, **14**, 1785-1800, doi: 10.1111/j.1365-2486.2008.01609.x.

Schaeffer, S. M., D. E. Anderson, S. P. Burns, R. K. Monson, J. Sun, D. R. Bowling, 2007: Canopy structure and atmospheric flows in relation to the dell3C of respired CO2 in a subalpine coniferous forest. *Agric. For. Meteorol.*, **148**, 592-605, doi: 10.1016/j.agrformet.2007.11.003.

Sean Burns Research Catalog

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Research Focus FY08:

Upper Troposphere and Lower Stratosphere (UTLS)

The Stratosphere-Troposphere Analyses of Regional Transport (START-08) campaign was to study the transport characteristics of the ExUTLS region is officially underway. This study incorporated data taken from instrumentation aboard the NSF-NCAR Gulfstream V, satellite imaging, and from various model simulations.

Community Airborne Research Instrumentation (CARI) Group

The CARI group maintains, develops and deploys a number of aircraft trace gas instruments, including instrumentation which can be requested via the NSF/LAOF process, NSF/NCAR GV (HIAPER) instruments (two of those are part of the HAIS suite), and other atmospheric chemistry instruments....more

Publications FY08:

DeCarlo, P. F., E. J. Dunlea, J. R. Kimmel, A. C. Aiken, D. Sueper, J. Crounse, P. O. Wennberg, L. Emmons, Y. Shinozuka, A. Clarke, J. Zhou, J. Tomlinson, D. R. Collins, D. Knapp, A. Weinheimer, D. Montzka, T. Campos, J. L. Jimenez, 2008: Fast airborne aerosol size and chemistry measurements above Mexico City and Central Mexico during the MILAGRO campaign. *Atmos. Chem. Phys.*, **8**, 4027-4048.4

Stith, J. L., W. Cooper, V. Ramanathan, D. C. Rogers, P. DeMott, T. Campos, B. Adhikary, 2008: Interactions of Asian Emissions with Storms in the Pacific Ocean: Early results from the Pacific Dust Experiment (PACDEX). *15th Intl. Conf. on Clouds and Precipitation*, Cancun, MX, 9.11.2

Heald, C. L., A. H. Goldstein, J. D. Allan, A. C. Aiken, E. C. Apel, E. L. Atlas, A. K. Baker, T. S. Bates, A. J. Beyersdorf, D. R. Blake, T. Campos, H. Coe, J. D. Crounse, P. F. DeCarlo, J. A. de Gouw, E. J. Dunlea, F. Flocke, A. Fried, P. Goldan, R. J. Griffin, S. C. Herndon, J. S. Holloway, R. Holzinger, J. L. Jimenez, W. Junkermann, W. C. Kuster, A. C. Lewis, S. Meinardi, D. B. Millet, T. Onasch, A. Polidori, P. K. Quinn, D. D. Riemer, J. M. Roberts, D. Salcedo, B. Sive, A. L. Swanson, R. Talbot, C. Warneke, R. J. Weber, P. Weibring, P. O. Wennberg, D. R. Worsnop, A. E. Wittig, R. Zhang, J. Zheng, W. Zheng, 2008: Total observed organic carbon (TOOC) in the atmosphere: a synthesis of North American observations. *Atmos. Chem. Phys.*, **8**, 2007-2025.4

Peltier, R. E., A. H. Hecobian, R. J. Weber, A. Stohl, E. L. Atlas, D. D. Riemer, D. R. Blake, E. C. Apel, T. Campos, T. Karl, 2008: Investigating the sources and atmospheric processing of fine particles from Asia and the Northwestern United States measured during INTEX B. *Atmos. Chem. Phys.*, **8**, 1835-1853.4

Shim, C., Q. Li, M. Luo, S. Kulawik, H. Worden, J. Worden, A. Eldering, G. Diskin, G. Sachse, A. Weinheimer, D. Knapp, D. Montzca, T. Campos, 2007: Characterizing mega-city pollution with TES O3 and CO measurement. *Atmos. Chem. Phys. Discuss.*, 7, 15189-15212.

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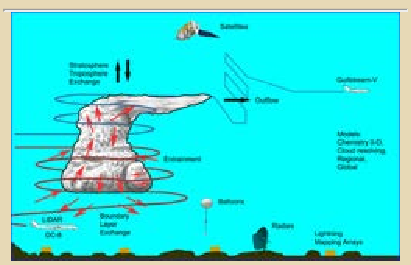
Research Focus FY08:

Inlet configuration for HOx instrumentation on the NASA DC-8 during ARCTAS (2008). The top inlet is for peroxy radicals, and the bottom one is for OH and sulfuric acid. The small stainless tubes provide air inlets that are used to generate ions that are exposed to the sampled air. High resolution figure



The DC3 Field Experiment will characterize the effect of midlatitude, continental convection on the transport and transformation of ozone and its precursors. Along with measurements of hydrogen oxide radicals, their precursors, and nitrogen oxides in both the inflow and outflow regions of deep convection, measurements of cloud microphysical properties, storm kinematics, and lightning discharges will be conducted. High resolution figure

The fast photochemical processes taking place in the troposphere are central to understanding the removal of trace gases. One important pathway is the reaction of free radicals with hydrocarbons, sulfur- and nitrogen-containing compounds, carbon monoxide and other species. Our research focuses on the development, improvement and deployment of mass spectrometric-based instrumentation for measurement of hydroxyl (OH), hydroperoxy (HO2) and organic peroxy radicals (RO2) (and other species), and interpretation of the data from those deployments.

Background Information:

- HOx Free Radical research and the Photochemical Oxidants and Products (POP) Group
- Photochemical Oxidation and Products (POP) ACD summary
- Laboratory Studies of HO2 Chemistry (Kinetics Group)

The instrumentation and software went through a major redevelopment after being accepted to fly on the NASA DC8 for the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) field campaigns in the spring & summer of 2008. Work is also underway to develop a smaller, lighter, and autonomous instrument for future flights on the NCAR-NSF Gulfstream V aircraft (GV, aka HIAPER) aircraft before the Upper Troposphere-Lower Stratosphere (UTLS), Deep Convective Clouds & Chemistry Experiment (DC3) Field experiment planned for 2011.

The Deep Convective Clouds & Chemistry Experiment (DC3 - dee-cee three) study is designed to improve understanding of the role of deep convection in modifying the composition of upper troposphere and lower stratosphere. The PI team consists of Mary Barth (MMM/ACD), Chris Cantrell (ACD), Bill Brune (Pennsylvania State), and Steve Rutledge (Colorado State) who, along with a scientific steering committee composed of university and national laboratory scientists, are leading the planning of a community-wide comprehensive study that will utilize ground-based radars, mesonets, fully configured aircraft platforms and satellite data to address several important scientific questions. A workshop took place in August 2008 and the development of the Scientific and Experimental Overview documents are well underway.

Field Programs FY08:

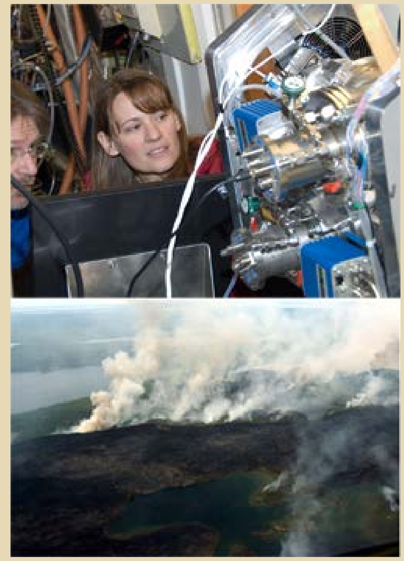
Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)

Spring Deployment: Fairbanks, Alaska, Tulle, Greenland,
Summer Deployment: Cold Lake, Alberta & Palmdale, California

The Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) field campaign is poised to help scientists identify how air pollution contributes to climate changes in the Arctic. During the spring deployment, which took place in April in Fairbanks, Alaska, scientists gathered information about the effects of Arctic haze, stratosphere-troposphere exchange, and sunrise photochemistry (chemical reactions that occur when sunlight returns to the Arctic in spring). The summer deployments for the DC-8 in July & July utlized two sites, Cold Lake, Alberta and Fairbanks in their invetigation on how emissions from northern wildfires affect the Arctic's atmosphere. In additional, the NOAA P-3B was in Yellowknife during part of the summer deployment.

- ARCTAS: Measuring the Arctic's Haze and Smoke: NCAR
- NASA Launches Airborne Study of Arctic Atmosphere, Air Pollution: NASA
- ARCTAS: NASA

The Arctic is undergoing significant environmental changes related to global climate change. NASA is extensively studying the role of air pollution in this climate-sensitive region as part of the ARCTAS field campaign, the largest airborne experiment ever to do so. Credit: NASA



Chris Cantrell and Becky Anderson of the National Center for Atmospheric Research, Boulder, Colo., assess an instrument's operation on NASA's DC-8 aircraft during preparations for the ARCTAS field campaign. Credit: NASA
High resolution figure

Comparison Study

September 2008, NCAR

Professor Yoshizumi Kajii of Tokyo Metropolitan University and his students brought their HO2/RO2 instrumentation to compare with the ARS PeRCIMS instrument. These comparisons were conducted in the FL0 laboratory and included calibrator exchanges and side-by-side measurements of ambient air.

Community Service FY08:

- Associate Editor: Journal of Geophysical Research - Atmospheres
- Langley Atmospheric Composition Review, NASA Langley
- NASA Atmospheric Composition Laboratory Studies Proposal Panel, NASA Headquarters

Scientific Talks FY08:

- Behavior of Peroxy Radicals as measured on the C-130 during MIRAGE (Boulder, CO, June 2008)
- Role of Tropospheric Photochemistry in the Earth System (Boulder, CO, October 2007)

Publications FY08:

Cantrell, C., 2008: Technical Note: Review of methods for linear least-squares fitting of data and application to atmospheric chemistry problems. *Atmos. Chem. Phys.*, **8**, 5477-5487.1

Shon, Z. H., S. Madronich, S.-K. Song, F. M. Flocke, D. J. Knapp, R. S. Anderson, R. E. Shetter, C. A. Cantrell, S. R. Hall, 2008: Characteristics of the NO-NO2-O3 system in different chemical regimes during the MIRAGE-Mex field campaign. *Atmos. Chem. Phys. Discuss.*, 8, 2275-2309.4

Chris Cantrell Research Catalog

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In Brief:

Terri began working for NCAR in 1999 working in the then ATD (now EOL) in the administrative office. In 2001 she moved to HAO but left NCAR to travel with her husband, Chris Cantrell (ACD) in August 2003 for his year as a Associate Program Director rotator at National Science Foundation (NSF). Terri returned to NCAR working as needed for TIIMES in late 2005 and more permanently in 2006.

The main focus of her work include the TIIMES website, graphic arts, the annual NAR metrics & LAR Reports, and event planning and coordination. She also actively avoids getting her picture taken by always being on the other end of the camera.

Community Service FY08:

- Webmaster for a variety of non-profit organizations
- President & Newsletter Editor Rose Hill Grange (RHG)
- Board of Director: International Choreographed Ballroom Dance Association (ICBDA)
- Editor ICBDA Techincal Dance Manual
- Programmer and other duties for the Colorado Round Dance Association (CRDA)

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Research Focus FY08:

In addition to his varied duties as the director of the TIIMES Institute, Rit Carbone also finds time to continue to pursue his research interests.

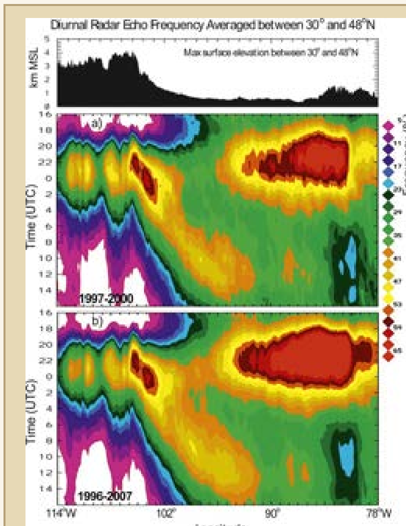
Rit Carbone: the newest member of the AMS Executive Committee

Congratulations to Dr. Carbone for being elected a member of the AMS Executive Committee. The American Meteorological Society (AMS) promotes the development and dissemination of information and education on the atmospheric and related oceanic and hydrologic sciences and the advancement of their professional applications. Founded in 1919, AMS has a membership of more than 11,000 professionals, professors, students, and weather enthusiasts. AMS publishes nine atmospheric and related oceanic and hydrologic journals — in print and online — sponsors more than 12 conferences annually, and offers numerous programs and services.

The Executive Committee is the executive arm of the Council (the principal governing body). The Committee meets as often as necessary and is empowered to interpret and execute Council policies when the Council is not in session to ensure that reasonable actions are taken to accomplish the purposes of the Society - scientific, fiscal, and organizational. It is composed of six past AMS Presidents and two rotating positions. Dr. Carbone has been appointed until 2010.

Rainfall occurrence in the U.S. warm season: The diurnal cycle

The diurnal occurrence of warm-season rainfall over the U.S. mainland is examined, particularly in light of forcings at multiple scales. The analysis is based on a radar dataset of 12-seasons duration covering the U.S. mainland from the Continental Divide eastward. The dataset resolves 2-km features at 15-min intervals, thus providing a detailed view of both large- and regional-scale diurnal patterns, as well as the statistics of events underlying these patterns. The results confirm recent findings with respect to the role of propagating rainfall systems and the high frequency at which these are excited by sensible heating over elevated terrain. Between the Rockies and the Appalachians,   60% of midsummer rainfall occurs in this manner. more....



Diurnal radar echo frequency of occurrence in the continental domain, JJA: (a) 1997–2000 (after CAR02) and (b) 1996–2007. A longer period of record yields a substantially similar diurnal pattern.

Comparison of ground-based radar and geosynchronous satellite climatologies of warm season precipitation over the United States

Studies in the past several years have documented the climatology of warm season precipitation episode statistics (propagation speed, span and duration) over the United States using a national composited radar dataset. Recently these climatological studies have been extended to other continents including Asia, Africa, and Australia. Unfortunately continental regions outside of the United States have insufficient radar coverage and the newer studies have had to rely on geostationary satellite data at infrared (IR) frequencies as a proxy for rainfall. It is well known that the use of IR brightness temperatures to infer rainfall is subject to large errors. In this study the statistics of warm season precipitation episodes derived from radar and satellite IR measurements over the U.S. are compared and biases introduced by the satellite data evaluated. It is found that the satellite span and duration statistics are highly dependent upon the brightness temperature

High resolution figure

threshold used, but with the appropriate choices of thresholds can be brought into good agreement to those based upon radar data. The propagation speed statistics of satellite events are on average ~4 m s−1 faster than radar events and are relatively insensitive to the brightness temperature threshold. A simple correction procedure based upon the difference between the steering winds for the precipitation core and the winds at the level of maximum anvil outflow is developed. more....

The propagation and diurnal cycles of deep convection in northern tropical Africa

The propagation and diurnal cycle of organized convection in northern tropical Africa are examined using five years (1999-2003) of digital infrared imagery for May-August. Reduced-dimension techniques are used to document the properties of cold clouds - proxies for deep convection and precipitation. Large-scale environments are diagnosed from global analyses. more...

Propagation and diurnal evolution of warm season cloudiness in the Australian and Maritime continent region

Warm season cold cloud-top climatology in the Austral-Indonesian region is examined for evidence of propagating modes of precipitation that originate from elevated heat sources and the diurnal heating cycle. Using satellite-inferred cloudiness from the period 1996-2001 as a proxy for rainfall, this coherent regeneration process and subsequent event propagation is found to consistently occur from the midlatitudes (30°-40°S) to the tropics (10°-20°S) in the Austral region. more...

Community Service FY08:

- Member (2008-2011): Executive Committee, American Meteorological Society
- Councilor (2007-2009): American Meteorological Society
- Chairman (2007-2008): NRC Study Committee on Developing Mesoscale Meteorological Observing Capabilities to Meet Multiple National Needs
- Member (2006-2009): NOAA Climate Working Group

Scientific Talks FY08:

- 2008 AMS Summer Community Meeting, 12 August 2008 · Boulder, Colorado, Study on Mesoscale Observations to Meet Multiple National Needs (Boulder, CO USA, October 08)
- 2008 NCAR Undergraduate Leadership Workshop, Boulder, CO 16 June 2008 (Boulder, CO USA, October 08)
- Colorado State University, Dept of Atmospheric Sciences, May 2008: The diurnal cycle of summertime rainfall occurrence. (Fort Collins, CO USA, October 08)
- NOAA Climate Working Group Summer Retreat, 24 June 2008: Issues, Opportunities and Threats Associated with a National Climate Service (Boulder, CO USA, October 08)
- NSF Atmospheric Sciences Directorate, Lower Atmosphere Section, Arlington VA 22 July 2008: The BEACHON research project. (Arlington, VA USA, October 08)
- NSF Earth Systems Directorate, Arlington VA, 4 Sept 2008: Research Programs in The Institute for Integrative and Multidisciplinary Earth Studies. (Arlington, VA USA, October 08)
- NSF Earth Systems Directorate, Surface Processes Section, Arlington VA 22 July 2008: Biosphere-Hydrosphere-Atmosphere interactions research at NCAR. (Arlington, VA USA, October 08)
- Plinius Conference, Nicosia Cyprus, 24 Sept 2008: Keynote on Storms - On the systematic occurrence of warm season precipitation episodes. (Nicosia, CYP, October 08)
- University of Hawaii, Manoa Honolulu, HI: informal seminar on organized convection and climate 24 April 2008 (Honolulu, HI USA, October 08)
- Vaisala Corporation Board of Directors, Boulder, CO 9 Sept 2008 : Study on Mesoscale Observations to Meet Multiple National Needs (Boulder, CO USA, October 08)

Publications FY08:

Carbone, R. E., J. Block, G. R. Carmichael, F. H. Carr, V. C. Chandrasekar, E. Gruntfest, R. M. Hoff, W. F. Krajewski, M. A. LeMone, T. W. Schlatter, E. S. Takle, J. Titlow, S. E. Bosselly, J. F. Purdom, 2009: Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs. *Natl. Research Council of the Natl. Acad. Sci., BASC*, Richard E. Carbone, Ed., National Academies Press. (In Press)

Pereira, A., R.E. Carbone, J.E. Janowiak, P. Arkin, R. Hallak, C.G.M Ramos, 2008: Satellite rainfall estimates over South America – Potential applications on water management of large watersheds. *J. of the Amer. Water Res. Assoc.* (Submitted)

Wang, C.-C., T.-J. Chen, R. E. Carbone, 2009: A preliminary study on the relationship between warm-season cloud/precipitation episodes and dynoptic weather regimes over the East Asian continent. *Mon. Wea. Rev.*. (Submitted)

Tuttle, J. D., R. E. Carbone, P. A. Arkin, 2008: Comparison of ground-based radar and geosynchronous satellite climatologies of warm season precipitation over the United States. *J. Appl. Meteor. Climat.*, doi: 10.1175/2008JAMC2000.1. (In Press)

Carbone, R. E., J. D. Tuttle, 2008: Rainfall occurrence in the U.S. warm season: The diurnal cycle. *J. Climate*, **21**, 4132-4146, doi: 10.1175/2008JCLI2275.1.

Laing, A. G., R. E. Carbone, V. Levizzani, 2008: The propagation of deep convection in Africa: Implications for predictability of precipitation. *Quantification and Reduction of Predictive Uncertainty for Sustainable Water Resources Management*, E. Boegh, H. Kunstmann, T. Wagener, A. Hall, L. Bastidas, S. Franks, H. Gupta, D. Rosbjerg, J. Schaake, Eds., IAHS Press, 313, 24-32.

Laing, A. G., R. E. Carbone, V. Levizzani, J. D. Tuttle, 2008: The propagation and diurnal cycles of deep convection in northern tropical Africa. *Quart. J. Roy. Meteor. Soc.*, **134**, 93-109, doi: 10.1002/qj.194.

Keenan, T., R. E. Carbone, 2008: Propagation and diurnal evolution of warm season cloudiness in the Australian and maritime continent region. *Mon. Wea. Rev.*, **136**, 973-994, doi: 10.1175/2007MWR2152.1.

Richard Carbone Research

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CGD Research Catalog

Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

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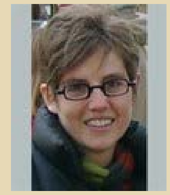
CGD 2008 PROFILES IN SCIENCE: JULIE CARON

Summary of achievements



Julie Caron

Julie Caron has been heavily involved in the Nested Regional Climate Model (NRCM). She has been working on data quality control from the channel simulation, as well as in deriving & updating climate fields for diagnostics as the data are ready. She is also analyzing the Madden-Julian Oscillation (MJO) in the NRCM for publication in an upcoming special issue.

Julie has also been helping expand the AMWG diagnostics package to accomodate more analyses for the upcoming CAM 4. This includes converting her code for the MJO analyses & adding more wave filters for inclusion in the diagnostics package. She's also added microphysics diagnostics & is currently adding radiation & sea ice diagnostics to the package. As a result of her work on diagnostics for the NRCM, she was also involved in the conversion & debugging of the Wheeler & Kiladis diagrams in the variability diagnostics to remove shared object dependence, and assure the package works robustly across a variety of horizontal resolutions. She has also helped various efforts for CAM 4 development, such as producing plots of trace constituents for comparison of different boundary layer schemes.

Julie is also wrapping up the analyses for a paper on the diurnal cycle of the Low-Level Jet in CAM compared with the North American Regional Reanalyses.

Julie has been working with Jim Hack, Phil Rasch, John Truesdale, and Dennis Shea on the above activities, & will primarily be working with Jim Hurrell on future activities.

Publications

Hurrell, J. W., J. J. Hack, D. Shea, J. M. Caron, and J. Rosinski, 2008: A new sea surface temperature and sea ice boundary data set for the Community Atmosphere Model, Journal of Climate, 21, 5145-5153.

Abstract: A new surface boundary forcing data set for uncoupled simulations with the Community Atmosphere Model is described. It is a merged product based on the monthly mean Hadley Centre sea ice and SST data set version 1 (HadISST1) and version 2 of the National Oceanic and Atmospheric Administration (NOAA) weekly optimum interpolation (OI) SST analysis. These two source data sets were also used to supply ocean surface information to the European Centre for Medium-Range Weather Forecasts 40-year reanalysis project (ERA-40). Our merged product provides monthly mean sea surface temperature and sea ice concentration data from 1870 to the present: it is updated monthly, and it is freely available for community use. The merging procedure was designed to take full advantage of the higher resolution SST information inherent in the NOAA OI.v2 analysis.

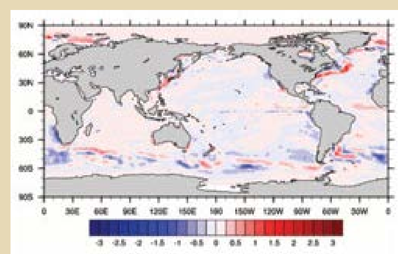


Figure 1.

High resolution figure

Figure caption: Differences between the 30-yr 1971-2000 SST climatologies (OI.v2 - HadISST1) in °C. The color contours are 0.25°C up to absolute 3°C.

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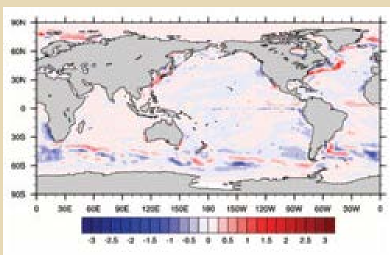
Research Focus FY08:



Differences between the 30-year 1971-2000 SST climatologies (OI.v2 - HadISST1) in °C. The color contours are 0.25°C up to absolute 3°C.

[High resolution figure](#)

Julie Caron has been heavily involved in the Nested Regional Climate Model (NRCM). She has been working on data quality control from the channel simulation, as well as in deriving & updating climate fields for diagnostics as the data are ready. She is also analyzing the Madden-Julian Oscillation (MJO) in the NRCM for publication in an upcoming special issue.

Julie has also been helping expand the AMWG diagnostics package to accomodate more analyses for the upcoming CAM 4. This includes converting her code for the MJO analyses & adding more wave filters for inclusion in the diagnostics package. She's also added microphysics diagnostics & is currently adding radiation & sea ice diagnostics to the package. As a result of her work on diagnostics for the NRCM, she was also involved in the conversion & debugging of the Wheeler & Kiladis diagrams in the variability diagnostics to remove shared object dependence, and assure the package works robustly across a variety of horizontal resolutions. She has also helped various efforts for CAM 4 development, such as producing plots of trace constituents for comparison of different boundary layer schemes.

Julie is also wrapping up the analyses for a paper on the diurnal cycle of the Low-Level Jet in CAM compared with the North American Regional Reanalyses.

Julie has been working with Jim Hack, Phil Rasch, John Truesdale, and Dennis Shea on the above activities, & will primarily be working with Jim Hurrell on future activities.

In addition, related to TIIMES, Julie and Bill Large have just started on a project that incorporates the diurnal cycle into stand-alone CAM.

Publications FY08 [(abstract)](#):

Hurrell, J. W., J. J. Hack, D. Shea, J. M. Caron, and J. Rosinski, 2008: A new sea surface temperature and sea ice boundary data set for the Community Atmosphere Model, Journal of Climate, **21**, 5145–5153.

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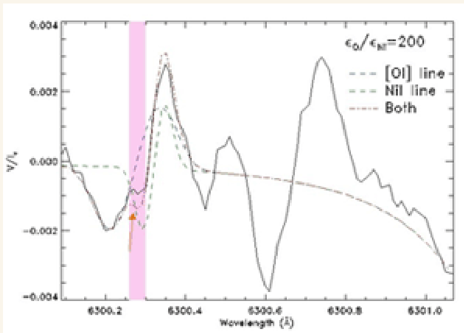
CENTENO, REBECCA

A new approach to the solar oxygen abundance problem



Oxygen is the third most abundant chemical element in the Universe, after Hydrogen and Helium, and the one that is most frequently produced by nuclear fusion in stellar interiors. Its abundance in the Sun was thought to be well established since the 1980s (850 +/- 80 parts per million particles, ppm; Anders & Grevesse 1989; more recently 680 +/- 100 Grevesse & Sauval 1998). However, a recent work (Asplund et al. 2004) using a new 3D hydrodynamical model of the solar atmosphere (as well as updated atomic and molecular data) recommends a revision of the O abundance to a lower value of 460 +/- 50 ppm. The revised solar composition fits better within its galactic environment but it also creates a serious problem, namely it ruins the exceptionally good agreement between the sound speed predicted by solar interior models and that inferred from helioseismology. Since chemical abundances are not directly measurable and imply a model-dependent inference, the observations are not conclusive and arguments exist both in favor and against the revision. The controversy on whether the proposed revision should be adopted and the doubts that it would cast on stellar structure and evolution models is serious enough that it is often referred to as the solar oxygen crisis (Ayres et al. 2006).

In this work, we present new data that sets strong constraints on the solar Oxygen abundance. Our approach, based on the analysis of spectro-polarimetric observations, is almost model-independent and therefore extremely robust. The asymmetry of the Stokes V profile of the 6300 Å [O I] and Ni I blend measured in the umbra of a sunspot is used as an indicator of the relative abundances of these two elements. The peculiar shape of the profile requires a value of 710 +/- 100 ppm. The uncertainty range includes the model dependence as well as uncertainties in the oscillator strengths of the lines. We emphasize that the very low degree of model dependence in our analysis makes it very reliable compared to traditional determinations.

Figure caption: *Averaged Stokes V spectrum observed in a sunspot umbra. Black, solid: Observation. Red, dash-dotted: Synthesis of the OI , NiI and FeI lines combined. Blue, dashed: Synthesis of [OI] and FeI lines only. Green, dashed: Synthesis of NiI and FeI lines only. All profiles are normalized to the average disk-center quiet-Sun continuum. Notice how the [OI] and NiI lines have similar amplitudes. However, the differences in their rest wavelengths and effective Lande factors give rise to a peculiar and strongly asymmetric shape of the blend when they are combined together. Particularly interesting is the feature marked by the arrow in the figure, exactly at the switchover point between the [OI] and the NiI blue lobes. This feature constrains the ratio of the relative abundance of O and Ni.*

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FEI CHEN

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Research Focus FY08:

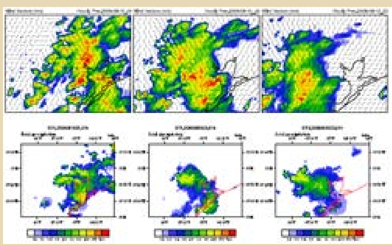

Figure 1: Hourly precipitation valid at 2100 UTC (left), 2200 UTC (middle), and 2300 UTC (right) on 10 August 2006. The Upper panel is WRF/UCM simulation and the lower panel is 4-km Stage-IV precipitation analysis.

High resolution figure

Land Atmospheric Interaction and Modeling Group (webpage)

To understand, through theoretical and observational studies, the complex interactions (biophysical, hydrological, and bio-geochemical) between the land-surface and the atmosphere at micro- and mesoscales. The ultimate goal is to integrate such knowledge into numerical mesoscale weather prediction and regional climate models to improve prediction of the impacts of land-surface processes on regional weather, climate, and hydrology.

Develop the community Noah land surface model

As a major collaborative effort among NCAR, NECP, NASA/GSFC, AFWA and several university groups, we supported the development of the Unified Noah land surface model (LSM) and its implementation in the Weather Research and Forecast (WRF) model. The Unified Noah LSM V3.0 was released in April 2008. Future enhancements include: a groundwater module; multi-layer canopy vegetation; improved snow albedo treatment, multi-layer snowpack, and new frozen soil scheme; 1-km MODIS land-use and land-cover data; and a multi-layer urban module.

Colorado Headwater

The Noah LSM is enhanced for use in Colorado Headwater project and for long-term Arctic simulations to investigate cold-season land-atmospheric interactions and evolution of snow packs. These enhancements include more and deeper soil layers, zero-flux bottom boundary condition, new time-varying snow albedo parameterization, and multi-layer snow model.

MEGAN

A prototype is developed to couple the Noah LSM, a multi-layer canopy model, a biogenic emission model (MEGAN), and a photosynthesis-based canopy resistance model (GEM). This prototype was employed to conduct 10-year HRLDAS simulations to analyze the impact of precipitation and soil water storage on biogenic emission.

Land-atmospheric interactions

The coupled WRF/Noah modeling system was combined with the IHOP_02 field data to analyze surface energy budgets, effects of mesoscale land-surface heterogeneity on the evolution of water vapor in the summer convective boundary layer, and regional feedbacks between soil moisture and summer precipitation.

Urbanization

An integrated WRF/urban canopy model (UCM) was developed and used to investigate the urban heat island for major metropolitan regions and their effects of urbanization on summer convective rainfall. We focus on evaluating the ability of the WRF model to simulate these fine-scale convective processes and investigating the impact of urban area on the evolution and characteristics of such convective systems. As shown in Fig. 1, the WRF/UCM simulation reasonably captures the important characteristics of a heavy rainfall on 10 August 2006 over the Greater Houston region.

Publications FY08:

Alfieri, J., X. Xiao, D. Niyogi, R. A. Pielke, Sr., F. Chen, M. A. LeMone, 2008: Satellite-based modeling of transpiration and evaporation of grasslands and croplands in the Southern Great Plains, USA. *Global Planetary Changes*. (In Press)

Miao, S., F. Chen, M. A. LeMone, M. Tewari, Q. Li, Y. Wang, 2008: An observational and modeling study of characteristics of urban heat island and boundary layer structures in Beijing. *J. Appl. Meteor. Climat.*. (In Press)

Alfieri, J., D. Niyogi, P. Blanken, F. Chen, M. A. LeMone, K. Mitchell, M. Ek, A. Kumar, 2008: Estimation of the minimum canopy resistance for croplands and grasslands using data from the 2002 International H20 Project. *Mon. Wea. Rev.*. (In Press)

LeMone, M. A., M. Tewari, F. Chen, J. G. Alfieri, D. Niyogi, 2008: Evaluation of the Noah land-surface model using data from a fair-weather IHOP_2002 day with heterogeneous surface fluxes. *Mon. Wea. Rev.*. (In Press)

Wyszogrodzki, A., F. Chen, M. Shiguang, 2008: Coupling between meso-scale (WRF) and urban-scale (EULAG) models to enhance contaminant transport and dispersion modeling in urban areas. *DTRA-SBIR/CFDRC Report*.1

Trier, S. B., F. Chen, K. W. Manning, M. A. Lemone, C. A. Davis, 2008: Sensitivity of the PBL and precipitation in 12-day simulations of warm-season convection using different land surface models and soil wetness conditions. *Mon. Wea. Rev.*, **136**, 2321-2343, doi: 10.1175/2007MWR2289.1.

Lin, C.-Y., F. Chen, J. C. Huang, W.-C. Chen, Y.-A. Liou, W.-N. Chen, S.-C. Liu, 2008: Urban Heat Island effect and its impact on boundary layer development and land-sea circulation over northern Taiwan. *Atmos. Environ.*, **42**, 5635-5649, doi: 10.1016/j.atmosenv.2008.03.015.

Liu, Y., T. T. Warner, J. F. Bowers, L. Carson, F. Chen, C. A. Clough, C. A. Davis, C. H. Egeland, C. Halvorson, T. W. Huck, L. Lachapelle, R. E. Malone, D. L. Rife, R.-S. Sheu, S. P. Swerdlin, D. S. Weingarten, 2008: The operational mesogamma-scale analysis and forecast system of the U.S. Army Test and Evaluation Command. Part 1: Overview of the modeling system, the forecast products. *J. Appl. Meteor. Climat.*, **47**, 1077-1093.

Miao, S., F. Chen, 2008: Formation of horizontal convective rolls in urban areas. *Atmos. Res.*, **89**, 298-304.

Niyogi, D., H. I. Chang, F. Chen, L. Gu, A. Kumar, S. Menon, R. A. Pielke, Sr., 2007: Potential impacts of aerosol-land-atmosphere interactions on the Indian monsoonal rainfall characteristics. *Natural Hazards*, **42**, 345-359, doi: 10.1007/s11069-006-9085-y.

Chen, F., J. Ching, 2007: Effects of using high-resolution urban land-use and building morphological data sets on the WRF/urban coupled model simulations for the Houston-Galveston areas. *CMAS Conf.*, Chapel Hill, NC, US, CMAS.

Jiang, X.Y., C. Wiedinmyer, F. Chen, Z.-L. Yang, and J. C. F. Lo, 2008: Predicted Impacts of Climate and Land-Use Change on Surface Ozone in the Houston, Texas, Area. *J. Geophys. Res.*, 113, D20312, doi:10.1029/2008JD009820.

Gao, Y., F. Chen, M. Barlage, W. Liu, Y. Ran, H. Li, H. Peng, and M. Ma, 2008: Enhancement of Land Surface Information and its Impact on Atmospheric Modeling in the Heihe River Basin, Northwest China. *J. Geophys. Res*., 113, D20S90, doi:10.1029/2008JD010359.

Couvreux, F., F. Guichard, P. Austino, and F. Chen, 2008: Nature of the mesoscale boundary-layer height and water-vapor variability observed the 14 June 2002 during the IHOP 2002 campaign. *Mon. Wea. Rev.*, in press.

Alapaty K., D. Niyogi, F. Chen, P. Pyle, A. Chandrasekar, N. Seaman, 2008: Development of the Flux-Adjusting Surface Data Assimilation System for Mesoscale Models, *J. Appl. Meteorol. Clim.*, in press.

Zhang, C., F. Chen, S. Miao, Q. Li, and C. Xuan, 2007: Impacts of Urbanization and Future Green-Planting on Summer Precipitation in the Greater Beijing Metropolitan Area. *J Geophys. Res*., in press.

Bastin, S., F. Chen, P. Drobinski, C. Flamant, C. Kiemle, J. Pelon, 2007: Impact of land surface heterogeneities on the atmospheric water vapor distribution within the boundary layer during the IHOP_2002 29 may 2002 case. *Mon. Wea. Rev.*, submitted.

Fei Chen Research Catalog

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CGD 2008 PROFILES IN SCIENCE: JACK CHEN

Summary of achievements

Since August 2007, Chih-Chieh Chen has been involved in a research project which investigates strategies to counteract global warming effects due to the increase of anthropogenic greenhouse gases (called "geoengineering"). In collaborating with Drs. Phil Rasch and John Latham, he has focused the scope of his research on the strategy of enhancing cloud albedo through warm cloud seeding and studying its impact on global and regional climate. Various warm cloud seeding schemes are proposed and their impact on global and regional climate is under investigation through a fully coupled modeling framework (CCSM).

Publications

Latham, John, P. Rasch, C.-C. Chen, L. Kettles, A. Gadian, A. Gettelman, H. Morrison, and K. Bower, 2008: Global temperature stabilization via controlled albedo enhancement of low-level maritime clouds, Phil. Trans. R. Soc., in press.

Abstract: An assessment is made herein of the proposal that controlled global cooling sufficient to balance global warming resulting from increasing atmospheric CO2 concentrations might be achieved by seeding low-level, extensive maritime clouds with seawater particles which act as cloud condensation nuclei, thereby activating new droplets and increasing cloud albedo (and possibly longevity). This paper focuses on scientific and meteorological aspects of the scheme. Associated technological issues are addressed in a companion paper.

Analytical calculations, cloud modelling and (particularly) GCM computations suggest that if outstanding questions are satisfactorily resolved, the controllable, globally averaged negative forcing resulting from deployment of this scheme might be sufficient to balance the positive forcing associated with a doubling of CO2 concentration. This statement is supported by recent observational evidence. This technique could thus be adequate to hold the Earth's temperature constant for many decades.

More work - especially assessments of possible meteorological and climatological ramifications - is required on several components of the scheme, which possesses the advantages that (1), it is ecologically benign - the only raw materials being wind and seawater: (2), the degree of cooling could be controlled: (3), if unforeseen adverse effects occurred the system could be immediately switched off, with the forcing returning to normal within a few years (although the response would take a much longer time).

Rasch, P. J., S. Tilmes, R. P. Turco, A. Robock, L. Oman, C.-C. Chen, G. Stenchikov, and R. Garcia, 2008: An overview of geoengineering of climate using stratospheric sulfate aerosols, Phil. Trans. R. Soc., in press.

Abstract: We provide an overview of geoengineering by stratospheric sulfate aerosols. The state of understanding about this topic as of early 2008 is reviewed, summarising the past 30 years of work in the area, highlighting some very recent studies using climate models, and discussing methods used to deliver sulfur species to the stratosphere.

The studies reviewed here all suggest that sulfate aerosols can counteract the globally averaged temperature increase associated with increasing greenhouse gases, and reduce changes to some other components of the Earth system. There are likely to be remaining regional climate changes after geoengineering, with some regions experiencing significant changes in temperature or precipitation. The aerosols also serve as surfaces for heterogeneous chemistry resulting in increased ozone depletion. The delivery of sulfur species to the stratosphere in a way that will produce particles of the right size is shown to be a complex and potentially very difficult task. Two simple delivery scenarios are explored, but similar exercises will be needed for other suggested delivery mechanisms. While the introduction of the geoengineering source of sulfate aerosol will perturb the sulfur cycle of the stratosphere significantly, it is a small perturbation to the total (stratosphere and troposphere) sulfur cycle. The geoengineering source would thus be a small contributor to the total global source of "acid rain" which could be compensated for through improved pollution control of anthropogenic tropospheric sources.

Some areas of research remain unexplored. Although ozone may be depleted, with a consequent increase to solar ultraviolet0B (UVB) energy reaching the surface and a potential impact on health and biological populations, the aerosols will also scatter and attenuate this part of the energy spectrum, and thus may compensate the UVB enhancement by ozone. The aerosol will also change the ratio of diffuse to direct energy reaching the surface, and this may influence ecosystems. The impact of geoengineering on these components of the Earth system has not yet been studied. Representations for the formation, evolution, and removal of aerosol and distribution of particle size are still very crude, and more work will be needed to gain confidence in our understanding the deliberate production of this class of aerosols and their role in the climate system.

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YONGSHENG CHEN

2008 Publications

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. Mon. Wea. Rev., 136, 1990-2005, doi: 10.1175/2007MWR2085.1.

ABSTRACT

Real-time forecasts of five landfalling Atlantic hurricanes during 2005 using the Advanced Research Weather Research and Forecasting (WRF) (ARW) Model at grid spacings of 12 and 4 km revealed performance generally competitive with, and occasionally superior to, other operational forecasts for storm position and intensity. Recurring errors include 1) excessive intensification prior to landfall, 2) insufficient momentum exchange with the surface, and 3) inability to capture rapid intensification when observed. To address these errors several augmentations of the basic community model have been designed and tested as part of what is termed the Advanced Hurricane WRF (AHW) model. Based on sensitivity simulations of Katrina, the inner-core structure, particularly the size of the eye, was found to be sensitive to model resolution and surface momentum exchange. The forecast of rapid intensification and the structure of convective bands in Katrina were not significantly improved until the grid spacing approached 1 km. Coupling the atmospheric model to a columnar, mixed layer ocean model eliminated much of the erroneous intensification of Katrina prior to landfall noted in the real-time forecast.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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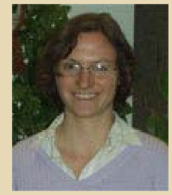
CGD 2008 PROFILES IN SCIENCE: DANI COLEMAN

Summary of achievements

I completed and analyzed runs using the slab-ocean configuration of CAM to investigate the geo-engineering effects of injected sulfur dioxide in the stratosphere. I modified the aerosol package in CAM to enable a collaborator, Tami Bond, to run more sophisticated experiments involving black carbon. I continued to support the implementation of alternative physical parameter schemes in CAM by debugging and merging source code from the UW research team. I worked with members of DSS to transfer ownership and location of all the NCEP operational data that we had archived for better access to the community.



Dani Coleman

Publications

Rasch, P. J., P. J. Crutzen, and D. B. Coleman, 2008: Exploring the geoengineering of climate using stratospheric sulfate aerosols: The role of particle size. Geophys. Res. Lett., 35, L02809, doi:10.1029/2007GL032179.

Abstract: Aerosols produced in the lower stratosphere can brighten the planet and counteract some of the effects of global warming. We explore scenarios in which the amount of precursors and the size of the aerosol are varied to assess their interactions with the climate system. Stratosphere-troposphere exchange processes change in response to greenhouse gas forcing and respond to geoengineering by aerosols. Nonlinear feedbacks influence the amount of aerosol required to counteract the warming. More aerosol precursor must be injected than would be needed if stratosphere troposphere exchange processes did not change in response to greenhouse gases or aerosols. Aerosol particle size has an important role in modulating the energy budget. A prediction of aerosol size requires a much more complex representation and assumptions about the delivery mechanism beyond the scope of this study, so we explore the response when particle size is prescribed. More aerosol is required to counteract greenhouse warming if aerosol particles are as large as those seen during volcanic eruptions (compared to the smaller aerosols found in quiescent conditions) because the larger particles are less effective at scattering incoming energy, and trap some outgoing energy. About 1.5 Tg S/yr are found to balance a doubling of CO_2 if the particles are small, while perhaps double that may be needed if the particles reach the size seen following eruptions.

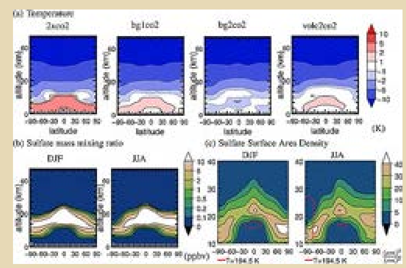


Figure 1.

High resolution figure

Figure caption: (top) Zonal average of annually averaged temperature. (bottom) The seasonal aerosol mixing ratio and surface area for June, July, August (JJA) and December January February (DJF) for experiment bg2co2 (see Table 1).The red contour shows the 194.5 K temperature isotherm.

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Table of Contents

Strategic Goals: Science, Facilities & Technology

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GLOBAL TROPOSPHERIC MODELING GROUP

Group Members

Jean-Francois Lamarque (Group Leader)
Louisa Emmons
Gabriele Pfister
Avelino Arellano
Andrew Conley
Francis Vitt

MOZART in the analysis of tropospheric observations

Impacts of the Fall 2007 California Wildfires on Surface Ozone: Integrating Local Observations with Global Model Simulations

In this study we quantified the impact of the fires in California in fall 2007 on regional air quality and in particular on surface ozone by analyzing surface observations of ozone concentrations together with MOZART simulations (Pfister et al., GRL, in press). The simulations include a synthetic tracer providing information about the amount of ozone produced from the fires. A clear increase in observed ozone is found when the model predicts a strong impact of pollution from the fires, where measured afternoon 8-hour concentrations increased, on average, by about 10 ppb. The findings demonstrate that intense wildfire periods can significantly increase the frequency of ozone concentrations exceeding current U.S. health standards, and might cause violations also during photochemically less active seasons. The study also demonstrates the far-reaching impact of ozone production from the fires.

Figure 1 shows observed and modeled 8-hour O_3 concentrations for 10-18 LT, 11-19LT and 12-20 LT binned by the model fire tracer O_3^{FIRE}. Shown is the deviation from the mean concentrations (ppb) separately for rural, urban and suburban sites, and for the two main fire periods (Sep 1-30 and Oct 8 - Nov 8).

This work was funded by NSF and NASA. In FY09 similar studies will be made of the extensive California fires of Summer 2008 as part of the analysis of the NASA/ARCTAS-CARB aircraft experiment.

Contribution of fires to ozone from Mexico City pollution

During the MIRAGE experiment during March 2006, numerous wildfires were evident in the hillsides surrounding Mexico City, complicating the characterization of the urban emissions and resulting pollution. Using the MOZART global chemical transport model run at a horizontal resolution of 0.7 degrees, the ozone burden resulting from the total emissions in the Mexico City region, as well as only from open fires, has been simulated. By tagging the NO emissions from a single type or region of sources in the model, the ozone produced from that source can be quantified. In the middle of the MIRAGE experiment (on March 20) a period of rainy weather began, significantly dampening the fire activity around Mexico City. Figure 2 shows the ozone produced from all of the NO emissions from Mexico City and its environs (urban and fires) and ozone from only the fire emissions, for the periods before and after the rain event.

These results show that, for ozone, the open fires in the vicinity of Mexico City are a fairly small, but non-negligible contribution (20%) to the regional ozone pollution. Other studies have shown, however, that other components of Mexico City pollution, in particular particles, have significant contributions from fire emissions. Some of these sources could be cooking, heating and trash burning, which are not included in the tagged fire emissions in the MOZART simulations.

This work was funded by NSF and NASA. Analysis of the MIRAGE observations using MOZART will continue in FY09.

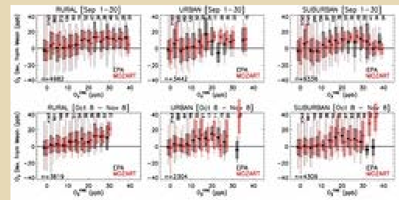

Figure 1. Deviation from the mean of observed and modeled midday 8-hour O_3 concentrations binned by the model fire tracer. Results are sorted by rural, urban and suburban sites, and for the two main fire periods.

High resolution figure

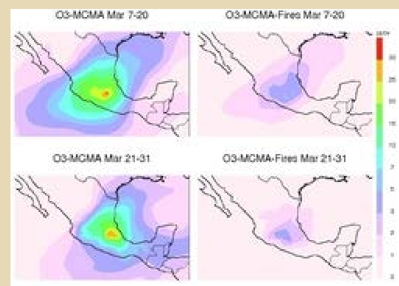

Figure 2. Ozone from all Mexico City emissions (left panels) and from just fire emission (right panel) for before (top row) and after (bottom row) the significant rain event.

High resolution figure

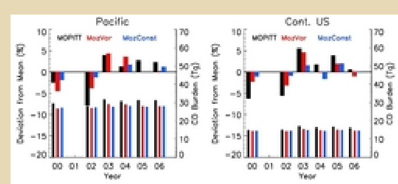

Figure 3. Variability in the tropospheric CO burden over the Pacific and continental US as derived from MOPITT and two MOZART simulations (MozVar: varying emissions; MozConst: constant emissions).

High resolution figure

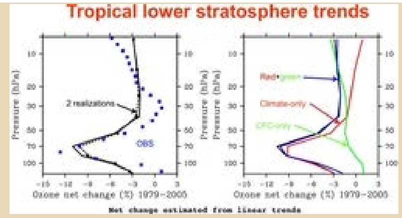

Figure 4.

High resolution figure

Globalization of air quality and intercontinental transport

Transpacific Pollution Transport during INTEX-B: Spring 2006 in Context to Previous Years

We analyze the transport of pollution across the Pacific during the NASA INTEX-B (Intercontinental Chemical Transport Experiment) campaign in spring 2006 and examine how this year compares to the time period 2000-2006. In addition to aircraft measurements collected during INTEX-B, we include multi-year satellite observations of CO from the Measurements of Pollution in the Troposphere (MOPITT) instrument. We integrate these measurements with simulations from the chemistry transport model MOZART-4. Model tracers are used to examine the contributions of different regions to pollution levels over the Pacific and to estimate the O_3 production from NOx sources in Asia to O_3 loadings over the Pacific and North America. Additional modeling studies are performed to separate the impacts of inter-annual variability in meteorology and dynamics from changes in source strength. Figure 3 shows the variability in the tropospheric CO burden (relative deviation from mean and absolute amounts) over the Pacific and the contiguous US as derived from MOPITT data and two model simulations, one with emissions that vary by year (MozVar) and one with constant emissions (MozConst).

This work was funded by NASA and NSF. This work will be published in FY09 and similar studies made in the analysis of the NASA ARCTAS aircraft experiment.

Chemistry-Climate Coupling: Past and Future

1. Lower stratospheric trends

In continuation of the work performed under FY2008, we have expanded our analysis of the lower stratospheric as simulated by CAM-chem (paper published in Journal of Geophysical Research, 2008). In this subsequent analysis, we focus on the understanding of the trend in the lower stratospheric tropical (20°S-20°N); using different simulations with different subsets of forcing agents we show that, based on this model, climate change (as identified here by changes in CO2 and sea-surface temperatures) is the largest contributor to the ozone trend in that region, much larger than the contribution of ozone-depleting substances; this work is submitted to Geophysical Research Letters. Additional studies will be performed during FY2009; in particular, focus will be given on changes in the width of the tropics and changes in tropospheric composition. Work funded by DOE.

2. Impact of sectoral emission change

In support of the US Climate Change Science Program (DOE), we have performed and analyzed in collaboration with NASA-GISS and NOAA-GFDL a series of simulations where emissions from specific sectors (transportation for example) are reduced by 30% over a specific region. This is to identify the potential chemistry and climate impact regional pollution control measures; in particular, over the United States, transportation is the sector which has the largest impact. This work in submitted to Atmospheric Chemistry and Physics Discussions. Work funded by DOE.

3. Methane clathrates

In continuation of the work performed under FY2008, we have furthered our investigation of the potential role for methane clathrates to act as a strong methane source during the 21^{st} century. Using a combination of model simulations from IPCC AR4 and model results for under the seafloor methane destabilization, we show that it is unlikely that methane from clathrate destabilization will be a strong source of methane by the time CO_2 as doubled over pre-industrial conditions (i.e. second half of 21st century). This work is in press in Geophysical Research Letters. Work funded by DOE.

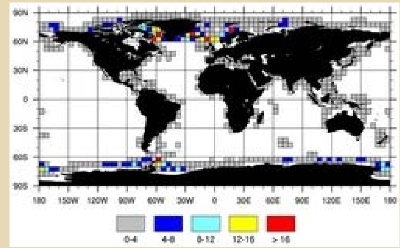

Figure 5. Geographical distribution (averaged over a 5° latitude-longitude grid) of the model-mean potential methane flux (in Tg(CH_4)/year) at the bottom of the ocean based on the 100-yr temperature increase from each model.

High resolution figure

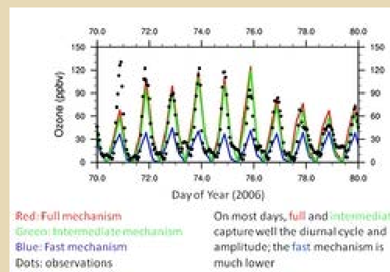

Figure 6. Comparison with surface observations in Mexico City (RAMA).

High resolution figure

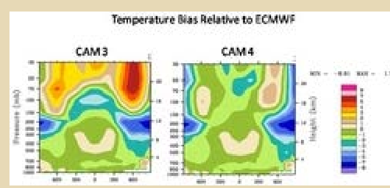

Figure 7.

High resolution figure

Developing community models

MOZART

The Model for Ozone and Related chemical Tracers (MOZART) is a global offline chemical transport model. Version 2 (MOZART-2) is available to the public through the NCAR Community Data Portal and has been downloaded by 110 users.

Two new versions, MOZART-3 and MOZART-4 have been recently completed and are actively used by ACD scientists. MOZART-3 is an extension of MOZART-2 into the stratosphere, with the addition of halogen chemistry and heterogeneous processes on polar stratospheric clouds (Kinnison et al., JGR, 2007). MOZART-4 has been updated over MOZART-2 to improve tropospheric chemistry simulations, with more detailed representation of hydrocarbons and tropospheric aerosols.

The chemical schemes of MOZART-3 and MOZART-4 have been incorporated in the coupled chemistry-climate models WACCM and CAM-Chem.

MOZART-3 and MOZART-4 (source code and documentation) will be made available to the public on the NCAR CDP by the end of 2008.

CAM CHEM

CAM is the latest in a series of global atmosphere models developed at NCAR for the weather and climate research communities. CAM also serves as the atmospheric component of the Community Climate System Model (CCSM). The continued incorporation of interactive chemistry capability in the Community Atmosphere Model (CAM) has reached a fairly stable state and now encompasses a variety of options to accommodate the needs of the coupled climate model, including a full interaction with the cloud microphysics (to represent the indirect effect, through collaboration with CGD and MMM scientist); in particular, using the implemented MOZART framework, CAM-chem can now be configured to combine prognostic and diagnostic variables. As a result. aerosols can either be prescribed, simulated using simple input oxidant fields, or simulated using the full MOZART-4 aerosol parameterization, or a combination of both; this flexibility is important to understand the specific role (radiatively and through cloud-aerosol interaction). In addition, the flexibility enabled the quick implementation of the modal (3 and 7 modes) aerosol scheme developed by S. Ghan (PNNL).

In addition, a version of CAM-chem with a representation of stratospheric chemistry was developed as a tool to represent ozone changes in the lower stratosphere; simulations over 1970-2005 indicate a very good comparison of ozone trends with respect to observations. This version will be used in 2009 for chemistry simulations in support of IPCC AR5.

For extended chemistry-climate studies, a number of different options exist for simulating aerosols and chemistry to facilitate using the model in the optimal configuration. In collaboration with scientists from Lawrence Livermore National Laboratory and University of California, Irvine, we have extensively tested 3 chemical mechanisms for tropospheric chemistry with increasing complexity of non-methane hydrocarbon (NMHC) representation; the overall goal is an understanding of how much chemistry is needed for specific applications (regional pollution chemistry or climate). In particular, comparison with the Mexico City (MIRAGE) campaign indicates (Figure 6) that an intermediate representation of NMHC is sufficient to represent ozone at the surface.

CAM-chem is now being merged with WACCM to allow for more flexibility in the model configuration and added ease of maintenance; indeed, this approach has eliminated code redundancy as much as possible. This merged code will now be the only version of CAM-chem or WACCM to be developed; this will allow for improvement from one science community to directly benefit the other one.

FY2009 plans include continued evaluation of the model performance under the different options described above. This work is funded by NSF/NCAR, NSF Biocomplexity, and DOE.

Radiation Transfer Model

The computation of the radiative effects of the atmospheric composition is central to efforts to understand climate. A new radiative transfer model (RRTMG), developed by AER, Inc., has been incorporated into CAM/CCSM. The interface between the atmospheric specifications in CAM and the radiative solver has significantly improved user flexibility in testing new optics and testing radiative forcing due to changes in atmospheric composition as well the extensibility for new species. Microphysical specifications in CAM have been made consistent with optical parameterizations. Collaborators from LBL, UC Berkeley, PNNL, DRI, and AER have contributed optics, solvers, and validated the new package. This work is funded by DOE/SCIDAC.

FY2009 plans include efforts to study the new radiation budget of the climate system.

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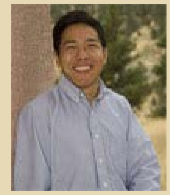
CGD 2008 PROFILES IN SCIENCE: DR. AIGUO DAI

Summary of achievements

In FY08, Dr. Dai continues his research in the fields of the hydrologic cycle, hydrometeorology, and climate change. In particular, he has expanded his research in applying satellite observations to document precipitation variability and evaluate models. His Climate Dynamics study is the first comprehensive analysis to quantify the frequency, intensity and diurnal cycle of precipitation over the globe using both in-situ surface and satellite observations. His GRL paper presents the first global analysis of the temperature and pressure dependence of the snow-rain phase transition and provides an analytic parameterization for use in climate and hydrologic modeling and remote sensing. During this period, Dr. Dai also has had productive collaborations with several non-NCAR groups, including scientists in Australia and China.



Aiguo Dai

Publications

Dai, A., X. Lin, and K-Lin Hsu, 2008: The frequency, intensity, and diurnal cycle of precipitation in surface and satellite observations over low- and mid-latitudes. Climate Dynamics, doi:10.1007/s00382-007-0260-y.

Abstract: Global precipitation data sets with high spatial and temporal resolution are needed for many applications, but they were unavailable before the recent creation of several such satellite products. Here, we evaluate four different satellite data sets of hourly or 3-hourly precipitation (namely CMORPH, PERSIANN, TRMM 3B42 and a microwave-only product referred to as MI) by comparing the spatial patterns in seasonal mean precipitation amount, daily precipitation frequency and intensity, and the diurnal and semidiurnal cycles among them and with surface synoptic weather reports.

We found that these high-resolution products show spatial patterns in seasonal mean precipitation amount comparable to other monthly products for the low- and mid-latitudes, and the mean daily precipitation frequency and intensity maps are similar among these pure satellite-based precipitation data sets and consistent with the frequency derived using weather reports over land. The satellite data show that spatial variations in mean precipitation amount come largely from precipitation frequency rather than intensity, and that the use of satellite infrared (IR) observations to improve sampling does not change the mean frequency, intensity and the diurnal cycle significantly.

Consistent with previous studies, the satellite data show that sub-daily variations in precipitation are dominated by the 24-h cycle, which has an afternoon-evening maximum and mean-to-peak amplitude of 30-100% of the daily mean in precipitation amount over most land areas during summer. Over most oceans, the 24-h harmonic has a peak from midnight to early morning with an amplitude of 10-30% during both winter and summer. These diurnal results are broadly consistent with those based on the weather reports, although the time of maximum in the satellite precipitation is a few hours later (especially for TRMM and PERSIANN) than that in the surface observations over most land and ocean, and it is closer to the phase of showery precipitation from the weather reports. The TRMM and PERSIANN precipitation shows a spatially coherent time of maximum around 0300-0600 local solar time (LST) for a weak (amplitude <20%) semi-diurnal (12-h) cycle over most mid- to high-latitudes, comparable to 0400-0600 LST in the surface data. The satellite data also confirm the notion that the diurnal cycle of precipitation amount comes mostly from its frequency rather than its intensity over most low and mid-latitudes, with the intensity has only about half of the strength of the diurnal cycle in the frequency and amount. The results suggest that these relatively new precipitation products can be useful for many applications.

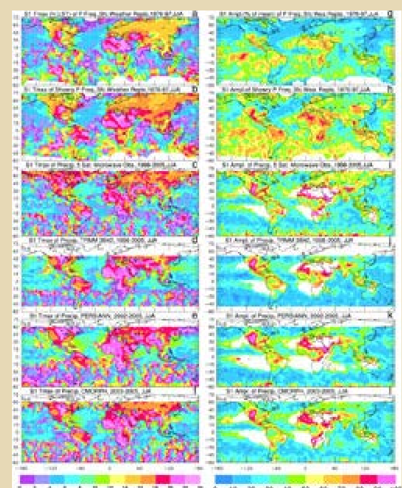


Figure 1.

High resolution figure

Figure caption: The phase (local solar time in hrs of the maximum, left column) and amplitude (in % of daily mean, right column) of the 24-hr harmonic estimated from the mean diurnal anomalies of JJA precipitation frequency for non-drizzle and showery precipitation from surface weather reports (top two rows), and of JJA precipitation amount from MI (3rd row), TRMM 3B42 (4th row), PRESIANN (5th row), and CMORPH (bottom row). Note the normalized amplitude is not shown (i.e., white color) over the subtropical areas where the mean precipitation is less than 0.1 mm/day.

Support: Supported by NASA Grant No. NNX07AD77G and NCAR TIIMES Water Cycle Program.

Sun, Y., S. Solomon, A. Dai, and R.W. Portmann, 2007: How Often Will It Rain? J. Climate, 20, 4801-4818.

Abstract: Daily precipitation data from climate change simulations using the latest generation of coupled climate system models are analyzed for potential future changes in precipitation characteristics. For the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) B1 (a low projection), A1B (a medium projection), and A2 (a high projection) during the twenty-first century, all the models consistently show a shift toward more intense and extreme precipitation for the globe as a whole and over various regions. For both SRES B1 and A2, most models show decreased daily precipitation frequency and all the models show increased daily precipitation intensity. The multimodel averaged percentage increase in the precipitation intensity (2.0% K^{-1}) is larger than the magnitude of the precipitation frequency decrease (-0.7% K^{-1}). However, the shift in precipitation frequency distribution toward extremes results in large increases in very heavy precipitation events (>50 mm day^{-1}), so that for very heavy precipitation, the percentage increase in frequency is much larger than the increase in intensity (31.2% versus 2.4%). The climate model projected increases in daily precipitation intensity are, however, smaller than that based on simple thermodynamics (~7% K-1). Multimodel ensemble means show that precipitation amount increases during the twenty-first century over high latitudes, as well as over currently wet regions in low- and midlatitudes more than other regions. This increase mostly results from a combination of increased frequency and intensity. Over the dry regions in the subtropics, the precipitation amount generally declines because of decreases in both frequency and intensity. This indicates that wet regions may get wetter and dry regions may become drier mostly because of a simultaneous increase (decrease) of precipitation frequency and intensity.

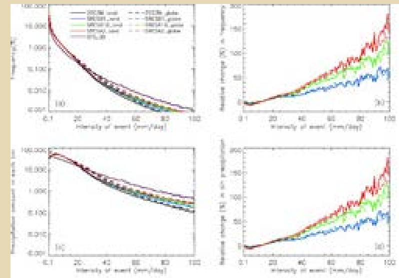


Figure 2.

High resolution figure

Figure caption: (a) Globally (dashed line) and land (solid line) averaged distribution of daily precipitation frequency as a function of precipitation intensity (bin size is 1 mm day^{-1} fro observations (GTS_3D, 1980-1999) and 11-model ensemble of simulations for present (20C3M, 1980-1999), and future (2080-2099) climates under SRES B1, A1B and A2 scenarios; (b) Same as (a) but for percentage changes; (c) same as (a), but for precipitation amount (mm) in each bin; and (d) same as (c) but for percentage changes.

Support: Supported by NRC, NOAA, NSF Grant #ATM-0233568, NCAR's Water Cycle Program, and Chinese NSF Grant #40605020.

Dai, A. 2008: Temperature and pressure dependence of the rain-snow phase transition over land and ocean. Geophys. Res. Lett., 35, L12802, doi:10.1029/2008GL033295.

Abstract: The phase of precipitation is important for weather forecasts, land hydrology and remote sensing. To quantify the temperature and pressure dependence of snow frequency (F, in %) when precipitation occurs, we have analyzed 3-hourly weather reports of surface air temperature (T_s, °C) and pressure (P_s), and snow and rain occurrences from over 15,000 land stations and available ship observations from 1977-2007. It is found that the phase transition occurs over a fairly wide range of temperature from about -2°C to +4°C over (low-elevation) land and -3°C to +6°C over ocean. The F-T_s relationship can be represented by a hyperbolic tangent: $F(T_s) = a [\tanh (b (T_s - c)) - d]$, with the slope parameter b close to 0.7 over land and 0.4 over ocean. The pressure-dependence is only secondary and reflected in the parameters. Results show that snow occurs often (F > 50%) for T_s = 1.2°C over land and T_s = 1.9°C over ocean, and are non-negligible (F > 5%) for T_s = 3.8°C over land and T_s = 5.5°C over ocean. This "warm bias" results from the falling of snowflakes into warmer surface layers, which is especially true over ocean. The warm bias is higher when air pressure is below ~750 hPa because snow falls faster in thin air.

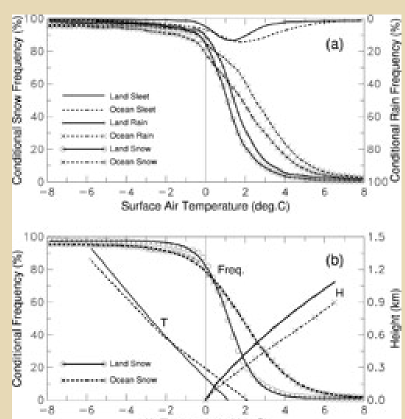


Figure 3.

High resolution figure

Figure caption: ((a) Observed temperature-dependence of the conditional snow, rain, and sleet frequency (read on the right ordinate) during all seasons from 1977-2007 over global land (solid line) and ocean (dashed line). (b) The snow frequency over land (circles) and ocean (stars) from (a) overlaid by the fitted frequency (lines) using Eq.(1). Also shown in (b) is the mean temperature profiles (denoted by "T", right ordinate, which is the height above the surface) derived from the 6-hourly ERA-40 reanalysis [Uppala et al., 2005] from 1980-1989 by averaging over the land (solid line, slope=-5.1°C km^{-1} for the lowest 1km) and ocean (dashed line, slope=-6.6°C km^{-1}) areas where surface air temperature (T_s) is within the snow-rain transition range (-2°C to 4°C for land and -3°C to +6°C for ocean). The mean height of the freezing level as a function of T_s is also shown (denoted by "H", solid line=land, dashed=ocean).

Support: This work was supported by NASA Grant No. NNX07AD77G and NCAR's Water Cycle Program.

Hobbins, M. T., A. Dai, M. L. Roderick, and G. D. Farquhar. 2008: Revisiting the parameterization of potential evaporation as a driver of long-term water balance trends. Geophys. Res. Lett., 35, L12403, doi:10.1029/2008GL033840.

Abstract: We examine the effects of two different parameterizations of potential evaporation on long-term trends in soil moisture, evaporative flux and runoff simulated by the water balance model underlying the Palmer Drought Severity Index. The first, traditional parameterization is based on air temperature alone. The second parameterization is derived from observations of evaporation from class-A pans. Trends in potential evaporation from the two parameterizations are opposite in sign (±) at almost half the stations tested over Australia and New Zealand. The sign of trends in the modelled soil moisture, evaporative flux and runoff depends on the parameterization used and on the prevailing climatic regime: trends in water-limited regions are driven by precipitation trends, but the choice of parameterization for potential evaporation is shown to be critical in energy-limited regions.

Figure 4.

High resolution figure

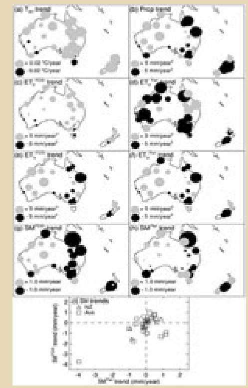


Figure caption: Annual trends at 27 stations in Australia and eight in New Zealand over the periods 1975-2004 (Australia) and 1974-2002 (New Zealand). Maps show direction and scale of trends for (a) Prcp, (b) T_{air}, (c) ET_p^{PDSI}, (d) ET_p^{Pan}, (e) ET_a^{PDSI}, (f) ET_a^{Pan}, (g) SM^{PDSI}, and (h) SM^{Pan}. Grey circles indicate positive trends, black circles negative, with areas proportional to trend magnitudes. (i) plots the station-trends in SMP^{DSI} from (g) against those in SM^{Pan} from (h).

Support: Supported by a Gary Comer Award and NCAR's Water Cycle Program.

Tian, X., Z. Xie, and A. Dai, 2008:A land surface soil moisture data assimilation system based on the dual-UKF method and the Community Land Model. J. Geophys. Res., 113, D14127, doi:10.1029/2007JD009650.

Abstract: Many studies have shown the deficiencies of the Extended Kalman Filter (EKF), even though it has become a standard technique used in nonlinear estimation. In the EKF method, the state distribution is propagated analytically through the first-order linearization of the nonlinear system, which can introduce large errors in variable estimation and may lead to sub-optimal performance and sometimes divergence of the filter. The Unscented Kalman Filter (UKF) addresses these problems using a deterministic sampling approach to capture the posterior mean and covariance accurate to the 3rd order for any nonlinearity, while the dual UKF method uses two UKF filters (one for state variables and one for parameters, in contrast to only one filter in the usual UKF) to simultaneously optimize the model states and parameters using observational data. In this paper, we employ the dual UKF method to account for the effects of land surface subgrid-scale heterogeneity and soil water thawing and freezing, and implement it into the NCAR Community Land Model version 2.0 (CLM2) to build a data assimilation system for assimilating satellite observations of soil moisture. Experiments for two sites in North and South China show that this dual UKF-based assimilation system outperforms the usual UKF- and EKF-based methods in reproducing the temporal evolution of daily soil moisture, especially under freezing conditions. Furthermore, the improvement also propagates, albeit to a lesser extent, to lower layers where observations are unavailable.

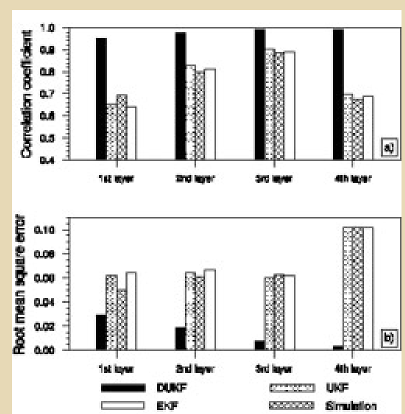


Figure 5.

High resolution figure

Figure caption: a) Correlation coefficients between the observed and assimilated or simulated daily soil moisture (the sample size is 72). b) Root mean square (rms) errors (m^3/m^3) for assimilated or simulated daily soil moisture content.

Support: Supported by the National Natural Science Foundation of China under Grant Nos. 40705035, the Knowledge Innovation Project of Chinese Academy of Sciences under Grant Nos. KZCX2-YW-217 and KZCX2-YW-126-2, and the National Basic Research Program under the Grant 2005CB321704, K. C. Wang Education Foundation, Hong Kong, and the U.S. National Science Foundation.

Oleson, K. W., et al., 2008: Improvements to the Community Land Model and their impact on the hydrological cycle. J. Geophys. Res., 113, G01021, doi:10.1029/2007JG000563.

Abstract: The Community Land Model version 3 (CLM3) is the land component of the Community Climate System Model (CCSM). CLM3 has energy and water biases resulting from deficiencies in some of its canopy and soil parameterizations related

to hydrological processes. Recent research by the community that utilizes CLM3 and the family of CCSM models has indicated several promising approaches to alleviating these biases. This paper describes the implementation of a selected set of these parameterizations and their effects on the simulated hydrological cycle. The modifications consist of surface data sets based on Moderate Resolution Imaging Spectroradiometer products, new parameterizations for canopy integration, canopy interception, frozen soil, soil water availability, and soil evaporation, a TOPMODEL-based model for surface and subsurface runoff, a groundwater model for determining water table depth, and the introduction of a factor to simulate nitrogen limitation on plant productivity. The results from a set of offline simulations were compared with observed data for runoff, river discharge, soil moisture, and total water storage to assess the performance of the new model (referred to as CLM3.5). CLM3.5 exhibits significant improvements in its partitioning of global evapotranspiration (ET) which result in wetter soils, less plant water stress, increased transpiration and photosynthesis, and an improved annual cycle of total water storage. Phase and amplitude of the runoff annual cycle is generally improved. Dramatic improvements in vegetation biogeography result when CLM3.5 is coupled to a dynamic global vegetation model. Lower than observed soil moisture variability in the rooting zone is noted as a remaining deficiency.

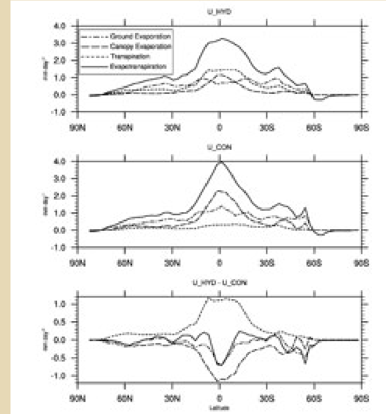


Figure 6.

High resolution figure

Figure caption: Total water storage anomalies (mm) for U_HYD (CLM3.5) and U_CON (CLM3.0) compared to two sources of GRACE data (GRACE1 [Seo and Wilson, 2005] and GRACE2 [Chen et al., 2005]). Model total water storage anomalies are calculated from the sum of snow water, canopy water, total column soil water, and aquifer water. GRACE data were interpolated to the model resolution.

Support: This work was supported by the NCAR Water Cycles Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

Zhou, L. A. Dai, Y. Dai, R. S. Vose, C.-Z. Zou, Y. Tian, and H. Chen, 2008: Spatial Dependence of Diurnal Temperature Range Trends on Precipitation from 1950 to 2004. Climate Dynamics, DOI 10.1007/s00382-008-0387-5.

Abstract: This paper analyzes the spatial dependence of annual diurnal temperature range (DTR) trends from 1950-2004 on the annual climatology of three variables: precipitation, cloud cover, and leaf area index (LAI), by classifying the global land into various climatic regions based on the climatological annual precipitation. The regional average trends for annual minimum temperature (T min) and DTR exhibit significant spatial correlations with the climatological values of these three variables, while such correlation for annual maximum temperature (T max) is very weak. In general, the magnitude of the downward trend of DTR and the warming trend of T min decreases with increasing precipitation amount, cloud cover, and LAI, i.e., with stronger DTR decreasing trends over drier regions. Such spatial dependence of T min and DTR trends on the climatological precipitation possibly reflects large-scale effects of increased global greenhouse gases and aerosols (and associated changes in cloudiness, soil moisture, and water vapor) during the later half of the twentieth century.

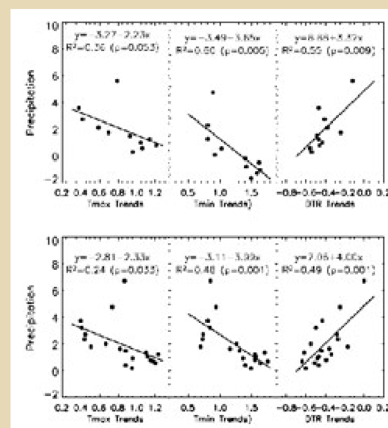


Figure 7.

High resolution figure

Figure caption: Dependence of trends (°C/55yrs) of observed annual mean maximum and minimum temperature and DTR on climatological annual mean precipitation averaged by climate zones over the global 5° by 5° grid boxes for the period of 1950-2004. The global grid boxes are classified into 11 (upper panels) and 19 (lower panels) climate zones, from dry to wet, based on their climatological annual mean precipitation amount from 1950 to 2004. A linear regression line is fit between the precipitation and the temperature trends.

Support: Supported by the NSF grant ATM-0720619 and the DOE grant DE-FG02-01ER63198. The National Center for Atmospheric Research is supported by the National Science Foundation.

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AIGUO DAI

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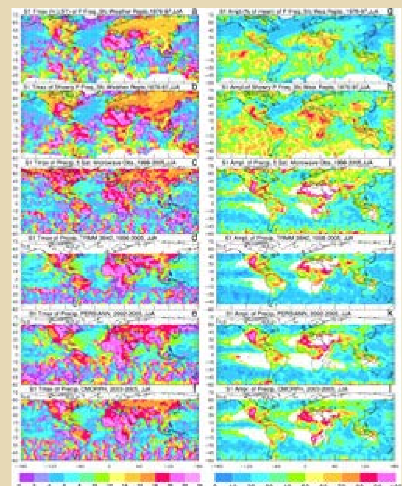
Research Focus FY08:

In FY08, Dr. Dai continues his research in the fields of the hydrologic cycle, hydrometeorology, and climate change. In particular, he has expanded his research in applying satellite observations to document precipitation variability and evaluate models. His Climate Dynamics study is the first comprehensive analysis to quantify the frequency, intensity and diurnal cycle of precipitation over the globe using both in-situ surface and satellite observations. His GRL paper presents the first global analysis of the temperature and pressure dependence of the snow-rain phase transition and provides an analytic parameterization for use in climate and hydrologic modeling and remote sensing. During this period, Dr. Dai also has had productive collaborations with several non-NCAR groups, including scientists in Australia and China.



The phase (local solar time in hrs of the maximum, left column) and amplitude (in % of daily mean, right column) of the 24-hr harmonic estimated from the mean diurnal anomalies of JJA precipitation frequency for non-drizzle and showery precipitation from surface weather reports (top two rows), and of JJA precipitation amount from MI (3rd row), TRMM 3B42 (4th row), PRESIANN (5th row), and CMORPH (bottom row). Note the normalized amplitude is not shown (i.e., white color) over the subtropical areas where the mean precipitation is less than 0.1 mm/day.

High resolution figure

Community Service FY08:

- AMS Committee on Climate Variability and Change, American Meteorological Society (AMS)
- NASA's Precipitation Science Team, NASA
- NRC Committee to Review of CCSP Report SAP 1.3, The National Research Council (NRC)
- Co-Chair: Organizing Committee for AMS 19th Symposium on Climate Variability and Change, American Meteorological Society (AMS)
- Chair: Organizing Committee for AMS 20th Symposium on Climate Variability and Change, American Meteorological Society (AMS)
- Overseas Team on Coupled Model Development, Chinese Academy of Sciences
- Graduate Research Advisor: Hongmei Li, Institute of Atmospheric Research, Chinese Academy of Sciences (Beijing)
- Thesis Committee (PhD): Todd Ellis, Colorado State University, Fort Collins, CO

Publications FY08 (abstracts):

Wang, J., A. Dai, 2008: Understanding warm-season precipitation diurnal cycle over the central U.S.. *Geophys. Res. Lett.*. (Submitted)1

Oleson, K. W., G.-Y. Niu, Z.-L. Yang, D. M. Lawrence, P. Thornton, P. Lawrence, R. Stockli, R. Dickinson, G. Bonan, S. Levis, A. Dai, T. Qian, 2008: Improvements to the community land model and their impact on the hydrological cycle. *J. Geophys. Res.*, **113**, G01021, doi: 10.1029/2007JG000563.4

Hobbins, M. T., A. Dai, M. L. Roderick, G. D. Farquhar, 2008: Revisiting the parameterization of potential evaporation as a driver of long-term water balance trends. *Geophys. Res. Lett.*, **35**, L12403, doi: 10.1029/2008GL033840.2

Zhou, L., A. Dai, Y. Dai, R. S. Vose, C.-Z. Zou, Y. Tian, H. Chen, 2008: Spatial dependence of diurnal temperature range trends on precipitation from 1950 to 2004. *Clim. Dyn.*, doi: 10.1007/s00382-008-0387-5.4

Dai, A., 2008: Temperature and pressure dependence of the rain-snow phase transition over land and ocean. *Geophys. Res. Lett.*, **35**, L12802, doi: 10.1029/2008GL033295.1

Tian, X., Z. Xie, A. Dai, 2008: A land surface soil moisture data assimilation system based on the dual-UKF method and the Community Land Model. *J. Geophys. Res.*, **113**, D14127, doi: 10.1029/2007JD009650.3

Wang, J., L. Zhang, A. Dai, T. VanHove, J. Van Baelen, 2007: A near-global, 2-hourly data set of atmospheric precipitable water from ground-based GPS measurements. *J. Geophys. Res.*, **112**, D11107, doi: 10.1029/2006JD007529.3

Sun, Y., S. Solomon, A. Dai, R. Portmann, 2007: How often will it rain? *J. Climate*, **20**, 4801-4818, doi: 10.1175/JCLI4263.1.3

Aiguo Dai Research Catalog

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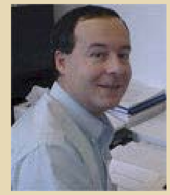
CGD 2008 PROFILES IN SCIENCE: DR. GOKHAN DANABASOGLU

Summary of achievements



Gokhan Danabasoglu

The general subjects of my research are understanding the role of the oceans in the earth's climate system and computational modeling of the ocean as geophysical fluid. In FY08, I devoted about half of my research effort to developing, implementing, testing, and evaluating subgrid-scale parameterizations within the ocean component of the Community Climate System Model (CCSM). This work supports in approximately equal balance both my personal research and collaborations with university and U.S. Government scientists involved in the CCSM Ocean Model Working Group (OMWG) and the U.S. CLIVAR Climate Process Teams (CPTs) on ocean mixing and gravity currents. As a co-chair of the CCSM OMWG, I have been spending time both actively helping and coordinating various efforts to finalize the CCSM4 ocean component for use in the next IPCC assessment studies. I spent the other half of my research effort focusing on curiosity driven research projects that included investigating the driving mechanisms and potential predictability associated with the multi-decadal variability of the North Atlantic Meridional Overturning Circulation, as well as multi-disciplinary research that reef bleaching and adaptation.

Publications

Kleypas, J. A. , G. Danabasoglu, and J. M. Lough, 2007: Potential role of the ocean thermostat in determining regional differences in coral reef bleaching events. Geophysical Research Letters, v35, L03613, doi:10.1029/2007GL032257.

Abstract: Several negative feedback mechanisms have been proposed by others to explain the stability of maximum sea surface temperature (SST) in the western Pacific warm pool (WPWP). If these "ocean thermostat" mechanisms effectively suppress warming in the future, then coral reefs in this region should be less exposed to conditions that favor coral reef bleaching. In this study we look for regional differences in reef exposure and sensitivity to increasing SSTs by comparing reported coral reef bleaching events with observed and modeled SSTs of the last fifty years. Coral reefs within or near the WPWP have had fewer reported bleaching events relative to reefs in other regions. Analysis of SST data indicate that the warmest parts of the WPWP have warmed less than elsewhere in the tropical oceans, which supports the existence of thermostat mechanisms that act to depress warming beyond certain temperature thresholds.

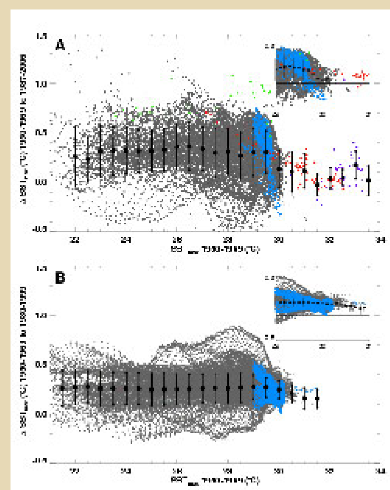


Figure 1.

High resolution figure

Figure caption: (A) Warming of average maximum SSTs between 1950-69 and 1987-2006 based on observations from HadISST data set; mean (large black dots) and standard deviations (vertical lines) are shown for 0.5°C intervals. Inset expands data for 29-31°C, with mean and standard deviation at 0.1°C intervals. Blue=Western Pacific Warm Pool, red=Red Sea; purple=Persian Gulf, green=Gulf of California, gray=all other locations. (B) As in A, based on CCSM3 four-member ensemble of 20th Century integrations. Note that 1980-99 range is used for the later years in B. The difference between SSTmax for 1950-69 and 1987-2006 based on observations shows that warming averages 0.2-0.4°C while SSTmax < 29.5°C; above 29.5°C the degree of warming drops off rapidly. Model data also agree with observations in that warming of maximum SSTs was less for regions with higher maximum SSTs. However, the modeled temperature where warming dropped off was higher than in observations and the reduction in warming at higher modeled SSTmax was also less pronounced than in the observations.

Support: NCAR is sponsored by the National Science Foundation.

Danabasoglu, G., R. Ferrari, and J.C. McWilliams, 2008: Sensitivity of an Ocean General Circulation Model to a Parameterization of Near-Surface Eddy Fluxes. J. Climate, 21, 1192-1208.

Abstract: A simplified version of the near-boundary eddy flux parameterization developed recently by Ferrari et al. has been implemented in the NCAR Community Climate System Model (CCSM3) ocean component for the surface boundary only.

This scheme includes the effects of diabatic mesoscale fluxes within the surface layer. The experiments with the new parameterization show significant improvements compared to a control integration that tapers the effects of the eddies as the surface is approached. Such surface tapering is typical of present implementations of eddy transport in some current ocean models. The comparison is also promising versus available observations and results from an eddy-resolving model. These improvements include the elimination of strong, near-surface, eddy-induced circulations and a better heat transport profile in the upper ocean. The experiments with the new scheme also show reduced abyssal cooling and diminished trends in the potential temperature drifts. Furthermore, the need for any ad hoc, near-surface taper functions is eliminated. The impact of the new parameterization is mostly associated with the modified eddy-induced velocity treatment near the surface. The new parameterization acts in the depth range exposed to enhanced turbulent mixing at the ocean surface. This depth range includes the actively turbulent boundary layer and a transition layer underneath, composed of waters intermittently exposed to mixing. The mixed layer, that is, the regions of weak stratification at the ocean surface, is found to be a good proxy for the sum of the boundary layer depth and transition layer thickness.

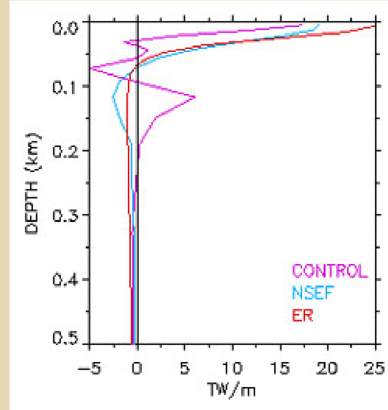


Figure 2.

High resolution figure

Figure caption: Upper-ocean vertical profiles of zonally-integrated, time-mean total advective (Eulerian mean + eddy-induced) heat transport at 49.4°S from CONTROL, NSEF which uses the new surface eddy flux parameterization, and an eddy-resolving model (ER) as a measure of "truth". The most dramatic effects of the elimination of the strong near-surface eddy-induced circulation with the new parameterization are evident in the vertical structure of the heat transports. In particular, the NSEF profile is in remarkably good agreement with the profile from ER, both in magnitude and shape. In contrast, the CONTROL profile has alternating northward and southward transports in the upper 200 m, reflecting the dominance of the near-surface eddy-induced circulation.

Support: This research was partially supported by the NSF grant OCE-0336827 for the Climate Process Team on Eddy Mixed-Layer Interactions (CPT-EMILIE). The computational resources were provided by the Scientific Computing Division of the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation.

Jochum, M., G. Danabasoglu, M. Holland, Y.-O. Kwon, and W. G. Large, 2008: Ocean viscosity and climate. J. Geophys. Res., 113, C06017, doi:10.1029/2007JC004515.

Abstract: The impacts of parameterized lateral ocean viscosity on climate are explored using three 120-year integrations of a fully coupled climate model. Reducing viscosity leads to a generally improved ocean circulation at the expense of increased numerical noise. Five domains are discussed in detail: the equatorial Pacific, where the emergence of tropical instability waves reduces the cold tongue bias; the Southern Ocean, where the Antarctic Circumpolar Current increases its kinetic energy but reduces its transport; the Arctic Ocean, where an improved representation of the Atlantic inflow leads to a better sea-ice distribution; the North Pacific, where the more realistic path of the Kuroshio leads to more realistic temperatures across the midlatitude Pacific; and the northern marginal seas, where stronger boundary currents lead to significantly less sea-ice. Although the ocean circulation and sea-ice distribution improve, the oceanic heat uptake, the poleward heat transport, and the large scale atmospheric circulation are not changed significantly. In particular, the improvements to the equatorial cold tongue did not lead to better representation of tropical precipitation or El Niño.

Figure caption: Anisotropic horizontal viscosity coefficients A and B at 100-m depth from (a-b) CONT, (c-d) NOSMAG, and (e-f) LOWVISC. Units are 1000 m^2 s^{-1}. All panels use the same color scale.

Support: NCAR is sponsored by the National Science Foundation.

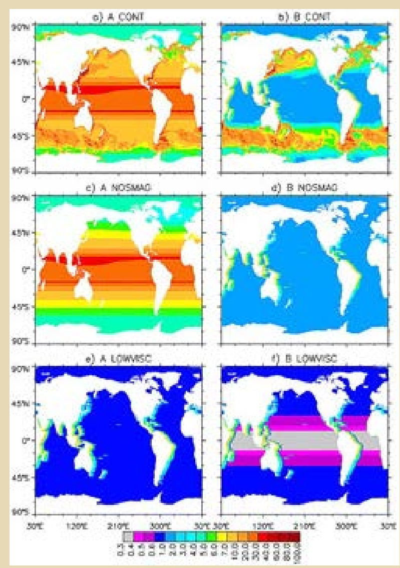


Figure 3.

High resolution figure

Danabasoglu, G., 2008: On multi-decadal variability of the Atlantic meridional overturning circulation in the Community Climate System Model version 3 (CCSM3). J. Climate, in press.

Abstract: Multi-decadal variability of the Atlantic meridional overturning circulation (MOC) is investigated diagnostically in the NCAR CCSM3 present-day simulations, using the highest (T85x1) resolution version. This variability has a

21-year period and is present in many other ocean fields in the North Atlantic. In MOC, the oscillation amplitude is about 4.5 Sv, corresponding to 20% of the mean maximum MOC transport. The northward heat transport (NHT) variability has an amplitude of about 0.12 PW, representing 10% of the mean maximum NHT. In sea surface temperature (SST) and salinity (SSS), the peak-to-peak changes can be as large as 6-7°C and 3 psu, respectively. The Labrador Sea region is identified as the deep water formation (DWF) site associated with the MOC oscillations. In contrast with some previous studies, temperature and salinity contributions to the total density in this DWF region are almost equal and in-phase. The heat and freshwater budget analyses performed for the DWF site indicate a complex relationship between the DWF, MOC, North Atlantic Oscillation (NAO), and subpolar gyre circulation anomalies. Their complicated interactions appear to be responsible for the maintenance of this multi-decadal oscillation. In these interactions, the atmospheric variability associated with the model's NAO plays a prominent role. In particular, the NAO modulates the subpolar gyre strength and contributes to the formation of the temperature and salinity anomalies that lead to positive / negative density anomalies at the DWF site. In addition, the wind stress curl anomalies occurring during the transition phase between the positive and negative NAO states produce fluctuations of the subtropical-subpolar gyre boundary, thus creating mid-latitude SST and SSS anomalies. Comparisons with observations show that neither the pattern nor the magnitude of this dominant SST variability is realistic.

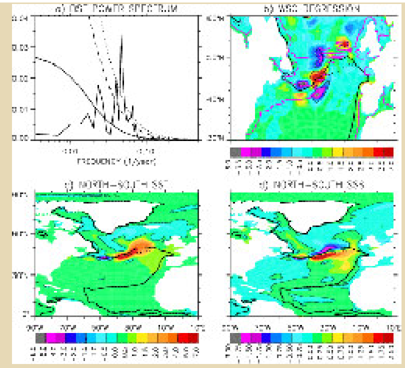


Figure 4.

High resolution figure

Figure caption: a) Power spectrum of the time series of the barotropic streamfunction (BSF) subtropical-subpolar gyre boundary north-south shifts along 30°W, b) simultaneous wind stress curl (WSC) regressions with the time series of the BSF subtropical-subpolar gyre boundary shifts in 10^{-8} N m^{-3} per degree; NORTH-SOUTH difference distributions for c) SST in °C, and d) SSS in psu. In (a), the Hanning window is applied, and the reference red noise spectrum with the same total variance is given by the thick solid line, and the dashed and dotted lines show its 95% and 99% confidence limits, respectively. In (b-d), the solid and dotted lines show the most northward and southward mean positions of the zero BSF contour line, respectively. These positions are based on 6 episodes, each 4 years long, when the gyre boundary is at its most northern (NORTH) and southern (SOUTH) positions, respectively. In (b), the thin solid and pink lines show the 95% significance level, using the two-sided Student's t-test, and the zero contour line for the time-mean WSC, respectively. In (c-d), the zero contour lines are drawn. In (a), the power spectrum shows that the highest power occurs at a period of 21 years. Panel (b), clearly indicates that the NAC path shifts southward and northward in response to the negative and positive WSC anomalies centered at about 45°W, 43°N and 35°W, 45°N, respectively. Because these shifts occur in regions with large meridional SST and SSS gradients, the resulting SST and SSS changes are rather large as demonstrated by the NORTH-SOUTH difference distributions of (c) and (d). The patterns and magnitudes of these difference distributions are very similar to their respective EOF1 patterns and magnitudes.

Support: NCAR is sponsored by the National Science Foundation.

Eden, C., M. Jochum, and G. Danabasoglu, 2008: Effects of different closures for thickness diffusivity. Ocean Modelling, in press.

Abstract: The effects of spatial variations of the thickness diffusivity (K) appropriate to the parameterization of Gent and McWilliams (1990) are assessed in a coarse resolution global ocean general circulation model. Simulations using three closures yielding different lateral and/or vertical variations in K are compared with a simulation using a constant value. Although the effects of changing K are in general small and all simulations remain biased compared to observations, we find systematic local sensitivities of the simulated circulation on K. In particular, increasing K near the surface in the tropical ocean lifts the depth of the equatorial thermocline, the strength of the Antarctic Circumpolar Current decreases while the subpolar and subtropical gyre transports in the North Atlantic increase by increasing K locally. We also find that the lateral and vertical structure of K given by a recently proposed closure reduces the negative temperature biases in the western North Atlantic by adjusting the pathways of the Gulf Stream and the North Atlantic Current to a more realistic position.

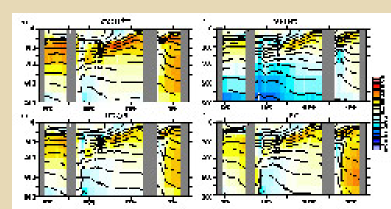


Figure 5.

High resolution figure

Figure caption: Annual-mean temperature differences between simulations and the climatology of Levitus and Boyer (1994) in experiment CONST (a), VMHS (b), NSQR (c) and EG (d) after 500 years integration at the equator. Also shown are contour lines of temperature (2C contour spacing). In CONST, the thickness diffusivity is constant in both space and time (except for tapering). VMHS, NSQR, and EG use Visbeck et al. (1997), Danabasoglu and Marshall (2007), and Eden and Greatbatch (2008) formulations, respectively, for the thickness diffusivity. The differences from observations are significantly reduced in NSQR and EG simulations compared to CONST and VMHS in the Pacific basin. In contrast, VMHS compares more favorably with observations in the Atlantic basin.

Support: This study was supported by the Deutsche Forschungsgemeinschaft within the SPP 1158 and by the NSF grant OCE-0336827 for the Climate Process Team on Eddy Mixed-Layer Inter actions (CPT-EMILIE). The computational resources were provided by the Scientific Computing Division of the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation.

Griffies, S. M., A. Biastoch, C. Boning, F. Bryan, G. Danabasoglu, E. P. Chassignet, M. H. England, R. Gerdes, H. Haak, R. W. Hallberg, W. Hazeleger, J. Jungclaus, W. G. Large, G. Madec, A. Pirani, B. L. Samuels, M. Scheinert, A. S. Gupta, C. A. Severijns, H. L. Simmons, A. M. Treguier, M. Winton, S. Yeager, J. Yin, 2008: Coordinated Ocean-ice Reference Experiments (COREs). Ocean Modelling, in press.

Abstract: Coordinated Ocean-ice Reference Experiments (COREs) are presented as a tool to explore the behavior of global ocean-ice models under forcing from a common atmospheric dataset. We highlight issues arising when designing coupled global ocean and sea ice experiments, such as difficulties formulating a consistent forcing methodology and experimental protocol. Particular focus is given to the hydrological forcing, the details of which are key to realizing simulations with stable meridional overturning circulations.

The atmospheric forcing from Large and Yeager (2004) was developed for coupled ocean and sea ice models. We found it to be suitable for our purposes, even though its evaluation originally focused more on the ocean than on the sea-ice. Simulations with this atmospheric forcing are presented from seven global ocean-ice models using the CORE-I design (repeating annual cycle of atmospheric forcing for 500 years). These simulations test the hypothesis that global ocean-ice models run under the same atmospheric state produce qualitatively similar simulations. The validity of this hypothesis is shown to depend on the chosen diagnostic. The CORE simulations provide feedback to the fidelity of the atmospheric forcing, with identification of biases promoting avenues for model and/or forcing dataset development.

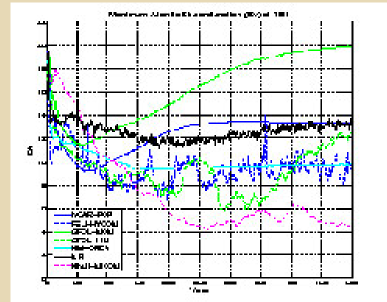


Figure 6.

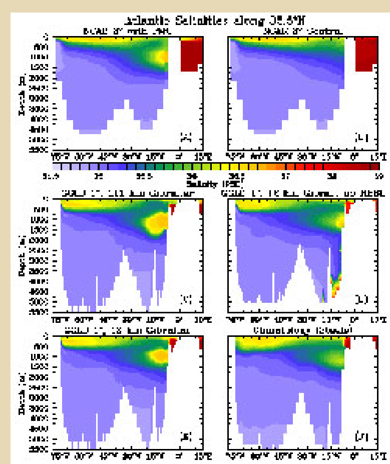
High resolution figure

Figure caption: Time series of the annual mean Atlantic meridional overturning circulation (AMOC) index (vertical axis) for model years 1-500 (horizontal axis) in units of Sv from the seven participating models in this study. The index is computed as the maximum AMOC streamfunction at 45N in the region beneath the wind driven Ekman layer. Note that the GFDL-MOM simulation was extended to 600 years to verify that it was reaching a steady state for the overturning. An AMOC with realistic transport strength and structure is important for maintaining a realistic ocean climate. It is sometimes quite difficult to realize a stable overturning circulation, especially in ocean-ice models. The behavior of the ocean-ice models in this study indeed reflects on this sensitivity, with some models ``refusing'' to stabilize at a circulation reflecting observations (e.g., for North Atlantic Deep Water (NADW), about 15 Sv), whereas others appear to reach a stable value either with a very weak salinity restoring (NCAR-POP, FSU-HYCOM, and MPI), or stronger restoring (GFDL-MOM and Kiel-ORCA). It is notable that the two isopycnal models appear to have the most difficulty reaching a steady state, with the GFDL-HIM simulation showing large amplitude variations, whereas the KNMI-MICOM simulation settles into a very weak, nearly absent, overturning circulation in the NADW cell. We also note that the FSU-HYCOM simulation exhibits a nontrivial level of interannual variability relative to the simulations from NCAR-POP, GFDL-MOM, Kiel-ORCA, and MPI. Given the steady nature of the repeating annual forcing, the FSU-HYCOM variability is internally generated. The mechanism for variability has not been determined.

Support: NCAR is sponsored by the National Science Foundation.

Legg, S., B. Briegleb, Y. Chang, E. P. Chassignet, G. Danabasoglu, T. Ezer, A. L. Gordon, S. Griffies, R. Hallberg, L. Jackson, W. Large, T. M. Ozgokmen, H. Peters, J. Price, U. Riemenschneider, W. Wu, X. Xu, and J. Yang, 2008: Improving oceanic overflow representation in climate models: The Gravity Current Entrainment Climate Process Team. BAMS, in press.

Abstract: Oceanic overflows are bottom-trapped density currents originating in semi-enclosed basins such as the Nordic seas, or on continental shelves such as the Antarctic shelf. Overflows are the source of most of the abyssal waters, and so play an important role in the large-scale ocean circulation, forming a component of the sinking branch of the thermohaline circulation. As they descend the continental slope, overflows mix vigorously with the surrounding oceanic waters, changing their density and transport significantly. These mixing processes occur on spatial scales well below the resolution of ocean climate models, with the result that deep waters and deep western boundary currents are simulated poorly. The Gravity Current Entrainment Climate Process Team was established by US CLIVAR to accelerate the development and implementation of improved representations of overflows within large-scale climate models, bringing together climate model developers with those conducting observational, numerical and laboratory process studies of overflows. Here the organization of the Climate Process Team is described and a few of the successes and lessons learned during this collaboration are highlighted, with some emphasis on the well-observed Mediterranean overflow. The Climate Process Team has developed several different overflow parameterizations, which are examined in a hierarchy of ocean models, from comparatively well-resolved regional models to the largest-scale global climate



models.

Figure 7.

High resolution figure

Figure caption: Salinity cross-sections in the Atlantic Ocean at the latitude of the Strait of Gibraltar. The top two panels compare the results after 30 years with the NCAR ocean-only simulations with the parameterized Mediterranean outflow (PMO) and a control experiment in which the Strait of Gibraltar is blocked. These simulations use the nominal 3-degree resolution version of the model. The improvements due to the PMO are obvious: The Mediterranean Salt Tongue is completely missing in the control integration, but clearly present in the PMO simulation. The next 3 panels show the results after 5 years in GFDL's 1-degree isopycnal coordinate model, GOLD, with Gibraltar open at 111 km (1 grid point) width, with Gibraltar restricted to 12 km but without the Hallberg Bottom Boundary Layer (HBBL) parameterization, and finally with both Turner-Ellison (TE) parameterization and HBBL parameterizations activated. With the inclusion of the HBBL parameterization in GOLD, the outflow plume now has a salinity, density, and volume much closer to that seen in observations. The final panel shows the salinity in the Steele ocean climatology; the data processing behind this climatology includes enough temporal and spatial smoothing that the "climatological" salinity of the plume is lower by several tenths of a PSU compared with raw profiles, but it should be reflective of the depth and extent of the plume.

Support: This study was supported by NSF Grant OCE-0336834 for the Climate Process Team on Gravity Current Entrainment. The computational resources were partially provided by the Scientific Computing Division of the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation.

Doney, S. C., S. Yeager, G. Danabasoglu, W. G. Large, and J. C. McWilliams, 2007: Mechanisms governing interannual variability of upper ocean temperature in a global ocean hindcast simulation. J. Phys. Oceanogr., 37, 1918-1938.

Abstract: The interannual variability in upper-ocean (0-400 m) temperature and governing mechanisms for the period 1968-97 are quantified from a global ocean hindcast simulation driven by atmospheric reanalysis and satellite data products. The unconstrained simulation exhibits considerable skill in replicating the observed interannual variability in vertically integrated heat content estimated from hydrographic data and monthly satellite sea surface temperature and sea surface height data. Globally, the most significant interannual variability modes arise from El Niño-Southern Oscillation and the Indian Ocean zonal mode, with substantial extension beyond the Tropics into the midlatitudes. In the well-stratified Tropics and subtropics, net annual heat storage variability is driven predominately by the convergence of the advective heat transport, mostly reflecting velocity anomalies times the mean temperature field. Vertical velocity variability is caused by remote wind forcing, and subsurface temperature anomalies are governed mostly by isopycnal displacements (heave). The dynamics at mid- to high latitudes are qualitatively different and vary regionally. Interannual temperature variability is more coherent with depth because of deep winter mixing and variations in western boundary currents and the Antarctic Circumpolar Current that span the upper thermocline. Net annual heat storage variability is forced by a mixture of local air-sea heat fluxes and the convergence of the advective heat transport, the latter resulting from both velocity and temperature anomalies. Also, density-compensated temperature changes on isopycnal surfaces (spice) are quantitatively significant.

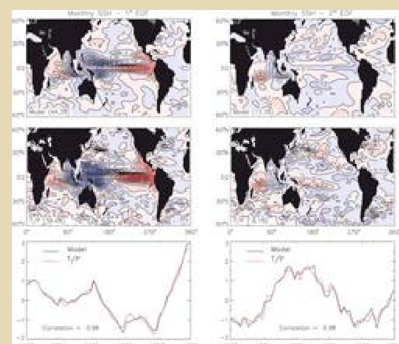


Figure 8.

High resolution figure

Figure caption: Spatial maps of the (left) first and (right) second EOF (1993-97) for the (top) model and (middle) T/P monthly SSH anomalies after the removal of the average seasonal cycle for 1993-95. The contour interval is 1 cm, and the variances associated with each EOF are given as percentages of the respective total variances. (bottom) The time series of the TOPEX/Poseidon and model first-mode principal components.

CGD Research Catalog

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CHRISTOPHER DAVIS

2008 Publications

Musgrave, K. D., C. A. Davis, M. T. Montgomery, 2008: Numerical simulations of the formation of Hurricane Gabrielle (2001). Mon. Wea. Rev., 136, 3151-3167, doi: 10.1175/2007MWR2110.1.

ABSTRACT

This study examines the formation of Hurricane Gabrielle (2001), focusing on whether an initial disturbance and vertical wind shear were favorable for development. This examination is performed by running numerical experiments using the fifth-generation Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model (MM5). Gabrielle is chosen as an interesting case to study since it formed in the subtropics only a few days before making landfall in Florida. Three simulations are run: a control run and two sensitivity experiments. The control run is compared with observations to establish the closeness of the model output to Gabrielle's observed formation. The two sensitivity experiments are designed to test the response of the developing tropical cyclone to alterations in the initial conditions. The first sensitivity experiment removes the initial (or precursor) disturbance, a midtropospheric vortex located over Florida. The second sensitivity experiment reduces the vertical wind shear over the area of formation. The control run produces a system comparable to Gabrielle. The convection in the control run is consistently located downshear of the center of circulation. In the first sensitivity experiment, with the removal of the initial disturbance, no organized system develops. This indicates the importance of the midtropospheric vortex in Gabrielle's formation. The second sensitivity experiment, which reduces the vertical wind shear over the area of Gabrielle's formation, produces a system that can be identified as Gabrielle. This system, however, is weaker than both the control run and the observations of Gabrielle. This study provides direct evidence of a favorable influence of modest vertical wind shear on the formation of a tropical cyclone in this case.

Trier, S. B., F. Chen, K. W. Manning, M. A. Lemone, C. A. Davis, 2008: Sensitivity of the PBL and precipitation in 12-day simulations of warm-season convection using different land surface models and soil wetness conditions. Mon. Wea. Rev., 136, 2321-2343, doi: 10.1175/2007MWR2289.1.

ABSTRACT

A coupled land surface–atmospheric model that permits grid-resolved deep convection is used to examine linkages between land surface conditions, the planetary boundary layer (PBL), and precipitation during a 12-day warm-season period over the central United States. The period of study (9–21 June 2002) coincided with an extensive dry soil moisture anomaly over the western United States and adjacent high plains and wetter-than-normal soil conditions over parts of the Midwest. A range of possible atmospheric responses to soil wetness is diagnosed from a set of simulations that use land surface models (LSMs) of varying sophistication and initial land surface conditions of varying resolution and specificity to the period of study.

Results suggest that the choice of LSM [Noah or the less sophisticated simple slab soil model (SLAB)] significantly influences the diurnal cycle of near-surface potential temperature and water vapor mixing ratio. The initial soil wetness also has a major impact on these thermodynamic variables, particularly during and immediately following the most intense phase of daytime surface heating. The soil wetness influences the daytime PBL evolution through both local and upstream surface evaporation and sensible heat fluxes, and through differences in the mesoscale vertical circulation that develops in response to horizontal gradients of the latter. Resulting differences in late afternoon PBL moist static energy and stability near the PBL top are associated with differences in subsequent late afternoon and evening precipitation in locations where the initial soil wetness differs among simulations. In contrast to the initial soil wetness, soil moisture evolution has negligible effects on the mean regional-scale thermodynamic conditions and precipitation during the 12-day period.

Davis, C. A., C. S. Snyder, A. C. Didlake, 2008: A vortex-based perspective of eastern Pacific tropical cyclone formation. Mon. Wea. Rev., 136, 2461-2477, doi: 10.1175/2007MWR2319.1.

ABSTRACT

Tropical cyclone formation over the eastern Pacific during 2005 and 2006 was examined using primarily global operational analyses from the National Centers for Environmental Prediction. This paper represents a "vortex view" of genesis, adding to previous work on tropical cyclone formation associated with tropical waves. Between 1 July and 30 September during 2005 and 2006, vortices at 900 hPa were tracked and vortex-following diagnostic quantities were computed. Vortices were more abundant during periods of an enhanced "Hadley" circulation with monsoon westerlies around 10°N in the lower troposphere. This zonally confined Hadley circulation was significantly stronger during the genesis of developing vortices. Developing vortices were stronger at the outset, with a deeper potential vorticity maximum, compared to nondeveloping vortices. This implies that developing disturbances were selected early on by favorable synoptic-scale features.

The characteristic time-mean reversal of the meridional gradient of absolute vorticity in the lower troposphere was found to nearly vanish when the aggregate contribution of strong vortices was removed from the time-mean vorticity. This finding implies that it is difficult to unambiguously attribute development to a preexisting enhancement of vorticity on the synoptic scale. The time-mean enhancement of cyclonic vorticity primarily results from the accumulated effect of vortices. It is suggested that horizontal deformation in the background state helps distinguish developing vortices from nondevelopers, and also biases the latitude of development poleward of the climatological ITCZ axis.

Weisman, M. L., C. A. Davis, W. Wang, K. Manning, 2008: Experiences with 0-36h explicit convective forecasts with the WRF-ARW model. Wea. Forecasting, 23, 407-437, doi: 10.1175/2007WAF2007005.1.

ABSTRACT

Herein, a summary of the authors' experiences with 36-h real-time explicit (4 km) convective forecasts with the Advanced Research Weather Research and Forecasting Model (WRF-ARW) during the 2003–05 spring and summer seasons is presented. These forecasts are compared to guidance obtained from the 12-km operational Eta Model, which employed convective parameterization (e.g., Betts–Miller–Janjic). The results suggest significant value added for the high-resolution forecasts in representing the convective system mode (e.g., for squall lines, bow echoes, mesoscale convective vortices) as well as in representing the diurnal convective cycle. However, no improvement could be documented in the overall guidance as to the timing and location of significant convective outbreaks. Perhaps the most notable result is the overall strong correspondence between the Eta and WRF-ARW guidance, for both good and bad forecasts, suggesting the overriding influence of larger scales of forcing on convective development in the 24–36-h time frame. Sensitivities to PBL, land surface, microphysics, and resolution failed to account for the more significant forecast errors (e.g., completely missing or erroneous convective systems), suggesting that further research is needed to document the source of such errors at these time scales. A systematic bias is also noted with the Yonsei University (YSU) PBL scheme, emphasizing the continuing need to refine and improve physics packages for application to these forecast problems.

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. Mon. Wea. Rev., 136, 1990-2005, doi: 10.1175/2007MWR2085.1.

Abstract

Real-time forecasts of five landfalling Atlantic hurricanes during 2005 using the Advanced Research Weather Research and Forecasting (WRF) (ARW) Model at grid spacings of 12 and 4 km revealed performance generally competitive with, and occasionally superior to, other operational forecasts for storm position and intensity. Recurring errors include 1) excessive intensification prior to landfall, 2) insufficient momentum exchange with the surface, and 3) inability to capture rapid intensification when observed. To address these errors several augmentations of the basic community model have been designed and tested as part of what is termed the Advanced Hurricane WRF (AHW) model. Based on sensitivity simulations of Katrina, the inner-core structure, particularly the size of the eye, was found to be sensitive to model resolution and surface momentum exchange. The forecast of rapid intensification and the structure of convective bands in Katrina were not significantly improved until the grid spacing approached 1 km. Coupling the atmospheric model to a columnar, mixed layer ocean model eliminated much of the erroneous intensification of Katrina prior to landfall noted in the real-time forecast.

Liu, Y., T. T. Warner, J. F. Bowers, L. Carson, F. Chen, C. A. Clough, C. A. Davis, C. H. Egeland, C. Halvorson, T. W. Huck, L. Lachapelle, R. E. Malone, D. L. Rife, R.-S. Sheu, S. P. Swerdlin, D. S. Weingarten, 2008: The operational mesogamma-scale analysis and forecast system of the U.S. Army Test and Evaluation Command. Part 1: Overview of the modeling system, the forecast products. J. Appl. Meteor. Climat., 47, 1077-1093.

McTaggart-Cowan, R., G. D. Deane, L. F. Bosart, C. A. Davis, T. J. Galarneau, 2008: Climatology of tropical cyclogenesis in the North Atlantic. Mon. Wea. Rev., 136, 1284-1304.4

ABSTRACT

The threat posed to North America by Atlantic Ocean tropical cyclones (TCs) was highlighted by a series of intense landfalling storms that occurred during the record-setting 2005 hurricane season. However, the ability to understand—and therefore the ability to predict—tropical cyclogenesis remains limited, despite recent field studies and numerical experiments that have led to the development of conceptual models describing pathways for tropical vortex initiation. This study addresses the issue of TC spinup by developing a dynamically based classification scheme built on a diagnosis of North Atlantic hurricanes between 1948 and 2004. A pair of metrics is presented that describes TC development from the perspective of external forcings in the local environment. These discriminants are indicative of quasigeostrophic forcing for ascent and lower-level baroclinicity and are computed for the 36 h leading up to TC initiation. A latent trajectory model is used to classify the evolution of the metrics for 496 storms, and a physical synthesis of the results yields six identifiable categories of tropical cyclogenesis events. The nonbaroclinic category accounts for 40% of Atlantic TCs, while events displaying perturbations from this archetype make up the remaining 60% of storms. A geographical clustering of the groups suggests that the classification scheme is identifying fundamentally different categories of tropical cyclogenesis. Moreover, significant differences between the postinitiation attributes of the classes indicate that the evolution of TCs may be sensitive to the pathway taken during development.

Davis, C., S. C. Jones, M. Riemer, 2008: Hurricane vortex dynamics during Atlantic extratropical transition. J. Atmos. Sci., 65, 714-736, doi: 10.1175/2007JAS2488.1.

ABSTRACT

Simulations of six Atlantic hurricanes are diagnosed to understand the behavior of realistic vortices in varying environments during the process of extratropical transition (ET). The simulations were performed in real time using the Advanced Research Weather Research and Forecasting (WRF) model (ARW), using a moving, storm-centered nest of either 4- or 1.33-km grid spacing. The six simulations, ranging from 45 to 96 h in length, provide realistic evolution of asymmetric precipitation structures, implying control by the synoptic scale, primarily through the vertical wind shear.

The authors find that, as expected, the magnitude of the vortex tilt increases with increasing shear, but it is not until the shear approaches 20 m s-1 that the total vortex circulation decreases. Furthermore, the total vertical mass flux is proportional to the shear for shears less than about 20–25 m s-1, and therefore maximizes, not in the tropical phase, but rather during ET. This has important implications for predicting hurricane-induced perturbations of the midlatitude jet and its consequences on downstream predictability.

Hurricane vortices in the sample resist shear by either adjusting their vertical structure through precession (Helene 2006), forming an entirely new center (Irene 2005), or rapidly developing into a baroclinic cyclone in the presence of a favorable upper-tropospheric disturbance (Maria 2005). Vortex resiliency is found to have a substantial diabatic contribution whereby vertical tilt is reduced through reduction of the primary vortex asymmetry induced by the shear. If the shear and tilt are so large that upshear subsidence overwhelms the symmetric vertical circulation of the hurricane, latent heating and precipitation will occur to the left of the tilt vector and slow precession. Such was apparent during Wilma (2005).

Riemer, M., S. C. Jones, C. A. Davis, 2008: The impact of extratropical transition on the downstream flow: an idealized modelling study with a straight jet. Quart. J. Roy. Meteor. Soc., 134, 69-91, doi: 10.1002/qj.189.

Abstract

The interaction of a tropical cyclone undergoing extratropical transition (ET) with the midlatitude synoptic-scale flow is investigated using full-physics numerical experiments with idealized initial conditions. The emphasis is on the impact on the midlatitude flow downstream of the ET event. The midlatitude flow is represented by a balanced straight jet stream. As the tropical cyclone approaches the jet, a ridge-trough couplet and a distinct jet streak form in the upper-level flow. A midlatitude cyclone develops rapidly downstream of the ET system and the further evolution is characterized by downstream baroclinic development.

Based on Hovmöller diagrams, the upper-level development is interpreted as the excitation and subsequent dispersion of a Rossby wave train on the potential vorticity gradient associated with the jet. The characteristics of this wave train are sensitive to the structure of the jet and to moist processes in the midlatitudes. The tropical cyclone undergoing ET acts as a sustained forcing for the wave train and the structure of the ET system impacts the development most significantly one to two wavelengths downstream of ET.
Piecewise inversion of potential vorticity, complemented by the partitioning of the flow into its rotational and divergent parts, is applied to assess the impact of the ET system quantitatively. Both the cyclonic circulation and the outflow of the tropical cyclone are important contributors to the formation and amplification of the ridge-trough couplet. The outflow anomaly reduces the eastward motion of the ridge-trough couplet significantly and thus promotes phase-locking between the tropical cyclone and the upper-level pattern.

Liu, Y., T. T. Warner, E. G. Astling, J. F. Bowers, C. A. Davis, S. F. Halvorson, D. L. Rife, R.-S. Sheu, S. P. Swerdlin, M. Xu, 2008: The operational mesogamma-scale analysis and forecast system of the U.S. Army Test and Evaluation Command. Part 2: Inter-range comparison of the accuracy of model analyses and forecasts. J. Appl. Meteor. Climat., 47, 1093-1104.

Trenberth, K. E., C. A. Davis, J. Fasullo, 2007: Water and energy budgets of hurricanes: Case studies of Ivan and Katrina. J. Geophys. Res., 112, D23106, doi: 10.1029/2006JD008303.

Abstract

To explore the role of hurricanes in the climate system, a detailed analysis is made of the bulk atmospheric moisture budget of Ivan in September 2004 and Katrina in August 2005 from simulations with the Weather and Research Forecasting (WRF) model at 4 km resolution without parameterized convection. Heavy precipitation exceeding 20 mm h-1 in the storms greatly exceeds the surface flux of moisture through evaporation, and vertically integrated convergence of moisture in the lowest 1 km of the atmosphere from distances up to 1600 km is the dominant term in the moisture budget, highlighting the importance of the larger-scale environment. Simulations are also run for the Katrina case with sea surface temperatures (SSTs) increased by +1°C and decreased by -1°C as sensitivity studies. For hours 42 to 54 after the start of the simulation, maximum surface winds increased about 4.5 m s-1 (9%), and sea level pressure fell 11.5 hPa per 1°C increase in tropical SSTs. Overall, the hurricane expands in size as SSTs increase, the environmental atmospheric moisture increases at close to the Clausius-Clapeyron equation value of about 6% K-1 and the surface moisture flux also increases mainly from Clausius-Clapeyron effects and the changes in intensity of the storm. The environmental changes related to human influences on climate since 1970 have increased

SSTs and water vapor, and the results suggest how this may have altered hurricanes and increased associated storm rainfalls, with the latter quantified to date to be of order 6 to 8%.

MMM Research Catalog

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Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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CHRIS DAVIS

General Information

MMM - TIIMES
Senior Scientist
Water System

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Telephone: 303-497-8990
Email: cdavis@ucar.edu
Home Page - Vita

Research Focus FY08:

If it is mesoscale and it rotates, I am interested in it. This includes hurricanes, but also mesoscale convective systems with rotation. I am especially intruiged by the interplay between high frequency convective motions and low frequency rotational structures. I also am interested in how models simulate these behaviors. Moreover, I am pursuing new ways to evaluate mesoscale models for a variety of problems.

2008 UCAR Mentoring Award: Congratulations to CHRIS DAVIS

Awarded for mentoring efforts that have influenced and motivated numerous graduate students, postdoctoral researchers, and junior scientists - 2008 Outstanding Accomplishment Awards

Community Service FY08:

- Adjunct Professor: North Carolina State University
- Adjunct Professor: Colorado State University
- Adjunct Professor: Texas A&M University
- Graduator Advisor & Thesis Committee: Kate Musgrave (Colorado State University)
- Thesis Committee: Eric Hendricks (Colorado State University, graduated summer 2008)
- Thesis Committee: Gareth Berry (University at Albany, SUNY)
- Thesis Committee: Thomas Galarneau (University at Albany, SUNY)

Publications FY08 (abstracts):

Musgrave, K. D., C. A. Davis, M. T. Montgomery, 2008: Numerical simulations of the formation of Hurricane Gabrielle (2001). *Mon. Wea. Rev.*, **136**, 3151-3167, doi: 10.1175/2007MWR2110.1.

Trier, S. B., F. Chen, K. W. Manning, M. A. Lemone, C. A. Davis, 2008: Sensitivity of the PBL and precipitation in 12-day simulations of warm-season convection using different land surface models and soil wetness conditions. *Mon. Wea. Rev.*, **136**, 2321-2343, doi: 10.1175/2007MWR2289.1.

Davis, C. A., C. S. Snyder, A. C. Didlake, 2008: A vortex-based perspective of eastern Pacific tropical cyclone formation. *Mon. Wea. Rev.*, **136**, 2461-2477, doi: 10.1175/2007MWR2319.1.

Weisman, M. L., C. A. Davis, W. Wang, K. Manning, 2008: Experiences with 0-36h explicit convective forecasts with the WRF-ARW model. *Wea. Forecasting*, **23**, 407-437, doi: 10.1175/2007WAF2007005.1.

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. *Mon. Wea. Rev.*, **136**, 1990-2005, doi: 10.1175/2007MWR2085.1.

Liu, Y., T. T. Warner, J. F. Bowers, L. Carson, F. Chen, C. A. Clough, C. A. Davis, C. H. Egeland, C. Halvorson, T. W. Huck, L.

Lachapelle, R. E. Malone, D. L. Rife, R.-S. Sheu, S. P. Swerdlin, D. S. Weingarten, 2008: The operational mesogamma-scale analysis and forecast system of the U.S. Army Test and Evaluation Command. Part 1: Overview of the modeling system, the forecast products. *J. Appl. Meteor. Climat.*, **47**, 1077-1093.

McTaggart-Cowan, R., G. D. Deane, L. F. Bosart, C. A. Davis, T. J. Galarneau, 2008: Climatology of tropical cyclogenesis in the North Atlantic. *Mon. Wea. Rev.*, **136**, 1284-1304.

Davis, C., S. C. Jones, M. Riemer, 2008: Hurricane vortex dynamics during Atlantic extratropical transition. *J. Atmos. Sci.*, **65**, 714-736, doi: 10.1175/2007JAS2488.1.

Riemer, M., S. C. Jones, C. A. Davis, 2008: The impact of extratropical transition on the downstream flow: an idealized modelling study with a straight jet. *Quart. J. Roy. Meteor. Soc.*, **134**, 69-91, doi: 10.1002/qj.189.

Liu, Y., T. T. Warner, E. G. Astling, J. F. Bowers, C. A. Davis, S. F. Halvorson, D. L. Rife, R.-S. Sheu, S. P. Swerdlin, M. Xu, 2008: The operational mesogamma-scale analysis and forecast system of the U.S. Army Test and Evaluation Command. Part 2: Inter-range comparison of the accuracy of model analyses and forecasts. *J. Appl. Meteor. Climat.*, **47**, 1093-1104.

Ahijevych, D. A., E. Gilleland, B. G. Brown, E. Ebert, L. Holland, C. A. Davis, 2008: Intercomparison of spatial verification methods. *19th Conf. on Probability and Statistics in the Atmospheric Sciences*, American Meteorological Society, January.

Trenberth, K. E., C. A. Davis, J. Fasullo, 2007: Water and energy budgets of hurricanes: Case studies of Ivan and Katrina. *J. Geophys. Res.*, **112**, D23106, doi: 10.1029/2006JD008303.

Chris Davis Research Catalog

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Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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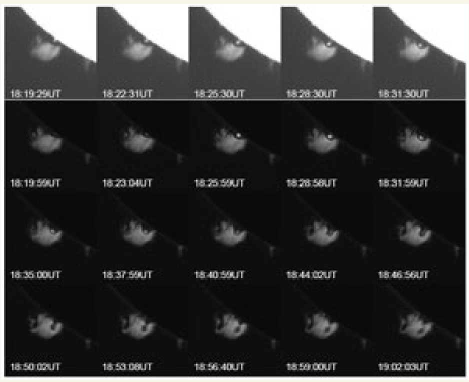
DE TOMA, GIULIANA

Rise of a Dark Bubble Through a Quiescent Prominence

G. de Toma, R. Casini, J. Burkepile, & B.C. Low



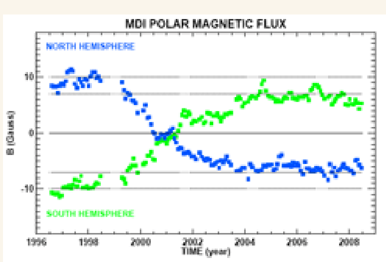
On November 8, 2007, we observed an unusual and dynamic event in a solar quiescent prominence which provides new insights into the physical nature of prominences. A large scale, well-formed dark "bubble" with a bright core rose vertically through a prominence on the SE limb without causing it to erupt. This event was observed in Hα and He I 1083nm with the instruments of the Mauna Loa Solar Observatory. The dark bubble had a size of over ~40 arcsec and moved upward from the prominence base, at an average speed of about 12km/s forming a bright compression front as it traversed the prominence. A compact bright core developed inside the bubble and accelerated from 12km/s to about 20km/s leaving a thin trail of material behind. Finally, the bubble assumed a "keyhole" shape before fading. A second elongated, dark bubble was also seen to rise at the north edge of the prominence almost simultaneously to the first one. These structures moved through the prominence without disrupting it. A similar event, although with a much fainter core, was observed on April 6, 2008. These observations indicates that similar disturbances do occur occasionally in prominences without changing them ignificantly and open questions on the nature and stability of prominences. We interpret the bubbles as well organized, closed magnetic structures where the strong magnetic pressure makes up for the weak plasma pressure. In this scenario, the bubbles are low density regions, with a dense core of compressed plasma, which become unstable and rise buoyantly through the prominence.

Solar cycle 23: Is this a different kind of solar minimum?

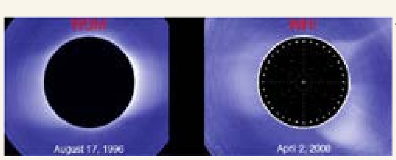
J. Burkepile, G. de Toma & S. Gibson in collaboration with the WHI team

Solar cycle 23 has been a weaker magnetic cycle than cycles 21 and 22. The lower rate of sunspot emergence combined with a slower meridional flow at the surface resulted into a slow polar reversal and a longer than average cycle. We are now observing the slow decline of the cycle into its minimum phase.

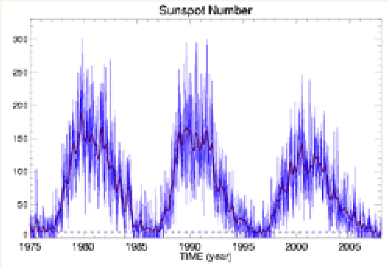
At present, the total magnetic flux on the Sun, the Sunspot Number and various solar acitvity indices, like F10.7, are comparable to the values observed during the previous solar minima, indicating we are in the minimum phase but have we reached the absolute minimum in magnetic activity? There were a few new-cycle spots on the Sun between January 2007 and September 2008 but the new cycle activity has been sparse and weak and we still have not seen the rise of cycle 24. This makes cycle 23 a long cycle of 12 years or more.



This solar minimum differs from the two previous ones in many ways. In particular, the polar fields are the weakest ever observed, about 30-40% less than in cycle 22 and 21. The weak poles combined with the presence of some old cycle activity at low latitudes give a more complex morphology to the solar corona which at present does not resemble a simple dipole. Furthermore, the polar coronal holes are smaller than in 1996 and there are several low-latitude coronal holes of significant size which are important sources of fast solar wind at the Earth.



The global magnetic field of the Sun now differs significantly from the one observed in 1996 when the open magnetic flux was originating mostly from the polar coronal holes and their equatorward extensions. The observed coronal morphology and variability in the solar wind are consistent with the complex, tilted shape of the heliospheric current sheet that is still observed in September 2008 vs. the simplest, flat current sheet observed in 1996 during the last minimum.



The differences between the minima in 1996 and 2008 have significant implications for the geospace and show that solar minima can differ in many ways even if the sunspot activity level is the same. To understand these differences during quiet times is one of the main goals of the WHI campaign.

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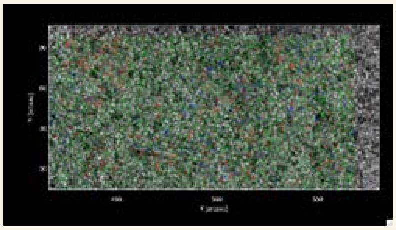
DE WIJN, ALFRED

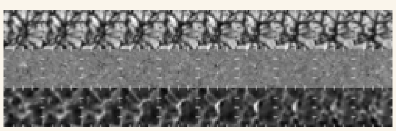
The relationship between locations of strong magnetic flux and mesogranulation



The sun's magnetic field organizes itself in ubiquitous "magnetic elements" in the solar photosphere. These elements are not uniformly distributed in the photosphere, but rather appear to form clusters, and outline cell-like structures on scales of several arcsec. Previous research has shown that they are highly dynamic and interact frequently. Also, it is now clear that they are not discrete structures, as the term "element" implies, but rather they are small-scale concentrations of flux. While it is widely assumed that magnetic elements are advected by gas flows, it is hard to verify because it is difficult to accurately measure horizontal flows on small scales in the photosphere. The cell-like pattern that the magnetic elements form on mesogranular scales suggests strongly that the locations of magnetic elements map the borders of mesogranular cells, in the same way that the magnetic network maps the borders of supergranular cells. In collaboration with Daniel Müller (ESA, NASA Goddard Space Flight Center), I have undertaken a study of the relationship between the positions of small concentrations of strong field and mesogranular cells. The latter must be defined from the tracking of granules in intensity images, while the former are derived from magnetograms.

Figure caption: *This figure shows a sample Fe I intensity image, with the locations of "corks" advected by the derived flow field overplotted as green dots. Locations of field concentrations are marked by red diamonds for positive polarity, and blue diamonds for negative polarity. The field concentrations appear to favor locations of high cork density.*

Interactions between reversed granulation, p-modes, and low-lying loops



Ca II H sequences from the Hinode telescope show many places where structures that resemble reversed granulation interact with p-modes. These features appear ubiquitously in the quiet sun. The locations are co-spatial with reversed granulation, i.e., above intergranular lanes in the photosphere, and the structures also display similar general properties, but have sharper edges and show faster brightness change. They also appear predominantly above wide intergranular lanes, indicating a potential connection with magnetic field. Such a connection must be verified using data sequences that incorporate a measurement of at least the line-of-sight field. If indeed such a connection exists, it could provide an excellent conduit to channel kinetic energy in the form of waves from the photosphere into the low chromopshere. These waves are expected to form shocks and dissipate, thus heating the chromosphere.

Figure caption: *This figure shows a sample event. The top row shows the photosphere. The bottom row shows the Ca II H intensity. In the middle row, a filter has been applied to the Ca II H intensity to extract the feature more clearly. Tick marks are every 1.74 arcsec (1.3 Mm). Time progresses from left to right, in steps of approximately 19 s. The arc-like structure is located above an intergranular lane that is wide and shows broken-up granulation, both strong indications of the presence of magnetic field. Less well-visible is the interaction of the structure with a p-mode. In movies of these events, such interactions are clearly visible in the Ca II H passband.*

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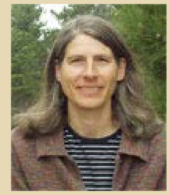
CGD 2008 PROFILES IN SCIENCE: DR. CLARA DESER

Summary of achievements



Clara Deser

Research published in 2008 covers a range of topics, from Arctic sea ice loss (Lawrence et al., and Deser and Teng) to diurnal variability (Ueyama and Deser, and Zeng et al.) to decadal variability in the northeast Pacific (Alexander et al.). These disparate projects reflect my interest in understanding a wide range of climate signals. The papers on Arctic sea ice loss examine the implications of future ice retreat for terrestrial land temperatures and permafrost degradation from a modeling perspective (Lawrence et al.), and the role of atmospheric circulation trends on the accelerating loss of Arctic sea ice over the past 30 years (Deser and Teng). The papers on diurnal variability use newly available observations to document with improved accuracy the vertical profile of the migrating atmospheric diurnal tide from COSMIC data (Zeng et al.) and the spatial distribution of diurnal and semidiurnal surface wind variations using data from the Tropical Atmosphere-Ocean (TAO) moored buoy array. The study on the role of the ocean mixed layer upon ecosystem variability in the northeast Pacific (Alexander et al.) extends previous work on the physical climate system to marine ecosystem impacts.

Publications

Deser, C., and H. Teng, 2008: Evolution of Arctic sea ice concentration trends and the role of atmospheric circulation forcing. 1979-2007, Geophys. Res. Lett., 35, L02504, doi:10.1029/2007GL032023.

Abstract: The retreat of Arctic sea ice in recent decades is a pre-eminent signal of climate change. What role has the atmospheric circulation played in driving the sea ice decline? To address this question, we document the evolution of Arctic sea ice concentration trends during the period January 1979-April 2007 in light of changing atmospheric circulation conditions, in particular an upward trend in the wintertime Northern Annular Mode during the first half of the record and a downward trend during the second half. The results indicate that concurrent atmospheric circulation trends contribute to forcing winter and summer sea ice concentration trends in many parts of the marginal ice zone during both periods. However, there is also an emerging signal of overall Arctic sea ice decline since 1979 in both winter and summer that is not directly attributable to a trend in the overlying atmospheric circulation.

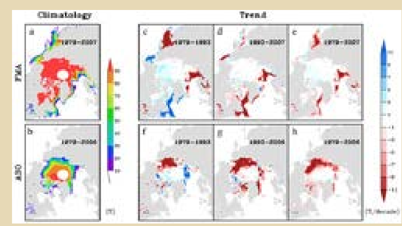


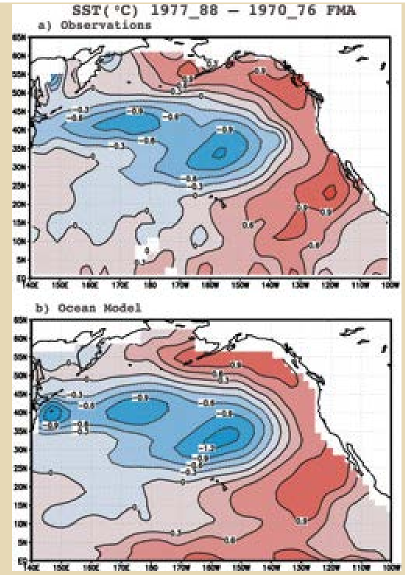
Figure 1.

High resolution figure

Figure caption: (left) Long-term mean sea ice concentrations (%) for (a) winter (February-April) and (b) summer (August-October) based on the period January 1979 - April 2007. The white ellipse around the North Pole indicates missing data. (right) (c)-(e) Winter and(f)-(h) summer sea ice concentration trends (% per decade) during 1979-1993 (Figures 1c and 1f), 1993-2007 (Figures 1d and 1g) and 1979-2007 (Figure 1e and 1h). Note that 2006 is the last year of data in summer.

Alexander, M., A. Capotondi, A. Miller, F. Chai, R. Brodeur, and C. Deser, 2008: Decadal variability in the northeast Pacific in a physical-ecosystem model: Role of mixed layer depth and trophic interactions. J. Geophys. Res., 113, C02017, doi:10.1029/2007JC004359.

Abstract: A basin-wide interdecadal change in both the physical state and the ecology of the North Pacific occurred near the end of 1976. Here we use a physical-ecosystem model to examine whether changes in the physical environment associated with the 1976-1977 transition influenced the lower trophic levels of the food web and if so by what means. The physical component is an ocean general circulation model, while the biological component contains 10 compartments: two phytoplankton, two zooplankton, two detritus pools, nitrate, ammonium, silicate, and carbon dioxide. The model is forced with observed atmospheric fields during 1960-1999. During spring, there is a ~40% reduction in plankton biomass in all four plankton groups during 1977-1988 relative to 1970-1976 in the central Gulf of Alaska (GOA). The epoch difference in plankton appears to be controlled by the mixed layer depth. Enhanced Ekman pumping after 1976 caused the halocline to shoal, and thus the mixed layer depth, which extends to



the top of the halocline in late winter, did not penetrate as deep in the central GOA. As a result, more phytoplankton remained in the euphotic zone, and phytoplankton biomass began to increase earlier in the year after the 1976 transition. Zooplankton biomass also increased, but then grazing pressure led to a strong decrease in phytoplankton by April followed by a drop in zooplankton by May: Essentially, the mean seasonal cycle of plankton biomass was shifted earlier in the year. As the seasonal cycle progressed, the difference in plankton concentrations between epochs reversed sign again, leading to slightly greater zooplankton biomass during summer in the later epoch.

Figure caption: Epoch difference, 1977-1988 minus 1970-1976 (Δ), in SST (°C) during February, March, and April (FMA) from (a) observations and (b) the model simulation. The observed values are from COADS.

Figure 2.

High resolution figure

Lawrence, D. M., A. G. Slater, R. A. Tomas, M. M. Holland, and C. Deser, 2008: Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. Geophys. Res. Lett., 35, L11506, doi:10.1029/2008GL033985.

Abstract: Coupled climate models and recent observational evidence suggest that Arctic sea ice may undergo abrupt periods of loss during the next fifty years. Here, we evaluate how rapid sea ice loss affects terrestrial Arctic climate and ground thermal state in the Community Climate System Model. We find that simulated western Arctic land warming trends during rapid sea ice loss are 3.5 times greater than secular 21st century climate-change trends. The accelerated warming signal penetrates up to 1500 km inland and is apparent throughout most of the year, peaking in autumn. Idealized experiments using the Community Land Model, with improved permafrost dynamics, indicate that an accelerated warming period substantially increases ground heat accumulation. Enhanced heat accumulation leads to rapid degradation of warm permafrost and may increase the vulnerability of colder permafrost to degradation under continued warming. Taken together, these results imply a link between rapid sea ice loss and permafrost health.

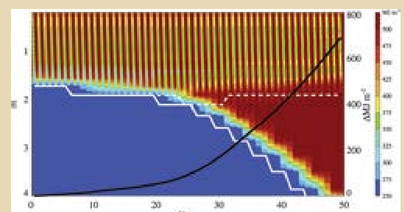


Figure 3.

High resolution figure

Figure caption: Time series of depth of warming (white solid line) and cooling (white dashed line) fronts from LINEAR experiment for warm permafrost case. Contours indicate SHC. Change in SHC is shown as black line.

Ueyama, R., and C. Deser, 2008: A Climatology of Diurnal and Semidiurnal Surface Wind Variations over the Tropical Pacific Ocean Based on the Tropical Atmosphere Ocean Moored Buoy Array. J. Climate, 21, 593-607.

Abstract: Hourly measurements from 51 moored buoys in the Tropical Atmosphere Ocean array (9°N-8°S, 165°E-95°W) during 1993-2004 are used to document the climatological seasonal and annual mean patterns of diurnal and semidiurnal near-surface wind variability over the tropical Pacific Ocean. In all seasons, the amplitude of the semidiurnal harmonic is approximately twice as large as the diurnal harmonic for the zonal wind component, while the diurnal harmonic is at least 3 times as large as the semidiurnal harmonic for the meridional wind component, both averaged across the buoy array. Except for the eastern equatorial Pacific, the semidiurnal zonal wind harmonic exhibits uniform amplitude (~0.14 m s^{-1}) and phase [maximum westerly wind anomalies ~0325/1525 local time (LT)] across the basin in all seasons. This pattern is well explained by atmospheric thermal tidal theory. The semidiurnal zonal wind signal is diminished over the cold surface waters of the eastern equatorial Pacific where it is associated with enhanced boundary layer stability. Diurnal meridional wind variations tend to be out of phase north and south of the equator (maximum southerly wind anomalies ~0700 LT at 5°N and ~1900 LT at 5°S), while a noon southerly wind anomaly maximum is observed on the equator in the eastern Pacific particularly during the cold season (June-November). The diurnal

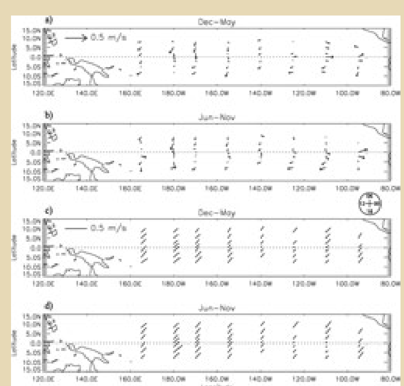


Figure 4.

High resolution figure

meridional wind variations result in enhanced divergence along the equator and convergence along the southern border of the intertropical convergence zone ~0700 LT (opposite conditions ~1900 LT); the amplitude of the divergence diurnal cycle is ~5 × 10^{-7} s^{-1}. The diurnal meridional wind variations are largely consistent with the diurnal pressure gradient force.

Figure caption: December-May and June-November amplitudes and phases of the (a), (b) diurnal and (c), (d) semidiurnal harmonics of the zonal wind. The length of each vector represents amplitude of the corresponding harmonic [scales at top-left corners of (a) and (c)] and the direction represents the LT of maximum westerly wind anomaly (clock at middle right).

Zeng, Z., W. Randel, S. Sokolovskiy, C. Deser, Y.-H. Kuo, M. Hagan, J. Du, and W. Ward, 2008: Detection of migrating diurnal tide in the tropical upper troposphere and lower stratosphere using the Challenging Minisatellite Payload radio occultation data. J. Geophys. Res., 113, D03102, doi:10.1029/2007JD008725.

Abstract: The atmospheric limb sounding technique making use of radio signals transmitted by the Global Positioning System (GPS) has already proven to be a promising approach for global atmospheric measurements. In this study, we assess for the first time the potential of GPS radio occultation soundings for detecting the migrating diurnal tide. Retrieved temperatures between 10 and 30 km in the tropics from the Challenging Minisatellite Payload (CHAMP) occultation observations during May 2001 to August 2005 are analyzed using space-time spectrum analysis to isolate diurnal waves. Because of incomplete local time (LT) coverage of the monthly CHAMP occultation data in any given year, data from all available years are merged to obtain complete 24-h LT coverage. The effects of aliasing associated with uneven data sampling and measurement noise are estimated using synthetic data. The results show the feasibility of determining tidal structures from the composite CHAMP occultation data, and the vertical, seasonal, and latitudinal structures of the diurnal tide are presented. The estimated diurnal amplitude generally increases with altitude, exhibiting a maximum of order 1 K at 30 km. The estimated phase indicates an upward propagating mode above 14 km with a vertical wavelength about 20 km. The observed diurnal tide at 30 km exhibits a distinct seasonal-latitudinal variation. Comparison of the observed diurnal tide to the simulated tide in the extended Canadian Middle Atmosphere Model (CMAM) and Global-Scale Wave Model Version 2 (GSWM02) indicates that CMAM overestimates the amplitude but reproduces the seasonal-latitudinal variation of the diurnal tide while GSWM02 simulates well the annual mean amplitude but lacks the seasonal-latitudinal variation of the diurnal tide.

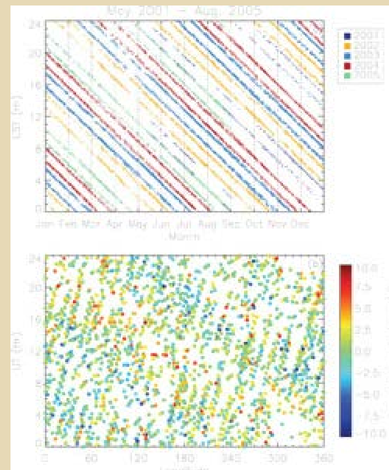


Figure 5.

High resolution figure

Figure caption: (a) Distribution of CHAMP RO soundings between 5°S and 5°N in the coordinates of local solar time (LT) and month. Different colors correspond to different years as indicated. (b) Distribution of CHAMP RO residual temperatures (K) at 30 km for 90-d composite data centered at 15 January between 5°S and 5°N in longitude and UT coordinates.

CGD Research Catalog

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Table of Contents

Strategic Goals: Science, Facilities & Technology

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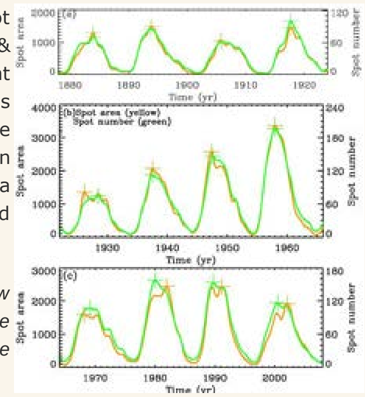
DIKPATI, MAUSUMI

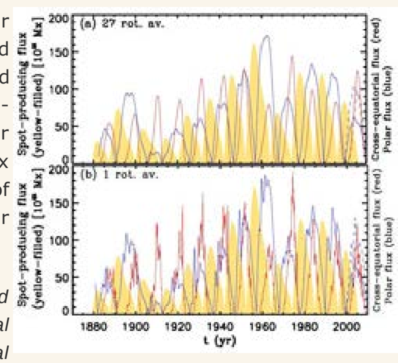
The Waldmeier effect: an artifact of definition of Wolf sunspot number?



The well-known 'Waldmeier effect'is the anti-correlation between the peak in sunspot number of a cycle, and the time from minimum to reach that peak. We (Dikpati, Gilman & de Toma, 2008, *ApJ*, **673**, L99-L101) have shown that the Waldmeier effect is not present in the sunspot area data. Hathaway et al. previously showed that the Waldmeier effect is much weaker (r = -0.34) in sunspot group number. Thus the Waldmeier effect may be specific to only the Wolf sunspot number. Given the near coincidence of solar minima in the two data sets, the main differences in rise-time of spot number data and spot area data occur from the differences in timing of maxima (see the positions of the green and yellow crosses in Figure 1).

Figure 1: *Comparison of Zürich sunspot number (green curves) and sunspot area (yellow curves, in millionths of the visible hemisphere) for cycles 12-23. Colored crosses denote the amplitude and time of cycle maxima for each type of data. To place the curves on the same scale, we multiply the y-axis for sunspot number by 16.5.*

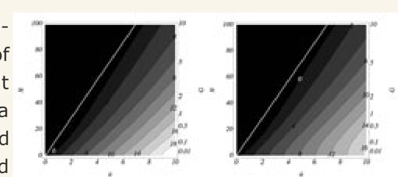
Polar flux, cross-equatorial flux and dynamo-generated tachocline toroidal flux as predictors of solar cycles



On the verge of upcoming solar cycle 24, three solar cycle predictors, namely polar magnetic flux, flux crossing the equator and tachocline toroidal flux, have received attention. We (Dikpati, de Toma & Gilman, 2008, ApJ, 675, 920-930) have evaluated the skill of these three predictors using observations as well as a calibrated flux-transport dynamo model. We have shown in the context of a flux-transport solar dynamo that the (n-1)th cycle's tachocline toroidal flux and the (n-1)th cycle's flux crossing the equator can be good predictors for nth cycle's peak, but the polar flux of (n-1)th cycle poorly correlates with nth cycle peak. In flux-transport dynamos, polar flux is the follower of a cycle rather than being precursor to it (see Figure 2).

Figure 2: *Comparison of simulated polar flux (blue curves), cross-equatorial flux (red curves), and spot-producing toroidal flux integral (yellow shading) for surface poloidal flux input data averaged over (a) 27 rotations, and (b) 1 rotation. The meridional circulation used varies according to observations since 1995 (steady flow case is shown in dashed curves). Note particularly how much short term variability remains in the 1 rotation average case in the cross-equatorial and polar fluxes, compared to the spot producing toroidal flux integral. Also note that the slow-down in the flow during 1995-2005 causes an increase in the cross-equatorial flux (solid red curve has a higher peak than dashed red curve), but the same slow-down in that flow causes a decrease in the polar flux (solid blue curve has a smaller peak than a dashed blue curve).*

Axisymmetric instabilities in solar/stellar tachocline



Over the past decade extensive studies have shown that HD and MHD non-axisymmetric instabilities should occur in the solar tachocline for a wide range of toroidal field profiles, amplitudes and latitude locations. It has been shown that axisymmetric instabilities (m=0) do not exist in 2D, and they barely get excited in a quasi-3D shallow-water system, only for a very high field strength of the toroidal band (2 million Gauss). We (Dikpati, Cally, Gilman & Miesch, 2008, ApJ, to be submitted shortly; Cally, Dikpati & Gilman, MNRAS, 2008, accepted), have investigated MHD axisymmetric instabilities using a 3D thin-shell model of the solar/stellar tachocline, employing two possible approaches, namely a hydrostatic, non-Boussinesq system and a non-hydrostatic Boussinesq system. We find that the two approaches produce similar results which are basically the same (see Figure 3), except when the effective gravity G=0. The toroidal bands become unstable to axisymmetric perturbations for solar-like field strengths (100 kG). The e-folding time can be months or even a few hours if the field strength is a million

Gauss or higher, which might occur in the solar core, white dwarf or neutron stars. These instabilities exist without rotation, with rotation and with differential rotation, although the differential rotation has a stabilizing effect. Broad toroidal fields are stable. The onset of an m=0 instability occurs from poleward shoulder of banded profiles. The non-axisymmetric instability tips or deforms a band; however as a consequence of axisymmetric instability, the fluid can roll in latitude and radius, and can break up bands in radial direction. The velocity produced by this instability in the case of low-latitude bands crosses the equator and hence can provide a mechanism for hemispheric coupling.

Figure 3: *Growth rate contours in the G-a plane for hydrostatic-non-Boussinesq system (left) and non-hydrostatic-Boussinesq system (right) for a 10° toroidal band at 30° latitude.*

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JIMY DUDHIA

2008 Publications

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. Mon. Wea. Rev., 136, 1990-2005, doi: 10.1175/2007MWR2085.1.

ABSTRACT

Real-time forecasts of five landfalling Atlantic hurricanes during 2005 using the Advanced Research Weather Research and Forecasting (WRF) (ARW) Model at grid spacings of 12 and 4 km revealed performance generally competitive with, and occasionally superior to, other operational forecasts for storm position and intensity. Recurring errors include 1) excessive intensification prior to landfall, 2) insufficient momentum exchange with the surface, and 3) inability to capture rapid intensification when observed. To address these errors several augmentations of the basic community model have been designed and tested as part of what is termed the Advanced Hurricane WRF (AHW) model. Based on sensitivity simulations of Katrina, the inner-core structure, particularly the size of the eye, was found to be sensitive to model resolution and surface momentum exchange. The forecast of rapid intensification and the structure of convective bands in Katrina were not significantly improved until the grid spacing approached 1 km. Coupling the atmospheric model to a columnar, mixed layer ocean model eliminated much of the erroneous intensification of Katrina prior to landfall noted in the real-time forecast.

Chen, S.-H., J. Dudhia, J. S. Kain, T. Kindap, E. Tan, 2008: Development of the online MM5 tracer model and its applications to air pollution episodes in Istanbul, Turkey and Sahara dust transport. J. Geophys. Res., 113, doi: 10.1029/2007JD009244.

Abstract

An online tracer model, based on the fifth-generation Penn State/NCAR Mesoscale model, was developed. The new model includes full representation of processes for advection, boundary layer mixing, subgrid cumulus convective mixing, and sedimentation of tracers. The model was used in two very different applications to document its potential utility. The first application involves pollutant transport to Istanbul, Turkey, focusing on two high-pollution episodes in January 2002. To better maintain large scale features, model simulations were nudged to reanalysis for this application. Using a semi-idealized approach, it was shown that much of the pollution that affected Istanbul during these events may have come from other highly polluted cities located upstream, rather than just local emission sources. Pollutants from upstream sources were trapped in the boundary layer by statically stable low-level conditions and efficient transport to Istanbul was supported by strong northwesterly flow near the surface. The second application involves the transport of dust from the Sahara Desert to the Atlantic Ocean, and the potential role of this dust and the dry, warm Saharan Air Layer (SAL) in the genesis and development of Tropical Storm Chantal in 2001. No nudging was applied to this case study since it may degrade small scale features, which were important to dust saltation. The dust uplifting and transport during the earlier period of Chantal's life cycle were simulated to show a potential link between Sahara dust and Chantal's evolution. Results show strong evidence that Chantal started interacting with SAL and dust at a very early stage of storm development after propagating into the eastern Atlantic Ocean. Moreover, it was found that the peak of the averaged surface dust flux occurred in the early morning right before the mixed boundary layer developed, and the mechanism of dust uptake for this event, nocturnal low-level jets, was different from those previously documented.

Klemp, J. B., W. C. Skamarock, J. Dudhia, 2007: Conservative split-explicit time integration methods for the compressible nonhydrostatic equations. Mon. Wea. Rev., 135, 2897-2913, doi: 10.1175/MWR3440.1.

ABSTRACT

Historically, time-split schemes for numerically integrating the nonhydrostatic compressible equations of motion have not formally conserved mass and other first-order flux quantities. In this paper, split-explicit integration techniques are developed that numerically conserve these properties by integrating prognostic equations for conserved quantities represented in flux form. These procedures are presented for both terrain-following height and hydrostatic pressure (mass) vertical coordinates, two potentially attractive frameworks for which the equation sets and integration techniques differ significantly. For each set of equations, the linear dispersion equation for acoustic/gravity waves is derived and analyzed to determine which terms must be solved in the small (acoustic) time steps and how these terms are represented in the time integration to achieve stability. Efficient techniques for including numerical filters for acoustic and external modes are also presented. Simulations for several idealized test cases in both the height and mass coordinates are presented to demonstrate that these integration techniques appear robust over a wide range of scales, from subcloud to synoptic.

Das, S., R. Ashrit, M. W. Moncrieff, M. Dasgupta, J. Dudhia, C. Liu, S. R. Kalsi, 2007: Simulation of intense organized convective precipitation observed during the Arabian Sea Monsoon Experiment (ARMEX). J. Geophys. Res. - Atmos., 112, D20117, doi: 10.1029/2006JD007627.

Abstract

We examine a deep precipitating system that formed over the west coast of India during 26–28 June 2002 producing heavy rainfall of 2–61 cm day-1. The system developed into a well-marked low pressure area due to interaction between an eastward moving westerly trough and a westward moving monsoon low. We used the PSU/NCAR Mesoscale Model (MM5) to make 10-day interactively nested simulations at 90, 30, and 10 km grid-resolutions. We used observations from a special data set collected during an Arabian Sea Monsoon Experiment (ARMEX) conducted June–August, 2002. Nudging the observations produced a balanced atmosphere which, in turn, matched the location of vortex with cloud clusters observed from satellite. The simulated rainfall corresponded well with observations. We then use the simulated fields as forcing and boundary conditions for MM5 run in cloud-system resolving mode at 2 km grid-resolution to detail cloud-clusters embedded within the monsoon disturbance. We examined the sensitivity to different physical parameterizations and also the effect of continuous nudging four dimensional data assimilation (FDDA) on the rainfall forecasts. While the simulation of the convective event improved with certain combinations of physical parameterizations, the rainfall was not forecasted at the correct location, no matter which parameterization was used, unless continuous FDDA was performed in all domains throughout the integrations. Finally, cloud-cluster properties of the cloud-system resolving simulations were compared with observations.

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Table of Contents

Strategic Goals: Science, Facilities & Technology

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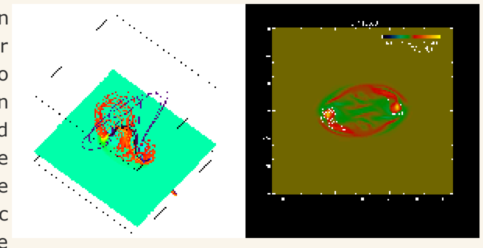
FAN, YUHONG

Simulations Of Magnetic Flux Emergence



The formation of twisted magnetic flux ropes in the solar corona which contain free magnetic energy and drives solar eruptions has its origin in the solar interior through the emergence of twisted active region magnetic flux. To understand the origin of CME precursor structures in the solar corona, Y. Fan is carrying out 3D MHD simulations of the dynamic emergence of a twisted magnetic flux tube from the top layer of the solar convection zone into the solar atmosphere and the corona. The goal is to investigate how the emergence, the resulting photospheric evolution, and the coronal magnetic field depend on the properties of the subsurface emerging tube. The simulations show that it is difficult for a twisted flux tube to emerge bodily into the corona as a whole due to the heavy mass trapped at the bottom concave parts of the twisted field lines. However, we find from the simulations that on the photosphere, after a brief stage of shearing motion during which the two polarities of the bipolar region become separated, significant rotational motion develops within each polarity (Figure 1, right panel), similar to the observed sunspot rotations, which transport a significant amount of twist into the corona. The rotational motions of the two polarities are found to twist up the inner field lines of the emerged fields such that they change their orientation into an inverse configuration (i.e. pointing from the negative polarity to the positive polarity over the neutral line). As a result, a flux rope with sigmoid-shaped dipped core fields forms in the corona (Figure 1, left panel). Sunspot rotation has been observed in many events preceding X-ray sigmoid brightening and the onset of eruptive flares. Our simulations show that such rotational motions take place during flux emergence as a result of the propagation of torsional Alfven waves along the flux tube which transports significant twist from the interior portion towards the expanded coronal portion. These results provide insight into the nature of the observed processes that lead up to solar eruptions.

Figure caption: *The left panel shows the 3D coronal magnetic field resulting from a 3D MHD simulation of the emergence of a twisted magnetic flux tube from the solar interior into the solar atmosphere. A flux rope with sigmoid-shaped, dipped core-fields (as represented by the red field lines) has formed in the corona. Significant rotational motions are present at the footpoints of these field lines at the photosphere as can be seen in the right panel, which shows the distribution of vertical vorticity at the photosphere in the emerging flux region. It shows concentrations of positive vertical vorticity, i.e. counter-clockwise rotational motion, centered at the peaks of the vertical magnetic field (shown as white contours, with solid and dotted contours indicating positive and negative magnetic polarities respectively). The rotational motion of the two polarities is caused by the propagation of torsional Alfvén waves along the flux tube which transport significant twist from the interior portion towards the expanded coronal portion.*

Modeling the subsurface evolution of emerging active region flux tubes

HAO scientist Y. Fan continues 3D modeling of the dynamic evolution of emerging active region flux tubes in the solar interior. Through a set of 3D spherical-shell MHD simulations of the buoyant rise of active region flux tubes in a model solar convective envelope, Fan (2008 ApJ, vol. 676, p.680) puts new constraints on the initial twist of the flux tubes in order for them to emerge with tilt angles consistent with the observed Joy's law of the mean tilt of solar active regions. Due to the asymmetric stretching of the Omega-shaped rising tubes by the Coriolis force, a field strength asymmetry develops with the leading side (leading in the direction of rotation) having a greater field strength and thus being more cohesive compared to the following side (Figure 1). Further analysis found that there is also a significant asymmetry in the twist and the upward helicity flux along the leading and the following legs of the emerging tube. The magnetic field lines in the leading leg show more coherent values of local twist, while the field lines in the following leg are more frayed and show large fluctuations and mixed signs of twist (Figure 2). Also at each height in the upper half of the convection zone, the p-ward helicity flux along the leading leg is significantly greater than that in the following (Figure 3). This may result in an asymmetric helicity flux in an emerging active region between its leading and following polarities, which has been reported in a recent observational study by Tian and Alexander (2008).

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CGD 2008 PROFILES IN SCIENCE: DR. JOHN FASULLO

Summary of achievements

John Fasullo

Over the past year I have been actively engaged in a wide array of collaborative science and community efforts here at NCAR. Foremost I would like to acknowledge the contributions of my collaborators, both here at NCAR (e.g. Kevin Trenberth) and at institutions in the US (Sergio Derada and John Kindle of NRL-Stennis, and Joaquim Goes and Fei Chai at the University of Maine) and abroad (Adnan Al-Azri at Sultan Quaboos University). They have played a key role in these highly synergistic activities.

Our science work is, in large part, directed towards better understanding the moisture and energy budgets of the climate system through satellite, reanalysis, and oceanographic fields. These efforts have led to the publication of multiple manuscripts that build on state of the art observations in documenting a best estimate of the flow of energy thought the climate system. We have recently applied these observations in evaluating the global coupled model simulations submitted to CMIP3 for the IPCC AR4. The goal of this work is to identify the major successes and shortcoming of current models in replicating the energy budget and its variability in order to guide the development of the next generation of coupled climate models. This work is ongoing and holds the prospects for substantially improving the realism of the energy budget in models - a component which serves as the fundamental driver of climate change.

Several ancillary projects have also stemmed from the above efforts. Among them has been the development of observable proxies of climate sensitivity based on processes that are tied strongly to feedbacks in the climate system relevant to climate change. By exploiting such relationships gleaned from the full suite of CMIP3 models, our initial results suggest the prospect of substantially reducing the uncertainty in projected climate sensitivity beyond estimates that can be provided from any single model. In the context of the energy and water budgets, we have also attempted to better understand the potential role of tropical cyclones in the climate system by estimating their cumulative global impact. The results suggest that these storms play an important role in the overall planetary budgets - a role that is marginalized or ignored by current coupled models. Finally, an additional component of out work includes a multi-disciplinary investigation into the influence of climate change in Eurasia on the southwest monsoon and biogeochemical cycles of the Arabian Sea. This project combines the efforts of a team of climate change scientists, monsoon meteorologists, oceanographers, and ecosystem modelers. Our goal is to explicitly model and understand the impact of climate change in the Eurasian and Arabian Sea region on the biogeochemistry and ecosystems of the Arabian Sea and their residual impacts on neighboring fisheries and societies.

Finally, an important component of my community service at NCAR includes roles as both an Editor for Meteorology and Atmospheric Physics and a reviewer of manuscripts and proposals for multiple journals and funding agencies.

Publications

Fasullo, J.T., and K.E. Trenberth, 2008: The Annual Cycle of the Energy Budget. Part I: Global Mean and Land-Ocean Exchanges. J. Climate, 21, 2297-2312.

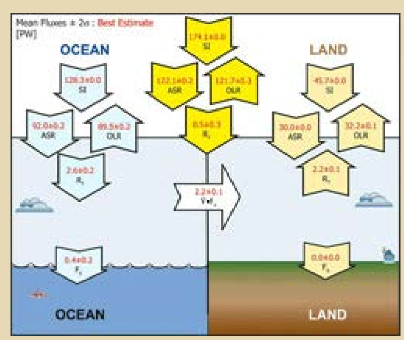


Figure 1.

High resolution figure

Abstract: The mean and annual cycle of energy flowing into the climate system and its storage, release, and transport in the atmosphere, ocean, and land surface are estimated with recent observations. An emphasis is placed on establishing internally consistent quantitative estimates with discussion and assessment of uncertainty. At the top of the atmosphere (TOA), adjusted radiances from the Earth Radiation Budget Experiment (ERBE) and Clouds and the Earth's Radiant Energy System (CERES) are used, while in the atmosphere the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis and 40-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40) estimates are used. The net upward surface flux (F_S) over ocean is derived as the residual of the TOA and atmospheric energy budgets, and is compared with direct calculations of ocean heat content (O_E) and its tendency (dO_E/dt) from several ocean temperature datasets. Over land, F_S from a stand-alone simulation of the Community Land Model forced by observed fields is used. A depiction of the full energy budget based on ERBE fluxes from 1985 to 1989 and CERES fluxes from 2000 to 2004 is constructed that matches estimates of the global, global ocean, and global land imbalances. In addition, the annual cycle of the energy budget during both periods is examined

and compared with ocean heat content changes.

The near balance between the net TOA radiation (R_T) and F_S over ocean and thus with O_E, and between R_T and atmospheric total energy divergence over land, are documented both in the mean and for the annual cycle. However, there is an annual mean transport of energy by the atmosphere from ocean to land regions of 2.2 ± 0.1 PW (1 PW = 10^{15} W) primarily in the northern winter when the transport exceeds 5 PW. The global albedo is dominated by a semiannual cycle over the oceans, but combines with the large annual cycle in solar insolation to produce a peak in absorbed solar and net radiation in February, somewhat after the perihelion, and with the net radiation 4.3 PW higher than the annual mean, as it is enhanced by the annual cycle of outgoing longwave radiation that is dominated by land regions. In situ estimates of the annual variation of OE are found to be unrealistically large. Challenges in diagnosing the interannual variability in the energy budget and its relationship to climate change are identified in the context of the episodic and inconsistent nature of the observations.

Figure caption: CERES-period-mean best-estimate FM1 TOA fluxes (PW) globally and for the (right) global land and (left) global ocean regions.

Fasullo, J.T., and K.E. Trenberth, 2008: The Annual Cycle of the Energy Budget. Part II: Meridional Structures and Poleward Transports. J. Climate, 21, 2313-2325.

Abstract: Meridional structure and transports of energy in the atmosphere, ocean, and land are evaluated holistically for the mean and annual cycle zonal averages over the ocean, land, and global domains, with discussion and assessment of uncertainty. At the top of the atmosphere (TOA), adjusted radiances from the Earth Radiation Budget Experiment (ERBE) and Clouds and Earth's Radiant Energy System (CERES) are used along with estimates of energy storage and transport from two global reanalysis datasets for the atmosphere. Three ocean temperature datasets are used to assess changes in the ocean heat content (OE) and their relationship to the net upward surface energy flux over ocean (FoS), which is derived from the residual of the TOA and atmospheric energy budgets. The surface flux over land is from a stand-alone simulation of the Community Land Model forced by observed fields.

In the extratropics, absorbed solar radiation (ASR) achieves a maximum in summer with peak values near the solstices. Outgoing longwave radiation (OLR) maxima also occur in summer but lag ASR by 1-2 months, consistent with temperature maxima over land. In the tropics, however, OLR relates to high cloud variations and peaks late in the dry monsoon season, while the OLR minima in summer coincide with deep convection in the monsoon trough at the height of the rainy season. Most of the difference between the TOA radiation and atmospheric energy storage tendency is made up by a large heat flux into the ocean in summer and out of the ocean in winter. In the Northern Hemisphere, the transport of energy from ocean to land regions is substantial in winter, and modest in summer. In the Southern Hemisphere extratropics, land - ocean differences play only a small role and the main energy transport by the atmosphere and ocean is poleward. There is reasonably good agreement between FoS and observed changes in OE, except for south of 40°S, where differences among several ocean datasets point to that region as the main source of errors in achieving an overall energy balance. The winter hemisphere atmospheric circulation is the dominant contributor to poleward energy transports outside of the tropics [6-7 PW (1 petawatt = 10^{15} W)], with summer transports being relatively weak (~3 PW)—slightly more in the Southern Hemisphere and slightly less in the Northern Hemisphere. Ocean transports outside of the tropics are found to be small (<2 PW) for all months. Strong cross-equatorial heat transports in the ocean of up to 5 PW exhibit a large annual cycle in phase with poleward atmospheric transports of the winter hemisphere.

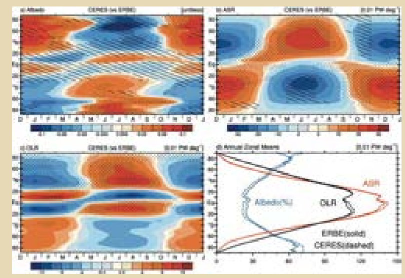


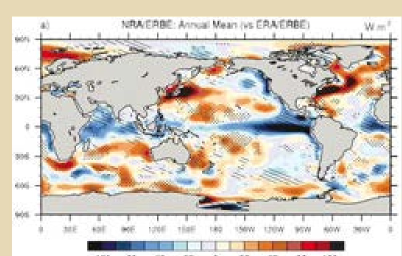
Figure 2.

High resolution figure

Figure caption: Zonal mean departures from the annual mean of (a) albedo (fraction), (b) ASR, and (c) OLR are shown based on CERES retrievals with positive (negative) differences from ERBE fields stippled (hatched) where they exceed ±2σI and ± W m^{-2} (or ±0.02 in the case of albedo). (d) The zonal annual mean terms as a function of latitude. The CERES values are based on averages from March 2000 to May 2004, the CERES period, while ERBE values are based on averages from February 1985 through April 1989, the ERBE period. For ASR and OLR the units are 0.01 PW $(°)^{-1}$.

Trenberth, K.E., and J.T. Fasullo, 2008: An Observational Estimate of Inferred Ocean Energy Divergence. J. Phys. Oceanogr., 38, 984-999.

Abstract: Monthly net surface energy fluxes (F_S) over the oceans are computed as residuals of the atmospheric energy budget using top-of-atmosphere (TOA) net radiation (R_T) and the complete atmospheric energy (A_E) budget tendency ($\delta A_E/\delta t$) and divergence (F_A). The focus is on TOA radiation from the Earth Radiation Budget Experiment (ERBE) (February 1985-April 1989) and the Clouds and Earth's Radiant Energy System (CERES) (March 2000-May 2004) satellite observations combined with results from two atmospheric reanalyses and three ocean datasets that enable a comprehensive estimate of uncertainties. Surface energy flux departures from the annual mean and the implied annual cycle in "equivalent ocean energy content" are compared with the directly observed ocean



energy content (O_E) and tendency ($\delta O_E/\delta t$) to reveal the inferred annual cycle of divergence (F_O). In the extratropics, the surface flux dominates the ocean energy tendency, although it is supplemented by ocean Ekman transports that enhance the annual cycle in ocean heat content. In contrast, in the tropics, ocean dynamics dominate O_E variations throughout the year in association with the annual cycle in surface wind stress and the North Equatorial Current. An analysis of the regional characteristics of the first joint empirical orthogonal function (EOF) of F_S, $\delta O_E/\delta t$, and F_O is presented, and the largest sources of uncertainty are attributed to variations in O_E. The mean and annual cycle of zonal mean global ocean meridional heat transports are estimated. The annual cycle reveals the strongest poleward heat transports in each hemisphere in the cold season, from November to April in the north and from May to October in the south, with a substantial across-equatorial transport, exceeding 4 PW in some months. Annual mean results do not differ greatly from some earlier estimates, but the sources of uncertainty are exposed. Comparison of annual means with direct ocean observations gives reasonable agreement, except in the North Atlantic, where transports from the ocean transects are slightly greater than the estimates presented here.

Figure 3.

High resolution figure

Figure caption: (a) Annual mean F_S as computed by the residual from R_T and NRA atmospheric energy budgets for the ERBE period (W m-2). Departure from the annual mean of the (b) JJA and (c) DJF surface flux out of the ocean (W m^{-2}). Stippling (hatching) denotes areas where NRA-based estimates exceed (fall below) those of ERA-40 by more than 10 W m^{-2} in (a) and by more than 30 W m^{-2} in (b) and (c).

Trenberth, K. E., and J. Fasullo, 2008: The energy budgets of Atlantic hurricanes and changes from 1970. Geochemistry, Geophysics, Geosystems., in press.

Abstract: Based on the current observational record of tropical cyclones and sea surface temperatures (SSTs) in the Atlantic, estimates are made of changes in surface sensible and latent heat fluxes and hurricane precipitation form 1970 to 2006. The best track dataset of observed tropical cyclones is used to estimate the frequency that storms of a given strength occur after 1970. Empirical expressions for the surface fluxes and precipitation are based on simulations of hurricane Katrina in August 2005 with the advanced Weather and Research Forecasting (WRF) model at 4 km resolution without parameterized convection. The empirical relationships are computed for the surface fluxes and precipitation within 400 km of the eye of the storm for all categories of hurricanes based upon the maximum simulated wind and the observed sea surface temperature and saturation specific humidity. Strong trends are not linear but are better depicted as a step function increase from 1994 to 1995, and the large variability reflects changes in SSTs and precipitable water, modulated by El Niño events. The environmental variables of SST and water vapor are nonetheless accompanied by clear changes in tropical cyclone activity using several metrics.

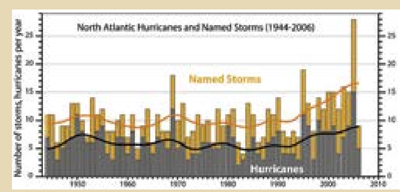


Figure 4.

High resolution figure

Figure caption: The record of numbers of named storms and hurricanes for the Atlantic from 1944 to 2006 based on the best track data. The smoothed curves show decadal variability using a 13 point filter with end values computed using reflected values.

Trenberth, K. E., J. T. Fasullo, and J. Kiehl, 2008: Earth's global energy budget. Bull. Amer. Meteor. Soc., in press.

Abstract: An update is provided on the Earth's global annual mean energy budget in the light of new observations and analyses. In 1997 Kiehl and Trenberth provided a review of past such estimates and performed a number of radiative computations to better establish the role of clouds and various greenhouse gases in the overall radiative energy flows, with top-of-atmosphere (TOA) values constrained by Earth Radiation Budget Experiment values form 1985 to 1989, when the TOA values were approximately in balance. The Clouds and the Earth's Radiant Energy System (CERES) measurements from March 2000 to May 2004 are used to TOA but adjusted to an estimated imbalance from the enhanced greenhouse effect of 0.9 W m^{-2}. Revised estimates of surface turbulent fluxes are made based on various sources. The partitioning of solar radiation in the atmosphere is based in part on the International Satellite Cloud Climatology Project (ISCCP) ISCCP-FD computations that utilize the global ISCCP cloud data every 3 hours, and also accounts for increased atmospheric absorpton by water vapor and aerosols. Surface upwards longwave radiation is adjusted to account for spatial and temporal variability. A lack of closure in the energy balance at the surface is accommodated by making modest changes to surface fluxes, with the downward longwave radiation as the main residual to ensure a balance. Values are also presented for the land and ocean domains that include a net transport of energy from ocean to land of 2.2 Petawatts (PW) of which 3.2 PW is from moisture (latent energy) transport, while net dry static energy transport is from land to ocean. Evaluations of atmospheric reanalyses reveal substantial biases.

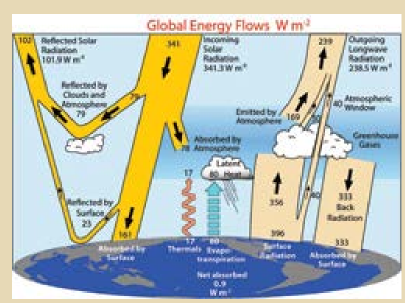


Figure 5.

High resolution figure

Figure caption: The global annual mean Earth's energy budget for the March 2000 to May 2004 period in W m^{-2}. The broad arrows indicate the schematic flow of energy in proportion to their importance.

Trenberth, K. E., C. A. Davis, and J. Fasullo, 2007: Water and energy budgets of hurricanes: Case studies of Ivan and Katrina. J. Geophys. Res., 112, D23106, doi:10.1029/2006JD008303.

Abstract: To explore the role of hurricanes in the climate system, a detailed analysis is made of the bulk atmospheric moisture budget of Ivan in September 2004 and Katrina in August 2005 from simulations with the Weather and Research Forecasting (WRF) model at 4 km resolution without parameterized convection. Heavy precipitation exceeding 20 mm h^{-1} in the storms greatly exceeds the surface flux of moisture through evaporation, and vertically integrated convergence of moisture in the lowest 1 km of the atmosphere from distances up to 1600 km is the dominant term in the moisture budget, highlighting the importance of the larger-scale environment. Simulations are also run for the Katrina case with sea surface temperatures (SSTs) increased by +1°C and decreased by -1°C as sensitivity studies. For hours 42 to 54 after the start of the simulation, maximum surface winds increased about 4.5 m s^{-1} (9%), and sea level pressure fell 11.5 hPa per 1°C increase in tropical SSTs. Overall, the hurricane expands in size as SSTs increase, the environmental atmospheric moisture increases at close to the Clausius-Clapeyron equation value of about 6% K-1 and the surface moisture flux also increases mainly from Clausius-Clapeyron effects and the changes in intensity of the storm. The environmental changes related to human influences on climate since 1970 have increased SSTs and water vapor, and the results suggest how this may have altered hurricanes and increased associated storm rainfalls, with the latter quantified to date to be of order 6 to 8%.

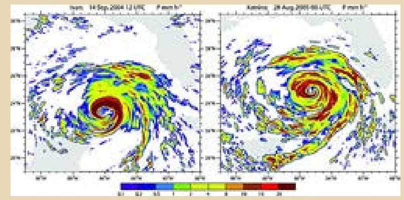


Figure 6.

High resolution figure

Figure caption: Precipitation (mm h^{-1}) fields for simulated hurricanes (left) Ivan at 1200 UTC 14 September 2004 and (right) Katrina at 0000 UTC 28 August 2005.

Trenberth, K. E., and J. Fasullo, 2007: Water and energy budgets of hurricanes and implications for climate change. J. Geophys. Res., 112, D23107, doi:10.1029/2006JD008304.

Abstract: On the basis of simulations of hurricane Katrina in August 2005 with the advanced Weather and Research Forecasting (WRF) model at 4 km resolution without parameterized convection, empirical relationships are computed between the maximum simulated wind and the surface fluxes and precipitation and provide a reasonable fit to the data. The best track data set of global observed tropical cyclones is used to estimate the frequency that storms of a given strength occur over the globe after 1970. For 1990-2005 the total surface heat loss by the tropical ocean in hurricanes category 1 to 5 within 400 km of the center of the storms is estimated to be about 0.53 x 10^{22} J a^{-1} (where a is year) (0.17 PW). The enthalpy loss due to hurricanes computed on the basis of precipitation is about a factor of 3.4 greater (0.58 PW), owing to the addition of the surface fluxes from outside 400 km radius and moisture convergence into the storms typically from as far from the eye as 1600 km. Globally these values correspond to 0.33 W m^{-2} for evaporation, or 1.13 W m^{-2} for precipitation. Changes over time reflect basin differences and a prominent role for El Niño, and the most active period globally was 1989 to 1997. Strong positive trends from 1970 to 2005 occur in these inferred surface fluxes and precipitation arising from increases in intensity of storms and also higher sea surface temperatures. Confidence in this result is limited by uncertainties in the best track tropical cyclone data. Nonetheless, the results highlight the importance of surface energy exchanges in global energetics of the climate system and are suggestive of the deficiencies in climate models owing to their inadequate representation of hurricanes.

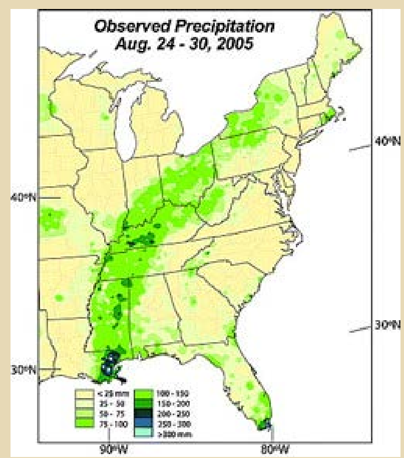


Figure 7.

High resolution figure

Figure caption: Estimate of observed precipitation based on surface gauges, adapted from a compilation by Climate Prediction Center, NOAA (printed with permission, courtesy Rich Tinker and Jay Lawrimore). These may be underestimates as many data were missing in the vicinity of New Orleans.

CGD Research Catalog

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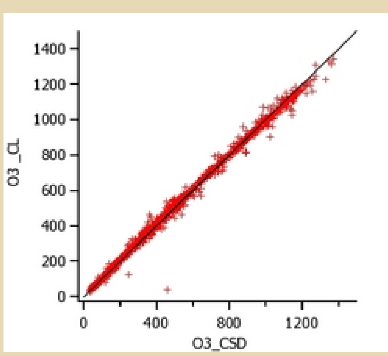
Research Focus FY08:

The new two-channel NO-NOy instrument.

High resolution figure



Comparison of the CARI fast-O3 HAIS instrument (O3_CL) with the NOAA UV absorption instrument (O3_CSD). The black line is a 1:1 line.

High resolution figure

Community Airborne Research Instrumentation Group (CARI)

The CARI group maintains, develops and deploys a number of aircraft trace gas instruments, including instrumentation which can be requested via the NSF/LAOF process, NSF/NCAR GV (HIAPER) instruments (two of those are part of the HAIS suite), and other atmospheric chemistry instruments. These instruments are:

CO	Two vacuum fluorescence instruments (Aerolaser, one certified for GV)
CO2	Two infrared absorption carbon dioxide instruments (Li-Cor, one certified for GV)
H2O	Two TDL infrared absorption open-path water vapor instruments (MayComm Instruments, one certified for GV)
Fast-O3	NO chemiluminescence instrument (home built and certified for GV - HAIS)
NO/NOy	Compact 2-channel chemiluminescence instrument / photolytic conversion /gold catalytic conversion (home built and certified for GV)
NOx/NOy/O3	4-channel chemiluminescence instrument / photolytic conversion /gold catalytic conversion (home built for various aircraft, not certified for GV)
PANs	Thermal dissociation Chemical Ionization Mass Spectrometer (built in collaboration with Georgia Tech)
VOC	TOGA fast GC-MS instrument measuring a variety of VOC (alkanes, alkenes, oxygeneates, aromatics, and others, about 40 compounds total) on a 2-min time scale (home built for GV - HAIS)

The group expects to take responsibility for one or more of the HAIS instruments after they have been delivered to EOL. One of these instruments is the CIMS instrument, developed and built by GA Tech, which will measure HNO3, HNO4, and SO2.

Field Experiments and instrument preparation/improvements

CARI participated in four major aircraft field experiments and an international laboratory study in the last year. The Pacific Sulfur Experiment (PASE) in Sept/Oct 2007 (funded by NSF), the Ice in Clouds Experiment (ICE-L) in November/December

2007 (funded by NSF), the Stratosphere-Troposphere Analyses of Regional Transport 2008 (START-08) mission in April/June of 2008 (funded by NSF), the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) mission in March/April and June/July 2008 (funded by NASA and NSF) and the VAMOS Ocean-Cloud-Atmosphere-Land Study – Regional Experiment (VOCALS-REx) experiment in October/November 2008 using the C-130 (funded by NSF). In October of 2007, CARI participated in the international water vapor intercomparison (AquaVit) in Germany (funded by the German BMBF and the EU with a contribution from NSF).

Two of these missions (ARCTAS and START08) were multi-intensive missions which spanned the entire spring and summer of 2008. In addition, the START08 payload had never been flown before. Due to this heavy field load, CARI had to focus most of it's efforts on post-mission instrument testing and data QA/QD which is still ongoing. All missions went well and complete data sets were collected. We expect to meet all deadlines for data submission later this fall and early next year. In addition, CARI is preparing a number of instruments for the OASIS field mission, which will start in February of 2009. ...more

Scientific Talks FY08:

- Reactive nitrogen chemistry in Mexico City outflow (San Francisco, CA December 2007)
- Atmos. Chem. Workgroup Summary (Boulder, CO October 2007)
- Graduate Research Advisor & Masters Thesis Committee: Dennis Kreamer (Fachhochschule Darmstadt, Germany)
- Graduate Research Advisor & Masters Thesis Committee: Matthias Bogar (Fachhochschule Darmstadt, Germany)
- Graduate Research Advisor & Masters Thesis Committee: Marcel Foeckler (Fachhochschule Juelich, Germany)

Publications FY08:

Atlas, E., J. De Gouw, F. Flocke, A. Fried, J. Holloway, A. Neuman, J. Nowak, J. Peischl, D. Richter, T. Ryerson, M. Trainer, J. G. Walega, C. Warneke, P. Weibring, W. Zheng, 2008: Rapid and Efficient Production of Ozone over Houston, October 6, 2006: A Case Study. , Austin, TX, US.

Heald, C. L., A. H. Goldstein, J. D. Allan, A. C. Aiken, E. C. Apel, E. L. Atlas, A. K. Baker, T. S. Bates, A. J. Beyersdorf, D. R. Blake, T. Campos, H. Coe, J. D. Crounse, P. F. DeCarlo, J. A. de Gouw, E. J. Dunlea, F. Flocke, A. Fried, P. Goldan, R. J. Griffin, S. C. Herndon, J. S. Holloway, R. Holzinger, J. L. Jimenez, W. Junkermann, W. C. Kuster, A. C. Lewis, S. Meinardi, D. B. Millet, T. Onasch, A. Polidori, P. K. Quinn, D. D. Riemer, J. M. Roberts, D. Salcedo, B. Sive, A. L. Swanson, R. Talbot, C. Warneke, R. J. Weber, P. Weibring, P. O. Wennberg, D. R. Worsnop, A. E. Wittig, R. Zhang, J. Zheng, W. Zheng, 2008: Total observed organic carbon (TOOC) in the atmosphere: a synthesis of North American observations. *Atmos. Chem. Phys.*, **8**, 2007-2025.

Eisele, F., D. D. Davis, D. Helmig, S. J. Oltmans, W. Neff, G. Huey, D. Tanner, G. Chen, J. Crawford, R. Arimoto, M. Buhr, L. Mauldin, M. Hutterli, J. Dibb, D. Blake, S. B. Brooks, B. Johnson, J. M. Roberts, Y. Wang, D. Tan, F. Flocke, 2008: Antarctic Tropodpheric Chemistry Investigation (ANTCI) 2003 overview. *Atmos. Environ.*, **42**, 2749-2761.

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Wolfe, G. M., J. A. Thornton, V. F. McNeill, D. A. Jaffe, D. Reidmiller, D. Chand, J. Smith, P. Swartzendruber, F. Flocke, W. Zheng, 2008: Influence of trans-Pacific pollution transport on acyl peroxy nitrate abundances and speciation at Mount Bachelor Observatory during INTEX-B. *Atmos. Chem. Phys.*, **7**, 5309-5325.

Frank Flocke Research Catalog

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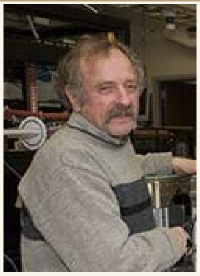

EOL - TIIMES
Senior Scientist
UTLS

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Research Focus FY08:

New Senior Scientist - Staff Notes

Group Summary

Alan manages EOL's Technology Development Facility, where he identifies and explores new opportunities for developing state-of-the-art instruments for atmospheric research. As part of this effort, he maintains a research program dedicated to developing new spectroscopic instruments for airborne platforms and associated measurements of trace gases, with the goal of improving our understanding of atmospheric processes and transformations related to hydrocarbon oxidation.

Alan and his group, in collaboration with atmospheric modelers, have been studying formaldehyde, an important trace gas and radical source, throughout the troposphere and lower stratosphere (see cover story). The studies are uncovering new processes and unexplained results as well as providing key model constraints in hydrocarbon oxidation studies. Most recently, Alan and colleagues have documented the importance of convective transport of formaldehyde and its precursors during summer months in forming radicals and ozone in the upper troposphere and lower stratosphere.

Community Service FY08:

- Guest Co-editor along with Jim Gord and Andreas Dreizler for a special issue of Applied Optics on Laser Applications to Chemical, Security, and Environmental Analysis, July 2007
- Member of the United States Army Environmental Analysis Expert Panel, "Background and Interferent Signature (BIS) Collection Science Panel
- Member of the NSF Facilities Assessment Subcommittee on Emerging Technologies
- Member of the NSF Facilities Users Workshop
- Member of the Scientific Advisory Board for NSF-sponsored Engineering Research Center on Mid-Infrared Technologies for Health and the Environment (MIRTHE)
- Summer Visitor, Bryan P. Wert, working on the high precision carbon dioxide isotope ratio spectrometer

Scientific Talks FY08:

- A. Fried, ARG Senior Scientist Seminar, March 12, 2008, "How Airborne Formaldehyde Studies Contribute to an Improved Understanding of Atmospheric Chemical Processing and Transformations", NCAR.
- D. Richter, J.G. Walega, P. Weibring, A. Fried, M.K. Trainer, and T.B. Ryerson, "Preliminary Results of Formaldehyde Measurements During TexAQS 2006", Poster Paper in Austin Texas, June 2007.
- E. Atlas, J. De Gouw, F. Flocke, A. Fried, J. Holloway, A. Neuman, J. Nowak, J. Peischi, D. Richter, T. Ryerson, M. Trainer, J. Walega,, C. Warneke, P. Weibring, and W. Zheng, " Rapid and Efficient Production of Ozone over Houston, October 6, 2006 a Case Study, Austin Texas, June 2007.

- D. Richter, J.G. Walega, P. Weibring, and A. Fried, "Fast Airborne Formaldehyde Measurements during the Texas Air Quality Study (TexAQS) in 2006, American Geophys. Union Fall meeting in San Francisco, Dec. 2007.
- D. Richter, B.P. Wert, P. Weibring, J.G. Walega, A. Fried, and F. Tittel, "High-Precision Carbon Isotope Laser Absorption Spectrometer (CILAS)", Stable Isotope Ratio Infrared Spectrometry (SIRIS) 2007 Conference, Florence, Italy, September, 2007.
- P. Weibring, D. Richter, J.G. Walega, and A. Fried, "Demonstration of an Ultra-Sensitive Airborne Difference Frequency Spectrometer: Performance Characterization and Ambient Measurements of Formaldehyde", Field Laser Applications in Industry and Research (FLAIR) 2007, Florence, Italy, September, 2007.
- D. Richter, P. Weibring, J.G. Walega, A. Fried, M.K. Trainer, and T.B. Ryerson, "Airborne Formaldehyde Measurements During TexAQS 2006 using a Difference Frequency Laser Based Absorption Spectrometer", Laser Applications to Chemical, Security, and Environmental Analysis, March 2008, St. Petersburg, Florida.

Publications FY08:

Fried, A., J. R. Olson, J. G. Walega, J. H. Crawford, G. Chen, P. Weibring, D. Richter, C. Roller, F. Tittel, M. Porter, H. Fuelberg, J. Halland, T. H. Bertram, R. C. Cohen, K. Pickering, B. G. Heikes, J. A. Snow, H. Shen, W. H. Brune, X. Ren, D. R. Blake, N. Blake, G. Sachse, G. S. Diskin, J. Podolske, S. A. Vay, R. E. Shetter, S. Hall, B. E. Anderson, L. Thornhill, A. D. Clarke, C. S. McNaughton, H. B. Singh, M. A. Avery, G. Huey, S. Kim, D. B. Millet, 2008: Role of convection in redistributing formaldehyde to the upper troposphere over North America and the North Atlantic during the summer 2004 INTEX campaign. *J. Geophys. Res.*, **113**, D17306, doi: 10.1029/2007JD009760.

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Choi, Y., S. Vay, K. Vadrevu, A. Soja, J.-H. Woo, S. Nolf, G. Sachse, G. Diskin, D. Blake, N. Blake, H. Singh, M. Avery, A. Fried, L. Pfister, H. Fuelberg, 2008: Characteristics of the Atmospheric CO2 Signal as Observed Over the Conterminous United States During INTEX-NA. *J. Geophys. Res.*, **113**, D07301, doi: 10.1029/2007JD008899.

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Dreizler, A. A. Fried**,** and J.R. Gord, Laser Applications to Chemical, Security, and Environmental Analysis: Introduction to the Feature Issue, Applied Optics, **46 (19),** 3909 – 3910, 2007.

Alan Fried Research Catalog

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. GERALD MEEHL

Summary of achievements

Gerald Meehl

The role of anthropogenic black carbon aerosols was studied to identify the role they have played in shaping climate trends we have observed over the past 50 years (Meehl et al. black carbon aerosol paper). An ensemble of 20th century simulations with CCSM3 that included only time evolving changes of black carbon aerosols was analyzed to show that the observed changes of seasonality of Indian monsoon rainfall, with greater rainfall in the pre-monsoon season and less rainfall during the monsoon season, have likely been due to increases in black carbon aerosols. These aerosols absorb solar radiation over India in the pre-monsoon season (thus heating the lower atmosphere) as well as shield the surface from solar radiation. The result is a cooler north Indian Ocean and Indian sub-continent, while the heated air is advected north over the Tibetan Plateau to contribute to an early elevated heat source that intensifies the tropospheric meridional temperature gradient, thus increasing pre-monsoon rainfall over India. However, during the monsoon season the cooler surface temperatures reduce the meridional temperature gradient and thus weaken monsoon season rainfall. This is the first time the role of black carbon aerosols has been isolated in a global coupled climate model to explain recent observed trends of monsoon rainfall.

The important role of the 11 year cycle of solar forcing is emerging in model simulations that have been analyzed, along with observations, to confirm earlier hypotheses (Meehl et al. 2003) and model results in that the effect of enhanced solar forcing is to strengthen the climatological precipitation regimes in the tropics. This produces a La Nina-like response in the tropical Pacific with teleconnections to the North Pacific that reduce precipitation with greater solar forcing in the Pacific northwest and northern California. A coupled air-sea mechanism, postulated in earlier work that examined the solar effects on early 20th century climate, is identified from 20th century simulations with PCM and CCSM3 that involves air-sea coupling in the tropical Pacific that produces the pattern in the observations (Meehl et al. 2008 solar). This response is different from La Nina events that also have a similar pattern (van Loon and Meehl, 2008). This is the first work that has identified a coupled air-sea mechanism in the Pacific that responds on the time scale of the 11 year solar cycle.

New work looking weather and climate extremes has shown that observed changes of heat extremes (e.g. reductions of frost days) are most likely due to increases of anthropogenic greenhouse gases. Additionally, projected future changes of El Niño teleconnections over North America (Meehl et al., 2007) that involve an eastward and northward shift of the PNA pattern, also affect patterns of temperature and precipitation extremes over North America that show a similar projected shift. This work documents for the first time the connections between anthropogenic forcing of changes of extremes, changes of El Niño teleconnections, and changes of the pattern of extremes associated with El Niño.

Publications

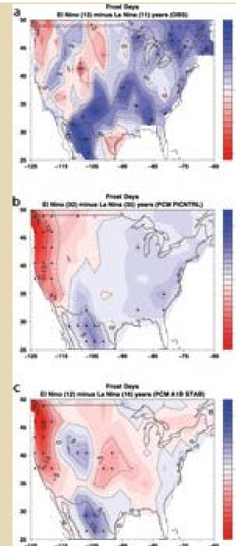
Meehl, G.A., C. Tebaldi, H. Teng, and T. Peterson, 2007: Current and future U.S. weather extremes and El Niño. Geophys. Res. Lett., 34, L20704, doi:10.1029/2007GL031027.

Abstract: A global coupled climate model representative of the current generation of models is shown to simulate most first order aspects of El Niño events, their teleconnections over North America, and the associated observed patterns of extremes in present-day climate. Future El Niño teleconnection patterns over the U.S. are projected to shift eastward and northward due in part to the different midlatitude base state atmospheric circulation in a warmer climate. Consequently, projections for the changes in the patterns of extremes over the U.S. during future El Niño events include: decreases of frost days over the southwestern U.S expand northward and eastward; increases in intense precipitation in the SW U.S. expands eastward and areas in the SE U.S. become stronger; and decreases of heat wave intensity over much of the southern tier of states turn to increases.

Figure 1.

High resolution figure

Figure caption: (a) Composites of observed frost days, El Niño events minus La Niña events (days), (b) same as Figure 2a except for the model control run, and (c) same as Figure 2b except for the stabilized A1B future climate experiment. Black dots indicate statistical significance at the 5% level from a bootstrap calculation.



Meehl, G.A., J.M. Arblaster and C. Tebaldi, 2007: Contributions of natural and anthropogenic forcing to changes in temperature extremes over the U.S. Geophys. Res. Lett., 34, L19709, doi:10.1029/2007GL030948.

Abstract: Observations averaged over the U.S. for the second half of the 20th century have shown a decrease of frost days, an increase in growing season length, an increase in the number of warm nights, and an increase in heat wave intensity. For the first three, a nine member multi-model ensemble shows similar changes over the U.S. in 20th century experiments that combine anthropogenic and natural forcings, though the relative contributions of each are unclear. Here we show results from two global coupled climate models run with anthropogenic and natural forcings separately. Averaged over the continental U.S., they show that the observed changes in the four temperature extremes are accounted for with anthropogenic forcings, but not with natural forcings (even though there are some differences in the details of the forcings). This indicates that most of the changes in temperature extremes over the U.S. are likely due to human activity.

Figure caption: Four temperature-related extremes indices averaged over the continental U.S. for model experiments with only natural forcings (blue line is multi-member ensemble average, blue shading is range across the ensembles), and only anthropogenic forcings (red line is multi-member ensemble average, red shading is range across the ensembles), four member ensembles for the PCM experiments, and five member ensembles for CCSM3. Each line is smoothed with a 5 year running mean. For the models, the 1890-1919 mean from each ensemble member is subtracted to form anomalies. An 1890-1919 mean is not available for the observations, so they are instead centered on the 1960-1999 mean of the anthropogenic runs from the models, the models are interpolated to the HadEX grid and only grid points with valid observations are used: (a) frost days for CCSM3, (b) frost days for PCM, (c) growing season length for CCSM3, (d) growing season length for PCM, (e) warm nights for CCSM3, (f) warm nights for PCM, (g) heat wave intensity for CCSM3, and (h) heat wave intensity for PCM.

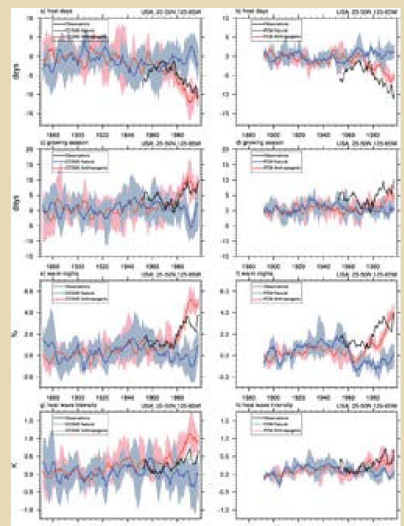


Figure 2.

High resolution figure

Meehl, G. A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J. F. B. Mitchell, R. J. Stouffer, and K. E. Taylor, 2007: The WCRP CMIP3 multi-model dataset: A new era in climate change research. Bulletin of the American Meteorological Society, 88, 1383--1394.

Abstract: The history of climate change modeling was first characterized in the 1980s by a number of distinct groups developing, running, and analyzing model output from their own models with little opportunity for anyone outside of those groups to have acces to the model data. This was partly a consequence of relatively primitive computer networking and data transfer capabilities, along with the daunting task of collecting and storing such large amounts of model data (Meehl 1995). Starting in the mid-1990s, a World Climate Research Programme (WCRP) committee [now named the WCRP/Climate Variability and Predictability (CLIVAR) Working Group on Coupled Models (WGCM0] organized the first global coupled climate model intercomparison exercise whereby modeling groups performed control runs and idealized 1%yr^{-1} C)$_2$ increase experiments (Meehl et al. 1997). A subset of model data was then collected and archived at the Program

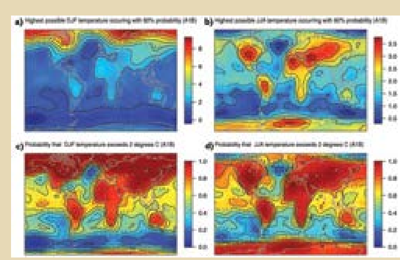


Figure 3.

High resolution figure

for Climate Model Diagnosis and Intercomparison (PCMDI) and made available to researchers outside the modeling groups. Subsequently there were several additional phases of the Coupled Model Intercomparison Project (CMIP), termed CMIP2 and CMIP2+ (Meehl et al. 2000, 2005b; Covey et al. 2003). The latter marked the first time that every field from each model component (atmosphere, ocean, land, and sea ice) from the control and 1% CO_2 increase experiments was collected and made available for analysis. However, only output from the control runs and 1% CO_2 experiments were collected because those represented the most scientifically straightforward response of the climate system to an unambiguous change in external forcing. Limitations in data transfer and storage still restricted the collection of output from the early climate change scenario experiments [e.g., experiments using the IS92a scenario as described in the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report; Kattenberg et al. 1996]. It was recognized that such an exercise would certainly be useful at some stage to open up the output of state-of-the-art climate change scenario experiments for analysis by the wider community.

Figure caption: Probabilistic climate change results from 2I AOGCMs, 2080-99 compared to 1980-99, for the A1B scenario, converted to a common 5° lat-lon grid: (a) DJF and (b) JJA values of temperature increase with an 80% change of occurrence by the end of the twenty-first century. Also shown are contours of probabilities of the occurrence of at least a 2°C warming for (c) DJF and (d) JJA (Furrer et al. 2007a).

Meehl, G.A., and H. Teng, 2007: Multi-model changes in El Niño teleconnections over North America in a warmer climate. Cli. Dyn., 29, 79-790, DOI 10.1007/s00382-007-0268-3.

Abstract: Previous studies with single models have suggested that El Niño teleconnections over North America could be different in a future warmer climate due to factors involving changes of El Niño event amplitude and/or changes in the midlatitude base state circulation. Here we analyze a six-member multi-model ensemble, three models with increasing future El Niño amplitude, and three models with decreasing future El Niño amplitude, to determine characteristics and possible changes to El Niño teleconnections during northern winter over the North Pacific and North America in a future warmer climate. Compared to observed El Niño events, all the models qualitatively produce general features of the observed teleconnection pattern over the North Pacific and North America, with an anomalously deepened Aleutian Low, a ridge over western North America, and anomalous low pressure over the southeastern United States. However, associated with systematic errors in the location of sea surface temperature and convective heating anomalies in the central and western equatorial Pacific (the models' anomaly patterns are shifted to the west), the anomalous low pressure center in the North Pacific is weaker and shifted somewhat south compared to the observations. For future El Niño events, two different stabilization experiments are analyzed, one with CO2 held constant at year 2100 concentrations in the SRES A1B scenario (roughly doubled present-day CO2), and another with CO2 concentrations held constant at 4XCO2. Consistent with the earlier single model results, the future El Niño teleconnections are changed in the models, with a weakened as well as an eastward- and northward-shifted anomalous low in the North Pacific. This is associated with weakened anomalous warming over northern North America, strengthened cooling over southern North America, and precipitation increases in the Pacific Northwest in future events compared to present-day El Niño event teleconnections. These changes are consistent with the altered base state upper tropospheric circulation with a wave-5 pattern noted in previous studies that is shown here to be consistent across all the models whether there are projected future increases or decreases in El Niño amplitude. The future teleconnection changes are most consistent with this anomalous wave-5 pattern in the models with future increases of El Niño amplitude, but less so for the models with future decreases of El Niño amplitude.

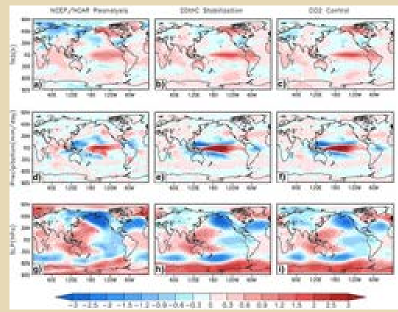


Figure 4.

High resolution figure

Figure caption: (a) Surface temperature anomalies (°C) for a composite of observed El Niño events, years 0 DJF minus long term mean, for the NCEP/NCAR reanalyses for events listed in the text; (b) same as a except for six-member multi-model composite of El Niño events from the 20th century stabilization reference experiment; (c) same as b except for the present day control experiment; (d) same as a except for precipitation (mm day^{-1}); (e) same as (b) except for precipitation; (f) same as (c) except for precipitation; (g) same as (a) except for SLP (hPa); (h) same as (b) except for SLP; (i) same as (c) except for SLP.

Meehl, G.A., J.M. Arblaster, and W.D. Collins, 2008: Effects of black carbon aerosols on the Indian monsoon. J. Climate, 21, 2869-2882.

Abstract: A six-member ensemble of twentieth-century simulations with changes to only time-evolving global distributions of black carbon aerosols in a global coupled climate model is analyzed to study the effects of black carbon (BC) aerosols on the Indian monsoon. The BC aerosols act to increase lower-tropospheric heating over South Asia and reduce the amount of solar radiation reaching the surface during the dry season, as noted in previous studies. The increased meridional tropospheric temperature gradient in the premonsoon months of March-April-May (MAM), particularly between the elevated heat source of the Tibetan Plateau and areas to the south, contributes to enhanced precipitation over India in those months. With the onset of the monsoon, the

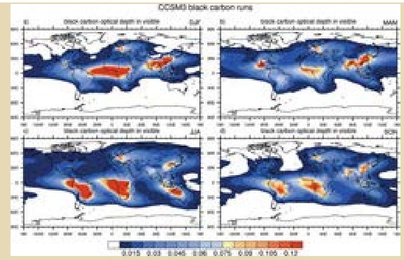


Figure 5.

High resolution figure

reduced surface temperatures in the Bay of Bengal, Arabian Sea, and over India that extend to the Himalayas act to reduce monsoon rainfall over India itself, with some small increases over the Tibetan Plateau. Precipitation over China generally decreases due to the BC aerosol effects. There is a weakened latitudinal SST gradient resulting from BC aerosols in the model simulations as seen in the observations, and this is present in the multiple-forcings experiments with the Community Climate System Model, version 3 (CCSM3), which includes natural and anthropogenic forcings (including BC aerosols). The BC aerosols and consequent weakened latitudinal SST gradient in those experiments are associated with increased precipitation during MAM in northern India and over the Tibetan Plateau, with some decreased precipitation over southwest India, the Bay of Bengal, Burma, Thailand, and Malaysia, as seen in observations. During the summer monsoon season, the model experiments show that BC aerosols have likely contributed to observed decreasing precipitation trends over parts of India, Bangladesh, Burma, and Thailand. Analysis of single ensemble members from the multiple-forcings experiment suggests that the observed increasing precipitation trends over southern China appear to be associated with natural variability connected to surface temperature changes in the northwest Pacific.

Figure caption: Distributions of black carbon optical depth for 1999 by season: (a) DJF, (b) MAM, (c) JJA, and (d) September-November (SON). This pattern was scaled back in time based on globally averaged human population.

Meehl, G.A., J.M. Arblaster, G. Branstator, and H. Van Loon, 2008: A coupled air-sea response mechanism to solar forcing in the Pacific region. J. Climate, 21, 2883-2897.

Abstract: The 11-yr solar cycle [decadal solar oscillation (DSO)] at its peaks strengthens the climatological precipitation maxima in the tropical Pacific during northern winter. Results from two global coupled climate model ensemble simulations of twentieth-century climate that include anthropogenic (greenhouse gases, ozone, and sulfate aerosols, as well as black carbon aerosols in one of the models) and natural (volcano and solar) forcings agree with observations in the Pacific region, though the amplitude of the response in the models is about half the magnitude of the observations. These models have poorly resolved stratospheres and no 11-yr ozone variations, so the mechanism depends almost entirely on the increased solar forcing at peaks in the DSO acting on the ocean surface in clear sky areas of the equatorial and subtropical Pacific. Mainly due to geometrical considerations and cloud feedbacks, this solar forcing can be nearly an order of magnitude greater in those regions than the globally averaged solar forcing. The mechanism involves the increased solar forcing at the surface being manifested by increased latent heat flux and evaporation. The resulting moisture is carried to the convergence zones by the trade winds, thereby strengthening the intertropical convergence zone (ITCZ) and the South Pacific convergence zone (SPCZ). Once these precipitation regimes begin to intensify, an amplifying set of coupled feedbacks similar to that in cold events (or La Niña events) occurs. There is a strengthening of the trades and greater upwelling of colder water that extends the equatorial cold tongue farther west and reduces precipitation across the equatorial Pacific, while increasing precipitation even more in the ITCZ and SPCZ. Experiments with the atmosphere component from one of the coupled models are performed in which heating anomalies similar to those observed during DSO peaks are specified in the tropical Pacific. The result is an anomalous Rossby wave response in the atmosphere and consequent positive sea level pressure (SLP) anomalies in the North Pacific extending to western North America. These patterns match features that occur during DSO peak years in observations and the coupled models.

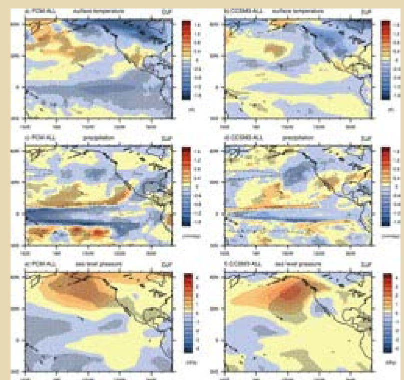


Figure 6.

High resolution figure

Figure caption: Ensemble average differences for DJF, peak solar years minus long-term climatology as described in the text: (a) surface temperature differences (°C) for PCM; (b) surface temperature differences for CCSM3; (c) precipitation differences (mm day^{-1}) for PCM, dashed line is the 7 mm day^{-1} contour from the long-term climatology; (d) precipitation differences for CCSM3; (e) SLP differences (hPa) for PCM; and (f) SLP differences for CCSM3. Stippling indicates areas of relative agreement among ensemble members, where the mean difference divided by the interensemble std dev exceeds 1.0.

Santer, B.D., C. Mears, F.J. Wentz, K.E. Taylor, P.J. Gleckler, T.M.L. Wigley, T.P. Barnett, J.S. Boyle, W. Bruggemann, N.P. Gillett, S.A. Klein, G.A. Meehl, T. Nozawa, D.W. Pierce, P.A. Stott, W.M. Washington, and M.F. Wehner, 2007: Identification of human-induced changes in atmospheric moisture content. Proc. Nat. Acad. Sci., 104, 15248--15253.

Abstract: Data from the satellite-based Special Sensor Microwave Imager (SSM/I)

show that the total atmospheric moisture content over oceans has increased by 0.41 kg/m2 per decade since 1988. Results from current climate models indicate that water vapor increases of this magnitude cannot be explained by climate noise alone. In a formal detection and attribution analysis using the pooled results from 22 different climate models, the simulated "fingerprint" pattern of anthropogenically caused changes in water vapor is identifiable with high statistical confidence in the SSM/I data. Experiments in which forcing factors are varied individually suggest that this fingerprint "match" is primarily due to human-caused increases in greenhouse gases and not to solar forcing or recovery from the eruption of Mount Pinatubo. Our findings provide preliminary evidence of an emerging anthropogenic signal in the moisture content of earth's atmosphere.

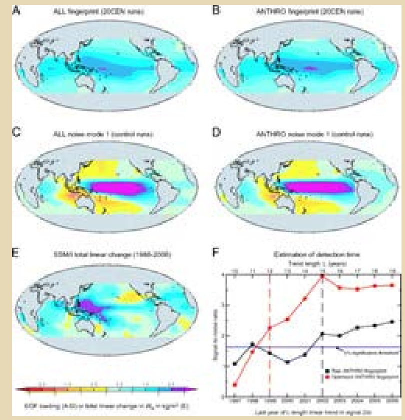


Figure 7.

High resolution figure

Figure caption: Simulated and observed spatial patterns of changes in W_o and estimation of detection time (10). Multimodel averages of the 20th century changes in W_o were used to calculate the ALL (A) and ANTHRO (B) fingerprints we search for in the observations. Also shown are the leading noise modes of the concatenated ALL (C) and ANTHRO (D) model control runs and the observed pattern of total linear changes in W_o over 1998-2006 (E). All calculations were performed on the common 10° × 10° latitude/longitude grid used for the fingerprint analysis.

Teng, H., W.M. Washington, and G.A. Meehl, 2007: Interannual variations and future change of wintertime extratropical cyclone activity over North America in CCSM3. Clim. Dyn., DOI 10.1007/s00382-007-0314-1.

Abstract: Climatology and interannual variations of wintertime extratropical cyclone frequency in CCSM3 twentieth century simulation are compared with the NCEP/NCAR reanalysis during 1950-1999. CCSM3 can simulate the storm tracks reasonably well, although the model produces slightly less cyclones at the beginning of the Pacific and Atlantic storm tracks and weaker poleward deflection over the Pacific. As in the reanalysis, frequency of cyclones stronger than 980 hPa shows significant correlation with the Pacific/North America (PNA) teleconnection pattern over the Pacific region and with the North Atlantic Oscillation (NAO) in the Atlantic sector. Composite maps are constructed for opposite phases of El Niño-Southern Oscillation (ENSO) and the NAO and all anomalous patterns coincide with observed. One CCSM3 twenty-first century A1B scenario realization indicates there is significant increase in the extratropical cyclone frequency on the US west coast and decrease in Alaska. Meanwhile, cyclone frequency increases from the Great Lakes region to Quebec and decreases over the US east coast, suggesting a possible northward shift of the Atlantic storm tracks under the warmer climate. The cyclone frequency anomalies are closely linked to changes in seasonal mean states of the upper-troposphere zonal wind and baroclinicity in the lower troposphere. Due to lack of 6-hourly outputs, we cannot apply the cyclone-tracking algorithm to the other eight CCSM3 realizations. Based on the linkage between the mean state change and the cyclone frequency anomalies, it is likely a common feature among the other ensemble members that cyclone activity is reduced on the East Coast and in Alaska as a result of global warming.

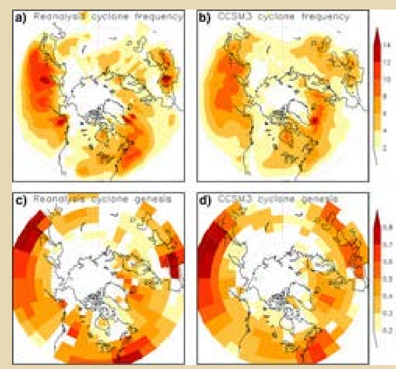


Figure 8.

High resolution figure

Figure caption: a, b Climatological winter cyclone frequency (events/winter per 5° × 5° lat/lon degree) in the Reanalysis and the CCSM3 historical run, respectively. c, d Climatological winter frequency of cyclone generation (percent of the total number of cyclones) in the Reanalysis and CCSM3, respectively .

Ebi, K., and G. A. Meehl, 2007: Heatwaves and Global Climate Change, The Heat is On: Climate Change and Heatwaves in the Midwest. In: Regional Impacts of Climate Change: Four Case Studies in the United States. Pew Center on Global Climate Change, Arlington, VA, 8--21.

Tebaldi, C., and G. A. Meehl, 2008: Beyond mean climate change: What climate models tell us about future climate extremes. In: Climate Extremes and Society, H.F. Diaz and R.J. Murnane, Eds., Cambridge University Press, 99--119.

Van Loon, H., and G.A. Meehl, 2008: The response in the Pacific to the Sun's decadal peaks and contrasts to Cold Events in the Southern Oscillation. J. Atmospheric and Solar-Terrestrial Physics, 70, 1046-1055.

Abstract: van Loon et al. [2007. Coupled air-sea response to solar forcing in the Pacific region during northern winter. Journal of Geophysical Research 112, D02108, doi:10.1029/2006JD007378] showed that the Pacific Ocean in northern winter is sensitive to the influence of the sun in its decadal peaks. We extend this study by three solar peaks to a total of 14, examine the response in the

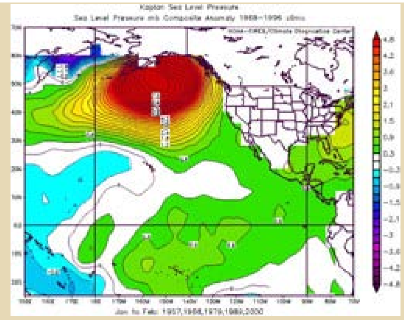


Figure 9.

High resolution figure

stratosphere, and contrast the response to solar forcing to that of cold events (CEs) in the Southern Oscillation. The addition of three solar peak years confirms the earlier results. That is, in solar peak years the sea level pressure (SLP) is, on average, above normal in the Gulf of Alaska and south of the equator, stronger southeast trades blow across the Pacific equator and cause increased upwelling and thus anomalously lower sea surface temperatures (SSTs). Since the effect on the Pacific climate system of solar forcing resembles CEs in the Southern Oscillation, we compare the two and note that, even though their patterns appear similar in some ways, they are particularly different in the stratosphere and are thus due to separate processes. That is, in July-August (JA) of the year leading into January-February (JF) of the solar peak years, the Walker cell expands in the Pacific troposphere, and the stratospheric wind anomalies are westerly below 25 hPa and easterly above, whereas this signal in the stratosphere is absent in CEs. Thus the large-scale east-west tropical atmospheric (Walker) circulation is enhanced, though not to the extent that it is in CEs in the Southern Oscillation, and the solar influence thus appears as a strengthening of the climatological mean regional precipitation maxima in the tropical Pacific. Additionally, CEs have a 1-year evolution, while the response to solar peaks extends across 3 years such that the signal in the Pacific SLP of the solar peaks is similar but weaker in the year leading into the peak and in the year after the peak. The concurrent negative SST anomalies develop during the year before the solar peak, and after the peak the anomalies are still present but are waning. In the stratosphere in solar peaks, the equatorial quasi-biennial oscillation (QBO) is amplified when it is in its westerly phase in the lower stratosphere and easterly phase above; and the QBO is suppressed when in its easterly phase below-westerly phase above. Such an association is not evident in CEs.

Figure caption: The same as Fig. 1a, but for the years 1957, 1968, 1979, 1989, 2000.

Hu, A., B. L. Otto-Bliesner, G. A. Meehl, W. Han, C. Morrill, E. C. Brady, and B. Briegleb, 2008: Response of thermohaline circulation to freshwater forcing under present day and LGM conditions. Journal of Climate, 21, 2239-2258.

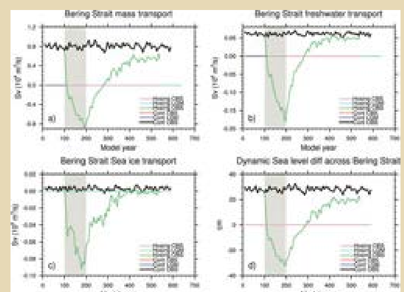


Figure 10.

High resolution figure

Abstract: Responses of the thermohaline circulation (THC) to freshwater forcing (hosing) in the subpolar North Atlantic Ocean under present-day and the last glacial maximum (LGM) conditions are investigated using the National Center for Atmospheric Research Community Climate System Model versions 2 and 3. Three sets of simulations are analyzed, with each set including a control run and a freshwater hosing run. The first two sets are under present-day conditions with an open and closed Bering Strait. The third one is under LGM conditions, which has a closed Bering Strait. Results show that the THC nearly collapses in all three hosing runs when the freshwater forcing is turned on. The full recovery of the THC, however, is at least a century earlier in the open Bering Strait run than the closed Bering Strait and LGM runs. This is because the excessive freshwater is diverged almost equally toward north and south from the subpolar North Atlantic when the Bering Strait is open. A significant portion of the freshwater flowing northward into the Arctic exits into the North Pacific via a reversed Bering Strait Throughflow, which accelerates the THC recovery. When the Bering Strait is closed, this Arctic to Pacific transport is absent and freshwater can only be removed through the southern end of the North Atlantic. Together with the surface freshwater excess due to precipitation, evaporation, river runoff, and melting ice in the closed Bering Strait experiments after the hosing, the removal of the excessive freshwater takes longer, and this slows the recovery of the THC. Although the background conditions are quite different between the present-day closed Bering Strait run and the LGM run, the THC responds to the freshwater forcing added in the North Atlantic in a very similar manner.

Figure caption: (a) The 13-yr low-pass-filtered Bering Strait mass, (b) freshwater, (c) ice transports, and (d) the dynamic sea level difference across the Bering Strait from the west side (Alaska side) to the east side (Siberian side). The unit for the transports is Sv and the unit for the dynamic sea level difference is cm. The shading indicates the 100-yr hosing period.

Knutti, R., M.R. Allen, P. Friedlingstein, J.M. Gregory, G.C. Hegerl, G.A. Meehl, M. Meinshausen, J.M. Murphy, G.-K. Plattner, S.C.B. Raper, T.F. Stocker, P.A. Stott, H. Teng, and T.M.L. Wigley, 2008: A review of uncertainties in global temperature projections over the twenty-first century. J. Climate, 21, 2651-2663.

Abstract: Quantification of the uncertainties in future climate projections is crucial for the implementation of climate policies. Here a review of projections of global temperature change over the twenty-first century is provided for the six illustrative emission scenarios from the Special Report on Emissions Scenarios (SRES) that assume no policy intervention, based on the latest generation of coupled general circulation models, climate models of intermediate complexity, and simple models, and uncertainty ranges and probabilistic projections from various published methods and models are assessed. Despite substantial improvements in climate models, projections for given scenarios on average have not changed much in recent years. Recent

progress has, however, increased the confidence in uncertainty estimates and now allows a better separation of the uncertainties introduced by scenarios, physical feedbacks, carbon cycle, and structural uncertainty. Projection uncertainties are now constrained by observations and therefore consistent with past observed trends and patterns. Future trends in global temperature resulting from anthropogenic forcing over the next few decades are found to be comparably well constrained. Uncertainties for projections on the century time scale, when accounting for structural and feedback uncertainties, are larger than captured in single models or methods. This is due to differences in the models, the sources of uncertainty taken into account, the type of observational constraints used, and the statistical assumptions made. It is shown that as an approximation, the relative uncertainty range for projected warming in 2100 is the same for all scenarios. Inclusion of uncertainties in carbon cycle-climate feedbacks extends the upper bound of the uncertainty range by more than the lower bound.

Liang, X.-Z., K. E. Kunkel, G. A. Meehl, R. G. Jones, and J. X. L. Wang, 2008: Regional climate models downscaling analysis of general circulation models present climate biases propagation into future change projections. Geophys. Res. Lett., 35, L08709, doi:10.1029/2007GL032849.

Abstract: A suite of eighteen simulations over the U.S. and Mexico, representing combinations of two mesoscale regional climate models (RCMs), two driving global general circulation models (GCMs), and the historical and four future anthropogenic forcings were intercompared. The RCMs' downscaling reduces significantly driving GCMs' present-climate biases and narrows inter-model differences in representing climate sensitivity and hence in simulating the present and future climates. Very high spatial pattern correlations of the RCM minus GCM differences in precipitation and surface temperature between the present and future climates indicate that major model present-climate biases are systematically propagated into future-climate projections at regional scales. The total impacts of the biases on trend projections also depend strongly on regions and cannot be linearly removed. The result suggests that the nested RCM-GCM approach that offers skill enhancement in representing the present climate also likely provides higher credibility in downscaling the future climate projection.

Figure caption: The precipitation (PR, mm day^{-1}) and surface 2-m air temperature (TA, °C) biases (from observations, left panels, a-d) of the driving GCMs (PCM, HAD) and differences (from the respective GCM) due to the RCM downscaling (PGR, HGR) in the present (1990s, middle panels, e-h) and future (2090s, right panels, i-l). Shown are summer averages of 10 years: 1991-2000 and A1Fi 2090-2099 for PCM, PGR, and 1980-1989 and A2 2090-2099 for HAD, HGR.

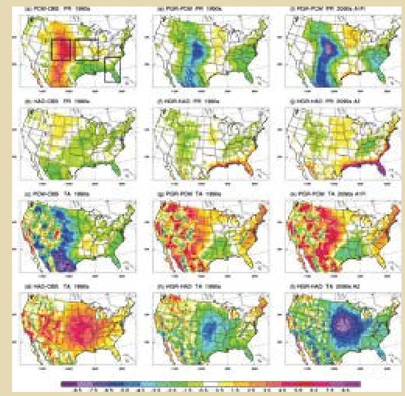


Figure 11.

High resolution figure

CCSP, 2008: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Thomas R. Karl, Gerald A. Meehl, Christopher D. Miller, Susan J. Hassol, Anne M. Waple, and William L. Murray (eds.)]. Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA, 164 pp.

Karl, T.R., G.A. Meehl, T.C. Peterson, K.E. Kunkel, W.J. Gutowski, Jr., and D.R. Easterling, 2008: Executive Summary. In: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. T.R. Karl, G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, and W.L. Murray (eds.). A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Washington, D.C., 1-9.

CGD Research Catalog

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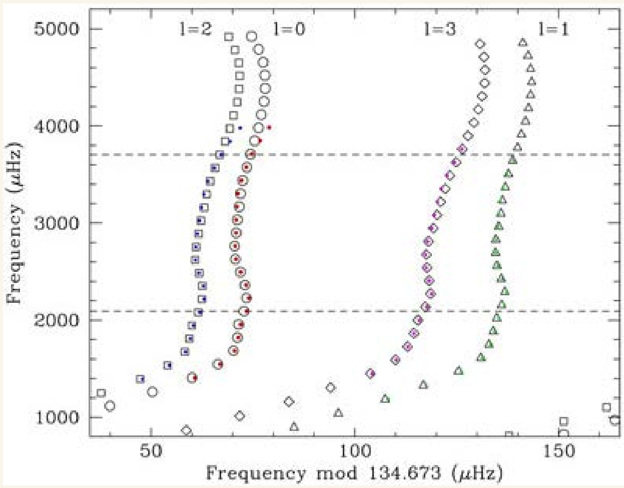
METCALFE, TRAVIS

Asteroseismology



In the past two decades, helioseismology has revolutionized our understanding of the interior structure of the Sun. Asteroseismology will soon place this knowledge into a broader context, by providing structural information for hundreds of solar-type stars. Solar-like oscillations have already been detected from the ground in about a dozen stars, and the launch of NASA's Kepler mission in April 2009 will unleash a flood of stellar pulsation data. To derive reliable asteroseismic information from these observations, I have developed an automated modeling pipeline in collaboration with Joergen Christensen-Dalsgaard (University of Aarhus), and Orlagh Creevey (Instituto de Astrofisica de las Canarias). Our first application of this tool was to the Sun observed as a star, with no spatial resolution across the surface. The modeling pipeline successfully matched the observed frequencies to better than 0.6 microHz (see figure) and faithfully recovered the known solar properties within reasonable tolerances. We are currently seeking funding from NASA to validate the pipeline using other solar-type stars with various masses and at different evolutionary stages.

Figure caption: *A diagram of the detectable oscillation frequencies from the Sun observed as a star (colored points) with the corresponding frequencies of the optimal model from our automated pipeline (open points). The fit only used the l=0-2 modes between the dashed lines, but it also provides a very good match to the lower frequency and higher degree (l=3) modes.*

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JOHN MICHALAKES

2008 Publications

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. Mon. Wea. Rev., 136, 1990-2005, doi: 10.1175/2007MWR2085.1.

Abstract

Real-time forecasts of five landfalling Atlantic hurricanes during 2005 using the Advanced Research Weather Research and Forecasting (WRF) (ARW) Model at grid spacings of 12 and 4 km revealed performance generally competitive with, and occasionally superior to, other operational forecasts for storm position and intensity. Recurring errors include 1) excessive intensification prior to landfall, 2) insufficient momentum exchange with the surface, and 3) inability to capture rapid intensification when observed. To address these errors several augmentations of the basic community model have been designed and tested as part of what is termed the Advanced Hurricane WRF (AHW) model. Based on sensitivity simulations of Katrina, the inner-core structure, particularly the size of the eye, was found to be sensitive to model resolution and surface momentum exchange. The forecast of rapid intensification and the structure of convective bands in Katrina were not significantly improved until the grid spacing approached 1 km. Coupling the atmospheric model to a columnar, mixed layer ocean model eliminated much of the erroneous intensification of Katrina prior to landfall noted in the real-time forecast.

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MIESCH, MARK

Global MHD modeling of solar and stellar interiors

HAO scientists and colleagues have continued to develop global three-dimensional models of convection and dynamo processes in the Sun and in other stars. Work in the past year has focused in particular on simulations of rapidly-rotating solar-type stars which exhibit modulated convection patterns wherein columnar convective cells group together in one or more localized longitudinal patches outside of which the flow is relatively quiescent. Magnetohydrodynamic (MHD) simulations of such stars exhibit strong dynamo action, with prominent, persistent bands of toroidal flux and quasi-periodic polarity reversals. Our recent solar simulations have demonstrated that the presence of a tachocline of rotational shear has a profound influence on dynamo action in the convective envelope, promoting mean-field generation. Strong toroidal flux structures are formed in the tachocline through turbulent pumping and shear that then feed back on the poloidal field component, enhancing and stabilizing the dipole moment.

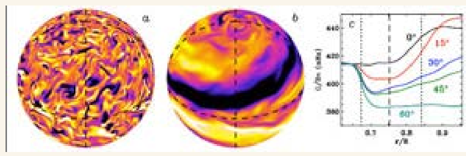
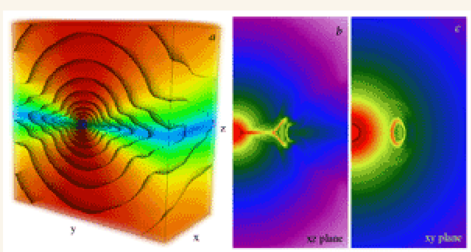


Figure caption: *Turbulent pumping, organization, and amplification of magnetic fields in a simulation of solar convection that incorporates a tachocline of rotational shear. The longitudinal field component is shown in an orthographic projection in (a) the mid convection zone and (b) the tachocline, with dashed lines denoting the equator and two meridians. The field in the convection zone is turbulent whereas the tachocline field is dominated by strong toroidal bands, antisymmetric about the equator. Frame (c) shows the angular velocity as a function of radius at different latitudes as indicated. The dashed line denotes the base of the convection zone while dotted lines denote the horizontal surfaces illustrated in frames (a) and (b).*

MHD Modeling of the Heliosphere



HAO scientists have continued to develop a dynamical model of the Heliosphere based on the FLASH code produced by the University of Chicago. FLASH solves the compressible MHD equations on an adaptive mesh using a finite volume discretization. Current modeling efforts have achieved a three-dimensional solar wind solution with an equatorial current sheet and have begun to investigate the propagation of disturbances through this background wind in order to better understand the evolution of coronal mass ejections. Work is also underway to couple this heliosphere model to numerical models of the underlying solar corona developed at HAO and elsewhere and to coordinate with observers on modeling specific features of the solar minimum corona during the recent Whole Heliosphere Interval (WHI).

Figure caption: *(a) Volume visualization illustrating the computational domain and the background solar wind in a simulation of the heliosphere. The domain extends from 20 solar radii to 1 AU (215 solar radii). Colors represent the radial velocity of the wind, ranging from 250 (blue) to 470 (red) km/s and surfaces represent logarithmic density contours. The magnetic field (not shown) is radially outward in the northern hemisphere and inward in the southern, producing an equatorial current sheet where the wind is relatively slow and dense. Frames (b) and (c) show a simple representation of a coronal mass ejection propagating through this ambient wind. Density images are shown in (b) a meridional plane and (c) the equatorial plane 2.5 days after a pressure pulse was introduced at the inner boundary at the equator.*

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LARRY MILOSHEVICH

2008 Publications

Shephard, M. W., R. L. Herman, B. M. Fisher, K. E. Cady-Pereira, S. A. Clough, V. H. Payne, D. N. Whiteman, J. P. Comer, H. Voemel, L. Miloshevich, R. Forno, M. Adam, G. B. Osterman, A. Eldering, J. R. Worden, L. R. Brown, H. M. Worden, S. S. Kulawik, D. M. Rider, A. Goldman, R. Beer, K. W. Bowman, C. D. Rodgers, M. Luo, C. P. Rinsland, M. Lampel, M. R. Gunson, 2008: Comparison of Tropospheric Emission Spectrometer (TES) nadir water vapor retrievals with in situ measurements. J. Geophys. Res., 113, D15S24, doi: 10.1029/2007JD008822,2008.

Abstract

Comparisons of Tropospheric Emission Spectrometer (TES) water vapor retrievals with in situ measurements are presented. Global comparisons of TES water vapor retrievals with nighttime National Centers for Environmental Prediction RS90/RS92 radiosondes show a small (<5%) moist bias in TES retrievals in the lower troposphere (standard deviation of ~20%), increasing to a maximum of ~15% bias (with standard deviation reaching ~40%) in the upper troposphere. This moist bias with respect to the sonde bias increases to a maximum of ~15% in the upper troposphere between ~300–200 hPa. The standard deviation in this region reaches values of ~40%. It is important to note that the TES reported water vapor comparison statistics are not weighted by the water vapor layer amounts. Global TES/radiosonde results are comparable with the Atmospheric Infrared Sounder reported unweighted mean of 25% and root-mean-square of ~55%. While such global comparisons help to identify general issues, inherent sampling errors and radiosonde measurement accuracy can limit the degree to which the radiosonde profiles alone can be used to validate satellite retrievals. In order to characterize the agreement of TES with in situ measurements in detail, radiance closure studies were performed using data from the Water Vapor Validation Experiment – Satellites/Sondes campaign from July 2006. Results indicate that estimated systematic errors from the forward model, TES measurements, in situ observations, retrieved temperature profiles, and clouds are likely not large enough to account for radiance differences between TES observations and forward model calculations using in situ profiles as input. Therefore, accurate validation of TES water vapor retrievals requires further campaigns with a larger variety of water vapor measurements that better characterize the atmospheric state within the TES field of view.

Suortti, T. M., A. Kats, R. Kivi, N. Kampfer, U. Leiterer, L. Miloshevich, R. Neuber, A. Paukkunen, P. Ruppert, H. Voemel, V. Yushkov, 2008: Tropospheric comparisons of Vaisala radiosondes and balloon-borne frost point and Lyman-alpha hygrometers during the LAUTLOS-WAVVAP experiment. J. Atmos. Ocean. Technol., 25, 149-166, doi: 10.1175/2007JTECHA887.1.

ABSTRACT

The accuracy of all types of Vaisala radiosondes and two types of Snow White chilled-mirror hygrosondes was assessed in an intensive in situ comparison with reference hygrometers. Fourteen nighttime reference comparisons were performed to determine a working reference for the radiosonde comparisons. These showed that the night version of the Snow White agreed best with the references [i.e., the NOAA frost-point hygrometer (FPH) and University of Colorado cryogenic frost-point hygrometer (CFH)], but that the daytime version had severe problems with contamination in the humid upper troposphere. Since the RS92 performance was superior to the other radiosondes and to the day version of the Snow White, it was selected to be the working reference. According to the reference comparison, the RS92 has no bias in the mid- and lower troposphere, with deviations <±5% in relative humidity (RH). In the upper troposphere, the RS92 has a ~5% RH wet bias, which is partly due to the RS92 time lag error and the termination of the heating cycle. It was shown that the time lag effects relating to Vaisala radiosondes can be corrected. Because these were nighttime comparisons, they can be considered to be free from solar radiation effects. Neither the radiosondes nor the Snow White succeeded in reproducing reference class hygrometer profiles in the stratosphere.

According to the 29 radiosonde intercomparisons, the RS92 and the modified RS90 (FN) had the best mutual agreement and no bias. The disagreement is largest (<±10% RH) at low temperatures (T « -30°C), where the FN underestimated (overestimated) in high (low) ambient RH. In comparison with the RS92, the RS90 had a semilinearly increasing wet bias with decreasing temperature, where the bias was ~10% RH at -60°C. The RS80-A suffers from a large temperature-dependent dry bias in high RH conditions, being over 30% RH at -60°C and ~5% RH near 0°C. The RS80-A dry bias can be almost totally removed with the correction algorithm by Leiterer et al., which was chosen as the best available. The other approach tested tends to overcorrect in high RH conditions when T < -50°C. For T > -30°C it is ineffective and does not correct the RS80-A dry bias in high ambient RH.

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CHIN-HOH MOENG

2008 Publications

Kim, S.-W., C.-H. Moeng, J. C. Weil, M. C. Barth, 2007: Comment on "Fumigation of pollutants in and above the entrainment zone into a growing convective boundary layer: A large-eddy simulation". Atmos. Environ., 41, 7679-7682, doi: 10.1016/j.atmosenv.2007.07.017.3

Abstract

The performance of two-way nesting for large-eddy simulation (LES) of PBL turbulence is investigated using the Weather Research and Forecasting (WRF) model frame- work. A pair of LES-within-LES experiments are performed where a finer-grid LES covering a smaller horizontal domain is nested inside a coarser-grid LES covering a larger horizontal domain. Both LESs are driven under the same environmental conditions, allowed to interact with each other, and expected to behave the same statistically. The first experiment of the free convective PBL reveals a mean temperature bias between the two LES domains, which generates a none zero mean vertical velocity in the nest domain while the mean vertical velocity averaged over the outer domain remains zero. The problem occurs when the horizontal extent of the nest domain is too small to capture an adequate sample of energy-containing eddies; this problem can be alleviated using a nest domain that is at least five times the PBL depth in both x and y. The second experiment of the neutral PBL exposes a bias in the prediction of the surface stress between the two LES domains, which is found due to the grid dependence of Smagorinsky type subgrid-scale (SGS) model. A new two-part SGS model is developed to solve this problem.

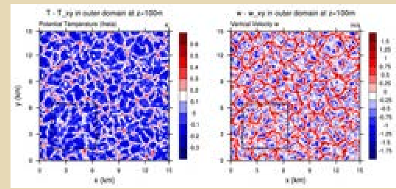

Figure 1: Contours of potential temperature (left) and vertical velocity (right) fluctuations at z=100 m from the two-way nest WRF-LES of a shear-free convective boundary layer. The squared box shows the inner-domain LES which has a three-times finer grid spacing compared to the outer-domain LES. Both LESs, forced by the same large-scale condition, generate similar turbulent flow fields that blend smoothly across the nest boundaries.

High resolution figure

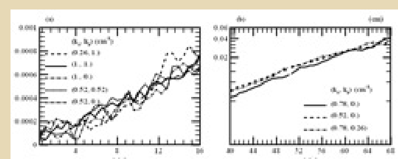

Figure 2: Time evolutions of wave amplitudes of (a) the five fastest growth waves at early stage, and (b) the three fastest growth waves at late stage. Note that linear coordinate is used in (a) but exponential coordinate in (b).

High resolution figure

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MITCHELL MONCRIEFF

2008 Publications

Lane, T. P., M. W. Moncrieff, 2008: Stratospheric gravity waves generated by multiscale tropical convection. J. Atmos. Sci., 65, 2598-2614, doi: 10.1175/2007JAS2601.1.

ABSTRACT

The generation of gravity waves by multiscale cloud systems evolving in an initially motionless and thermodynamically uniform environment is explored using a two-dimensional cloud-system-resolving model. The simulated convection has similar depth and intensity to observed tropical oceanic systems. The convection self-organizes into preferred horizontal and temporal scales involving weakly organized propagating cloud clusters. The multiscale systems generate a broad spectrum of gravity waves with horizontal scales that range from the cloud-system scale up to the cloud-cluster scale. The gravity waves with the largest horizontal scale play an important role in modifying layered tropospheric inflow and outflow to the cloud systems, which in turn influence the multiscale convective organization. Slower-moving short-scale gravity waves make the strongest individual contribution to the vertical flux of horizontal momentum and cause a robust peak in the momentum flux spectrum that corresponds to the lifetime and spatial scale of the individual cloud systems.

Liu, C.-H., M. W. Moncrieff, J. D. Tuttle, 2008: A note on propagating rainfall episodes over the Bay of Bengal. Quart. J. Roy. Meteor. Soc., 134, 787-792.3

Abstract

An observational analysis of precipitation episodes over the Bay of Bengal and the adjacent coastal region is conducted using the TRMM Real-Time Multi-Satellite Precipitation Analysis (MPA-RT) products for three warm seasons (i.e. May to September for 2002-2004). Time-distance diagrams (Hovmüller diagrams) of rainfall episodes reveal frequent travelling precipitation episodes having lifetimes greatly exceeding those of individual convective systems. The majority of the episodes translate southward and many do not appear to have a steering level (i.e. they propagate in a hydraulic-like manner), unlike those previously documented over midlatitude and tropical continents which usually have a steering level. On average, the coherent systems have a latitudinal span of 5 degrees and a 1-day duration and a meridional propagation speed of 8 m s-1, approximately. The episodes mostly initiate over the coastal land around midday and offshore around midnight.

Das, S., R. Ashrit, M. W. Moncrieff, M. Dasgupta, J. Dudhia, C. Liu, S. R. Kalsi, 2007: Simulation of intense organized convective precipitation observed during the Arabian Sea Monsoon Experiment (ARMEX). J. Geophys. Res. - Atmos., 112, D20117, doi: 10.1029/2006JD007627.

Abstract

We examine a deep precipitating system that formed over the west coast of India during 26–28 June 2002 producing heavy rainfall of 2–61 cm day-1. The system developed into a well-marked low pressure area due to interaction between an eastward moving westerly trough and a westward moving monsoon low. We used the PSU/NCAR Mesoscale Model (MM5) to make 10-day interactively nested simulations at 90, 30, and 10 km grid-resolutions. We used observations from a special data set collected during an Arabian Sea Monsoon Experiment (ARMEX) conducted June–August, 2002. Nudging the observations produced a balanced atmosphere which, in turn, matched the location of vortex with cloud clusters observed from satellite. The simulated rainfall corresponded well with observations. We then use the simulated fields as forcing and boundary conditions for MM5 run in cloud-system resolving mode at 2 km grid-resolution to detail cloud-clusters embedded within the monsoon disturbance. We examined the sensitivity to different physical parameterizations and also the effect of continuous nudging four dimensional data assimilation (FDDA) on the rainfall forecasts. While the simulation of the convective event improved with certain combinations of physical parameterizations, the rainfall was not forecasted at the correct location, no matter which parameterization was used, unless continuous FDDA was performed in all domains throughout the integrations. Finally, cloud-cluster properties of the cloud-system resolving simulations were compared with observations.

MMM Research Catalog

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MITCH MONCRIEFF

General Information

MMM - TIIMES
Senior Scientist
Water System - THORPEX - WCI - Gravity Waves

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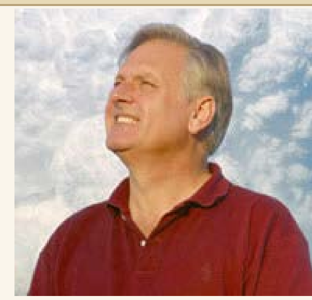

Research Focus FY08:

Numerical simulation and dynamical theory of precipitating convection, its multi-scale organization, and cross-scale interaction; parameterization of convective organization in global models; dynamical mechanisms associated with the atmospheric water and energy cycles; convection-wave interaction in the Tropics with emphasis on the Madden-Julian Oscillation (MJO); tropical-midlatitude interaction associated with THe Operational Research and Predictability EXperiment (THORPEX); collaboration with various international programs.

Community Service FY08:

- WCRP/CLIVAR MJO Working Group
- Deutsche Forschungsgemeinschaft Review Board
- NASA CloudSat Application Advisory Group
- Co-Chair: Year of Tropical Convection (YoTC) Planning Group of THORPEX-WCRP
- Co-Chair: MJO Focus Theme of CMMAP, Multiscale Modeling Framework (MMF), Colorado State University
- Adjunct Professor: Colorado State University
- Graduate Advisor: Ray Pallav, University of Miami
- Graduate Advisor: Gregory Elsaesser, Colorado State University

Scientific Talks FY08:

- Meso-convective organization in GCMs and CRMs: What's represented and what's not (Reading, GBR, 10/2007)
- Year of Tropical Convection (YOTC) (Reading, GBR, 10/2007)
- Challenges in the simulation of organized convection (London, GBR, 12/2007)
- Scientific Background to YOTC (Arlington, VA USA, 11/2007)
- Multiscale modeling at NCAR (Irvine, CA USA, 11/2007)
- Progress in the MJO Focus Theme (Los Angeles, CA USA, 01/2008)
- The Year of Tropical Convection (Seattle, WA USA, 08/2008)
- The Year of Tropical Convection (Geneva, CHE, 07/2008)

Publications FY08 (abstracts):

Donner, L., J. Gottschalck, H. Hendon, W. Higgins, I. Kang, E. Maloney, M. Moncrieff, S. Schubert, K. Sperber, W. Stern, F. Vitard, D. Waliser, B. Wang, W. Wang, K. Weickmann, M. Wheeler, S. Woolnough, C. Zhang, 2008: MJO simulation diagnostics. *J. Climate (CLIVAR special issue)*. (Submitted)

Lane, T. P., M. W. Moncrieff, 2008: Stratospheric gravity waves generated by multiscale tropical convection. *J. Atmos. Sci.*, **65**, 2598-2614, doi: 10.1175/2007JAS2601.1.

Tao, W.-K., M. Moncrieff, 2008: Status and prospects of cloud-system resolving modeling. *Rev. of Geophysics*. (Submitted)

Liu, C.-H., M. Moncrieff, 2008: Explicitly simulated tropical convection over idealized warm pools. *J. Geophys. Res.*. (Submitted)

Lamptey, B. L., R. E. Pandya, T. T. Warner, R. Boger, R. T. Bruintjes, P. A. Kucera, A. Laing, M. Moncrieff, M. K. Ramamurthy, T. C. Spangler, M. Weingroff, 2008: The UCAR Africa Initiative. *Bull. Amer. Meteor. Soc.*, doi: 10.1175/2008BAMS2452.1. (In Press)

Liu, C.-H., M. W. Moncrieff, J. D. Tuttle, 2008: A note on propagating rainfall episodes over the Bay of Bengal. *Quart. J. Roy. Meteor. Soc.*, **134**, 787-792.

Yoksas, T., R. Bruintjes, G. B. Foote, S. Heck, S. Herrmann, E. B. Hoswell, P. A. Kucera, A. G. Laing, B. Lamptey, M. Moncrieff, R. Pandya, M. Ramamurthy, R. Roberts, W. M. Spangler, T. T. Warner, M. Weingroff, 2008: The UCAR Africa Initiative - overview and update. *Conf. on Intl. Topics*, New Orleans, LA, US, American Meteorological Society.

Das, S., R. Ashrit, M. W. Moncrieff, M. Dasgupta, J. Dudhia, C. Liu, S. R. Kalsi, 2007: Simulation of intense organized convective precipitation observed during the Arabian Sea Monsoon Experiment (ARMEX). *J. Geophys. Res. - Atmos.*, **112**, D20117, doi: 10.1029/2006JD007627.

Mitch Moncrieff Research Catalog

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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HUGH MORRISON

2008 Publications

Morrison, H., A. Gettelman, 2008: A new two-moment bulk stratiform cloud microphysics scheme in the Community Atmosphere Model, version 3 (CAM3). Part I: Description and numerical tests. J. Climate, 21, 3642-3659, doi: 10.1175/2008JCLI2105.1.

ABSTRACT

A new two-moment stratiform cloud microphysics scheme in a general circulation model is described. Prognostic variables include cloud droplet and cloud ice mass mixing ratios and number concentrations. The scheme treats several microphysical processes, including hydrometeor collection, condensation/evaporation, freezing, melting, and sedimentation. The activation of droplets on aerosol is physically based and coupled to a subgrid vertical velocity. Unique aspects of the scheme, relative to existing two-moment schemes developed for general circulation models, are the diagnostic treatment of rain and snow number concentration and mixing ratio and the explicit treatment of subgrid cloud water variability for calculation of the microphysical process rates.

Numerical aspects of the scheme are described in detail using idealized one-dimensional offline tests of the microphysics. Sensitivity of the scheme to time step, vertical resolution, and numerical method for diagnostic precipitation is investigated over a range of conditions. It is found that, in general, two substeps are required for numerical stability and reasonably small time truncation errors using a time step of 20 min; however, substepping is only required for the precipitation microphysical processes rather than the entire scheme. A new numerical approach for the diagnostic rain and snow produces reasonable results compared to a benchmark simulation, especially at low vertical resolution. Part II of this study details results of the scheme in single-column and global simulations, including comparison with observations.

Gettelman, A., H. Morrison, S. J. Ghan, 2008: A new two-moment bulk stratiform cloud microphysics scheme in the Community Atmosphere Model, Version 3 (CAM3). Part II: Single-column and global results. J. Climate, 21, 3660-3679, doi: 10.1175/2008JCLI2116.1.

ABSTRACT

The global performance of a new two-moment cloud microphysics scheme for a general circulation model (GCM) is presented and evaluated relative to observations. The scheme produces reasonable representations of cloud particle size and number concentration when compared to observations, and it represents expected and observed spatial variations in cloud microphysical quantities. The scheme has smaller particles and higher number concentrations over land than the standard bulk microphysics in the GCM and is able to balance the top-of-atmosphere radiation budget with 60% the liquid water of the standard scheme, in better agreement with retrieved values. The new scheme diagnostically treats both the mixing ratio and number concentration of rain and snow, and it is therefore able to differentiate the two key regimes, consisting of drizzle in shallow, warm clouds and larger rain drops in deeper cloud systems. The modeled rain and snow size distributions are consistent with observations.

Morrison, H., W. W. Grabowski, 2008: A novel approach for representing ice microphysics in models: description and tests using a kinematic framework. J. Atmos. Sci., 65, 1528-1548, doi: 10.1175/2007JAS2491.1.

ABSTRACT

This paper documents the development of a novel approach for representing ice microphysics in numerical models. In this approach, the ice particle mass–dimension and projected-area–dimension relationships vary as a function of particle size and rimed mass fraction. All ice microphysical processes and parameters are calculated in a self-consistent manner in terms of these mass–dimension and area–dimension relationships. The rimed mass fraction is predicted locally by separately predicting the ice mixing ratios acquired through water vapor deposition and through riming. The third predicted variable is the number concentration of ice particles. This approach allows representing in a natural way the gradual transition from small to large ice particles due to growth by water vapor deposition and aggregation and from unrimed crystals to graupel due to riming. In traditional approaches, these processes are treated by separating ice particles into predefined categories (such as cloud ice, snow, and graupel) using fairly arbitrary thresholds and conversion rates. With some modifications, the new approach can be employed in either bin or bulk microphysical models.

In this paper, the new approach is implemented in a bulk two-moment microphysical scheme representing both warm-rain and ice processes and it is applied to an idealized 2D kinematic framework mimicking a shallow mixed-phase cumulus. The size distributions of cloud droplets, drizzle/rain drops, and ice particles are represented using gamma distributions. The new scheme is compared to a version of the scheme that uses the traditional approach for ice microphysics; that is, unrimed ice/snow and graupel are separate species, with threshold-based conversion rates between the former and the latter. The new and traditional schemes produce similar results, although the traditional scheme, unlike the new scheme, produces a distinct double maximum in the surface precipitation rate, corresponding to precipitation shafts consisting of either ice/snow or graupel. The relative magnitude of these peaks, as well as the ice water path and optical depth of the simulated cloud, is highly sensitive to the threshold for converting unrimed ice to graupel. In contrast, the new scheme does not require any conversion threshold and predicts formation of ice particles with wide range of rimed fractions.

Luo, Y., K.-M. Xu, H. Morrison, G. McFarquhar, 2008: Arctic mixed-phase clouds simulated by a cloud-resolving model: Comparison with ARM observations and sensitivity to microphysics parameterization. J. Atmos. Sci., 65, 1285-1303, doi: 10.1175/2007JAS2467.1.

ABSTRACT

Single-layer mixed-phase stratiform (MPS) Arctic clouds, which formed under conditions of large surface heat flux combined with general subsidence during a subperiod of the Atmospheric Radiation Measurement (ARM) Program's Mixed-Phase Arctic Cloud Experiment (MPACE), are simulated with a cloud-resolving model (CRM). The CRM is implemented with either an advanced two-moment [Morrison et al. (MCK)] or a commonly used one-moment [Lin et al. (LFO)] bulk microphysics scheme and a state-of-the-art radiative transfer scheme.

The MCK simulation, which uses the two-moment scheme and observed aerosol size distribution and ice nulei (IN) number concentration, reproduces the magnitudes and vertical structures of cloud liquid water content (LWC), total ice water content (IWC), and number concentration and effective radius of cloud droplets as suggested by the MPACE observations. The simulation underestimates ice crystal number concentrations by an order of magnitude and overestimates effective radius of ice crystals by a factor of 2–3. The LFO experiment, which uses the one-moment scheme, produces values of liquid water path (LWP) and ice plus snow water path (ISWP) that were about 30% and 4 times, respectively, those produced by MCK. The vertical profile of IWC exhibits a bimodal distribution in contrast to the constant distribution of IWC produced in MCK and observations.

A sensitivity test that uses the same ice–water saturation adjustment scheme as in LFO produces cloud properties that are more similar to the LFO simulation than MCK. The mean value of the intercept parameter of snow size spectra (N0s) from MCK is one order of magnitude smaller than that assumed in LFO. A sensitivity test that prescribes the larger LFO N0s results in 20% less LWP and 5 times larger snow water path than that in MCK. When an exponential ice size distribution replaces the gamma size distribution in MCK, the ISWP decreases by 70% but the LWP increases by 7% versus that in the MCK. Increasing the IN number concentration from the observed value of 0.16 to 3.2 L-1 forces the MPS clouds to become glaciated and dissipate, but the simulated ice number concentration agrees initially with the observations better. Physical explanations for these quantitative differences are provided. It is further shown that the differences between the LFO and MCK results are larger than those due to the estimated uncertainties in the prescribed surface fluxes. Additional observations and simulations of a variety of cases are required to further narrow down uncertainties in the microphysics schemes.

Morrison, H., W. W. Grabowski, 2008: Modeling supersaturation and subgrid-scale mixing with two-moment bulk warm microphysics. J. Atmos. Sci., 65, 792-812, doi: 10.1175/2007JAS2374.1.

ABSTRACT

This paper describes further developments of a two-moment warm rain bulk microphysics scheme suitable for addressing the indirect impact of atmospheric aerosols on ice-free clouds in large-eddy simulation (LES) models. The emphasis is on the prediction of supersaturation, activation of cloud droplets, and the representation of microphysical transformations during parameterized turbulent mixing. A comprehensive approach is proposed that is capable of simulating droplet activation at the cloud base, in the cloud interior due to increasing updraft strength, and at the lateral edges due to entrainment. Such an approach requires high spatial resolution to capture maximum supersaturation at cloud base as well as to resolve entraining eddies that lead to additional activation above the cloud base. This approach can be used as a benchmark for developing and testing schemes suitable for lower spatial resolutions.

A novel approach for predicting the supersaturation field is proposed, with an emphasis on its application in an Eulerian framework. This approach produces consistency among the thermodynamic variables and mitigates the problem of spurious cloud-edge supersaturation noted in the past. A new subgrid scheme is also developed to treat microphysical transformations during turbulent entrainment and mixing. This scheme is designed to be as flexible as possible, allowing for the entire range of mixing scenarios from homogeneous to extremely inhomogeneous.

The above developments are applied in 2D simulations of moist convection for an idealized rising thermal, assuming either pristine or polluted aerosol conditions. The mixing scenario has a substantial impact on the cloud microphysical and optical properties. As expected, extremely inhomogeneous mixing results in substantially smaller mean droplet number concentration, larger effective radius, and smaller cloud optical depth compared to the run with homogeneous mixing. The subgrid mixing of cloud condensation nuclei (CCN) and formation of CCN from evaporated droplets during extremely inhomogeneous mixing are relatively less important for this case.

Grabowski, W. W., H. Morrison, 2008: Toward the mitigation of spurious cloud-edge supersaturation in cloud

models. Mon. Wea. Rev., 136, 1224-1234, doi: 10.1175/2007MWR2283.1.

ABSTRACT

This paper presents a straightforward approach to mitigate the problem of spurious cloud-edge supersaturation in high-spatial-resolution cloud models (e.g., moist large-eddy simulation models). The central idea, following a 1989 J. Atmos. Sci. paper by Grabowski, is that supersaturation predicted by the supersaturation equation should be used to adjust the temperature and moisture solutions, rather than the other way around as in the standard approach in cloud modeling, where the temperature and moisture solutions are used to diagnose the supersaturation. Details of the adjustment scheme are discussed and illustrated through simple one-dimensional tests applying a two-moment warm-rain microphysics scheme that predicts the in-cloud supersaturation. Extension of this approach to bin microphysics models is also outlined.

Morrison, H., J. O. Pinto, J. A. Curry, G. M. McFarquhar, 2008: Sensitivity of modeled arctic mixed-phase stratocumulus to cloud condensation and ice nuclei over regionally-varying surface conditions. J. Geophys. Res., 113, D05203, doi: 10.1029/2007JD008729.

Abstract

A two-moment microphysics scheme implemented in the polar version of the mesoscale model MM5 is used to simulate a mixed-phase stratocumulus deck observed during the Fall 2004 Mixed-Phase Arctic Cloud Experiment (MPACE). In situ aircraft instrumentation and remote sensors gathered extensive microphysical and radiative data that serve as a testbed for the model. Model results are reasonably similar to observations in terms of the liquid microphysical properties, while the ice microphysical properties are more significantly biased, especially the ice crystal concentration. Sensitivity tests examine the impact of increased cloud condensation and ice nucleus concentrations. Increasing the concentration of cloud condensation nuclei to values typical for polluted ‘Arctic haze’ conditions substantially reduces the mean droplet size, but has little impact on the downwelling longwave flux because the cloud already emits as a blackbody (except near the Arctic Ocean pack ice edge). However, the smaller droplet size does lead to a slight increase in liquid water path and more significant decrease (~50%) in the ice water path and snowfall rate due to reduced collision-coalescence and riming of snow by droplets. Increasing the ice nucleus concentration specified from MPACE observations by 1–2 orders of magnitude produces a substantial reduction in liquid water path and downwelling longwave flux at the surface over interior northern Alaska, but has less impact over the open ocean and coastal regions. However, a large discrepancy between the observed ice nucleus and ice crystal concentrations, leading to the under-prediction of simulated crystal concentration, also suggests that additional ice initiation mechanisms (not included in current models) may have occurred in the real cloud layer.

Luo, Y., K.-M. Xu, H. Morrison, G. McFarquhar, Z. Wang, G. Zhang, 2008: Multi-layer arctic mixed-phase clouds simulated by a cloud-resolving model: Comparision with ARM observations and sensitivity experiments. J. Geophys. Res., 113, D12208, doi: 10.1029/2007JD009563.

Abstract

A cloud-resolving model (CRM) is used to simulate the multiple-layer mixed-phase stratiform (MPS) clouds that occurred during a three-and-a-half day subperiod of the Department of Energy-Atmospheric Radiation Measurement Program's Mixed-Phase Arctic Cloud Experiment (M-PACE) and to examine physical processes responsible for multilayer production and evolution. The CRM with a two-moment cloud microphysics is initialized with concurrent meteorological, aerosol, and ice nucleus measurements and is driven by time-varying large-scale advective tendencies of temperature and moisture and surface sensible and latent heat fluxes. The CRM reproduces the dominant occurrences of the single- and double-layer MPS clouds as revealed by the M-PACE observations although the simulated first cloud layer is lower and the second cloud layer is thicker compared to observations. The aircraft measurements suggest that the CRM qualitatively captures the major characteristics in the vertical distribution and interperiod variation of liquid water content (LWC), droplet number concentration, total ice water content (IWC), and ice crystal number concentration (nis). However, the magnitude of LWC is overestimated and those of IWC and nis are underestimated. In particular, the simulated nis is one order of magnitude smaller than the observed. Sensitivity experiments suggest that both the surface fluxes and large-scale advection control the formation of the lower cloud layer while the large-scale advection initiates the formation of the upper cloud layer but the maintenance of multilayer structures relies on the longwave (LW) radiative effect. The LW cooling near cloud top produces a more saturated environment and a stronger dynamical circulation while cloud base radiative warming of the upper layer creates the stability gap between the two cloud layers. Both cloud layers are sensitive to ice-forming nuclei number concentration since ice-phase microphysics provides a strong sink of cloud liquid water mass.

MMM Research Catalog

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REBECCA MORSS

2008 Publications

Morss, R. E., J. K. Lazo, B. G. Brown, H. E. Brooks, P. T. Ganderton, B. N. Mills, 2008: Societal and economic research and applications priorities for the North American THORPEX program. Bull. Amer. Meteor. Soc., 89 (3), 335-346, doi: 10.1175/BAMS-89-3-335.

Abstract

Societal and economic research and applications can significantly improve understanding of weather–society interactions, benefiting the meteorological community and society.

Morss, R. E., F. Zhang, 2008: Linking meteorological education to reality: a prototype undergraduate research study of public response to Hurricane Rita forecasts. Bull. Amer. Meteor. Soc., 89, 497-504, doi: 10.1175/BAMS-89-4-497.

Abstract

Collaborative research motivated by student interest can advance interdisciplinary knowledge, introduce students to societal perspectives on science, and provide unique educational experiences.

Zhang, F., R. E. Morss, J.-L. A. Sippel, T. K. Beckman, N. C. Clements, N. L. Hampshire, J. N. Harvey, J. M. Hernandez, Z. C. Morgan, R. M. Mosier, S. Wang, S. D. Winkley, 2007: An in-person survey investigating public perceptions of and response to Hurricane Rita forecasts along the Texas coast. Wea. Forecasting, 22, 1177-1190.

Demuth, J. L., E. Gruntfest, R. E. Morss, S. Drobot, J. K. Lazo, 2007: Weather and society * Integrated studies (WAS*IS): building a community for integrating meteorology and social science. Bull. Amer. Meteor. Soc., 88 (1), 1729-1737.

BSTRACT

Weather and Society*Integrated Studies (WAS*IS) is a grassroots movement to change the weather enterprise by comprehensively and sustainably integrating social science into meteorological research and practice. WAS*IS is accomplishing this by establishing a framework for a) building an interdisciplinary community of practitioners, researchers, and stakeholders who are dedicated to the integration of meteorology and social science, and b) providing this community with a means to learn and further examine ideas, methods, and examples related to integrated weather–society work.

In its first year, WAS*IS focused on achieving its mission primarily through several workshops. Between July 2005 and August 2006, there were three WAS*IS workshops with a total of 86 selected participants. The workshops focused on the following: laying the groundwork for conducting interdisciplinary work, teaching basic tools and concepts relevant to integrated weather–society efforts, using real-world examples to learn about effective integrated work, and developing opportunities and relationships for doing WAS*IS-type work. By emphasizing the importance of developing a lifelong cohort, as well as helping participants learn and apply social science tools and concepts, WAS*IS can address societal impacts of weather in powerful and sustained ways.

This article discusses the need and motivation for creating WAS*IS; the development, scope, and implementation of WAS*IS through summer of 2006; and WAS*IS-related outcomes thus far, as well as future prospects of the WAS*IS

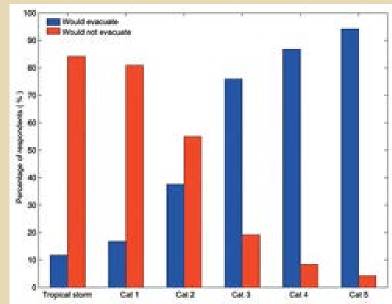

Figure 1: Percentage of respondents who would (blue) and would not (red) evacuate their household if local authorities recommended evacuation because of the storm conditions indicated on the x axis (tropical storm and category 1-5 hurricane). Results are shown as a percentage of all respondents (including those who did not provide a response for each hypothetical storm condition).

High resolution figure

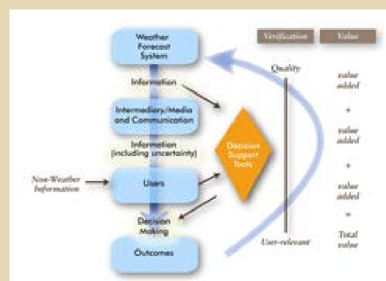

Figure 2: Simplified model of the chain from forecast creation to value realization and the five SERA priority themes.

High resolution figure

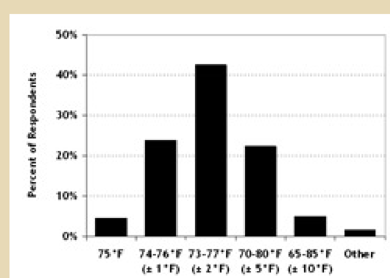

Figure 3: Respondents' expectations of tomorrow's actual high temperature, given a forecast high temperature of 75�F (survey Q13, N=1465).

movement.

High resolution figure

Morss, R. E., E. Wahl, 2007: An ethical analysis of hydrometeorological prediction and decision making: The case of the 1997 Red River flood. Environ. Hazards, 7, 342-352, doi: 10.1016/j.envhaz.2007.09.004.

Abstract

Weather, climate, and flood predictions are incorporated into human decisions in a wide variety of situations, including decisions related to hazardous hydrometeorological events. This article examines ethical aspects of such predictions and decisions, focusing on the case of the 1997 Red River flood in Grand Forks, North Dakota and East Grand Forks, Minnesota (US). The analysis employs a formal ethical framework and analytical method derived from medical and business ethics. The results of the analysis highlight issues related to forecast generation, communication of forecast meaning and uncertainty, responsibility for the use of forecasts in decision making, and trade-offs between the desire for forecast certainty and the risk of missed events. Implications of the analysis for the broader arenas of weather, climate, and flood prediction and disaster management are also discussed.

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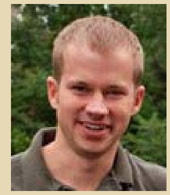
CGD 2008 PROFILES IN SCIENCE: DR. RICH NEALE

Summary of achievements



Rich Neale

The role of convection is central to the mean tropical climate and the fundamental observed modes of tropical variability. Efforts to enhance the role of free-troposphere humidity and reduce the role of boundary layer forcing in the existing deep convection parameterization in CCSM provide more realistic convective event evolution in simplified IOP forced models. Including these modifications to the representation of deep convection in CCSM leads to a better simulation of El Nino (Neale et al. 2008) in terms of frequency, intermittency and most strikingly global sea-surface temperature correlation patterns. The benefits of improved tropical convective parameterization also extend to the representation of the diurnal cycle of rainfall, the evolution of the Asian Monsoon, the sub-surface tropical Pacific temperature anomaly distribution during El Nino events and sub-seasonal variability due to the Madden Julian Oscillation (MJO).

Ongoing work is examining the relationship between precipitation and tropospheric humidity distributions. Studies have shown a significant pick-up in observed TRMM ocean precipitation rates at particular threshold values of mean tropospheric humidity that are not seen in high-resolution CCSM integrations. One possible explanation for this missing relationship is the absence of sub-grid scale organized convection in CCSM. Efforts to include a simple parameterization of convective organization in order to mimic the observed pick-up behavior are in progress and initial experiments have lead to further imporvements in the diurnal cycle of tropical ocean precipitation.

Publications

Neale, R. B._, M. Jochum and J. H. Richter, 2008: The impact of convection on ENSO: From a delayed oscillator to a series of events. doi:10.1175/2008JCLI2244.1, in press.

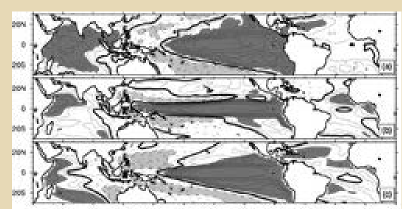


Figure 1.

High resolution figure

Abstract: The NCAR-Community Climate System Model (CCSM3) exhibits persistent errors in its simulation of the El Niño Southern Oscillation (ENSO) mode of coupled variability. The amplitude of the oscillation is too strong, the dominant 2-year period too regular and the width of the Sea Surface Temperature (SST) response in the Pacific too narrow, with positive anomalies extending too far into the western Pacific. Two changes in the parameterization of deep convection result in a significant improvement to many aspects of the ENSO simulation. The inclusion of Convective Momentum Transports (CMT) and a dilution approximation for the calculation of Convective Available Potential Energy (CAPE) are used in development integrations and a striking improvement in ENSO characteristics is seen. An increase in the periodicity of ENSO is achieved by a reduction in the strength of the existing "short-circuited" delayed-oscillator mode. The off-equatorial response is weaker and less tropically confined, largely as a result of the CMT and an associated redistribution of zonal momentum. The Pacific east-west structure is improved in response to the presence of convective dilution and cooling provided by increased surface fluxes. The initiation of El Niño events is fundamentally different. Enhanced intra-seasonal surface stress variability leads to absolute surface westerlies and a cooling-warming dipole between the Philippine Sea and western Pacific. Lag-regression analysis shows intra-seasonal variability may play a significant role in event initiation and maintenance as opposed to being a benign response to increased SSTs. Recent observational evidence appears to support such a leading relationship.

Figure caption: Lag-zero correlation of nino-3.4 and tropical SST anomalies for (a) HadISST, (b) C3OLD, and (C) C3NEW (contour interval is 0.1, and a correlation of >0.3 (filled contours) is significant at the 95% level for a conservative estimate of 40 degrees of freedom).

Field, P.R., A. Gettleman, R. B. Neale, R. Wood, P. J. Rasch, and H. Morrison, 2008: Midlatitude cyclone compositing to constrain climate model behavior using satellite observations. J. Climate, doi:10.1175/2008JCLI2235.1, in press.

Abstract: Identical composite analysis of midlatitude cyclones over oceanic regions has been carried out on both output from the NCAR (National Center for Atmospheric Research) CAM3 (Community Atmosphere Model version 3) and

multi-sensor satellite data. By focusing on mean fields associated with a single phenomenon we critically appraise the ability of the CAM3 to reproduce realistic midlatitude cyclones. A number of perturbations to the control model were tested against observations, including a candidate new microphysics package for the CAM. The new microphysics removes the temperature dependent phase determination of the old scheme and introduces representations of microphysical processes to convert from one phase to another and from cloud to precipitation species. By subsampling composite cyclones based on system-wide mean strength (mean wind speed) and system-wide mean moisture we believe we are able to make meaningful like-with-like comparisons between observations and model output. We find that all variations of the CAM tested overestimate the optical thickness of high-topped clouds in regions of precipitation. Over a system as a whole, the model can both over- and underestimate total high-topped cloud amounts. However, system-wide mean rainfall rates and composite structure appears to be in broad agreement with satellite estimates. When cyclone strength is taken into account, changes in moisture and rainfall rates from both satellite derived observations and model output as a function of changes in sea surface temperature are in accordance with the Clausius-Clapeyron equation. We find that the proposed new microphysics package shows improvement to composite liquid water path fields and cloud amounts.

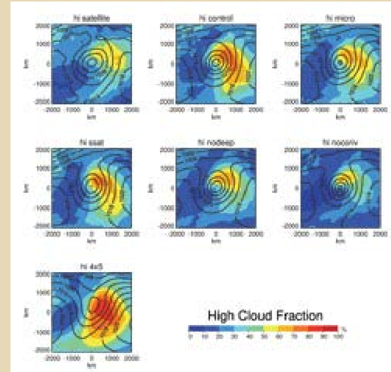


Figure 2.

High resolution figure

Figure caption: High-top (cloud top pressure <440 mb) composite cloud fraction in each 100km x 100km grid cell for the satellite observations and different model configurations. The 4000km x 4000km domain composite is for the medium moisture, greatest strength category generated from cyclones taken from all four oceanic regions for 2003-2004. The composite sea level pressure is overplotted (mb, solid lines)).

Bala, G., R.B. Rood, A. Mirin, J. McClean, K. Achutarao, D. Bader, P. Gleckler, R. Neale, and P. Rasch, 2008: Evaluation of a CCSM3 Simulation with a Finite Volume Dynamical Core for the Atmosphere at 1° Latitude × 1.25° Longitude Resolution. J. Climate, 21, 1467-1486.

Abstract: A simulation of the present-day climate by the Community Climate System Model version 3 (CCSM3) that uses a Finite Volume (FV) numerical method for solving the equations governing the atmospheric dynamics is presented. The simulation is compared to observations and to the well-documented simulation by the standard CCSM3, which uses the Eulerian spectral method for the atmospheric dynamics. The atmospheric component in the simulation herein uses a 1° latitude × 1.25° longitude grid, which is a slightly finer resolution than the T85-grid used in the spectral transform. As in the T85 simulation, the ocean and ice models use a nominal 1-degree grid. Although the physical parameterizations are the same and the resolution is comparable to the standard model, substantial testing and slight retuning were required to obtain an acceptable control simulation. There are significant improvements in the simulation of the surface wind stress and sea surface temperature. Improvements are also seen in the simulations of the total variance in the tropical Pacific, the spatial pattern of ice thickness distribution in the Arctic, and the vertically integrated ocean circulation in the Antarctic Circumpolar Current. The results herein demonstrate that the FV version of the CCSM coupled model is a state-of-the-art climate model whose simulation capabilities are in the class of those used for Intergovernmental Panel on Climate Change (IPCC) assessments. The simulated climate is very similar to that of the T85 version in terms of its biases, and more like the T85 model than the other IPCC models.

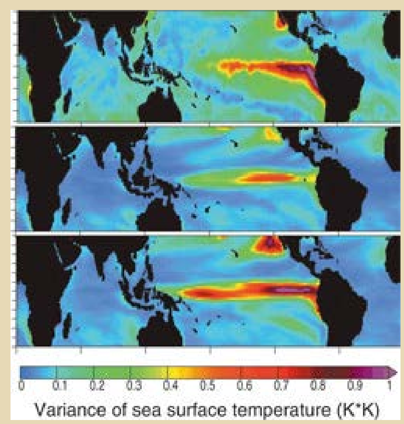


Figure 3.

High resolution figure

Figure caption: The total variance of the sea surface temperature (K^2) computed from the annual means of the (top) HadISST dataset (Rayner et al. 2003), and CCSM3 (middle) T85 and (bottom) FVx1 simulations.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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RICH NEALE

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Research Focus FY08:

The role of convection is central to the mean tropical climate and the fundamental observed modes of tropical variability. Efforts to enhance the role of free-troposphere humidity and reduce the role of boundary layer forcing in the existing deep convection parameterization in Community Climate System Model (CCSM) provide more realistic convective event evolution in simplified IOP forced models. Including these modifications to the representation of deep convection in CCSM leads to a better simulation of El Nino (Neale et al. 2008) in terms of frequency, intermittency and most strikingly global sea-surface temperature correlation patterns. The benefits of improved tropical convective parameterization also extend to the representation of the diurnal cycle of rainfall, the evolution of the Asian Monsoon, the sub-surface tropical Pacific temperature anomaly distribution during El Nino events and sub-seasonal variability due to the Madden Julian Oscillation (MJO).

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Scientific Talks FY08:

- CCSM3.5+ Coupled Experiments (Boulder, CO USA, 02/2008)
- Convection in an NCAR Earth System Model (ESM) (Boulder, CO USA, 04/2008)
- Current Plans for the Atmospheric Component of CCSM4 (CAM4) (Boulder, CO USA, 06/2008)
- ENSO in CCSM3.5 (Boulder, CO USA, 12/2007)
- High Resolution CAM in CCSM (Boulder, CO USA, 12/2007)
- Leveraging Sensitivites for Convective Parameterization in GCMs (Toulouse, FRA, 06/2008)
- Presentation to the NCAR Director (Boulder, CO USA, 09/2008)
- Recent CCSM Development Simulations: Towards CCSM4 (Breckenridge, CO USA, 06/2008)
- Research Reports (Boulder, CO USA, 12/2007)
- The Impact of Convection Improvements on Intra-seasonal Variability in CCSM3.5 (Irvine, CA USA, 11/2007)
- The Impact of Convection on El Nino: From a delayed Oscillator to A Series of Events (Reading, GBR, 05/2008)

Publications FY08 (abstracts):

Field, P. R., A. Gettelman, R. B. Neale, R. Wood, P. J. Rasch, H. Morrison, 2008: Midlatitude cyclone compositing to constrain climate model behavior using satellite observations. *J. Climate*, doi: 10.1175/2008JCLI2235.1. (In Press)

Bala, G., A. Mirrin, K. Achutarao, D. Bader, P. Gleckler, R. Rood, J. McClean, R. Neale, P. J. Rasch, 2007: Evaluation of a CCSM3 Simulation with a Finite Volume Dynamical Core for the Atmosphere at 10 Latitude W 1.250 Longitude Resolution. *J. Climate*, **21**, 1467-1486, doi: 10.1175/2007JCLI2060.1.

Rich Neale Research Catalog

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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DOUG NYCHKA

General Information

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Director of CISL's Institute for Mathematics Applied to Geosciences
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Research Focus FY08:

I am the Director of the Institute for Mathematics Applied to Geosciences (November, 2004 - present) (IMAGe) and also a Senior Scientist in Geophysical Statistics Project (**GSP**). My main task is to enrich the scientific and educational activity at NCAR through mathematical methods and models. Also, I use the large scientific projects at NCAR to engage the mathematical science communities in new applications and to motivate new mathematics.

Research Interests in Statistics:

- Nonparametric regression Smoothing splines, neural networks, inference for function estimates, response surface methodology.
- Time series Detection and properties of nonlinear systems, trend analysis, Kalman and related filters.
- Spatial statistics Spatial designs, nonstationary processes, spatial extremes.

Community Service FY08:

- Member and Chair, Scientific Advisory Panel, Center for Integrating Statistics and Environmental Sciences, Univerisity of Chicago. (2003- present)
- Member, Committee on Applied and Theoretical Statistics (CATS), Board on Mathematical Sciences, The National Academies. (2002 - present)

Scientific Talks FY08:

- Spatial statistics, black diamonds and the fields package (University of Wyoming, November 2008) PDF
- Where are statisticians in the Earth System? (Invited talk at JSM08 Denver, August 2008) PDF
- Climate Past, Climate Present, Climate Future, A tale told by a statistician (public lecture at the 7th World Congress in Probability and Statistics, Singapore, July 2008) PDF
- Statistical tools for estimating regional climate (University Warwick, UK, April 2008) PDF
- Statistical tools for estimating regional climate (Isaac Newton Institute, Cambridge, UK June 2008) PDF
- What can statistics tell us about the uncertainty of past climate? (American Public Health Association, San Diego October 2008) PDF
- A framework to understand the asymptotic properties of Kriging and splines (U Wyoming and U Colorado, November 2008) PDF

Publications FY08:

Whitcher, B., T.-C. Lee, J. B. Weiss, T. Hoar, D. W. Nychka, 2008: A multiresolution census algorithm for calculating vortex statistics in turbulent flows. *J. Roy. Stat. Soc.: Series C*, **57**, 293-321, doi: 10.1111/j.1467-9876.207.00614.

Li, B., D. W. Nychka, C. M. Ammann, 2008: The Hockey Stick and the 1990s: A statistical perspective on reconstructing hemispheric temperatures. *Tellus*, **59**, 591-598, doi: 10.1111/j.1600-0870.2007.00270.

Doug Nychka Research Catalog

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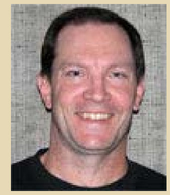
CGD 2008 PROFILES IN SCIENCE: DR. KEITH OLESON

Summary of achievements



Keith Oleson

Keith Oleson continues to support the development, testing, validation, and documentation of the land model component of CCSM (the Community Land Model (CLM)). Two manuscripts documenting the newest version of CLM, CLM3.5, were published. In recognition of the cooperative work in producing this improved version of the model, the CCSM Land Model Working Group was awarded the CCSM Distinguished Achievement Award at the 13th annual CCSM Workshop. Significant efforts are now underway to develop and test improved parameterizations for the next version of the model, CLM4.0. A second research focus is to develop models and diagnostic tools and conduct research relevant to assessing the impact of human-caused landcover change on climate. Two manuscripts documenting an urban canyon model coupled to CLM were published. Research is underway to extent the point scale and regional applications of the model to the global coupled system. Further testing of the model is in progress through participation in an urban model intercomparison study led by S. Grimmond and M. Best (U.K.).

Publications

Oleson, K.W., G.B. Bonan, J. Feddema, M. Vertenstein, and C.S.B. Grimmond, 2008: An urban parameterization for a global climate model. 1. Formulation and evaluation for two cities. J. Appl. Meteorol. Clim., 47, 1038-1060, doi:10.1175/2007JAMC1597.1.

Abstract: Urbanization, the expansion of built-up areas, is an important yet less studied aspect of land use/cover change in climate science. To date, most global climate models used to evaluate effects of land use/cover change on climate do not include an urban parameterization. Here, we describe the formulation and evaluation of a parameterization of urban areas that is incorporated into the Community Land Model, the land surface component of the Community Climate System Model. The model is designed to be simple enough to be compatible with structural and computational constraints of a land surface model coupled to a global climate model, yet complex enough to explore physically-based processes known to be important in determining urban climatology. The city representation is based upon the 'urban canyon' concept which consists of roofs, sunlit and shaded walls, and canyon floor. The canyon floor is divided into pervious (e.g., residential lawns, parks) and impervious (e.g., roads, parking lots, sidewalks) fractions. Trapping of longwave radiation by canyon surfaces and solar radiation absorption and reflection is determined by accounting for multiple reflections. Separate energy balances and surface temperatures are determined for each canyon facet. A one-dimensional heat conduction equation is solved numerically for a ten-layer column to determine conduction fluxes into and out of canyon surfaces. Model performance is evaluated against measured fluxes and temperatures from two urban sites. Results indicate the model does a reasonable job of simulating the energy balance of cities.

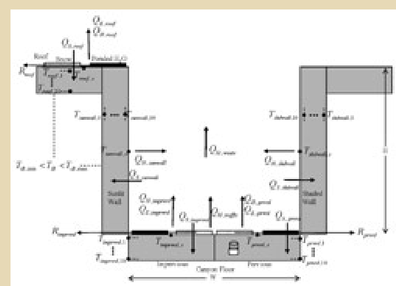


Figure 1.

High resolution figure

Figure caption: Schematic overview of the modeled urban land-unit. The canyon consists of roof, sunlit and shaded walls of height *H*, and a canyon floor of width *W* divided into pervious and impervious fractions. For each of these surfaces, temperatures (*T*), sensible (Q_H), latent (Q_E), and storage (Q_S) heat fluxes are simulated. Temperatures for each urban surface *u* include surface temperature ($T_{u,s}$) and internal temperatures for 10 layers ($T_{u,1...10}$). An internal building temperature (T_{iB}) is simulated that can be held at prescribed comfort levels, $T_{iB,min}$ and $T_{iB,\ max}$, thereby simulating heating and/or air conditioning. Hydrology on the roof and canyon floor is simulated, walls are hydrologically inactive. Snowpacks can form on the active surfaces. A certain amount of liquid water is allowed to pond on these surfaces which supports evaporation. Snow melt water or water in excess of the maximum ponding depth runs off (R_{roof}, $R_{imprvrd}$, R_{prvrd}). The pervious canyon floor has a soil moisture store to support evaporation. Anthropogenic fluxes from traffic ($Q_{H,traffic}$) or other sources such as heating and/or air conditioning waste heat ($Q_{H,waste}$) can be accommodated. Incident, reflected, and net solar and longwave radiation are calculated for each individual surface but are not shown for clarity.

Support: This research was supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402, the National Science Foundation grants ATM-0107404 and ATM-0413540, the National Center for

Atmospheric Research Water Cycle Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives, and the University of Kansas, Center for Research.

Oleson, K.W., G.B. Bonan, J. Feddema, and M. Vertenstein, 2008: An urban parameterization for a global climate model. 2. Sensitivity to input parameters and the simulated urban heat island in offline simulations. J. Appl. Meteorol. Clim., 47, 1061-1076, doi:10.1175/2007JAMC1598.1.

Abstract: In a companion paper (Oleson et al. 2007), we presented a formulation and evaluation of an urban parameterization designed to represent the urban energy balance in the Community Land Model. Here we test the robustness of the model through sensitivity studies and evaluate the model's ability to simulate urban heat islands in different environments. Findings show that heat storage and sensible heat flux are most sensitive to uncertainties in the input parameters within the atmospheric and surface conditions considered here. The sensitivity studies suggest that attention should be paid to not only accurately characterizing the structure of the urban area (e.g., height to width ratio), but also to the input data reflecting the thermal admittance properties of each of the city surfaces. Simulations of the urban heat island show that the urban model is able to capture typical observed characteristics of urban climates qualitatively. In particular, the model produces a significant heat island that increases with height to width ratio. In urban areas, daily minimum temperatures increase more than daily maximum temperatures resulting in a reduced diurnal temperature range compared to equivalent rural environments. The magnitude and timing of the heat island vary tremendously depending on the prevailing meteorological conditions and the characteristics of surrounding rural environments. The model also correctly increases the Bowen ratio and canopy air temperatures of urban systems as impervious fraction increases. In general, these findings are in agreement with those observed for real urban ecosystems. Thus, the model appears to be a useful tool for examining the nature of the urban climate within the framework of global climate models.

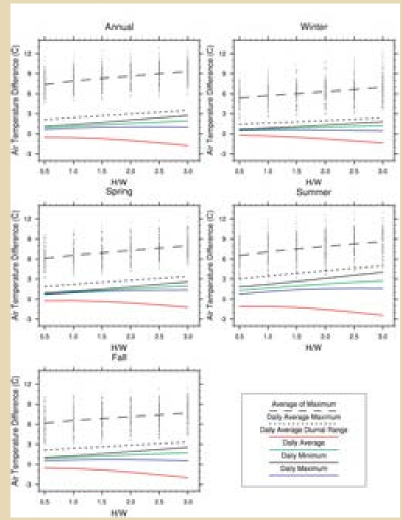


Figure 2.

High resolution figure

Figure caption: Annual and seasonal (winter-DJF, spring-MAM, summer-JJA, fall-SON) characteristics of urban and rural air temperature differences. Urban and rural air temperatures, T_{urban} and T_{rural}, are from hourly data as described in the text. The lines indicate air temperature differences averaged over all grid cells. The daily maximum (blue line) is $T_{urban, max}$ - $T_{rural, max}$ (with overbar) where $T_{urban, max}$ and $T_{rural, max}$ are the maximum urban and rural air temperature in a given day, and the overbar represents the average over the number of days in a given season. Similarly, the daily minimum (solid black line) is $T_{urban, min}$ - $T_{rural, min}$ (with overbar). The daily average (green line) is $T_{urban, avg}$ - $T_{rural, avg}$ (with overbar) where $T_{urban, avg}$ and $T_{rural, avg}$ are the daily average of the hourly urban and rural air temperatures. The daily average diurnal range (red line) is ($T_{urban, max}$ - $T_{urban, min}$) - ($T_{rural, max}$ - $T_{rural, min}$) (with overbar). The dots represent the maximum T_{urban} - T_{rural}at each grid cell for a given height to width ratio, while the long dashed line (average of maximum) represents the average of these at each height to width ratio.

Support: This research was supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402, the National Science Foundation grants ATM-0107404 and ATM-0413540, the National Center for Atmospheric Research Water Cycle Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives, and the University of Kansas, Center for Research.

Stockli, R., D. M. Lawrence, G. Y. Niu, K. W. Oleson, P. E. Thornton, Z. L. Yang, G. B. Bonan, A. S. Denning, and S. W. Running. 2008. Use of FLUXNET in the community land model development. Journal of Geophysical Research-Biogeosciences, doi:10.1029/2007JG000562.

Abstract: The Community Land Model version 3 (CLM3.0) simulates land-atmosphere exchanges in response to climatic forcings. CLM3.0 has known biases in the surface energy partitioning as a result of deficiencies in its hydrological and biophysical parameterizations. Such models, however, need to be robust for multidecadal global climate simulations. FLUXNET now provides an extensive data source of carbon, water and energy exchanges for investigating land processes, and it encompasses a global range of ecosystem-climate interactions. Data from 15 FLUXNET sites are used to identify and improve model deficiencies. Including a prognostic aquifer, a bare soil evaporation resistance formulation and numerous other changes in the model result in a significantly improved soil hydrology and energy partitioning. Terrestrial water storage increased by up to 300 mm in warm climates and decreased in cold climates. Nitrogen control of photosynthesis is revealed as another missing process in the model. These improvements increase the correlation coefficient of hourly and monthly latent heat fluxes from a range of 0.5-0.6 to the range of 0.7-0.9. RMSE of the simulated sensible heat fluxes decrease by 20-50%. Primary production is overestimated during the wet season in mediterranean and tropical ecosystems. This might be related to missing carbon-nitrogen dynamics as well as to site-specific parameters. The new model (CLM3.5) with

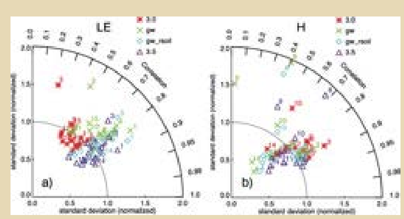


Figure 3.

High resolution figure

an improved terrestrial water cycle should lead to more realistic land-atmosphere exchanges in coupled simulations. FLUXNET is found to be a valuable tool to develop and validate land surface models prior to their application in computationally expensive global simulations.

Figure caption: Performance of four model versions at 15 FLUXNET towers (numbers 1-15). Statistics in the Taylor diagram are derived from hourly simulated and observed LE and H fluxes. Legend: CLM3.0: red asterisks; CLMgw: green crosses; CLMgw_rsoil: cyan diamonds; CLM3.5: violet triangles. In CLM3.0 H is off-scale for the two tropical sites 8 and 9 (and therefore not shown).

Support: We acknowledge the NASA Energy and Water Cycle Study (NEWS) grant NNG06CG42G as the main funding source of this study.

Oleson, K. W., et al., 2008: Improvements to the Community Land Model and their impact on the hydrological cycle. J. Geophys. Res., 113, G01021, doi:10.1029/2007JG000563.

Abstract: The Community Land Model version 3 (CLM3) is the land component of the Community Climate System Model (CCSM). CLM3 has energy and water biases resulting from deficiencies in some of its canopy and soil parameterizations related to hydrological processes. Recent research by the community that utilizes CLM3 and the family of CCSM models has indicated several promising approaches to alleviating these biases. This paper describes the implementation of a selected set of these parameterizations and their effects on the simulated hydrological cycle. The modifications consist of surface data sets based on Moderate Resolution Imaging Spectroradiometer products, new parameterizations for canopy integration, canopy interception, frozen soil, soil water availability, and soil evaporation, a TOPMODEL-based model for surface and subsurface runoff, a groundwater model for determining water table depth, and the introduction of a factor to simulate nitrogen limitation on plant productivity. The results from a set of offline simulations were compared with observed data for runoff, river discharge, soil moisture, and total water storage to assess the performance of the new model (referred to as CLM3.5). CLM3.5 exhibits significant improvements in its partitioning of global evapotranspiration (ET) which result in wetter soils, less plant water stress, increased transpiration and photosynthesis, and an improved annual cycle of total water storage. Phase and amplitude of the runoff annual cycle is generally improved. Dramatic improvements in vegetation biogeography result when CLM3.5 is coupled to a dynamic global vegetation model. Lower than observed soil moisture variability in the rooting zone is noted as a remaining deficiency.

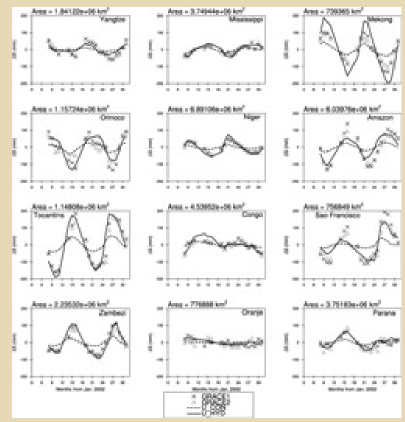


Figure 4.

High resolution figure

Figure caption: Total water storage anomalies (mm) for U_HYD (CLM3.5) and U_CON (CLM3.0) compared to two sources of GRACE data (GRACE1 [Seo and Wilson, 2005] and GRACE2 [Chen et al., 2005]). Model total water storage anomalies are calculated from the sum of snow water, canopy water, total column soil water, and aquifer water. GRACE data were interpolated to the model resolution.

Support: This work was supported by the NCAR Water Cycles Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives.

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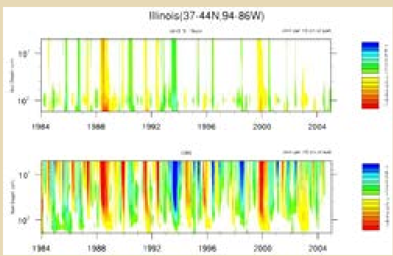
Research Focus FY08:



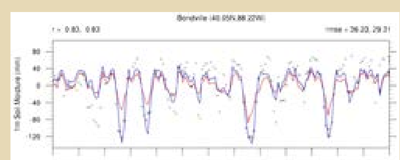
Soil Moisture Variability in the Community Land Model - Soil moisture anomalies in the top 2m of soil for CLM3.5 (top) and observations (bottom) for Illinois. High resolution figure

Simulating soil moisture variability in a land surface model

As reported in last fiscal year's report, a multi-year project to improve the hydrology of the Community Land Model version 3 (CLM3), the land component of the Community Climate System Model (CCSM), was completed. Two manuscripts documenting the new version, submitted last fiscal year, were revised and published this fiscal year (see below). In recognition of the cooperative work in producing this improved version of the model, the CCSM Land Model Working Group was awarded the CCSM Distinguished Achievement Award at the 13th annual CCSM Workshop in June, 2008.

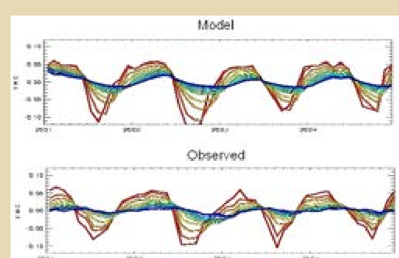
In Oleson et al. (2008), it was noted that despite the many hydrologic improvements exhibited by CLM3.5, the annual and interannual variability of soil moisture in the rooting zone appeared to be lower than observed. This translates into very little soil moisture stress simulated by the model which has important implications for simulating drought, dust, the carbon cycle, etc. An example of this for Illinois is shown in Slide 1 of the attached powerpoint presentation. It can also been seen from this figure that most of the soil moisture variability in CLM3.5 occurs deeper in the soil column, in contrast to observations.

Keith Oleson led a project to investigate causes and potential solutions to this problem. University collaborators included Robert Dickinson (Georgia Institute of Technology), Zong-Liang Yang and Guo-Yue Niu (University of Texas), and Xubin Zeng and Mark Decker (University of Arizona). NCAR collaborators included David Lawrence and Sean Swenson, an ASP post-doc with CGD. Early work showed that the presence of the shallow water table in the model produced strong upward fluxes of water to the rooting zone which essentially prevented the drying out of the rooting zone. It was theorized that the current hydraulic conductivity and soil matric potential formulations could be modified to slow down the upward flow of water. Alternative formulations were investigated; Slide 2 shows how one alternative formulation improved soil moisture variability. In particular, the drying events in 1983 and 1988 are better captured. However, there were issues of model stability and robustness.



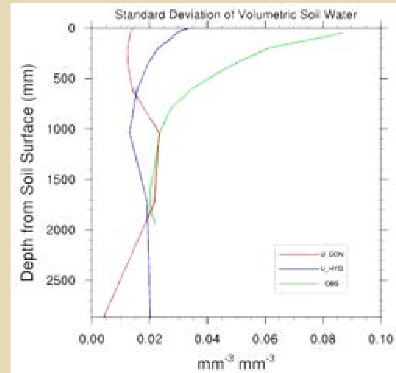
Soil Moisture Variability in the Community Land Model - Soil moisture anomalies in the top 1m of soil for CLM3.5 (red), observations (squares), and alternative formulations for hydraulic conductivity and matric potential (Liu 2004) (blue) for the Bondville, Illinois flux tower site. High resolution figure

Later work by Sean Swenson showed that the model was capable of reproducing quite well the Illinois soil moisture observations through a combination of reasonable site-specific changes to the model (deeper water table, decrease in hydraulic conductivity, corrected solar insolation, soil compaction, and increase in leaf area index). An example is shown in Slide 3 where the model shows similar soil moisture variability that is consistent with the observations in terms of amplitude, phase, and depth dependence. The main disadvantage of this approach is that it is difficult to apply globally.



At the June, 2008 CCSM workshop, project members met to decide on a final model configuration to improve soil moisture variability. The final configuration incorporates many of the ideas mentioned above and other ideas from university collaborators but is a compromise between matching limited observations of soil moisture variability and satisfying other global hydrologic constraints on the model as well as accounting for the influence of other concurrent model development (e.g., organic soil and litter). An example is shown in slide 4, where the unrealistic variability of soil moisture with depth in CLM3.5 is corrected in the modified model. These results will be submitted for publication once the performance of the new model (CLM4.0) has been demonstrated in coupled simulations.

Soil Moisture Variability in the Community Land Model - Volumetric soil moisture anomalies by soil layer for CLM with site-specific changes by S. Swenson (top), and observations (bottom). Red is the shallowest layer while blue is the deepest. Figure courtesy S. Swenson. High resolution figure



Soil Soil Moisture Variability in the Community Land Model - Standard deviation of volumetric soil water with depth for CLM3.5 (red), the new model (blue), and observations (green) for Illinois. High resolution figure

Publications FY08 (abstracts):

Stockli, R., D. M. Lawrence, G.-Y. Niu, K. W. Oleson, P. Thornton, Z.-L. Yang, G. Bonan, A. Denning, S. Running, 2008: Use of FLUXNET in the community land model development. *J. Geophys. Res.*, **113**, G01025, doi: 10.1029/2007JG000562.

Oleson, K. W., G.-Y. Niu, Z.-L. Yang, D. M. Lawrence, P. Thornton, P. Lawrence, R. Stockli, R. Dickinson, G. Bonan, S. Levis, A. Dai, T. Qian, 2008: Improvements to the community land model and their impact on the hydrological cycle. *J. Geophys. Res.*, **113**, G01021, doi: 10.1029/2007JG000563.

Oleson, K. W., G. B. Bonan, J. Feddema, M. Vertenstein, C. S. B. Gimmond, 2008: An urban parameterization for a global climate model. Part I. Formulation and evaluation for two cities. *J. Appl. Meteor. Climat.*, **47**, 1038-1060, doi: 10.1175/2007JAMC1597.1.

Oleson, K. W., G. B. Bonan, J. Feddema, M. Vertenstein, 2008: An urban parameterization for a global climate model. Part II. Sensitivity to input parameters and the simulated urban heat island in offline simulations. *J. Appl. Meteor. Climat.*, **47**, 1061-1076, doi: 10.1175/2007JAMC1598.1.

Keith Oleson Research Catalog

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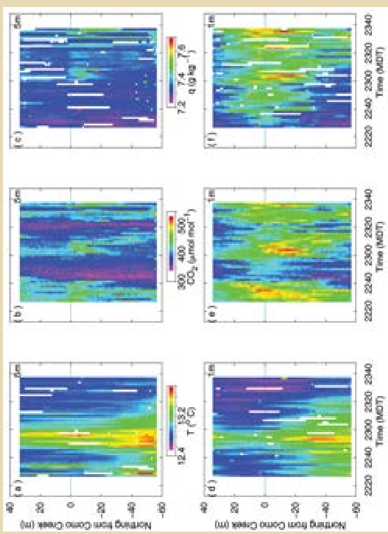
Research Focus FY08:



Time-distance cross-sections of temperature T (a,d), carbon dioxide concentrations CO2 (b,e), and specific humidity q (c,f) measured by TRAM. Distances are the position north of Como Creek. Three pulses of air that are CO2-rich, cool, and moist are seen during this 1hr period close to the ground (panels a--c). They are much less obvious at a height halfway up the canopy (panels d--f). This provides evidence of horizontal transport of CO2 within a canopy roughly following the path of water drainage; however, the transport is organized in relatively small-scale blobs.

High resolution figure

Horizontal Advection of Carbon Dioxide

My TIIMES research has been focused on understanding horizontal advection of carbon dioxide in forest canopies, which is thought to be a significant process controlling the Net Ecosystem Exchange (NEE) of carbon. This research has been a collaboration with Jielun Sun (MMM - TIIMES), Russ Monson (University of Colorado, Biology), and others. Because there exist very few data sets that investigate this problem, we are carrying out a series of experiments at the University of Colorado's Ameriflux site on Niwot Ridge, CO, in collaboration with Prof. Russ Monson.

Nivot07

2006-2007 (Niwot07): EOL deployed, for the first time, the TRAnsect Measurement (TRAM) system (also developed with TIIMES support) along a 110m-long path crossing Como Creek both in the trunk space and in the middle of the canopy space. Hydra and ASA were deployed along this transect and were used to anchor the TRAM measurements. These observations have shown that in-canopy advection of CO2 occurs quite close to the surface by organized blobs on the order of 20m wide and a few hundred meters long. Their track roughly follows Como Creek, though the highest CO2 concentrations can be 10s of meters away laterally. This research also is supported by a grant from NSF-Biocomplexity (with CU).

TRAM

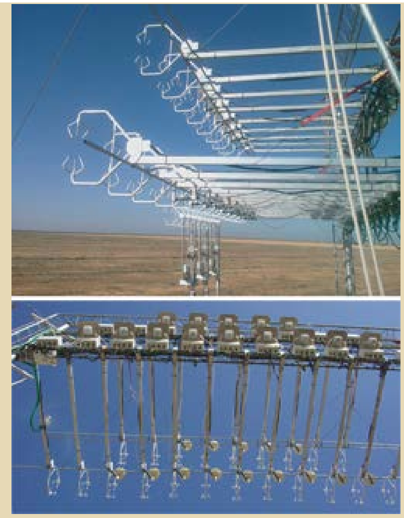
2008-2009 The TRAnsect Measurement (TRAM) track was redeployed in 2008, along with ASA networks measuring photosynthetically-active radiation (PAR), and soil temperature and moisture, to an area between the long-term CU and USGS towers. Differences in CO2 concentration measured at these towers have been observed that may be associated with a change in canopy density. The TRAM data system also was upgraded to accomodate the acquisition of more data channels (including PAR). These observations will continue through 2009.

CHATS

As part of the CHATS experiment, TIIMES-BEACHON supported the development of a fast-response barometer, capable of measuring turbulent fluctuations of pressure, p'. There have been few measurements of p' in the atmosphere and fewer still in the roughness sublayer (where form drag is important) due to the difficulty of finding a pressure port that doesn't add dynamic pressure errors. For

CHATS, we borrowed quad-disk probes (QDPs) patented and manufactured by NOAA-ETL and tested two commercial designs in the EOL wind tunnel. A simple modification to less expensive commercial QDPs appeared to perform nearly as well as the NOAA probes. We also operated two different transducer systems to determine the quality of the measurements. Data analysis is just beginning, though indications are that both systems operated as expected. This research is in collaboration with William Massman (US Forest Service, Rocky Mountain Research Station).

Experience with these sensors guided the design for a deployment of 14 such pressure sensors (along with 37 3-axis sonic anemometers) for the Advective Horizontal Array of Turbulence Study (AHATS) in Summer 2008. This study, led by Chenning Tong (Clemson University, SC), will investigate how pressure fluctuations interact with the production, redistribution, and destruction of the kinetic energy of turbulence at various spatial scales.



AHATS

High resolution figure

Scientific Talks FY08:

- Wireless sensor networks at EOL (CUAHSI, Boulder, CO, July 2008)

Publications FY08:

Burns, S. P., A. Delany, J. Sun, B. B. Stephens, S. P. Oncley, G. D. Maclean, S. R. Semmer, J. Schroter, J. Ruppert, 2008: An evaluation of calibration techniques for in-situ carbon dioxide measurements using a programmable portable trace-gas measuring system. *J. Atmos. Ocean. Technol.*, doi: 10.1175/2008JTECHA1080.1. (In Press)

Oncley, S. P., K. Schwenz, S. P. Burns, J. Sun, R. K. Monson, 2008: A cable-borne tram for atmospheric measurements along transects. *J. Atmos. Ocean. Technol.*, doi: 10.1175/2008JTECHA1158.1. (In Press)

Patton, E. G., T. Horst, D. H. Lenschow, P. P. Sullivan, S. P. Oncley, S. P. Burns, A. B. Guenther, T. Karl, S. D. Mayor, S. M. Spuler, J. Sun, A. A. Turnipseed, E. Allwine, S. Edburg, B. Lamb, R. Avissar, H. Holder, R. Calhoun, J. Kleissl, W. Massman, K. Tha Paw U, J. Weil, L. Rizzo, A. Held, 2008: The Canopy Horizontal Array Turbulence Study (CHATS). , Stockholm, SE, AMS, American Meteorological Society, 18A.1.

Oncley, S. P., W. Massman, E. G. Patton, 2008: Turbulent pressure fluctuations measured during CHATS. *18th Symp. On Boundary Layers and Turbulence*, Stockholm, SE, AMS, American Meteorological Society, 18A.3.

Zhong, S., W. Yao, T. Horst, C. Whiteman, S. P. Oncley, 2008: Basin temperature inversions and their relationship to ambient atmospheric conditions. , Stockholm, SE, AMS, American Meteorological Society, 14A.2.

Oncley, S. P., K. Schwenz, J. Sun, R. Monson, 2008: Measuring in-canopy advection of carbon dioxide using a new transect measurement system (TRAM). , Orlando, FL, US, J2.3.

Steve Oncley Research Catalog

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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John Orlando
Yongxin Tang

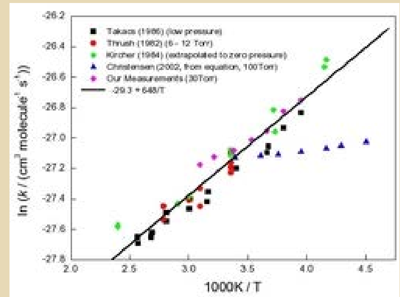

Figure 1. Arrhenius plot for the combination reaction of HO_2 radicals. The natural logarithm of the rate coefficient is plotted against reciprocal temperature. Results of 5 studies pertaining to low pressures (P < 150 mbar) are shown.

High resolution figure

ACD scientists have been studying the reaction kinetics and mechanisms of hydroperoxy radicals, HO_2, using a number of complementary techniques. HO_2 radicals are a member of the HOx family, which is comprised of OH and HO_2. Hydroxyl radicals, OH, are responsible for the oxidation of many organic and inorganic pollutants which are emitted into the troposphere. Following a series of reactions, HO_2 is usually produced, and then cycled back to OH by its reaction with nitric oxide, NO. However, measurements of radical concentrations in forested areas have shown unexpectedly high levels of OH, suggesting that some recycling of radicals is taking place. Normally this requires the presence of NO, but in clean areas other mechanisms may dominate.

The reactions of HO_2 radicals with organic peroxy radicals are being investigated in the laboratory using a combination of techniques (infrared spectrometry, gas chromatography and high performance liquid chromatography). These reactions were initially thought to form solely organic hydroperoxides, reasonably stable compounds that terminate the oxidative chain reactions. However, in a 2004 study in collaboration with Fresno State University [Hasson et al., 2004] it was shown that OH radicals could be produced in substantial yield from the reaction of HO_2 with acetyl peroxy radicals.

$$HO_2 + CH_3C(O)O_2 \rightarrow CH_3CO_2 + OH + O_2$$

The potential for recycling of HO_2 to OH in these reactions may be able to explain apparently high levels of OH radicals in relatively clean, forested areas. A systematic study of the OH yields from reaction of HO_2 with oxygenated peroxy radicals is currently underway.

In the lower stratosphere, OH and HO_2 radicals play a large role in controlling the concentration of ozone.

$$OH + O_3 \rightarrow HO_2 + O_2$$
$$HO_2 + O_3 \rightarrow OH + 2O_2$$

These oxidation chains can be terminated via the self reaction of HO_2 radicals, which forms hydrogen peroxide as a product.

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$$

The rate coefficient for this particular reaction depends on both the temperature and pressure, and water vapor concentration. Scientists in ACD have measured the variation of the rate coefficient with temperature at low pressure. The HO_2 radicals are produced by a pulse of ultraviolet laser radiation, which dissociates chlorine gas; the chlorine atoms then initiate the chemistry which forms the HO_2. The radicals are then detected using tunable diode laser spectroscopy. The technique allows the decay of the radicals to be followed in real time over a time span of tens of milliseconds, from which the rate coefficient can be determined.

There have been 4 previous determinations of the temperature dependence of the rate coefficient at low pressure. Whereas 3 measurements in the 1980s (Thrush and Tyndall, 1982; Kircher and Sander, 1984; Takacs and Howard, 1986) showed a dependence on temperature, a more recent one (Christensen et al, 2002) suggested that the reaction rate is independent of temperature. However, the new measurements indicate an increase in the rate coefficient at low temperature, in agreement with the earlier studies. A stronger temperature dependence to this reaction reduces the concentration of HO_2 radicals in the upper troposphere and lower stratosphere, and consequently reduces the amount of ozone depletion due to HOx radicals.

Laboratory studies of reaction kinetics and mechanisms will continue, with a focus on the formation mechanisms of organic nitrates. This work was funded by NSF/NCAR and NASA.

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CGD 2008 PROFILES IN SCIENCE: DR. BETTE OTTO-BLIESNER

Summary of achievements

Bette Otto-Bliesner

Building on successful "snapshot" simulations with CCSM, Bette Otto-Bliesner's glacial-interglacial simulations are now focusing on transient climate changes. In 2008, Bette and Esther Brady (CGD/CCR), Liu, Carlson, and He (University of Wisconsin), Clark (Oregon State), Jacobs (Argonne), and Erickson (Oak Ridge) continued using a large computing grant from DOE INCITE to run a set of synchronously coupled transient ocean-atmosphere-dynamic vegetation CCSM3 simulations of the past 21,000 years (TraCE-21). This simulation, which is now at 14.5 ky BP, provides a strong test on CCSM for its climate sensitivity to various forcings, especially, the greenhouse forcing, as well as its capability for the simulation of abrupt climate changes. It marks a new era in paleoclimate model-data comparison by allowing for a direct comparison of time series between model and data. A series of CCSM3 simulations to provide a detailed look at the 8.2ka event, an abrupt climate change associated with anomalous freshwater flow into the North Atlantic, is also in progress with Morrill and Wagner (CIRES). Two workshops, SynTraCE-21000, are being convened by Otto-Bliesner and her collaborators to prepare a three-dimensional synthesis and database of the transient evolution of the Earth system over the last 21,000 years.

Bette Otto-Bliesner is also working on simulations that fit closely with current and future themes of the Paleoclimate Modeling Intercomparison Project (PMIP). With Nan Rosenbloom (CGD/CCR), a CAM/CLM simulation has been run for the mid-Pliocene (~3 myrs ago), possibly the closest paleo analog for the equilibrium climate with current CO2 levels. In addition, working with SOARS student Zi Zi Searles of San Francisco State University, sensitivity simulations have shown the importance of warm sea surface temperatures off the coast of California for correctly simulating proxy indicators of a wetter western US during the mid-Pliocene. A coupled carbon-climate simulation of the Last Glacial Maximum with ocean and land biogeochemistry, as a first step towards determining what controls glacial-interglacial variations in the greenhouse gases, is currently in the spinup phase. This is a joint project with Mahowald (Cornell), Doney (WHOI), Moore (UC-Irvine), Joos (Bern), and Lindsay (CGD/OCE).

Bette Otto-Bliesner is also organizing the PMIP2 Workshop, to be held 14-19 September in Estes Park, where over 70 international participants will discuss future model-data intercomparison projects of PMIP and develop a White Paper of proposed paleoclimate simulations for AR5.

Publications

Otto-Bliesner, B.L., and E.C. Brady, 2008: PMIP2 Climate Model-Proxy Data Intercomparisons for LGM. PAGES Newsletter, 16, 18-20.

Abstract: PMIP initially focused on two periods, the Last Glacial Maximum (LGM; ca. 21 cal kyr BP) and the mid-Holocene (MH; ca. 6 cal kyr BP). The experiments were designed to examine the climate response to Milankovitch orbital forcings for the MH and the presence of large ice sheets and low greenhouse gas (GHG) concentrations for the LGM. Seventeen modeling groups participated in simulations of these time periods with atmosphere-only models (PMIP1), and twelve groups in the second phase of the project (PMIP2) using ocean-atmosphere or ocean-atmosphere-vegetation models. With the incorporation of coupled atmosphere-ocean-sea ice models into PMIP2, new comparisons to proxy data can now be used in evaluating the capabilities of current climate models to simulate climate conditions different than present. Here, we describe two such com-parisons of the PMIP2 LGM simulations to glacial proxy data: deep-ocean tempera tures and salinities in the Atlantic Ocean, and sea ice extent around Antarctica.

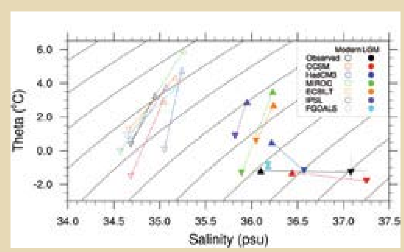

Figure 1.

High resolution figure

Figure caption: Theta (potential temperature) and salinity for modern (open symbols) and LGM (filled symbols) estimated from data (black symbols with error bars) at ODP sites (Adkins et al., Science, 2002) and predicted by PMIP2 models. Site 981 (Δ) is located in the North Atlantic (Feni Drift, 55°N, 15°W, 2184 m). Site 1093 ( ) is located in the South Atlantic (Shona Rise, 50°S, 6°E, 3626 m). Only CCSM included a 1 psu adjustment of ocean salinity at initialization to account for fresh water frozen into LGM ice sheets; predicted salinities for the other models have been adjusted to allow comparison.

Hu, A., B.L. Otto-Bliesner, G.A. Meehl, W. Han, C. Morrill, E.C. Brady, and B. Briegleb, 2008: Response of Thermohaline Circulation to Freshwater Forcing under Present-Day and LGM Conditions. J. Climate, 21, 2239-2258.

Abstract: Responses of the thermohaline circulation (THC) to freshwater forcing (hosing) in the subpolar North Atlantic Ocean under present-day and the last glacial maximum (LGM) conditions are investigated using the National Center for Atmospheric Research Community Climate System Model versions 2 and 3. Three sets of simulations are analyzed, with each set including a control run and a freshwater hosing run. The first two sets are under present-day conditions with an open and closed Bering Strait. The third one is under LGM conditions, which has a closed Bering Strait. Results show that the THC nearly collapses in all three hosing runs when the freshwater forcing is turned on. The full recovery of the THC, however, is at least a century earlier in the open Bering Strait run than the closed Bering Strait and LGM runs. This is because the excessive freshwater is diverged almost equally toward north and south from the subpolar North Atlantic when the Bering Strait is open. A significant portion of the freshwater flowing northward into the Arctic exits into the North Pacific via a reversed Bering Strait Throughflow, which accelerates the THC recovery. When the Bering Strait is closed, this Arctic to Pacific transport is absent and freshwater can only be removed through the southern end of the North Atlantic. Together with the surface freshwater excess due to precipitation, evaporation, river runoff, and melting ice in the closed Bering Strait experiments after the hosing, the removal of the excessive freshwater takes longer, and this slows the recovery of the THC. Although the background conditions are quite different between the present-day closed Bering Strait run and the LGM run, the THC responds to the freshwater forcing added in the North Atlantic in a very similar manner.

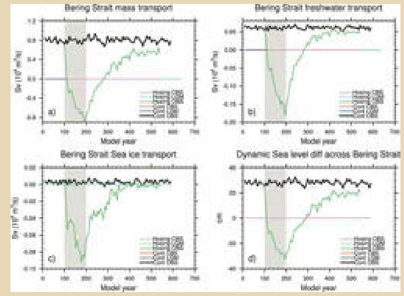

Figure 2.

High resolution figure

Lee, J. E., I. Fung, D. J. DePaolo, and B. Otto-Bliesner, 2008: Water isotopes during the last glacial maximum: New GCM calculations. Geochimica et Cosmochimica Acta, 72, A525-A525.

CGD Research Catalog

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Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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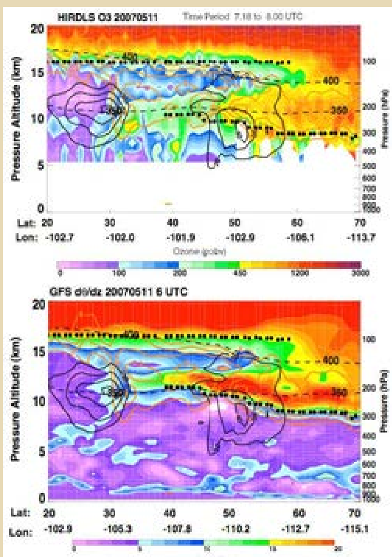

Figure 1 caption to the right - High resolution figure

Figure 1. Cross section along the High Resolution Dynamics Limb Sounder (HIRDLS) Field of View (FOV) track (shown on the NA map in next figure) on May 11, 2007. The layer structure of the intrusion is consistently shown in the ozone cross section measured by HIRDLS (upper) and the PTLR cross section based on the GFS analyses (lower). The GFS analyses thermal tropopause (black dots), zonal wind (black contour), 350 and 400 K isentropes (black broken) and PV (2, 4, 6, and 8 pvu) contours are shown on the cross sections.

Figure 2. Sandwiched stratosphere sampled by NCAR-NSF GV during START08 April 18, 2008. (a) The region of double tropopause over North America based on high resolution NCEP/GFS meteorological analyses. The colors represent the minimum potential temperature lapse rate (dq/dz (K/km)) between the two tropopauses. The red line marks the segment of the flight track shown in panel (b and c). (b)cross along the flight track with potential temperature lapse rate (color image), potential vorticity (purple contours), potential temperature (black contours) and the GV flight track (colored by the ozone values). (c) GV measurements during the segment including pressure altitude (gray), potential temperature (black), ozone (red) and carbon monoxide (blue).

Diagnosing transport from troposphere to stratosphere associated with the secondary tropopause, satellite data, meteorological field and aircraft observations

It has long been recognized that the temperature lapse rate based thermal tropopause definition produces breaks and multiple tropopauses in the extratropics. Recent analyses using global high resolution GPS data has shown that the area of double tropopause is much more extensive than previously realized. The trend of its occurrence in a changing climate is a question of research awaiting improved measurements with long enough of a record for this type of study. The transport of chemical species related to the double tropopause has been hinted by ozone measurements in the past (refs). Newly available satellite data from High Resolution Dynamics Limb Sounder (HIRDLS) on Aura demonstrated the connection between the occurrence of the secondary tropopause and the chemical transport from troposphere to stratosphere. Figure 1 shows an example of low ozone layer above the primary extratropical tropopause and below the secondary tropopause, which is an extension of the tropical tropopause. A similar structure is also found in the potential temperature lapse rate, derived from the NCEP/GFS meteorological analyses, for the same cross section. (Pan et al., submitted, 2008)

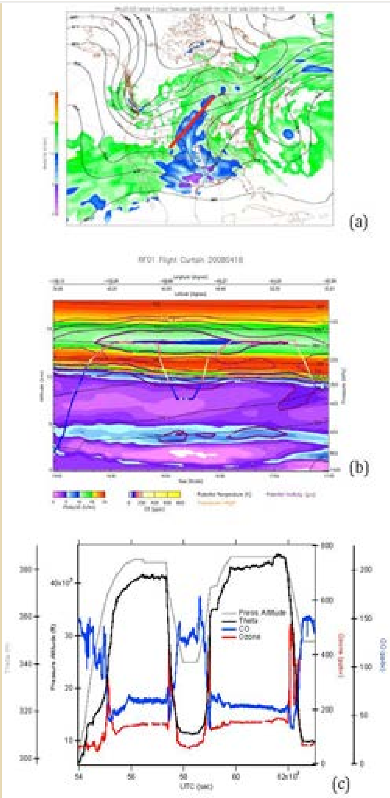

Figure 2 caption to the right - High resolution figure

This observation of relationship between the chemical structure and the meteorological field made it possible for the development of a forecast tool for aircraft observations, which in turn allowed successful in situ observations of this intruding tropospheric layer during the Stratosphere Troposphere Analyses of Regional Transport (START08) experiment. Figure 2 shows an example measurement from the NCAR-NSF Gulfstream V aircraft research flight on April 18, 2008, including meteorological analyses and in situ measurements. As indicated by the figure, the flight successfully observed an extensive layer of intruding tropospheric like air between the two tropopauses. The large suite of chemical species measured will help characterizing the chemical impact of this type of event. The analyses of these new data will be the focus of next year.

Community Service FY08:

- Principal investigator and mission scientist of START08 campaign, April-June 2008
- Member: International Commission on Middle Atmosphere (ICMA), The International Association of Meteorology and Atmospheric Sciences (IAMAS), 2007-2011
- Convener, Special symposium on climate processes in the upper troposphere and stratosphere, IAMAS/IAPSO Assembly, Montreal, Canada, July 2009

Scientific Talks FY08:

- The Use of the AIRS ozone data in the Research of Upper troposphere and Lower Stratosphere (UTLS) chemistry and dynamics (Greenbelt, MD, October 2007)
- Dynamical variability of ozone and mixing near the extratropical tropopause from Atmospheric Infrared Sounder (AIRS) data (San Francisco, CA, December 2007)
- START08 Science Overview (Boulder, CO, January 2008)
- START08 experiment and Tropospheric Intrusion associated with the secondary tropopause (Boulder, CO, January 2008)
- Transport diagnostics in the extratropical UTLS (Boulder, CO, March 2008)
- START08 Highlights (Boulder, CO, June 2008)
- GV experience during START08 (Boulder, CO, August 2008)
- START08 experiment: Scientific Concept and initial results (Juelich, Germany, September 2008)

Publications FY08:

Kinnison, D. E., G. P. Brasseur, S. Walters, R. R. Garcia, D. R. Marsh, F. Sassi, V. L. Harvey, C. E. Randall, L. Emmons, J.-F. Lamarque, P. Hess, J. J. Orlando, X. X. Tie, W. Randel, L. L. Pan, A. Gettelman, C. Granier, T. Diehl, U. Niemeier, A. J. Simmons, 2007: Sensitivity of chemical tracers to meteorological parameters in the MOZART-3 chemical transport model. *J. Geophys. Res.*, **112**, D20302, doi: 10.1029/2006JD007879.

Grubisic, V., J.D. Doyle, J. Kuettner, S. Mobbs, R.B. Smith, C.D. Whiteman, R. Dirks, S. Czyzyk, S.A. Cohn, S. Vosper, M. Weissmann, S. Haimov, S.F.J. De Wekker, L.L. Pan, and F.K. Chow, 2008: The Terrain-Induced Rotor Experiment. Bull. Amer. Meteor. Soc., **89**, 15131533.

Pan, L.L., W. J. Randel, J. C. Gille, W. D. Hall, B. Nardi, S. Massie, V. Yudin, R. Khosravi, P. Konopka, and D. Tarasick (2008), Tropospheric intrusions associated with the secondary tropopause, submitted to JGR, 2008.

Laura Pan Research Catalog

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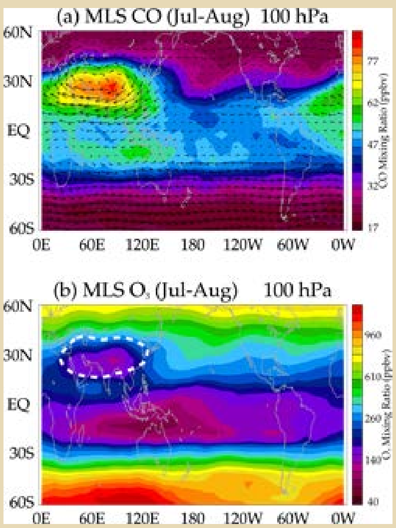

Near-global observations of carbon monoxide (CO) at 100 hPa obtained from Microwave Limb Sounder (MLS) observations during July-August 2005. The strong maximum over Asia is associated with the monsoon anticyclone in the upper troposphere, as identified by the wind vectors (from NCEP reanalysis data). From Park et al, 2007.

High resolution figure

The Satellite Data Analysis Group in ACD focuses on studies of global scale chemical behavior using satellite measurements, meteorological data sets and model simulations. Recent work has focused on understanding the chemical and dynamical behavior of the tropopause region, and its long-term variability, to help quantify processes which contribute to coupling in the upper troposphere - lower stratosphere (UTLS).

Mijeong Park used Microwave Limb Sounder (MLS) satellite observations to study constituent variability in the Asian summer monsoon anticyclone in the UTLS region. The monsoon anticyclone is a hemispheric-scale circulation associated with persistent deep convection over India and Southeast Asia during Northern Hemisphere summer (June-August). The strong circulation acts to confine and isolate air within the anticyclone in the UTLS region (~12-18 km). Carbon monoxide (CO) measured by MLS shows a persistent maximum within the anticyclone throughout summer (Fig. 2), which results from the vertical transport of near-surface air into the upper troposphere by deep convection. This association is supported by strong temporal correlation between CO and the underlying deep convection. MLS measurements of ozone and water vapor confirm this overall paradigm of upward transport and horizontal confinement. Ongoing work involves quantifying pathways for transport into and out of the anticyclone, plus studying the influence of the anticyclone on stratosphere-troposphere coupling.

Publications FY08:

Park, M., W. J. Randel, L. K. Emmons, P. F. Bernath, K. A. Walker, C. D. Boone, 2008: Chemical isolation in the Asian monsoon anticyclone observed in Atmospheric Chemistry Experiment (ACE-FTS) data. *Atmos. Chem. Phys.*, **8**, 757-764.

Randel, W. J., M. Park, F. Wu, N. Livesey, 2007: A large annual cycle in ozone above the tropical tropopause linked to the Brewer Dobson circulation. *J. Atmos. Sci.*, **64**, 4479-4488, doi: 10.1175/2007JAS2409.1.

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EDWARD PATTON

2008 Publications

Huang, J., X. Lee, E. G. Patton, 2007: A modeling study of flux imbalance and the influence of entrainment in the convective boundary layer. Bound.-Layer Meteor., 127, 273-292, doi: 10.1007/s10546-007.9254-x.

Abstract

It is frequently observed in field experiments that the eddy covariance heat fluxes are systematically underestimated as compared to the available energy. The flux imbalance problem is investigated using the NCAR’s large-eddy simulation (LES) model imbedded with an online scheme to calculate Reynolds-averaged fluxes. A top–down and a bottom–up tracer are implemented into the LES model to quantify the influence of entrainment and bottom–up diffusion processes on flux imbalance. The results show that the flux imbalance follows a set of universal functions that capture the exponential decreasing dependence on u */w *, where u * and w * are friction velocity and the convective velocity scale, respectively, and an elliptic relationship to z/z i , where z i is the mixing-layer height. The source location in the boundary layer is an important factor controlling the imbalance magnitude and its horizontal and vertical distributions. The flux imbalance of heat and the bottom–up tracer is tightly related to turbulent coherent structures, whereas for the top–down diffusion, such relations are weak to nonexistent. Our results are broadly consistent with previous studies on the flux imbalance problem, suggesting that the published results are robust and are not artefacts of numerical schemes.

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Table of Contents

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Research Focus FY08:

My research interests include a number of areas:

1. Statistics and structure of canopy turbulence and the interaction with larger-scale planetary boundary layer (PBL) turbulence,
2. Impact of orography on turbulent exchange,
3. Response of the boundary layer to coupled land surfaces,
4. Interactions between PBL/canopy turbulence and chemistry,
5. Dispersion as affected by vegetation, and
6. Impacts of vegetation within land-surface models.

Most of my work involves the use of numerical simulation (using LES) to relate larger-scale models and measurements through process-level understanding.

Turbulent flow over a train of canopy-covered sinusoidal hills.

Community Service FY08:

- Editorial Board: Agricultural and Forest Meteorology
- Member Boundary Layers and Turbulence: American Meteorological Society (AMS)

Scientific Talks FY08:

- A coupled canopy-soil model for the simulation of the modification of atmospheric turbulence by tall vegetation (Stockholm, Sweden, October 08)
- Canopy Horizontal Array Turbulence Study (CHATS): Directly linking measurements and models of ecosystem atmosphere exchange (Estes Park, CO, October 08)
- Canopy Turbulence (Boulder, CO, October 08)
- Canopy Turbulence: Impact of isolated ridges and other recent adventures (Wageningen, The Netherlands , October 08)
- Large-eddy simulation (LES); Momentum and scalar transport in canopy-covered terrain (Gembloux, Belgium, October 08)
- The Canopy Horizontal Array Turbulence Study (CHATS) (Stockholm, Sweden, October 08)
- Turbulence in canopies and orography. Lecture one: Canopy turbulence (Les Houches, France, October 08)
- Turbulence in canopies and orography. Lecture two: Canopy-covered hills (Les Houches, France, October 08)
- Turbulent Flow over Isolated Ridges; Influence of Vegetation (San Francisco, CA, October 08)

Publications FY08 (abstracts):

Karl, T., A. B. Guenther, A. A. Turnipseed, E. G. Patton, K. Jardine, 2008: Chemical sensing of plant stress at the ecosystem scale. *Biogeosciences Discuss.*, 5, 2381-2399.

Patton, E. G., T. Horst, D. H. Lenschow, P. P. Sullivan, S. P. Oncley, S. P. Burns, A. B. Guenther, T. Karl, S. D. Mayor, S. M. Spuler, J. Sun, A. A. Turnipseed, E. Allwine, S. Edburg, B. Lamb, R. Avissar, H. Holder, R. Calhoun, J. Kleissl, W. Massman, K. Tha Paw U, J. Weil, L. Rizzo, A. Held, 2008: The Canopy Horizontal Array Turbulence Study (CHATS). , Stockholm, SE, AMS, American Meteorological Society, 18A.1.

Oncley, S. P., W. Massman, E. G. Patton, 2008: Turbulent pressure fluctuations measured during CHATS. *18th Symp. On Boundary Layers and Turbulence*, Stockholm, SE, AMS, American Meteorological Society, 18A.3.

Huang, J., X. Lee, E. G. Patton, 2007: A modeling study of flux imbalance and the influence of entrainment in the convective boundary layer. *Bound.-Layer Meteor.*, **127**, 273-292, doi: 10.1007/s10546-007.9254-x.

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CGD 2008 PROFILES IN SCIENCE: DR. SYNTE PEACOCK

Summary of achievements

I am continuing work on using age-tracers to assess the bias in estimating Oxygen Utilization Rates in the ocean; I am also working on a more rigorous method to estimate Redfield Ratios in the ocean. I am continuing investigation into the budget of bomb radiocarbon in the global oceans. I am involved with work using Transit Time Distributions from ocean models with both resolved and unresolved meso-scale eddies to quantigy the role of eddies in interior ocean mixing, and to evaluate eddy parameterizations. I am also involved with an effort to improve the strong bias in Southern Ocean Mode Waters in CCSM, using CFCs as a water-mass tracer.

Synte Peacock

Publications

Peacock, S., E. Lane, and J. M. Restrepo, 2006: A possible sequence of events for the generalized glacial-interglacial cycle. Global Biogeochem. Cycles, 20, GB2010, doi:10.1029/2005GB002448.

Abstract: There is not yet widespread agreement as to the underlying cause of the 80-100 ppmv roughly 100-kyr-duration glacial-interglacial cycles in atmospheric pCO_2. Most of the mechanisms which have been proposed to account for the observed pCO_2 variations appear to in some way violate interpretations of paleo proxy data. The inability of a single mechanism to explain the observed cycles in atmospheric CO_2 (which show amazing similarity over the past 430,000 years) is perplexing, and leads us to consider whether a combination of mechanisms might be consistent with available evidence. Consistent with previous work, we find that physical changes (ocean circulation, temperature, mixing) can only explain part of the observed atmospheric pCO_2 variability; changes in ocean chemistry are invoked to explain the remainder. In order to account for the initial pCO_2 drawdown (from "interglacial" to "intermediate" levels), we invoke physical changes in the ocean (mixing, temperature). The transition from intermediate atmospheric pCO_2 levels to full glacial conditions involves a small increase in mean ocean nutrient levels and mean ocean alkalinity, accomplished by falling sea level and subsequent erosion of organic-rich shelf sediments. The first part of the transition out of full glacial conditions is achieved through increased temperature and increased mixing in the Southern Ocean. The final part of the atmospheric pCO_2 rise up to full interglacial conditions is accomplished through rising sea level and the subsequent change in mean ocean alkalinity and phosphate, and a rise in the Northern Hemisphere temperature and ocean mixing. The proposed sequence of events is consistent with most existing proxy evidence for paleo-nutrient levels and changes in export production over the last glacial-interglacial cycle. Furthermore, it is consistent with evidence for a whole-ocean shift in $\delta^{13}C$ toward significantly more negative values in the late glacial. The proposed scenario is also consistent with ice core-based timing constraints, as summarized by Broecker and Henderson (1998). We show that we are able to explain the full magnitude of the glacial-interglacial cycle in atmospheric pCO_2 without the need to invoke iron-fertilization in the Southern Ocean.

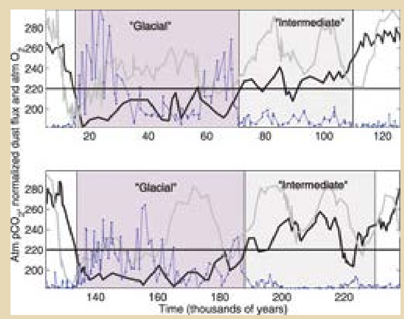

Figure 1.

High resolution figure

Figure caption: Records of normalized dust (blue), normalized, inverted atmospheric δ18O (gray), and pCO_2 (black) from the Vostok ice core over the last two glacials. Dust and oxygen records were normalized such that the minimum and maximum values over the time period 0-430,000 years scale to the minima and maxima of atmospheric pCO_2 over the same time period. The shading shows the partitioning into "intermediate" and "glacial" periods, as defined in the text.

Peacock, S., E. Lane, and J. M. Restrepo, 2006: A possible sequence of events for the generalized glacial-interglacial cycle. Tellus Series B-Chemical and Physical Meteorology, 58, 257-278, doi:10.1111/j.1600-0889.2006.00192.x.

Abstract: Most of the hypotheses put forward to explain glacial-interglacial cycles in atmospheric pCO(2) are centred on Southern-Ocean-based mechanisms. This is in large part because: (1) timing constraints rule out changes in the North Atlantic as the trigger; (2) the concept of "high-latitude sensitivity" eliminates changes in the non-polar oceans as likely contenders.

Many of the Southern-Ocean-based mechanisms for changing atmospheric pCO(2) on glacial-interglacial time-scales are based on results from highly simplified box models with prescribed flow fields and fixed particulate flux. It has been argued that box models are significantly more "high-latitude sensitive" than General Circulation Models. In light of this, it is important to understand whether this high-latitude sensitivity is a feature common to all box models, and whether the apparent degree of sensitivity changes for different tracers and parameters. We introduce a new metric for assessing how "high-latitude sensitive" a particular solution is to perturbations. With this metric, we demonstrate that a given model may be high-latitude sensitive to certain parameters but not to others. We find that the incorporation of a dynamic-based flow field and a Michaelis-Menten type nutrient feedback can have a significant impact on the apparent sensitivity of the model to perturbations. The implications of this for current box-model-based estimates of atmospheric pCO(2) drawdown are discussed.

Rutberg, R. L., and S. L. Peacock, 2006: High-latitude forcing of interior ocean δ^{13}C. Paleoceanography, 21, PA2012, doi:10.1029/2005PA001226.

Abstract: Transit time distribution probability density functions (TTDs) are used to investigate the possible role of changing boundary conditions in driving the δ^{13}C signal in the interior of a steady state ocean. We use idealized examples to investigate the general question of how a conservative tracer propagates from the surface ocean to interior ocean and to illustrate how a given tracer boundary signal will be "filtered" with increasing distance from its source region. We show that tracers in the deep southeast Atlantic Ocean will respond much more strongly to changes in the surface Southern Ocean than to changes in the high-latitude North Atlantic, while the opposite is true for waters at intermediate depths. The impact of a change in the Southern Ocean surface δ^{13}C on a profile from the western South Atlantic is estimated using model-derived transit time distributions, and it is shown that significant deep ocean δ^{13}C variations can be expected on glacial-interglacial timescales, even under a steady state circulation regime. Records of δ^{13}C from the high-latitude North Atlantic and Southern Ocean are used as a proxy for glacial-interglacial changes in the surface ocean boundary condition in regions of deepwater formation. By convolving these high-latitude boundary conditions with model-derived TTDs, we are able to explain a significant part of the observed variability in benthic δ^{13}C records spanning the last glacial cycle(s) from locations as diverse as the equatorial Atlantic Ocean, the Cape Basin, and the equatorial Pacific. This suggests that changing boundary conditions may be driving a significant fraction of benthic δ^{13}C variability previously attributed to changes in ocean circulation. Furthermore, we show that our results predict a slightly higher δ^{13}C than observed in high-productivity regions, consistent with the concept of a productivity-induced low-δ^{13}C overprint.

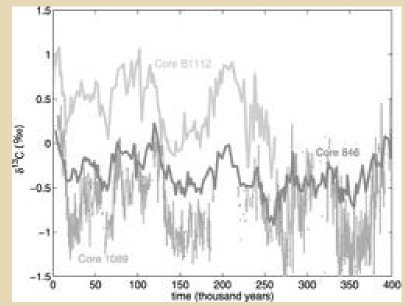

Figure 2.

High resolution figure

Figure caption: Benthic δ^{13}C records used in this study from the Cape Basin (1089), equatorial Pacific (846), and equatorial Atlantic (B1112).

Peacock, S., and M. Maltrud, 2006: Transit-Time Distributions in a Global Ocean Model. J. Phys. Oceanogr., 36, 474-495.

Abstract: Results from a simulation of the ocean "transit-time distribution" ("TTD") for global and regional ocean surface boundary conditions are presented based on a 5000-yr integration using the Parallel Ocean Program ocean general circulation model. The TTD describes the probability that water at a given interior point in the ocean was at some point on the ocean surface a given amount of time ago. It is shown that the spatial distribution of ocean TTDs can be understood in terms of conventional wisdom regarding time scales and pathways of the ventilated thermocline and the thermohaline circulation-driven deep-ocean circulation. The true mean age from the model (the first moment of the TTD) is demonstrated to be very large everywhere, because of very long-tailed distributions. Regional TTD distributions are presented for distinct surface boundary subregions, and it is shown how these can help in the interpretation of the global TTD. The spatial structure of each regional TTD is shown to become essentially the same at relatively long times. The form of the TTD at a given point in the ocean can be very simple, but some regions do exhibit more complicated multimodal distributions. The degree to which a simple functional approximation to the TTD is able to predict the spatial and temporal evolution of selected idealized tracers (for which interior sources and sinks are known or zero) with knowledge of only the tracer surface boundary condition is explored.

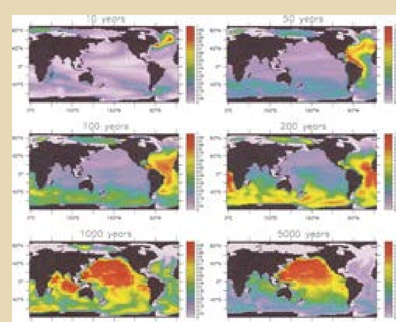

Figure 3.

High resolution figure

Figure caption: Column integral of the global TTD at various times after the pulse input. Each plot has been scaled by the maximum value of the field at that time. Note that for this and all following map-view figures, we show a projection that reflects the logical-space layout of the grid.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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CGD 2008 PROFILES IN SCIENCE: ADAM PHILLIPS

Summary of achievements

Adam Phillips

Adam Phillips supports the CCSM Climate Variability Working Group (CVWG) community by constructing and completing community atmosphere model (CAM) simulations, creating and running scripts that post-process CAM data, and by answering numerous requests from the community about the CVWG simulations and data. Phillips has also created and advertised a webpage for the climate community that details each CVWG simulation and points users to the locations of post-processed data.

Phillips recently completed a set of 11 CAM3.5 experiments as part of the CLIVAR Drought Working Group's model intercomparison project where numerous modeling centers forced their respective atmospheric general circulation model with a common set of idealized SST fields. These runs represent NCAR's contribution to the intercomparison project, and they are expected to be widely used by the climate community.

Phillips works closely with Dr. James Hurrell and Dr. Clara Deser on numerous scientific activities, ranging from exploratory research, to running CAM under a variety of conditions, to creating publication-quality figures for use in presentations and articles. Recently, Phillips has worked with Deser on a project concerning the differing effects of radiative and SST forcings in CAM simulations. (See paper abstract below.) Phillips' knowledge of CAM has also allowed him to assist numerous post-doctoral students in setting up and running CAM on various NCAR supercomputers.

For the Nested Regional Climate Model (NRCM) project, Phillips has been heavily involved in quality control procedures with regards to the set of experiments that are being coordinated through a collaboration between the Climate and Global Dynamics Division and the Mesoscale Modeling Division. Phillips has also had a direct hand in the running of the most recent set of NRCM model runs.

Phillips supports the NCAR Command Language (NCL) Development Team by adding numerous examples to the NCL website, frequently posts answers on the NCL-talk email list, provides scientific input to the NCL-development discussions, and fills in when needed to teach the graphics portion of the NCL-class.

Publications

Deser, Clara, and Adam S. Phillips, 2008: tmospheric Circulation Trends, 1950-2000: The Relative Roles of Oceanic and Atmospheric Radiative Forcing. Journal of Climate, in press.

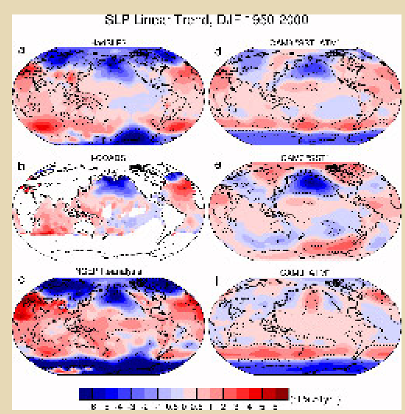

Figure 1.

High resolution figure

Abstract: The relative roles of direct atmospheric radiative forcing (due to observed changes in well-mixed greenhouse gases, tropospheric and stratospheric ozone, sulfate and volcanic aerosols, and solar output) and observed sea surface temperature (SST) forcing of global December-February atmospheric circulation trends during the second half of the 20th century are investigated by means of experiments with an atmospheric general ciculation model, Community Atmospheric Model Version 3 (CAM3). The model experiments are conducted by specifying the observed time-varying SSTs and atmospheric radiative quantities individually and in combination. This approach allows us to isolate the direct impact of each type of forcing agent, as well as to evaluate their combined effect and the degree to which their impacts are additive. CAM3 realistically simulates the global patterns of sea level pressure and 500 hPa geopotential height trends when both forcings are specified. SST forcing and direct atmospheric radiative forcing drive distinctive circulation responses that contribute about equally to the global pattern of circulation trends. These distinctive circulation responses are approximately additive and partially offsetting. Atmospheric radiative changes directly drive the strengthening and poleward shift of the middle latitude westerly winds in the southern hemisphere (and to a lesser extent may contribute to those over the Atlantic-Eurasian sector in the northern hemisphere), whereas SST trends (specifically those in the tropics) are responsible for the intensification of the Aleutian Low and weakening of the tropical Walker Circulation. Discrepancies between the atmospheric circulation trends simulated by CAM3 and Community Climate System Model Version 3 (CCSM3), a coupled model driven by the same atmospheric radiative forcing as CAM3, are

traced to differences in their tropical SST trends: in particular, a 60% weaker warming of the tropical Indo-Pacific in the CCSM3 ensemble mean than in nature.

Figure caption: Linear trends (color shading; hPa per 51 yrs) of December-February SLP during 1950-2000 from observations (left) and CAM3 model simulations (right). Results are shown for 3 observational data sets [a) HadSLP2, b) I-COADS, and c) NCEP Reanalyses] and 3 sets of CAM3 model simulations [d) "SST+ATM", e) "SST" and f) "ATM"]. Values south of 40°S are omitted in the left hand panels due to lack of reliable observations dating back to 1950. Dashed contours indicate trends that are significantly different from zero at the 95% level.

Support: Deser, supported by the National Science Foundation. Phillips, supported by NOAA CLIVAR.

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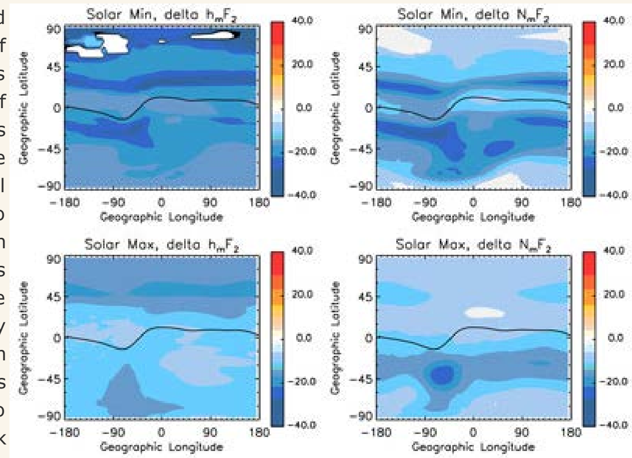
QIAN, LYING

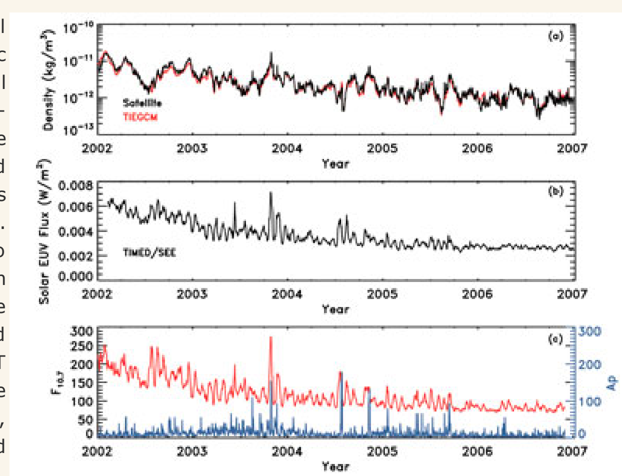
Understanding long-term changes in the upper atmosphere and ionosphere



Understanding global changes in the upper atmosphere and ionosphere not only has practical importance such as effect of these long-term changes on satellite drag, but also has important scientific interest. It can facilitate understanding of global change in the lower atmosphere since global changes in the lower atmosphere and upper atmosphere/ionosphere are closely linked and it can be easier to detect global changes in the upper atmosphere and ionosphere due to larger signal to noise ratio. In the area of global changes in the upper atmosphere and ionosphere, consistent results have emerged regarding trends of mesospheric temperature (negative), thermospheric density (negative), electron density in the ionospheric E- and F1- regions (positive), and E-region altitude (hmE, negative). These results support the hypothesis of cooling and contraction of the upper atmosphere due to greenhouse effect. However, trends of ionospheric F2 peak altitude (hmF2) and peak electron density (NmF2) remain controversial. The origin of trends of hmF2 and NmF2, whether it is natural or anthropogenic, is one of the greatest debates. Using NCAR thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM), we investigated greenhouse effect on trends of hmF2 and NmF2. It is found that increase of CO2 concentration changes temperature, large-scale circulation, and composition in the thermosphere and ionosphere, and thus causes long-term changes of hmF2 and NmF2. Trends of NmF2 due to greenhouse effect are negative; trends of hmF2 are negative during day and can be positive at night. Trends of NmF2 and hmF2 show strong variations with latitude, longitude, local time, season, and solar. Magnitude of trends of NmF2 is comparable to that of neutral composition changes. Dynamics play important role in trends of NmF2 and hmF2, with larger contribution under solar minimum condition. This study clearly demonstrates that greenhouse effect plays important role in trends of ionospheric peak altitude and peak electron density. The results of this studies was presented at 5th IAGA/ICMA/CAWSES workshop "Long-Term Changes and Trends in the Atmosphere" held in St. Petersburg, Russia, as an invited presentation.

Figure caption: *Changes of hmF2 and NmF2 (double CO2 - base CO2) at local noon for solar minimum (upper panels) and solar maximum (lower panel) conditions. Changes of hmF2 are absolution changes in km while changes of NmF2 are percentage changes. Solar minimum:* $F_{10.7} = \overline{F_{10.7}} = 70$ *; Solar maximum:* $F_{10.7} = \overline{F_{10.7}} = 200$ *. Geomagnetic Kp index is 1, i.e., under geomagnetic quiet condition. The black line in each figure is geomagnetic dip equator.*

Understanding long-term changes in the upper atmosphere and ionosphere



We investigated the role of eddy diffusion in the vertical coupling of the atmosphere. Measurements of thermospheric neutral density and composition show an annual/semiannual variation. Using NCAR thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM), we demonstrated how eddy diffusivity in the mesosphere and lower thermosphere (MLT) region can contribute to this annual/semiannual variation in the thermosphere. Thermosphere composition and temperature is sensitive to eddy diffusivity in the MLT region. Gravity wave breaking in the MLT region is considered to be the main source of the eddy diffusivity in this region. Such gravity wave is generated in the troposphere and propagates upwards into the MLT region and breaks due to wave instability. The troposphere can influence the themosphere through this process, demonstrating that the whole atmosphere is coupled together.

Figure caption: *Thermospheric neutral density simulated by the TIEGCM is in good agreement with satellite drag data, owing to improved seasonal variation introduced by an annual/semiannual variation of eddy diffusivity imposed at the model lower boundary (~97 km). Panel (a): Black: Satellite drag derived density; Red: TIEGCM simulation. Panel (b): the TIMED/SEE integrated (5-105 nm) solar EUV flux from day 2002039 to 2006365. The TIMED/SEE solar spectral irradiance measurements were used for solar input for the TIEGCM simulations. Panel (c): the corresponding solar activity index* $F_{10.7}$ *and geomagnetic activity index* A_p*, showing how density varies with solar activity and geomagnetic activity.*

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BILL RANDEL

General Information

ACD - TIIMES
ACD Division Director
UTLS

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PO Box 3000, Boulder, CO 80307-3000
Office: FL0-2030
Telephone: 303-497-1439
Email: randel@ucar.edu
Home Page - Vita

Research Focus FY08:

Flight path from Google Earth.

High resolution figure

I am the Division Director of the Atmospheric Chemistry Division (ACD) at NCAR. My personal research interests include dynamic variability and transport in the atmosphere, and understanding the variability of trace constituents using satellite observations.

More recent work has focused on behavior of the global tropopause. I have been a lead author for the World Meteorological Organization (WMO) - United Nations Environment Programme (UNEP) Assessments of stratospheric ozone and temperature trends, Intergovernmental Panel on Climate Change (IPCC) Assessments of Climate Change, and I am actively involved with a number of Stratospheric Processes And their Role in Climate (SPARC) activities.

I am currently on the Steering Group for the Network for the Detection of Atmospheric Composition Change (NDACC), and help lead the Upper Troposphere - Lower Stratosphere (UTLS) initiative at NCAR.

Community Service FY08:

- Associate Editor: Journal of Atmospheric Sciences
- Project Lead: World Climate Research Program / Stratospheric Processes and their Role in Climate (WCRP/SPARC)
- Thesis Committee: Rei Ueyama, Universityof Washington
- Thesis Committee: Kevin Grise, Colorado State University
- Editors Award, Geophysical Research Letters, AGU

Scientific Talks FY08:

- Seasonal to decadal variability of tropical stratospheric ozone observed with SHADOZ (San Francisco, CA USA, 12/2007)
- Comparisons between FTIR measurements and global model simulations (Kona, HI USA, 12/2007)
- The Asian monsoon anticyclone and chronic pollution near the tropopause (Boulder, CO USA, 06/2008)
- Using ACE hydrocarbons to constrain UTLS transport (Annecy, FRA, 09/2008)

Publications FY08:

Anthes, R. A., P. A. Bernhardt, Y. Chen, L. Cucurull, K. F. Dymond, D. Ector, S. B. Healy, S.-P. Ho, D. C. Hunt, Y.-H. Kuo, H. Liu, K. W. Manning, C. McCormick, T. K. Meehan, W. J. Randel, C. Rocken, W. S. Schreiner, S. V. Sokolovskiy, S. Syndergaard, D. C. Thompson, K. E. Trenberth, T.-K. Wee, N. L. Yen, Z. Zeng, 2008: The COSMIC/FORMOSAT-3 Mission: Early Results. *Bull. Amer. Meteor. Soc.*, **89**, 313-333, doi: 10.1175/BAMS-89-3-313.

Park, M., W. J. Randel, L. K. Emmons, P. F. Bernath, K. A. Walker, C. D. Boone, 2008: Chemical isolation in the Asian monsoon anticyclone observed in Atmospheric Chemistry Experiment (ACE-FTS) data. *Atmos. Chem. Phys.*, **8**, 757-764.

Zeng, Z., W. Randel, S. Sokolovskiy, C. Deser, Y.-H. Kuo, M. Hagan, J. Du, W. Ward, 2008: Detection of migrating diurnal tide in the tropical upper troposphere and lower stratosphere using the Challenging Minisatellite Payload radio occultation data. *J. Geophys. Res.*, **113**, D03102, doi: 10.1029/2007JD008725.

Seidel, D. J., Q. Fu, W. J. Randel, T. J. Reichler, 2008: Widening of the tropical belt in a changing climate. *Nature Geosci*, **1**, 21-24.

Shine, K. P., J. J. Barnett, W. J. Randel, 2008: Temperature trends derived from Stratospheric Sounding Unit radiances: The effect of increasing CO2 on the weighting function. *Geophys. Res. Lett.*, **35**, L02710, doi: 10.1029/2007GL032218.

Randel, W. J., M. Park, F. Wu, N. Livesey, 2007: A large annual cycle in ozone above the tropical tropopause linked to the Brewer Dobson circulation. *J. Atmos. Sci.*, **64**, 4479-4488, doi: 10.1175/2007JAS2409.1.

Randel, W. J., F. Wu, P. Forster, 2007: The Extratropical Tropopause Inversion Layer: Global Observations with GPS Data, and a Radiative Forcing Mechanism. *J. Atmos. Sci.*, **64**, 4489-4496, doi: 10.1175/2007JAS2412.1.

Seidel, D. J., W. J. Randel, 2007: Recent widening of the tropical belt: Evidence from tropopause observations. *J. Geophys. Res.*, **112**, D20113, doi: 10.1029/2007JD008861.

Kinnison, D. E., G. P. Brasseur, S. Walters, R. R. Garcia, D. R. Marsh, F. Sassi, V. L. Harvey, C. E. Randall, L. Emmons, J.-F. Lamarque, P. Hess, J. J. Orlando, X. X. Tie, W. Randel, L. L. Pan, A. Gettelman, C. Granier, T. Diehl, U. Niemeier, A. J. Simmons, 2007: Sensitivity of chemical tracers to meteorological parameters in the MOZART-3 chemical transport model. *J. Geophys. Res.*, **112**, D20302, doi: 10.1029/2006JD007879.

Bill Randel Research Catalog

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CGD Research Catalog

Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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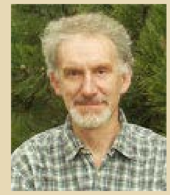
CGD 2008 PROFILES IN SCIENCE: DR. PHIL RASCH



Phil Rasch

Publications

Mitchell, D. L., P. Rasch, D. Ivanova, G. McFarquhar, and T. Nousiainen, 2008: Impact of small ice crystal assumptions on ice sedimentation rates in cirrus clouds and GCM simulations. Geophys. Res. Lett., 35, L09806, doi:10.1029/2008GL033552.

Abstract: In the prediction of climate change, the greatest uncertainty lies in the representation of clouds. Ice clouds are particularly challenging, and to date there is no accepted method for measuring the smaller ice crystals (D < 60 �m). This study examines the sensitivity of a global climate model to different assumptions regarding the number concentrations of small ice crystals when they are allowed to affect ice sedimentation rates. When their concentrations are relatively high, the GCM predicts a 12% increase in cloud ice amount and a 5.5% increase in cirrus cloud coverage globally. This produces a net cloud forcing of -5 W m-2 in the tropics and warms the upper tropical troposphere over 3°C. Ice crystal concentration differences assumed were modest in comparison to corresponding measurement uncertainties, revealing a potentially large source of uncertainty in the prediction of global climate.

Figure caption: (a) The annual average in-cloud ice water path (IWP) for the PSD2 run minus that for the PSD1 run, in g m^{-2}. Typical IWPs in the tropics were 30-40 g m^{-2} for the PSD1 run. (b) Annual average cirrus cloud coverage for the PSD2 simulation minus that for the PSD1 simulation, shown as percent difference.

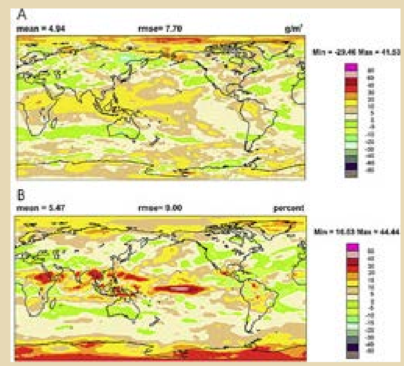
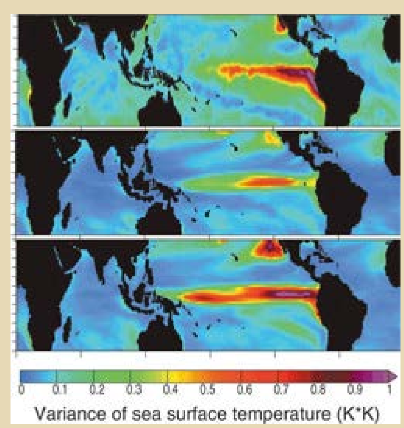


Figure 1.

High resolution figure

Bala, G., R.B. Rood, A. Mirin, J. McClean, K. Achutarao, D. Bader, P. Gleckler, R. Neale, and P. Rasch, 2008: Evaluation of a CCSM3 Simulation with a Finite Volume Dynamical Core for the Atmosphere at 1° Latitude � 1.25° Longitude Resolution. J. Climate, 21, 1467-1486.

Abstract: A simulation of the present-day climate by the Community Climate System Model version 3 (CCSM3) that uses a Finite Volume (FV) numerical method for solving the equations governing the atmospheric dynamics is presented. The simulation is compared to observations and to the well-documented simulation by the standard CCSM3, which uses the Eulerian spectral method for the atmospheric dynamics. The atmospheric component in the simulation herein uses a 1° latitude × 1.25° longitude grid, which is a slightly finer resolution than the T85-grid used in the spectral transform. As in the T85 simulation, the ocean and ice models use a nominal 1-degree grid. Although the physical parameterizations are the same and the resolution is comparable to the standard model, substantial testing and slight retuning were required to obtain an acceptable control simulation. There are significant improvements in the simulation of the surface wind stress and sea surface temperature. Improvements are also seen in the simulations of the total variance in the tropical Pacific, the spatial pattern of ice thickness distribution in the Arctic, and the vertically integrated ocean circulation in the Antarctic Circumpolar Current. The results



herein demonstrate that the FV version of the CCSM coupled model is a state-of-the-art climate model whose simulation capabilities are in the class of those used for Intergovernmental Panel on Climate Change (IPCC) assessments. The simulated climate is very similar to that of the T85 version in terms of its biases, and more like the T85 model than the other IPCC models.

Figure 2.

High resolution figure

Figure caption: The total variance of the sea surface temperature (K^2) computed from the annual means of the (top) HadISST dataset (Rayner et al. 2003), and CCSM3 (middle) T85 and (bottom) FVx1 simulations.

Richter, J.H., and P.J. Rasch, 2008: Effects of Convective Momentum Transport on the Atmospheric Circulation in the Community Atmosphere Model. Version 3. J. Climate, 21, 1487-1499.

Abstract: Transport of momentum by convection is an important process affecting global circulation. Owing to the lack of global observations, the quantification of the impact of this process on the tropospheric climate is difficult. Here an implementation of two convective momentum transport parameterizations, presented by Schneider and Lindzen and Gregory et al., in the Community Atmosphere Model, version 3 (CAM3) is presented, and their effect on global climate is examined in detail. An analysis of the tropospheric zonal momentum budget reveals that convective momentum transport affects tropospheric climate mainly through changes to the Coriolis torque. These changes result in improvement of the representation of the Hadley circulation: in December-February, the upward branch of the circulation is weakened in the Northern Hemisphere and strengthened in the Southern Hemisphere, and the lower northerly branch is weakened. In June-August, similar improvements are noted. The inclusion of convective momentum transport in CAM3 reduces many of the model's biases in the representation of surface winds, as well as in the representation of tropical convection. In an annual mean, the tropical easterly bias, subtropical westerly bias, and the bias in the 60°S jet are improved. Representation of convection is improved along the equatorial belt with decreased precipitation in the Indian Ocean and increased precipitation in the western Pacific. The improvements of the representation of tropospheric climate are greater with the implementation of the Schneider and Lindzen parameterization.

Figure 3.

High resolution figure

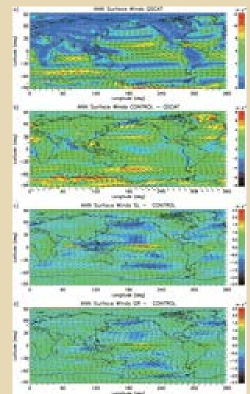


Figure caption: Annually averaged near-surface winds (m s^{-1}) for (a) QSCAT observations, (b) Control - observations, (c) SL simulation - Control, and (d) GR simulation - Control. Color shading represents wind speed in (a) and wind speed difference in (b)-(d). The vectors depict wind direction in (a) and vector wind difference in (b)-(d).

Pfister, G. G., P. G. Hess, L. K. Emmons, P. J. Rasch, and F. M. Vitt, 2008: Impact of the summer 2004 Alaska fires on top of the atmosphere clear-sky radiation fluxes. J. Geophys. Res., 113, D02204, doi:10.1029/2007JD008797.

Abstract: In this study we estimate the radiative impact of wildfires in Alaska during the record wildfire season of 2004 by integrating model simulations and satellite observations of the top of the atmosphere (TOA) radiative fluxes and aerosol optical depth. We compare results for the summer of 2004 to results for the summer of 2000 when fire activity in the boreal zone was low. Both observations and model show a decrease in TOA clear-sky fluxes over the Alaska fire region during summer 2004 of -7 ± 6 W m-2 and -10 ± 4 W m-2, respectively. About two thirds of the change occurs in the longwave, and one third in the shortwave, spectral range. On the bases of detailed model analysis we estimate that the changes in the longwave flux are predominantly explained by a higher surface temperature in summer 2004 compared to 2000. The change in the shortwave flux is largely caused by scattering of solar radiation on organic carbon aerosols emitted from the 2004 fires. This cooling is somewhat mitigated by the warming effect due to absorbing black carbon aerosols emitted from the fires and to a lesser extent by ozone and other greenhouse gases produced and released from the fires. Sensitivity studies with varying aerosol emission scenarios indicate that the ratio of black to organic carbon aerosol emissions of the boreal fires used in this study needs to be increased considerably to match both observations of aerosol optical depth and TOA radiation fluxes, or the biomass burning aerosols must be considerably more absorbing than parameterized in the model. While this study cannot resolve the cause of this discrepancy, it presents a powerful methodology to constrain aerosol emissions. This methodology will benefit from future improvements in measurements and modeling techniques.

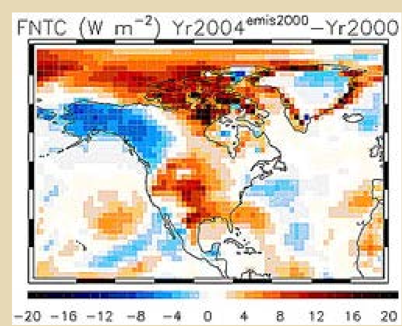


Figure 4.

High resolution figure

Figure caption: Estimated changes in the TOA clear-sky net radiation (W m^{-2}) due to the higher surface temperature in 2004 compared to 2000. Shown is the difference in the TOA net radiation fluxes between the year 2004 simulation and the year 2000 simulation with fire emissions for 2000.

Rasch, P. J., P. J. Crutzen, and D. B. Coleman, 2008: Exploring the geoengineering of climate using stratospheric sulfate aerosols: The role of particle size. Geophys. Res. Lett., 35, L02809, doi:10.1029/2007GL032179.

Abstract: Aerosols produced in the lower stratosphere can brighten the planet and counteract some of the effects of global warming. We explore scenarios in which the amount of precursors and the size of the aerosol are varied to assess their interactions with the climate system. Stratosphere-troposphere exchange processes change in response to greenhouse gas forcing and respond to geoengineering by aerosols. Nonlinear feedbacks influence the amount of aerosol required to counteract the warming. More aerosol precursor must be injected than would be needed if stratosphere troposphere exchange processes did not change in response to greenhouse gases or aerosols. Aerosol particle size has an important role in modulating the energy budget. A prediction of aerosol size requires a much more complex representation and assumptions about the delivery mechanism beyond the scope of this study, so we explore the response when particle size is prescribed. More aerosol is required to counteract greenhouse warming if aerosol particles are as large as those seen during volcanic eruptions (compared to the smaller aerosols found in quiescent conditions) because the larger particles are less effective at scattering incoming energy, and trap some outgoing energy. About 1.5 Tg S/yr are found to balance a doubling of CO_2 if the particles are small, while perhaps double that may be needed if the particles reach the size seen following eruptions.

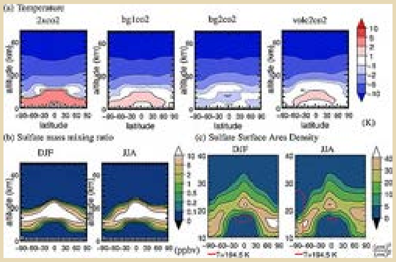


Figure 5.

High resolution figure

Figure caption: (top) Zonal average of annually averaged temperature. (bottom) The seasonal aerosol mixing ratio and surface area for June, July, August (JJA) and December January February (DJF) for experiment bg2co2 (see Table 1).The red contour shows the 194.5 K temperature isotherm.

P. R. Field, A. Gettelman, R. Neale, R. Wood, P. J. Rasch and H. Morrison, 2008: Midlatitude cyclone compositing to constrain climate model behavior using satellite observations. J. Climate, doi:10.1175/2008JCLI2235.1, in press.

Abstract: Identical composite analysis of midlatitude cyclones over oceanic regions has been carried out on both output from the NCAR (National Center for Atmospheric Research) CAM3 (Community Atmosphere Model version 3) and multi-sensor satellite data. By focusing on mean fields associated with a single phenomenon we critically appraise the ability of the CAM3 to reproduce realistic midlatitude cyclones. A number of perturbations to the control model were tested against observations, including a candidate new microphysics package for the CAM. The new microphysics removes the temperature dependent phase determination of the old scheme and introduces representations of microphysical processes to convert from one phase to another and from cloud to precipitation species. By sub-sampling composite cyclones based on system-wide mean strength (mean wind speed) and system-wide mean moisture we believe we are able to make meaningful like-with-like comparisons between observations and model output. We find that all variations of the CAM tested overestimate the optical thickness of high-topped clouds in regions of precipitation. Over a system as a whole, the model can both over- and underestimate total high-topped cloud amounts. However, system-wide mean rainfall rates and composite structure appears to be in broad agreement with satellite estimates. When cyclone strength is taken into account, changes in moisture and rainfall rates from both satellite derived observations and model output as a function of changes in sea surface temperature are in accordance with the Clausius-Clapeyron equation. We find that the proposed new microphysics package shows improvement to composite liquid water path fields and cloud amounts.

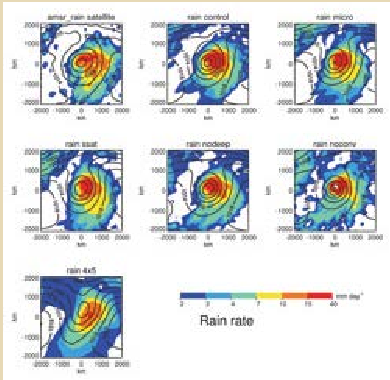


Figure 6.

High resolution figure

Figure caption: Composite rainfall rate in each 100km x 100km grid cell for the satellite observations and different model configurations. The 4000km x 4000km domain composite is for the medium moisture, greatest strength category generated from cyclones taken from all four oceanic regions for 2003-2004. The composite sea level pressure is overplotted (mb, solid lines).

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ROY RASMUSSEN

General Information

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Research Focus FY08:

TIIMES Retreat - High resolution figure

I spent most of my time on TIIMES this year leading and coordinating the Water System Program including a Headwaters Workshop in March 2008.

In addition ot the Water System Program I also have an activie role with the BEACHON project in collaboration with Alex Guenther and Beth Holland.

I also coordinated the TIIMES retreat held in November 2007. This was an opportunity to showcase the various projects and programs within TIIMES, exchange ideas, and help plan for the future direction of TIIMES.

Other activities include:

Hydrometeorology and Water Resources (HAP):
The Hydrometeorological Applications Program works to understand how water vapor, precipitation, and land surface hydrology interact across scales to define the hydrological cycle. Research results are used to improve weather and climate forecasts and to aid decision makers in a variety of water resource management applications such as flash flood prediction.

Snowfall and Freezing Precipitation:
Airport ground deicing operations are significantly effected by both snow and freezing precipitation (rain and drizzle), thus improved detection and forecasts of these conditions will increase both the safety and efficiency of airline and airport operations.

Weather Support to Deicing Decision Making (WSDDM):
The accumulation of ice on aircraft prior to take off has long been recognized as one of the most significant safety hazards affecting the aviation industry today. As little as 0.08 mm of ice on a wing surface can increase drag and reduce airplane lift by 25%. Acutely aware of the impacts these icing hazards can have on aviation, the Federal Aviation Administration (FAA) began supporting ground de-icing research at the National Center for Atmospheric Research (NCAR) in 1991. As a direct result of this FAA program, scientists at the Research Applications Program (the principal division of NCAR responsible for aviation weather projects) have developed a state-of-the-art, integrated display system that depicts accurate, real-time nowcasts of snowfall rate, plus current temperature, humidity, wind speed and direction.

Hotplate snowgauge and de-icing operations.

High resolution figure

NCAR-RAP's Marshall Field Site: Winter Weather Group

Activities of the Meteorology Sub-committee of the FAA/Industry Aircraft Ground Deicing Working Group
co-chairs: Tom Fahey (Northwest Airlines), Warren Underwood (FAA), Roy Rasmussen (NCAR)
9 October 2008

Community Service FY08:

- ASOS Technical Review Board, National Weather Service

Scientific Talks FY08:

- Overview of Hydromet Application Laboratory (Boulder, CO, October 08)
- Overview of Water System Program (Estes Park, CO, October 08)
- WSDDM System (Denver, CO, October 08)
- NCAR Water Cycle Research (Boulder, CO, October 08)
- NCAR Water Cycle Research (Boulder, CO, October 08)
- Overview of the Wyoming Weather Modification Pilot Program (Laramie, WY, October 08)
- Overview of Hydromet Application Laboratory (Boulder, CO, October 08)
- Colorado Headwater's Project (Boulder, CO, October 08)
- WSDDM System applied to the Vancouver Olympics (Whistler, BC Canada, October 08)
- NCAR Water Cycle Research (Tsukuba, Japan, October 08)
- Colorado Headwater's Project (Vienna, Austria, October 08)
- WSDDM, Check Time and LWE (Helsinki, Finland, October 08)
- Evaluation of 10 degree tilt of a wind on snowfall rate (Warsaw, Poland, October 08)
- LWE System (Warsaw, Poland, October 08)
- Summary of FAA/Industry Ground Deicing Working Group Acitivities (Warsaw, Poland, October 08)
- Overview of Water System Program (Boulder, CO, October 08)
- Evaluation of the Wyoming Weather Modification Project (Alpine, WY, October 08)
- Overview of the NCAR Water System Program (Arlington, VA, October 08)

Publications FY08:

Ikeda, K., R. M. Rasmussen, C.-H. Liu, G. Thompson, L. Xue, 2008: Investigation of the dependence of squall line structure and dynamics on microphysical parameterization. *15th Intl. Conf. on Clouds and Precipitation*, Cancun, MX, International Association of Meteorology and Atmospheric Science.

Ikeda, K., R. M. Rasmussen, E. A. Brandes, F. McDonough, 2008: Freezing drizzle detection with WSR-88D radars. *J. Appl. Meteor. Climat.*, doi: 10.1175/2008JAMC1939.1.

Tardif, R., R. M. Rasmussen, 2008: Process-oriented analysis of environmental conditions associated with precipitation fog events in the New York City region. *J. Appl. Meteor. Climat.*, **47(6)**, 1681-1703, doi: 10.1175/2007JAMC1734.1.

Thompson, G., P. R. Field, R. M. Rasmussen, W. D. Hall, 2008: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part II: Implementation of a new snow parameterization. *Mon. Wea. Rev.*, doi: 10.1175/2008MWR2387.1. (In Press)

Phillips, C., J. O. Pinto, M. Steiner, R. M. Rasmussen, N. Oien, R. E. Bateman, 2008: Statistical assessment of explicit model forecasts of convection using a new object-based approach. *13th Conf. on Aviation, Range and Aerospace Meteorology*, New Orleans, LA, US, American Meteorological Society, 11.5, 10 pp.

Wolfson, M. M., W. J. Dupree, R. M. Rasmussen, M. Steiner, S. G. Benjamin, S. S. Weygandt, 2008: Consolidated Storm Prediction for Aviation (CoSPA). *8th ICNS Conf.*, New Orleans, LA, US, American Meteorological Society, J6.5, 16 pp.

Brandes, E. A., K. Ikeda, G. Zhang, M. Schonhuber, R. M. Rasmussen, 2007: A statistical and physical description of hydrometeor distributions in Colorado snow storms using a video disdrometer. *J. Appl. Meteor. Climat.*, American Meteorological Society, **46**, 634-650.

Brandes, E. A., K. Ikeda, G. Zhang, M. Schonhuber, R. M. Rasmussen, 2007: A statistical and physical description of hydrometeor distributions in Colorado snowstorms using a video disdrometer. *J. Appl. Meteor. Climat.*, **46**, 634-650, doi: 10.1175/JAM2489.1. (Accepted)

Roy Rasmussen Research Catalog

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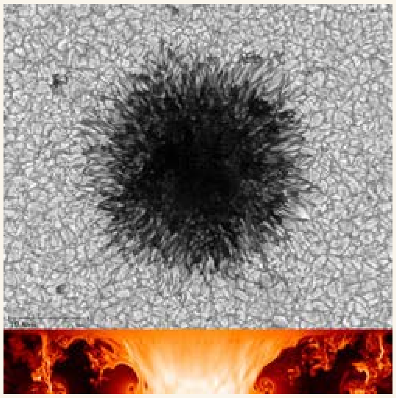
REMPEL, MATTHIAS

Radiative MHD Simulations of Sunspot Structure



Sunspots are regions of strong magnetic field (~3000 G) in the solar photosphere with a typical size of several 10000 km. Sunspots consist of a dark central region (umbra) surrounded by a region of very often similar size with filamentary structure. More detailed observations reveal a fine structure in both regions down to the resolution limit of current instrumentation. Numerical simulations of sunspot structure are very challenging, primarily due to the strong variation of density and Alfven velocity encounterd in photospheric strong field regions. In collaboration with the Max-Planck Intitute for Solar System Research (MPS) in Germany, we have modified the MURaM MHD code to cope with the numerical challenges and allow for self-consistent simulations of sunspots surrounded by granulation. Our simulated sunspots show a division in a central dark umbral region with bright dots and a penumbra showing bright filaments of about 3 to 4 Mm length with central dark lanes. By a process similar to the formation of umbral dots, the penumbral filaments result from magneto-convection in the form of upflow plumes, which become elongated by the presence of an inclined magnetic field and form additional convection rolls in the uppermost part of the plume structure. Expansion and flux expulsion causes a strong reduction of the field strength and increases of the inclination angle of the magnetic field in the upper part of the rising plume, where a dark lane forms owing to the piling up of matter near the cusp-shaped top and the upward bulging of the surfaces of constant optical depth. The simulated penumbral structure corresponds well to the observationally inferred interlocking-comb structure of the magnetic field with Evershed outflows along dark-laned filaments with nearly horizontal magnetic field and roll-type perpendicular motion, which are embedded in a background of stronger and less inclined field.

Figure caption: *Snapshot of a numerical simulation in a domain of 50x50x8 Mm containing a sunspot of about 25 Mm diameter. The top shows an intensity map (visible light image) of the simulated spot showing the central dark umbra with a few more bright umbral dots. The umbra is surrounded by a filamentary penumbral region formed by filaments of a few Mm in length. The outer parts of the domain show granulation with a few pores formed from magnetic flux that got eroded from the sunspot. The bottom panel shows the field strength on a vertical slice through the center of the spot. The maximum field strength at the bottom of the domain is 8kG, the field strength in the umbra of the spot reaches a peak value of 3.5 kG in the center.*

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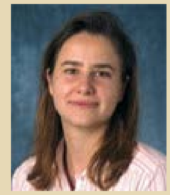
CGD 2008 PROFILES IN SCIENCE: DR. JADWIGA RICHTER

Summary of achievements



Jadwiga Richter

J. Richter has developed a new gravity wave parameterization for WACCM. This parameterization replaces the old arbitrarily specified gravity wave source spectrum with a source oriented approach. The new parameterization explicitly treats gravity wave generation from fronts and convection. This parameterization provides more realistic spatial and temporal distribution of gravity wave sources. As a result, the simulation of the middle atmospheric climate in WACCM is improved as compared to the previous version of the model. The greatest improvement is seen in the improvement of variability and the improved frequency of Sudden Stratospheric Warmings.

J. Richter is exploring changes to the gravity wave parameterization and top lid in CAM to improve some of CAM's biases, in particular: the sea level pressure and surface stresses in the Northern Pacific.

Publications

Richter, J. H., F. Sassi, R. R. Garcia, K. Matthes, and C. A. Fischer, 2008: Dynamics of the middle atmosphere as simulated by the Whole Atmosphere Community Climate Model, version 3 (WACCM3). J. Geophys. Res., 113, D08101, doi:10.1029/2007JD009269.

Abstract: The Whole Atmosphere Community Climate Model, version 3 (WACCM3) is a state-of-the-art climate model extending from the Earth's surface to the lower thermosphere. In this paper we present a detailed climatology of the dynamics of the middle atmosphere as represented by WACCM3 at various horizontal resolutions and compare them to observations. In addition to the mean climatological fields, we examine in detail the middle atmospheric momentum budget as well as several lower and upper atmosphere coupling phenomena including stratospheric sudden warmings, the 2-day wave, and the migrating diurnal tide. We find that in large part, differences between WACCM3 and observations and the mean state of the model at various horizontal resolutions are related to gravity wave drag, which is parameterized in WACCM3 (and similar models). All three lower and upper atmosphere coupling processes examined show high sensitivity to the model's resolution.

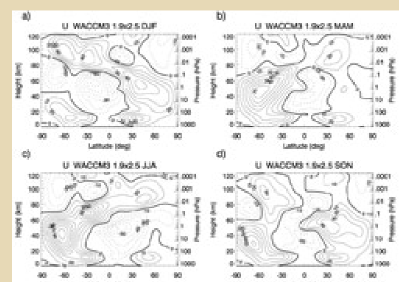


Figure 1.

High resolution figure

Figure caption: Seasonally averaged zonal wind in m s^{-1} averaged over 30 years of WACCM3 simulation at 1.9° x 2.5° resolution.

Richter, J.H., and P.J. Rasch, 2008: Effects of Convective Momentum Transport on the Atmospheric Circulation in the Community Atmosphere Model, Version 3. J. Climate, 21, 1487-1499.

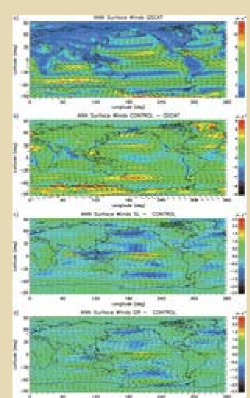


Figure 2.

High resolution figure

Abstract: Transport of momentum by convection is an important process affecting global circulation. Owing to the lack of global observations, the quantification of the impact of this process on the tropospheric climate is difficult. Here an implementation of two convective momentum transport parameterizations, presented by Schneider and Lindzen and Gregory et al., in the Community Atmosphere Model, version 3 (CAM3) is presented, and their effect on global climate is examined in detail. An analysis of the tropospheric zonal momentum budget reveals that convective momentum transport affects tropospheric climate mainly through changes to the Coriolis torque. These changes result in improvement of the representation of the Hadley circulation: in December-February, the upward branch of the circulation is weakened in the Northern Hemisphere and strengthened in the Southern Hemisphere, and the lower northerly branch is weakened. In June-August, similar improvements are noted. The inclusion of convective momentum transport in CAM3 reduces many of the model's biases in the representation of surface winds, as well as in the representation of tropical convection. In an annual mean, the tropical easterly bias,

subtropical westerly bias, and the bias in the 60°S jet are improved. Representation of convection is improved along the equatorial belt with decreased precipitation in the Indian Ocean and increased precipitation in the western Pacific. The improvements of the representation of tropospheric climate are greater with the implementation of the Schneider and Lindzen parameterization.

Figure caption: Annually averaged near-surface winds (m s^{-1}) for (a) QSCAT observations, (b) Control - observations, (c) SL simulation - Control, and (d) GR simulation - Control. Color shading represents wind speed in (a) and wind speed difference in (b)-(d). The vectors depict wind direction in (a) and vector wind difference in (b)-(d).

Chang, L., S. Palo, M. Hagan, J. Richter, R. Garcia, D. Riggin, D. Fritts, 2008: Structure of the migrating diurnal tide in the Whole Atmosphere Community Climate Model (WACCM) J. Climate, 41, 1397-1406, doi:10.1016/j.asr.2007.03.035 .

Abstract: As part of an ongoing effort to understand the migrating diurnal tide generated by the NCAR Whole Atmosphere Community Climate Model, version 3 (WACCM3), we compare the WACCM3 migrating diurnal tide in the horizontal wind and temperature fields to similar results from the Global Scale Wave Model (GSWM). The WACCM3 diurnal tidal wind fields are also compared to tropical radar measurements at Kauai (22°N, 200.2°E) and Rarotonga (21.3°S, 199.7°E). The large-scale features of the WACCM3 results, such as the global spatial structure and the semiannual amplitude variation are in general agreement with past tidal studies; however, several differences do exist. WACCM3 exhibits a much higher degree of hemispheric asymmetry, lower overall amplitudes around the equinoxes, and peaks which are more confined in latitude when compared with the GSWM. Factors which may contribute to such differences between WACCM3 and GSWM are the solar heating profiles from ozone and water vapor, dissipation, and the zonal mean zonal winds. We find that the internally generated heating in WACCM3 and eddy dissipation values are both smaller than the values specified in the GSWM; the eddy dissipation fields and zonal mean zonal winds of the two models also display measurable differences in spatial structure. Comparisons with radar data show several differences in spatial and seasonal structure. In particular, the diurnal tide zonal winds in WACCM3 above Kauai are considerably larger in amplitude than those observed in the radar data, due to contributions from nonmigrating tidal components including wave numbers eastward I through 3, westward 2, and stationary components, which interfere constructively with the migrating component around equinox in WACCM3. (C) 2007 COSPAR. Published by Elsevier Ltd. All rights reserved.

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JADWIGA 'YAGA' RICHTER

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Gravity Waves

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Research Focus FY08:

Gravity waves play an important role in the coupling of various atmospheric regions. Therefore, the study of gravity waves is a focal point of lower, middle, and upper atmospheric research, being of strong inter-disciplinary interest.

J. Richter has developed a new gravity wave parameterization for the Whole-Atmosphere Community Climate Model (WACCM). This parameterization replaces the old arbitrarily specified gravity wave source spectrum with a source oriented approach. The new parameterization explicitly treats gravity wave generation from fronts and convection. This parameterization provides more realistic spatial and temporal distribution of gravity wave sources. As a result, the simulation of the middle atmospheric climate in WACCM is improved as compared to the previous version of the model. The greatest improvement is seen in the improvement of variability and the improved frequency of Sudden Stratospheric Warmings.

J. Richter is exploring changes to the gravity wave parameterization and top lid in CAM to improve some of CAM's biases, in particular: the sea level pressure and surface stresses in the Northern Pacific.

Additional Information:

Representing gravity waves in General Circulation Models

Scientific Talks FY08:

- Effects of Changes in Gravity Wave Parameterization on the Troposphere and Lower Stratosphere (Boulder, CO USA, 02/2008)
- Gravity Waves in CAM3.5 (Breckenridge, CO USA, 06/2008)
- Source oriented GW parameterization in WACCM3 (Breckenridge, CO USA, 06/2008)

Publications FY08: (abstracts)

Richter, J. H., P. J. Rasch, 2008: Effects of convective momentum transport on the atmospheric circulation in the Community Atmosphere Model, Version 3. *J. Climate*, **21**, 1487-1499, doi: 10.1175/2007JCLI1789.1.

Richter, J. H., F. Sassi, R. R. Garcia, K. Matthes, C. Fischer, 2008: Dynamics of the middle atmosphere as simulated by the Whole Atmosphere Community Climate Model, version 3 (WACCM3). *J. Geophys. Res.*, **113**, D08101, doi: 10.1029/2007JD009269.

Chang, L., S. Palo, M. Hagan, J. Richter, R. Garcia, D. Riggin, D. Fritts, 2008: Structure of the migrating diurnal tide in the Whole Atmosphere Community Climate Model (WACCM). *Adv. Space Res.*, **41**, 1397-1406, doi: 10.1016/j.asr.2007.03.035.

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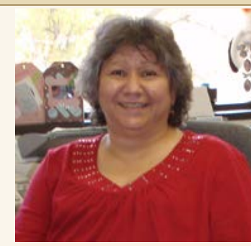

Research Focus FY08:

Teresa began working for NCAR over 30 years (1976) as a receptionist for HAO. At the time, she was raising two young sons, and she had also legally adopted her two younger brothers—so she needed to reserve time for her family. "I was looking for a job that would mean I would be home weekends and evenings," she says. After a year, "I wanted a little more opportunity for advancement." She landed a job as a secretary in the Atmospheric Quality Modification Division, which subsequently became ACD. She worked her way up, winning an administrative support award (now known as an outstanding accomplishment award) in 1983 and, in 1990, becoming a division administrator. In 2005 Teresa moved to the newly created TIIMES as the Institute Administrator working with Director, Rit Carbone. During her career at NCAR, Teresa has also participated in a variety of committees, including Delphi Co-Coordinator with Nancy Wade (2002-2006).

Community Service FY08:

- SOARS Writing Mentor: Luna Rodriguez-Manzanet
- Spanish/English translation (written and oral) for UCAR/NCAR groups
- UCAR liaison to Boulder Valley Schools Latino Youth Leadership Conference 2004-present
- Mentor community parents to enhance school involvement and communication
- Mentoring Administrator Peers (MAP)
- Co-President: Latina League
- Special Transit Board of Directors: Special Transit is a private, nonprofit organization located in Boulder, Colorado. Mission is to promote independence and self-sufficiency for people with limited mobility by providing caring, customer-focused transportation options.

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LUCIANA RIZZO

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Research Focus FY08:

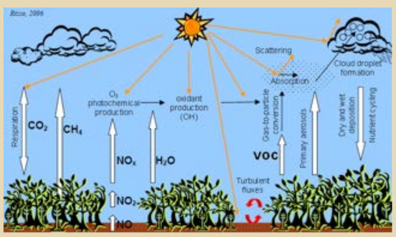

Figure 1: Biosphere-atmosphere interactions: aerosols emitted through the metabolism of the forest interact with solar radiation, which in turn affects photosynthesis, photochemistry and nutrient cycling - High resolution figure

Secondary Organic Aerosol Formation in the Amazon Rainforest

The term 'aerosol' is defined as a suspension of solid or liquid particles in a gas. In remote regions such as the Amazon rainforest, most of the atmospheric aerosols arise from biogenic sources, directly emitted as pollen, bacteria, leaf and insect fragments, and secondarily emitted as a result of gas-to-particle conversion. Once released in the atmosphere, these micrometric particles interact with solar radiation by absorption and scattering of light, and indirectly through the formation of cloud condensation nuclei (CCN) (Fig.1). The radiation balance at the surface is linked with photosynthesis and biomass carbon assimilation. Dry and wet deposition processes remove aerosols from the atmosphere, playing a role on the forest nutrient cycling. Therefore, the biosphere and the atmosphere are closely related, and the biogenic aerosols are an integrant part of the ecosystem dynamics...more

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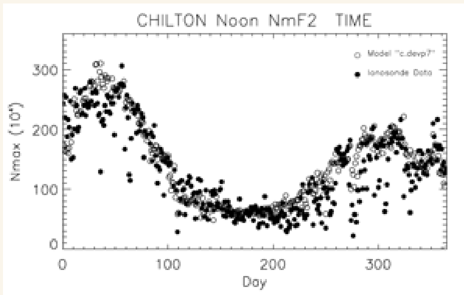
ROBLE, RAY

Detailed Modeling of the Global Thermosphere / Ionosphere F-region Structure for the year 2002.



Ionosonde data from 10 stations covering both the high and low latitudes of the Northern and Southern hemisphere were analyzed to determine the global diurnal structure of the ionospheric F-region for the entire year 2002. These data were compared with predictions made by the Thermosphere/Ionosphere/Mesosphere/Electrodynamics General Circulation Model (TIME-GCM) for the same period and same station locations. Good agreement between model predictions and observations were obtained for the overall ionospheric variation for the northern hemisphere stations (Chilton, Moscow, Wallops, Eglin, Wakkanai) but there were discrepancies with the Southern Hemisphere stations (Hobart and Port Stanley). Good overall agreement was obtained at the equatorial stations (Jicamarca, Darwin, Ascension Island). Although the overall structure was well simulated the station variability was not suggesting that atmospheric coupling from the lower atmosphere was stonger than that in the model simulations. The model had tidal, planetary wave and uniform gravity wave forcing at the lower boundary but an additional source of variability of about 50% is needed to match the simulations. The Southern hemisphere discrepancies may be related to the strong planetary wave activity and a major Sudden Stratospheric Warming that occured in the southern polar winter and spring in 2002. These data/model simulations will continue to be studied to determine the coupling between lower and upper atmosphere processes.

This research is a collaborative effort between Henry Rishbeth (Southampton University, England), Michael Mendillo and Joei Wroten (Boston University) and Raymond Roble(HAO,ESSL).

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Research Focus FY08:

Responsible for the support and development of RAF's airborne capabilities for measuring cloud and aerosol particles and collaboration with NCAR and other investigators on research projects in support of RAF's

Publications FY08:

Stith, J. L., W. Cooper, V. Ramanathan, D. C. Rogers, P. DeMott, T. Campos, B. Adhikary, 2008: Interactions of Asian Emissions with Storms in the Pacific Ocean: Early results from the Pacific Dust Experiment (PACDEX). *15th Intl. Conf. on Clouds and Precipitation*, Cancun, MX, 9.11.

Rauber, R. M., B. Stevens, H. T. Ochs III, C. Knight, B. A. Albrecht, A. M. Blyth, C. W. Fairall, J. B. Jensen, S. G. Lasher-Trapp, O. L. Mayol-Bracero, G. Vali, J. R. Anderson, B. A. Baker, A. R. Bandy, F. Burnet, J.-L. Brenguier, W. A. Brewer, P. R. A. Brown, P. Chuang, W. R. Cotton, L. Di Girolamo, B. Geert, H. Gerber, S. Goeke, L. Gomes, B. G. Heikes, J. G. Hudson, P. Kollias, R. P. Lawson, P. Jonas, S. K. Krueger, D. H. Lenschow, L. Nuijens, D. W. O'Sullivan, R. A. Rilling, D. C. Rogers, A. P. Siebesma, E. Snodgrass, J. L. Stith, D. C. Thornton, S. Tucker, C. H. Twohy, P. Zuidema, 2007: Rain in (shallow) cumulus over the ocean - the RICO campaign. *Bull. Amer. Meteor. Soc.*, **88**, 1912-1928, doi: 10.1175/BAMS-88-12-1912.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. NAN ROSENBLOOM

Summary of achievements

Nan Rosenbloom

Nan Rosenbloom is the CCSM paleoclimate liaison for the Quaternary (Holocene and Pleistocene Epochs) and late Neogene (Pliocene Epoch) periods. In this role Nan helps modelers from the paleoclimate community set up and run experiments using CCSM3.0. She is currently collaborating with multiple research groups on experiments that include time slices from 8.2 ka, 11 ka, 21ka (LGM), 485ka (MIS 13), and 3Ma (Pliocene). Nan also contributed to a deep-time experiment for the mid-Cretaceous (100 Ma).

In a collaborative project with the University of Colorado and NOAA, Nan is running a series of experiments that focus on an 8.2ka cooling event in the North Atlantic. At 8.2ka the region experienced abrupt cooling, presumed to be in response to freshwater drainage from glacial Lake Agassiz into Hudson Bay. Understanding the response of the Atlantic meridional overturning circulation (MOC) to this melt-water pulse will help to identify reasonable model projections of future change in the Atlantic MOC.

Nan is modeling the mid-Pliocene (3Ma) as part of a model inter-comparison project (PlioMIP).

The Pliocene Epoch extends from 5Ma - 1.8Ma during which time the world transitioned from generally warmer climates into the much cooler climate realm that culminated in the Pleistocene glaciations. We are focusing on a mid-Pliocene warm period (3.15Ma-2.9Ma). The period is of great interest to paleoclimate modelers as an analog for potential future climate because the paleogeography and continental configurations were generally similar to present day.

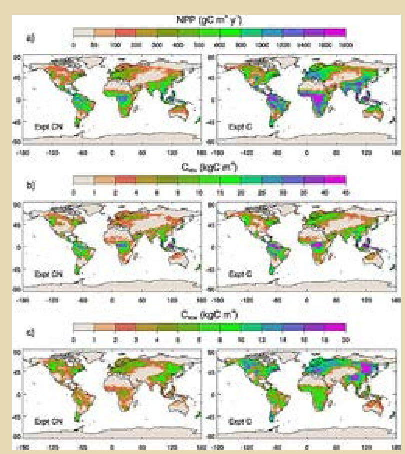
In FY2008 Nan co-mentored a SOARS protégé, Zi Zi Searles, on another Pliocene modeling experiment that incorporated new proxy SST temperatures from ODP cores into the PRISM2 (Pliocene Research, Interpretation and Synoptic Mapping) dataset. By comparing results from the existing CAM3 model Pliocene experiment (which used the original PRISM2 dataset) to the new experiment with revised SSTs, Zi Zi was able to quantify the effect of warmer SSTS on Pliocene climate.

In a sensitivity experiment, Nan looked at the effect of removing the West Antarctic Ice Sheet (WAIS) on Antarctic atmospheric circulation and on circulation in the Southern Ocean. The WAIS may not have been present during the mid-Pliocene (3Ma).

To coordinate data analysis of CCSM model results for paleoclimate modelers, Nan maintains paleo-friendly versions the diagnostics packages for each component model (ocn, atm, lnd, ice).* *Nan has also contributed to updating the CCSM documentation for paleoclimate modelers.

Publications

Thornton, P. E., J.-F. Lamarque, N. A. Rosenbloom, and N. M. Mahowald, 2007: Influence of carbon-nitrogen cycle coupling on land model response to CO2 fertilization and climate variability. Global Biogeochem. Cycles, 21, GB4018, doi:10.1029/2006GB002868.



Abstract: Nutrient cycling affects carbon uptake by the terrestrial biosphere and imposes controls on carbon cycle response to variation in temperature and precipitation, but nutrient cycling is ignored in most global coupled models of the carbon cycle and climate system. We demonstrate here that the inclusion of nutrient cycle dynamics, specifically the close coupling between carbon and nitrogen cycles, in a terrestrial biogeochemistry component of a global coupled climate system model leads to fundamentally altered behavior for several of the most critical feedback mechanisms operating between the land biosphere and the global climate system. Carbon-nitrogen cycle coupling reduces the simulated global terrestrial carbon uptake response to increasing atmospheric CO_2 concentration by 74%, relative to a carbon-only counterpart model. Global integrated responses of net land carbon exchange to variation in temperature and precipitation are significantly damped by carbon-nitrogen cycle coupling. The carbon cycle responses to temperature and precipitation variation are reduced in magnitude as atmospheric CO_2 concentration rises for the coupled carbon-nitrogen model, but increase in magnitude for the carbon-only counterpart. Our results suggest that previous carbon-only treatments of climate-carbon cycle coupling likely overestimate the terrestrial biosphere's capacity to ameliorate atmospheric CO2 increases through direct fertilization. The next generation of coupled climate-biogeochemistry model projections for future atmospheric CO2 concentration and climate change should include explicit, prognostic treatment of terrestrial carbon-nitrogen cycle coupling.

Figure 1.

High resolution figure

Figure caption: Example annual mean flux and state variables from final 25 a of control simulations for C-N (Experiment CN) and carbon-only (Experiment C) model configurations. (a) Net primary production (NPP). (b) Total vegetation carbon (C_{veg}). (c) Total soil organic matter carbon (C_{SOM}).

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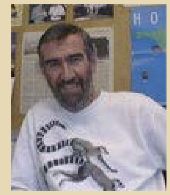
CGD 2008 PROFILES IN SCIENCE: DR. PETER GENT

Summary of achievements

Peter spent the large majority of his time over the last year as Chairman of the CCSM Science Steering Committee. The CCSM project is in the middle of development of the next version of the model, CCSM4. This version will have many improvements in the physical components of the model. In addition, it will have an explicit carbon-nitrogen cycle component, a chemistry component, an upper atmosphere version, and a very early version of a land ice component. The CCSM is supposed to be ready by the end of 2008. It is Peter's and the steering comittee's job to oversee this development, and to assure that it is completed on time.



Peter Gent

Publications

Goes, M., I. Wainer, P. R. Gent, and F. O. Bryan, 2008: Changes in subduction in the South Atlantic Ocean during the 21st century in the CCSM3. Geophys. Res. Lett., 35, L06701, doi:10.1029/2007GL032762.

Abstract: The Community Climate System Model version 3 is used to analyse changes in water mass subduction rates in the South Atlantic Ocean over the 21st century. The model results are first compared to observations over 1950-2000, and shown to be rather good. The subduction rates do not change significantly over the 21st century, but the densities at which water masses form become significantly lighter. The strong westerly winds in this region do not change much, which suggests small changes to the rate at which the Atlantic sector of the Southern Ocean takes up heat and carbon dioxide over the 21st century.

Figure caption: Plot of zonal average salinity and density contours in the South Atlantic Ocean: a) Levitus observations, b) CCSM3 ensemble average <1950-1999>, and c) CCSM3 ensemble average <2080-2099>.

Support: National Science Foundation.

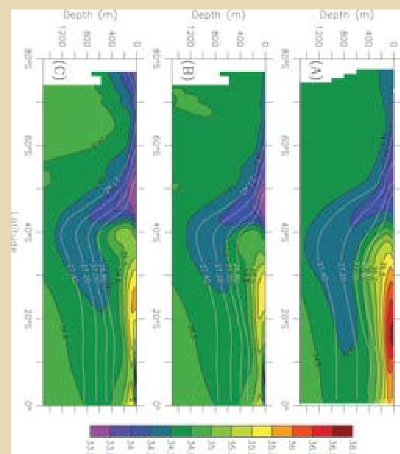


Figure 1:

High resolution figure

Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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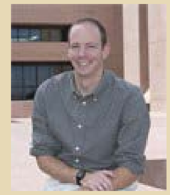
CGD 2008 PROFILES IN SCIENCE: DR. ANDREW GETTELMAN

Summary of achievements

My work focuses on the upper troposphere and lower stratosphere, and extends into understanding the representation of clouds of all types in the atmosphere, especially ice and mixed clouds. This region of the atmosphere sets the chemical boundary conditions of the stratosphere (with impacts on the stratospheric ozone layer) and also is important for the impact of clouds and water vapor in this region on the earth's energy balance (and hence climate). My work encompasses both models and measurements. I work extensively with observations and simulation of ice and mixed phase clouds, and have been also working on understanding aerosol indirect effects for liquid and ice clouds.



Andrew Gettelman

Publications

A. Gettelman, T. Birner, V. Eyring, H. Akiyoshi, D. A. Plummer, M. Dameris, S. Bekki, F. Lefevre, F. Lott, C. Brühl, K. Shibata, E. Rozanov, E. Mancini, G. Pitari, H. Struthers, W. Tian, and D. E. Kinnison, 2008: The Tropical Tropopause Layer 1960-2100. Atmos. Chem. Phys. Discuss., 8, 1367-1413.

Abstract: The representation of the Tropical Tropopause Layer in 13 different Chemistry Climate Models designed to represent the stratosphere is analyzed. Simulations for 1960-present and 1980-2100 are analyzed and compared to reanalysis model output. Results indicate that the models are able to reproduce the basic structure of the TTL. There is a large spread in cold point tropopause temperatures that may be linked to variation in TTL ozone values. The models are generally able to reproduce historical trends in tropopause pressure obtained from reanalysis products. Simulated historical trends in cold point tropopause temperatures and in the meridional extent of the TTL are not consistent across models. The pressure of both the tropical tropopause and the level of main convective outflow appear to be decreasing (increasing altitude) in historical runs. Similar trends are seen in the future. Models consistently predict decreasing tropopause and convective outflow pressure, by several hPa/decade. Tropical cold point temperatures increase by 0.2 K/decade. This indicates that tropospheric warming dominates stratospheric cooling at the tropical tropopause. Stratospheric water vapor at 100 hPa increases by up to 0.5-1 ppmv by 2100. This is less than implied directly by the temperature and methane increases, highlighting the correlation of tropopause temperatures with stratospheric water vapor, but also the complex nature of TTL transport.

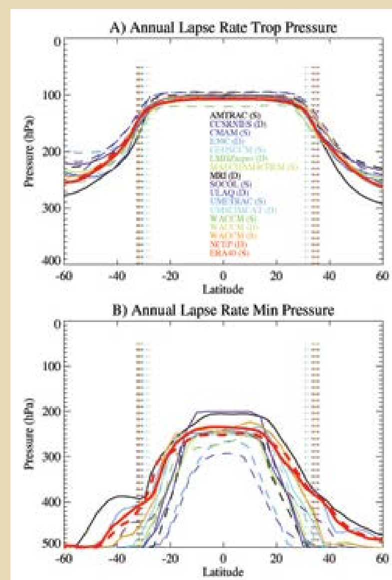


Figure 1.

High resolution figure

Figure caption: Zonal mean (A) Lapse Rate Tropopause Pressure and (B) Lapse Rate Miniumum Pressure from CCMVal models (REF1 scenarios, 1980-2005). Vertical Dotted lines are meridional tropopause edges. Thick Red lines are NCEP/NCAR (dashed) and ERA40 (solid) Reanalyses. Models are either solid (S) or dashed (D) lines as indicated in the legend in (A).

Morrison, H. and A. Gettelman, 2008: A new two-moment bulk stratiform cloud microphysics scheme in the Community Atmospheric Model (CAM3), Part I: Formulation and Numerical Tests. J. Climate, 21:15, 3642-3659.

Abstract: A new two-moment stratiform cloud microphysics scheme in a general circulation model is described. Prognostic variables include cloud droplet and cloud ice mass mixing ratios and number concentrations. The scheme treats several microphysical processes, including hydrometeor collection, condensation/ evaporation, freezing, melting, and sedimentation. The activation of droplets on aerosol is physically based and coupled to a subgrid vertical velocity. Unique aspects of the scheme, relative to existing two-moment schemes developed for

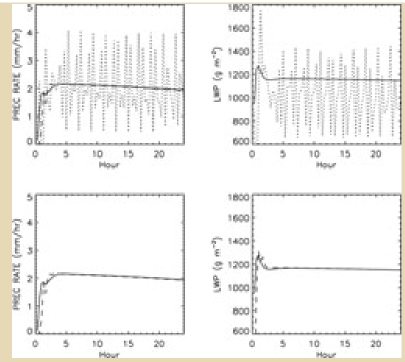


Figure 2.

High resolution figure

general circulation models, are the diagnostic treatment of rain and snow number concentration and mixing ratio and the explicit treatment of subgrid cloud water variability for calculation of the microphysical process rates.

Numerical aspects of the scheme are described in detail using idealized one-dimensional offline tests of the microphysics. Sensitivity of the scheme to time step, vertical resolution, and numerical method for diagnostic precipitation is investigated over a range of conditions. It is found that, in general, two substeps are required for numerical stability and reasonably small time truncation errors using a time step of 20 min; however, substepping is only required for the precipitation microphysical processes rather than the entire scheme. A new numerical approach for the diagnostic rain and snow produces reasonable results compared to a benchmark simulation, especially at low vertical resolution. Part II of this study details results of the scheme in single-column and global simulations, including comparison with observations.

Figure caption: (top) Time evolution of grid-mean surface precipitation rate and LWP using the 30-s benchmark time step (solid) and 1200-s time step with a single substep (dotted) and (bottom) using the 30-s benchmark time step (solid) and 1200-s time step with two substeps (dash).

Gettelman, A., H. Morrison, and S.J. Ghan, 2008: A New Two-Moment Bulk Stratiform Cloud Microphysics Scheme in the Community Atmosphere Model, Version 3 (CAM3). Part II: Single-Column and Global Results. J. Climate, 21, 3660-3679.

Abstract: The global performance of a new two-moment cloud microphysics scheme for a general circulation model (GCM) is presented and evaluated relative to observations. The scheme produces reasonable representations of cloud particle size and number concentration when compared to observations, and it represents expected and observed spatial variations in cloud microphysical quantities. The scheme has smaller particles and higher number concentrations over land than the standard bulk microphysics in the GCM and is able to balance the top-of-atmosphere radiation budget with 60% the liquid water of the standard scheme, in better agreement with retrieved values. The new scheme diagnostically treats both the mixing ratio and number concentration of rain and snow, and it is therefore able to differentiate the two key regimes, consisting of drizzle in shallow, warm clouds and larger rain drops in deeper cloud systems. The modeled rain and snow size distributions are consistent with observations.

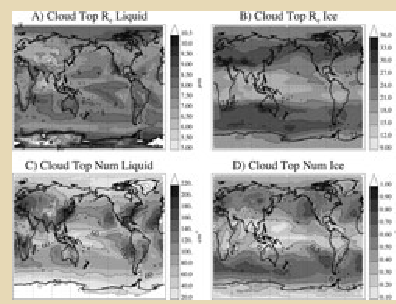


Figure 3.

High resolution figure

Figure caption: Annual mean cloud-top (a) cloud drop (liquid) effective radius (μm), (b) cloud ice effective radius (μm), (c) in-cloud droplet number concentration (cm^{-3}), (d) in-cloud ice number concentration (cm^{-3}).

Gettelman, A. and Q. Fu, 2008: Observed and Simulated Upper Tropospheric Water Vapor Feedbacks. J. Climate, 21:13, 3282-3289.

Abstract: Satellite measurements from the Atmospheric Infrared Sounder (AIRS) in the upper troposphere over 4.5 yr are used to assess the covariation of upper-tropospheric humidity and temperature with surface temperatures, which can be used to constrain the upper-tropospheric moistening due to the water vapor feedback. Results are compared to simulations from a general circulation model, the NCAR Community Atmosphere Model (CAM), to see if the model can reproduce the variations. Results indicate that the upper troposphere maintains nearly constant relative humidity for observed perturbations to ocean surface temperatures over the observed period, with increases in temperature ~1.5 times the changes at the surface, and corresponding increases in water vapor (specific humidity) of 10%-25% °C^{-1}. Increases in water vapor are largest at pressures below 400 hPa, but they have a double peak structure. Simulations reproduce these changes quantitatively and qualitatively. Agreement is best when the model is sorted for satellite sampling thresholds. This indicates that the model reproduces the moistening associated with the observed upper-tropospheric water vapor feedback. The results are not qualitatively sensitive to model resolution or model physics.

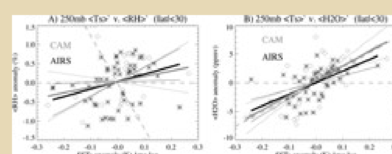


Figure 4.

High resolution figure

Figure caption: (a) RH and (b) specific humidity (Q) from both AIRS data (black asterisks) and CAM simulation (gray diamonds). Thick lines illustrate bootstrap fits from AIRS (black) and CAM (gray), and thin lines are ±two std dev (2&3963;) from the linear fit for AIRS and CAM. The thin dashed lines represent constant relative and specific humidity as a function of surface temperature as described in the text.

Burkhardt, U., B. Kärcher, M. Ponater, K. Gierens, and A. Gettelman, 2008: Contrail cirrus supporting areas in model and observations. Geophys. Res. Lett., 35, L16808, doi:10.1029/2008GL034056.

Abstract: Contrails form and persist dependent on the surrounding moisture, temperature and pressure fields and on fuel and aircraft specific variables. After formation, contrail persistence requires only supersaturation relative to ice. The fractional area in which contrails can form is called potential contrail coverage. We introduce a potential contrail cirrus coverage equivalent to the cloud free supersaturated area. This field, simulated by the ECHAM4 climate model, agrees fairly well with estimates of supersaturation frequency as inferred from aircraft and satellite measurements. In areas where the two potential coverages are different, especially at lower flight levels, potential contrail coverage is not a valid estimate of maximum attainable contrail cirrus coverage. We parameterize both potential coverages consistently with the ECHAM4 cloud cover parameterization. A comparison of the potential contrail coverage with an earlier estimate reveals substantial differences especially at upper height levels in the tropics.

Figure caption: Annual mean tropospheric (a) potential contrail cirrus coverage from ECHAM4 at 275 hPa and (b) frequency of supersaturation from AIRS in 250-300 hPa in %.

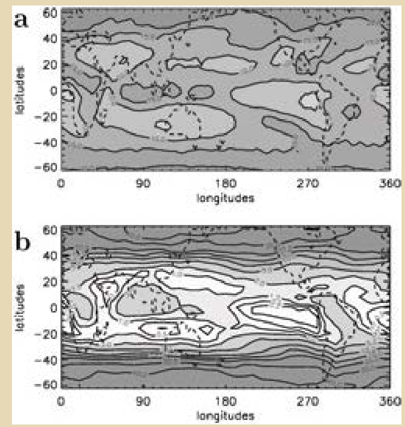


Figure 5.

High resolution figure

B. H. Kahn, C. K. Liang, A. Eldering, A. Gettelman, Q. Yue and K. N. Liou, 2008: Tropical thin cirrus and relative humidity observed by the Atmospheric Infrared Sounders. Atmos. Chem. Phys., 8, 1501-1518.

Abstract: Global observations of cloud and humidity distributions in the upper troposphere within all geophysical conditions are critically important in order to monitor the present climate and to provide necessary data for validation of climate models to project future climate change. Towards this end, tropical oceanic distributions of thin cirrus optical depth (tau), effective diameter (D-e), and relative humidity with respect to ice (RHi) within cirrus (RHic) are simultaneously derived from the Atmospheric Infrared Sounder (AIRS). Corresponding increases in D-e and cloud temperature are shown for cirrus with tau > 0.25 that demonstrate quantitative consistency to other surface-based, in situ and satellite retrievals. However, inferred cirrus properties are shown to be less certain for increasingly tenuous cirrus. In-cloud supersaturation is observed for 8-12% of thin cirrus and is several factors higher than all-sky conditions; even higher frequencies are shown for the coldest and thinnest cirrus. Spatial and temporal variations in RHic correspond to cloud frequency while regional variability in RHic is observed to be most prominent over the N. Indian Ocean basin. The largest cloud/clear sky RHi anomalies tend to occur in dry regions associated with vertical descent in the sub-tropics, while the smallest occur in moist ascending regions in the tropics. The characteristics of RHic frequency distributions depend on tau and a peak frequency is located between 60-80% that illustrates RHic is on average biased dry. The geometrical thickness of cirrus is typically less than the vertical resolution of AIRS temperature and specific humidity profiles and thus leads to the observed dry bias, shown with coincident cloud vertical structure obtained from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO). The joint distributions of thin cirrus microphysics and humidity derived from AIRS provide unique and important regional and global-scale insights on upper tropospheric processes not available from surface, in situ, and other contemporary satellite observing platforms.

Kay, J. E., T. L'Ecuyer, A. Gettelman, G. Stephens, and C. O'Dell. 2008: The contribution of cloud and radiation anomalies to the 2007 Arctic sea ice extent minimum. Geophys. Res. Lett., 35, L08503, doi:10.1029/2008GL033451.

Abstract: Reduced cloudiness and enhanced downwelling radiation are associated with the unprecedented 2007 Arctic sea ice loss. Over the Western Arctic Ocean, total summertime cloud cover estimated from spaceborne radar and lidar data decreased by 16% from 2006 to 2007. The clearer skies led to downwelling shortwave (longwave) radiative fluxes increases of +32 Wm^{-2} (-4 Wm^{-2}) from 2006 to 2007. Over three months, simple calculations show that these radiation differences alone could enhance surface ice melt by 0.3 m, or warm the surface ocean by 2.4 K, which enhances basal ice melt. Increased air temperatures and decreased relative humidity associated with an anti-cyclonic atmospheric circulation pattern explain the reduced cloudiness. Longer-term observations show that the 2007 cloudiness is anomalous in the recent past, but is not unprecedented. Thus, in a warmer world with thinner ice, natural summertime circulation and cloud variability is an increasingly important control on sea ice

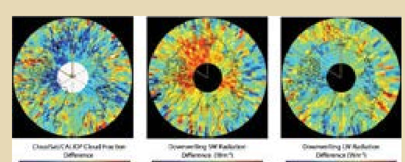


Figure 6.

High resolution figure

extent minima.

Figure caption: Clouds and downwelling radiation 2007-2006 differences (June 15-Sept 15). (left) Total cloud fraction differences based on radar and lidar data. (middle) Downwelling SW radiative flux difference. (right) Downwelling LW radiative flux difference. The Western Arctic Ocean is outlined in brown.

Ryoo, J. M., D. W. Waugh, and A. Gettelman, 2008: Variability of subtropical upper tropospheric humidity. Atmospheric Chemistry and Physics, 8, 2643-2655.

Abstract: Analysis of Atmospheric Infrared Sounder (AIRS) measurements for five years shows significant longitudinal variations in the winter subtropical upper tropospheric relative humidity (RH), not only in the climatological mean values but also in the local distributions and temporal variability. The largest climatological mean values occur over the central-eastern Pacific and Atlantic oceans, where there is also large day-to-day variability. In contrast, there are smaller mean values, and smaller variability that occurs at lower frequency, over the Indian and western Pacific oceans. These differences in the distribution and variability of subtropical RH are related to differences in the key transport processes in the different sectors. The large variability and intermittent high and low RH over the central-eastern Pacific and Atlantic oceans are due to intrusions of high potential vorticity air into the subtropics. Intrusions seldom occur over the eastern Indian and western Pacific oceans, and here the subtropical RH is more closely linked to the location and strength of subtropical anticyclones. During northern winter there are eastward propagating features in the subtropical RH in this region that are out of phase with the tropical RH, and are caused by modulation of the subtropical anticyclones by the Madden-Julian Oscillation.

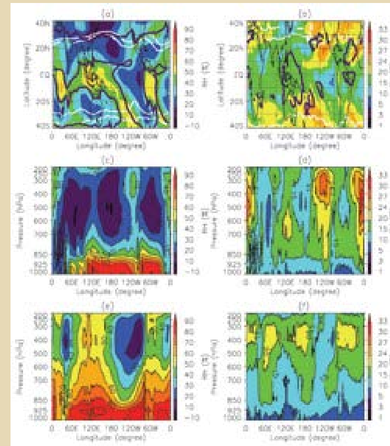


Figure 7.

High resolution figure

Figure caption: Climatological DJF distributions of RH. Maps of (a) mean and (b) standard deviation at 250hPa. Vertical cross sections of (c) mean and (d) standard deviation for average over 15.5°N to 25.5°N, and (e) mean and (f) standard deviation for average over 5.5° S to 5.5°N. The white curves are PV=±1.5 and 2.5 PVU contours and black curves are OLR=240 W/m^2 contours in (a) and OLR=70 W/m^2 contours in (b).

P. R. Field, A. Gettelman, R. Neale, R. Wood, P. J. Rasch and H. Morrison, 2008: Midlatitude cyclone compositing to constrain climate model behavior using satellite observations. J. Climate, doi:10.1175/2008JCLI2235.1, in press.

Abstract: Identical composite analysis of midlatitude cyclones over oceanic regions has been carried out on both output from the NCAR (National Center for Atmospheric Research) CAM3 (Community Atmosphere Model version 3) and multi-sensor satellite data. By focusing on mean fields associated with a single phenomenon we critically appraise the ability of the CAM3 to reproduce realistic midlatitude cyclones. A number of perturbations to the control model were tested against observations, including a candidate new microphysics package for the CAM. The new microphysics removes the temperature dependent phase determination of the old scheme and introduces representations of microphysical processes to convert from one phase to another and from cloud to precipitation species. By sub-sampling composite cyclones based on system-wide mean strength (mean wind speed) and system-wide mean moisture we believe we are able to make meaningful like-with-like comparisons between observations and model output. We find that all variations of the CAM tested overestimate the optical thickness of high-topped clouds in regions of precipitation. Over a system as a whole, the model can both over- and underestimate total high-topped cloud amounts. However, system-wide mean rainfall rates and composite structure appears to be in broad agreement with satellite estimates. When cyclone strength is taken into account, changes in moisture and rainfall rates from both satellite derived observations and model output as a function of changes in sea surface temperature are in accordance with the Clausius-Clapeyron equation. We find that the proposed new microphysics package shows improvement to composite liquid water path fields and cloud amounts.

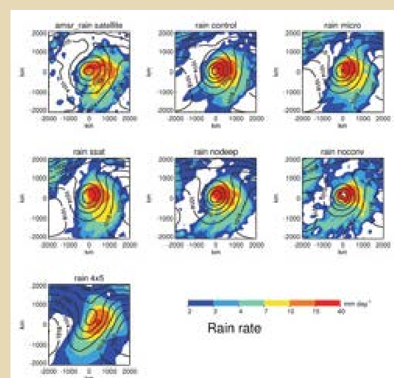


Figure 8.

High resolution figure

Figure caption: Composite rainfall rate in each 100km x 100km grid cell for the satellite observations and different model configurations. The 4000km x 4000km domain composite is for the medium moisture, greatest strength category generated from cyclones taken from all four oceanic regions for 2003-2004. The composite sea level pressure is overplotted (mb, solid lines).

Latham, J., P. J. Rasch, C. C. Chen, L. Kettles, A. Gadian, A. Gettelman, H. Morrison and K. Bower, 2008: Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds. Phil. Trans. Roy. Soc., in press.

Abstract: An assessment is made herein of the proposal that controlled global cooling sufficient to balance global warming resulting from increasing atmospheric CO_2 concentrations might be achieved by seeding low-level, extensive maritime clouds with seawater particles which act as cloud condensation nuclei, thereby activating new droplets and increasing cloud albedo (and possibly longevity). This paper focuses on scientific and meteorological aspects of the scheme. Associated technological issues are addressed in a companion paper.

Analytical calculations, cloud modelling and (particularly) GCM computations suggest that if outstanding questions are satisfactorily resolved, the controllable, globally averaged negative forcing resulting from deployment of this scheme might be sufficient to balance the positive forcing associated with a doubling of CO_2 concentration. This statement is supported by recent observational evidence. This technique could thus be adequate to hold the Earth's temperature constant for many decades.

More work - especially assessments of possible meteorological and climatological ramifications - is required on several components of the scheme, which possesses the advantages that (1), it is ecologically benign - the only raw materials being wind and seawater: (2), the degree of cooling could be controlled: (3), if unforeseen adverse effects occurred the system could be immediately switched off, with the forcing returning to normal within a few days (although the response would take a much longer time).

Figure caption: Five-year mean distributions of cloud-top effective radius r_{eff} (μm) for all layer cloud. (a) control; (b) with N = 375 cm^{-3} in regions of low-level maritime cloud.

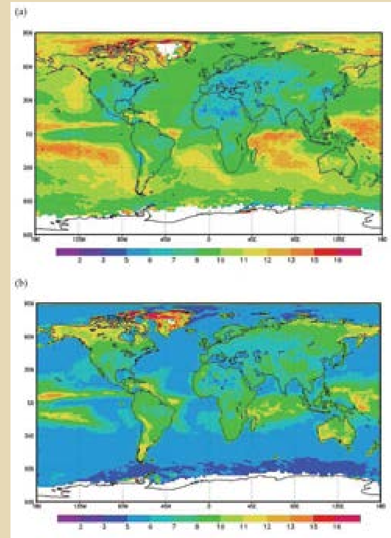


Figure 9.

High resolution figure

Yang, Q., Q. Fu, J. Austin, A. Gettelman, F. Li, and H. Vomel, 2008: Observationally Derived and GCM Simulated Tropical Stratospheric Upward Mass Fluxes. J. Geophys. Res., doi:10.1029/2008JD009945.

Abstract: We quantify the vertical velocity and upward mass flux in the tropical lower stratosphere based on accurate radiative heating rate calculations using eight-year Southern Hemisphere Additional Ozonesondes balloon-borne measurements of temperature and ozone and cryogenic frost-point hygrometer measured water vapor in the tropics (15°S - 10°N). The impact of tropospheric clouds on the stratospheric heating rates is considered using cloud distributions from the International Satellite Cloud Climatology Project. We find a nearly constant annual mean upward mass flux in the tropical lower stratosphere above the top of the tropical tropopause layer (i.e. ~70 hPa), which is 1.13±0.40 $kgm^{-2}day^{-1}$ for the 40-30 hPa layer, and 0.89±0.48$kgm^{-2}day^{-1}$ for the 70-50 hPa layer. A strong seasonal cycle exists in the upward mass flux and it is found that the mass flux below ~70 hPa is decoupled from that above in the NH summer.

Simulations of the tropical lower stratosphere from two stratospheric General Circulation Models (GCMs) are compared with observations. The annual mean upward mass fluxes from both GCMs for the 40-30 hPa layer agree well with observations, while the simulated mass fluxes for the 70-50 hPa layer are twice as large. Both GCMs also simulate seasonal variation of the mass flux reasonably well but are incapable of simulating the observed inter-annual variability of the upward mass flux, which is closely correlated with the quasi-biennial oscillations.

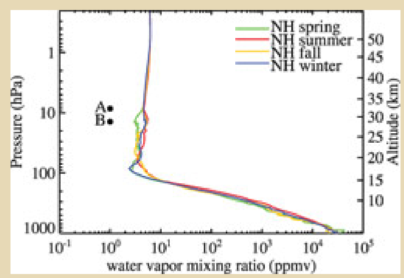


Figure 10.

High resolution figure

Figure caption: Merged seasonal mean water vapor profiles. Below point B: the seasonal mean profiles from soundings. Above point A: the seasonal mean profiles from HALOE. Four straight lines between point A and point B are used to connect sounding data and HALOE data.

Gettelman, A., and T. Birner, 2007: Insights into Tropical Tropopause Layer processes using global models. J. Geophys. Res., 112, D23104, doi:10.1029/2007JD008945.

Abstract: The climatology of the Tropical Tropopause Layer (TTL) in two state-of-the-art general circulation models is compared with observations. Results indicate that global models are able to resolve key features of the TTL, including the mean state and the variability of temperature, ozone, clouds, and thermal structure. The agreement indicates that large-scale processes, and the large-scale effects of small-scale processes, such as convection, are likely the dominant contributors to the observed climatological structure of the TTL and to the observed annual cycle and variability at scales larger than several hundred kilometers. Cloud processes are still uncertain due to their heavily parameterized treatment in models, and

limited observations of clouds in the TTL. The bulk treatment of clouds appears sufficient to properly resolve the large-scale structure of the TTL.

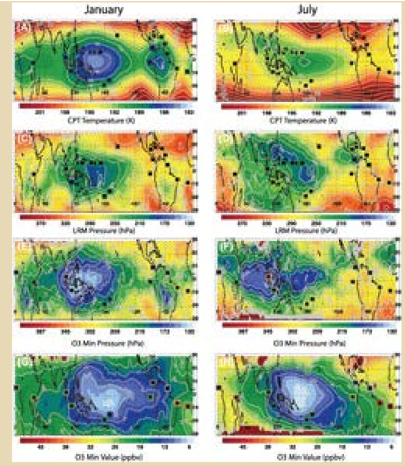


Figure caption: TTL maps of (a and b) Cold Point Tropopause temperature (in K), (c and d) pressure of the minimum lapse rate (in hPa), (e and f) pressure (hPa), and (g and h) value (ppbv) of the TTL ozone minimum, for (a, c, e, and g) January and (b, d, f, and h) July from CMAM. Asterisks indicate locations of observations from radiosondes and/or SHADOZ ozonesondes. Colored square indicates observed value. Undefined TTL ozone minima (minO3 pressure >500 hPa in more that 50% of the profiles) are marked by dark red colors (model) and black squares (sondes).

Figure 11.

High resolution figure

Nassar, R., P. F. Bernath, C. D. Boone, A. Gettelman, S. D. McLeod, and C. P. Rinsland, 2007: Variability in HDO/H2O abundance ratios in the tropical tropopause layer. J. Geophys. Res., 112, D21305, doi:10.1029/2007JD008417.

Abstract: The dehydration of air in the tropical tropopause layer (TTL) and mechanisms for the entry of water vapor into the stratosphere are investigated by an analysis of ACE-FTS profiles of temperature, water vapor, and the ratio [HDO]/[H2O] expressed in dD notation. Month-to-month comparisons indicate greater seasonal variability than interannual variability between 25°S-25°N, thus comparisons are made between February, April, August, and October averages for the years 2004 and 2005 combined. The data indicate a pattern of seasonal variability which is clearer in the Northern Hemisphere tropics and a relationship between minimum temperature, minimum water vapor, and maximum HDO depletion, which exists beyond the estimated uncertainty in these values. The range of values observed for HDO depletion and comparisons to modeled Rayleigh distillation curves indicate an important contribution from convection in addition to gradual dehydration. Multiple factors including the shape of the dD profiles suggest that a likely mechanism for the convective influence is the lofting of ice particles in the tropical troposphere.

Figure 12.

High resolution figure

Figure caption: Distribution of ACE-FTS tropical (25°S-25°N latitude) measurements during 2004 and 2005 (based on the position of the 17.5 km point) used in this work. Different markers indicate the month: February (black squares), April (green triangles), August (blue diamonds), and October (red circles), with more details given in the text and Table 2.

Kinnison, D. E., et al.,2007: Sensitivity of chemical tracers to meteorological parameters in the MOZART-3 chemical transport model. J. Geophys. Res., 112, D20302, doi:10.1029/2006JD007879.

Abstract: The Model for Ozone and Related Chemical Tracers, version 3 (MOZART-3), which represents the chemical and physical processes from the troposphere through the lower mesosphere, was used to evaluate the representation of long-lived tracers and ozone using three different meteorological fields. The meteorological fields are based on (1) the Whole Atmosphere Community Climate Model, version 1b (WACCM1b), (2) the European Centre for Medium-Range Weather Forecasts (ECMWF) operational analysis, and (3) a new reanalysis for year 2000 from ECMWF called EXP471. Model-derived tracers (methane, water vapor, and total inorganic nitrogen) and ozone are compared to data climatologies from satellites. Model mean age of air was also derived and compared to in situ CO_2 and SF_6 data. A detailed analysis of the chemical fields simulated by MOZART-3 shows that even though the general features characterizing the three dynamical sets are rather similar, slight differences in winds and temperature can produce substantial differences in the calculated distributions of chemical tracers. The MOZART-3 simulations that use meteorological fields from WACCM1b and ECMWF EXP471 represented best the distribution of long-lived tracers and mean age of air in the stratosphere. There was a significant improvement using the ECMWF EXP471 reanalysis data product over the ECMWF operational data product. The effect of the quasi-biennial oscillation circulation on long-lived tracers and ozone is examined.

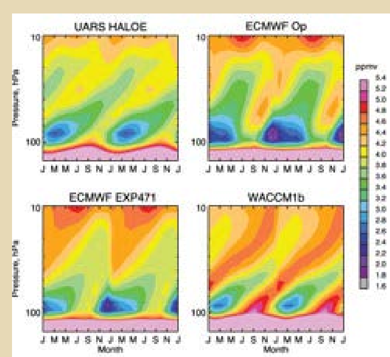


Figure 13.

High resolution figure

Figure caption: Height-time sections of water vapor volume mixing ratio derived in the equatorial region (averaged between 12°S and 12°N). Observations are based on HALOE data. Two consecutive seasonal cycles are shown in each diagram.

CGD Research Catalog

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ANDREW GETTELMAN

General Information

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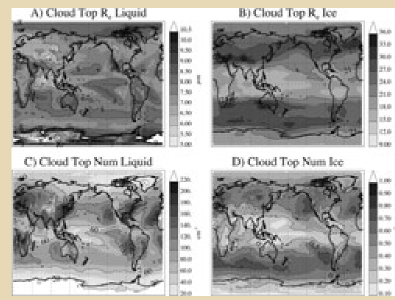
Research Focus FY08:

My work focuses on the upper troposphere and lower stratosphere, and extends into understanding the representation of clouds of all types in the atmosphere, especially ice and mixed clouds. This region of the atmosphere sets the chemical boundary conditions of the stratosphere (with impacts on the stratospheric ozone layer) and also is important for the impact of clouds and water vapor in this region on the earth's energy balance (and hence climate). My work encompasses both models and measurements. I work extensively with observations and simulation of ice and mixed phase clouds, and have been also working on understanding aerosol indirect effects for liquid and ice clouds.



Annual mean cloud-top (a) cloud drop (liquid) effective radius (μm), (b) cloud ice effective radius (μm), (c) in-cloud droplet number concentration (cm-3), (d) in-cloud ice number concentration (cm-3).

High resolution figure

Community Service FY08:

- Assistant Editor-Special Session: Journal of Geophysical Research - Atmospheres
- Member: Atmospheric Chemistry and Climate, Stratospheric Processes And their Role in Climate (SPARC)
- Communications secretary: Atmospheric Sciences Execuctive Committee, American Geophysical Union (AGU)
- Co-coordinator: Chemistry Climate Model Validation Activity (CCMVal), Stratospheric Processes And their Role in Climate (SPARC)
- Member: Middle Atmosphere Committee, American Meteorological Society (AMS)
- Member: Steering Committee: Atmospheric Chemistry and Climate Project, Stratospheric Processes And their Role in Climate (SPARC) - International Global Atmospheric Chemistry (IGAC)
- Coordinator: Tropopause Initiative, Stratospheric Processes And their Role in Climate (SPARC)
- Graduate Research Advisor & Thesis Committee: Qiong Yang, University of Washington, Seattle, WA

Scientific Talks FY08:

- Evaluation of Coupled Chemistry-Climate Models in the Upper Troposphere and Lower Stratosphere (Boulder, CO, January 2008)
- Structure of the Tropical Tropopause Layer and processes that maintain the TTL (San Francisco, CA, December 2007)
- The impact of supersaturation on climate and chemistry (Boulder, CO, March 2008)
- The tropical tropopause layer and the impact of supersaturation on the atmosphere (Munich, Germany, January 2008)
- The tropical tropopause layer and the impact of supersaturation on the atmosphere (Boulder, CO, April 2008)

Publications FY08 (abstracts):

Latham, J., P. J. Rasch, C.-C. Chen, L. Kettles, A. Gadian, A. Gettelman, H. Morrison, S. Salter, 2008: Global temperature stabilization via controlled albedo enhancement of low-level maritime clouds. *Phil. Trans. R. Soc. A*. (Accepted)4

Burkhardt, U., B. Kaercher, M. Ponater, K. Gierens, A. Gettelman, 2008: Contrail cirrus supporting areas in model and observations. *Geophys. Res. Lett.*, **35**, L16808, doi: 10.1029/2008GL034056.3

Field, P. R., A. Gettelman, R. B. Neale, R. Wood, P. J. Rasch, H. Morrison, 2008: Midlatitude cyclone compositing to constrain climate model behavior using satellite observations. *J. Climate*, doi: 10.1175/2008JCLI2235.1. (In Press)2

Morrison, H., A. Gettelman, 2008: A new two-moment bulk stratiform cloud microphysics scheme in the Community Atmosphere Model, version 3 (CAM3). Part I: Description and numerical tests. *J. Climate*, **21**, 3642-3659, doi: 10.1175/2008JCLI2105.1.1

Gettelman, A., H. Morrison, S. J. Ghan, 2008: A new two-moment bulk stratiform cloud microphysics scheme in the Community Atmosphere Model, Version 3 (CAM3). Part II: Single-column and global results. *J. Climate*, **21**, 3660-3679, doi: 10.1175/2008JCLI2116.1.3

Gettelman, A., Q. Fu, 2008: Observed and Simulated Upper-Tropospheric Water Vapor Feedback. *J. Climate*, **21**, 3282-3289, doi: 10.1175/2007JCLI2142.1.2

Kahn, B. H., C. K. Liang, A. Eldering, A. Gettelman, Q. Yue, K. N. Liou, 2008: Tropical thin cirrus and relative humidity observed by the Atmospheric Infrared Sounder. *Atmos. Chem. Phys.*, **8**, 1501-1518.4

Kay, J. E., A. Gettelman, G. Stephens, 2008: The contribution of cloud and radiation anomalies to the 2007 Arctic sea ice extent minimum. *Geophys. Res. Lett.*, **35**, L08503, doi: 10.1029/2008GL033451.2

Ryoo, J., D. W. Waugh, A. Gettelman, 2008: Variability of subtropical upper tropospheric humidity. *Atmos. Chem. Phys. Discuss.*, 8, 1041-1067.4

Gettelman, A., T. Birner, V. Eyring, H. Akiyoshi, D. A. Plummer, M. Dameris, S. Bekki, F. Lefevre, F. Lott, C. Bruhl, K. Shibata, E. Rozanov, E. Mancini, G. Pitari, H. Struthers, W. Tian, D. E. Kinnison, 2008: The Tropical Tropopause Layer 1960-2100. *Atmos. Chem. Phys. Discuss.*, 8, 1367-1413.4

Gettelman, A., T. Birner, 2007: Insights into Tropical Tropopause Layer processes using global models. *J. Geophys. Res.*, **112**, D23104, doi: 10.1029/2007JD008945.2

Nassar, R., P. F. Bernath, C. D. Boone, A. Gettelman, S. D. McLeod, C. P. Rinsland, 2008: Variability in HDO/H2O abundance ratios in the tropical tropopause layer. *J. Geophys. Res.*, **112**, D21305, doi: 10.1029/2007JD008417.4

Kinnison, D. E., G. P. Brasseur, S. Walters, R. R. Garcia, D. R. Marsh, F. Sassi, V. L. Harvey, C. E. Randall, L. Emmons, J.-F. Lamarque, P. Hess, J. J. Orlando, X. X. Tie, W. Randel, L. L. Pan, A. Gettelman, C. Granier, T. Diehl, U. Niemeier, A. J. Simmons, 2007: Sensitivity of chemical tracers to meteorological parameters in the MOZART-3 chemical transport model. *J. Geophys. Res.*, **112**, D20302, doi: 10.1029/2006JD007879.4

Andrew Gettelman Research

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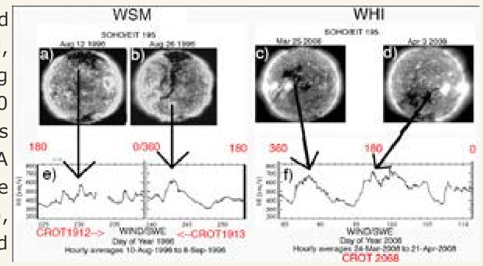
GIBSON, SARAH

Whole Heliosphere Interval

Sarah Gibson and Barbara Thompson (WHI coordinators)
CIR study colllaborators also include: Giuliana de Toma, Barbara Emery, Janet Kozyra, and Pete Riley, along with other members of the "WHI Team", which includes ~200 researchers around the world, see WHI the people.
(partially supported -- i.e. travel for invited WHI presentations by Gibson -- by Opportunities Fund for Heliosphere -- Miesch P.I.)

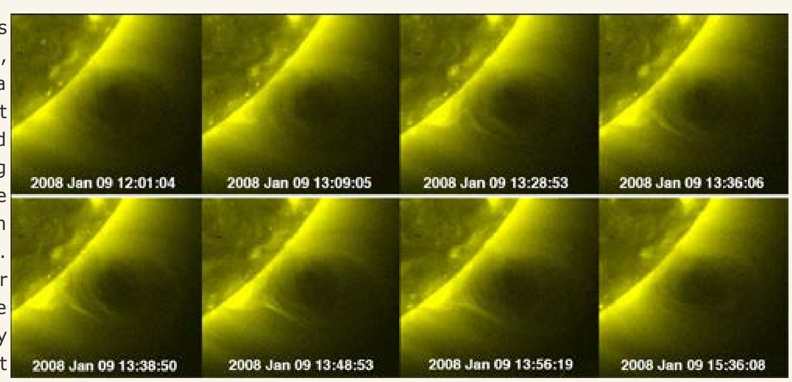


The Whole Heliosphere Interval (WHI) is an internationally coordinated observing and modeling effort to characterize the three-dimensional, interconnected, solar-heliospheric-planetary system at solar minimum, using observations originating at the Sun during Carrington Rotation 2067: March 20 - April 16, 2008. WHI's science begins with the solar interior and extends through the heliosphere and interplanetary space out to the heliopause. A primary WHI science goal is to trace the origins and impacts of solar structure and activity from Sun to Earth. These include coronal mass ejections (CMEs), as well as corotating interaction regions (CIRs): high-speed solar wind streams that recur from solar rotation to solar rotation. With regards to CIRs, it is very interesting to compare WHI to a period of similar coordinated observations that took place during the last cycle's solar minimum, known as the "Whole Sun Month" (WSM). Despite having similar low sunspot-numbers, WHI and WSM differed significantly in the distribution of open magnetic flux at the Sun, as manifested by polar vs. low-latitude coronal holes. Because these regions are the source of high-speed wind streams, the differences in the nature of these low-latitude coronal holes: how broad, how permanent, etc., ultimately resulted in differences in how geospace was driven during these two solar minimum periods.

Figure caption: *Low-latitude coronal holes and their associated high speed streams during (left) the Whole Sun Month (WSM) and (right) the Whole Heliosphere Interval (WHI). The degree of impact of a high-speed stream on geospace depends on how fast and how long-lasting the stream is in its intersection with the Earth. This in turn depends on the structure of the 3-D heliospheric magnetic field. Top images (a-d) show coronal holes, which are associated with open magnetic flux at the solar surface, as dark regions in extreme-ultraviolet emission. Bottom images (e-f) show hourly averages of solar wind velocity measured at the Earth by the Solar Wind Experiment (SWE) on board the WIND satelite. The WSM period includes portions of Carrington Rotations 1912 and 1913, and the WHI period corresponded to Carrington Rotation 2068. The Carrington Longitudes and respective Rotations are indicated in red. Note that because the Sun rotates counter-clockwise, longitude increases from right to left on this plot as time increases from left to right. Also note that a four-day average wind travel time from the Sun has been assumed in associating the WIND observations with a source Carrington Longitude.*

Coronal cavities

Sarah Gibson, Jim Fuller, Don Schmit
Don Schmit (graduate student) is funded via the CU-LASP CISM effort.



The genesis of solar coronal mass ejections (CMEs) is both an intellectually intriguing, fundamental unsolved problem in plasma astrophysics, and a societally relevant subject critical to space weather prediction and mitigation. Dark coronal cavities surrounding cool, dense prominence material are observed within CMEs, but also as equilibrium states in the magnetically-dominated corona. Their plasma properties as observed in their quiescent phase provide clues to the nature of such equilibria and how they may ultimately be lost during CMEs. In an effort led by University of Colorado graduate student, Don Schmit (Schmit et al., in preparation, 2008), we are attempting for the first time to establish the plasma temperature in coronal cavities as compared to overlying helmet streamers. This is a critical observational constraint on cavity models. In order to achieve this, over the past year we have run multiple campaigns that take advantage of new advances in high resolution soft-X-ray and extreme-ultraviolet observations and coronal observations from multiple vantage points. Our preliminary analysis implies that cavity plasma is hot relative to helmet streamers. This would be consistent with the results of a related effort led by undergraduate summer visitor Jim Fuller (Fuller and Gibson, in preparation, 2008), in which density profiles have ben calculated for 21 cavity systems observed in white light by HAO's Mauna Loa Solar Observatory (MLSO) Mark 4 K-Coronameter. This analysis confirmed previous results from a single white light cavity, i.e. that cavity densities fall off with a flatter radial profile than that of the surrounding streamer in a manner consistent with hydrostatic models where cavities are hotter than their surrounding streamer. It also demonstrated that smaller cavities tend to have higher tops, relative to their widths, than larger ones, and indeed there seems to be an upper limit on cavity-top height, at approximately 0.5 Rsun above the solar surface. This may be related to independently-established upper limits on prominence heights, and indicative of limits on the stability of pre-CME equilibrium states.

Figure caption: *January 9, 2008 Hinode-XRT cavity in soft-Xray with apparent reconnection event. This cavity is the limb manifestation of a portion of a polar-crown filament channel that was visible from January-July 2008. We have obtained spectroscopic data from the Hinode and SOHO spacecraft at several points of its evolution, and are currently analyzing these to establish cavity temperature. Hinode is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway).*

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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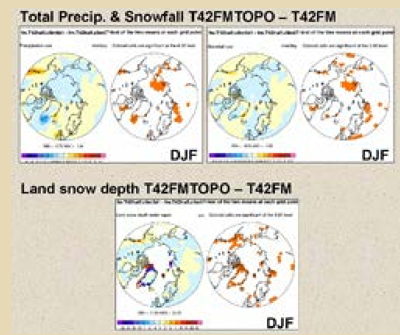
Research Focus FY08:



Effects of fine-mesh topography on large-scale circulation. The total precipitation and snow fall are impacted as is the snowpack structure.

High resolution figure

Fine Mesh Project

The Fine Mesh Project wrapped up this year with a paper summarizing the results from the fine-mesh modeling work within the Community Atmosphere Model - Community Land Model (CAM - CLM) climate model. more...

Headwaters

In support of Colorado Headwaters research efforts, work has been initiated on testing and evaluating a distributed version of the Noah-distributed hydrological model for use over the mountainous regions of Colorado. This work forms the basis for modeling spring snow-pack, snowmelt and runoff processes under both current and future climate scenarios.

Minutes that Save Lives: New Warning System Boosts Flash-Flood Prediction

With a 30-minute head start, emergency managers can dramatically reduce flash-flood risk along Colorado's Front Range. The Front Range, with its steep topography and intense summer storms, is unusually vulnerable to summertime flash floods. A new forecasting system that underwent testing and development during summer 2008 may soon provide emergency managers with information on the likelihood of a flash flood minutes or even hours before waters start rising...more *(from the NCAR 2008 Annual Report)*

BEACHON

In support of the BEACHON project, extensive hydrometeorological and hydroclimatological field data is being collected starting during the summer of 2008. These observations of critical terrestrial hydrological and biogeochemical processes will form the basis for understanding the controls on biogenic emissions from water-limited ecosystems, a principal goal of the BEACHON program. To date a network of precipitation observing equipment has been deployed around the BEACHON site which includes: rain gauges, precipitation radar, disdrometers, rainwater collectors (for chemical analysis), soil moisture and soil temperature profiles. Additionally, several more in-situ measurements are being made in an effort to characterize the hydrologic, hydraulic and bioegeochemical function of the MEF ecosystem.

Plans for FY09 and Beyond

1. Continue planning and development of the BEACHON and Colorado Headwaters research programs.
2. Continue field data collection under the BEACHON research effort at the Manitou Experimental Forest.
3. Upon completion of testing of the Noah-distributed hydrological model over the Colorado Headwater region, work will initiate on adapting the distributed modeling framework to permit use of the CLM/CN land surface model instead of the Noah land surface model in detailed hydrobiogeochemical studies. This work is directly linked to that outlined in #2 above and is targeted for development and use within the BEACHON research program.

Community Service FY08:

- Guest Editor: CLIVAR Exchanges
- Member: NOAA CPPA Advisory Panel
- Chair: North American Monsoon Experiment (NAME) Science Working Group, NOAA & CLIVAR
- Member: Variability of American Monsoon Systems (VAMOS) Panel, CLIVAR
- Member: Water Cycle Science Steering Group, U.S. Climate Change Science Program (CCSP)
- Graduate Research Advisor: Cedric David (University of Texas, Austin)
- Graduate Research Advisor: Seshadri Rajagopal (University of Arizona, Tucson)
- Thesis Committee - PhD: Kazungu Maitaria (University of Arizona, Tucson)
- Thesis Committee - PhD: Hernan Moreno (New Mexico Tech, Socorro, NM)
- Thesis Committee - Masters: Angela Rowe (Colorado State University, Fort Collins)
- Thesis Committee - PhD: Chunmei Zhu (University of Washington, Seattle)
- 5th Grade Science Lecture (Colorado Springs, CO September 2008)

Scientific Talks FY08:

- Assessing Snowpack from Colorado's Headwater Basins using a Very High Resolution Atmospheric Model (Boulder, CO, August 2008)
- Flash Flood Prediction for the Colorado Front Range (Fort Collins, CO, September 2008)
- Land – Atmosphere Interactions in the U.S. Great Plains (Amarillo, TX, March 2008)
- Precipitation – History, Forecasting and Modeling (Amarillo, TX, March 2008)
- Statistical Downscaling of Warm Season Medium-Range Precipitation Predictions in the Core North American Monsoon Region with Application to Water Resources Forecasting (Talahassee, FL, October 2007)
- The hydrologically-enhanced Noah-distributed land surface model (Boulder, CO, March 2008)
- The hydrologically-enhanced Noah-distributed land surface model (Laramie, WY, August 2008)

Publications FY08:

Lyon, S. W., F. Dominguez, D. J. Gochis, N. A. Brunsell, C. L. Castro, F. K. Chow, Y. Fan, D. Fuka, Y. Hong, P. A. Kucera, S. W. Nesbitt, N. Salzmann, J. Schmidli, P. K. Snyder, A. J. Tueling, T. E. Twine, S. Levis, J. D. Lundquist, G. G. Salvucci, A. M. Sealy, M. T. Walter, 2008: Coupling terrestrial and atmospheric water dynamics to improve prediction in a changing environment. *Bulletin of the American Physical Society*, doi: 10.1175/2008BAMS2547.1.4

Liebman, B., I. Blade, N. A. Bond, D. J. Gochis, D. Allured, G. T. Bates, 2008: Characteristics of North American summertime rainfall with emphasis on the monsoon. *J. Climate*, **21(6)**, 1277-1294.3

Kursinski, E. R., R. A. Bennett, D. J. Gochis, S. I. Gutman, K. L. Holub, R. Mastaler, C. M. Sosa, I. M. Sosa, T. van Hove, 2008: Water vapor and surface observations in northwestern Mexico during the 2004 NAME enhanced observing period. *Geophys. Res. Lett.*, **35(3)**, L03815.4

Gochis, D. J., 2008: A view from the golden years of the North American Monsoon Experiment. *CLIVAR Exchgs. Newslett.*, 13(2) April.1

Vivoni, E. R., C. J. Watts, J. C. Rodriguez, J. Garatuza-Payan, L. A. Mendez-Barroso, E. A. Yepez, J. Saiz-Hernandez, D. J. Gochis, 2008: Relation between surface flux measurements and hydrologic conditions in a stubtropical scrubland during the North American Monsoon. *CLIVAR Exchgs. Newslett.*, 13(2) April.4

Nesbitt, S., D. J. Gochis, T. Lang, 2008: The diurnal cycle of clouds and precipitation along the Sierra Madre Occidental observed during NAME-2004: Implications for warm season precipitation estimation in complex terrain. *J. Hydrometeorol.*, **9**, 728-743.2

David J. Gochis Research Catalog

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WOJCIECH GRABOWSKI

2008 Publications

Grabowski, W. W., 2007: Representation of turbulent mixing and buoyancy reversal in bulk cloud models. J. Atmos. Sci., 64, 3666-3680.

Abstract:

This paper discusses representation of subgrid-scale turbulent mixing in bulk models of warm (ice-free) clouds, which assume instantaneous adjustment to grid-scale saturation. This is a reasonable assumption for condensation of water vapor because supersaturations inside clouds are typically small (~ 0.1% or smaller), except near cloud bases where about order of magnitude larger supersaturations are anticipated. For the cloud evaporation, however, instantaneous adjustment to grid-scale saturation is questionable, especially when evaporation occurs as a result of turbulent mixing between a cloud and its unsaturated environment. This is because turbulent mixing between initially separated volumes of cloudy and cloud-free environmental air proceeds through a gradual filamentation of these volumes, with progressively increasing evaporation of cloud water during the approach to final homogenization. A relatively simple model of this chain of events is included in a bulk model of moist nonprecipitating thermodynamics. The model delays adjustment to saturation for cloud evaporation following the turbulent mixing until the volume can be assumed homogeneous. An additional prognostic variable, the width of a cloudy filament, is added to represent the progress of turbulent mixing and approach to homogenization. Theoretical developments are illustrated by idealized 2D simulations of moist thermals rising from rest and realistic large-eddy simulations of a cloud field.

Grabowski, W. W., and H. Morrison, 2008: Toward the mitigation of spurious cloud-edge supersaturation in cloud models. Mon. Wea. Rev., 136, 1224-1234.

Abstract:

This paper presents a straightforward approach to mitigate the problem of spurious cloud-edge supersaturation in high-spatial-resolution cloud models (e.g., moist large-eddy simulation models). The central idea, following Grabowski (J. Atmos. Sci., 1989), is that supersaturation predicted by the supersaturation equation should be used to adjust the temperature and moisture solutions, rather than the other way around as in the standard approach in cloud modeling, where the temperature and moisture solutions are used to diagnose the supersaturation. Details of the adjustment scheme are discussed and illustrated through simple one-dimensional tests applying a two-moment warm-rain microphysics scheme that predicts the in-cloud supersaturation. Extension of this approach to bin microphysics models is also outlined.

Slawinska, J., W. W. Grabowski, H. Pawlowska, and A. A. Wyszogrodzki, 2008: Optical properties of shallow convective clouds diagnosed from a bulk-microphysics large-eddy simulation. J. Climate, 21, 1639-1647.

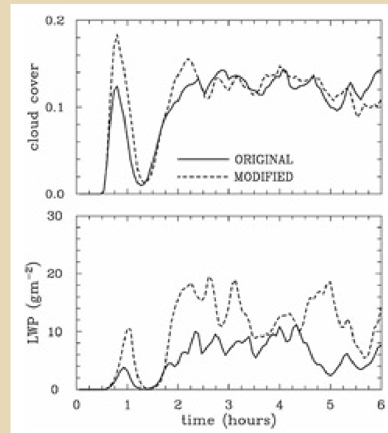

Figure 1: The figure highlights differences between LES simulations of a field of shallow tropical convective clouds applying either the original bulk model (solid lines) or a modified approach with the prediction of a progress of turbulent mixing between clouds and their environment (dashed lines). The upper panel shows the cloud cover (the fraction of the horizontal area with column containing some cloud water). The panel shows that both approaches provide (after about 2 hrs model spinup) practically the same results. However, the clouds using the modified approach are characterized by the higher liquid water path because clouds are taller and contain on average more cloud water (not shown). This is consistent with suppression of the cloud water evaporation in the modified approach.

High resolution figure

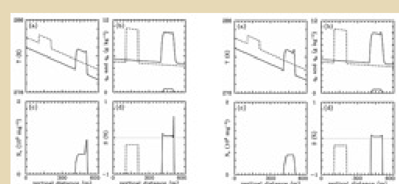

Figure 2: The figures illustrate the developments described in this paper using a simple 1D advection-condensation test. In both figures, panel (a) shows the potential temperature profile, (b) - the water vapor and cloud water profiles, (c) - the concentration of cloud droplets profile, and (d) - the supersaturation profile. The dashed and solid lines are for initial and final condition of the test. The left figure shows

results when the standard approach is used in the two-moment bulk warm rain microphysics (condensation only). Note the overshoot of the supersaturation field at the leading (rhs) edge of the perturbation that leads to the overshoot of the droplet concentration. The right figure shows the profiles derived with the additional adjustment step that removes the spurious overshoots of the supersaturation and cloud droplet concentration.

High resolution figure

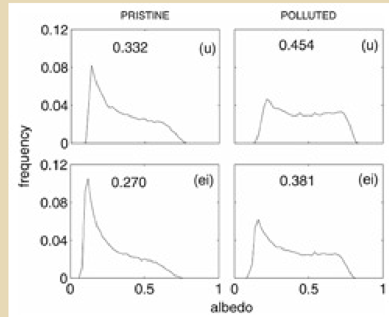

Figure 3: The figure shows histograms of the top-of-the-atmosphere albedo for model columns with LWP larger than 0.005 kg m-2 for pristine (left) and polluted (right) conditions. Upper panels are for assumed uniform droplet concentration (u), and bottom panels are for the extremely inhomogeneous mixing (ei). The mean albedo is shown in each panel. The main point is that the mean albedo changes substantially depending on both the assumed characteristics of nucleated aerosols and on the assumed mixing scenario.

High resolution figure

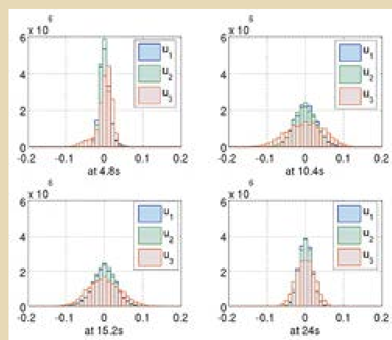

Figure 4: The figure shows histograms of velocity fluctuations in DNS simulation of cloud-clear air interfacial mixing at various times. The horizontal velocity components are marked by u1 and u2, whereas the vertical component is u3. Please note that the histograms of the vertical velocity are wider than those for the horizontal velocity, especially in the early stages. This feature is also observed in data from laboratory experiments.

High resolution figure

MMM Research Catalog

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Research Focus FY08:

Manitou Experimental Forest (MEF), Woodland Park, Colorado

BEACHON - Southern Rocky Mountains Summer 2008 Study (BEACHON-SRM08)

July - September 2008, Manitou Experimental Forest (MEF), Woodland Park, Colorado

SRM08 is the initial research phase in the four year BEACHON research program in water-limited Western U.S. pin forest ecosystems that will improve the understanding of fundamental biogeochemical processes that are central to achieving the objectives of the BEACHON research program. BEACHON-SRM08 is considered a pre-study in advance of long-term measurements of key atmospheric and ecosystem parameters at the same site as well as a more comprehensive regional campaign in 2010. Because of this, the study has practical objectives relating to the setup and operation of the MEF site in addition to specific scientific foci on atmospheric chemistry and aerosol processes.

Publications FY08:

Boy, M., T. Karl, A. Turnipseed, R. L. Mauldin, E. Kosciuch, J. Greenberg, J. Rathbone, J. Smith, A. Held, K. Barsanti, B. Wehner, S. Bauer, A. Wiedensohler, B. Bonn, M. Kulmala, A. Guenther, 2008: New particle formation in the Front Range of the Colorado Rocky Mountains. *Atmos. Chem. Phys.*, **8**, 1577-1590.

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VANDA GRUBIŠIĆ

General Information

TIIMES - Desert Research Institute (DRI)
Visiting Scientist - NCAR Affiliate Scientist 2008-2011 (EOL & TIIMES)
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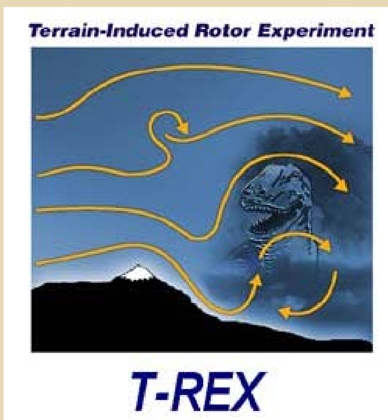
Research Focus FY08:



Dr. Grubišić is currently project director and principal investigator for the Terrain-induced Rotor Experiment (T-REX UTLS / EOL), a multi-year effort with major funding from the National Science Foundation to study mountain-wave induced rotors in Owens Valley in the lee of Sierra Nevada in eastern California. Major past studies include rotor studies in the Sierra Rotors project in Owens Valley in 2004, airflow and potential vorticity generation in the wake of the Alps in the Mesoscale Alpine Programme experiment in 1999, and wake formation in Hawaii in HaRP in 1990. AMS Special Collection.

Dr. Grubišić runs the Mesosocale Dynamics and Modeling Laboratory (MDML) at Desert Research Institute (DRI) focusing on numerical modeling and visualization of mesoscale atmospheric phenomena. She has also initiated and led the state-wide program in Advanced Computing in Environmental Science (ACES), which has created new capabilities for multidisciplinary research in Nevada, centered on computer modeling, scientific visualization, and other data-intensive techniques in environmental research. She directs the ACES VisLab, the state-of-the-art visualization laboratory established by the ACES program.

She was involved in IPY-THORPEX and spent some time in the field campaign in Andoya, Norway, Feb 25-Mar 6, 2008. The focus of the field campaign was on polar lows, their formation and dynamics, and interaction with complex terrain.

Dr. Grubišić also organized the 2008 T-REX Workshop, Dept Geology and Geophysics, Yale University, New Haven, CT, 12-13 March, 2008.

In the News:

- Bad decisions in the air lead to tragedy in Sierra
- Pilots have little margin for error navigating Sierra

Community Service FY08:

- NSF Advisory Committee for the Geoscience Directorate (AC/GEO)
- UCAR Unidata Policy Committee
- NSF/NCAR Observing Facilities Assessment Panel (OFAP)
- UCAR President's Advisory Committee on University Relations (PACUR)
- AMS Committee on History of the Atmospheric Sciences
- AMS Committee on Mesoscale Processes
- Graduate Student Advisor and Thesis Committee: DRI

Scientific Talks FY08:

- Terrain-induced Rotor Experiment: New Insights into Lee Waves and Atmospheric Rotors. Department of Meteorology and Geophysics, University of Vienna, Austria, October 2008
- Wave-induced Turbulence in the Lower Troposphere: A T-REX Perspective, Observing the Turbulent Atmosphere: Sampling Strategies, Technology and Application, IMAGe Theme of the Year 2008 Workshop, 28-30 May 2008, NCAR, Boulder, CO, Invited Presentation (N.B. The slides for this one should be available on the IMAGe TOY web pages)
- Terrain-induced Rotor Experiment: New Insights into Lee Waves and Atmospheric Rotors, Environmental Fluid Dynamics Program, Arizona State University, Tempe, AZ, May 2008
- Terrain-induced Rotor Experiment: New Insights into Lee Waves and Atmospheric Rotors, Department of Meteorology, Colorado State University, Fort Collins, CO, March 2008
- Terrain-induced Rotor Experiment: New Insights into Lee Waves and Atmospheric Rotors, Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, NC, February 2008
- Terrain-induced Rotor Experiment: New Insights into Lee Waves and Atmospheric Rotors, Department of Meteorology Department, Penn State, State College, PA, February 2008Wave-induced Turbulence in the Lower Troposphere: A T-REX Perspective, Observing the Turbulent Atmosphere: Sampling Strategies, Technology and Application, IMAGe Theme of the Year 2008 Workshop, 28-30 May 2008, NCAR, Boulder, CO, *Invited Presentation*
- Terrain-induced Rotor Experiment: New Insights into Lee Waves and Atmospheric Rotors, Department of Meteorology, Colorado State University, Fort Collins, CO, March 2008
- Terrain-induced Rotor Experiment: New Insights into Lee Waves and Atmospheric Rotors, Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, NC, February 2008
- Terrain-induced Rotor Experiment: New Insights into Lee Waves and Atmospheric Rotors, Department of Meteorology Department, Penn State, State College, PA, February 2008

Publications FY08:

Grubišić, V., J. D. Doyle, J. Kuettner, S. Mobbs, R. B. Smith, C. D. Whiteman, R. Dirks, S. Czyzyk, S. A. Cohn, S. Vosper, M. Weissmann, S. Haimov, S. F. J. DeWekker, L. L. Pan, F. K. Chow, 2008: The Terrain-induced Rotor Experiment: An overview of the field campaign and some highlights of special observations. *Bull. Amer. Meteor. Soc.*, **89**, 1513-1533.

Smith, R. B., B. K. Woods, J. Jensen, W. A. Cooper, J. D. Doyle, Q. Jiang, and V. Grubišić, 2008: Mountain waves entering the stratosphere. *J. Atmos. Sci.*, **65**, 2543–2562.

Grubišić, V., and B. J. Billings, 2008: Climatology of the Sierra Nevada mountain wave events. *Mon. Wea. Rev.*, **136**, 757–768.

Li, Y., R. B. Smith, and V. Grubišić, 2008: Using diurnal surface pressure variations to study atmospheric circulation in Owens Valley. *Mon. Wea. Rev.*, Accepted.

Grubišić, V., and B. J. Billings, 2008: Summary of the Sierra Rotors Project wave and rotor events. *Atmos. Sci. Letters.*, In press.

Grubišić, V., and I. Stiperski, 2008: Lee wave resonances over double bell-shaped orography. *J. Atmos. Sci.*, In press.

Doyle, J. D., V. Grubišić, W. O. J. Brown, S. F. J. De Wekker, A.Dörnbrack, Q. Jiang, S. Mayor, and M. Weissmann, 2008: Observations andnumerical simulations of subrotor vortices during T-REX. *J. Atmos.Sci*., In press.

Conference Abstracts & Posters FY08:

Grubišić, V., J. R. French, S. J. Haimov, L. Oolman, B. J. Billings, and M. Xiao, 2008: Lower-tropospheric waves and wave-induced turbulence zones: Insights from T-REX. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Billings, B. J., and V. Grubišić, 2008: A study of the onset of westerly downslope winds in Owens Valley. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Billings, B. J., and V. Grubišić, 2008: A numerical study of the effects of diurnal heating, moisture, and downstream topography on downslope winds within a valley. Poster. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Stiperski, I., and V. Grubišić, 2008: The effect of boundary layer on lee waves over double bell-shaped orography. *AMS 13th Conference on Mountain Meteorology,* Whistler, BC, Canada, Amer. Meteor. Soc.

Stiperski, I., and V. Grubišić, 2008: Lee-wave interferences over double bell-shaped orography. Poster. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Doyle, J. D., S. Gaberšek, L. R. Bernardet, J. M. Brown, A. Dörnbrack, E. Filaus, V. Grubišić, Q. Jiang, D. J. Kirshabaum, O. Knoth, S. Koch, I. Stiperski, S. Vosper, and S. Zhong, 2008: Intercomparison of T-REX mountain wave simulations. Poster. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Doyle, J. D., V. Grubišić, W. O. J. Brown, S. F. J. De Wekker, A. Dörnbrack, Q. Jiang, S. D. Mayor, and M. Weissmann, 2008: Observations and numerical simulations of intense atmospheric subrotor vortices during T-REX. Poster. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Jiang, Q., J. D. Doyle, V. Grubišić, and R. B. Smith, 2008: Waves eddies and turbulence observed over Owens Valley. Poster. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

French, J. R., S. Haimov, L. Oolman, V. Grubišić, and D. Leon, 2008: Airborne radar observations of breaking waves/rotors in the lee of the Medicine Bow Mountains in SE Wyoming, USA. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Oolman, L. D., J. R. French, S. Haimov, D. Leon, and V. Grubišić, 2008: Observations of strong mountain waves in the lee of the Medicine Bow Mountains of southeast Wyoming. Poster. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Rejmánek, H., S.-H. Chen, V. Grubišić, and J. D. Doyle, 2008: Utilizing the smoke plume of Volcano Villarrica to examine the dynamics and detailed structure of its wave and rotor. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Barstad, I., and V. Grubišić, 2008: Observations of a gap flow at 80 N. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Schmidli, J., B. J. Billings, R. Burton, F. K. Chow, S. F. J. De Wekker, J. D. Doyle, V. Grubisic, T. R. Holt, Q. Jiang, K. A. Lundquist, A. N. Ross, P. Sheridan, S. Vosper, C. D. Whiteman, A. A. Wyszogrodzki, G. Zaengl, S. Zhong, 2008: The T-REX valley wind intercomparison project. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Večenaj. Ž., S. F. J. De Wekker, and V. Grubišić, 2008: Spatial and temporal features of mountain wave related turbulence. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Cohn, S. A., W. O. J. Brown, and V. Grubišić, 2008: Wind profiler direct observations of an atmospheric rotor: T-REX IOP 3. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Brown, W. O. J., S. A. Cohn, V. Grubišić, and J. D. Doyle, 2008: ISS observations of small-scale features and an easterly wind events during T-REX. *AMS 13th Conference on Mountain Meteorology*, Whistler, BC, Canada, Amer. Meteor. Soc.

Haimov, S., V. Grubišić, J. French, and L. Oolman, 2008: Multi-Doppler measurements of atmospheric rotors and turbulent mountain waves. 2008 IEEE International Geoscience & Remote Sensing Symposium (IGARSS), Boston, MA.

Rassmussen, R. M., C. Liu, K. Ikeda, F. Chen, D. Yates, D. Gochis, and V. Grubisic, 2008: Assessing snowpack from Colorados' Headwater basins using a very high resolution atmospheric model. *European Geophysical Union (EGU) General Assembly 2008*, Vienna, Austria.

Grubišić, V., and I. Stiperski, 2008: Lee waves over double bell-shaped orography. *European Geophysical Union (EGU) General Assembly 2008*, Vienna, Austria.

Vanda Grubisic Research Catalog

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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Research Focus FY08:

Biosphere-Atmosphere Interactions Group (BAI)

To advance understanding of global biosphere - atmosphere interactions and to predict the response of the earth system to future perturbations. This is being accomplished through multidisciplinary field, laboratory and modeling studies of the processes controlling these interactions on various scales (e.g., leaf to canopy to landscape to global).

Biosphere-atmosphere Exchange of Aerosols within Cloud, Carbon and Hydrologic cycles, including Organics and Nitrogen (BEACHON)

The BEACHON project conducts experimental and numerical research studies to enhance understanding of the roles of biogenic aerosols, nitrogen trace gases and oxidants in linking and regulating the carbon and water cycles.

Headed up a large BEACHON Retreat, November 2007, whose purpose was to develop a broadly collaborative and interdisciplinary research plan for the new initiatve with an emphasis on connections between the hydrologic cycle and surface-atmophsere fluxes.

Pine Bark Beetles

When pine bark beetles kill trees, scientists believe they may also alter local weather patterns and air quality. In the News coverage:

- Pine Bark Beetles Affecting More than Forests (NSF)
- Pine bark beetles affecting more than forests (eScienceNews)
- Pine Beetles Changing Rocky Mountain Air Quality, Weather (Environment News Service)
- Pine beetle bite may be leaving mark in air too (Denver Post)
- Study: Beetles affect weather, air quality (Times of the Internet)
- Pine Beetles Changing Rocky Mountain Air Quality, Weather (Mountain Pine Beetle)
- Pine Beetles Changing Rocky Mountain Air Quality, Weather (The Westerner)
- Study looks at beetles' effects on weather (USA Today)

Pine bark beetles are taking a toll throughout the Rocky Mountains. The loss of pine trees may affect local weather patterns and air quality. Picture by Carlye Calvin, UCAR
High resolution figure

Plants Make Their Own Painkillers

Walnut trees respond to stress by producing significant amounts of a chemical form of aspirin, scientists have discovered: Thomas Karl, Alex Guenther, Andrew Turnipseed, Edward Patton, & Kolby Jardine. In the News:

- Walnut Trees Emit Aspirin-Like Chemical to Deal With Stress (NSF)
- Plants Make Own Painkillers (LiveScience)
- Plants make their own version of aspirin, researchers find (Los Angeles Times)

Scientists used specially-equipped towers to measure chemical emissions from plants in a walnut grove in California. Picture by Carlye Calvin, UCAR
High resolution figure

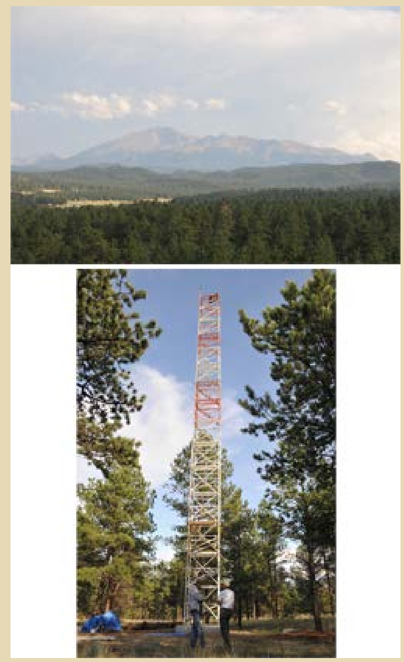
- Stressed plants release aspirin-like chemical (Reuters)
- Stressed plants produce an aspirin-like chemical (What is life science)
- Stressed plants produce Aspirin (Medical & Pharmacy News)
- Mother Nature's little helper (nature.com)

Field Programs FY08:

BEACHON - Southern Rocky Mountains Summer 2008 Study (BEACHON-SRM08)

July - September 2008, Woodland Park, Colorado

SRM08 is the initial research phase in the four year BEACHON research program in water-limited Western U.S. pin forest ecosystems that will improve the understanding of fundamental biogeochemical processes that are central to achieving the objectives of the BEACHON research program. BEACHON-SRM08 is considered a pre-study in advance of long-term measurements of key atmospheric and ecosystem parameters at the same site as well as a more comprehensive regional campaign in 2010. Because of this, the study has practical objectives relating to the setup and operation of the MEF site in addition to specific scientific foci on atmospheric chemistry and aerosol processes.



BEACHON-SRM08 pictures by Jim Smith
High resolution figure

The field study took place at the Manitou Experimental Forest (MEF) from 21 July – 19 September 2008. Several specific scientific objectives will be addressed during this pre-study, listed below.

- The formation and growth of atmospheric nanoparticles: The goals are to understand and quantify the formation of new particles and to determine the mechanism by which these particles grow to become important participants in atmospheric chemistry and climate.
- Emissions and reactions of Biogenic Volatile Organic Compounds (BVOCs) and other important trace gases and oxidants: These measurements are designed to reduce uncertainties of the concentrations and fluxes of important trace gases, including BVOCs and primary oxidants such as O_3, NO_3, OH, and HO_2/RO_2.
- The formation and hygroscopic properties of biogenic Secondary Organic Aerosols (SOA) and primary particles.
- Terrestrial and canopy controls on the emission and deposition of water, nutrients and aerosols: Several measurements focusing on processes relevant to the biology and hydrology of this ecosystem will start during the campaign. These are expected to develop into a more comprehensive suite of measurements over time.
- Characterize transport in canopy and from canopy to cloud: One unique aspect of the current study is the exploration of the use of ground-based remote sensing for obtaining insights into the transport of trace gases and aerosols from canopy to cloud.
- BEACHON Modeling of Aerosol-Cloud-Emissions Interactions: Two 3-dimensional models, the Large Eddy Simulation (NCAR LES) coupled with chemistry and WRF-Chem, will be used to investigate interactions between biogenic emissions, atmospheric oxidants, aerosols, and clouds. Both of these models will simulate representative conditions of those sampled in the field. Initially cases will focus on the Manitou Experimental Forest field site in the Colorado Rockies. To conduct these simulations, both measurements for initializing and evaluating the models and model development are needed.

Amazon Aerosol Characterization Experiment (AMAZE-08)

January - March 2008, Manaus, Brazil

The main objectives of AMAZE-08 are to understand the sources and regulators of

AMAZE-08 pictures by Michel Flores

High resolution figure

organic particle mass in a pristine continental environment and the connections between particle chemistry and particle optical and hygroscopic properties.

The AMAZE-08 tower measurements were conducted between February 7 and March 14, 2008 during the rainy reason. The site was 60 km NNW of Manaus and located within a mostly pristine rainforest. The winds were predominantly from the ENE across 1600 km of untouched forest. Except for episodes of long-range transport from Europe and Africa and infrequent transport from Manaus, the site was free of anthropogenic influences and allowed the study of pristine biological aerosol particles.

Particle instrumentation included two high-resolution aerosol mass spectrometers (HR-ToF-AMS) with thermodenuder, two cloud condensation nuclei counters (CCNC), a continuous flow diffusion chamber (CFDC) for ice nuclei measurements, three optical particle counters (OPC), an ultraviolet aerodynamic particle sizer (UV-APS) for measurement of biologically active particles, two tapered element oscillating microbalances (TEOM), two scanning mobility particle sizers (SMPS), two multiwavelength nephelometers, three condensation particle counters (CPC) a multi-angle absorption photometer (MAAP), an athelometer, coarse- and fine-mode filters for elemental and ion analysis, an AErosol RObotic NETwork (AERONET - NASA) sunphotometer including photosynthetically active radiation (PAR), and LIDAR system. Gas instrumentation included a proton-transfer mass spectrometer (PTR-MS), gas adsorption cartridge for off-line chromatographic analysis, and measurement of O3, CO, CO2, NO, and NOx.

Community Service FY08:

- Editorial Board: Atmospheric Chemistry and Physics
- Editorial Board: Atmospheric Environment
- Co-Chair: International Geosphere Biosphere Program (IGBP) – Analysis and Integration of Models of the Earth System (AIMES) – Global Emissions Inventory Activity (GEIA)
- Graduate Research Advisor & Thesis/Dissertation Committee: Kolby Jardine (SUNY Stonybrook, NY)
- Graduate Research Advisor & Thesis/Dissertation Committee: Monica Madronich (CU)
- Thesis/Dissertation Committee: Xiaoyan Jiang (PhD University of Texas)
- Thesis/Dissertation Committee: Tanarit Sakulyanontvittaya (PhD CU)

Scientific Presentations FY08:

- The Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, H2O, Organics & Nitrogen (BEACHON) project: First results and future plans (New Orleans, LA)
- What are the right precursors to SOA? (Manaus, Brazil)
- Surface-Atmosphere Exchange Measurements:Alternatives to Eddy Covariance (Pellston, MI)
- Biogenic trace gases and SOA (Reykjavik, Iceland)
- The changing earth system (Kota Kinabalu, Malaysia)
- Identifying and Describing the Processes Controlling Biogenic VOC Emissions (Helsingborg, Sweden)
- Sources and Sinks of Atmospheric Compounds:Biogenic Volatile Organic Compound Emissions (Wageningen, Netherlands)
- The Role of Biogenic VOC Emissions in the Earth System (Pullman, WA)

Publications FY08:

Boy, M., T. Karl, A. Turnipseed, R. L. Mauldin, E. Kosciuch, J. Greenberg, J. Rathbone, J. Smith, A. Held, K. Barsanti, B. Wehner, S. Bauer, A. Wiedensohler, B. Bonn, M. Kulmala, A. Guenther, 2008: New particle formation in the Front Range of the Colorado Rocky Mountains. *Atmos. Chem. Phys.*, **8**, 1577-1590.

Duhl, T. R., D. Helmig, A. B. Guenther, 2008: Sesquiterpene emissions from vegetation: a review. *Biogeosciences*, **5**, 761-777
Guenther, A. B., 2008: Are plant emissions green? *Nature*, **452**, 701-702.

Heald, C. L., D. K. Henze, L. W. Horowitz, J. Feddema, J.-F. Lamarque, A. Guenther, P. G. Hess, F. Vitt, J. H. Seinfeld, A. H. Goldstein, I. Fung, 2008: Predicted change in global secondary organic aerosol concentrations in response to future climate, emissions, and land-use change. *J. Geophys. Res.*, **113**, D05211, doi: 10.1029/2007JD009092.

Jardine, K., P. Harley, T. Karl, A. B. Guenther, M. Lerdau, J. E. Mak, 2008: Plant physiological and environmental controls over the exchange of acetaldehyde between forest canopies and the atmosphere. *Biogeosciences*. (Submitted)

Karl, T., A. B. Guenther, A. A. Turnipseed, E. G. Patton, K. Jardine, 2008: Chemical sensing of plant stress at the ecosystem scale. *Biogeosciences Discuss.*, 5, 2381-2399.

Matsunaga, S. N., A. B. Guenther, M. J. Potosnak, E. C. Apel, 2008: Emission of sunscreen salicylic esters from desert vegetation and their contribution to aerosol formation. *Atmos. Chem. Phys.*. (Submitted)

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Millet, D. B., D. J. Jacob, K. F. Boersma, T.-M. Fu, T. P. Kurosu, K. Chance, C. L. Heald, A. Guenther, 2008: Spatial distribution of isoprene emissions from North America derived from formaldehyde column measurements by th OMI satellite sensor. *J. Geophys. Res.*, **113**, D02307.

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Research Focus FY08:

Ethan is currently a Postdoctoral Fellow (2008 - 2010) with the Advanced Studies Program (ASP) at NCAR.

His dissertation from the University of Colorado in Geology, looked at the relationship between soil hydraulic properties and surface temperature. Soil hydraulic properties control the movement of water within the soil. This in turn partitions rainfall into runoff, infiltration, and evapotranspiration (ET). Soil hydraulic properties are important parameters in climate models, weather prediction, flood forecasting, and aquifer recharge studies. However, the spatial distribution of these properties is very poorly understood. Ethan hopes to use the relationship between surface temperatures and soil hydraulic properties to determine hydraulic properties from remotely sensed surface temperatures.

Gutmann also writes scientific news articles for ArsTechnica.com and is an avid photographer.

Trip to Nepal, picture by Ethan Guttman

Community Service FY08:

- Instructor: University of Colorado, Writing in Geosciences, Spring 2009
- Member: ASP seminar series organizing committee

Publications FY08:

Larson, K.M., Small, E.E., Gutmann, E.D., Bilich, A., Axelrad, P., Braun, J., Zavorotny, V., 2008: Use of GPS receivers as a soil moisture network for water cycle studies. Geophysical Research Letters, 35, L24405, doi:10.1029/2008GL036013.

Larson, K.M., Small, E.E., Gutmann, E.D., Bilich, A., Axelrad, P., Braun, J., 2008: Using GPS multipath to measure soil moisture fluctutations: Initial results, GPS Solutions, doi:10.1007/s10291-007-0076-6

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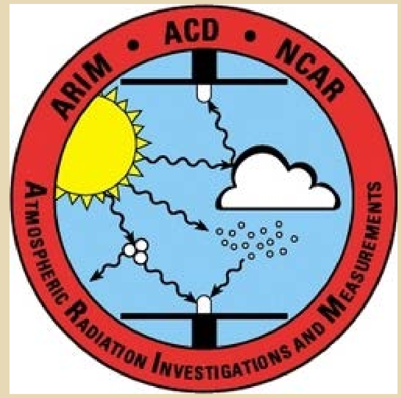
ATMOSPHERIC RADIATION INVESTIGATIONS AND MEASUREMENTS (ARIM)

Group Members

Samuel Hall
Richard Shetter (Group Leader)
Kirk Ullmann

http://arim.acd.ucar.edu



High resolution figure

Overview

Photochemical reactions provide the driving force for much of the chemistry in the atmosphere, affecting the recovery of stratospheric ozone, the magnitude of the greenhouse effect, tropospheric air quality and evolution, and changes in surface ultraviolet (UV) radiation. Thus, *in situ* solar radiation measurements are critical to atmospheric composition research. The ARIM group measures spectrally resolved UV and visible actinic flux and derives photolysis frequencies for a variety of important chemical species, including O_3, NO_2, CH_2O, HONO, HNO_3, N_2O_5, HO_2NO_2, PAN, H_2O_2, CH_3OOH, CH_3ONO_2, $CH_3CH_2ONO_2$, CH_3COCH_3 , CH_3CHO, CH_3CH_2CHO, CHOCHO, CH_3COCHO, $CH_3CH_2CH_2CHO$, and $CH_3COCH_2CH_3$. Additionally, the actinic flux measurements, in conjunction with radiative transfer calculations, are used derive ozone column abundances. These ozone columns have proven to be very useful for satellite validation activities.

Instrumentation

The group maintains Charged-coupled device Actinic Flux Spectroradiometers (CAFS) and Scanning Actinic Flux Spectroradiometers (SAFS) to measure up and down-welling wavelength dependent actinic flux in the UV and visible wavelengths. The measurements are based on a 2π steradian hemispherical zenith and nadir optical collectors coupled with UV enhanced fiber optic bundles to small, lightweight, monolithic CCD monochromators and double monochromator with photomultiplier tube detection, respectively. The instruments have an excellent record of performance on the NCAR HIAPER GV and C-130, the NASA DC-8, WB-57 and P-3B, the NOAA WP-3D and at numerous ground stations.

Figure 1. Zenith and nadir optics and instrument rack on the NASA DC-8 aircraft during ARCTAS.

High resolution figure

The ARIM optical calibration facility is equipped with precision radiometric power supplies and multiple NIST traceable 1000W quartz tungsten halogen lamps to determine the spectral response of each instrument. Secondary lamp standards are applied in the field. Mercury line calibrations are also performed to track the wavelength accuracy.

The ARIM work supports the ACD goals of understanding the regional and global air quality and the role of chemistry in the climate system.

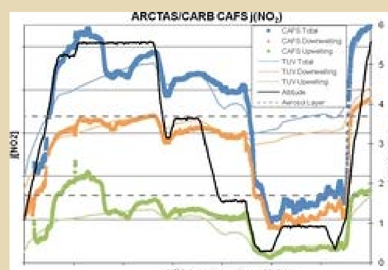


Figure 2. CAFS measured and TUV (clear sky) modeled j(NO2) during the ARCTAS/CARB deployment. The measurement/model differences are due to clouds and aerosol layers.

High resolution figure

Accomplishments

Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)

The 2008 ARCTAS (funded by NASA) mission investigated the transport and transformation of gases and aerosols affecting the Arctic. The winter phase was based in Fairbanks, AK, and explored the transport of pollution across the Arctic, with a focus on arctic haze, tropospheric ozone and surface deposited black carbon. The summer phase was based in Cold Lake, Alberta, and concentrated on the contribution of boreal fires to the atmospheric composition and climate of the Arctic region.

CAFS instruments were deployed on the NASA DC-8 aircraft for the full campaign to provide photolysis frequencies for the critical chemical constituents of the arctic. In particular, the photolysis contributes to the study of the evolution of pollution plumes and the tropospheric oxidant chemistry. Several factors specific to the

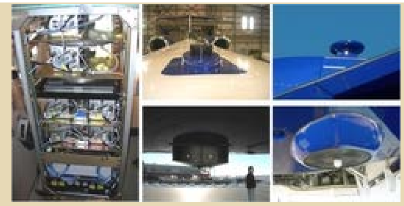


Figure 3. HARP rack installed on the NSF HIAPER GV aircraft, irradiance and actinic flux zenith and nadir optics.

High resolution figure

arctic affected the actinic flux. The scattering in arctic haze tends to increase the flux while absorption in boreal fire emissions decreases the flux. Surface deposited black carbon also decreases the flux by reducing the surface albedo. Thus, the in situ measurements were critical to assessing the local radiation field.

Prior to the summer phase in Cold Lake, Alberta, the California Air Resources Board funded a series of flights based from the NASA Palmdale facility to study the dynamics of the transport of Asian pollution into California, local anthropogenic pollution and greenhouse gas emissions. Again, the actinic flux measurements were critical to understand the local chemistry and evolution of the emissions. The extensive California wildfires were also studied. The actinic flux was often dramatically reduced within the fire plumes, slowing the photolysis chemistry.

The CAFS instruments were redesigned for DC-8 installation, including new instrument housings, PC-104 computers and electronics, and upgrades to the data acquisition and control software. Data coverage was near 100% for the entire mission.

HIAPER Aircraft Instrumentation Solicitation Experimental Flight Test – 2008 (HEFT-08)

The ARIM team, in collaboration with Peter Pilewskie and Bruce Kindel of the University of Colorado, Manfred Wendisch of the Leibniz-Institute for Tropospheric Research, Rainer Schmitt of Metcon, Inc and Dieter Schell of Enviscope GmbH, Germany, developed the HIAPER Airborne Radiation Package (HARP), a comprehensive atmospheric radiation suite to measure *in situ* actinic flux and irradiance. The package is part of the HIAPER Aircraft Instrumentation Solicitation (HAIS), funded by NSF. The ARIM group developed the actinic flux package using a CAFS detection and was responsible for building the spectrometer computer systems, creating the data acquisition and control software, coordinating the assembly of the racks, equipment, input optics and stabilized platforms, and leading the integration and flight management of the instrumentation.

The irradiance measurements rely on horizontal stabilization to determine layer properties, such as reflectance, transmittance and absorbance. Thus, the HARP irradiance package is mounted on zenith and nadir stabilized platforms to account for aircraft attitude changes. The platform was tested during HEFT-08. The stabilized platform performed well and responded precisely to positional commands. However, the navigation signals used to determine aircraft attitude were inaccurate due to signal timing delays and noise on the signal line. To eliminate these external errors, the HARP system has been upgraded to receive direct GPS antenna signals. Final testing and delivery of the HARP instrumentation is forthcoming.

Publications

The recent ARIM group publications cover a broad range, including chemical measurement and model studies, satellite validation of ozone columns, and atmospheric heating rates.

Measurement of HO2NO2 in the Free Troposphere during INTEX-NA 2004, S. Kim, L.G. Huey, R.E. Stickel, D.J. Tanner, J. H. Crawford, J.R. Olson, G. Chen, W. H. Brune, X. Ren, R. Lesher, P. J. Wooldridge, T. H. Bertram, A. Perring, R.C. Cohen, B., B. Lefer, R. E. Shetter, M. Avery, G. Diskin, and I. Sokolik, *J. Geophys. Res.*, 112, D12S01, doi: 10.1029/2006JD007676.

Improving regional ozone modeling through systematic evaluation of errors using the aircraft observations during the International Consortium for Atmospheric Research on Transport and Transformation, Mena-Carrasco, M., Y. Tang, G. R. Carmichael, T. Chai, N. Thongbongchoo, J. E. Campbell, S. Kulkarni, L. Horowitz, J. Vukovich, M. Avery, W. Brune, J. E. Dibb, L. Emmons, F. Flocke, G. W. Sachse, D. Tan, R. Shetter, R. W. Talbot, D. G. Streets, G. Frost, D. Blake, 2007:. *J. Geophys. Res.*, 112, D12S19, doi: 10.1029/2006JD007762.

HOx chemistry during INTEX-A 2004: Observation, model calculations and comparison with previous studies, Ren, X., J. R. Olson, J. H. Crawford, W. H. Brune, J. Mao, R. B. Long, Z. Chen, G. Chen, M. A. Avery, G. W. Sachse, J. D. Barrick, G. S. Diskin, L. G. Huey, A. Fried, R. C. Cohen, B. Heikes, P. Wennberg, H. B. Singh, D. R. Blake, R. E. Shetter, , *Journal of Geophysical Research*, 113, D05310, doi:10.1029/2007JD009166, 2007.

Algorithm for the charge-coupled-device scanning actinic flux spectroradiometer ozone retrieval in support of the Aura satellite validation, Petropavlovskikh, I., R. Shetter, S. Hall, K. Ullmann, P. K. Bhartia, , *J. of Appl. Remote Sens.* 1, 013540 (2007), doi:10.11171.2802563.

OMI total ozone column validation with Aura-AVE CAFS observations, Kroon, M., I. Petropavlovskikh, R. Shetter, S. Hall, K. Ullmann, J. P. Veefkind, R. D. McPeters, E. V. Browell, and P. F. Levelt (2008), , *J.Geophys. Res.*, 113, D15S13, doi:10.1029/2007JD008795.

In-flight validation of Aura MLS ozone with CAFS partial ozone columns, Petropavlovskikh, I., L. Froidevaux, R. Shetter, S. Hall, K. Ullmann, P. K. Bhartia, M. Kroon, and P. Levelt (2008), , *J. Geophys. Res.*, 113, D16S41,doi:10.1029/2007JD008690.

Calculations of solar shortwave heating rates due to black carbon and ozone absorption using in situ measurements, Gao, R. S., S. R. Hall, W. H. Swartz, J. P. Schwarz, J. R. Spackman, L. A. Watts, D. W. Fahey, K. C. Aikin, R. E. Shetter, and T. P. Bui (2008), , *J. Geophys. Res.*, 113, D14203, doi:10.1029/2007JD009358.

Role of convection in redistributing formaldehyde to the upper troposphere over North America and the North Atlantic during the summer 2004 INTEX campaign, Fried, A., et. al.(2008), *J. Geophys. Res.*, doi:10.1029/2007JD009760.

FY 2009 PLANS

The ARIM group will continue data analysis on previous missions and publication of the results from the MIRAGE, TC4, CR-AVE and ARCTAS missions. In addition, we will begin comprehensive improvements to the CAFS measurements. These include quantification of stray light in the instruments, wavelength assignment corrections, and a calibration source intercomparison. We plan to investigate extending the CAFS wavelength range and optimizing the integration time and internal averaging with signal to noise. Instrument modifications will focus on improving the temperature and relative humidity control and monitoring, to provide a safe and optimal measurement environment. We will also continue collaborating with Irina Petropavlovskikh at NOAA/SRRB to improve the ozone column calculations.

OASIS (Ocean-Atmosphere-Sea Ice-Snowpack)

The February-April 2008, OASIS project (funded by NSF) in Barrow, Alaska will investigate fluxes between the atmosphere and snowpack, ozone depletion events, halogen chemistry and arctic haze. These are all driven by the photochemistry, so the ARIM surface actinic flux will be a critical measurement. The photochemistry will ramp up dramatically during the two month deployment, as the day will expand from 6 to 17 sun hours and the maximum solar zenith elevation increases from approximately 7 degrees to 29 degrees.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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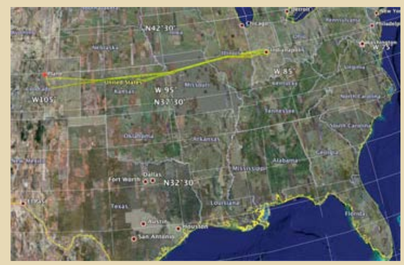
Research Focus FY08:

UTLS-TIMES



Google Earth flight path for START-08.
High resolution figure

Work with Laura Pan on the Upper Troposphere-Lower Stratosphere (UTLS) project performing chemical transport analysis in the tropopause region using available model, aircraft, and satellite data sources.

He has also working on the following projects with the external & internal collaborators listed:

- Modeling Cloud-Aerosol interactions with detailed particle and hydrometer spectra: W.W Wobrock and A.I Flossmann, Université Blaise Pascal, Clermont-Ferrand, France
- Modeling winter time snow clouds over the Japan Sea: Masatak Murakami Meteorological Research Institute, Ibaraki JAPAN
- Modeling aerosol effects on precipitation formation:- Roelof Bruintjes, RAL, NCAR.
- The development of an improved two-moment microphysical scheme with improved aerosol physics: Richard Farley , Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, South Dakota

RAL - Modeling Aircraft Turbulence Events

Bill works with Bob Sharman on modeling aircraft turbulence events using high resolution meso-scale models.

Field Programs FY08:

START-08

I parcipitated in the Stratosphere-Troposphere Analyses of Regional Transport (START-08) Field project by providing forecasting and data merging support during and after the project, 21 April - 28 June 2008.

Community Service FY08:

- Thesis Committee: Delphine Leroy, , PhD, Université Blaise Pascal, Clermont-Ferrand II, FRA

Publications FY08:

Thompson, G., P. R. Field, R. M. Rasmussen, W. D. Hall, 2008: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part II: Implementation of a new snow parameterization. *Mon. Wea. Rev.*, doi: 10.1175/2008MWR2387.1. (In Press)

Bill Holm Research Catalog

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CGD 2008 PROFILES IN SCIENCE: CÉCILE HANNAY

Summary of achievements

Cécile Hannay

Cécile Hannay has concentrated on short-range forecasts with global climate models. The forecasts are initialized from atmospheric analyses and compared to observations and analyses to examine process errors associated with the model formulation. This approach provides an excellent method of examining parameterizations as it allows direct comparison of the parameterized variables (e.g. clouds) with observations from field campaigns.

Cécile used the forecast framework for an atmospheric model intercomparison of Southeast Pacific stratocumulus with the ECWMF, NCAR and GFDL models. She showed that a key problem common to the models is that the planetary boundary layer (PBL) is too shallow compared to observations. However, as the complexity of the PBL scheme increases, the models produce deeper PBL. All the models capture a strong diurnal cycle in the liquid water path but there are large differences in the amplitude and the phase compared to observations. This, in turn, affects the radiative fluxes at the surface and the surface energy budget. This is particularly relevant for coupled simulations as this can lead to large SSTs bias. Cécile recently submitted a paper documenting this intercomparison.

Cécile is involved in the ongoing international GCSS Pacific Cross-section Intercomparison (GPCI). The GPCI compares both forecast and climate model simulations along a vertical cross-section extending from the California coast to the central Pacific ITCZ. The main goal of this intercomparison is to evaluate and improve the representation of tropical and subtropical cloud and precipitation processes in weather and climate prediction models. Cécile contributed to climate and forecasts simulations for the formal intercomparison. She also analyzed forecasts along the cross-section to assess candidate parameterizations for the next generation model, CAM4.

Cécile is also deeply involved in the CAM development. In particular, she contributed to the evaluation of new parameterizations and help to understand their interactions with the rest of the model. She has assisted various efforts for CAM 4 development and has helped scientists from the AMP and visitors.

Publications

Cécile Hannay, Dave Williamson, Jerry Olson, Rich Neale, Andrew Gettelman, Hugh Morrison, Sungsu Park and Chris Bretherton. (2008), *Short Term forecasts along the GCSS Pacific Cross-section: Evaluating new Parameterizations in the Community Atmospheric Model.* 4th PAN-GCSS Meeting on advances in modeling and observing clouds and convection, 2-6 June 2008, Toulouse, France.

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Table of Contents

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Research Focus & Field Studies FY08:

Model of Emissions of Gases and Aerosols from Nature (MEGAN)

My TIIMES research focuses on quantifying trace gas emissions from plants and elucidating short-term and long-term environmental controls over those emissions. These efforts involve both laboratory and field measurements, and are conducted within the framework of the Model of Emissions of Gases and Aerosols from Nature (MEGAN). Initially, these efforts were focused on the potential impacts of biogenic emissions on tropospheric oxidant chemistry, but now increasingly relate to the involvement of trace gas emissions on formation and growth of secondary organic aerosols.

MEGAN Community Data Portal

MEGAN Interactions Group

Work this fiscal year has included studies of low molecular weight oxygenated compounds (e.g., methanol, acetone, acetaldehyde) and attempts to better quantify emissions of high molecular weight terpenoids such as sesquiterpenes. Both of these efforts have been facilitated by the development of a laboratory-based FLUXTRON platform for the measurement of emissions under controlled environmental conditions.

Future plans involve continuing these efforts under the umbrella of BEACHON. In particular, the development of a convenient and well-equipped field site in the Manitou Experimental Forest as part of BEACHON-SRM08 will greatly aid this work in the future, facilitating long-term measurements and the characterization of seasonal and interannual variations in BVOC emissions.

Biological & physical controls over emission of potential SOA precursors from vegetation

NCAR PI(s): Peter Harley, Jim Greenberg, Alex Guenther, Thomas Karl
Brief description of the project objectives and approach:

Through a combination of laboratory (including NCAR greenhouse and Fluxtron facilities) and field measurements, we will improve our estimation of the magnitude of emissions of BVOC from vegetation and our understanding of the controls over those emissions. In the context of BEACHON, we will focus on those BVOC implicated in formation and growth of secondary organic aerosol (a list including, but not necessarily restricted to: isoprene, methylbutenol, monoterpenes and sesquiterpenes). Abiotic controls include light and temperature, possibly CO_2, and stresses such as drought and elevated O_3. Potential biological controls include plant phenology and stress due to herbivory. Though emissions of these compounds are incorporated into the current version of MEGAN, realistic parameterizations will require substantially more emissions data from a wide variety of plant species and growth forms. Elucidation of controls over emissions requires a combination of controlled experiments under laboratory conditions, and long-term field measurements obtained over complete (and ideally multiple) growing seasons.

BEACHON-SRM08 at the Manitou Experiment Forest from 21 July - 19 September 2008.

High resolution figure

Measurements will be accomplished using a variety of vegetation enclosure systems, from temperature controlled leaf cuvettes to branch enclosures to whole plant enclosures, and BVOC identification and quantitation will be accomplished using a variety of analytical techniques including GC-FID, GC-MS, and PTR-MS. Leaf enclosure experiments will also incorporate simultaneous measurements of net photosynthesis, evapotranspiration, and stomatal conductance.

FY2008 accomplishments:

- Instrument development and preliminary measurements to determine the role of light and temperature in establishing the atmospheric compensation point for light weight oxygenated species such as methanol, acetaldehyde and acetone. Ultimately, these measurements and algorithms will be incorporated into MEGAN.
- Measurement of secondary organic aerosol precursors (primarily mono- and sesquiterpenes) from dominant vegetation species in the rainforest of Borneo. This work was carried out as part of OP3 (Oxidant and Particle Photochemical Processes above a South-East Asian tropical rain forest) sponsored by the Natural Environment Research Council in the UK and the University of Malaysia Sabah.
- As part of BEACHON-SRM08, I participated in the development of a long-term research site at the Manitou Experimental Forest north of Woodland Park, CO. Measurements were initiated to elucidate short and long-term controls over emissions of biogenic VOC (methylbutenol, mono- and sesquiterpenes) from needles of Ponderosa pine, the dominant tree species at the site.

Relevance to BEACHON:

To the extent that SOA (and ice nuclei from biogenic sources) contribute to cloud formation and determination of cloud radiative properties and precipitation, better understanding of the sources of biogenic SOA precursors is essential. Understanding of potential feedbacks on BVOC emissions due to alterations in cloud properties and precipitation will require far better understanding of the effects of light and, especially, effects of soil moisture, on these emissions. Measurements of above-canopy BVOC fluxes are a significant component of BEACHON-SRM08, and concomitant measurements at the leaf or branch scale will both constrain above-canopy flux estimates and help explain observed variations in fluxes on diurnal and seasonal (interseasonal) time scales.

Community Service FY08:

- Mentoring two Colorado College undergraduates participating in the BEACHON-SRM08 Field Study (Woodland Park, CO, July - September 2008)

Scientific Talks FY08:

- The BEACHON Project - Southern Rocky Mountain Intensive (Woodland Park, CO, August 2008)
- Obtaining estimates of Farquhar model parameters from measured photosynthesis data (University of Colorado Mountain Research Station, CO, July 2008

Publications FY08:

Jardine, K., P. Harley, T. Karl, A. B. Guenther, M. Lerdau, J. E. Mak, 2008: Plant physiological and environmental controls over the exchange of acetaldehyde between forest canopies and the atmosphere. *Biogeosciences*. (Submitted)

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

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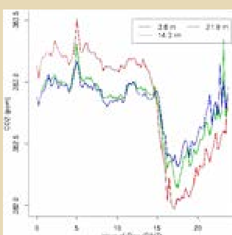
Research Focus FY08:



First data from the Navajo Nation site - High resolution figure

Deployment of AIRCOA - High resolution figure

Carbon Dioxide Instrumentation, Data Analysis, Education and Outreach in Kenya, Africa and Navajo Reservation

Principle Investigators: Sherri L. Heck, University of Colorado & Britton Stephens, NCAR

I am a graduate student in the Department of Atmospheric and Oceanic Sciences at the University of Colorado, Boulder working on my doctoral thesis with Dr. Britton Stephens of TIIMES and EOL. My research entails a combination of studying regional carbon dioxide surface fluxes of forest ecosystems in complex terrain and an education and outreach (E&O) component. I am focusing on underrepresented people in terms of the E&O and under-sampled areas in terms of the carbon dioxide data.

In October 2007, in cooperation with the Bureau of Indian Affairs and Marnie Carroll, the Dinè (Navajo) College Environmental Science Director, we deployed the Autonomous Robust CO2 Analyzer (AIRCOA, designed by Britt Stephens and Andy Watt, photos) at Roof Butte on the Navajo Nation in Northeastern Arizona in order to determine the regional carbon dioxide surface fluxes in this southwestern mountainous area. Dinè College Conference Report: Building a Successful Student Research Program Through Collaboration.

In 2008, a second carbon dioxide analyzer will be deployed atop Mount Kenya, Africa in order to study the regional carbon dioxide fluxes at this mountain site and to also help fill a key gap in available African carbon dioxide data. This project is in cooperation with Mr. John Mwikya, Deputy Principal, of the University of Nairobi and Ngotho Nyaga Ephantus, Deputy Director of the Kenya Meteorological Department.

In partnership with The Digital Library for Earth System Education (DLESE) and the Earth Exploration Toolbook (EET), I have created curriculum that utilizes the data from each of our sites entitled "**The Breathing Forest: Exploring the Carbon Cycle and Climate Change in the Classroom using Rocky RACCOON carbon dioxide data**". Website: Rocky Raccoon: Using Data to explore Carbon in the Rocky Mountains

Working with students in the

In the News:

Webcast: Planning for Seven Generations: The Perspective of the Next Generation

(April 25, 2008)
Webcast: Panel on the Prespective of the Next Generation (April 25, 2008)
UCAR Highlight 2007 - Africa in Mind
UCAR Quarterly - The African Link

Navajo Nation on instrument operation, maintenance and data analysis possibilities.
High resolution figure

Science and Education in Kenya

I would like to thank the following divisions, institutes, etc. for this incredible opportunity: NCAR Directorate and Diversity Initiative, EOL, ESSL, Africa Initiative, TIIMES and Biogeosciences, UCAR Education and Outreach Division and GLOBE.

Overall Goals and Objectives

The project's overarching goals are to provide valuable scientific data, promote technological transfer and help NCAR meet its diversity and education goals. By focusing on underrepresented people in terms of the education and outreach (E&O) and under-sampled areas in terms of the carbon dioxide (CO2) concentration data (these two areas often coincide), the project is providing invaluable data to the science community and bolstering science education in areas that would have most likely otherwise been ignored. It is vital to not only further educate students so as to motivate them to continue with their education and therefore improve a country's science literacy; it is also important to fill in the key gaps of CO2 concentration data so that a more representative picture of regional to global CO2 concentration and flux distribution can be determined...more

Community Service FY08:

- Education and Outreach: Worked with students on instrument operation, maintenance and data analysis possibilities. Navajo Nation, Arizona
- Deployed carbon dioxide sensor (AIRCOA) atop Roof Butte with students and researchers at Dine College on the Navajo Nation, Arizona.
- Earthworks Education Outreach Program (Weather & Climate): Atmospheric Chemistry - Monitoring Factors that Effect Ultraviolet (UV) Radiation (Teachers: Debbie Dogancay, Patti Grammens, Cheryl Manning, Sarah Wilson | Scientists: Marsha Fisher, Lars Kalnajs, Melissa Trainer, Sarah Tessendorf, Sherri Heck) Final Report

Scientific Talks FY08:

- Carbon Dioxide Measurements: Presented to students and faculty at Dine College on the Navajo Nation (New Mexico, October 2007)
- Carbon Dioxide Fluxes in the US and Africa. Africa Initiative (Sahel Conference, Burkina Faso, Africa)
- Regional Scale Study of Carbon Dioxide Fluxes on the Navajo Nation: A Scientific and Personal Perspective (Planning for Seven Generations Conference: Indigenous and Scientific Approaches to Climate Change, Boulder, CO, March 2008)
- Poster: Regional and Local Carbon Flux Information from a Continuous Atmospheric CO2 Network in the Rocky Mountains (American Geophysical Union, San Francisco, CA, December 2007)
- University of Colorado, Department of Atmospheric Sciences – successfully defended thesis proposal and passed oral exams (April 2008)

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ANDY HELD

General Information

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BEACHON

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Research Focus FY08:

I am a research fellow of the German Research Foundation (DFG) visiting the Ultrafine Aerosol Research Group and the Biosphere Atmosphere Interactions (BAI) Group in the Atmospheric Chemistry Division at NCAR. The goal of my research project is to develop and apply innovative instrumentation for the simultaneous quantification of the chemical composition and the turbulent transport of atmospheric nanoparticles in the ultrafine size range.

For this purpose, a thermal desorption chemical ionization ion trap mass spectrometer was built based on the TDCIMS technique established at NCAR. The ion trap development was supported by a BEACHON instrument development grant.

The ion trap mass spectrometer was specifically designed for application in a micrometeorological technique to investigate the turbulent transport of aerosol compounds. Aerosol number flux measurements evaluating the conceptual validity of this approach were carried out during the CHATS field experiment.

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ANDREW HEYMSFIELD

2008 Publications

Matrosov, S. Y., A. J. Heymsfield, 2008: Estimating ice content and extinction in precipitating cloud systems from CloudSat radar measurements. J. Geophys. Res., 113, D00A05, doi: 10.1029/2007JD009633.2

Abstract

Relations between W band radar reflectivity and ice cloud water content and visible extinction coefficient are developed using a large microphysical data set. These relations are specifically tuned for CloudSat radar to derive ice content and optical thickness of ice parts of precipitating systems where other types of measurements have limitations. Accounting for nonsphericity is essential for larger particles, which produce higher reflectivities (Z e > 0 dBZ) and often dominate ice content of precipitating clouds. Typical values of median sizes in such clouds are about 1–2 mm, and they vary modestly. The modest particle size variability and strong non-Rayleigh scattering reduce data scatter in the derived relations and increase an exponent in best fit power law approximations for ice water content–reflectivity and extinction-reflectivity relations. The data scatter for high-reflectivity clouds is smaller than for low-reflectivity nonprecipitating clouds. It is about 33% for the reflectivity-ice water content relation, and it is about 50% for the reflectivity-extinction relation. For higher reflectivities, the temperature dependence of the ice water content-reflectivity relations is not very distinct, and uncertainties due to temperature variations are not expected to be high compared to possible errors due to particle shape variability. Uncertainties in particle aspect ratio, mass-size relation assumptions, and underrepresentation of smaller particles in samples can produce additional retrieval errors, so cloud ice content estimates can have uncertainties of about 50%, and extinction estimates can have uncertainties as large as a factor of 2.

Skofronick-Jackson, G., A. J. Heymsfield, E. Holthaus, C. Albers, M.-J. Kim, 2008: Correction to "Nonspherical and spherical characterization of ice in Hurricane Erin for wideband passive microwave comparisons". J. Geophys. Res., 113, D14210, doi: 10.1029/2008JD010387.4

Halverson, J., M. Black, S. Braun, D. Cecil, M. Goodman, A. J. Heymsfield, G. Heymsfield, R. Hood, T. Krishnamurti, G. McFarquhar, M. J. Mahoney, J. Molinari, R. Rogers, J. Turk, C. Velden, D.-L. Zhang, E. Zipser, R. Kahar, 2008: NASA's tropical cloud systems and processes (TCSP) experiment: Investigating tropical cyclogenesis and hurricane intensity change. Bull. Amer. Meteor. Soc., 88, 867-882, doi: 10.1175/BAMS-88-6-867.4

Abstract

High altitude research flights during the active 2005 Atlantic and eastern Pacific hurricane season yielded interesting and surprising observations, both within and above the clouds.

Jenkins, G. S., A. S. Pratt, A. J. Heymsfield, 2008: Possible linkages between Saharan dust and tropical cyclone rain band invigoration in the eastern Atlantic during NAMMA-06. Geophys. Res. Lett., 35, L08815, doi: 10.1029/2008GL034072.2

Abstract

The Saharan Air Layer (SAL) is a dominant feature that influences the large-scale environment from West Africa to the western tropical North Atlantic. While the SAL can create hostile thermodynamic and kinematic environmental conditions for tropical cyclogenesis, it also provides an infusion of cloud condensation and ice nuclei which can potentially invigorate convection. Here we show that these mechanisms may have been involved with the development of Tropical Storm (TS) Debby and Tropical Depression (TD) 8 (later Hurricane Helene) in 2006. Satellite imagery and rawinsondes indicate SAL outbreaks just prior to the emergence of these disturbances over the extreme Eastern tropical Atlantic Ocean. Here we examine the invigoration of convective bands associated with TS Debby and TD-8 based on satellite and direct aircraft measurement. In-situ aircraft measurements show enhanced cloud water content, cloud and precipitation sized particles, lightning and a 26 ms-1 updraft just south of the SAL with TD-8.

Field, P. R., A. J. Heymsfield, A. Bansemer, C. H. Twohy, 2008: Determination of the combined ventilation factor and capacitance for ice crystal aggregates from airborne observations in a tropical anvil cloud. J. Atmos. Sci., 65, 376-391, doi: 10.1175/2007JAS2391.1.2

ABSTRACT

The ventilation factor and capacitance used in numerical models to represent ice crystal aggregates directly affects the growth rate of the ice crystal aggregates, and consequently the sink of atmospheric water vapor. Currently, numerical models that prognose ice water content (IWC) and water vapor mixing ratio represent the capacitance and ventilation factor of precipitation-sized particles with simplified geometries, such as hexagonal plates. The geometries of actual precipitation-sized particles are often more complex, and a test of the values being employed is needed. Aircraft observations obtained during a Lagrangian spiral descent through the sublimation zone of a tropical anvil cloud have been used to determine an estimate of combined dimensionless capacitance and ventilation factor for the nonpristine geometries exhibited by ice crystal aggregates. By combining measurements of bulk ice water content, the particle size distribution, and environmental subsaturation, the change in ice water content was modeled throughout the spiral descent and compared with observations of the change in ice water content. Uncertainties resulting from potential systematic biases in the measurements and parameterizations used in the analysis were investigated with sensitivity tests. Most of the uncertainty was related to an assumed maximum potential bias in the measurement of IWC of ±45%. The resulting combined ventilation factor and dimensionless capacitance value was 1.3 (with a range of 0.6–1.9, defined by 68% of sensitivity test trials) for a particle size–weighted mean value of (Sc)1/3(Re)1/2 = 14.9 ± 1.7, where Sc is the Schmidt number and Re is the Reynolds number. Results from commonly adopted combinations of ventilation factor relations and capacitances are compared with the observations presented here, and, finally, surrogate dimensionless capacitances are suggested that when combined with commonly used ventilation factor relations are consistent with the results presented herein.

Skofronick-Jackson, G., A. J. Heymsfield, E. Holthaus, C. Albers, M.-J. Kim, 2008: Nonspherical and spherical characterization of ice in Hurricane Erin for wideband passive microwave comparisons. J. Geophys. Res., 113, D06201, doi: 10.1029/2007JD008866.4

Abstract

In order to better understand the characteristics and physical-to-radiative relationships of frozen hydrometeors in hurricane systems, computed brightness temperatures (TB) from 10.7 to 183 ± 10 GHz were compared with radiometric observations of Hurricane Erin (2001) from the NASA ER-2 aircraft. The focus was on the high frequencies (=85 GHz) that are particularly sensitive to frozen hydrometeors. In order to initialize the cloud profiles used in the radiative transfer calculations, data from airborne radars, dropsondes, and cloud models were used. Three different ice habit and size parameterizations were used with these cloud profiles to obtain the particle radiative signatures including (1) spherical particles with size distributions derived from in situ observations, (2) spherical "fluffy" snow and graupel particles with modified Marshall-Palmer size distributions, and (3) a non-spherical bullet rosette habit where the radiation attributes (scattering, absorption, and asymmetry properties) were computed using the Discrete Dipole Approximation. In addition, three different reflectivity to ice water content (Z-IWC) relationships were used with the three habit and size parameterizations to provide a measure of the sensitivity of the Z-IWC relationship. This work showed that both the scattering and asymmetry coefficients, along with the ice water content in each layer, play an important role in determining the resultant high frequency brightness temperatures. All low frequency (<40 GHz) calculations matched the observations with correlation coefficients greater than 0.9. At higher frequencies (> 90 GHz), correlation coefficients ranged from 0.7 to 0.92. Comparing between the three ice habit and size parameterizations showed less than a 0.2 difference in correlation coefficient, while the comparisons between the three Z-IWC relationships caused changes of up to 0.15 in the correlation coefficients, but they had a significant effect on the mean differences between the observations and the calculations.

Heymsfield, A. J., A. Bansemer, S. Matrosov, L. Tian, 2008: The 94-GHz radar dim band: Relevance to ice cloud properties and cloudsat. Geophys. Res. Lett., 35, L03802, doi: 10.1029/2007GL03136.3

Abstract

Details of the microphysics are shown to be responsible for a region of ice cloud which, when probed from above, has decreasing radar reflectivity (Z e) downwards at 94 GHz but increasing Z e at 9.7 GHz. This 94-GHz radar dim band is found to be due to the combination of ice particle aggregation and non-Rayleigh scattering effects. Observations and model calculations indicate that it occurs when the particle size distribution (PSD) broadens such that its slope, as derived from fitted PSD, decreases below about 15 cm-1, or equivalently, to a median volume diameter exceeding 0.25 cm. Dimming occurs at temperatures (T) primarily between -5 and 0°C but can occur at -30°C or below in convectively-generated ice clouds (anvils). The dimming effect may produce an appreciable low bias in the ice water content (IWC) retrieved from Z e measured by CloudSat's 94-GHz radar. Methods to estimate the IWC in the dim band are proposed.

Heymsfield, A. J., A. Protat, D. Bouniol, R. T. Austin, R. J. Hogan, J. Delanoe, H. Okamoto, K. Sato, G.-J. vanZadelhoff, D. P. Donovan, Z. Wang, 2008: Testing IWC retrieval methods using radar and ancillary measurements with in-situ data. J. Appl. Meteor. Climat., 47, 135-163, doi: 10.1175/2007JAMC1606.1.4

ABSTRACT

Vertical profiles of ice water content (IWC) can now be derived globally from spaceborne cloud satellite radar (CloudSat) data. Integrating these data with Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data may further increase accuracy. Evaluations of the accuracy of IWC retrieved from radar alone and together with other measurements are now essential. A forward model employing aircraft Lagrangian spiral descents through mid- and low-latitude ice clouds is used to estimate profiles of what a lidar and conventional and Doppler radar would sense. Radar reflectivity Ze and Doppler fall speed at multiple wavelengths and extinction in visible wavelengths were derived from particle size distributions and shape data, constrained by IWC that were measured directly in most instances. These data were provided to eight teams that together cover 10 retrieval methods. Almost 3400 vertically distributed points from 19 clouds were used. Approximate cloud optical depths ranged from below 1 to more than 50. The teams returned retrieval IWC profiles that were evaluated in seven different ways to identify the amount and sources of errors. The mean (median) ratio of the retrieved-to-measured IWC was 1.15 (1.03) ± 0.66 for all teams, 1.08 (1.00) ± 0.60 for those employing a lidar–radar approach, and 1.27 (1.12) ± 0.78 for the standard CloudSat radar–visible optical depth algorithm for Ze > -28 dBZe. The ratios for the groups employing the lidar–radar approach and the radar–visible optical depth algorithm may be lower by as much as 25% because of uncertainties in the extinction in small ice particles provided to the groups. Retrievals from future spaceborne radar using reflectivity–Doppler fall speeds show considerable promise. A lidar–radar approach, as applied to measurements from CALIPSO and CloudSat, is useful only in a narrow range of ice water paths (IWP) (40 < IWP < 100 g m-2). Because of the use of the Rayleigh approximation at high reflectivities in some of the algorithms and differences in the way nonspherical particles and Mie effects are considered, IWC retrievals in regions of radar reflectivity at 94 GHz exceeding about 5 dBZe are subject to uncertainties of ±50%.

Schmitt, C. G., A. J. Heymsfield, 2007: On the occurrence of hollow bullet rosette- and column-shaped ice crystals in midlatitude cirrus. J. Atmos. Sci., 64, 4514-4519, doi: 10.1175/2007JAS2317.1.1

ABSTRACT

Cirrus clouds in mid- and high latitudes are frequently composed of bullet rosette– and column-shaped ice crystals, which can have hollow ends. Bullet rosette–shaped ice crystals are composed of a number of bullets radiating from a central point. Research has shown that the light-scattering properties of ice particles with hollow ends are different from the scattering properties of solid ice particles. Knowledge of the frequency of occurrence of hollow particles is important to more accurately calculate the radiative properties of cirrus clouds.

This note presents the results of a survey of cirrus cloud ice crystal replicas imaged from balloon-borne Formvar (polyvinyl formal) replicators. Fifty percent to 80% of the replicated bullet rosette– and column-shaped particles had hollow ends. In bullets longer than 150 μm in length, the length of the hollows of the bullets averaged 88% of the total length of the bullet. The combined length of both hollow portions of column-shaped ice crystals varied from 50% of the length of the column for 30-μm-long columns to 80% of the length of the columns longer than 200 μm. Asymmetry parameter values estimated from cirrus cloud aircraft particle size distributions are higher by 0.014 when hollow crystals are considered. This difference leads to a 2.5 W m-2 increase for hollow crystals at the surface for a 0.5 optical depth cloud, demonstrating the importance of the incorporation of hollow particle scattering characteristics into radiative transfer calculations.

Field, P. R., A. J. Heymsfield, A. Bansemer, 2007: Snow size distribution parameterization for midlatitude and tropical ice clouds. J. Atmos. Sci., 64, 4346-4365, doi: 10.1175/2007JAs2344.1

ABSTRACT

Many microphysical process rates involving snow are proportional to moments of the snow particle size distribution (PSD), and in this study a moment estimation parameterization applicable to both midlatitude and tropical ice clouds is proposed. To this end aircraft snow PSD data were analyzed from tropical anvils [Tropical Rainfall Measuring Mission/Kwajelein Experiment (TRMM/KWAJEX), Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE)] and midlatitude stratiform cloud [First International Satellite Cloud Climatology Project Research Experiment (FIRE), Atmospheric Radiation Measurement Program (ARM)]. For half of the dataset, moments of the PSDs are computed and a parameterization is generated for estimating other PSD moments when the second moment (proportional to the ice water content when particle mass is proportional to size squared) and temperature are known. Subsequently the parameterization was tested with the other half of the dataset to facilitate an independent comparison. The parameterization for estimating moments can be applied to midlatitude or tropical clouds without requiring prior knowledge of the regime of interest. Rescaling of the tropical and midlatitude size distributions is presented along with fits to allow the user to recreate realistic PSDs given estimates of ice water content and temperature. The effects of using different time averaging were investigated and were found not to be adverse. Finally, the merits of a single-moment snow microphysics versus multimoment representations are discussed, and speculation on the physical differences between the rescaled size distributions from the Tropics and midlatitudes is presented.

Heymsfield, A. J., 2007: On measurements of small ice particles in clouds. Geophys. Res. Lett., 34, L23812, doi: 10.1029/2007GL030951.1

Abstract

For many years it has been recognized that some aircraft cloud microphysical measurements may be contaminated by ice hydrometeors shattering on probe inlets. Small ice particle concentrations measured by the forward scattering spectrometer probe (FSSP) have been commonly accepted but are especially liable to overestimates. This study investigates this result for two additional airborne microphysical sensors, the cloud and aerosol spectrometer (CAS) and the cloud integrating nephelometer (CIN). The results indicate that conclusions from previous studies of the radiative effects of small ice particles need to be reevaluated. A model has been developed describing probe responses to different combinations of ice water content (IWC) and large ice particle concentrations that may be useful in identifying areas where contributions from small particles are significant.

McFarquhar, G. M., G. Zhang, M. R. Poellot, G. L. Kok, R. McCoy, T. Tooman, A. Fridlind, A. J. Heymsfield, 2007: Ice properties of single-layer stratocumulus during the Mixed-Phase Arctic Cloud Experiment: 1 Observations. J. Geophys. Res., 112, D24201, doi: 10.1029/2007JD008633.4

Abstract

During the Department of Energy's Atmospheric Radiation Measurement Program's Mixed-Phase Arctic Cloud Experiment (M-PACE) in fall 2004, the University of North Dakota Citation measured 53 profiles within single-layer stratus clouds by executing spiral ascents and descents over Barrow and Oliktok Point, Alaska, and by flying ramped ascents and descents between. Cloud phase was identified from an algorithm that uses voltage change from the Rosemount ice detector, the size distribution (SD) shape measured by the Forward Scattering Spectrometer Probe (FSSP), and manual identification of particles imaged by the Cloud Particle Imager, the two-dimensional cloud probe (2DC) and the high-volume precipitation sampler (HVPS). Size and mass distribution functions were derived using data from the FSSP, one-dimensional cloud probe, 2DC and HVPS in conjunction with total water content (TWC) measured by the Counterflow Virtual Impactor. With clouds defined as locations where TWC > 0.001 g m-3, there were a total of 513 30-s averaged SDs in single-layer clouds, of which 71% were in mixed-phase parcels, 23% in ice-phase and 6% in liquid-phase. The mixed-phase parcels were dominated by contributions from liquid drops, with the liquid mass fraction fl having averages and standard deviations of 0.89 ± 0.18 with 75% of cases having fl > 0.9. For these single-layer clouds, fl increased with normalized cloud altitude zn, defined as linearly increasing from 0 at cloud base to 1 at cloud top with fl averaging 0.96 ± 0.13 near zn = 1 and 0.70 ± 0.30 near zn = 0. The effective radius of water droplets rew increased with zn, from an average of 6.9 ± 1.8 μm near zn = 0 to 11.4 ± 2.4 μm near zn = 1, whereas the effective radius of ice crystals rei (25.2 ± 3.9 μm) was nearly independent of zn. The averaged cloud droplet number concentration and concentrations of ice crystals with maximum dimensions greater than 53 μm were 43.6 ± 30.5 × 103 L-1 and 2.8 ± 6.9 L-1, respectively, and nearly independent of zn. In contrast to past measurements in mixed-phase clouds combined from many geographical locations where fl increased with temperature, fl decreased from -12° to -3°C as clouds typically consisted of a liquid topped layer with precipitating ice below.

Fridlind, A. M., A. S. Ackerman, G. M. McFarquhar, G. Zhang, M. R. Poellot, P. J. DeMott, A. J. Prenni, A. J. Heymsfield, 2007: Ice properties of single-layer stratocumulus during the Mixed-Phase Arctic Cloud Experiment: 2 Model results. J. Geophys. Res., 112, D24202, doi: 10.1029/2007JD008646.4

Abstract

Measurements from the US Department of Energy Atmospheric Radiation Measurement Program's 2004 Mixed-Phase Arctic Cloud Experiment (M-PACE) provide a unique opportunity to study poorly understood ice formation processes in mixed-phase stratocumulus. Using meteorological, aerosol, and ice nucleus measurements to initialize large-eddy simulations with size-resolved microphysics, we compare predicted liquid and ice mass, number, and size distribution with observations from a typical flight. We find that ambient ice nuclei appear insufficient by a few orders of magnitude to explain observed ice, consistent with past literature. We also find that two processes previously hypothesized to explain the discrepancy, shatter of freezing drops and fragmentation during ice-ice collisions, were not significant sources of ice based on parameterizations from existing studies. After surveying other mechanisms that have been hypothesized to explain ice formation in mixed-phase clouds generally, we find two that may be strong enough: (1) formation of ice nuclei from drop evaporation residuals, a process suggested by sparse and limited measurements to date, and (2) drop freezing during evaporation, a process suggested only by inference at this time. The first mechanism can better explain the persistence of mixed-phase conditions in simulations of less vigorous stratus observed during the Beaufort Arctic Storms Experiment (BASE). We consider conditions under which emission of nuclei from the ocean surface or activation through cloud-phase chemistry could provide alternative explanations for M-PACE observations. Additional process-oriented measurements are suggested to distinguish among ice formation mechanisms in future field studies.

Delanoe, J., A. Protat, D. Bouniol, A. J. Heymsfield, A. Bansemer, P. Brown, 2007: The characterization of ice cloud properties from Doppler radar measurements. J. Appl. Meteor. Climat., 46, 1682-1698, doi: 10.1175/JAM2543.1.4

ABSTRACT

The paper describes an original method that is complementary to the radar–lidar algorithm method to characterize ice cloud properties. The method makes use of two measurements from a Doppler cloud radar (35 or 95 GHz), namely, the radar reflectivity and the Doppler velocity, to recover the effective radius of crystals, the terminal fall velocity of hydrometeors, the ice water content, and the visible extinction from which the optical depth can be estimated. This radar method relies on the concept of scaling the ice particle size distribution. An error analysis using an extensive in situ airborne microphysical database shows that the expected errors on ice water content and extinction are around 30%–40% and 60%, respectively, including both a calibration error and a bias on the terminal fall velocity of the particles, which all translate into errors in the retrieval of the density–diameter and area–diameter relationships. Comparisons with the radar–lidar method in areas sampled by the two instruments also demonstrate the accuracy of this new method for retrieval of the cloud properties, with a roughly unbiased estimate of all cloud properties with respect to the radar–lidar method. This method is being systematically applied to the cloud radar measurements collected over the three-instrumented sites of the European Cloudnet project to validate the representation of ice clouds in numerical weather prediction models and to build a cloud climatology.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

NCAR is sponsored by the National Science Foundation.

ANDREW HEYMSFIELD

General Information

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Research Focus FY08:

ICE-L Researchers in front of the NSF/NCAR C-130, November - December 2007.
High resolution figure

Andy's Wave Cloud.
High resolution figure

I led the Ice in Clouds-Layer Experiment (ICE-L) in November and December, 2007 and was the scientist onboard the C130 for sixty of the seventy research and test flight hours. In that capacity, I organized and ran the daily planning meetings and directed the C130 to locations and clouds amenable to wave clouds. We had thirteen research flights and six of them are exceptionally valuable for studying ice formation processes and quantifying ice nuclei and ice crystal concentrations. We worked closely with modelers who used WRF and to model probable wave cloud locations, heights and vertical motion fields. The combination of the upward-looking lidar and the upward and downward looking cloud Doppler radar provide an unprecedented view of ice formation locations and streamlines. We had eight different probe measuring droplets, drops, and small ice.

I continue to uncover major errors in earlier observations from instruments that measure or sense ice particle size distributions. I developed analytic relationships--a set of four equations--to quantify the shattering signal. From these relations, I can duplicate many earlier observations of particle size distributions in ice clouds. More importantly, these relations allow me to subtract out the shattering component to find where small ice particles actually are occurring. I can now identify regions of homogeneous ice nucleation and mixed-phase cloud. I submitted an article to {*Geophys. Res. Ltrs.*}, reporting on this work. The article was published in December.

I extended this work to the workhorse of particle probes, the 2D-C. The 2D-C sizes particle from about 50 microns to several mm. More than a half-dozen articles have shown from spiral descent through ice clouds that the slopes of snow size distributions decrease to a value of about 9 per cm and then remaining there. Several theoretical arguments have been proposed to explain this finding. In the article I submitted, I show that the result is an artifact due to ice shattering on the 2D-C's leading edge.

I assembled a group of investigators to describe the current state of knowledge of the microphysical processes and properties of contrails, how they morph into contrail cirrus, the long-term effects of aviation-produced carbon aerosols, and how contrail microphysics is represented in climate models. The study also suggested what can be done in the next several years to improve the representation of contrails in climate models and what is still needed but currently unavailable to reduce the current uncertainty in the radiative impacts of contrails.

I received funding this year from NASA for a three-year effort to improve the representation of ice microphysics in climate models. As part of this effort, I found an interesting feature in CloudSat observations. The hope is that CloudSat will be able to derive snow precipitation rates in region of cloud above the melting layer from radar reflectivity. What I found was that CloudSat (94 GHz) cannot reliably determine these rates because of an interesting feature that is related to Mie scattering. The larger particles in the first 1 km or so above the melting layer actually reduce the reflectivity below the values measure above them because of their interference of the radar signal because the particle size is comparable or larger than the radar wavelength. This feature can produce a factor of up to four underestimate in the precipitation rate. I studied the process from a theoretical standpoint and developed theoretical/analytic methods to correct for it.

Community Service FY08:

- Editor: Journal of Atmospheric Sciences
- CloudSat Science Team, NASA
- Graduate Advisor: Carl Schmitt, University of Colorado
- Graduate Advisor: Aaron Pratt, Howard Univeristy, Washington D.C.
- Graduate Advisor: Udaya Bhaskar, Massachusetts Institute of Technology, Boston, MA
- Graduate Advisor: Norm Wood, Colorado State University, Fort Collins, CO
- Thesis Committee: Matt Shupe, University of Colorado
- Thesis Committee: Sean Davis, University of Colorado

Scientific Talks FY08:

- Ice formation in clouds at temperatures from -10 to -30C (Cancun, Mexico, July 2008)
- Ice Cloud Properies (Leeds, UK, June 2008)
- Aerosols and Clouds (Utrecht, Netherlands, April 2008)
- The ICE-L field program: measurements and results (Manchester, UK, June 2008)
- Ice Formation thru heterogeneous nucleation (Vienna, Austria, April 2008)
- Contrail microphysics (Virginia Beach, VA February 2008)
- In-situ/radar observations from TC4 (Virginia Beach, VA February 2008)
- Ice Cloud Properties (Stockholm, Sweden, September 2008)

Publications FY08 (abstracts):

Twohy, C., S. M. Kreidenweis, T. Eidhammer, E. V. Browell, A. J. Heymsfield, A. Bansemer, B. E. Anderson, G. Chen, S. Ismail, P. J. Demott, S. C. Van Den Heever, 2008: Saharan dust particles nucleate droplets in eastern Atlantic clouds. *Geophys. Res. Lett.*. (Submitted)

Heymsfield, A. J., P. Field, A. Bansemer, 2008: Explaining the lower limit to slopes of ice particle size distributions. *J. Atmos. Sci.*. (In Press)

Hong, G., P. Yang, B. A. Baum, A. J. Heymsfield, F. Weng, Q. Liu, 2008: Scattering database in the millimeter and submillimeter wave range of 100-1000 GHz for nonspherical ice crystals. *J. Geophys. Res.*. (In Press)

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McFarquhar, G. M., G. Zhang, M. R. Poellot, G. L. Kok, R. McCoy, T. Tooman, A. Fridlind, A. J. Heymsfield, 2007: Ice properties of single-layer stratocumulus during the Mixed-Phase Arctic Cloud Experiment: 1 Observations. *J. Geophys. Res.*, **112**, D24201, doi: 10.1029/2007JD008633.

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Andrew Heymsfield Research

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. KATHY HIBBARD

Summary of achievements

Kathy Hibbard

Primary activities have included collaboration between AIMES and the WCRP's Working Group on Coupled Models (WGCM) towards next generation climate change experiments, both long term (to 2100 and beyond) as well as decadal prediction. Communication between Earth system and integrated assessment modeling as well as impacts, adaptation and vulnerability communities have resulted in a comprehensive, extensively reviewed report on the development of New Scenarios that was accepted by IPCC's XXVIIIth Plenary Session. It is anticipated that four representative concentration pathways as produced by revised SRES scenarios developed by the Integrated Assessment Modeling Consortium (IAMC) will be used as forcing for the climate modeling communities for a 5th IPCC Assessment Report. Parallel activities utilizing climate and Earth system model output will be used towards the development of New Scenarios for a possible 6th IPCC Assessment Report. In addition, AIMES has collaborated with WGCM and the IAMC as well as other international global change projects towards the development of a consistent data system for historical through to present and future and use/land cover and emissions. AIMES has also moved forward in developing communicative bridges between the social and natural sciences as well as humanities for the IHOPE project through an integrative panel held at the Resilience 2008 Conference held at the Stockholm Resilience Centre in Sweden. Finally, AIMES collaborated with the Past Global Changes (PAGES) project on a Young Scholar's Network meeting held at NCAR in July on Cultural Use and Impacts of Fire: Past, Present and Future.

Publications

Costanza, R., L. J Graumlich, W. Steffen, C. Crumley, J. Dearing, , K. Hibbard, R. Leemans, C. Redman, and D. Schimel, 2007: Sustainability or collapse: What can we learn from integrating the history of humans and the rest of nature?, Ambio, 36[7],522-517.

Abstract: Understanding the history of how humans have interacted with the rest of nature can help clarify the options for managing our increasingly interconnected global system. Simple, deterministic relationships between environmental stress and social change are inadequate. Extreme drought, for instance, triggered both social collapse and ingenious management of water through irrigation. Human responses to change, in turn, feed into climate and ecological systems, producing a complex web of multidirectional connections in time and space. Integrated records of the co-evolving human-environment system over millennia are needed to provide a basis for a deeper understanding of the present and for forecasting the future. This requires the major task of assembling and integrating regional and global historical, archaeological, and paleoenvironmental records. Humans cannot predict the future. But, if we can adequately understand the past, we can use that understanding to influence our decisions and to create a better, more sustainable and desirable future.

Figure caption: Selected indicators of environmental and human history.

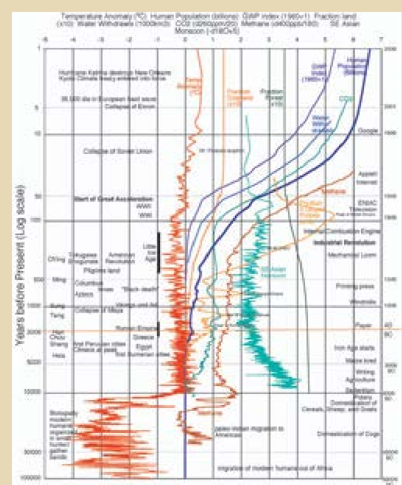

Figure 1.

High resolution figure

Hibbard, K.A., Meehl, G., Cox, P., and P. Friedlingstein. 2007: A strategy for climate change stabilization experiments., EOS 88(20):217,219,221.

Abstract: Climate models used for climate change projections are on the threshold of including much greater biological and chemical detail than previous models. Today, standard climate models (referred to generically as atmosphere-ocean general circulation models, or AOGCMs) include components that simulate

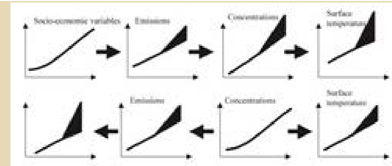

Figure 2.

High resolution figure

the coupled atmosphere, ocean, land, and sea ice. Some modeling centers are now incorporating carbon cycle models into AOGCMs in a move toward an Earth system model (ESM) capability. Additional candidate components to include in ESMs are aerosols, chemistry, ice sheets, and dynamic vegetation. In this article, we discuss a new strategy for using climate system models as part of a coupled biophysical-climate and integrated model assessment approach. The motivation is to develop a next-generation experimental design that follows on the scenario approach where concentrations and their derived emissions based on story lines were used in the development of the Intergovernmental Panel on Climate Change (IPCC) third and fourth assessment reports. We specifically address recent developments in climate system models that can shed light on greenhouse emissions scenarios. Complementary aspects of ongoing model development (e.g., observations and paleoclimate experiments) are important components of a much larger research strategy of which the modeling approach proposed here is one part.

Figure caption: (top) Traditional progression of derived emissions to climate system response starting from socioeconomic variables, emissions, concentrations, and climate change. (bottom) New strategy starts with benchmark concentration scenarios from IPCC WGIII scientists to modeling groups, from which emissions are calculated, and supplied to WGIII scientists to derive socioeconomic variables consistent with emissions stabilization pathways. The climate system response is still generated from concentrations (arrow from concentrations to temperature). This figure was revised and improved upon in the Moss et al. 2008 publication (below).

Moss T., M. Babiker, S. Brinkman, E. Calvo, T. Carter, J. Edmonds, I. Elgizouli, S. Emori, L. Erda, K. Hibbard, R. Jones, M. Kainuma, J. Kelleher, J-F. Lamarque, M. Manning, B. Matthews, G. Meehl, L. Meyer, J. Mitchell, N. Nakic'enovic', B. O'Neill, T. Pichs, K. Riahi, S. Rose, P. Runci, R. Stouffer, D. van Vuuren, J. Weyant, T. Wilbanks, J. P. van Ypersele, and M. Zurek, 2008: Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies., Intergovernmental Panel on Climate Change, Geneva, 132 pp.

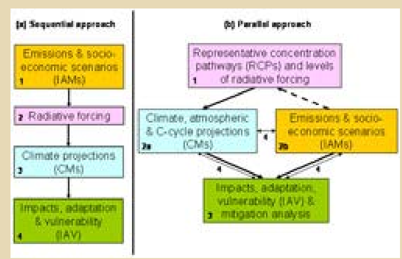

Figure 3.

High resolution figure

Abstract: Scenarios of potential future anthropogenic climate change, underlying driving forces, and response options have always been an important component of the work of the Intergovernmental Panel on Climate Change (IPCC). In the past, the IPCC coordinated the process of developing scenarios for its assessments. During its 25th session (Mauritius, 26-28 April 2006), the IPCC decided that rather than directly coordinating and approving new scenarios itself, the process of scenario development should now be coordinated by the research community. The IPCC would seek to "catalyze" the timely production by others of new scenarios for a possible Fifth Assessment Report (AR5) by convening an expert meeting to consider the scientific community's plans for developing new scenarios, and to identify a set of "benchmark emissions scenarios" (now referred to in this report as "Representative Concentration Pathways—RCPs" —for reasons discussed in Section I.2). The RCPs will be used to initiate climate model simulations for developing climate scenarios for use in a broad range of climate-change related research and assessment and were requested to be "compatible with the full range of stabilization, mitigation and baseline emissions scenarios available in the current scientific literature." The expert meeting was held on 19-21 September 2007 in Noordwijkerhout, The Netherlands. The meeting brought together over 130 participants, including users of scenarios and representatives of the principal research communities involved in scenario development and application. The representatives of the scenario user community included officials from national governments, including many participating in the United Nations Framework Convention on Climate Change (UNFCCC), international organizations, multilateral lending institutions, and nongovernmental organizations (NGOs). The principal research communities represented at the expert meeting were the integrated assessment modeling (IAM) community; the impacts, adaptation, and vulnerability (IAV) community; and the climate modeling (CM) community. Because of this broad participation, the meeting provided an opportunity for the segments of the research community involved in scenario development and application to discuss their respective requirements and coordinate the planning process. This summary provides an overview of a new parallel process for scenario development and the RCPs discussed and refined at the expert meeting. It briefly reviews recommendations for institutional developments and increased participation of experts and users from developing countries and countries with an economy in transition that would further strengthen the process.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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ELISABETH HOLLAND

General Information

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Senior Scientist
BGS - BEACHON

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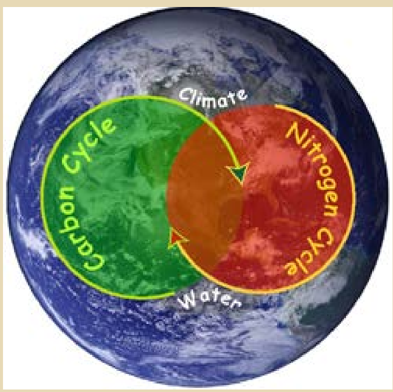


The overarching BGS goal is to model the biogeochemical cycles within the Earth system consistent with analyses of observations. This synergy between observations and models to understand and integrate biogeochemical cycles across scales is a core value of the BGS program and the broader NCAR effort. *Figure by James Sultzman*

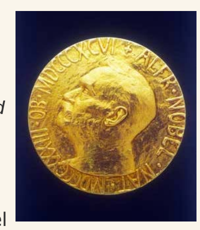
High resolution figure

Elisabeth Holland leads the Biogeoscience Program (BGS) and is a lead scientist in the Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, H2O, Organics & Nitrogen (BEACHON) project.

The Role of the Nitrogen Cycle in the Climate System: Scientists are stepping up research on the role of nitrogen in the climate system, and they are beginning to incorporate the nitrogen cycle in computer models. This talk will preview new directions in nitrogen research. Nitrogen has a direct impact on climate change, because it both affects the ability of plants to absorb carbon dioxide from the atmosphere and influences atmospheric methane concentrations. Nitrogen also has implications for air quality because nitric oxide is a necessary precursor for ozone formation.

Nitrogen in the Earth System (UCAR) Includes: Nitrogen Cycle; Human activities and the nitrogen cycle; Harmful effects of nitrogen deposition.

In The News:



Nobel Peace Prize 2007: *IPCC Shares Nobel Peace Prize with Al Gore* (11 October 2007) - Guy Brasseur, William Collins, Elisabeth Holland, Reto Knutti, Linda Mearns, Gerald Meehl, Kevin Trenberth, additional NCAR authors: *"for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."* IPCC Shares Nobel Peace Prize with Al Gore Congratulations to the United Nation's Intergovernmental Panel on Climate Change (IPCC) and Al Gore on their Nobel Peace Prize award. Since 1990, the IPCC has issued four reports highlighting the growing understanding of the climate change issue. Scientists both at NCAR and within our wider research community contributed significantly to these reports. Published this year, the IPCC's Fourth Assessment Report leverages computer modeling that depicts global climate with unprecedented detail. Through support of the U.S. Department of Energy and the National Science Foundation's supercomputing centers, and partnership with Japan's Central Research Institute of Electric Power Industry, the NCAR-based Parallel Climate Model and Community Climate System Model provided a wealth of scientific data to the IPCC report. Related: Article by the Associated Press, Thousands of Scientists Share Nobel....more

Nobel Peace Prize Press Release

Working Group I: Summary | NCAR Scientiests & biographies who made major contributions

Working Group II: Summary | NCAR Scientiests & biographies who made major contributions

General Information: Understanding Climate Change (UCAR)

A few of the many other press coverage links:
- Standing on the Shoulders of Giants (Women's Magazine Online by Erin Love 8 March

2008)
- Holland lead author in IPCC fourth assessment (Aldo Leopold Leadership Program 2 February 2008)
- Gore says prize must spur action (BBC News, 13 October 2007)
- Gore Shares Peace Prize for Climate Change Work (New York Times, 13 October 2007)
- Gore and U.N. Panel Share Peace Prize (Washingtonpoast.com, 13 October 2007)
- Gore shares Nobel Peace Prize with U.N. panel (CNN.com, 12 October 2007)
- Gore and UN panel win Nobel prize (BBC News, 12 October 2007)
- Boulder's IPCC lead authors (Daily Camera, 13 October 2007)
- Local scientists part of Nobel-winning effort (Daily Camera by Laura Snider, 12 October 2007)
- NCAR Scientists & Technical Staff Share in Nobel Peace Prize with IPCC Colleagues Around the World (NCAR News Release, 11 October 2007)
- Colorado Scientists share in Nobel Prize (Rocky Mountain News, 13 October 2007)
- Boulder's IPCC lead authors (Daily Camera 13 October 2007)
- Local scientists part of Nobel-winning effort (Daily Camera by Laura Snider 12 October 2007)

Study looks at transportation's effects on global warming (USA Today by Doyle Rice - 9 January 2008 - article) Elisabeth Holland, a senior scientist at the National Center for Atmospheric Research in Boulder, who was not part of the study, was impressed with the research: "This is a comprehensive study," she says, "that takes a careful look at how all the emissions from the transport sector are handled." ...more

Diversity Work:

Standing Committee on Women in Science (SCWS): In support of the NSF strategic plan, NCAR is committed to expanding efforts to broaden participation from underrepresented groups and diverse institutions in all NCAR activities and to increase the diversity of our workforce. Elisabeth Holland was appointed the first Chair of the SCWS.

Planning for Seven Generations: Indigenous & Scientific Approaches to Climate Change (March 2008, conference website). News Articles & Press Releases:
- UCAR Press Release
- Indigenous insight (by Bob Henson)
- Native Americans, Scientists To Discuss Climate Change at Landmark Symposium (Newswise - 6 March 2008)
- Native Americans, scientists to discuss climate change at landmark symposium (Eurekalert.org by David Hosansky - 6 March 2008)
- Climate Change Threatens Native Livelihoods (NPR by Kirk Siegler - 25 March 2008)
- Bridging divides at climate change symposium (Indian Country Today by Carol Berry - 31 March 2008)

Community Service FY08:

- Session Co-chair, American American Geophysical Union, Special Session, San Francisco, California, December, 2007
- Advisory Board (2002-2007) - Commission on Atmospheric Chemistry and Global Pollution
- Advisory Board (2005-2009) - International Advisory Board, Quantifying and Understanding the Earth System (QUEST), Natural Environment Research Council, UK
- Affiliate Professor - Forest, Rangeland & Watershed Stewardship Dept, Colorado State University, Fort Collins, CO
- Affiliate Research Professor - Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO
- Chair steering committee - American Meteorological Society's Committee on Atmospheric Biogeoscience, American Meteorological Society (AMS)
- Graduate Faculty, Environmental Population Organismic Biology, University of Colorado, Boulder, CO
- National Research Council Committee for the Board on Atmospheric Sciences, “Strategic Guidance for NSF’s Support of the Atmospheric Sciences”, 2004-2007

Scientific Talks FY08:

- Our Changing Climate from IPCC Working Group 1: The Physical Science Basis - Keynote Speaker: Planning for Seven Generations: Indigenous & Scientific Approaches to Climate Change (March 2008) webcast

Publications FY08:

Lara, L.L.S, E.A. Holland, P. Artaxo, P.B. Camargo, and L.A. Martinelli, 2008: Land use and expanding industrialization are changing nitrogen deposition in Brazil. Biogeochemistry, in press.

Elisabeth Holland Research

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GREG HOLLAND

2008 Publications

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. Mon. Wea. Rev., 136, 1990-2005, doi: 10.1175/2007MWR2085.1.

Abstract

Real-time forecasts of five landfalling Atlantic hurricanes during 2005 using the Advanced Research Weather Research and Forecasting (WRF) (ARW) Model at grid spacings of 12 and 4 km revealed performance generally competitive with, and occasionally superior to, other operational forecasts for storm position and intensity. Recurring errors include 1) excessive intensification prior to landfall, 2) insufficient momentum exchange with the surface, and 3) inability to capture rapid intensification when observed. To address these errors several augmentations of the basic community model have been designed and tested as part of what is termed the Advanced Hurricane WRF (AHW) model. Based on sensitivity simulations of Katrina, the inner-core structure, particularly the size of the eye, was found to be sensitive to model resolution and surface momentum exchange. The forecast of rapid intensification and the structure of convective bands in Katrina were not significantly improved until the grid spacing approached 1 km. Coupling the atmospheric model to a columnar, mixed layer ocean model eliminated much of the erroneous intensification of Katrina prior to landfall noted in the real-time forecast.

Gutowski, W., G. Hegerl, G. J. Holland, T. Knutson, L. O. Mearns, R. Stouffer, P. Webster, F. Zwiers, 2008: How well do we understand the causes of observed changes in extremes, and what are the projected future changes? Weather and Climate Extremes in a Changing Climate, CCSP Synthesis and Assessment Product 3.3, Karl, T et al., Eds., NOAA, 81-116.

Abstract

Attribution of Observed Changes

Changes in some weather and climate extremes are attributable to human-induced emissions ofgreenhouse gases.

- Human-induced warming has likely caused much of the average temperature increase • in North America over the past 50 years. This affects changes in temperature extremes.
- Heavy precipitation events averaged over North America have increased over the past 50 years, consistent with the observed increases in atmospheric water vapor, which have been associated with human-induced increases in greenhouse gases.
- It is very likely that the human-induced increase in greenhouse gases has contributed to the increase in sea surface temperatures in the hurricane formation regions. Over the past 50 years there has been a strong statistical connection between tropical Atlantic sea surface temperatures and Atlantic hurricane activity as measured by the Power Dissipation Index (which combines storm intensity, duration, and frequency). This evidence suggests a human contribution to recent hurricane activity. However, a confident assessment of human influence on hurricanes will require further studies using models and observations, with emphasis on distinguishing natural from human-induced changes in hurricane activity through their influence on factors such as historical sea surface temperatures, wind shear, and atmospheric vertical stability

Projected Changes

- Future changes in extreme temperatures will generally follow changes in average temperature:
  - Abnormally hot days and nights and heat waves are very likely to become more frequent.
  - Cold days and cold nights are very likely to become much less frequent.
  - The number of days with frost is very likely to decrease.
  - Droughts are likely to become more frequent and severe in some regions as higher air temperatures increase the potential for evaporation.
- Over most regions, precipitation is likely to be less frequent but more intense, and precipitation extremes are very likely to increase.

- For North Atlantic and North Pacific hurricanes and typhoons:
    - It is likely that hurricane/typhoon wind speeds and core rainfall rates will increase in response to human-caused warming. Analyses of model simulations suggest that for each 1°C increase in tropical sea surface temperatures, hurricane surface wind speeds will increase by 1 to 8% and core rainfall rates by 6 to 18%.
    - Frequency changes are currently too uncertain for confident projec-tions.
    - The spatial distribution of hurricanes/ t yphoons wi l l l ikel y change.
    - Storm surge levels are likely to increase due to projected sea level rise, though the degree of projected increase has not been adequately studied.
- There are likely to be more frequent deep low-pressure systems (strong storms) outside the tropics, with stronger winds and more extreme wave heights.

Holland, G. J., P. J. Webster, 2007: Heightened tropical cyclone activity in the North Atlantic: Natural variability or climate trend. Proc. Roy. Soc. A, 365, 2695-2716, doi: 10.1098/rsta.2007.2083.

Abstract

We find that long-period variations in tropical cyclone and hurricane frequency over the past century in the North Atlantic Ocean have occurred as three relatively stable regimes separated by sharp transitions. Each regime has seen 50% more cyclones and hurricanes than the previous regime and is associated with a distinct range of sea surface temperatures (SSTs) in the eastern Atlantic Ocean. Overall, there appears to have been a substantial 100-year trend leading to related increases of over 0.7°C in SST and over 100% in tropical cyclone and hurricane numbers. It is concluded that the overall trend in SSTs, and tropical cyclone and hurricane numbers is substantially influenced by greenhouse warming. Superimposed on the evolving tropical cyclone and hurricane climatology is a completely independent oscillation manifested in the proportions of tropical cyclones that become major and minor hurricanes. This characteristic has no distinguishable net trend and appears to be associated with concomitant variations in the proportion of equatorial and higher latitude hurricane developments, perhaps arising from internal oscillations of the climate system. The period of enhanced major hurricane activity during 1945–1964 is consistent with a peak period in major hurricane proportions.

Holland, G. J., 2007: Misuse of landfall as a proxy for Atlantic tropical cyclone activity. EOS Trans. Amer. Geophys. Union, 88, 349-350, doi: 10.1029/2007EO36001,2007.

Abstract

Recent studies [Solow and Moore, 2000; Landsea, 2007] have used an assumed constant ratio of landfalling cyclones to all tropical cyclones in the basin to assess potential trends and archive quality for basin-wide North Atlantic tropical cyclones. The underlying assumption is that landfalling storms have been well observed compared with storms over the ocean that do not make landfall. Thus, a trend toward decreasing ratios of landfalling storms is assumed to imply an increasing number of unobserved oceanic storms as we go back in time. The results from these studies depend entirely on the assumption that landfalling ratios are constant over long time periods; yet neither study addressed the veracity of this assumption.

MMM Research Catalog

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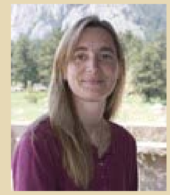
CGD 2008 PROFILES IN SCIENCE: DR. MARIKA HOLLAND

Summary of achievements

Marika Holland's research focuses on the role of the polar regions in the global climate system. In 2008, her work involved studies related to the simulation and projected changes in various aspects of the Arctic system. This included studies on the Arctic hydrological cycle; its depiction in global climate models and projected changes in response to rising atmospheric greenhouse gas concentrations. Work also focused on understanding the mechanisms of Arctic sea ice loss and the potential for abrupt reductions in the future summer Arctic ice cover. Additionally, Marika was involved in a number of studies that examined the influence of changing Arctic sea ice conditions for other aspects of the Arctic system, including permafrost and polar bear habitat loss.



Marika Holland

Publications

DeWeaver, E., E. Hunke, and M.M. Holland, 2008: Sensitivity of Arctic sea ice thickness to inter-model variations in surface energy budget simulation, AGU Monograph on "Arctic Sea Ice Decline", in press.

Abstract: Sea ice simulations from an ensemble of climate models show large differences in the mean thickness of perennial Arctic sea ice. To understand the large thickness spread, we assess the sensitivity of thickness to the ensemble spread of the surface energy budget. Inter-model thickness and energy flux variations are related through a diagnostic calculation of thickness from surface temperature and energy fluxes. The calculation shows that an ensemble range of 60 W m-2 in energy fluxes, as simulated by climate models, results in an approximate range of 1-5 m in ice thickness. The ensemble mean value of the melt season energy flux, together with a budget residual term that represents the effects of ocean heat exchange and ice divergence are the key factors that determine the range in ice thickness owing to the flux spread. The ensemble spread in summertime energy flux is strongly related to the spread in surface albedo, while differences in longwave radiative forcing, due in part to cloud simulation errors, play a smaller role.

Figure caption: (a) Mean September to April thickness for perennial Arctic gridpoints from model output (light shading) and from diagnostic calculation (dark shading), described in scetion 4.1. Model output is obtained from the Program for Climate Model Diagnosis and Intercomparison (PCMDI), and data is from run 1 of each model. (b) Asterisks: scatter of Sˆ (denominator in 4) and diagnostic thickness h_D from 20C3M model output. +: h_D calculated using the ensemble-mean value of the numerator in (4). Solid line: h_D as a continuous function of Sˆ using the ensemble-mean value of the numerator in (4).

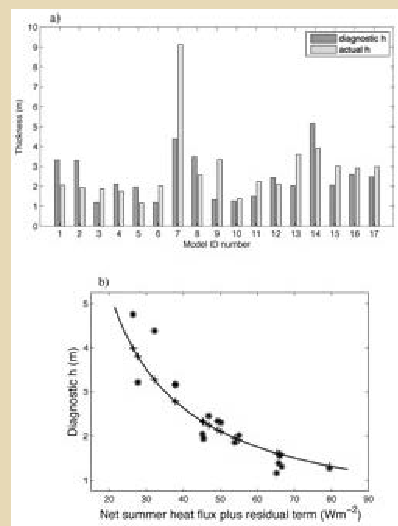


Figure 1.

High resolution figure

Durner, G.M., D.C. Douglas, R.M. Nielsen, S.C. Amstrup, T.L McDonald I. Stirling, M. Mauritzen, E.W. Born, O. Wiig, E. DeWeaver, M.C. Serreze S.E. Belikov, M.M. Holland, J. Maslanik, J. Aars, D.A. Bailey, and A.E. Derocher, 2008: Predicting 21st Century Polar Bear Habitat Distribution from Global Climate Models, Ecological Monographs, in press.

Abstract: Projections of polar bear (*Ursus maritimus*) sea ice habitat distribution in the polar basin during the 21st century were developed to understand the consequences of anticipated sea ice reductions on polar bear populations. We used location data from satellite-collared polar bears and environmental data (e.g., bathymetry, distance to coastlines, and sea ice) collected from 1985-1995 to build Resource Selection Functions (RSF). RSFs described habitats polar bears preferred in summer, autumn, winter and spring. When applied to independent data from 1996-2006, the RSFs consistently identified habitats most frequently used by polar bears. We applied the RSFs to monthly maps of 21st century sea ice concentration

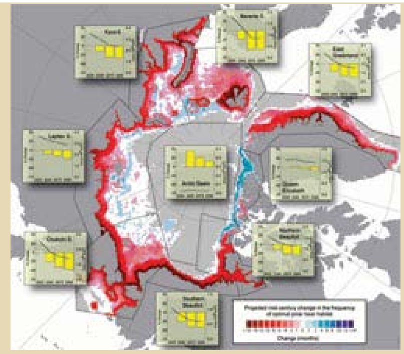


Figure 2.

High resolution figure

projected by 10 general circulation models (GCMs) used in the Intergovernmental Panel of Climate Change Fourth Assessment Report, under the A1B greenhouse-gas forcing scenario. Despite variation in their projections, all GCMs indicated habitat losses in the polar basin during the 21st century. Losses in the highest-valued RSF habitat (optimal habitat) were greatest in the southern seas of the polar basin, especially the Chukchi and Barents seas, and least along the Arctic Ocean shores of Banks Island to northern Greenland. Average loss of optimal polar bear habitat was greatest during summer; from an observed 1.0 million km^2 in 1985-1995 (baseline) to a projected multi-model average of 0.32 million km^2 in 2090-2099 (-68% change). Projected winter losses of polar bear habitat were less; from 1.7 million km^2 in 1985-1995 to 1.4 million km^2 in 2090-2099 (-17% change). Habitat losses based on GCM multi-model averages may be conservative; simulated rates of habitat loss during 1985-2006 from many GCMs were less than observed rates of loss. Although a reduction in the total amount of optimal habitat will likely reduce polar bear populations, exact relationships between habitat losses and population demographics remain unknown. Density and energetic effects may become important as polar bears make long distance annual migrations from traditional winter ranges to remnant high-latitude summer sea ice. These impacts will likely affect specific sex and age groups differently and may ultimately preclude bears from seasonally returning to their traditional ranges.

Figure caption: Projected changes (based on 10 IPCC AR-4 GCM models run with the SRES-A1B forcing scenario) in the spatial distribution and integrated annual area of optimal polar bear habitat. Base map shows the cumulative number of months per decade where optimal polar bear habitat was either lost (red) or gained (blue) from 2001-2010 to 2041-2050. Offshore gray shading denotes areas whre optimal habitat was absent in both periods. Insets show the average annual (∑ 12 months) cumulative area of optimal habitat (right y-axis, line plot) for four 10-year periods in the 21st century (x-axis midpoints), and their associated percent change in area (left y-axis, histograms) relative to the first decade (2001-2010).

Holland, M.M., C.M. Bitz, B. Tremblay, D.A. Bailey, 2008: The role of natural versus forced change in future rapid summer Arctic ice loss, AGU Monograph on "Arctic Sea Ice Decline", in press.

Abstract: Climate model simulations from the Community Climate System Model (CCSM3) suggest that Arctic sea ice could undergo rapid September ice retreat in the 21st century. A previous study indicated that this results from a thinning of sea ice to more vulnerable conditions, a "kick" in the form of pulse-like increases in ocean heat transport and positive feedbacks that accelerate the retreat. Here we further examine the factors affecting these events, including the role of natural versus forced change and the possibility of threshold-like behavior in the simulated sea ice cover. We find little indication that a critical sea ice state is reached that then leads to rapid ice loss. Instead our results suggest that the rapid ice loss events result from anthropogenic change reinforced by growing intrinsic variability. The natural variability in summer ice extent increases in the 21st century due to the thinning ice cover. As the ice thins, large regions can easily melt out resulting in considerable ice extent variations. The important role of natural variability in the simulated rapid ice loss is such that we find little capability for predicting these events based on a knowledge of prior ice and ocean conditions. This is supported by results from sensitivity simulations initialized several years prior to an event, which exhibit little predictive skill.

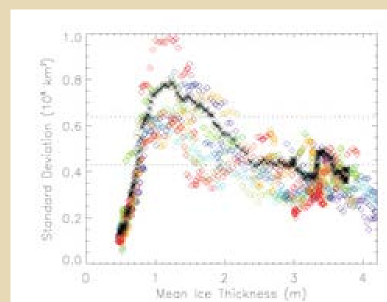


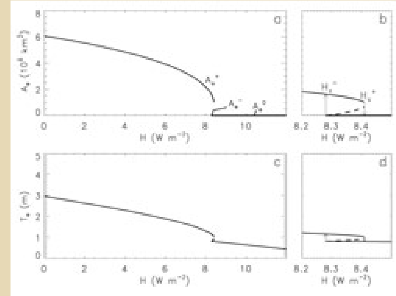
Figure 3.

High resolution figure

Figure caption: The standard deviation of the total Arctic September ice extent anomaly for running 20-year intervals versus the mean Arctic ice thickness from each 20-year interval. The September ice extent anomaly is computed as the September ice extent timeseries from each ensemble member minus the ensemble mean September ice extent. Each of the eight ensemble members is shown and is indicated by a different color. The black points show the standard deviation computed across all of the ensemble members for a running 20-year time period.

Merryfield, W.J., M.M. Holland, and A.H. Monahan, 2008: Multiple equilibria and abrupt transitions in Arctic summer sea ice extent, AGU Monograph on "Arctic Sea Ice Decline", in press.

Abstract: An application of bifurcation theory to the stability of Arctic sea ice cover is described. After reviewing past such efforts, a simple mathematical representation is developed of processes identified as contributing essentially to abrupt decreases in 21st century Arctic summer sea ice extent in climate model simulations of the Community Climate System Model, version 3 (CCSM3). The resulting nonlinear equations produce abrupt sea ice transitions resembling those



in CCSM3, and also plausibly represent further gross aspects of simulated Arctic sea ice evolution such as the accelerating decline in summer ice extent in the late 20th and early 21st centuries. The equations feature multiple equilibria in a physically relevant parameter regime. This enables abrupt changes to be triggered by infinitesimal changes in forcing in the vicinity of the bifurcation, or alternatively by finite perturbations some distance from the bifurcation, although numerical experiments suggest that abrupt transitions in CCSM3 may arise mainly from the increasing sensitivity of sea ice to fluctuations in ocean heat transport as ice thickness and extent diminish. A caveat is that behavior following a complete seasonal loss of ice cover is sensitive to aspects of the parameterization of ocean shortwave absorption.

Figure 4.

High resolution figure

Figure caption: (a) Equilibria A_e of September ice extent, for parameters representative of CCSM3, as a function of ocean heat transport H; (b) close-up of multiple equilibrium regime for A_e, showing hysteretic transitions at H^-_c and H^+_c (arrows); (c) Equilibria T_e of March ice thickness; (d) close-up of multiple equilibrium regime for T_e. Solid curves denote stable equilibria and dashed curves unstable equilibria.

DeWeaver, E.T., E.C. Hunke, and M.M. Holland, 2008: Comment on "On the reliability of simulated Arctic sea ice in global climate models" by I. Eisenmann, N. Untersteiner, and J.S. Wettlaufer, Geophys. Res. Lett., 35, L04501, doi:10.1029/2007GL031325.

Jochum, M., G. Danabasoglu, M. Holland, Y.-O. Kwon, and W. G. Large, 2008: Ocean viscosity and climate. J. Geophys. Res., 113, C06017, doi:10.1029/2007JC004515.

Abstract: The impacts of parameterized lateral ocean viscosity on climate are explored using three 120-year integrations of a fully coupled climate model. Reducing viscosity leads to a generally improved ocean circulation at the expense of increased numerical noise. Five domains are discussed in detail: the equatorial Pacific, where the emergence of tropical instability waves reduces the cold tongue bias; the Southern Ocean, where the Antarctic Circumpolar Current increases its kinetic energy but reduces its transport; the Arctic Ocean, where an improved representation of the Atlantic inflow leads to a better sea-ice distribution; the North Pacific, where the more realistic path of the Kuroshio leads to more realistic temperatures across the midlatitude Pacific; and the northern marginal seas, where stronger boundary currents lead to significantly less sea-ice. Although the ocean circulation and sea-ice distribution improve, the oceanic heat uptake, the poleward heat transport, and the large scale atmospheric circulation are not changed significantly. In particular, the improvements to the equatorial cold tongue did not lead to better representation of tropical precipitation or El Niño.

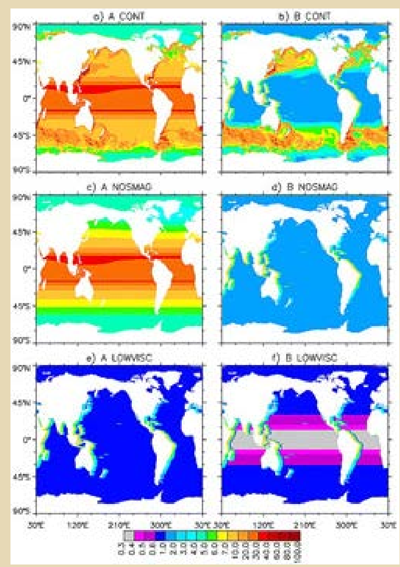


Figure caption: Anisotropic horizontal viscosity coefficients A and B at 100-m depth from (a-b) CONT, (c-d) NOSMAG, and (e-f) LOWVISC. Units are 1000 $m^2\ s^{-1}$. All panels use the same color scale.

Figure 5.

High resolution figure

Lawrence, D.M., A.G. Slater, R.A. Tomas, M.M. Holland, and C. Deser, 2008: Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. Geophys. Res. Lett., 35, L11506, doi:10.1029/2008GL033985.

Abstract: Rises in surface and lower troposphere air temperatures through the 21st century are projected to be especially pronounced over the Arctic Ocean during the cold season. This Arctic amplification is largely driven by loss of the sea ice cover, allowing for strong heat transfers from the ocean to the atmosphere. Consistent with observed reductions in sea ice extent, fields from the NCEP/NCAR reanalysis suggest emergence of surface-based Arctic amplification in the last decade.

Figure caption: (a) Composite anomaly time series of September sea ice extent (solid line) and OND T_{air} (dashed line) over Arctic land area (65°-80°N, 60°-300°E). Composites are formed by nine 31-yr anomaly time series. Each of the nine time series are centered about the mid-point of a CCSM3 rapid sea ice loss event (lag 0 years) and are anomalies from the lag -10 to -5 year mean. (b) Average monthly Arctic land air temperature trends during rapid sea ice loss periods and outside sea ice loss periods. Trend is statistically significant at the 90% (*) and 95% (**) levels. (c) Maps of air temperature trends for OND during and outside abrupt sea ice loss periods.

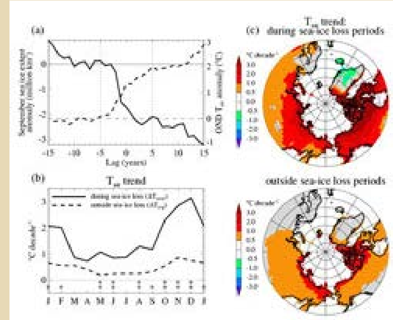


Figure 6.

High resolution figure

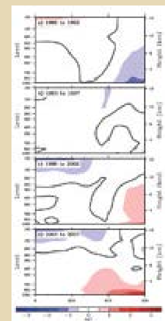
Serreze, M. C., A.P. Barrett, J.C. Stroeve, D.N. Kindig, and M.M. Holland, 2008: The emergence of surface-based Arctic amplification. The Cryosphere Discuss., 2, 601-622.

Abstract: Rises in surface and lower troposphere air temperatures through the 21st century are projected to be especially pronounced over the Arctic Ocean during the cold season. This Arctic amplification is largely driven by loss of the sea ice cover, allowing for strong heat transfers from the ocean to the atmosphere. Consistent with observed reductions in sea ice extent, fields from the NCEP/NCAR reanalysis suggest emergence of surface-based Arctic amplification in the last decade.

Figure caption: Latitude by height (hPa) cross sections of autumn (September through November) temperature anomalies relative to 1979-2007 means; a) 1988-1992, b) 1993-1997, c)1998-2002, d)2003-2007.

Figure 7.

High resolution figure



Stroeve, J., M. Serreze, S. Drobot, S. Gearhead, M. Holland, J. Maslanik, W. Meier, and T. Scambos, 2008: Arctic sea ice plummets in 2007. EOS, 89, 2, 13-14.

Abstract: Arctic sea ice declined rapidly to unprecedented low extents in the summer of 2007, raising concern that the Arctic may be on the verge of a fundamental transition toward a seasonal ice cover. Arctic sea ice extent typically attains a seasonal maximum in March and minimum in September. Over the course of the modern satellite record (1979 to present), sea ice extent has declined significantly in all months, with the decline being most pronounced in September. By mid-July 2007, it was clear that a new record low would be set during the summer of 2007.

Figure caption: Sea ice concentration for September 2007, along with median extent from 1953-2000 (red line), 1979-2000 (orange line) and mean extent for September 2005 (green line). September ice extent time-series from 1953-2007 is shown at the bottom.

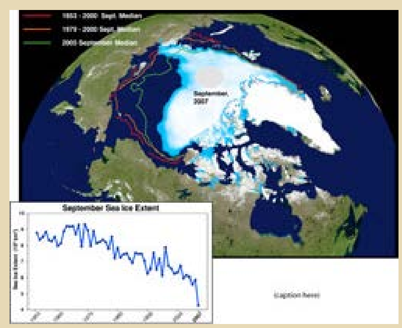
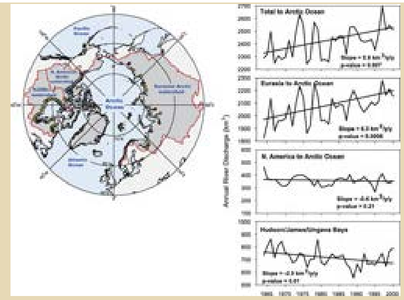


Figure 8.

High resolution figure

White, D., et al. 2007: The arctic freshwater system: Changes and impacts. J. Geophys. Res., 112, G04S54, doi:10.1029/2006JG000353.

Abstract: Dramatic changes have been observed in the Arctic over the last century. Many of these involve the storage and cycling of fresh water. On land, precipitation and river discharge, lake abundance and size, glacier area and volume, soil moisture, and a variety of permafrost characteristics have changed. In the ocean, sea ice thickness and areal coverage have decreased and water mass circulation patterns have shifted, changing freshwater pathways and sea ice cover dynamics. Precipitation onto the ocean surface has also changed. Such changes are expected to continue, and perhaps accelerate, in the coming century,



enhanced by complex feedbacks between the oceanic, atmospheric, and terrestrial freshwater systems. Change to the arctic freshwater system heralds changes for our global physical and ecological environment as well as human activities in the Arctic. In this paper we review observed changes in the arctic freshwater system over the last century in terrestrial, atmospheric, and oceanic systems.

Figure caption: Map showing watersheds of the Arctic Ocean and Hudson, James and Ungava Bays (HJUBs), with discharge trends for rivers draining these different watersheds shown in the accompanying graph. Colored dots on the map mark the mouths of the 72 rivers included in the analysis, with colors indicating discharge categories. Blue represents <6 $km^3 a^{-1}$, yellow represents 6-60 $km^3 a^{-1}$, and red represents 60-600 $km^3 a^{-1}$.

Figure 9.

High resolution figure

Finnis, J., M. M. Holland, M. C. Serreze, and J. J. Cassano, 2007: Response of Northern Hemisphere extratropical cyclone activity and associated precipitation to climate change, as represented by the Community Climate System Model. J. Geophys. Res., 112, G04S42, doi:10.1029/2006JG000286.

Abstract

The projected effects of rising CO_2 levels on Northern Hemisphere extratropical cyclone activity and cyclone-associated precipitation are examined for September-May, using output from version 3 of the Community Climate System Model (CCSM3). A cyclone identification algorithm was applied to a five member ensemble of CCSM3 20th and 21st century output, along with a method of isolating precipitation produced by each cyclone. Mean seasonal statistics describing cyclone activity and the character of associated precipitation were calculated over several study regions for 20 a periods. The dominant change in cyclone activity is a marked midlatitude decrease in frequency during autumn, winter, and spring. Few significant shifts in storm tracks or cyclone intensity were identified. Total daily precipitation from these events is found to increase into the 21st century, largely because of increases in available atmospheric moisture with rising temperatures. This thermodynamic increase in precipitation leads to large rises in total seasonal cyclone-associated precipitation over high latitudes, while over midlatitudes the thermodynamic increase is offset by the dynamic effect associated with decreased cyclone frequency.

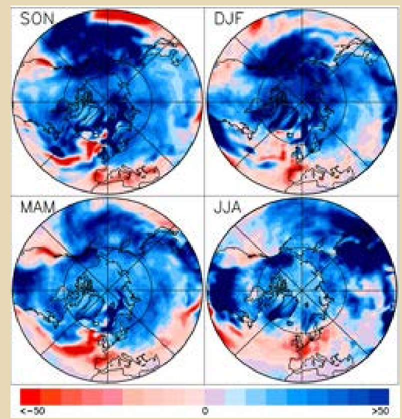


Figure caption: Change in total seasonal precipitation (mm), presented as the 20th century ensemble mean subtracted from 21st century ensemble mean.

Figure 10.

High resolution figure

Holland, M. M., J. Finnis, A. P. Barrett, and M. C. Serreze. 2007: Projected changes in Arctic Ocean freshwater budgets. J. Geophys. Res., 112, G04S55, doi:10.1029/2006JG000354.

Abstract

Arctic Ocean freshwater budgets are examined from 10 models participating in the Intergovernmental Panel on Climate Change Fourth Assessment Report. This includes an analysis of sea ice transport and storage, ocean transport and storage, and net surface flux exchange. Simulated budgets for the late 20th century are compared to available observations, followed by an analysis of simulated changes from 1950 to 2050. The consistent theme over this period is an acceleration of the Arctic hydrological cycle, which is expressed as an increase in the flux of water passing through the hydrologic elements. Increased freshwater inputs to the ocean from net precipitation, river runoff, and net ice melt result. While generally attended by a larger export of liquid freshwater to lower latitudes, primarily through Fram Strait, liquid freshwater storage in the Arctic Ocean increases. In contrast, the export and storage of freshwater in the form of sea ice decreases. The qualitative agreement between models for which the only common forcing is rising greenhouse gas concentrations implicates this greenhouse gas loading as the cause of the change. Although the models perform quite well in their simulations of net precipitation over the Arctic Ocean and terrestrial drainage, they differ significantly regarding the magnitude of the trends and their representation of contemporary mean ocean and sea ice budget terms. To reduce uncertainty in future projections of the Arctic freshwater cycle, the climate models as a group

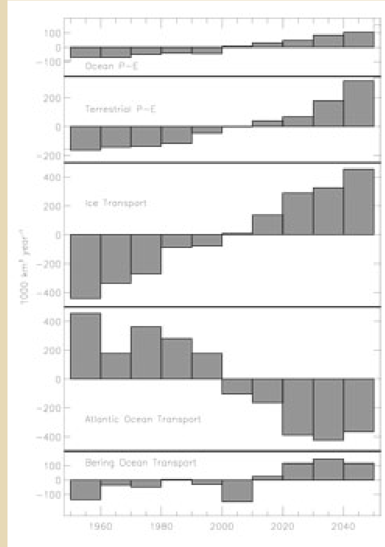


Figure 11.

High resolution figure

require considerable improvement in these aspects of their simulations.

Figure caption: The decadal changes in the multi-model ensemble mean Arctic Ocean freshwater budget terms from 1950-2050, expressed as anomalies with respect to the 1950-2050 mean. The terms are the net precipitation over the Arctic Ocean, net precipitation over the terrestrial drainage assumed as equivalent to river runoff, the total ice transport through Fram Strait and the Barents Sea, the total ocean freshwater exchange with the North Atlantic (Fram Strait+Barents Sea contributions) and the Bering Strait transport. The sign convention is such that a positive anomaly is an increasing source (or decreasing sink) of freshwater for the Arctic Ocean.

CGD Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. AIXUE HU

Summary of achievements

Aixue Hu

Aixue Hu has been continuing working on the climate change research using CCSM3 in 2008. His recent publication (Hu et al., 2008) highlights the importance of the Bering Strait on global climate. Although this strait is narrow and shallow, the status of the this strait is important to the stability of the global climate, as such a closed Bering Strait can make the important ocean circulation - the Atlantic meridional overturning circulation (MOC, or the thermohaline circulation, THC) be more sensitive to the freshwater forcing added into the subpolar North Atlantic due the fluctuation of the ice sheets in the North America and the Greenland. An open Bering Strait makes the MOC be less sensitive to the freshwater forcing. He is also leading the work of the effect of hurricanes on the MOC and meridional heat transport in the Atlantic basin, the effect of the melting Greenland Ice Sheet on the MOC and global climate, and the importance of the Bering Strait on global sea level changes. He involved the studies of the dynamics of the intraseasonal sea level and thermocline variability in the equatorial Atlantic, the influence of the weakened Atlantic MOC on ENSO, the mid-1970s Pacific climate shift in the Pacific and the relative roles of forced versus inherent decadal variability. He is also working on the decadal predictability research.

Publications

Hu, A., B.L. Otto-Bliesner, G.A. Meehl, W. Han, C. Morrill, E.C. Brady, and B. Briegleb, 2008: Response of Thermohaline Circulation to Freshwater Forcing under Present-Day and LGM Conditions. J. Climate, 21, 2239-2258.

Abstract: Responses of the thermohaline circulation (THC) to freshwater forcing (hosing) in the subpolar North Atlantic Ocean under present-day and the last glacial maximum (LGM) conditions are investigated using the National Center for Atmospheric Research Community Climate System Model versions 2 and 3. Three sets of simulations are analyzed, with each set including a control run and a freshwater hosing run. The first two sets are under present-day conditions with an open and closed Bering Strait. The third one is under LGM conditions, which has a closed Bering Strait. Results show that the THC nearly collapses in all three hosing runs when the freshwater forcing is turned on. The full recovery of the THC, however, is at least a century earlier in the open Bering Strait run than the closed Bering Strait and LGM runs. This is because the excessive freshwater is diverged almost equally toward north and south from the subpolar North Atlantic when the Bering Strait is open. A significant portion of the freshwater flowing northward into the Arctic exits into the North Pacific via a reversed Bering Strait Throughflow, which accelerates the THC recovery. When the Bering Strait is closed, this Arctic to Pacific transport is absent and freshwater can only be removed through the southern end of the North Atlantic. Together with the surface freshwater excess due to precipitation, evaporation, river runoff, and melting ice in the closed Bering Strait experiments after the hosing, the removal of the excessive freshwater takes longer, and this slows the recovery of the THC. Although the background conditions are quite different between the present-day closed Bering Strait run and the LGM run, the THC responds to the freshwater forcing added in the North Atlantic in a very similar manner.

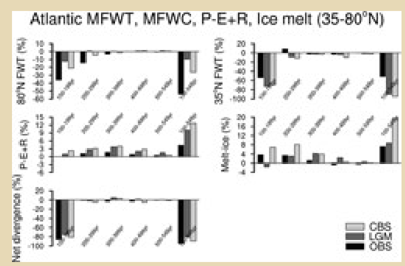

Figure 1.

High resolution figure

Figure caption: The anomalous meridional freshwater transport at 80°N, 35°N; the surface freshwater input anomaly from precipitation, evaporation, and river runoff (P _ E R); the melt-ice flux anomaly; and the net freshwater divergence in the region of the North Atlantic between 35° and 80°N in the three hosing runs. Values shown in these figures are the percentage of the total freshwater anomaly added into the subpolar North Atlantic during the 100-yr hosing period. The bars show the anomalous freshwater transport (or input) in the given period in the figures. Bars from darker to lighter color represent the OBS, LGM, and CBS cases, respectively. Negative (positive) values are freshwater being transported out (added into) the Atlantic between 35° and 80°N.

Support: A portion of this study was supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement DE-FC02-97ER62402. Weiqing Han was supported by NSF OCE-0452917 and NASA Ocean Vector Winds Program Award Number 1283568.

Han, W., P. J. Webster, J. Lin, W. T. Liu, R. Fu, D. Yuan, and A. Hu, 2008: Dynamics of intraseasonal sea level and thermocline variability in the equatorial Atlantic during 2002-2003. J. of Physical Oceanography, 38, 945-967.

Abstract: Satellite and in situ observations in the equatorial Atlantic Ocean during

2002-03 show dominant spectral peaks at 40-60 days and secondary peaks at 10-40 days in sea level and thermocline within the intraseasonal period band (10-80 days). A detailed investigation of the dynamics of the intraseasonal variations is carried out using an ocean general circulation model, namely, the Hybrid Coordinate Ocean Model (HYCOM). Two parallel experiments are performed in the tropical Atlantic Ocean basin for the period 2000-03: one is forced by daily scatterometer winds from the Quick Scatterometer (QuikSCAT) satellite together with other forcing fields, and the other is forced by the low-passed 80-day version of the above fields. To help in understanding the role played by the wind-driven equatorial waves, a linear continuously stratified ocean model is also used.

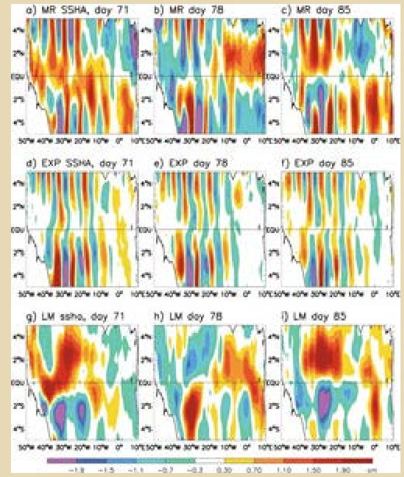

Figure 2.

High resolution figure

Within 3°S-3°N of the equatorial region, the strong 40-60-day sea surface height anomaly (SSHA) and thermocline variability result mainly from the first and second baroclinic modes equatorial Kelvin waves that are forced by intraseasonal zonal winds, with the second baroclinic mode playing a more important role. Sharp 40-50-day peaks of zonal and meridional winds appear in both the QuikSCAT and Pilot Research Moored Array in the Tropical Atlantic (PIRATA) data for the period 2002-03, and they are especially strong in 2002. Zonal wind anomaly in the central-western equatorial basin for the period 2000-06 is significantly correlated with SSHA across the equatorial basin, with simultaneous/lag correlation ranging from -0.62 to 0.74 above 95% significance. Away from the equator (3°-5°N), however, sea level and thermocline variations in the 40-60-day band are caused largely by tropical instability waves (TIWs).

On 10-40-day time scales and west of 10°W, the spectral power of sea level and thermocline appears to be dominated by TIWs within 5°S-5°N of the equatorial region. The wind-driven circulation, however, also provides a significant contribution. Interestingly, east of 10°W, SSHA and thermocline variations at 10-40-day periods result almost entirely from wind-driven equatorial waves. During the boreal spring of 2002 when TIWs are weak, Kelvin waves dominate the SSHA across the equatorial basin (2°S-2°N). The observed quasi-biweekly Yanai waves are excited mainly by the quasi-biweekly meridional winds, and they contribute significantly to the SSHA and thermocline variations in 1°-5°N and 1°-5°S regions.

Figure caption: The 10-40-day bandpassed HYCOM MR SSHA in the equatorial Atlantic basin during spring, day 71 of 2002; (b), (c) same as in (a), but for days 78 and 85; (d)-(f) same as in (a)-(c), but for SSHA from HYCOM EXP; (g)-(i) same as in (a)-(c), but for SSHA from LM MR solution.

Support: Weiqing Han was supported by NSF OCE-0452917 and NASA Ocean Vector Winds Program award 1283568, Peter J. Webster by NSF ATM-0531771, Jia-Lin Lin by NOAAOGP/CVP and NASA MAP Programs, W. Timothy Liu by NASA Ocean Vector Winds and Physical Oceanography Programs, R. Fu by NASA Ocean Vector Winds Program and NOAA Climate Prediction Program for the Americas, D. Yuan by the National Basic Research of China ("973 program") project 2006CB403603, the "100-Expert Program" of the Chinese Academy of Sciences, and the NSF project 40676020, and Aixue Hu partly by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402.

Timmermann, A., Y. Okumura, S.-I. An, A. Clement, B. Dong, E. Guilyardi, A. Hu, J. Jungclaus, U. Krebs, M. Renold, T. F. Stocker, R. J. Stouffer, R. Sutton, S.-P. Xie, J. Yin, 2007: The influence of a weakening of the Atlantic meridional overturning circulation on ENSO. J. Climate, 20, 4899-4919.

Abstract: The influences of a substantial weakening of the Atlantic meridional overturning circulation (AMOC) on the tropical Pacific climate mean state, the annual cycle, and ENSO variability are studied using five different coupled general circulation models (CGCMs). In the CGCMs, a substantial weakening of the AMOC is induced by adding freshwater flux forcing in the northern North Atlantic. In response, the well-known surface temperature dipole in the low-latitude Atlantic is established, which reorganizes the large-scale tropical atmospheric circulation by increasing the northeasterly trade winds. This leads to a southward shift of the intertropical convergence zone (ITCZ) in the tropical Atlantic and also the eastern tropical Pacific. Because of evaporative fluxes, mixing, and changes in Ekman divergence, a meridional temperature anomaly is generated in the northeastern tropical Pacific, which leads to the development of a meridionally symmetric thermal background state. In four out of five CGCMs this leads to a substantial weakening of the annual cycle in the eastern equatorial Pacific and a subsequent intensification of ENSO variability due to nonlinear interactions. In one of the CGCM simulations, an ENSO intensification occurs as a result of a zonal mean thermocline shoaling.

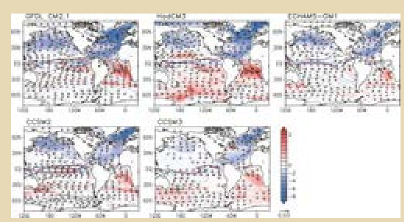

Figure 3.

High resolution figure

Analysis suggests that the atmospheric circulation changes forced by tropical Atlantic SSTs can easily influence the large-scale atmospheric circulation and hence tropical eastern Pacific climate. Furthermore, it is concluded that the existence of the present-day tropical Pacific cold tongue complex and the annual cycle in the eastern equatorial Pacific are partly controlled by the strength of the AMOC. The results may have important implications for the interpretation of global multidecadal variability and paleo-proxy data.

Figure caption: SST anomaly (K) and wind stress anomaly (N m generated by the shutdown of the AMOC for the (top left) GFDL CM2.1, (top middle) HadCM3, (top right) MPIO-M1, (bottom left) CCSM2, and (bottom right) CCSM3. The red and blue lines represent the annual mean $\Gamma_y = 0$ lines in the control and waterhosing experiments, respectively. Note the asymmetric temperature scale.

Meehl, G. A., A. Hu, and B. D. Santer, 2008: The mid-1970s climate shift in the Pacific and the relative roles of forced versus inherent decadal variability. J Clim, in press.

Abstract: A significant shift from cooler to warmer tropical Pacific sea surface temperatures (SSTs), part of a pattern of basin-wide SST anomalies involved with a transition to the positive phase of the Interdecadal Pacific Oscillation (IPO), occurred in the mid-1970s with effects that extended globally. One view is that this change was entirely natural and was a product of internally-generated decadal variability of the Pacific climate system. However, during the mid-1970s there was also a significant increase of global temperature and changes to a number of other quantities that have been associated with changes in external forcings, particularly increases of greenhouse gases from the burning of fossil fuels. We analyze observations, an unforced control run from a global coupled climate model, as well as 20th century simulations with changes in external forcings to show that the observed 1970s climate shift had a contribution from changes in external forcing superimposed on what was likely an inherent decadal fluctuation of the Pacific climate system. Thus this inherent decadal variability associated with the IPO delayed to the 1970s what likely would have been a forced climate shift in the 1960s from a negative to positive phase of the IPO.

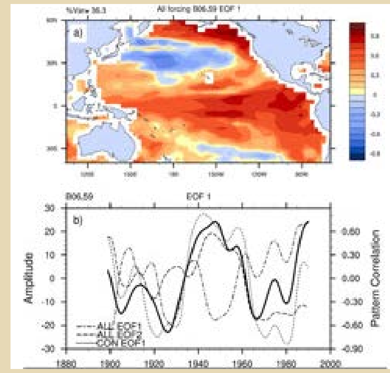

Figure 4.

High resolution figure

Figure caption: a) the first EOF from a single ensemble member from the all-forcings experiment, and b) the PC time series from the single ensemble member (solid), and pattern correlations from projecting the first EOF from the control run (Fig. 3) on to the low pass filtered SST data from the single ensemble member (dotted), and similarly from projecting the first (dash-dot) and second (dashed) EOFs from the ensemble mean all-forcings experiment (Fig. 4a and c, respectively) on to the low pass filtered SST data from the single ensemble member. The left axis labels refer to the amplitude of the PC time series (dark solid line), and the right axis labels are for the amplitude of the pattern correlations (dash-dot, dashed, and dotted lines). Thin vertical lines denote 1965, 1975 and 1980 as discussed in text.

Support: Portions of this study were supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402, and the National Science Foundation. The National Center for Atmospheric Science is sponsored by the National Science Foundation.

Yuko M. Okumura, Clara Deser, and Aixue Hu, Axel Timmermann and Shang-Ping Xie, 2008: North Pacific Climate Response to Freshwater Forcing in the Subarctic North Atlantic: Oceanic and Atmospheric Pathways. J Clim., in press.

Abstract: Sudden changes of the Atlantic meridional overturning circulation (AMOC) are believed to have caused large, abrupt climate changes over many parts of the globe during the last glacial and de-glacial period. This study investigates the mechanisms by which a large freshwater input to the subarctic North Atlantic and an attendant rapid weakening of the AMOC influence North Pacific climate by analyzing four different ocean-atmosphere coupled general circulation models (GCMs) under present-day or pre-industrial boundary conditions. When the coupled GCMs are forced with a 1 Sv freshwater flux anomaly in the subarctic North Atlantic, the AMOC nearly shuts down and the North Atlantic cools significantly. The South Atlantic warms slightly, shifting the Atlantic intertropical convergence zone southward. In addition to this Atlantic oceanatmosphere response, all the models exhibit cooling of the North Pacific, especially along the oceanic frontal zone, and deepening of the wintertime Aleutian Low, consistent with paleoclimate reconstructions.

Detailed analysis of one coupled GCM identifies both oceanic and atmospheric pathways from the Atlantic to the North Pacific. The oceanic teleconnection contributes a large part of the North Pacific cooling: the freshwater input to the North Atlantic raises sea level in the Arctic Ocean and reverses the Bering Strait throughflow, transporting colder, fresher water from the Arctic Ocean into the North Pacific. When the Bering Strait is closed, the cooling is greatly reduced while the Aleutian Low response is enhanced. Tropical SST anomalies in both the Atlantic and Pacific are found to be important for the equivalent barotropic response of the Aleutian Low during boreal winter. The atmospheric bridge from the tropical North Atlantic is particularly important, and quite sensitive to the mean state, which is poorly simulated in many coupled GCMs. The enhanced Aleutian Low, in turn, cools the North Pacific by increasing surface heat fluxes and southward Ekman transport. The closure of the Bering Strait during the last glacial period suggests that the atmospheric bridge from the tropics and air-sea interaction in the North Pacific played a crucial role in the AMOC-North Pacific teleconnection.

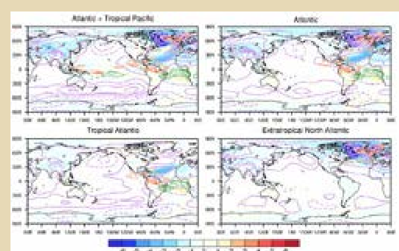

Figure 5.

High resolution figure

Figure caption: Atmospheric anomalies simulated by CAM2 forced with SST and sea ice anomalies from the CCSM2 closed Bering Strait experiment. SST and sea ice anomalies are prescribed over (top left) the Atlantic (25°S-75°N) and tropical Pacific (15°S-15°N), (top right) Atlantic (25°S-75°N), (bottom left) tropical Atlantic (25°S-30°N), and (bottom right) extratropical North Atlantic (40°-75°N). Surface temperature (shading; °C), sea-level pressure (purple contours at intervals of 1 hPa; negative contours dashed), and precipitation (green contours > 1 mm day^{-1} and orange contours < -1 mm day^{-1} at intervals of 1 mm day^{-1}) anomalies are averaged over October-March.

Support: Okumura is supported by the NOAA Climate and Global Change Postdoctoral Fellowship. A. Timmermann and S.-P. Xie acknowledge support from the Japan Agency for Marine-Earth Science and technology (JAMSTEC), NASA through grant No. NNX07AG53G, and NOAA through grant No. NA17RJ1230. A. Timmermann is also supported by NSF grant No. ATM06-28393. This study was in part supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402. The CAM2 simulations were conducted using computational resources from the NCAR Director's Reserve.

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CGD 2008 PROFILES IN SCIENCE: DR. JAMES HURRELL

Summary of achievements

James Hurrell

Jim Hurrell's research continues to increase understanding of observed regional climate variability and change through parallel development and analysis of observational and model-generated datasets and through systematic numerical experimentation to allow attribution of observed variability to processes and causes. In particular, Jim has sought to identify factors driving fluctuations in surface temperature and precipitation on the regional scale by employing a hierarchy of existing climate model simulations, as well as new experiments targeted specifically to elucidate the role of oceanic variability. His most recent research has found multi-decadal variations and trends in sea surface temperature to have primarily determined the spatial patterns, time history and seasonality of observed changes in African and North American climate over the past century, as well as being a key driver of wintertime North Atlantic climate change, including changes to the phase and amplitude of the North Atlantic Oscillation (NAO). Jim, with colleagues from the Hadley Centre, has an article (in press) illustrating that the summer climate in the North Atlantic-European sector possesses a principal pattern of year-to-year variability that is the parallel of the well-known NAO in winter. A related paper (highlighted below) reconstructs this "summer NAO" over the past 500 years from tree-ring chronologies. With collaborators from Georgia Tech and other institutions, Jim has written a paper (submitted) documenting an observed delay of the wet season onset and an increase in drought severity over the Amazon. The paper also discusses the implication of these changes for future climate change over the region.

Jim has collaborated with members of the GLOBEC (Global Ocean Ecosystem Dynamics) community over the past year to produce two new papers (in press) describing and reviewing modal variability over the Northern Hemisphere. Dominant regional modes of atmospheric circulation variability have profound impacts on a variety of ecological processes and, consequently, patterns of species abundance and dynamics. Another new paper (submitted, with GLOBEC co-authors) summarizes the current state-of-the-art in predicting ocean ecosystem responses to future global change scenarios, addresses the limitations and uncertainties of these predictions, and identifies future challenges.

With respect to climate modeling and prediction, Jim has submitted an article emphasizing that all climate system predictions, regardless of timescale, may require initialization of coupled general circulation models with best estimates of the current observed state of the atmosphere, oceans, cryosphere, and land surface. Fundamental barriers to advancing prediction on time scales from days to years, as well as long-standing systematic errors in weather and climate models, are also partly attributable to our limited understanding and capability to simulate the complex, multi-scale interactions intrinsic to atmospheric and oceanic fluid motions. Therefore, Jim has invested considerable time over the past year building an effort to develop a community Nested Regional Climate Model (NRCM), which is a major new initiative toward prediction across scales. Initial NRCM simulations will be the subject of a special future (2009) issue of Climate Dynamics. Jim is an author on several papers in this special issue, and he is serving as the coordinating Editor. Finally, Jim has a new paper (in press) with NCAR colleagues documenting a new surface boundary forcing data set for uncoupled simulations with the Community Atmosphere Model. This new data product is updated monthly and it is freely available for community use.

Jim continues to serve national and international science-planning efforts. He remains extensively involved in the World Climate Research Programme (WCRP) on Climate Variability and Predictability (CLIVAR), including a current role as co-chair of the Scientific Steering Group (SSG) of International CLIVAR. Jim is also involved in the International Geosphere-Biosphere Programme (IGBP) as a member of the GLOBEC SSG and the CLIVAR-PAGES (Past Global Changes) working group. Jim has been involved in assessment activities of the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Climate Change Science Program (CCSP). He has served on a National Research Council (NRC) panel the past three years providing strategic advice to the CCSP. Finally, Jim was recently elected to the Council of the American Meteorological Society (AMS).

Publications

Hurrell, J. W., 2008: Decadal climate prediction: challenges and opportunities. Proc. Scientific Discovery through Advanced Discovery. R. Stevens, Ed., July 13-17, 2008, Seattle, WA, 125, 012018, doi:10.1088/1742-6596/125/1/012018.

Abstract: The scientific understanding of climate change is now sufficiently clear to show that climate change from global warming is already upon us, and the rate of change as projected exceeds anything seen in nature in the past 10,000 years. Uncertainties remain, however, especially regarding how climate will change at regional and local scales where the signal of natural variability is large. Addressing

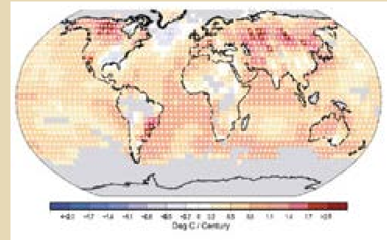

Figure 1.

High resolution figure

many of these uncertainties will require a movement toward high resolution climate system predictions, with a blurring of the distinction between shorter-term predictions and longer-term climate projections. The key is the realization that climate system predictions, regardless of timescale, will require initialization of coupled general circulation models with best estimates of the current observed state of the atmosphere, oceans, cryosphere, and land surface. Formidable challenges exist: for instance, what is the best method of initialization given imperfect observations and systematic errors in models? What effect does initialization have on climate predictions? What predictions should be attempted, and how would they be verified? Despite such challenges, the unrealized predictability that resides in slowly evolving phenomena, such as ocean current systems, is of paramount importance for society to plan and adapt for the next few decades. Moreover, initialized climate predictions will require stronger collaboration with shared knowledge, infrastructure and technical capabilities among those in the weather and climate prediction communities. The potential benefits include improved understanding and predictions on all time scales.

Figure caption: Linear trend of annual temperatures for 1901 to 2005 (°C century^{-1}). Areas in grey have insufficient data to produce reliable trends. Trends significant at the 5% level are indicated by white + marks. The figure is taken from Trenberth et al. [2].

Hurrell, J. W., J. J. Hack, D. Shea, J. M. Caron, and J. Rosinski, 2008: A new sea surface temperature and sea ice boundary data set for the Community Atmosphere Model, Journal of Climate, 21, 5145-5153.

Abstract: A new surface boundary forcing data set for uncoupled simulations with the Community Atmosphere Model is described. It is a merged product based on the monthly mean Hadley Centre sea ice and SST data set version 1 (HadISST1) and version 2 of the National Oceanic and Atmospheric Administration (NOAA) weekly optimum interpolation (OI) SST analysis. These two source data sets were also used to supply ocean surface information to the European Centre for Medium-Range Weather Forecasts 40-year reanalysis project (ERA-40). Our merged product provides monthly mean sea surface temperature and sea ice concentration data from 1870 to the present: it is updated monthly, and it is freely available for community use. The merging procedure was designed to take full advantage of the higher resolution SST information inherent in the NOAA OI.v2 analysis.

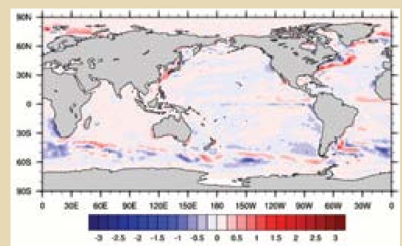

Figure 2.

High resolution figure

Figure caption: Differences between the 30-yr 1971-2000 SST climatologies (OI.v2 - HadISST1) in °C. The color contours are 0.25°C up to absolute 3°C.

Hurrell, J. W., and C. Deser, 2008: North Atlantic climate variability: the role of the North Atlantic Oscillation. Journal of Marine Systems, in press.

Abstract: Marine ecosystems are undergoing rapid change at local and global scales. To understand these changes, including the relative roles of natural variability and anthropogenic effects, and to predict the future state of marine ecosystems requires quantitative understanding of the physics, biogeochemistry and ecology of oceanic systems at mechanistic levels. Central to this understanding is the role played by dominant patterns or "modes" of atmospheric and oceanic variability, which orchestrate coherent variations in climate over large regions with profound impacts on ecosystems. We review the spatial structure of extratropical climate variability over the Northern Hemisphere and, specifically, focus on modes of climate variability over the extratropical North Atlantic.

A leading pattern of weather and climate variability over the Northern Hemisphere is the North Atlantic Oscillation (NAO). The NAO refers to a redistribution of atmospheric mass between the Arctic and the subtropical Atlantic, and swings from one phase to another produce large changes in surface air temperature, winds, storminess and precipitation over the Atlantic as well as the adjacent continents. The NAO also affects the ocean through changes in heat content, gyre circulations, mixed layer depth (Fig. 1), salinity, high latitude deep water formation and sea ice cover. Thus, indices of the NAO have become widely used to document and understand how this mode of variability alters the structure and functioning of marine ecosystems.

There is no unique way, however, to define the NAO. Several approaches are discussed, including both linear (e.g., principal component analysis) and nonlinear (e.g., cluster analysis) techniques. The former, which have been most widely used, assume

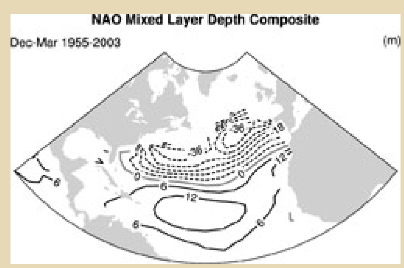

Figure 3.

High resolution figure

preferred atmospheric circulation states come in pairs, in which anomalies of opposite polarity have the same spatial structure. In contrast, nonlinear techniques search for recurrent patterns of a specific amplitude and sign. They reveal, for instance, spatial asymmetries between different phases of the NAO that are likely important for ecological studies.

It also follows that there is no universally accepted index to describe the temporal evolution of the NAO. Several of the most common measures are presented and compared. All reveal that there is no preferred time scale of variability for the NAO: large changes occur from one winter to the next and from one decade to the next. There is also a large amount of within-season variability in the patterns of atmospheric circulation of the North Atlantic, so that most winters cannot be characterized solely by a canonical NAO structure. A better understanding of how the NAO responds to external forcing, including sea surface temperature changes in the tropics, stratospheric influences, and increasing greenhouse gas concentrations, is crucial to the current debate on climate variability and change.

Figure caption: Difference in mean winter (December - March) ocean mixed layer depth (m) between years when an index of the NAO exceeds one standard deviation over 1955-2003. The contour increment is 6m and positive (negative) differences are given by the solid (dashed) contours.

Support: Support for this work was provided by the CLIVAR Program of the NOAA Office of Global Programs. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

Folland, C., J. Knight, H. Linderholm, D. Fereday, S. Ineson, and J. W. Hurrell, 2008: The summer North Atlantic Oscillation: past, present and future. Journal of Climate, in press.

Abstract: Summer climate in the North Atlantic-European sector possesses a principal pattern of year-to-year variability that is the parallel of the well-known North Atlantic Oscillation in winter. This 'Summer North Atlantic Oscillation' (SNAO) is defined here as the first empirical orthogonal function (EOF) of observed summertime extratropical North Atlantic pressure at mean sea level. It is shown to be characterised by a more northerly location and smaller spatial scale than its winter counterpart. The SNAO is also detected by cluster analysis and has a near equivalent barotropic structure on daily and monthly time scales. Although of lesser amplitude than its wintertime counterpart, the SNAO exerts a strong influence on Northern European rainfall, temperature and cloudiness through changes in the position of the North Atlantic storm track. It is, therefore, of key importance in generating summer climate extremes, including flooding, drought and heat stress in North Western Europe. The El Niño/Southern Oscillation (ENSO) phenomenon is known to influence summertime European climate; however, interannual variations of the SNAO are only weakly influenced by ENSO. On interdecadal time scales, both modelling and observational results indicate that SNAO variations are partly related to the Atlantic Multidecadal Oscillation. It is shown that SNAO variations extend far back in time, as evidenced by reconstructions of SNAO variations back to 1706 using tree-ring records. Very long instrumental records, such as Central England Temperature, are used to validate the reconstruction. Finally, two climate models are shown to simulate the present-day SNAO and predict a trend towards a more positive index phase in the future under increasing greenhouse gas concentrations. This implies the long-term likelihood of increased summer drought for North Western Europe.

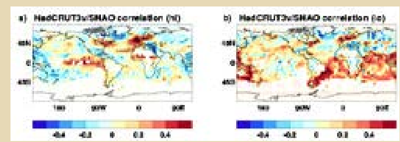

Figure 4.

High resolution figure

Figure caption: (a) Simultaneous correlation of worldwide land surface temperature (2m) air temperature and sea surface temperature, 1900-2007, with the July-August mean of the daily high summer North Atlantic Oscillation (SNAO). Temperature and SNAO data are filtered on time scales <10 years. Crosses represent correlations locally significant at the 5% level. Significance is assessed using a two-tailed test based on correlating temperature at each gridpoint with 1,000 time series, derived by randomly reordering and then appropriately filtering the original SNAO series. Autocorrelation of the original SNAO series is not significantly different from that of the randomly reordered SNAO series used in significance testing. (b) As in (a) but for time scales >10 years.

Linderholm, H.W., C.K. Folland, and J. W. Hurrell, 2008: Reconstructing Summer North Atlantic Oscillation (SNAO) variability over the last five centuries In: Tree rings in archaeology, climatology and ecology, Elferts D et al. (Eds.), TRACE, 6, 8-16.

Abstract: Summer climate in the North Atlantic-European sector possesses a principal pattern of year-to-year variability that is the parallel of the well-known North Atlantic Oscillation in winter. This 'Summer North Atlantic Oscillation' (SNAO) is defined as the first empirical orthogonal function (EOF) of observed summertime extratropical North Atlantic pressure at mean sea level. It is shown to be characterized by a more northerly location and smaller spatial scale than its winter counterpart. The SNAO is also detected by cluster analysis and has a near equivalent barotropic structure on daily and monthly time scales. Although of lesser amplitude than its wintertime counterpart, the SNAO exerts a strong influence on Northern European rainfall, temperature and cloudiness through changes in the position of the North Atlantic storm track. It is, therefore, of key importance in generating summer climate extremes, including flooding, drought and heat stress in North Western Europe. SNAO variations extend far back in time, as evidenced by reconstructions of SNAO variations back through five centuries

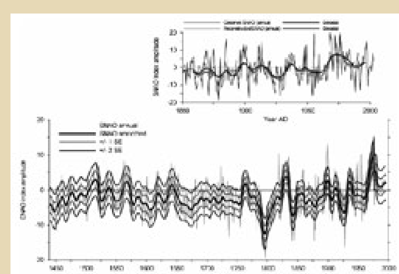

Figure 5.

using tree-ring records.

High resolution figure

Figure caption: Reconstruction of the SNAO. Upper figure shows reconstructed vs. observed (from instrumental measurements) SNAO 1850-1995. Lower figure shows the full reconstruction, with 1 and 2 standard errors (SE) based on decadal values. Thick black lines represents smoothed (Gaussian filtered, σ=3) values, highlighting variability on timescales longer than 10 years.

Contributing Author

Ramanathan, V., and co-authors, 2007: Evaluating Progress of the U.S. Climate Change Science Program: Methods and Preliminary Results. National Research Council, National Academies Press, Washington, D.C., 178 pp.

Non-Refereed

Hurrell, J. W., 2008: The North Atlantic Oscillation: Climatic significance and environmental impact. Proc. Catastrophe Modeling Forum: Changing Climatic Dynamics and Catastrophe Model Projections. P. Epstein, Ed., June 11-12, 2008, New York, New York, 8 pp.

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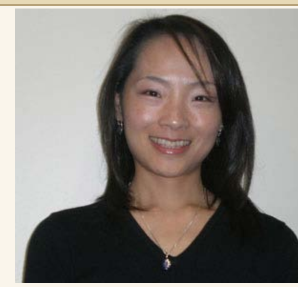

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Vita

Research Focus FY08:

I continue to investigate the impact of cloud microphysical parameterizations on simulations of organized convective systems while participating in a study that will focus on comparisons of partitioning of various microphysical processes among the Lin, 6-class graupel-phase microphysical model (WSM6), and Thompson microphysical schemes.

Colorado Headwaters Program

(Collaborators: Changhai Liu, Mitch Moncrieff, Roy Rasmussen, Xianfan Ma, Aijuan Bai, John Tuttle & others)

The Colorado Headwaters Program is a key project of NCAR's Water System Program in this fiscal year. Its major objective is to assess the projected Upper Colorado Snowpack and Runoff by global climate models using a very high resolution regional climate model. We started from the present-day cold season simulations in this region to evaluate the sensitivity of the simulated snowfall and snowpack to both the horizontal and vertical grid spacings as well as the various physical parameterizations. We have performed a series of 2~30-km resolution experiments over two multi-day periods (i.e., November 19 -- December 8, 2002; February 1--16, 2008) with the WRF model. North American Regional Reanalysis (NARR) data are used to provide the initial and boundary conditions in our simulations. The Snow Telemetry network (SNOTEL) and PRISM observations are used to evaluate the simulated snowfall. The preliminary analysis indicates that 1) the high-resolution simulations with 2~4-km grid spacing can well capture the heavy snowfall episodes during the two periods; 2) the simulated snowfall has little dependence on the choice of the PBL and land-surface schemes, but shows considerable sensitivity to the choice of microphysics parameterizations; and 3) the model performance gradually degrades when the grid spacing is coarser and coarser.

Publications FY08:

Ikeda, K., R. M. Rasmussen, C.-H. Liu, G. Thompson, L. Xue, 2008: Investigation of the dependence of squall line structure and dynamics on microphysical parameterization. *15th Intl. Conf. on Clouds and Precipitation*, Cancun, MX, International Association of Meteorology and Atmospheric Science.

Ikeda, K., R. M. Rasmussen, E. A. Brandes, F. McDonough, 2008: Freezing drizzle detection with WSR-88D radars. *J. Appl. Meteor. Climat.*, doi: 10.1175/2008JAMC1939.1.

Cao, Q., G. Zhang, E. A. Brandes, T. Schuur, . Ryzhkov, K. Ikeda, 2007: Analysis of video disdrometer and polarimetric radar data to characterize rain microphysics in Oklahoma. *J. Appl. Meteor. Climat.*, **47**, 2238-2255.

Brandes, E. A., K. Ikeda, G. Zhang, M. Schonhuber, R. M. Rasmussen, 2007: A statistical and physical description of hydrometeor distributions in Colorado snowstorms using a video disdrometer. *J. Appl. Meteor. Climat.*, **46**, 634-650, doi: 10.1175/JAM2489.1. (Accepted)

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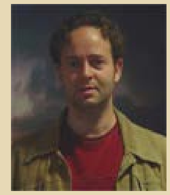
CGD 2008 PROFILES IN SCIENCE: DR. MARKUS JOCHUM

Summary of achievements

Markus Jochum's focuses on identifing the ocean parts and processes that are important for climate, and then improving the representation of important but poorly represented processes. The results obtained over the last several years show that thermocline diffusivity is surprisingly relevant for tropical precipitation, whereas mesoscale eddies are not. Most of his research is driven by serendipity, and a nice overview of its effect can be found in 'Ocean Viscosity and Climate'.



Markus Jochum

Publications

Jochum, M. and J. Potemra, 2008: Sensitivity of tropical rainfall to Banda Sea diffusivity in the Community Climate System Model. doi:10.1175/2008JCLI2230.1.

Abstract: Several observational studies suggest that the vertical diffusivity in the Indonesian marginal seas is an order of magnitude larger than in the open ocean and what is used in most ocean general circulation models. The experiments described in the present study show that increasing the background diffusivity in the Banda Sea from the commonly used value of 0.1 cm^2 / s to the observed value of 1 cm^2 / s improves the water mass properties there by reproducing the observed thick layer of Banda Sea water. The resulting reduced sea surface temperatures lead to weaker convection and a redistribution of precipitation, away from the Indonesian Seas towards the equatorial Indian and Pacific oceans. In particular, the boreal summer precipitation maximum of the Indonesian Seas shifts northward from the Banda Sea towards Borneo, which reduces a longstanding bias in the simulation of the Austral-Asian Monsoon in the Community System Climate Model. Because of the positve feedback mechanisms inherent in tropical atmosphere dynamics, a reduction in Banda Sea heat loss of only 5% leads locally to a reduction in convection of 20%.

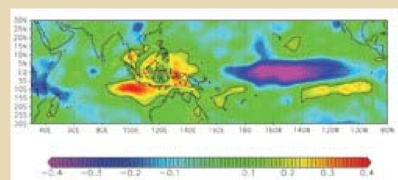


Figure 1.

High resolution figure

Figure caption: Correlation of SST anomalies (relative to the climatology of the seasonal cycle) in the Java, Flores and Banda Sea (region outlined with box) to precipitation anomalies four months later [based on NCEP, *Kalnay et al.* 1996]. The correlation for the 95% confidence interval (= 0.15) is marked with a black contour line.

Jochum, M., G. Danabasoglu, M. Holland, Y.-O. Kwon, and W. G. Large. 2008: Ocean viscosity and climate. J. Geophys. Res., 113, C06017, doi:10.1029/2007JC004515.

Abstract: The impacts of parameterized lateral ocean viscosity on climate are explored using three 120-year integrations of a fully coupled climate model. Reducing viscosity leads to a generally improved ocean circulation at the expense of increased numerical noise. Five domains are discussed in detail: the equatorial Pacific, where the emergence of tropical instability waves reduces the cold tongue bias; the Southern Ocean, where the Antarctic Circumpolar Current increases its kinetic energy but reduces its transport; the Arctic Ocean, where an improved representation of the Atlantic inflow leads to a better sea-ice distribution; the North Pacific, where the more realistic path of the Kuroshio leads to more realistic temperatures across the midlatitude Pacific; and the northern marginal seas, where stronger boundary currents lead to significantly less sea-ice. Although the ocean circulation and sea-ice distribution improve, the oceanic heat uptake, the poleward heat transport, and the large scale atmospheric circulation are not changed significantly. In particular, the improvements to the equatorial cold tongue did not lead to better representation of tropical precipitation or El Niño.

Figure caption: Anisotropic horizontal viscosity coefficients A and B at 100-m depth from (a-b) CONT, (c-d) NOSMAG, and (e-f) LOWVISC. Units are 1000 $m^2 s^{-1}$. All panels use the same color scale.

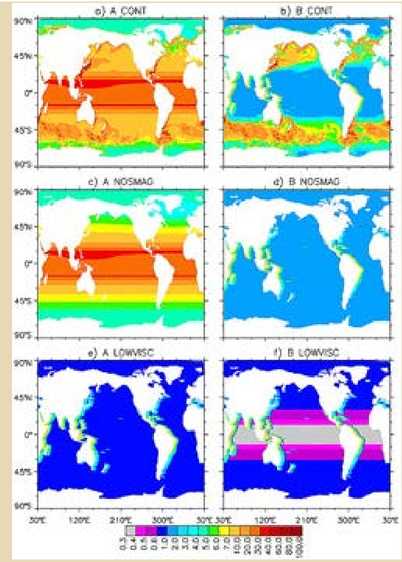


Figure 2.

High resolution figure

Seo, H., M. Jochum, R. Murtugudde, A.J. Miller, and J.O. Roads, 2008: Precipitation from African Easterly Waves in a Coupled Model of the Tropical Atlantic. J. Climate, 21, 1417-1431.

Abstract: A regional coupled climate model is configured for the tropical Atlantic to explore the role of synoptic-scale African easterly waves (AEWs) on the simulation of mean precipitation in the marine intertropical convergence zone (ITCZ). Sensitivity tests with varying atmospheric resolution in the coupled model show that these easterly waves are well represented with comparable amplitudes on both fine and coarse grids of the atmospheric model. Significant differences in the model simulations are found in the precipitation fields, however, where heavy rainfall events occur in the region of strong cyclonic shear of the easterly waves only on the higher-resolution grid. This is because the low-level convergence due to the waves is much larger and more realistic in the fine-resolution simulation, which enables heavier precipitation events that skew the rainfall distributions toward longer tails. The variability in rainfall on these time scales accounts for more than 60%-70% of the total variability. As a result, the simulation of mean rainfall in the ITCZ and its seasonal migration improves in the higher-resolution case. This suggests that capturing these transient waves and the resultant strong low-level convergence is one of the key ingredients for improving the simulation of precipitation in global coupled climate models.

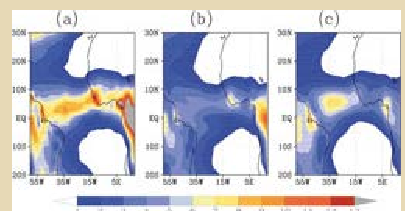


Figure 3.

High resolution figure

Figure caption: Six-year (1999-2004) mean rainfall (mm day^{-1}) from model: (a) HH, (b) HL, and (c) the observations from the GPCP. The model precipitation in (a) and (b) is regridded to the GPCP grids at 2.5° × 2.5°. Precipitation >13 mm day^{-1} is shaded in gray.

Zhou, L., R. Murtugudde, and M. Jochum, 2008: Dynamics of the Intraseasonal Oscillations in the Indian Ocean South Equatorial Current. J. Phys. Oceanogr., 38, 121-132.

Abstract: The spatial and temporal features of intraseasonal oscillations in the southwestern Indian Ocean are studied by analyzing model simulations for the Indo-Pacific region. The intraseasonal oscillations have periods of 40-80 days with a wavelength of ~650 km. They originate from the southeastern Indian Ocean and propagate westward as Rossby waves with a phase speed of ~25 cm s^{-1} in boreal winter and spring. The baroclinic instability is the main driver for these intraseasonal oscillations. The first baroclinic mode dominates during most of the year, but during boreal winter and spring the second mode contributes significantly and often equally. Consequently, the intraseasonal oscillations are relatively strong in boreal winter and spring. Whether the atmospheric intraseasonal oscillations are also important for forcing the oceanic intraseasonal oscillations in the southwestern Indian Ocean needs further investigation.

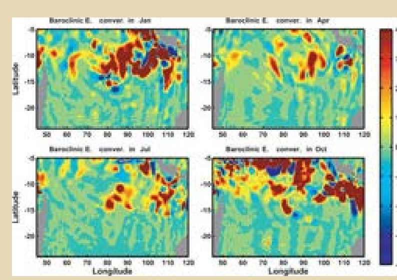


Figure 4.

High resolution figure

Figure caption: Baroclinic energy conversion (10^{-3} W m^{-3}) averaged over 20 yr and above the thermocline in four months.

Zhou, L., R. Murtugudde, and M. Jochum, 2008: Seasonal Influence of Indonesian Throughflow in the Southwestern Indian Ocean J. Phys. Oceanogr., 38, 1529-1541.

Abstract: The influence of the Indonesian Throughflow (ITF) on the dynamics and the thermodynamics in the southwestern Indian Ocean (SWIO) is studied by analyzing a forced ocean model simulation for the Indo-Pacific region. The warm ITF waters reach the subsurface SWIO from August to early December, with a detectable influence on weakening the vertical stratification and reducing the stability of the water column. As a dynamical consequence, baroclinic instabilities and oceanic intraseasonal variabilities (OISVs) are enhanced. The temporal and spatial scales of the OISVs are determined by the ITF-modified stratification. Thermodynamically, the ITF waters influence the subtle balance between the stratification and the mixing in the SWIO. As a result, from October to early December an unusual warm entrainment occurs, and the SSTs warm faster than just net surface heat flux-driven warming. In late December and January, the signature of the ITF is seen as a relatively slower warming of SSTs. A conceptual model for the processes by which the ITF impacts the SWIO is proposed.

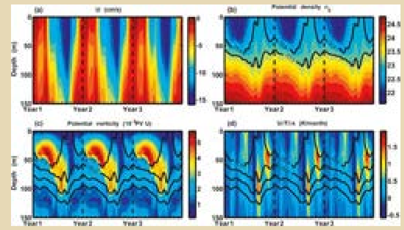


Figure 5.

High resolution figure

Figure caption: (a) Zonal velocity, (b) potential density, (c) EPV, and (d) zonal temperature advection averaged from 10° to 15°S along 114°E over 3 yr.

Seo, H., M. Jochum, R. Murtugudde, A. J. Miller, and O. Roads, 2008: Feedback of Tropical Instability-Wave-Induced Atmospheric Variability onto the Ocean Journal of Climate, 20, 5842-5855, doi:10.1175/JCLI4330.1.

Abstract: The effects of atmospheric feedbacks on tropical instability waves (TIWs) in the equatorial Atlantic Ocean are examined using a regional high-resolution coupled climate model. The analysis from a 6-yr hindcast from 1999 to 2004 reveals a negative correlation between TIW-induced wind perturbations and TIW-induced ocean currents, which implies damping of the TIWs. On the other hand, the feedback effect from the modification of Ekman pumping velocity by TIWs is small compared to the contribution to TIW growth by baroclinic instability. Overall, the atmosphere reduces the growth of TIWs by adjusting its wind response to the evolving TIWs. The analysis also shows that including ocean current (mean + TIWs) in the wind stress parameterization reduces the surface stress estimate by 15%-20% over the region of the South Equatorial Current. Moreover, TIW-induced perturbation ocean currents can significantly alter surface stress estimations from scatterometers, especially at TIW frequencies. Finally, the rectification effect from the atmospheric response to TIWs on latent heat flux is small compared to the mean latent heat flux.

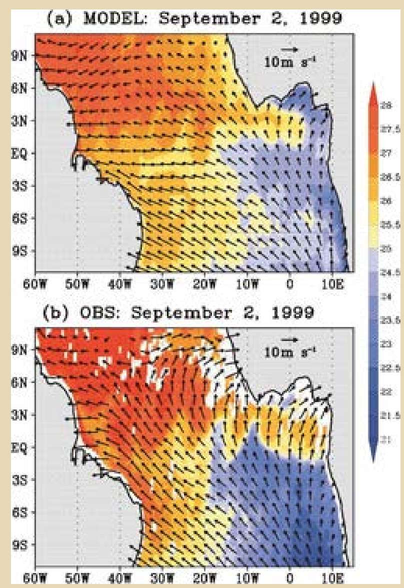


Figure 6.

High resolution figure

Figure caption: Three-day-averaged SST and 10-m winds centered on 2 Sep 1999 (a) in the model and (b) from the satellite of the TMI tropical instability waves and the QuikSCAT scatterometers. The TIWs are shown as undulations of the SST front near the equator. The TRMM SST and the QuikSCAT wind vectors are regridded to the model grid in (a). The vectors are shown on every 10 (5) grid points in x (y).

Neale, R. B., M. Jochum and J. H. Richter, 2008: The impact of convection on ENSO: From a delayed oscillator to a series of events. doi:10.1175/2008JCLI2244.1, in press.

Abstract: The NCAR-Community Climate System Model (CCSM3) exhibits persistent errors in its simulation of the El Niño Southern Oscillation (ENSO) mode of coupled variability. The amplitude of the oscillation is too strong, the dominant 2-year period too regular and the width of the Sea Surface Temperature (SST) response in the Pacific too narrow, with positive anomalies extending too far into the western Pacific. Two changes in the parameterization of deep convection result in a significant improvement to many aspects of the ENSO simulation. The inclusion of Convective Momentum Transports (CMT) and a dilution approximation for the calculation of Convective Available Potential Energy (CAPE) are used in development integrations and a striking improvement in ENSO characteristics is seen. An increase in the periodicity of ENSO is achieved by a reduction in the

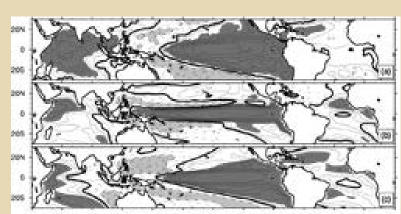


Figure 7.

strength of the existing "short-circuited" delayed-oscillator mode. The off-equatorial response is weaker and less tropically confined, largely as a result of the CMT and an associated redistribution of zonal momentum. The Pacific east-west structure is improved in response to the presence of convective dilution and cooling provided by increased surface fluxes. The initiation of El Niño events is fundamentally different. Enhanced intra-seasonal surface stress variability leads to absolute surface westerlies and a cooling-warming dipole between the Philippine Sea and western Pacific. Lag-regression analysis shows intra-seasonal variability may play a significant role in event initiation and maintenance as opposed to being a benign response to increased SSTs. Recent observational evidence appears to support such a leading relationship.

High resolution figure

Figure caption: Lag-zero correlation of nino-3.4 and tropical SST anomalies for (a) HadISST, (b) C3OLD, and (C) C3NEW (contour interval is 0.1, and a correlation of >0.3 (filled contours) is significant at the 95% level for a conservative estimate of 40 degrees of freedom).

THOMAS KARL

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Research Focus FY08:

Scientists used specially-equipped towers to measure chemical emissions from plants in a walnut grove in California. Picture by Carlye Calvin, UCAR
High resolution figure

Biosphere-Atmosphere Interactions (BAI)

The research of the BAI group is designed to advance understanding of global biosphere - atmosphere interactions and to predict the response of the earth system to future perturbations. This is being accomplished through multidisciplinary field, laboratory and modeling studies of the processes controlling these interactions on various scales (e.g., leaf to canopy to landscape to global).

Additional Information: BAI

Plants Make Their Own Painkillers

Walnut trees respond to stress by producing significant amounts of a chemical form of aspirin, scientists have discovered: Thomas Karl, Alex Guenther, Andrew Turnipseed, Edward Patton, & Kolby Jardine. In the News:

- Walnut Trees Emit Aspirin-Like Chemical to Deal With Stress (NSF)
- Plants Make Own Painkillers (LiveScience)
- Plants make their own version of aspirin, researchers find (Los Angeles Times)
- Stressed plants release aspirin-like chemical (Reuters)
- Stressed plants produce an aspirin-like chemical (What is life science)
- Stressed plants produce Aspirin (Medical & Pharmacy News)
- Mother Nature's little helper (nature.com)

Community Service FY08:

- Co-Editorial Board: Atmospheric Chemistry and Physics
- Scientific Committee: EGU Division on Atmospheric Sciences, Sub Division AS2: Boundary Layer Processes
- Graduate Research Advisor & Thesis/Dissertation Committee: Irina Herdlinger (University of Innsbruck)

Publications FY08:

Karl, T., A. B. Guenther, A. A. Turnipseed, E. G. Patton, K. Jardine, 2008: Chemical sensing of plant stress at the ecosystem scale. *Biogeosciences Discuss.*, 5, 2381-2399.

Yokelson, R. J., T. Christian, T. Karl, A. B. Guenther, 2008: The tropical forest and fire emissions experiment: laboratory fire measurements and synthesis of campaign data. *Atmos. Chem. Phys.*, **8**, 3509-3527.

Patton, E. G., T. Horst, D. H. Lenschow, P. P. Sullivan, S. P. Oncley, S. P. Burns, A. B. Guenther, T. Karl, S. D. Mayor, S. M. Spuler, J. Sun, A. A. Turnipseed, E. Allwine, S. Edburg, B. Lamb, R. Avissar, H. Holder, R. Calhoun, J. Kleissl, W. Massman, K. Tha Paw U, J. Weil, L. Rizzo, A. Held, 2008: The Canopy Horizontal Array Turbulence Study (CHATS). , Stockholm, SE, AMS, American Meteorological Society, 18A.1.

Jardine, K., P. Harley, T. Karl, A. B. Guenther, M. Lerdau, J. E. Mak, 2008: Plant physiological and environmental controls over the exchange of acetaldehyde between forest canopies and the atmosphere. *Biogeosciences*. (Submitted)

Peltier, R. E., A. H. Hecobian, R. J. Weber, A. Stohl, E. L. Atlas, D. D. Riemer, D. R. Blake, E. C. Apel, T. Campos, T. Karl, 2008: Investigating the sources and atmospheric processing of fine particles from Asia and the Northwestern United States measured during INTEX B. *Atmos. Chem. Phys.*, **8**, 1835-1853.

Thomas Karl Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. JEFFREY KIEHL

Summary of achievements

Jeffrey Kiehl

Jeff Kiehl continues to work in two major areas of climate research, namely climate sensitivity and paleoclimate simulations. He continued his research on Earth's climate sensitivity by comparing a range of fully coupled climate models that were used to simulate the climate of 20th century. All of these models provide reasonable agreement with the warming at the end of the century, yet the model climate sensitivity varies by more than a factor of two. Kiehl was able to show that this agreement was due to compensation between the forcing applied to the models and the climate sensitivity. Kiehl also collaborated on studies that inter-compared the radiative kernel between climate models. Kiehl also carried out research on deep time climates. Kiehl and Christine Shields used the CCSM3 to model the climate of the Latest Permian (251 Ma). They have also been collaborating on simulations of the Paleocene Eocene Thermal Maximum (55 Ma), the Cretaceous (100 Ma), and the Latest Ordovician (445 Ma). These are times of extreme climates that test the robustness of the CCSM3 for large forcing conditions.

Publications

Shell, K.M., J.T. Kiehl, and C.A. Shields, 2008: Using the Radiative Kernel Technique to Calculate Climate Feedbacks in NCAR's Community Atmospheric Model. J. Climate, 21, 2269-2282.

Abstract: Climate models differ in their responses to imposed forcings, such as increased greenhouse gas concentrations, due to different climate feedback strengths. Feedbacks in NCAR's Community Atmospheric Model (CAM) are separated into two components: the change in climate components in response to an imposed forcing and the "radiative kernel," the effect that climate changes have on the top-of-the-atmosphere (TOA) radiative budget. This technique's usefulness depends on the linearity of the feedback processes. For the case of CO_2 doubling, the sum of the effects of water vapor, temperature, and surface albedo changes on the TOA clear-sky flux is similar to the clear-sky flux changes directly calculated by CAM. When monthly averages are used rather than values from every time step, the global-average TOA shortwave change is underestimated by a quarter, partially as a result of intramonth correlations of surface albedo with the radiative kernel. The TOA longwave flux changes do not depend on the averaging period. The longwave zonal averages are within 10% of the model-calculated values, while the global average differs by only 2%. Cloud radiative forcing (ΔCRF) is often used as a diagnostic of cloud feedback strength. The net effect of the water vapor, temperature, and surface albedo changes on ΔCRF is -1.6 W m-2, based on the kernel technique, while the total ΔCRF from CAM is -1.3 W m^{-2}, indicating these components contribute significantly to ΔCRF and make it more negative. Assuming linearity of the ΔCRF contributions, these results indicate that the net cloud feedback in CAM is positive.

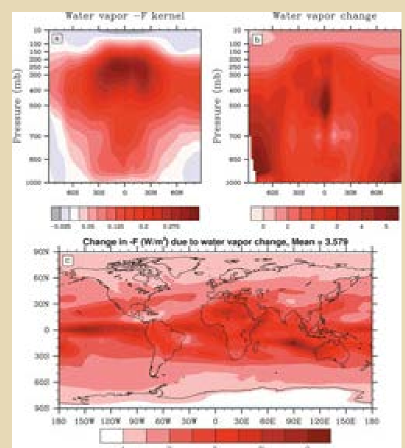

Figure 1.

High resolution figure

Figure caption: Example of the kernel technique. (a) The annual-average outgoing longwave flux (F) kernel for water vapor in units of W m^{-2} per 100 mb for a specific humidity increase corresponding to a 1-K temperature increase and constant relative humidity. (b) The annual-average specific humidity changes for the doubled-CO_2 case, divided by a specific humidity increase corresponding to a 1-K temperature increase and constant relative humidity (i.e., the specific humidity anomaly used to calculate the radiative kernel). (c) The resulting flux changes for the doubled-CO_2 case, obtained by combining the kernel and variable anomalies.

Support: Shell, supported by NCAR ASP. Kiehl, supported by DOE, Science of Climate Change Predicition Program. Shields, supported by NOAA GFDL.

Soden, B.J., I.M. Held, R. Colman, K.M. Shell, J.T. Kiehl, and C.A. Shields, 2008: Quantifying Climate Feedbacks Using Radiative Kernels. J. Climate, 21, 3504-3520.

Abstract: The extent to which the climate will change due to an external forcing depends largely on radiative feedbacks, which act to amplify or damp the surface temperature response. There are a variety of issues that complicate the analysis of radiative feedbacks in global climate models, resulting in some confusion regarding their strengths and distributions. In this paper, the authors present a method for quantifying climate feedbacks based on "radiative kernels" that describe the differential response of the top-of-atmosphere radiative fluxes to incremental changes in the feedback variables. The use of radiative kernels enables one to decompose the feedback into one factor that depends on the radiative transfer algorithm and the unperturbed climate state and a second factor that arises from the climate response of the feedback variables. Such decomposition facilitates an understanding of the spatial characteristics of the feedbacks and the causes of intermodel differences. This technique provides a simple and accurate way to compare feedbacks across different models using a consistent methodology. Cloud feedbacks cannot be evaluated directly from a cloud radiative kernel because of strong nonlinearities, but they can be estimated from the change in cloud forcing and the difference between the full-sky and clear-sky kernels. The authors construct maps to illustrate the regional structure of the feedbacks and compare results obtained using three different model kernels to demonstrate the robustness of the methodology. The results confirm that models typically generate globally averaged cloud feedbacks that are substantially positive or near neutral, unlike the change in cloud forcing itself, which is as often negative as positive.

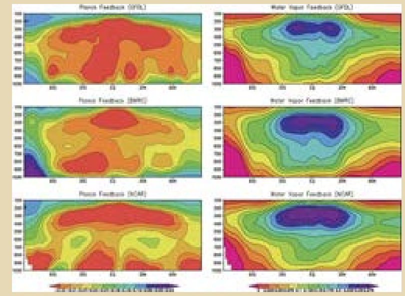

Figure 2.

High resolution figure

Figure caption: The annual-mean, zonal-mean temperature K^T and water vapor K^ω kernels under total-sky conditions for the (top) GFDL, (middle) CAWCR, and (bottom) NCAR models in units of W m^{-2} K^{-1} /100 hPa.

Support: Shell, supported by NCAR ASP. Kiehl, supported by DOE, Science of Climate Change Predicition Program. Shields, supported by NOAA GFDL.

Kiehl, J. T., 2007: Twentieth century climate model response and climate sensitivity. Geophys. Res. Lett., 34, L22710, doi:10.1029/2007GL031383.

Abstract: Climate forcing and climate sensitivity are two key factors in understanding Earth's climate. There is considerable interest in decreasing our uncertainty in climate sensitivity. This study explores the role of these two factors in climate simulations of the 20th century. It is found that the total anthropogenic forcing for a wide range of climate models differs by a factor of two and that the total forcing is inversely correlated to climate sensitivity. Much of the uncertainty in total anthropogenic forcing derives from a threefold range of uncertainty in the aerosol forcing used in the simulations.

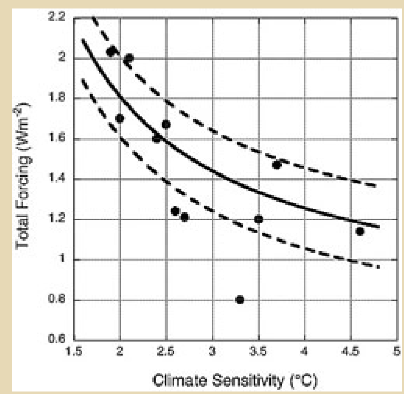

Figure 3.

High resolution figure

Figure caption: Total Anthropogenic Forcing (Wm^{-2}) versus equilibrium climate sensitivity (°C) from nine coupled climate models and two energy balance models that were used to simulate the climate of the 20th century. Solid line is theoretical relationship from equation (4). Dashed lines arise from assuming a ±0.2 Wm^{-2} uncertainty in ocean energy storage in equation (4).

Trenberth, K. E., J. T. Fasullo, and J. Kiehl, 2008: Earth's global energy budget. Bull. Amer. Meteor. Soc., in press.

Abstract: An update is provided on the Earth's global annual mean energy budget in the light of new observations and analyses. In 1997 Kiehl and Trenberth provided a review of past such estimates and performed a number of radiative computations to better establish the role of clouds and various greenhouse gases in the overall radiative energy flows, with top-of-atmosphere (TOA) values constrained by Earth Radiation Budget Experiment values form 1985 to 1989, when the TOA values were approximately in balance. The Clouds and the Earth's Radiant Energy System (CERES) measurements from March 2000 to May 2004 are used to TOA but adjusted to an estimated imbalance from the enhanced greenhouse effect of 0.9 W m^{-2}. Revised estimates of surface turbulent fluxes are made based on various sources. The partitioning of solar radiation in the atmosphere is based in part on the International Satellite Cloud Climatology Project (ISCCP) ISCCP-FD computations that utilize the global ISCCP cloud data every 3 hours, and also accounts for increased atmospheric absorpton by water vapor and aerosols. Surface upwards longwave radiation is adjusted to account for

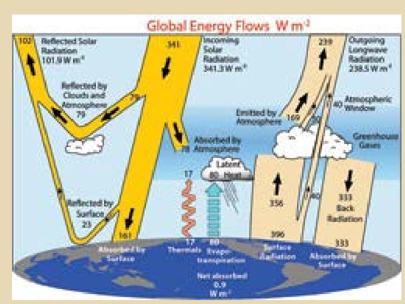

Figure 4.

High resolution figure

spatial and temporal variability. A lack of closure in the energy balance at the surface is accommodated by making modest changes to surface fluxes, with the downward longwave radiation as the main residual to ensure a balance. Values are also presented for the land and ocean domains that include a net transport of energy from ocean to land of 2.2 Petawatts (PW) of which 3.2 PW is from moisture (latent energy) transport, while net dry static energy transport is from land to ocean. Evaluations of atmospheric reanalyses reveal substantial biases.

Figure caption: The global annual mean Earth's energy budget for the March 2000 to May 2004 period in W m^{-2}. The broad arrows indicate the schematic flow of energy in proportion to their importance.

Kiehl, J. T., 2008: Modelling climates of the Late Palaeozoic. Williams, M., Haywood, A. M., Gregory, F. J. & Schmidt, D. N. (eds) Deep-Time Perspectives on climate Change: Marrying the Signal from Computer Models and Biological Proxies. The Micropalaeontological Society, Special Publications. The Geological Society, London, 157-167. 1747-602X/07.

Abstract: Climate models are comprehensive tools for studying Earth's past, present and future climate conditions. A spectrum of climate models is described with special focus on three-dimensional coupled atmosphere, ocean, land and cryosphere models. At present, these are the most sophisticated models to look at Earth's climate. Three time periods of the Late Palaeozoic are considered: the Carboniferous, the middle Permian and the latest Permian. Modelling the climate of these periods is reviewed to illustrate how models are applied to understanding past climates. Finally, the future development of climate modelling of the Late Palaeozoic is discussed.

Figure caption: Latest Permian surface temperatures (°C) for June-July-August (top) and December-January-February (bottom). Differences os zonal mean land surface temperatures from the present-day simulation are shown on the right (from Kiehl & Shields 2005).

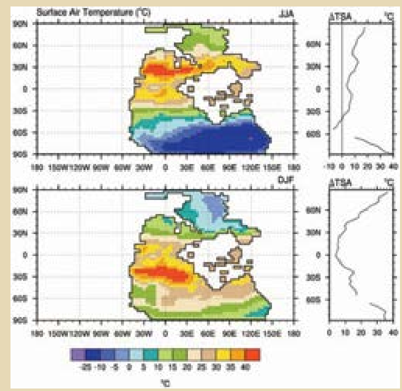

Figure 5.

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RICHARD ROTUNNO

2008 Publications

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. Mon. Wea. Rev., 136, 1990-2005, doi: 10.1175/2007MWR2085.1.

ABSTRACT

Real-time forecasts of five landfalling Atlantic hurricanes during 2005 using the Advanced Research Weather Research and Forecasting (WRF) (ARW) Model at grid spacings of 12 and 4 km revealed performance generally competitive with, and occasionally superior to, other operational forecasts for storm position and intensity. Recurring errors include 1) excessive intensification prior to landfall, 2) insufficient momentum exchange with the surface, and 3) inability to capture rapid intensification when observed. To address these errors several augmentations of the basic community model have been designed and tested as part of what is termed the Advanced Hurricane WRF (AHW) model. Based on sensitivity simulations of Katrina, the inner-core structure, particularly the size of the eye, was found to be sensitive to model resolution and surface momentum exchange. The forecast of rapid intensification and the structure of convective bands in Katrina were not significantly improved until the grid spacing approached 1 km. Coupling the atmospheric model to a columnar, mixed layer ocean model eliminated much of the erroneous intensification of Katrina prior to landfall noted in the real-time forecast.

Tan, Z.-M., F. Zhang, R. Rotunno, C. Snyder, 2008: Corrigendum. J. Atmos. Sci., 65.

ABSTRACT

In a seminal paper, E. N. Lorenz proposed that flows with many scales of motion in which smaller-scale error spreads to larger scales and in which the error-doubling time decreases with decreasing scale have a finite range of predictability. Although the Lorenz theory of limited predictability is widely understood and accepted, the model upon which the theory is based is less so. The primary objection to the model is that it is based on the two-dimensional vorticity equation (2DV) while simultaneously emphasizing results using a basic turbulent flow with a "-5/3" energy spectrum in the atmospheric synoptic scale instead of those using a more theoretically and observationally consistent "-3" spectrum. The present work generalizes the Lorenz model so that it may apply to the surface quasigeostrophic equations (SQGs), which are mathematically very similar to 2DV but are known to have a -5/3 kinetic energy spectrum downscale from a large-scale forcing. This generalized Lorenz model is applied here to both 2DV (with a -3 spectrum) and SQG (with a -5/3 spectrum), producing examples of flows with unlimited and limited predictability, respectively. Comparative analysis of the two models allows for the identification of the distinctive attributes of a many-scaled flow with limited predictability.

Rotunno, R., C. Snyder, 2008: A generalization of Lorenz's model for the predictability of flows with many scales of motion. J. Atmos. Sci., 65, 1063-1076, doi: 10.1175/2007JAS2449.1.

Bryan, G. H., R. Rotunno, 2008: Gravity currents in a deep anelastic atmosphere. J. Atmos. Sci., 65, 536-556, doi: 10.1175/2007JAS2443.1.

ABSTRACT

This study presents analytic results for steady gravity currents in a channel using the deep anelastic equations. Results are cast in terms of a nondimensional parameter H/H0 that relates the channel depth H to a scale depth H0 (the depth at which density goes to zero in an isentropic atmosphere). The classic results based on the incompressible equations correspond to H/H0 = 0. For cold gravity currents (at the bottom of a channel), assuming energy-conserving flow, the nondimensional current depth h/H is much smaller, and nondimensional propagation speed C/(gH)1/2 is slightly smaller as H/H0 increases. For flows with energy dissipation, C/(gH)1/2 decreases as H/H0 increases, even for fixed h/H. The authors conclude that as H/H0 increases the normalized hydrostatic pressure rise in the cold pool increases near the bottom of the channel, whereas drag decreases near the top of the channel; these changes require gravity currents to propagate slower for steady flow to be maintained. From these results, the authors find that steady cold pools have a likely maximum depth of 4 km in the atmosphere (in the absence of shear). For warm gravity currents (at the top of a channel), h/H is slightly larger and C/(gH)1/2 is much larger as H/H0 increases. The authors also conduct two-dimensional numerical simulations of "lock-exchange flow" to provide an independent evaluation of the analytic results. For cold gravity currents the simulations support the analytic results. However, for warm gravity currents the simulations show unsteady behavior that cannot be captured by the analytic theory and which appears to have no analog in incompressible flow.

Reeves, H. D., Y.-L. Lin, R. Rotunno, 2008: Dynamic forcing and mesoscale variability of heavy precipitation events over the Sierra Nevada mountains. Mon. Wea. Rev., 136, 62-77, doi: 10.1175/2007MWR2164.1.

ABSTRACT

The aim of this research is to investigate the causes for an isolated maximum in precipitation that is typically found along the northern half of the Sierra Nevada mountains of California, in the vicinity of Plumas National Forest (PNF), during moderate to heavy precipitation events. Particular attention was paid to the role various mesoscale (i.e., <200 km) terrain features may have played in localizing the precipitation at PNF. Numerical simulations and sensitivity experiments for two cases of heavy precipitation at PNF reveal that the extent to which terrain acts to focus precipitation is case sensitive. In the first case, the upstream flow was characterized by a strong horizontal gradient in wind speed and moisture. This gradient led to differential deflection of airstreams incident to the range and, consequently, localized convergence and enhanced rain rates at PNF. This localized enhancement occurred regardless of whether any terrain variations were present in the simulations or not. The second case was characterized by more a horizontally uniform upstream flow and showed a much stronger sensitivity to terrain variations, in particular, short- and long-wavelength undulations along the leading (west) edge of the Sierra Nevada range. When these undulations were removed, no localized maxima in precipitation occurred.

Kirshbaum, D. J., R. Rotunno, G. H. Bryan, 2007: The spacing of orographic rainbands triggered by small-scale topography. J. Atmos. Sci., 64, 4222-4245, doi: 10.1175/2007JAS2335.1.

ABSTRACT

A combination of idealized numerical simulations and analytical theory is used to investigate the spacing between convective orographic rainbands over the Coastal Range of western Oregon. The simulations, which are idealized from an observed banded precipitation event over the Coastal Range, indicate that the atmospheric response to conditionally unstable flow over the mountain ridge depends strongly on the subridge-scale topographic forcing on the windward side of the ridge. When this small-scale terrain contains only a single scale (?) of terrain variability, the band spacing is identical to ?, but when a spectrum of terrain scales are simultaneously present, the band spacing ranges between 5 and 10 km, a value that is consistent with observations. Based on the simulations, an inviscid linear model is developed to provide a physical basis for understanding the scale selection of the rainbands. This analytical model, which captures the transition from lee waves upstream of the orographic cloud to moist convection within it, reveals that the spacing of orographic rainbands depends on both the projection of lee-wave energy onto the unstable cap cloud and the growth rate of unstable perturbations within the cloud. The linear model is used in tandem with numerical simulations to determine the sensitivity of the band spacing to a number of environmental and terrain-related parameters.

Antonelli, M., R. Rotunno, 2007: Large-eddy simulation of the onset of the sea breeze. J. Atmos. Sci., 64, 4445-4457, doi: 10.1175/2007JAS23261.1.

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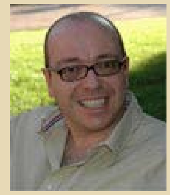
CGD 2008 PROFILES IN SCIENCE: DR. FABRIZIO SASSI



Fabrizio Sassi

Publications

Richter, J. H., F. Sassi, R. R. Garcia, K. Matthes, and C. A. Fischer, 2008: Dynamics of the middle atmosphere as simulated by the Whole Atmosphere Community Climate Model, version 3 (WACCM3). J. Geophys. Res., 113, D08101, doi:10.1029/2007JD009269.

Abstract: The Whole Atmosphere Community Climate Model, version 3 (WACCM3) is a state-of-the-art climate model extending from the Earth's surface to the lower thermosphere. In this paper we present a detailed climatology of the dynamics of the middle atmosphere as represented by WACCM3 at various horizontal resolutions and compare them to observations. In addition to the mean climatological fields, we examine in detail the middle atmospheric momentum budget as well as several lower and upper atmosphere coupling phenomena including stratospheric sudden warmings, the 2-day wave, and the migrating diurnal tide. We find that in large part, differences between WACCM3 and observations and the mean state of the model at various horizontal resolutions are related to gravity wave drag, which is parameterized in WACCM3 (and similar models). All three lower and upper atmosphere coupling processes examined show high sensitivity to the model's resolution.

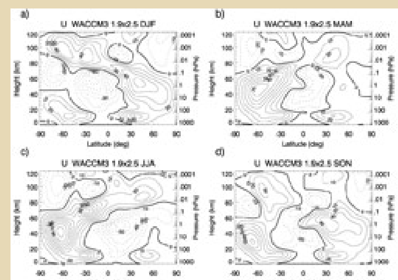


Figure 1.

High resolution figure

Figure caption: Seasonally averaged zonal wind in m s^{-1} averaged over 30 years of WACCM3 simulation at 1.9° x 2.5° resolution.

Yuan, T., C.-Y. She, D. A. Krueger, F. Sassi, R. Garcia, R. G. Roble, H.-L. Liu, and H. Schmidt, 2008: Climatology of mesopause region temperature, zonal wind, and meridional wind over Fort Collins, Colorado (41°N, 105°W), and comparison with model simulations. J. Geophys. Res., 113, D03105, doi:10.1029/2007JD008697.

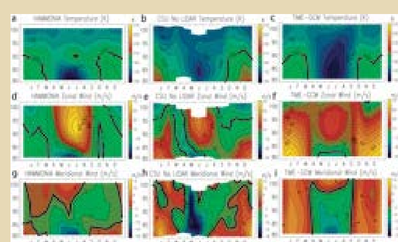


Figure 2.

High resolution figure

Abstract: Between May 2002 and April 2006, many continuous observations of mesopause region temperature and horizontal wind, each lasting longer than 24 h (termed full-diurnal-cycle observations), were completed at the Colorado State University Na Lidar Facility in Fort Collins, Colorado (41°N, 105°W). The combined data set consists of 120 full-diurnal-cycle observations binned on a monthly basis, with a minimum of 7 cycles in April and a maximum of 18 cycles in August. Each monthly data set was analyzed to deduce mean values and tidal period perturbations. After removal of tidal signals, monthly mean values are used for the study of seasonal variations in mesopause region temperature, zonal and meridional winds. The results are in qualitative agreement with our current understanding of mean temperature and wind structures in the midlatitude mesopause region with an observed summer mesopause of 167 K at 84 km, summer peak eastward zonal wind of 48 m/s at 94 km, winter zonal wind reversal at ~95 km, and peak summer (pole) to winter (pole) meridional flow of 17 m/s at 86 km. The observed mean state in temperature, zonal and meridional winds are compared with the predictions of three current general circulation models, i.e., the Whole Atmosphere Community Climate Model version 3 (WACCM3) with two different simulations of gravity wavefields, the Hamburg Model of the Neutral and Ionized Atmosphere (HAMMONIA), and the 2003 simulation of the Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM). While general agreement is found between

observation and model predictions, there exist discrepancies between model prediction and observation, as well as among predictions from different models. Specifically, the predicted summer mesopause altitude is lower by 3 km, 8 km, 3 km, and 1 km for WACCM3 the two WACCM runs, HAMMONIA, and TIME-GCM, respectively, and the corresponding temperatures are 169 K, 170 K, 158 K, and 161 K. The model predicted summer eastward zonal wind peaks to 71 m/s at 102 km, to 48 m/s at 84 km, to 75 m/s at 93 km, and to 29 m/s at 94 km, in the same order. The altitude of the winter zonal wind reversal and seasonal asymmetry of the pole-to-pole meridional flow are also compared, and the importance of full-diurnal-cycle observations for the determination of mean states is discussed.

Figure caption: Comparison between Na-lidar with HAMMONIA and TIME-GCM predictions. (a-c) Temperature, (d-f) zonal wind, and (g-i) meridional wind. Figures 4a, 4d, and 4g are for HAMMONIA; Figures 4b, 4e, and 4h are for Na_lidar; and Figures 4c, 4f, and 4i are for TIME-GCM. Positive winds are eastward for zonal wind and northward for meridional wind.

Agostini, R., F. Sassi, and M. M. Del viva, 2007: Spatial integration of contours: Orientation counts when local elements are close. Perception, 36, 36-36.

Tilmes, S., D. E. Kinnison, R. R. Garcia, R. Müller, F. Sassi, D. R. Marsh, and B. A. Boville, 2007: Evaluation of heterogeneous processes in the polar lower stratosphere in the Whole Atmosphere Community Climate Model. J. Geophys. Res., 112, D24301, doi:10.1029/2006JD008334.

Abstract: Chemical ozone loss in the polar lower stratosphere is derived from an ensemble of three simulations from the Whole Atmosphere Community Climate Model (WACCM3) for the period 1960-2003, using the tracer-tracer correlation technique. We describe a detailed model evaluation of the polar region by applying diagnostics such as vortex temperature, sharpness of the vortex edge, and the potential of activated chlorine (PACl). Meteorological and chemical information about the polar vortex, temperature, vortex size, and activation time, and level of equivalent effective stratospheric chlorine, are included in PACl. Discrepancies of the relationship between chemical ozone loss and PACl between model and observations are discussed. Simulated PACl for Antarctica is in good agreement with observations, owing to slightly lower simulated temperatures and a larger vortex volume than observed. Observed chemical ozone loss of 140 ± 30 DU in the Antarctic vortex core are reproduced by the WACCM3 simulations. However, WACCM3 with the horizontal resolution used here (4 × 5) is not able to simulate the observed sharp transport barrier at the polar vortex edge. Therefore the model does not produce an homogeneous cold polar vortex. Warmer temperatures in the outer region of the vortex result in less chemical ozone loss over the entire polar vortex than observed. For the Arctic, WACCM3 temperatures are biased high (by 2-3 degrees in the annual average) and the vortex volume and chlorine activation period is significantly smaller than observed. WACCM3 Arctic chemical ozone loss only reaches 20 DU for cold winters, where observations suggest ~80-120 DU.

Figure caption: Distribution of different species, O_3 (first row), N_2O (second row), HNO_3 (third row), and H_2O (fourth row) in the Antarctic polar vortex on the 475 K isentropic surface for different days of one WACCM3 realization. White lines indicate the poleward edge, the edge, and the equatorward edge of the polar vortex; see section 3. The black line indicates the area below 195 K, the approximate temperature threshold for chlorine activation.

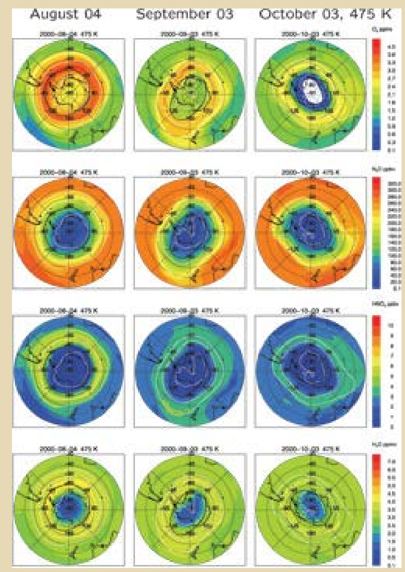


Figure 3.

High resolution figure

Marsh, D. R., R. R. Garcia, D. E. Kinnison, B. A. Boville, F. Sassi, S. C. Solomon, and K. Matthes,2007: Modeling the whole atmosphere response to solar cycle changes in radiative and geomagnetic forcing. J. Geophys. Res., 112, D23306, doi:10.1029/2006JD008306.

Abstract: The NCAR Whole Atmosphere Community Climate Model, version 3 (WACCM3), is used to study the atmospheric response from the surface to the lower thermosphere to changes in solar and geomagnetic forcing over the 11-year solar cycle. WACCM3 is a general circulation model that incorporates interactive chemistry that solves for both neutral and ion species. Energy inputs include solar radiation and energetic particles, which vary significantly over the solar cycle. This paper presents a comparison of simulations for solar cycle maximum and solar cycle minimum conditions. Changes in composition and dynamical variables are clearly seen in the middle and upper atmosphere, and these in turn affect terms in the energy budget. Generally good agreement is found between the model response and that derived from satellite observations, although significant differences remain. A small but statistically significant response is predicted in tropospheric winds and temperatures which is consistent with signals observed in reanalysis data sets.

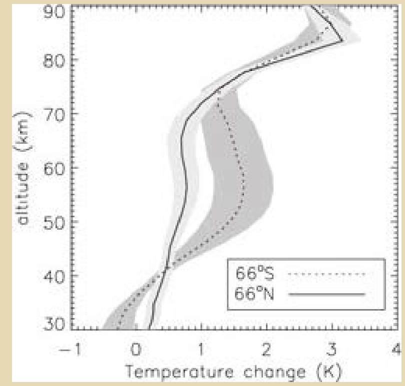


Figure caption: WACCM solar maximum minus minimum annual mean temperature differences at ±66° latitude. Shaded regions indicate 1-sigma uncertainties.

Figure 4.

High resolution figure

Kinnison, D. E., et al.,2007: Sensitivity of chemical tracers to meteorological parameters in the MOZART-3 chemical transport model. J. Geophys. Res., 112, D20302, doi:10.1029/2006JD007879.

Abstract: The Model for Ozone and Related Chemical Tracers, version 3 (MOZART-3), which represents the chemical and physical processes from the troposphere through the lower mesosphere, was used to evaluate the representation of long-lived tracers and ozone using three different meteorological fields. The meteorological fields are based on (1) the Whole Atmosphere Community Climate Model, version 1b (WACCM1b), (2) the European Centre for Medium-Range Weather Forecasts (ECMWF) operational analysis, and (3) a new reanalysis for year 2000 from ECMWF called EXP471. Model-derived tracers (methane, water vapor, and total inorganic nitrogen) and ozone are compared to data climatologies from satellites. Model mean age of air was also derived and compared to in situ CO2 and SF6 data. A detailed analysis of the chemical fields simulated by MOZART-3 shows that even though the general features characterizing the three dynamical sets are rather similar, slight differences in winds and temperature can produce substantial differences in the calculated distributions of chemical tracers. The MOZART-3 simulations that use meteorological fields from WACCM1b and ECMWF EXP471 represented best the distribution of long-lived tracers and mean age of air in the stratosphere. There was a significant improvement using the ECMWF EXP471 reanalysis data product over the ECMWF operational data product. The effect of the quasi-biennial oscillation circulation on long-lived tracers and ozone is examined.

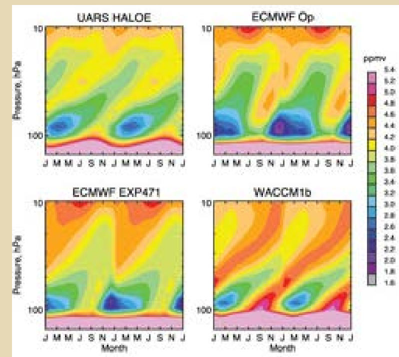


Figure 5.

High resolution figure

Figure caption: Height-time sections of water vapor volume mixing ratio derived in the equatorial region (averaged between 12°S and 12°N). Observations are based on HALOE data. Two consecutive seasonal cycles are shown in each diagram.

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SUE SCHAUFFLER

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Research Focus FY08:

In addition to her role as ACD Associate Director, Sue Schauffler is involved with the TIIMES Upper Troposphere - Lower Stratosphere (UTLS) initiative focusing on the following topics. She is also a member of the UTLS Steering Committee.

- Measurement of trace gases in the atmosphere and ocean
- Chemical and biological oceanography
- Stratospheric bromine budget

Scientific Talks FY08:

- Short-Lived Organic Compounds in the UT/LS: First results from the TC4 mission (San Francisco, CA USA, 12/2007)
- First results from the TC4 mission: Short-Lived Organic Compounds in the UT/LS (Virginia Beach, VA USA, 02/2008)
- Contribution of Short-Lived Organic Halogens to the Tropical UTLS (Annecy, FRA, 09/2008)

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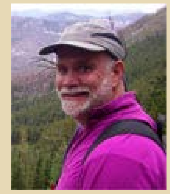
CGD 2008 PROFILES IN SCIENCE: DR. DAVID SCHIMEL



David Schimel

Publications

Keller, M., D. Schimel, and W. W. Hargrove, 2008: A continental strategy for the National Ecological Observatory Network. Frontiers in Ecology and the Enviornment, 6, 282-284.

---

von Fischer, J. C., L. L. Tieszen, and D. S. Schimel, 2008: Climate controls on C3 vs. C4 productivity in North American grasslands from carbon isotope composition of soil organic matter. Global Change biology, 14, 1141-1155, doi:10.1111/j.1365-2486.2008.01552.x

Abstract: We analyzed the d13C of soil organic matter (SOM) and fine roots from 55 native grassland sites widely distributed across the US and Canadian Great Plains to examine the relative production of C3 vs. C4 plants (hereafter %C4) at the continental scale. Our climate vs. %C4 results agreed well with North American field studies on %C4, but showed bias with respect to %C4 from a US vegetation database (statsgo) and weak agreement with a physiologically based prediction that depends on crossover temperature. Although monthly average temperatures have been used in many studies to predict %C4, our analysis shows that high temperatures are better predictors of %C4. In particular, we found that July climate (average of daily high temperature and month's total rainfall) predicted %C4 better than other months, seasons or annual averages, suggesting that the outcome of competition between C3 and C4 plants in North American grasslands was particularly sensitive to climate during this narrow window of time. Root d13C increased about 1% between the A and B horizon, suggesting that C4 roots become relatively more common than C3 roots with depth. These differences in depth distribution likely contribute to the isotopic enrichment with depth in SOM where both C3 and C4 grasses are present.

Figure 1.

High resolution figure

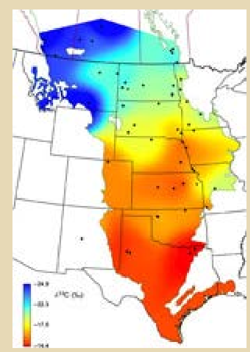


Figure caption: Map of $\delta^{13}C$ of A-horizon SOM interpolated over the Great Plains ecoregion. Points mark sampling sites; kriging is by inverse weighting with exponential decay. SOM, soil organic matter.

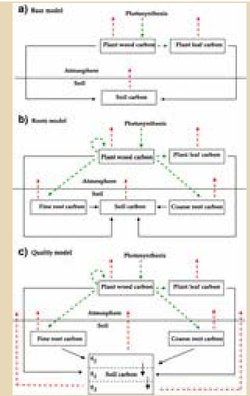
Agostini, R., F. Sassi, and M. M. Del viva, 2007: Spatial integration of contours: Orientation counts when local elements are close. Perception, 36, 36-36.

Zobitz, J. M., D. J. P. Moore, W. J. Sacks, R. K. Monson, D. R. Bowling, and D. S. Schimel, 2008: Integration of Process-based Soil Respiration Models with Whole-Ecosystem CO2 Measurements. Ecosystems, 11, 250-269, doi:10.1007/s10021-007-9120-1.

Abstract: We integrated soil models with an established ecosystem process model (SIPNET, simplified photosynthesis and evapotranspiration model) to investigate the influence of soil processes on modelled values of soil CO_2 fluxes (R Soil). Model parameters were determined from literature values and a data assimilation routine that used a 7-year record of the net ecosystem exchange of CO_2 and environmental variables collected at a high-elevation subalpine forest (the Niwot Ridge AmeriFlux site). These soil models were subsequently evaluated in how they estimated the seasonal contribution of R Soil to total ecosystem respiration (TER)

Figure 2.

High resolution figure



and the seasonal contribution of root respiration (R Root) to R Soil. Additionally, these soil models were compared to data assimilation output of linear models of soil heterotrophic respiration. Explicit modelling of root dynamics led to better agreement with literature values of the contribution of R Soil to TER. Estimates of R Soil/TER when root dynamics were considered ranged from 0.3 to 0.6; without modelling root biomass dynamics these values were 0.1-0.3. Hence, we conclude that modelling of root biomass dynamics is critically important to model the R Soil/TER ratio correctly. When soil heterotrophic respiration was dependent on linear functions of temperature and moisture independent of soil carbon pool size, worse model-data fits were produced. Adding additional complexity to the soil pool marginally improved the model-data fit from the base model, but issues remained. The soil models were not successful in modelling R Root/R Soil. This is partially attributable to estimated turnover parameters of soil carbon pools not agreeing with expected values from literature and being poorly constrained by the parameter estimation routine. We conclude that net ecosystem exchange of CO2 alone cannot constrain specific rhizospheric and microbial components of soil respiration. Reasons for this include inability of the data assimilation routine to constrain soil parameters using ecosystem CO_2 flux measurements and not considering the effect of other resource limitations (for example, nitrogen) on the microbe biomass. Future data assimilation studies with these models should include ecosystem-scale measurements of R Soil in the parameter estimation routine and experimentally determine soil model parameters not constrained by the parameter estimation routine.

Figure caption: SIPNET pools and fluxes for carbon. Photosynthesis, respiration, and allocation fluxes are denoted with dashed lines. Turnover fluxes are denoted with solid lines.

D. S. Schimel, 2007: Carbon cycle conundrums. Proc. of the Nat. Acad. of Sciences, doi:10.1073/pnas.0709331104.

What will control future rates of climate change? The carbon cycle is the largest contributor to anthropogenic climate change, yet despite decades of research (1), significant mysteries about its behavior remain. Global analyses show that the Earth system absorbs approximately half of anthropogenic fossil fuel emissions. This uptake is partitioned between absorption by the oceans and storage in terrestrial ecosystems. Uptake by the Earth system reduces the climate effects of emitted CO_2 to approximately half of what would occur without sinks. Models tend to project sinks, particularly terrestrial sinks, into the future based on assumptions about the behavior of mechanisms derived from small plot or laboratory studies.

The observational record is now long enough and rich enough to provide strong constraints on both the human and the biogeochemical behavior of the carbon cycle. In this issue of PNAS, Canadell et al. (2) report an increase in the rate of increase in CO_2 in the atmosphere (henceforth called the "growth rate"). They analyze the historical carbon record and industrial and biogeochemical causes to changes in its behavior over time. Industrial growth is responsible for ~65% of the change in the growth rate, 17% is caused by increasing carbon intensity (fossil fuel use/gross world product), and 18% is caused by reduced sinks in the Earth system. The reduction over time of the efficiency of the sinks is of great concern because it implies a weakening in the ability of the Earth system to mitigate the effects of fossil fuel emissions and a potential positive feedback that may strengthen in the future.

Matson, P. A., W. C. Clark, A. Gadgil, D. M. Liverman, R. L. Naylor, I. Ray, and D. S. Schimel, 2007: Preface. Annual Review of Environment and Resources, 32, VI-VI .

Doney, S. C. and D. S. Schimel, 2007: Carbon and climate system coupling on timescales from the Precambrian to the anthropocene. Annual Review of Environment and Resources, doi:10.1146/annurev.energy.32.041706.124700.

Abstract: Over a range of geological and historical timescales, warmer climate conditions are associated with higher atmospheric levels of CO2, an important climate-modulating greenhouse gas. Coupled carbonclimate interactions have the potential to introduce both stabilizing and destabilizing feedback loops into Earth's system. Here we bring together evidence on the dominant climate, biogeochemical and geological processes organized by timescale, spanning interannual to centennial climate variability, Holocene millennial variations and Pleistocene glacial-interglacial cycles, and million-year and longer variations over the Precambrian and Phanerozoic. Our focus is on characterizing, and where possible quantifying, internal coupled carbon-climate system dynamics and responses to external forcing from tectonics, orbital dynamics, catastrophic events, and anthropogenic fossil-fuel emissions. One emergent property is clear across timescales: atmospheric CO_2 can increase quickly, but the return to lower levels through natural processes is much slower. The consequences of human carbon cycle perturbations will far outlive the emissions that caused them.

Costanza, R., L. Graumlich, W. Steffen, C. Crumley, J. Dearing, K. Hibbard, R. Leemans, C. Redman, and D. S. Schimel, 2007: Sustainability or to collapse: What can we learn from integrating the history of humans and the rest of nature? Ambio, 36, 522-527.

Abstract: Understanding the history of how humans have interacted with the rest of nature can help clarify the options for managing our increasingly interconnected global system. Simple, deterministic relationships between environmental stress and social change are inadequate. Extreme drought, for instance, triggered both social collapse and ingenious management of water through irrigation. Human responses to change, in turn, feed into climate and ecological systems, producing a complex web of multidirectional connections in time and space. Integrated records of the co-evolving human-environment system over millennia are needed to provide a basis for a deeper understanding of the present and for forecasting the future. This requires the major task of assembling and integrating regional and global historical, archaeological, and paleoenvironmental records. Humans cannot predict the future. But, if we can adequately understand the past, we can use that understanding to influence our decisions and to create a better, more sustainable and desirable future.

Figure caption: Selected indicators of environmental and human history.

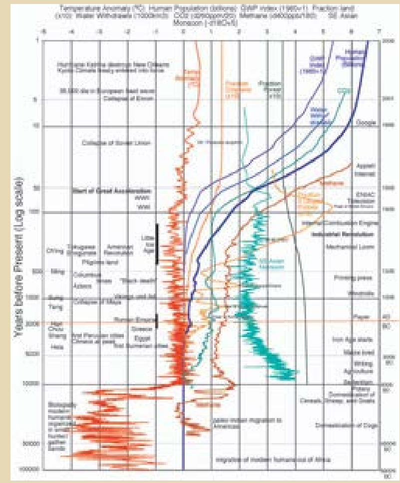


Figure 3.

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CARL SCHMIDT

2008 Publications

Schmitt, C. G., A. J. Heymsfield, 2007: On the occurrence of hollow bullet rosette- and column-shaped ice crystals in midlatitude cirrus. J. Atmos. Sci., 64, 4514-4519, doi: 10.1175/2007JAS2317.1.1

Abstract

Cirrus clouds in mid- and high latitudes are frequently composed of bullet rosette– and column-shaped ice crystals, which can have hollow ends. Bullet rosette–shaped ice crystals are composed of a number of bullets radiating from a central point. Research has shown that the light-scattering properties of ice particles with hollow ends are different from the scattering properties of solid ice particles. Knowledge of the frequency of occurrence of hollow particles is important to more accurately calculate the radiative properties of cirrus clouds.

This note presents the results of a survey of cirrus cloud ice crystal replicas imaged from balloon-borne Formvar (polyvinyl formal) replicators. Fifty percent to 80% of the replicated bullet rosette– and column-shaped particles had hollow ends. In bullets longer than 150 μm in length, the length of the hollows of the bullets averaged 88% of the total length of the bullet. The combined length of both hollow portions of column-shaped ice crystals varied from 50% of the length of the column for 30-μm-long columns to 80% of the length of the columns longer than 200 μm. Asymmetry parameter values estimated from cirrus cloud aircraft particle size distributions are higher by 0.014 when hollow crystals are considered. This difference leads to a 2.5 W m-2 increase for hollow crystals at the surface for a 0.5 optical depth cloud, demonstrating the importance of the incorporation of hollow particle scattering characteristics into radiative transfer calculations.

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CARL SCHMITT

General Information

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Research Focus FY08:

The bulk of my TIIMES research has been spent researching the properties of tropical cirrus cloud microphysical data from aircraft field projects. The properties of tropical cirrus cloud particles are important for a better understanding of Upper Troposphere/Lower Stratosphere (UTLS) water vapor exchange as well as for radiative transfer applications.

We have been working on data from the Video Ice Particle Sampler Probe* (VIPS) taken during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment (CRYSTAL-FACE: EOL Project page - NASA page - photo gallery) and Pre-Aura Validation Experiment** (Pre-AVE) field programs during time periods when the aircraft was in thin tropical cirrus. Our data analysis is focused on better understanding the fall speed and mass dimensional properties as they relate to climate model parameterizations. Mass weighted fall speeds calculated from the terminal velocity estimates and particle size distributions indicate that GCM parameterizations over estimate fall speeds. The fall speeds of sub-visible cirrus clouds is particularly important as slower fall speeds leads to longer cloud lifetimes. We are also working on laboratory measurements that will enable us to make better estimates of the mass of very small ice crystals similar to those observed in the UTLS cirrus.

*** Video Ice Particle Sampler**: An aircraft-mounted instrument which first collects cloud particles then images them and records them on videotape. It has collected ice particles as small as 5 microns and is an important complement to the 2D-C imaging probes which provide information on much larger particles. Provides unique and important means of assessing cloud microphysical composition with the accuracy and resolution necessary to consider crucial questions relating to the role of clouds in affecting global climate.

**** Pre-AVE**: (Pre Aura Validation Experiment) occurred in January - February 2004 in Costa Rica, sponsored by NASA. It has produced some key data about water and clouds in the tropics.

Scientific Talks FY08:

- International Conference on Clouds and Precipitation (Cancun, Mexico, July 2008)
- UTLS/START08 Cirrus Cloud Properties (Boulder, Colorado, August 2008)

Publications FY08 (abstract):

Schmitt, C. G., A. J. Heymsfield, 2007: On the occurrence of hollow bullet rosette- and column-shaped ice crystals in midlatitude cirrus. *J. Atmos. Sci.*, **64**, 4514-4519, doi: 10.1175/2007JAS2317.1.

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Director's Message

Table of Contents

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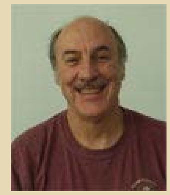
CGD 2008 PROFILES IN SCIENCE: DENNIS SHEA

Summary of achievements



Dennis Shea

In recent years, dataset creation and software development and training are my primary activities:

(a) The created datasets form the basis for research and model evaluation. The original observationally based datasets are from a myriad of sources (NCEP, ECMWF, JRA, ...), file formats (GRIB-1, GRIB-2, netCDF3, HDF4-SDS and HDF-EOS2) and different resolutions both horizontally and vertically. These datasets have strengths and weaknesses and should not be used blindly. Careful comparisons such as those performed by the Climate Analysis Section reveal assorted issues and limitations. Converting the datasets to assorted basic resolutions and netCDF format facilitate use via a variety of commonly used software tools. Recently, numerous datasets used in Chapters 3 and 10 of the 2007 IPCC report were made available.(http://cdp.ucar.edu/)

(b) The NCAR Command Language (NCL) is a collaborative effort between CGD and CISL to develop a free, portable software tool capable of easily handling multiple data formats, performing computations and creating high quality graphics (http://www.ncl.ucar.edu/). In early 1997, NCL was chosen as the "official" tool for CCSM related activities. Since then, I have been actively involved in NCL's development, user support and training. Mary Haley (CISL) and I have been involved in teaching numerous NCL Workshops (http://www.ncl.ucar.edu/Training/Workshops/). One example of CCSM support was the development of the NCL's Taylor diagram which is used for model evaluation (http://www.ncl.ucar.edu/Applications/taylor.shtml).

Prior to the above activities, I was actively involved in research including El Niño/La Niña, the potential for long-range prediction and solar/climate connections. I have authored and co-authored 28 peer reviewed journal articles and 30 technical reports and proceedings papers.

Publications

Referreed

Hurrell, J. W., J. J. Hack, D. Shea, J. M. Caron, and J. Rosinski, 2008: A new sea surface temperature and sea ice boundary data set for the Community Atmosphere Model, Journal of Climate, 21, 5145-5153.

Abstract: A new surface boundary forcing data set for uncoupled simulations with the Community Atmosphere Model is described. It is a merged product based on the monthly mean Hadley Centre sea ice and SST data set version 1 (HadISST1) and version 2 of the National Oceanic and Atmospheric Administration (NOAA) weekly optimum interpolation (OI) SST analysis. These two source data sets were also used to supply ocean surface information to the European Centre for Medium-Range Weather Forecasts 40-year reanalysis project (ERA-40). Our merged product provides monthly mean sea surface temperature and sea ice concentration data from 1870 to the present: it is updated monthly, and it is freely available for community use. The merging procedure was designed to take full advantage of the higher resolution SST information inherent in the NOAA OI.v2 analysis.

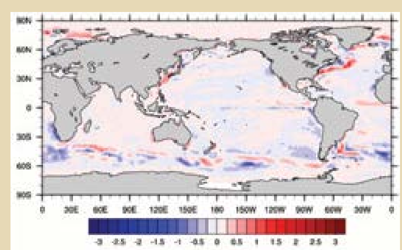


Figure 1.

High resolution figure

Figure caption: Differences between the 30-yr 1971-2000 SST climatologies (OI.v2 - HadISST1) in °C. The color contours are 0.25°C up to absolute 3°C.

van Loon, H., G. A. Meehl, and D. J. Shea (2007), Coupled air-sea response to solar forcing in the Pacific region during northern winter. J. Geophys. Res., 112, D02108, doi:10.1029/2006JD007378

Non-Referreed

Brown, D.; M. Haley, F. Clare, D. Shea; D. Middleton: Frameworks for geoscience data analysis and visualization. Presented at the EGU General Assembly 2008.

Shea, D.J., S.J. Worley, I.A. Stern and T.J. Hoar, 1996 (updated 2007): An Introduction to Atmospheric and Oceanographic Data. NCAR/TN-404+IA. 134pp. (WWW version: http://www.cgd.ucar.edu/cas/tn404/)

CGD Research Catalog

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STEPHEN SHERTZ

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TIIMES
Engineer III

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Research Focus FY08:

Steve is the TIIMES engineer working on a variety of projects for the Water System, BEACHON, and Biogeochemistry projects. A few of the many projects, field studies and instruments he is or has been involved with include:

- Development and FAA certification of aircraft based instruments.
- Global Biogeochemical Cycles
- Regional Carbon Cycle
- Community Airborne Oxygen Instrument Development
- Oxygen & Carbon Dioxide Calibration, Profiles, & Measurements
- Regional Atmospheric Continuous CO2 Network in the Rocky Mountains (Rocky RACCOON)
- Airborne Carbon in the Mountains Experiment (ACME) with the Airborne CO2 Instrument
- Carbon in the Mountain Experiment (CME)
- Intermittent Sampler: a collaboratorive effort (EOL, MMM, ACD) lead by Al Cooper & Steve Shertz. The sampler provides a method for measuring high-rate fluxes with slow-response instruments. The sampler uses fast-response valves to capture air samples that can be measured with slow-response chemical sensors.
- MOPITT Airborne/Algorithm Test Radiometer (MATR): Ues gas filter correlation radiometry to measure tropospheric carbon monoxide (CO) with three optical channels or methane (CH4) with one channel..
- BOREAS: Field Project Examines Interactions Between Forests and the Atmosphere

Steve was a co-author in the 1992 Outstanding Publication Award: Ralph Keeling and Stephen Shertz, "Seasonal and interannual variations in atmospheric oxygen and implications for the global carbon cycle," *Nature 358* (1992), 723-727.

Water Vapor Reference Sounding System

He is also a member of the Earth Observing Laboratory (EOL) Technology Development Facility responsible for the Water Vapor Reference Sounding System and the EOL Engineering Group. This collaboration between NSF/EOL and Southwest Sciences Incorporated (SWI) is aimed at exploring the feasibility of balloon-borne tunable diode laser (TDL) technology for in-situ water vapor measurements with verifiable accuracy. Such measurements are badly needed by the climate community. Status: Significant progress has been achieved on this project. A test facility that will be used to introduce known water vapor mixing ratios at a variety of pressures and temperatures indicative of the surface to ~ 30 km has been designed and a design review carried out. Valuable suggestions for improvements to this design are now being incorporated in the final design. This facility will challenge two TDL systems from SWI at various intervals over a yearlong time period. Many system components have been ordered and machining of the test chamber will begin once the two laser systems arrive at NCAR sometime within the next month. Completion of the test facility is anticipated this fall and the formal tests will commence.

Community Service FY08:

- Front Range Rescue Dogs (FRRD): Volunteers from Boulder County dedicated to training dogs and each other to assist on searches for the missing child, hiker, hunter, skier, water enthusiast or accident victim.

Stephen Shertz Research Catalog

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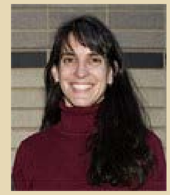
CGD 2008 PROFILES IN SCIENCE: CHRISTINE SHIELDS

Summary of achievements



Christine Shields

As the CCSM deep time paleoclimate liason, Christine has been involved with several deep time community research efforts including studies on the Permian (250 million years ago), the Cretaceous (100 million years ago), the Paleo-Eocene Thermal Maximum (PETM) (55 million years ago), and most recently, the Ordovician (445 million years ago). Christine works with Jeff Kiehl fostering collaborations aimed at providing better interaction between the university paleo-geography community and climate modellers.

A large part of Christine's work involves designing, modifying, and running the CCSM for deep time paleoclimatic periods. In FY2008, she worked on the design and creation of a fully coupled CCSM for the late Ordovician (a world of of high CO2 yet glacial conditions where the first of earth's five major extinctions occured). Other research projects in FY2008 included studies on CO2 weathering rates, warm polar climates (specifically in the Permian and PETM), and projects on Permian variability (covering topics such as hurricanes to monsoons to Arctic Oscillation-type phenomena). For deep time warm polar climates, the disparity between model results and data proxies has long been a subject of interest to the paleoclimate community.

Christine also works with Jeff Kiehl on climate sensitivity questions. In FY2008, she worked with Jeff Kiehl, Phil Rasch, and Jim Hack on developing a tuned version of eularian low-resolution (T31) CAM3.5. Although difficulties still exist with the tuning process, Christine began development of a web-based tuning tool for use with future CAM versions.

Publications

Shell, K.M., J.T. Kiehl, and C.A. Shields, 2008: Using the Radiative Kernel Technique to Calculate Climate Feedbacks in NCAR's Community Atmospheric Model. J. Climate, 21, 2269-2282.

Abstract: Climate models differ in their responses to imposed forcings, such as increased greenhouse gas concentrations, due to different climate feedback strengths. Feedbacks in NCAR's Community Atmospheric Model (CAM) are separated into two components: the change in climate components in response to an imposed forcing and the "radiative kernel," the effect that climate changes have on the top-of-the-atmosphere (TOA) radiative budget. This technique's usefulness depends on the linearity of the feedback processes. For the case of CO_2 doubling, the sum of the effects of water vapor, temperature, and surface albedo changes on the TOA clear-sky flux is similar to the clear-sky flux changes directly calculated by CAM. When monthly averages are used rather than values from every time step, the global-average TOA shortwave change is underestimated by a quarter, partially as a result of intramonth correlations of surface albedo with the radiative kernel. The TOA longwave flux changes do not depend on the averaging period. The longwave zonal averages are within 10% of the model-calculated values, while the global average differs by only 2%. Cloud radiative forcing (ΔCRF) is often used as a diagnostic of cloud feedback strength. The net effect of the water vapor, temperature, and surface albedo changes on ΔCRF is -1.6 W m-2, based on the kernel technique, while the total ΔCRF from CAM is -1.3 W m^{-2}, indicating these components contribute significantly to ΔCRF and make it more negative. Assuming linearity of the ΔCRF contributions, these results indicate that the net cloud feedback in CAM is positive.

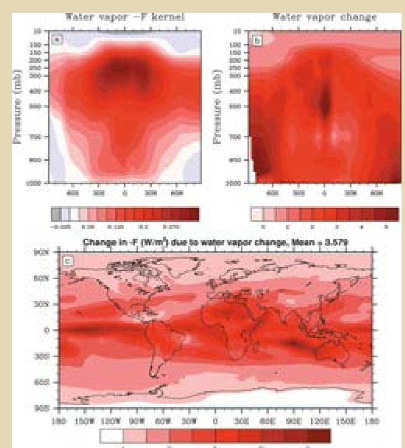


Figure 1.

High resolution figure

Figure caption: Example of the kernel technique. (a) The annual-average outgoing longwave flux (F) kernel for water vapor in units of W m^{-2} per 100 mb for a specific humidity increase corresponding to a 1-K temperature increase and constant relative humidity. (b) The annual-average specific humidity changes for the doubled-CO_2 case, divided by a specific humidity increase corresponding to a 1-K temperature increase and constant relative humidity (i.e., the specific humidity anomaly used to calculate the radiative kernel). (c) The resulting flux changes for the doubled-CO_2 case, obtained by combining the kernel and variable anomalies.

Support: Shell, supported by NCAR ASP. Kiehl, supported by DOE, Science of Climate Change Predicition Program. Shields,

supported by NOAA GFDL and DOE.

Soden, B.J., I.M. Held, R. Colman, K.M. Shell, J.T. Kiehl, and C.A. Shields, 2008: Quantifying Climate Feedbacks Using Radiative Kernels. J. Climate, 21, 3504-3520.

Abstract: The extent to which the climate will change due to an external forcing depends largely on radiative feedbacks, which act to amplify or damp the surface temperature response. There are a variety of issues that complicate the analysis of radiative feedbacks in global climate models, resulting in some confusion regarding their strengths and distributions. In this paper, the authors present a method for quantifying climate feedbacks based on "radiative kernels" that describe the differential response of the top-of-atmosphere radiative fluxes to incremental changes in the feedback variables. The use of radiative kernels enables one to decompose the feedback into one factor that depends on the radiative transfer algorithm and the unperturbed climate state and a second factor that arises from the climate response of the feedback variables. Such decomposition facilitates an understanding of the spatial characteristics of the feedbacks and the causes of intermodel differences. This technique provides a simple and accurate way to compare feedbacks across different models using a consistent methodology. Cloud feedbacks cannot be evaluated directly from a cloud radiative kernel because of strong nonlinearities, but they can be estimated from the change in cloud forcing and the difference between the full-sky and clear-sky kernels. The authors construct maps to illustrate the regional structure of the feedbacks and compare results obtained using three different model kernels to demonstrate the robustness of the methodology. The results confirm that models typically generate globally averaged cloud feedbacks that are substantially positive or near neutral, unlike the change in cloud forcing itself, which is as often negative as positive.

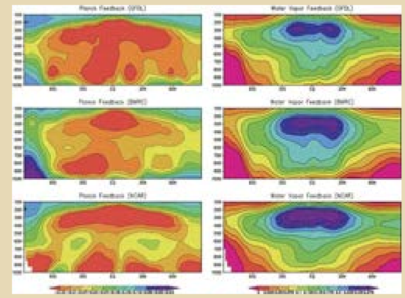


Figure 2.

High resolution figure

Figure caption: The annual-mean, zonal-mean temperature K^T and water vapor K^ω kernels under total-sky conditions for the (top) GFDL, (middle) CAWCR, and (bottom) NCAR models in units of W m^{-2} K^{-1} /100 hPa.

Support: Shell, supported by NCAR ASP. Kiehl, supported by DOE, Science of Climate Change Predicition Program. Shields, supported by NOAA GFDL and DOE.

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WILLIAM SKAMAROCK

2008 Publications

Skamarock, W. C., 2008: A linear analysis of the NCAR CCSM finite-volume dynamical core. Mon. Wea. Rev., 136, 2112-2119, doi: 10.1175/MWR2217.1.

ABSTRACT

The NCAR Community Climate System Model (CCSM) finite-volume atmospheric core uses a C–D-grid discretization to solve the equations of motion. A linear analysis of this discretization shows that it behaves as a D grid to leading order; it possesses the poor response of the D grid for short-wavelength divergent modes, the poor response of the C and D grids for short-wavelength rotational modes, and is only first-order accurate in time and damping. The scheme combines a modified forward–backward time integration for gravity waves with forward-in-time upwind-biased advection schemes, and the solver uses a vector-invariant form of the momentum equations. Other approaches using these equations are considered that circumvent some of the problems inherent in the current approach.

Skamarock, W. C., J. B. Klemp, 2008: A time-split non-hydrostatic atmospheric model for weather research and forecasting applications. J. Comput. Phys., 227, 3465-3485, doi: 10.1016/j.jcp.2007.01.037.

Abstract

The sub-grid-scale parameterization of clouds is one of the weakest aspects of weather and climate modeling today, and the explicit simulation of clouds will be one of the next major achievements in numerical weather prediction. Research cloud models have been in development over the last 45 years and they continue to be an important tool for investigating clouds, cloud-systems, and other small-scale atmospheric dynamics. The latest generation are now being used for weather prediction. The Advanced Research WRF (ARW) model, representative of this generation and of a class of models using explicit time-splitting integration techniques to efficiently integrate the Euler equations, is described in this paper. It is the first fully compressible conservative-form nonhydrostatic atmospheric model suitable for both research and weather prediction applications. Results are presented demonstrating its ability to resolve strongly nonlinear small-scale phenomena, clouds, and cloud systems. Kinetic energy spectra and other statistics show that the model is simulating small scales in numerical weather prediction applications, while necessarily removing energy at the gridscale but minimizing artificial dissipation at the resolved scales. Filtering requirements for atmospheric models and filters used in the ARW model are discussed.

Klemp, J. B., W. C. Skamarock, J. Dudhia, 2007: Conservative split-explicit time integration methods for the compressible nonhydrostatic equations. Mon. Wea. Rev., 135, 2897-2913, doi: 10.1175/MWR3440.1.

ABSTRACT

Historically, time-split schemes for numerically integrating the nonhydrostatic compressible equations of motion have not formally conserved mass and other first-order flux quantities. In this paper, split-explicit integration techniques are developed that numerically conserve these properties by integrating prognostic equations for conserved quantities represented in flux form. These procedures are presented for both terrain-following height and hydrostatic pressure (mass) vertical coordinates, two potentially attractive frameworks for which the equation sets and integration techniques differ significantly. For each set of equations, the linear dispersion equation for acoustic/gravity waves is derived and analyzed to determine which terms must be solved in the small (acoustic) time steps and how these terms are represented in the time integration to achieve stability. Efficient techniques for including numerical filters for acoustic and external modes are also presented. Simulations for several idealized test cases in both the height and mass coordinates are presented to demonstrate that these integration techniques appear robust over a wide range of scales, from subcloud to synoptic.

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JIM SMITH

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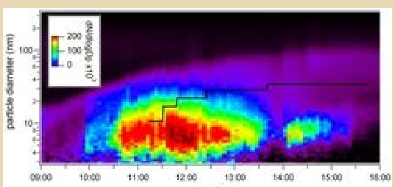
Research Focus FY08:



Contour plot of the particle size distribution on 16 March 2006 in Tecamac, Mexico, during the MILAGRO campaign, show a new particle formation "tomato" event that started just before 10am local time. Also plotted in black is the particle diameter used for TDCIMS chemical composition measurements - High resolution figure

Ultrafine Aerosols Group

I am a scientist and the head of the Ultrafine Aerosols Research Group (UA) in the Atmospheric Chemistry Division (ACD) at NCAR. This year I was also the coordinator for the TIIMES BEACHON Southern Rocky Mountains 2008 Study (BEACHON-SRM08) Field Study in Manitou Forest Observatory, Woodland Park, CO.

The UA group conducts measurements to understand how particles form in the atmosphere and how they grow to become important participants in atmospheric chemistry and climate. Ultrafine aerosols are particles with diameters smaller than 100 nm. They can be formed in the atmosphere over spatial scales of hundreds of kilometers by a process known as nucleation. Measurements by the UA group and its collaborators performed in atmospheric environments as diverse as Mexico City and the boreal forests in central Finland confirm that new particle formation from nucleation occurs frequently, and often is the fundamental process that controls particle number. Understanding and modeling this process and the mechanisms by which newly formed particles grow to become cloud condensation nuclei (CCN) are essential for reducing uncertainties in the roles that aerosols play in climate.

The research activities of the UA group during the past year have addressed three fundamental questions:

- Can we develop new measurements for characterizing ultrafine aerosol physico-chemical properties and their impacts on climate?
- How do newly formed aerosols grow to become important participants in chemistry/climate?
- What are the impacts of biogenic emissions on aerosol formation and growth?

Main 30 m tower surrounded by Ponderosa pine at the Manitou Experimental Forest Observatory - High resolution figure

The focus for FY08 included:

- Developing new measurements for charaterizing ultrafine aerosol physico-chemical properties and their impacts on climate
- Studying the growth of particles formed by nucleation
    - Thermal Desorption Chemical Ionization Mass Spectrometer (TDCIMS) measurements from the Megacity Initiative: Local and Global Research Observations (MILAGRO: Windows to the Universe, EOL site) field study in Mexico City, Mexico
    - Thermodynamic modeling of organic salt formation as a mechanism for nanoparticle growth at MILAGRO and in the boreal forests in central Finland
- The impacts of biogenic emissions on aerosol formation and growth during the TIIMES BEACHON Southern Rocky

Mountains 2008 Study (BEACHON-SRM08)

Additional Information

Community Service FY08:

- Board of Directors: American Association for Aerosol Research
- Thesis Committee: Sara Lance (Georgia Institute of Technology)
- Thesis Committee: Alex Huffman (University of Colorado)
- Head of Organizing Committee, "Biogenic Secondary Organic Aerosols: Observations to Global Modeling," workshop series sponsored by NSF, Stockholm Univ., and the Nordic Center for Excellence: BACCI.

Scientific Talks FY08:

- The roles of acid-base chemistry in atmospheric aerosol formation and growth (Boulder, CO USA, 09/2008)
- Atmospheric nanoparticle composition and its implications for climate (Telluride, CO USA, 08/2008)
- Atmospheric Nanoparticles: What compounds are responsible for their growth and why should we care? (3 Talks: Kuopio, FIN, 06/2008, Helsingor, DEN, 06/2008, Newark, DE USA, 03/2008)
- Measurements of the Chemical Composition of Atmospheric Nanoparticles (New Orleans, LA USA, 03/2008)
- The Formation and Growth of Atmospheric Aerosols: Recent Results from MILAGRO (San Francisco, CA USA, 12/2007)

Publications FY08:

Smith, J. N., 2008: Aerosols. *Encyclopedia of Global Warming and Climate Change*, S. G. Philander, Ed., Sage Publications, Inc., 8-9.

Iida, K., M. R. Stolzenburg, P. H. McMurry, J. N. Smith, 2008: Estimating nanoparticle growth rates from size-dependent charged fractions: Analysis of new particle formation events in Mexico City. *J. Geophys. Res. - Atmos.*, **113**, D05207, doi: 10.1029/2007JD009260.

Boy, M., T. Karl, A. Turnipseed, R. L. Mauldin, E. Kosciuch, J. Greenberg, J. Rathbone, J. Smith, A. Held, K. Barsanti, B. Wehner, S. Bauer, A. Wiedensohler, B. Bonn, M. Kulmala, A. Guenther, 2008: New particle formation in the Front Range of the Colorado Rocky Mountains. *Atmos. Chem. Phys.*, **8**, 1577-1590.

Smith, J. N., M. J. Dunn, T. M. VanReken, K. Iida, M. R. Stolzenburg, P. H. McMurry, L. G. Huey, 2008: Chemical composition of atmospheric nanoparticles formed from nucleation in Tecamac, Mexico: Evidence for an important role for organic species in nanoparticle growth. *Geophys. Res. Lett.*, **35**, L04808, doi: 10.1029/2007GL032523.

Smith, J. N., J. Rathbone, 2008: Carboxylic acid characterization in nanoparticles by Thermal Desorption Chemical Ionization Mass Spectrometry. *Intl. J. Mass Spectrometry*, **274**, 8-13.

Held, A., T. Karl, L. Rizzo, A. Turnipseed, E. Patton, J. Smith, and A. Guenther, 2008: Relaxed eddy accumulation flux simulations of aerosol number and potential proxy scalars. Boundary-Layer Meteorology, in press.

Held, A., G. G. J. Rathbone, and J. N. Smith, 2008: A Thermal desorption chemical ionization ion trap mass spectrometer for the chemical characterization of ultrafine aerosol particles. Aerosol Science & Technology, in press.

Barsanti, K. C., P. H. McMurry, and J. N. Smith, 2008: The potential contribution of organic salts to new particle growth. Atmospheric Chemistry and Physics, submitted.

Lance, S., L. Padro, A. Sullivan, R. Weber, T. Onasch, D. R. Worsnop, X. Yu, L. Alexander, M. Stolzenburg, P. H. McMurry, J. N. Smith, and A. Nenes, 2008: Inferring the aerosol mixing-state from measured cloud activation spectra. Atmospheric Chemistry and Physics, submitted.

McMurry, P. H., A. K. Ghimire, H. Sakurai, and J. N. Smith, 2008: Sampling nanoparticles for chemical analysis by low resolution electrical mobility classification. Environmental Science & Technology, submitted.

McMurry, P. H. and J. N. Smith, 2008: Atmospheric new particle formation: Physical and chemical measurements. Aerosol Measurement - Principles, Techniques, and Applications, 3rd ed. P. Baron, P. Kulkarni, and K. Willeke, Eds., John Wiley & Sons, in preparation.

Smith, J. N., T. M. VanReken, and P. H. McMurry, 2008: Observations of particulate phase amines in atmospheric nanoparticles: Implications for aerosol formation and growth. Atmospheric Chemistry and Physics, in preparation.

Barsanti, K. C., J. N. Smith, and J. F. Pankow, 2008: Application of the carbon number-polarity grid in simulating secondary organic aerosol formation from alpha-pinene oxidation. Atmospheric Environment, in preparation.

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CGD 2008 PROFILES IN SCIENCE: DR. LESLEY SMITH

Summary of achievements

In 2008, Lesley focused on atmospheric energy and moisture budgets. She computed vertically-integrated atmospheric energy and moisture budgets for 1979-2004 for the Japanese reanalysis, and compared them to the results from other reanalyses.

In particular, the moistening, diabatic heating and total energy forcing of the atmosphere were computed as residuals from the analyses using the moisture, dry energy and total atmospheric energy budget equations, and from model output based on the assimilating model parameterizations. This study revealed JRA model biases in radiation and precipitation, and the energy and moisture budget-derived quantities are more realistic than the model output and better depict the real atmosphere.

Lesley also expanded reanalyses studies of the vertically-integrated energy and moisture budgets of the atmosphere to three spatial dimensions. Utilizing ERA40, it was discovered the vertical integrals of the moisture, energy and heat budget equations computed analytically act as a very strong constraint on any local computational results of the vertical structure. Vertical interpolation destroys delicate mass balances and can lead to inconsistencies, and using the advective rather than flux form of the equations greatly reduces the contamination from such effects.

Publications

Trenberth, K. E., and L. Smith, 2008: The three dimensional structure of the atmospheric energy budget: methodology and evaluation. Climate Dynamics, in press. doi:10.1007/s00382-008-0389-3.

Abstract: Studies of the vertically-integrated energy and moisture budgets of the atmosphere are expanded to three dimensions. The vertical integrals of the moisture, energy and heat budget equations computed analytically act as a very strong constraint on any local computational results of the vertical structure. This paper focuses on the methodology and difficulties in closing the budgets and satisfying constraints, given the need to use a pressure coordinate because model coordinates all differ. Vertical interpolation destroys delicate mass balances and can lead to inconsistencies, such as from how geopotential or vertical motion is computed. Using the advective rather than flux form of the equations greatly reduces the contamination from these effects. Results are documented for January 1989 using European Centre for Medium Range Weather Forecasts reanalysis (ERA-40) data. The moistening, diabatic heating and total energy forcing of the atmosphere are computed as a residual from the analyses using the moisture, dry energy (dry static energy plus kinetic energy) and total atmospheric (moist static plus kinetic) energy equations. The components from the monthly averaged flow and transients, as a function of layer in the atmosphere, and as quasi-horizontal and vertical fluxes of dry static, latent and kinetic energy are examined. Results show the moistening of the atmosphere at the surface, its release as latent heat in precipitation and transformation into dry static energy, and thus net radiative cooling as a function of height and location. The vertically integrated forcings computed from the model parameterizations are compared with available observations and budget-derived values, and large ERA-40 model biases are revealed in radiation and precipitation. The energy and moisture budget-derived quantities are more realistic, although results depend on the quality of the analyses which are not constructed to conserve mass, moisture or energy, owing to analysis increments.

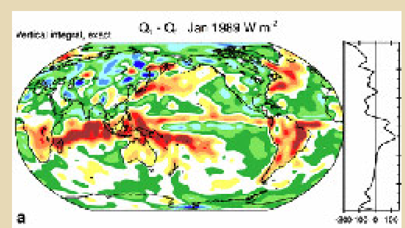

Figure 1.

High resolution figure

Figure caption: For Jan 1989 based on ERA-40 analyses, a) vertically integrated Q_1-Q_f truth versus b) results from the advective method, and c)differences between the two. The right hand side panels show the zonal averages. The plots are smoothed to T42 resolution and the units are Watts per square meter.

Trenberth, K. E., and L. Smith, 2008: Atmospheric energy budgets in the Japanese Reanalysis: Evaluation and variability. J. Meteor. Soc. Japan, in press.

Abstract: The vertically-integrated atmospheric energy and moisture budgets have been computed for all available months for the Japanese reanalysis (1979 to 2004), and results are described in detail for the month of January 1989 and compared with those of other reanalyses. Time series are also presented. The moistening, diabatic heating and total energy forcing of the atmosphere are computed as a residual from the analyses using the moisture, dry energy (dry static energy plus kinetic energy) and total atmospheric (moist static plus kinetic) energy budget equations. These fields are also computed from the model output

based on the assimilating model parameterizations. Moreover, some component fields can also be computed from observations to evaluate the results. In particular, when the vertically-integrated forcings computed from the model parameterizations are compared with available observations and the budget-derived values, significant JRA model biases are revealed in radiation and precipitation. The energy and moisture budget-derived quantities are more realistic than the model output and better depict the real atmosphere. However, low frequency decadal variability is spurious and is mainly associated with changes in the observing system. Results also depend on the quality of the analyses which are not constructed to conserve mass, moisture or energy, owing to analysis increments. By emphasizing the differences and the errors, there is a tendency to overlook the considerable progress in depicting diabatic components of the atmosphere, while also pointing to where research can make further improvements.

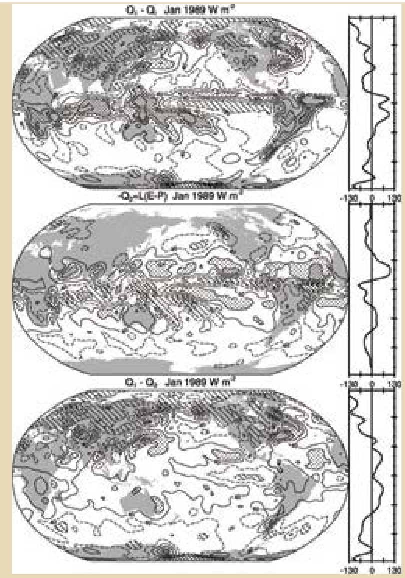

Figure 2.

High resolution figure

Figure caption: For Jan 1989 based on JRA analyses, vertically integrated Q_1, -Q_2 and Q_1 - Q_2. The right hand side panels show the zonal averages. The plots are smoothed to T42 resolution and the units are W m^{-2}. Contour interval is 80 W m^{-2}, and stipple and hatching begin at ±120 W m^{-2} and more densely at ±200 W m^{-2}.

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Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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PIOTR SMOLARKIEWICZ

2008 Publications

Prusa, J. M., P. K. Smolarkiewicz, A. A. Wyszogrodzki, 2008: EULAG, a computational model for multiscale flows. Comput. Fluids, 37, 1193-1207, doi: 10.1016/j.compfluid.2007.12.001.

Abstract

EULAG (Eulerian/semi-Lagrangian fluid solver) is an established computational model for simulating thermo-fluid flows across a wide range of scales and physical scenarios. It is noteworthy for its nonoscillatory integration algorithms, robust elliptic solver, and generalized coordinate formulation enabling grid adaptivity technology. In this paper we highlight the key model ingredients, demonstrate its capabilities with a select subset of recent applications, and show its performance both in terms of accuracy and scalability on massively parallel processor architectures. A comprehensive list of references is provided to facilitate more detailed study.

Malinowski, S. P., M. Andrejczuk, W. W. Grabowski, P. Korczyk, T. A. Kowalewski, P. K. Smolarkiewicz, 2008: Laboratory and modeling studies of cloud-clear air interfacial mixing: anisotropy of small-scale turbulance due to evaporative cooling. New J. Phys., 10, 075020, doi: 10.1088/1367-2630/10/7/075020.

Abstract

Small-scale mixing between cloudy air and unsaturated clear air is investigated in numerical simulations and in a laboratory cloud chamber. Despite substantial differences in physical conditions and some differences in resolved scales of motion, results of both studies indicate that small-scale turbulence generated through cloud–clear air interfacial mixing is highly anisotropic. For velocity fluctuations, numerical simulations and cloud chamber observations demonstrate that the vertical velocity variance is up to a factor of two larger than the horizontal velocity variance. The Taylor microscales calculated separately for the horizontal and vertical directions also indicate anisotropy of turbulent eddies. This anisotropy is attributed to production of turbulent kinetic energy (TKE) by buoyancy forces due to evaporative cooling of cloud droplets at the cloud–clear air interface. Numerical simulations quantify the effects of buoyancy oscillations relative to the values expected from adiabatic and isobaric mixing, standardly assumed in cloud physics. The buoyancy oscillations result from microscale transport of liquid water due to the gravitational sedimentation of cloud droplets. In the particular modeling setup considered here, these oscillations contribute to about a fifth of the total TKE production.

Waite, M. L., P. K. Smolarkiewicz, 2008: Instability and breakdown of a vertical vortex pair in a strongly stratified fluid. J. Fluid Mech., 606, 239-273, doi: 10.1017/S0022112008001912.

Abstract

The dynamics of a counter-rotating pair of columnar vortices aligned parallel to a stable density gradient are investigated. By means of numerical simulation, we extend the linear analyses and laboratory experiments of Billant & Chomaz (J. Fluid Mech. vol. 418, p. 167; vol. 419, pp. 29, 65 (2000)) to the fully nonlinear, large-Reynolds-number regime. A range of stratifications and vertical length scales is considered, with Frh < 0.2 and 0.1 < Frz < 10. Here Frh = U/(NR) and Frz = Ukz/N are the horizontal and vertical Froude numbers, U and R are the horizontal velocity and length scales of the vortices, N is the Brunt–Väisälä frequency, and 2p/kz is the vertical wavelength of a small initial perturbation. At

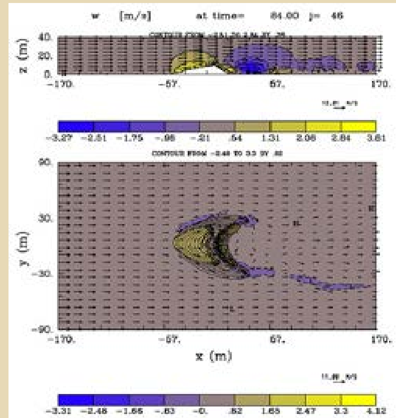

Figure 1: Large eddy simulation of boundary layer past a rapidly evolving sand dune; after [33]. Countours of vertical velocity *w* are shown together with flow vectors and the simulated time-dependent orography of the dune in the central *xz* plane and along the lower *xy* surface of the model.

High resolution figure

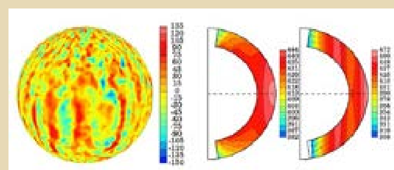

Figure 2: EULAG simulations of solar convection after [12]. Left panel shows the vertical velocity [ms^{-1}] on a horizontal surface near the middle of the domain for the implicit large eddy simulation run. Central and right panels show the time-averaged angular velocity [nHz] for, respectively, direct and implicity large eddy simulations runs.

High resolution figure

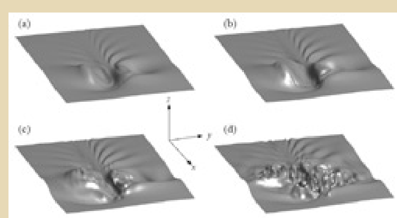

Figure 3: The isopycnal with equilibrium height at the inflection level z = $lambda_z$ / 4 for Fr_h = 0.1 and Fr_z = 0.628 at tU/R = 9

early times with Frz < 1, linear predictions for the zigzag instability are reproduced. Short-wavelength perturbations with Frz > 1 are found to be unstable as well, with growth rates only slightly less than those of the zigzag instability but with very different structure. At later times, the large-Reynolds-number evolution diverges profoundly from the moderate-Reynolds-number laboratory experiments as the instabilities transition to turbulence. For the zigzag instability, this transition occurs when density perturbations generated by the vortex bending become gravitationally unstable. The resulting turbulence rapidly destroys the vortex pair. We derive the criterion ?/R ˜ 0.2/Frz for the onset of gravitational instability, where ? is the maximum horizontal displacement of the bent vortices, and refine it to account for a finite twisting disturbance. Our simulations agree for the fastest growing wavelengths 0.3 < Frz < 0.8. Short perturbations with Frz > 1 saturate at low amplitude, preserving the columnar structure of the vortices well after the generation of turbulence. Viscosity is shown to suppress the transition to turbulence for Reynolds number Re xs2272 80/Frh, yielding laminar dynamics and, under certain conditions, pancake vortices like those observed in the laboratory.

(a), 10 (b), 11 (c), and 12 (d). The vertical coordinate has been stretched by a factor of four, exaggerating the isopycnal displacement for clarity. The surface has dimensions 4*R* x 4*R*

High resolution figure

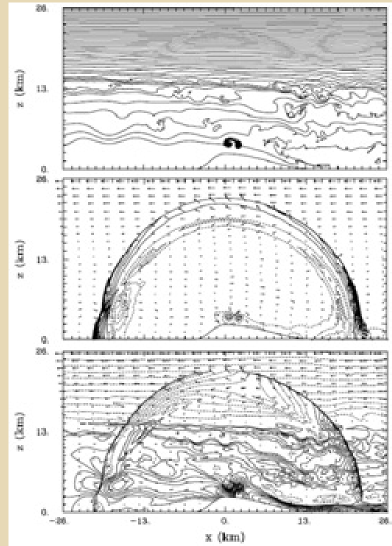

Figure 4: Large-amplitude acoustic wave propagation in a fully developed orographic flow.

High resolution figure

Miller, M. J., P. K. Smolarkiewicz, 2008: Predicting weather, climate and extreme events: Preface. J. Comput. Phys., 227, 3429-3430, doi: 10.1016/j.jcp.2008.01.001.

Abstract

Day-to day weather, and the highly topical and crucial subject of our changing climate continue to engage us all. Furthermore, recent weather related natural disasters amplify our interest in how we predict weather and climate and also in how skilful are these predictions. Much of the public's appreciation of what is involved in forecasting natural phenomena comes from media dramatization and news reporting. This special issue of the Journal of Computational Physics aims at presenting to a broad scientific community the niche that meteorology occupies in modern interdisciplinary science, crossing boundaries between physics, mathematics and chemistry, and representing one of the largest users of scientific supercomputing. The idea underlying this special issue is to portray the integrated efforts of the entire meteorological community that serves the public on a daily basis all over the world with state-of-the-art prognoses of weather, climate and extreme events. In order to achieve this goal, we invited a series of technical papers with some spirit of review – the degree of which was left to the authors' judgment – which would expose our models, techniques and computational methods to the broad interdisciplinary readership of the Journal. The series should also reflect on the difficulties, controversies and unresolved problems, and provide a reference point for further technical reading.

The issue is organized such as to outline representative operational models, aspects of modelling the whole Earth-System, and to highlight some key elements essential for their success. Hence, following a historical review of the development and challenges of Numerical Weather Prediction (NWP), three papers describe current models used for numerical weather prediction and climate studies at very high spatial resolutions. These papers are followed by a contribution on Ensemble Prediction. Meteorology has pioneered the use of ensemble methods for quantifying uncertainty in its predictions, because the evolution of the Earths atmosphere has a fundamentally chaotic component. Initially ensembles were used for forecasts on the timescale of a week or so, but nowadays are increasingly used on all timescales from less than a day to a century or more. The following three papers then discuss the extension of the basic atmospheric modelling to include air quality, ocean surface waves and the ocean itself, all key components for describing and predicting the whole Earth system. Papers on two important application-oriented forecasting systems are those for seasonal to inter-annual and regional climate respectively. The former combining key aspects of weather and climate prediction, while the regional climate models provide the higher resolution, local climate-related data that applications demand. The volume concludes with three contributions on specific aspects (from an admittedly much longer list) of relevance to the overall aims of improving our predictive capabilities described in the issue's title.

As in many branches of science, meteorology keeps advancing on a daily basis, not least because of its operational status whereby its prognoses are challenged and verified continuously. It develops from the cumulative efforts of universities, research laboratories and operational centers, and it is impossible, in a single volume, to account for and acknowledge in any detail all broad research activities contributing to present and future progress. Thus many ongoing and exciting activities were left out, and indeed this rate of growth and change and the need for timeliness of publication would readily justify a second special issue such as this.

Smolarkiewicz, P. K., A. Doernbrack, 2008: Conservative integrals of adiabatic Durran's equations. Int. J. Numer. Meth. Fluids, 56, 1513-1519, doi: 10.1002/fld.1601.

Abstract

Potential advances are investigated in the area of generalized anelastic approximations. Consistent control-volume integrals are designed and compared for the established Lipps-Hemler form (of anelastic approximation) and Durran's pseudo-incompressible form. The Durran system provides a unique theoretical tool - useful for research of geophysical and stellar flows - within the existing set of reduced, Boussinesq-type fluid models. It represents thermal aspects of compressibility free of sound waves, yet the momentum equation is unapproximated. The latter admits unabbreviated baroclinic production of vorticity, thus facilitating separation of compressibility and baroclinicity effects per se. Compared with other reduced fluid models, there is little cumulative experience with integrating the Durran system. Perhaps the first conservative integrations of Durran's equations are presented, using flux-form transport methods and exact projection for the associated elliptic problem. Because the resulting code is built from a preexisting anelastic model, the consistency of the numerics is assured thus minimizing uncertainties associated with ad hoc code comparisons. While broader physical implications are addressed, theoretical considerations are illustrated with examples of atmospheric flows.

Wedi, N. P., P. K. Smolarkiewicz, 2008: A reduced model of the Madden-Julian oscillation. Int. J. Numer. Meth. Fluids, 56, 1583-1588, doi: 10.1002/fld.1612.

Abstract

We have extended our virtual laboratory for internal wave motions (Int. J. Numer. Meth. Fluids 2005; 47:1369-1374) to the case of rotating fluids on an equatorial -plane. A virtual wave-maker is introduced via a time-dependent coordinate transformation in the meridional direction, represented by two lateral boundary meanders. The technique is consistently incorporated into the numerical algorithm of the nonhydrostatic model EULAG. The modelling framework is applied in simulations of equatorial wave motions to enhance our understanding of the Madden-Julian oscillation (MJO). The simulation of a realistic MJO in global circulation and climate models is a continuing challenge - in part, due to the failure of existing theories to explain the ubiquitous modelling difficulties of the phenomenon. Virtual laboratory experiments appear ideal complementary tools to isolate and study particular geophysical flow structures. In these laboratory-scale climate simulations we observe eastward propagating low-frequency horizontal structures consistent with Rossby solitary wave theory, representing a particular solution of the Korteweg-de Vries equation for the evolution of the wave amplitude under a given forcing. The latter extends the linear shallow water theory - commonly used to explain different modes of equatorial wave motions - to the weakly nonlinear regime. One important outcome of our simulations is the finding that these structures depend on strong stratification, and may be easily destroyed or weakened if substantial near-surface perturbations and associated vertical motions exist. This could play a role in the failure to simulate a realistic MJO, but it may also provide an explanation why solitary waves are not as readily observed in oceans as they are in models and theory. Ultimately, our research aims at constructing a simplified dynamical apparatus to reproduce MJO-like structures in a laboratory analogue, in the spirit of the Plumb-McEwan experiment for the quasi-biennial oscillation and vis-a-vis its numerical equivalent.

Smolarkiewicz, P., J. Szmelter, 2008: An MPDATA based solver for compressible flows. Int. J. Numer. Meth. Fluids, 56, 1529-1534, doi: 10.1002/fld.1702.

Abstract

The theory of the high-resolution multidimensional positive-definite advection transport algorithm (MPDATA) has been extensively developed since its invention in the early eighties. Many successful applications for geophysical flows followed. This paper introduces the original development of an MPDATA solver operating on a classical set of conservation laws, applicable to high-speed compressible flows. The solver belongs to a general class of the second-order nonoscillatory forward-in-time schemes. Theoretical considerations are supported with numerical examples. An elementary three-dimensional spherical wave-propagation problem illustrates that MPDATA correctly captures signal transfer in acoustic flows.

Smolarkiewicz, P. K., L. G. Margolin, A. A. Wyszogrodzki, 2007: Implicit large-eddy simulation in meteorology: from boundary layers to climate. J. Fluid. Eng., 129, 1533-1539, doi: 10.1115/1.2801678.

Abstract

The dynamics of the atmosphere and oceans pose a severe challenge to the numerical modeler, due in large part to the broad range of scales of length and time that are encompassed. Modern numerical methods based on nonoscillatory finite volume (NFV) approximations provide a simple and effective means for mitigating this challenge by reproducing the large scale behavior of turbulent flows with no need for explicit subgrid-scale models. In this paper, we describe the remarkable properties of a particular NFV model, multidimensional positive definite advection transport algorithm, and highlight its application to a variety of meteorological and turbulent flows.

Smolarkiewicz, P. K., R. Sharman, J. Weil, S. G. Perry, D. Heist, G. Bowker, 2007: Building resolving large-eddy simulations and comparison with wind tunnel experiments. J. Comput. Phys., 227, 633-653, doi: 10.1016/j.jcp.2007.08.005.

Abstract

We perform large-eddy simulations (LES) of the flow past a scale model of a complex building. Calculations are accomplished using two different methods to represent the edifice. The first method employs the standard Gal-Chen and Somerville terrain-following coordinate transformation, common in mesoscale atmospheric simulations. The second method uses an immersed boundary approach, in which fictitious body forces in the equations of motion are used to represent the building by attenuating the flow to stagnation within a time comparable to the time step of the model. Both methods are implemented in the same hydrodynamical code (EULAG) using the same nonoscillatory forward-in-time (NFT) incompressible flow solver based on the multidimensional positive definite advection transport algorithms (MPDATA). The two solution methods are compared to wind tunnel data collected for neutral stratification. Profiles of the first- and second-order moments at various locations around the model building show good agreement with the wind tunnel data. Although both methods appear to be viable tools for LES of urban flows, the immersed boundary approach is computationally more efficient. The results of these simulations demonstrate that, contrary to popular opinion, continuous mappings such as the Gal-Chen and Somerville transformation are not inherently

limited to gentle slopes. Calculations for a strongly stratified case are also presented to point out the substantial differences from the neutral boundary layer flows.

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CHRIS SNYDER

2008 Publications

Davis, C. A., C. S. Snyder, A. C. Didlake, 2008: A vortex-based perspective of eastern Pacific tropical cyclone formation. Mon. Wea. Rev., 136, 2461-2477, doi: 10.1175/2007MWR2319.1.

ABSTRACT

Tropical cyclone formation over the eastern Pacific during 2005 and 2006 was examined using primarily global operational analyses from the National Centers for Environmental Prediction. This paper represents a “vortex view” of genesis, adding to previous work on tropical cyclone formation associated with tropical waves. Between 1 July and 30 September during 2005 and 2006, vortices at 900 hPa were tracked and vortex-following diagnostic quantities were computed. Vortices were more abundant during periods of an enhanced “Hadley” circulation with monsoon westerlies around 10°N in the lower troposphere. This zonally confined Hadley circulation was significantly stronger during the genesis of developing vortices. Developing vortices were stronger at the outset, with a deeper potential vorticity maximum, compared to nondeveloping vortices. This implies that developing disturbances were selected early on by favorable synoptic-scale features.

The characteristic time-mean reversal of the meridional gradient of absolute vorticity in the lower troposphere was found to nearly vanish when the aggregate contribution of strong vortices was removed from the time-mean vorticity. This finding implies that it is difficult to unambiguously attribute development to a preexisting enhancement of vorticity on the synoptic scale. The time-mean enhancement of cyclonic vorticity primarily results from the accumulated effect of vortices. It is suggested that horizontal deformation in the background state helps distinguish developing vortices from nondevelopers, and also biases the latitude of development poleward of the climatological ITCZ axis.

Tan, Z.-M., F. Zhang, R. Rotunno, C. Snyder, 2008: Corrigendum. J. Atmos. Sci., 65.

Rotunno, R., C. Snyder, 2008: A generalization of Lorenz's model for the predictability of flows with many scales of motion. J. Atmos. Sci., 65, 1063-1076, doi: 10.1175/2007JAS2449.1.

ABSTRACT

In a seminal paper, E. N. Lorenz proposed that flows with many scales of motion in which smaller-scale error spreads to larger scales and in which the error-doubling time decreases with decreasing scale have a finite range of predictability. Although the Lorenz theory of limited predictability is widely understood and accepted, the model upon which the theory is based is less so. The primary objection to the model is that it is based on the two-dimensional vorticity equation (2DV) while simultaneously emphasizing results using a basic turbulent flow with a “-5/3” energy spectrum in the atmospheric synoptic scale instead of those using a more theoretically and observationally consistent “-3” spectrum. The present work generalizes the Lorenz model so that it may apply to the surface quasigeostrophic equations (SQGs), which are mathematically very similar to 2DV but are known to have a -5/3 kinetic energy spectrum downscale from a large-scale forcing. This generalized Lorenz model is applied here to both 2DV (with a -3 spectrum) and SQG (with a -5/3 spectrum), producing examples of flows with unlimited and limited predictability, respectively. Comparative analysis of the two models allows for the identification of the distinctive attributes of a many-scaled flow with limited predictability.

Plougonven, R., C. Snyder, 2007: Inertia-gravity waves spontaneously generated by jets and fronts, Part 1: Different baroclinic life cycles. J. Atmos. Sci., 64, 2502-2520, doi: 10.1175/JAS3953.1.

ABSTRACT

The spontaneous generation of inertia–gravity waves in idealized life cycles of baroclinic instability is investigated using the Weather Research and Forecasting Model. Two substantially different life cycles of baroclinic instability are obtained by varying the initial zonal jet. The wave generation depends strongly on the details of the baroclinic wave’s development. In the life cycle dominated by cyclonic behavior, the most conspicuous gravity waves are excited by the upper-level jet and are broadly consistent with previous simulations of O’Sullivan and Dunkerton. In the life cycle that is dominated by anticyclonic behavior, the most conspicuous gravity waves even in the stratosphere are excited by the surface fronts, although the fronts are no stronger than in the cyclonic life cycle. The anticyclonic life cycle also reveals waves in the lower stratosphere above the upper-level trough of the baroclinic wave; these waves have not been previously identified in idealized simulations. The sensitivities of the different waves to both resolution and dissipation are discussed.

Snyder, C., D. J. Muraki, R. Plougenven, F. Zhang, 2007: Inertia-gravity waves generated within a dipole vortex. J. Atmos. Sci., 64, 4417-4431, doi: 10.1175/2007JAS2351.1.

ABSTRACT

Vortex dipoles provide a simple representation of localized atmospheric jets. Numerical simulations of a synoptic-scale dipole in surface potential temperature are considered in a rotating, stratified fluid with approximately uniform potential vorticity. Following an initial period of adjustment, the dipole propagates along a slightly curved trajectory at a nearly steady rate and with a nearly fixed structure for more than 50 days. Downstream from the jet maximum, the flow also contains smaller-scale, upward-propagating inertia–gravity waves that are embedded within and stationary relative to the dipole. The waves form elongated bows along the leading edge of the dipole. Consistent with propagation in horizontal deformation and vertical shear, the waves' horizontal scale shrinks and the vertical slope varies as they approach the leading stagnation point in the dipole's flow. Because the waves persist for tens of days despite explicit dissipation in the numerical model that would otherwise damp the waves on a time scale of a few hours, they must be inherent features of the dipole itself, rather than remnants of imbalances in the initial conditions. The wave amplitude varies with the strength of the dipole, with waves becoming obvious once the maximum vertical vorticity in the dipole is roughly half the Coriolis parameter. Possible mechanisms for the wave generation are spontaneous wave emission and the instability of the underlying balanced dipole.

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Table of Contents

Strategic Goals: Science, Facilities & Technology

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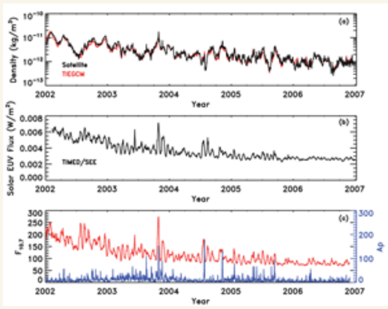
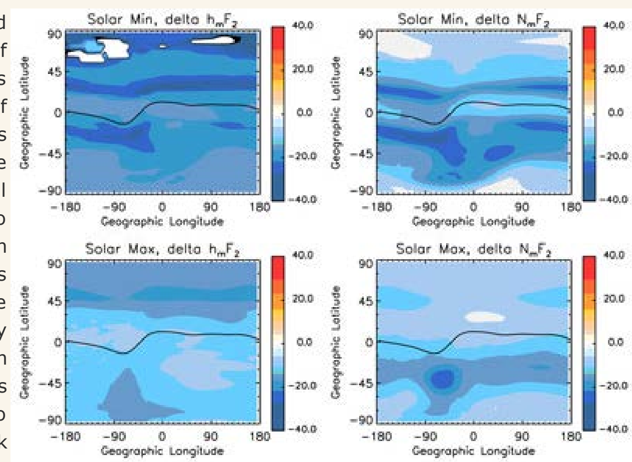
SOLOMON, STAN

Simulation of Thermospheric Density Change during the Solar Cycle.



Data from the Solar Extreme-ultraviolet Experiment (SEE) on the NASA TIMED satellite were used as input to the NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) for a simulation spanning the declining phase of solar cycle 23 from 2001-2007. Model simulations of the neutral thermospheric density at ~400 km were compared with density measurements obtained from observations of the atmospheric drag on five spherical satellites in low-Earth orbit. The solar observations greatly improve the model fidelity, and both solar-rotational and solar-cycle variations are accounted for. Additionally, the effects of impulsive geomagnetic storms can be can be seen in the model/data comparison (e.g., the "Halloween storms" in October-November 2003), and a surprisingly strong seasonal pattern is revealed, especially clear during solar minimum. These results are described in Qian et al., *J. Geophys. Res.*, in press, 2008.

Understanding long-term changes in the upper atmosphere and ionosphere



Understanding global changes in the upper atmosphere and ionosphere not only has practical importance such as effect of these long-term changes on satellite drag, but also has important scientific interest. It can facilitate understanding of global change in the lower atmosphere since global changes in the lower atmosphere and upper atmosphere/ionosphere are closely linked and it can be easier to detect global changes in the upper atmosphere and ionosphere due to larger signal to noise ratio. In the area of global changes in the upper atmosphere and ionosphere, consistent results have emerged regarding trends of mesospheric temperature (negative), thermospheric density (negative), electron density in the ionospheric E- and F1- regions (positive), and E-region altitude (hmE, negative). These results support the hypothesis of cooling and contraction of the upper atmosphere due to greenhouse effect. However, trends of ionospheric F2 peak altitude (hmF2) and peak electron density (NmF2) remain controversial. The origin of trends of hmF2 and NmF2, whether it is natural or anthropogenic, is one of the greatest debates. Using NCAR thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM), we investigated greenhouse effect on trends of hmF2 and NmF2. It is found that increase of CO2 concentration changes temperature, large-scale circulation, and composition in the thermosphere and ionosphere, and thus causes long-term changes of hmF2 and NmF2. Trends of NmF2 due to greenhouse effect are negative; trends of hmF2 are negative during day and can be positive at night. Trends of NmF2 and hmF2 show strong variations with latitude, longitude, local time, season, and solar. Magnitude of trends of NmF2 is comparable to that of neutral composition changes. Dynamics play important role in trends of NmF2 and hmF2, with larger contribution under solar minimum condition. This study clearly demonstrates that greenhouse effect plays important role in trends of ionospheric peak altitude and peak electron density. The results of this studies was presented at 5th IAGA/ICMA/CAWSES workshop "Long-Term Changes and Trends in the Atmosphere" held in St. Petersburg, Russia, as an invited presentation.

Figure caption: *Changes of hmF2 and NmF2 (double CO2 - base CO2) at local noon for solar minimum (upper panels) and solar maximum (lower panel) conditions. Changes of hmF2 are absolution changes in km while changes of NmF2 are percentage changes. Solar minimum:* $F_{10.7} = \overline{F_{10.7}} = 70$ *; Solar maximum:* $F_{10.7} = \overline{F_{10.7}} = 200$ *. Geomagnetic Kp index is 1, i.e., under geomagnetic quiet condition. The black line in each figure is geomagnetic dip equator.*

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Research Focus FY08:

Data from three mountain top stations in the Regional Atmospheric Continuous CO2 Network in the Rocky Mountains (Rocky RACCOON) are used to investigate atmospheric controls on temporal and spatial variability of CO2 in mountainous terrain and the usefulness of mountain top measurement for the estimation of regional CO2 fluxes. The three mountain top locations are: Niwot Ridge, near Ward, Colorado (NIWOT); Storm Peak Laboratory (SPL) near Steamboat Springs, Colorado; and Hidden Peak, near Snowbird, Utah (HDP).Data from mountaintop sites are frequently used to represent background data. However, an understanding of local meteorological effects is required to develop a background selection method. We found that there is a clear diurnal variation in summer at the mountaintop sites with lower concentrations in the afternoon due to vegetation assimilation. In winter, the diurnal variation is less clear than in winter and often times, a peak in the CO2 concentration can be found in the late morning or afternoon. Atmospheric boundary layer processes including boundary layer growth and thermally driven flows play important roles causing an afternoon peak (De Wekker et al., 2007).

Our current investigations focus on the effect of cold air pool dynamics on mountain top CO2 concentrations at Hidden Peak (HDP). Radiosonde data from Salt Lake Airport and surface meteorological data from Salt Lake Valley and HDP surface stations are used to identify a persistent cold air pool event in the late of January 2007. The continuous CO2 measurements at valley sites are compared to the measurements at HDP during this period. The comparison shows that the peak at HDP is highly correlated with a sharp decrease of the CO2 concentration at the Valley Station. CO2 concentrations gradually increase in the cold air pool prior to the large decrease (De Wekker et al., 2008). Currently, a meso-scale model is used to investigate the evolution and break-up of a persistent cold air pool in the Salt Lake Valley. In addition, the effect of the depth and strength of the cold air pool on the amount of CO2 accumulated in the valley and the magnitude of the CO2 peak at the mountain top site after the cold air pool breaks up are being investigated.

Publications FY08:

De Wekker, S.F.J. , Z. Vecenaj, M. Lingvai, A. Ameen, Y. S. Lau, and G. Song 2008: A New Meteorological Research Facility in the Shenandoah National Park. 13th Conference on Mountain Meteorology, Whistler, Canada, August 2008

De Wekker, S.F.J., A. Ameen, G. Song, W. J. Steenburgh, and B. Stephens, 2008: An Investigation of the Effect of Valley Boundary Layer Structure on Atmospheric CO2 Concentrations at a Mountain Top Location. 13th conference on Mountain Meteorology, Whistler. BC, 11-15 August 2008.

De Wekker, S.F.J., G. Song, A. Ameen, and B.B. Stephens, 2008: Boundary Layer Effects on Atmospheric CO2 Concentrations at Mountaintop Locations. 18th Symposium on Boundary Layer and Turbulence, Stockholm, Sweden, 9-13 June 2008.

De Wekker, S.F.J., G. Song, and B.B. Stephens, 2007: On Using CO2 Concentration Measurements at Mountain top and Valley Locations in regional flux studies. American Geophysical Union 2007 Annual Conference, San Francisco, California, December 2007. abstract

Guan Song Research Catalog

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Research Focus FY08:

Britton Stephens' TIIMES research is focused on advancing our understanding of global carbon cycling and supporting the biogeosciences research community. This work has included airborne and ground-based field observations targeting regional scale carbon fluxes, analyses of background observations to investigate global carbon cycling, and instrument development for tower and aircraft applications.

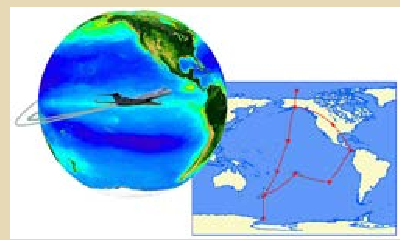

Figure 1: The project HIAPER Pole-to-Pole Observations of Atmospheric Tracers (HIPPO) will conduct five global loops over the next three years, profiling from the tropopause to the surface. Investigators from Harvard, NCAR, Scripps, and NOAA will measure CO_2, O_2, CH_4, CO, N_2O, H_2, SF_6, COS, CFCs, HCFCs, O_3, H_2O, black carbon, and selected hydrocarbons - High resolution figure

Figure 2: The NCAR Airborne Oxygen Instrument (AO2) measures O_2 concentration (reported as O_2:N_2 ratio) using a vacuum-ultraviolet absorption technique. It consists of a pump module, a cylinder module, and an instrument module - High resolution figure

HIAPER Pole-to-Pole Observations of Atmospheric CO2 and Related Tracers (HIPPO)

There exists > 100 % uncertainty in localizing the terrestrial uptake of anthropogenic carbon to specific latitudinal zones and this uncertainty is directly linked to vertical transport biases in the coarse-resolution atmospheric transport models used in CO_2 inversion studies. Comprehensive measurements of atmospheric CO_2 and related tracers, particularly at altitude and in previously undersampled regions, are needed to challenge these models and improve our understanding of global carbon cycling. This is the aim of the project HIAPER Pole-to-Pole Observations of Atmospheric CO_2 and Related Tracers (HIPPO), a Harvard-NCAR-Scripps-NOAA collaboration to measure cross sections of atmospheric concentrations approximately pole-to-pole, from the surface to the tropopause, five times during different seasons over the next three-years (see Figure 1).

A comprehensive suite of tracers of the carbon cycle and related species will be measured: CO_2, O_2:N_2 ratio, CH_4, CO, N_2O, 13CO_2:12CO_2, H_2, SF_6, COS, CFCs, HFCs, HCFCs, black carbon, and selected hydrocarbons. HIPPO will transect the mid-Pacific ocean and return over the Eastern Pacific. The program will provide the first comprehensive, global survey of atmospheric trace gases, covering the full troposphere in all seasons and multiple years. HIPPO will quantify the sources of major carbon cycle and greenhouse gases by region at the global scale.

Britt Stephens is supporting several key systems on these flights, including the NCAR Airborne Oxygen instrument (AO2, see Figure 2) and the MEDUSA flask sampler. These systems flew during the START-08/pre-HIPPO campaign in April-June of 2008. In this campaign, AO2 made the first successful airborne measurements of oxygen variations. This vacuum-ultraviolet absorption instrument is based on an existing NCAR laboratory instrument, but has been designed specifically for airborne use to minimize motion and thermal sensitivity and with a pressure and flow controlled inlet system. AO2 has a precision of +/- 2 per meg on a 4-second measurement which is the equivalent to detecting the removal of one O_2 molecule from 2.5 million molecules of air. Such measurements are very useful in discriminating various influences on atmospheric CO_2 (see Figure 3). The flasks collected during this campaign are being analyzed at Scripps for O_2, Ar, and isotopes of CO_2.

Regional Atmospheric Continuous CO2 Network in the Rocky Mountains (Rocky RACCOON)

In order to improve our understanding of regional carbon fluxes in the Rocky Mountain West, Britt Stephens has developed and deployed autonomous, inexpensive, and robust CO_2 analyzers (AIRCOA) at six sites throughout Colorado, Utah, and Arizona over the past three years (http://raccoon.ucar.edu). Analysis of the diurnal cycles in CO_2 concentration and CO_2 variability at these sites provide insight as to when and under what conditions mountaintop CO_2 signals are regionally representative, as well as first-order constraints on boundary-layer heights and flux rates for use in evaluating model fidelity (Figure 4). Comparisons between the RACCOON measurements and estimates of free-tropospheric background concentrations reveal regional-scale CO_2 flux signals that are generally consistent with one another and our expectation of peak CO_2 uptake in mountain forests during spring (Figure 5). Combining these differences with information on boundary-layer mixing can lead to quantitative estimates of monthly regional CO_2 fluxes. These data have also been used in the NOAA CarbonTracker flux estimation system as well as the GlobalView data product used by modeling groups around the world, and are a key NCAR contribution to the multi-agency North American Carbon Program (NACP).

The RACCOON observations at Fraser Experimental Forest have occurred while the trees in the St. Louis creek drainage have experienced widespread mortality due to mountain pine bark beetle infestation. The CO_2 measurements at the base of this valley show large increases in CO_2 at night as the valley drainage flow pools respiration from a large area. This nocturnal build-up has decreased over the past three years (Figure 6), suggesting a decrease in ecosystem respiration in response to the insect outbreak. This decrease indicates that the reduction in autotrophic respiration is greater than any short-term increase in litter fall, and will be a valuable test of models predicting the impact of the recent outbreaks on regional scale carbon fluxes.

Plans for FY09 and beyond

Britt Stephens will deploy AO2 and the MEDUSA sampler on the NCAR GV as part of the first HIPPO global campaign in January of 2009, then again in 4 more campaigns in 2009-2011. Both AO2 and MEDUSA are planned for long-term availability to community researchers.

Future plans to address regional carbon fluxes include in depth analysis of ACME-07 and Rocky RACCOON data and synthesis with modeling efforts to

1. Define regional-scale monthly to interannual carbon fluxes for the U.S. Central Rocky Mountains and Southwest
2. Assess key drivers of variability and trends including drought, fires, and insects
3. Optimize community CO_2 observational efforts across the Mountain West

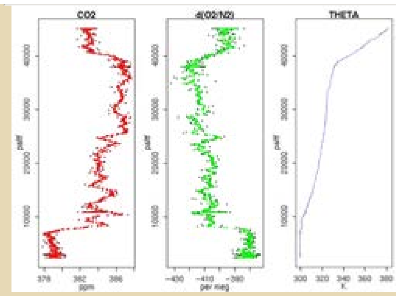

Figure 3: Measurements of atmospheric O_2 and CO_2, made by the AO2 instrument on the NCAR GV during the START-08/pre-HIPPO campaign, while descending from the stratosphere to the surface over Grand Forks, ND in the mid afternoon. Correlated O_2 and CO_2 variations reflect the influence of stratospheric air age across the tropopause, pollution and boundary-layer air plumes in the free troposphere, and photosynthetic CO_2 drawdown and O_2 enhancement in the boundary layer - High resolution figure

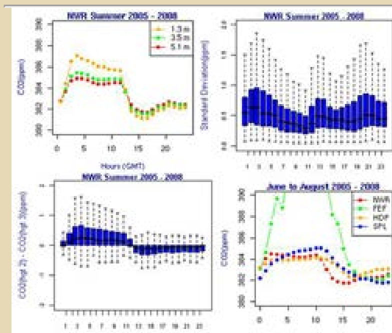

Figure 4: Summertime RACCOON data averaged over the months June-August. a) Calibrated CO_2 values from three heights at NWR b) Boxplot of the distribution of hourly standard deviations at NWR. c) Boxplot showing the distribution of 3.5 m to 5.1 m vertical gradients at NWR. d) Filtered diurnal cycles from four sites are generally representative of concentrations over large regions - High resolution figure

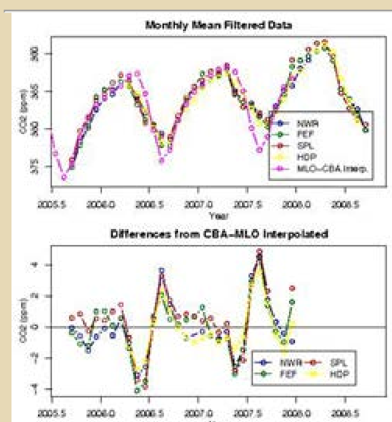

Figure 5: Monthly mean RACCOON CO_2 concentrations at four sites and differences from marine boundary layer concentrations interpolated to the same latitude. The differences indicate strong CO_2 uptake during

Community Service FY08:

- Graduated Research Advisor & Thesis Committee: Sherri Heck, University of Boulder spring in the Central Rocky Mountains - High resolution figure

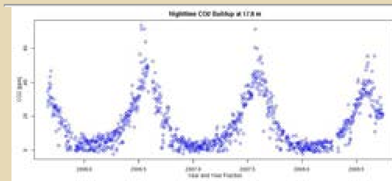

Figure 6: Nighttime valley CO_2 buildup measured at the Fraser Experimental Forest site. The decreasing trend indicates reduced ecosystem respiration following widespread beetle mortality - High resolution figure

- member: Wallowa Mountain Institute Advisory Board
- Scientific Steering Committee: 8th International Carbon Dioxide Conference
- U.S. National Ecological Observatory Network (NEON) Fundamental Instrument Unit Tiger Team, 2007 - present.
- North American Carbon Program (NACP) Mid-Continent Intensive (MCI) working groups: MCI Science Team, MCI Coordination, MCI Topic 2 Region-wide Inversion Analyses, 2006 – present.
- The Surface Ocean - Lower Atmosphere Study (SOLAS) Implementation Group 3, 2003 - present.
- SOLAS/Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) Carbon Group (SIC), 2005 - present.

Scientific Talks FY08:

- Atmospheric Oxygen Measurements during HIPPO: HIAPER Pole-to-Pole Observations of Atmospheric Tracers (NCAR EOL Science Group meeting, Boulder, CO, September, 2008)
- HIAPER Pole-to-Pole Observations of Atmospheric Tracers (NCAR TIIMES Science Advisory Committee meeting, Boulder, CO, June, 2008)
- HIAPER Pole-to-Pole Observations of Atmospheric Tracers: Global Carbon Cycle (START-08 planning meeting, Boulder, CO, January, 2008)
- Closing in on the Missing Carbon Sink: Implications for Climate Research and Mitigation (U.N. Climate Change Conference, Bali, Indonesia, December, 2007)

Publications FY08:

Obrist, D., A. Hallar, I. McCubbin, B. B. Stephens, T. Rahn, 2008: Atmospheric mercury concentrations at Storm Peak Laboratory in the Rocky Mountains: Evidence for long-range transport from Asia, boundary layer contributions, and plant mercury uptake. *Atmos. Environ.*, doi: 10.1016/j.atmosenv.2008.06.051. (In Press)

Burns, S. P., A. Delany, J. Sun, B. B. Stephens, S. P. Oncley, G. D. Maclean, S. R. Semmer, J. Schroter, J. Ruppert, 2008: An evaluation of calibration techniques for in-situ carbon dioxide measurements using a programmable portable trace-gas measuring system. *J. Atmos. Ocean. Technol.*, doi: 10.1175/2008JTECHA1080.1. (In Press)

Kort, E.A., Eluszkiewicz, J., Stephens, B.B., Miller, J.B., Gerbig, C., Nehrkorn, T., Daube, B.C., Kaplan, J.O., Houweling, S., Wofsy, S.C., Emissions of CH_4 and N_2 O over the United States and Canada based on a receptor-oriented modeling framework and COBRA-NA atmospheric observations, */Geophysical Research Letters/*, 35, L18808, doi:10.1029/2008GL034031, 2008.

Brit Stephens Research Catalog

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PETER SULLIVAN

2008 Publications

Sullivan, P. P., J. B. Edson, T. Hristov, J. C. McWilliams, 2008: Large eddy simulations and observations of atmospheric marine boundary layers above non-equilibrium surface waves. J. Atmos. Sci., 65, 1225-1245, doi: 10.1175/2007JAS2427.1.

ABSTRACT

Winds and waves in marine boundary layers are often in an unsettled state when fast-running swell generated by distant storms propagates into local regions and modifies the overlying turbulent fields. A large-eddy simulation (LES) model with the capability to resolve a moving sinusoidal wave at its lower boundary is developed to investigate this low-wind/fast-wave regime. It is used to simulate idealized situations with wind following and opposing fast-propagating waves (swell), and stationary bumps. LES predicts momentum transfer from the ocean to the atmosphere for wind following swell, and this can greatly modify the turbulence production mechanism in the marine surface layer. In certain circumstances the generation of a low-level jet reduces the mean shear between the surface layer and the PBL top, resulting in a near collapse of turbulence in the PBL. When light winds oppose the propagating swell, turbulence levels increase over the depth of the boundary layer and the surface drag increases by a factor of 4 compared to a flat surface. The mean wind profile, turbulence variances, and vertical momentum flux are then dependent on the state of the wave field. The LES results are compared with measurements from the Coupled Boundary Layers Air–Sea Transfer (CBLAST) field campaign. A quadrant analysis of the momentum flux from CBLAST verifies a wave age dependence predicted by the LES solutions. The measured bulk drag coefficient CD then depends on wind speed and wave state. In situations with light wind following swell, CD is approximately 50% lower than values obtained from standard bulk parameterizations that have no sea state dependence. In extreme cases with light wind and persistent swell, CD < 0.

Jonker, H. J., T. Heus, P. P. Sullivan, 2008: A refined view of vertical transport by cumulus convection. Geophys. Res. Lett., 35, L07810, doi: 10.1029/2007GL032606,2008.

Abstract

The purpose of this letter is to show that the traditional view of transport by shallow cumulus clouds needs important refinement. On the basis of a straightforward geometrical analysis of Large Eddy Simulation results of shallow cumulus clouds, we conclude: 1) that the upward transport by clouds is strongly dominated by regions close to the edge of clouds rather than by the core region of clouds; and 2) that the downward transport is dominated by processes just outside the cloud. The latter finding contradicts the accepted view of a uniformly descending dry environment. We therefore advocate a refined view which distinguishes between the near-cloud environment and the distant environment. The near-cloud environment is characterized by coherent descending motions, whereas the distant environment is rather quiescent and plays no significant role in vertical transport.

Sullivan, P. P., J. C. McWilliams, W. K. Melville, 2007: Surface gravity wave effects in the oceanic boundary layer: large-eddy simulation with vortex force and stochastic breakers. J. Fluid Mech., 593, 405-452, doi: 10.1017/S002211200700897x.

Abstract

The wind-driven stably stratified mid-latitude oceanic surface turbulent boundary

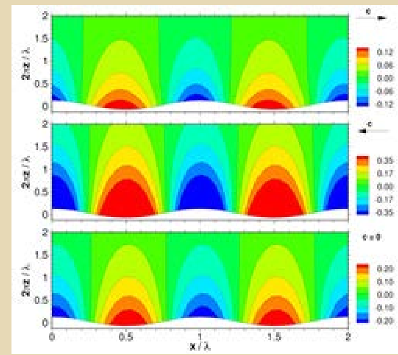

Figure 1: Contours of the non-dimensional and y-averaged pressure field $[p^*]/U_g^2$ close to the water surface for cases with moving and stationary waves. The winds are from left to right. Negative contours are indicated by dashed lines. Top panel wind following waves; middle panel wind opposing waves; and, bottom panel stationary bumps. The vertical and horizontal coordinates are made dimensionless with the surface wavelength λ.

High resolution figure

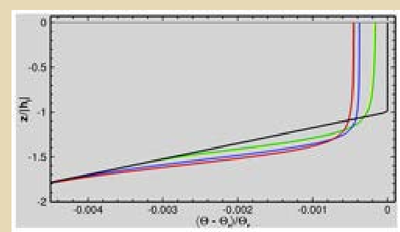

Figure 2: Profiles of normalized temperature for simulations: yellow line no wave effects; green line breaking only wave age $c_p/u_{*a} = 30$; blue line Stokes drift only; and, red line Stokes drift plus breaking with wave age $c_p/u_{*a} = 19$. The mixed layer depth and temperature are normalized by the initial value $h_i = -32.4$m and the reference temperature $\theta_r = 283.5$K, respectively. The time averaging is over 10,000s starting at $t = 40,000$s for each simulation. For reference, the initial mixed layer sounding is shown as a solid black line. Notice how the temperature profiles from all simulations relax back to the initial sounding for $z/|h_i| \ll -1$.

High resolution figure

layer is computationally simulated in the presence of a specified surface gravity-wave field. The gravity waves have broad wavenumber and frequency spectra typical of measured conditions in near-equilibrium with the mean wind speed. The simulation model is based on (i) an asymptotic theory for the conservative dynamical effects of waves on the wave-averaged boundary-layer currents and (ii) a boundary-layer forcing by a stochastic representation of the impulses and energy fluxes in a field of breaking waves. The wave influences are shown to be profound on both the mean current profile and turbulent statistics compared to a simulation without these wave influences and forced by an equivalent mean surface stress. As expected from previous studies with partial combinations of these wave influences, Langmuir circulations due to the wave-averaged vortex force make vertical eddy fluxes of momentum and material concentration much more efficient and non-local (i.e. with negative eddy viscosity near the surface), and they combine with the breakers to increase the turbulent energy and dissipation rate. They also combine in an unexpected positive feedback in which breaker-generated vorticity seeds the creation of a new Langmuir circulation and instigates a deep strong intermittent downwelling jet that penetrates through the boundary layer and increases the material entrainment rate at the base of the layer. These wave effects on the boundary layer are greater for smaller wave ages and higher mean wind speeds.

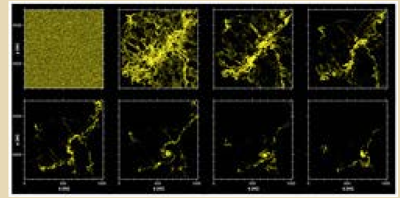

Figure 3: Visualization of particles released in a convective PBL at $z/z_i \sim 0.2$ over a limited horizontal extent from a 1024^3 simulation of convection. The area viewed is $\sim$ 3.8\% of the total horizontal domain. Notice the evolution of the larger scale line of convection into small scale vortical dust devils. Time advances from left to right beginning along the top row of images.

High resolution figure

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JIELUN SUN

2008 Publications

Schaeffer, S. M., D. E. Anderson, S. P. Burns, R. K. Monson, J. Sun, D. R. Bowling, 2007: Canopy structure and atmospheric flows in relation to the dell3C of respired CO2 in a subalpine coniferous forest. Agric. For. Meteorol., 148, 592-605, doi: 10.1016/j.agrformet.2007.11.003.

Abstract

Stable isotopes provide insight into ecosystem carbon cycling, plant physiological processes, atmospheric boundary-layer dynamics, and are useful for the integration of processes over multiple scales. Of particular interest is the carbon isotope content (d13C) of nocturnal ecosystem-respired CO2 (dR). Recent advances in technology have made it possible to continuously examine the variation in dR within a forest canopy over relatively long time-scales (months–years). We used tunable diode laser spectroscopy to examine dR at within- and below-canopy spatial locations in a Colorado subalpine forest (the Niwot Ridge AmeriFlux site). We found a systematic pattern of increased dR within the forest canopy (dR-c) compared to that near the ground (dR-g). Values of dR-c were weakly correlated with the previous day's mean maximum daytime vapor pressure deficit (VPD). Conversely, there was a negative but still weak correlation between dR-g and time-lagged (0–5 days) daily mean soil moisture. The topography and presence of sustained nightly drainage flows at the Niwot Ridge forest site suggests that, on nights with stable atmospheric conditions, there is little mixing of air near the ground with that in the canopy. Atmospheric stability was assessed using thresholds of friction velocity, stability above the canopy, and bulk Richardson number within the canopy. When we selectively calculated dR-g and dR-c by removing time periods when ground and canopy air were well mixed, we found stronger correlations between dR-c and VPD, and dR-g and soil moisture. This suggests that there may be fundamental differences in the environmental controls on dR at sub-canopy spatial scales. These results may help explain the wide variance observed in the correlation of dR with different environmental parameters in other studies.

Lenschow, D. H., J. Sun, 2007: The spectral composition of fluxes and variances over land and sea out to the mesoscale. Bound.-Layer Meteor., 125, 63-84, doi: 10.1007/s10546-007-9191-8.

Abstract

We discuss the accuracy requirements for measuring mesoscale (roughly horizontal scales > 10 km or 5 to 10 times the planetary boundary-layer (PBL) depth) fluxes in the convective PBL, and the ability of current research aircraft to achieve this accuracy. We conclude that aircraft equipped with inertial nagivation systems capable of < 3 km hr-1 navigational accuracy are able to resolve mesoscale fluctuations in velocity, and thus variances and fluxes on the mesoscale. We then discuss measurements of velocity and scalar spectra, and cospectra of vertical velocity with horizontal velocity components and scalars, obtained from long flight legs with the National Center for Atmospheric Research Electra aircraft over the boreal forest of Canada in summer during the BOreal Ecosystem-Atmosphere Study (BOREAS), over the tropical Pacific Ocean from the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE), and over the East China Sea during wintertime cold-air outbreaks from the Air Mass Transformation Experiment (AMTEX). Each of these studies has somewhat different forcings and boundary conditions, so we can compare their consequences on the spectra and cospectra. On average, we found no significant scalar or momentum fluxes for horizontal scales > 10 km. We also develop a simple model based on observed thermal structure to explain the phase angle between vertical velocity and the along-wind horizontal velocity as a function of height, which shows good agreement with the observed phase angle in AMTEX.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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JIELUN SUN

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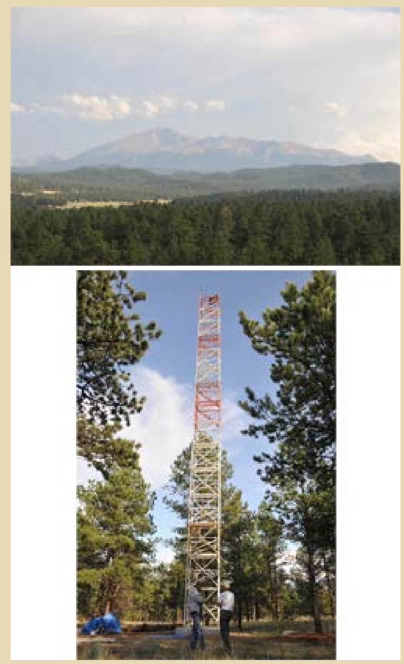
Research Focus FY08:

I continued my work on Carbon in the Mountain Experiment (CME-04) and Airborne Carbon in the Mountain Experiment (ACME-04) data analysis investigating CO_2/H_2O transport over complex terrain on a relatively large scale and within canopy.

I am also investigating how water body affects CO_2 transport at night by analyzing Niwot-07 data.

Based on my results on Cooperative Atmosphere-Surface Exchange Study (CASES99), I am focusing on trace gas transport over and within canopies by analyzing both CME-04 and Canopy Horizontal Array Turbulence Study (CHATS) datasets. CHATS infrared Images.



BEACHON-SRM08 pictures by Jim Smith
High resolution figure

BEACHON - Southern Rocky Mountains Summer 2008 Study (BEACHON-SRM08)

July - September 2008, Woodland Park, Colorado at the Manitou Experimental Forest (MEF)

SRM08 is the initial research phase in the four year BEACHON research program in water-limited Western U.S. pin forest ecosystems that will improve the understanding of fundamental biogeochemical processes that are central to achieving the objectives of the BEACHON research program. BEACHON-SRM08 is considered a pre-study in advance of long-term measurements of key atmospheric and ecosystem parameters at the same site as well as a more comprehensive regional campaign in 2010. Because of this, the study has practical objectives relating to the setup and operation of the MEF site in addition to specific scientific foci on atmospheric chemistry and aerosol processes.

Community Service FY08:

- Associate Editor: Journal of Applied Meteorology
- Editorial Member: Boundary Layer Meteorology

Publications FY08 (abstracts):

Sun, J., Y. Zhang, 2008: Analysis and prediction of a squall line observed during IHOP using multiple WSR-88D observations. *Mon. Wea. Rev.*, **136**, 2364-2388, doi: 10.1175/2007MWR2205.1.

Sun, J., 2008: Nocturnal stable boundary layer parameterization: Part I: Momentum flux. *Bound.-Layer Meteor.*. (Submitted)

Sun, J., 2008: Nocturnal stable boundary layer parameterization: Part II: Heat flux. *Bound.-Layer Meteor.*. (Submitted)

Burns, S. P., A. Delany, J. Sun, B. B. Stephens, S. P. Oncley, G. D. Maclean, S. R. Semmer, J. Schroter, J. Ruppert, 2008: An evaluation of calibration techniques for in-situ carbon dioxide measurements using a programmable portable trace-gas measuring system. *J. Atmos. Ocean. Technol.*, doi: 10.1175/2008JTECHA1080.1. (In Press)

Oncley, S. P., K. Schwenz, S. P. Burns, J. Sun, R. K. Monson, 2008: A cable-borne tram for atmospheric measurements along transects. *J. Atmos. Ocean. Technol.*, doi: 10.1175/2008JTECHA1158.1. (In Press)

Patton, E. G., T. Horst, D. H. Lenschow, P. P. Sullivan, S. P. Oncley, S. P. Burns, A. B. Guenther, T. Karl, S. D. Mayor, S. M. Spuler, J. Sun, A. A. Turnipseed, E. Allwine, S. Edburg, B. Lamb, R. Avissar, H. Holder, R. Calhoun, J. Kleissl, W. Massman, K. Tha Paw U, J. Weil, L. Rizzo, A. Held, 2008: The Canopy Horizontal Array Turbulence Study (CHATS). , Stockholm, SE, AMS, American Meteorological Society, 18A.1.

Oncley, S. P., K. Schwenz, J. Sun, R. Monson, 2008: Measuring in-canopy advection of carbon dioxide using a new transect measurement system (TRAM). , Orlando, FL, US, J2.3.

Schaeffer, S. M., D. E. Anderson, S. P. Burns, R. K. Monson, J. Sun, D. R. Bowling, 2007: Canopy structure and atmospheric flows in relation to the dell3C of respired CO2 in a subalpine coniferous forest. *Agric. For. Meteorol.*, **148**, 592-605, doi: 10.1016/j.agrformet.2007.11.003.

Lenschow, D. H., J. Sun, 2007: The spectral composition of fluxes and variances over land and sea out to the mesoscale. *Bound.-Layer Meteor.*, **125**, 63-84, doi: 10.1007/s10546-007-9191-8.

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JUANZHEN (JENNY) SUN

2008 Publications

Xiao, Q., E. Lim, D.-J. Won, J. Sun, W.-C. Lee, M.-S. Lee, W.-J. Lee, J.-Y. Cho, Y.-H. Kuo, D. M. Barker, D.-K. Lee, H. S. Lee, 2008: Doppler radar data assimilation in KMA's operational forecasting. Bull. Amer. Meteor. Soc., 89, 39-43, doi: 10.1175/BAMS-89-1-39.4

Abstract

During 2001–03, the Mesoscale and Microscale Meteorology Division (MMM) at the National Center for Atmospheric Research (NCAR) partnered with the Korean Meteorological Administration (KMA) and Seoul National University (SNU) to use Doppler radar data in the MM5 with the Weather Research and Forecasting (WRF) 3-dimensional variational (3D-Var) data-assimilation system. After case studies and one-month comparison experiments with and without radar data assimilation in 2004, the system proceeded to semioperational testing in 2005 and was implemented for full operational production in 2006. The case studies showed benefits of radar data assimilation, and further tests indicated that Doppler radar data assimilation in WRF 3D-Var performed robustly and improved rainfall forecasting. The procedure for KMA Doppler radar data assimilation is rather sophisticated: it includes data preprocessing (quality control, error statistics, and formatting), assimilation with WRF 3D-Var, and analysis update cycling. The algorithms for direct assimilations of radial velocity and reflectivity are advanced and innovative. The transfer of the developed system from research mode at NCAR to operational mode at KMA has been very smooth and successful. With great efforts from all parties, KMA is running the advanced system operationally and benefiting Korea. The WRF 3D-Var Doppler radar data-assimilation system now resides in both NCAR and KMA and serves as a very useful tool for research.

Sun, J., Y. Zhang, 2008: Analysis and prediction of a squall line observed during IHOP using multiple WSR-88D observations. Mon. Wea. Rev., 136, 2364-2388, doi: 10.1175/2007MWR2205.1.

Abstract

This paper presents a case study on the assimilation of observations from multiple Doppler radars of the Next Generation Weather Radar (NEXRAD) network. A squall-line case documented during the International H2O Project (IHOP_2002) is used for the study. Radar radial velocity and reflectivity observations from four NEXRADs are assimilated into a convection-permitting model using a four-dimensional variational data assimilation (4DVAR) scheme. A mesoscale analysis using a supplementary sounding, velocity–azimuth display (VAD) profiles, and surface observations from Meteorological Aerodrome Reports (METAR) are produced and used to provide a background and boundary conditions for the 4DVAR radar data assimilation. Impact of the radar data assimilation is assessed by verifying the skill of the subsequent very short-term (5 h) forecasts.

Assimilation and forecasting experiments are conducted to examine the impact of radar data assimilation on the subsequent precipitation forecasts. It is found that the 4DVAR radar data assimilation significantly reduces the model spinup required in the experiments without radar data assimilation, resulting in significantly improved 5-h forecasts. Additional experiments are conducted to study the sensitivity of the precipitation forecasts with respect to 4DVAR cycling configurations. Results from these experiments suggest that the forecasts with three 4DVAR cycles are improved over those with cold start, but the cycling impact seems to diminish with more cycles. The impact of observations from each of the individual radars is also examined by conducting a set of experiments in which data from each radar are alternately excluded. It is found that the accurate analysis of the environmental wind surrounding the convective cells is important in successfully predicting the squall line.

Xiao, Q., J. Sun, 2007: Multiple radar data assimilation and short-range Quantitative Precipitation Forecasting of a squall line observed during IHOP 2002. Mon. Wea. Rev., 135, 3381-3404, doi: 10.1175/MWR3471.1.

ABSTRACT

The impact of multiple–Doppler radar data assimilation on quantitative precipitation forecasting (QPF) is examined in this study. The newly developed Weather Research and Forecasting (WRF) model Advanced Research WRF (ARW) and its three-dimensional variational data assimilation system (WRF 3DVAR) are used. In this study, multiple–Doppler radar data assimilation is applied in WRF 3DVAR cycling mode to initialize a squall-line convective system on 13 June 2002 during the International H2O Project (IHOP_2002) and the ARW QPF skills are evaluated for the case. Numerical experiments demonstrate that WRF 3DVAR can successfully assimilate Doppler radial velocity and reflectivity from multiple radar sites and extract useful information from the radar data to initiate the squall-line convective system. Assimilation of both radial velocity and reflectivity results in sound analyses that show adjustments in both the dynamical and thermodynamical fields that are consistent with the WRF 3DVAR balance constraint and background error correlation. The cycling of the Doppler radar data from the 12 radar sites

at 2100 UTC 12 June and 0000 UTC 13 June produces a more detailed mesoscale structure of the squall-line convection in the model initial conditions at 0000 UTC 13 June. Evaluations of the ARW QPF skills with initialization via Doppler radar data assimilation demonstrate that the more radar data in the temporal and spatial dimensions are assimilated, the more positive is the impact on the QPF skill. Assimilation of both radial velocity and reflectivity has more positive impact on the QPF skill than does assimilation of either radial velocity or reflectivity only. The improvement of the QPF skill with multiple-radar data assimilation is more clearly observed in heavy rainfall than in light rainfall. In addition to the improvement of the QPF skill, the simulated structure of the squall line is also enhanced by the multiple–Doppler radar data assimilation in the WRF 3DVAR cycling experiment. The vertical airflow pattern shows typical characteristics of squall-line convection. The cold pool and its related squall-line convection triggering process are better initiated in the WRF 3DVAR analysis and simulated in the ARW forecast when multiple–Doppler radar data are assimilated.

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CGD 2008 PROFILES IN SCIENCE: DR. HAIYAN TENG

Summary of achievements

In FY2008, I have examined future changes in the wintertime storm activity over North America in CCSM3 (Teng et. al). I also worked with Clara Deser to investigate the role of atmospheric circulation trends on Arctic sea ice changes using satellite observations (Deser and Teng), with Jerry Meehl to study projected future changes of El Nino teleconnections over North America (Meehl and Teng, and Meehl et al.). In addition, I have assisted CCWG and CVWG to carry out 30-member ensemble simulations. The only difference among the 30 members is the atmosphere initial state. I'm currently collaborating with Grant Branstator to study predictability of the Pacific decadal oscillation in the large ensemble experiment.

Haiyan Teng

Publications

Teng, H., W. M. Washington, and G. A. Meehl, 2008: Interannual variations and future change of wintertime extratropical cyclone activity over North America in CCSM3. Climate Dynamics, 30, 673-686, doi:10.1007/s00382-007-0314-1.

Abstract: Climatology and interannual variations of wintertime extratropical cyclone frequency in CCSM3 twentieth century simulation are compared with the NCEP/NCAR reanalysis during 1950-1999. CCSM3 can simulate the storm tracks reasonably well, although the model produces slightly less cyclones at the beginning of the Pacific and Atlantic storm tracks and weaker poleward deflection over the Pacific. As in the reanalysis, frequency of cyclones stronger than 980 hPa shows significant correlation with the Pacific/North America (PNA) teleconnection pattern over the Pacific region and with the North Atlantic Oscillation (NAO) in the Atlantic sector. Composite maps are constructed for opposite phases of El Nino-Southern Oscillation (ENSO) and the NAO and all anomalous patterns coincide with observed. One CCSM3 twenty-first century A1B scenario realization indicates there is significant increase in the extratropical cyclone frequency on the US west coast and decrease in Alaska. Meanwhile, cyclone frequency increases from the Great Lakes region to Quebec and decreases over the US east coast, suggesting a possible northward shift of the Atlantic storm tracks under the warmer climate. The cyclone frequency anomalies are closely linked to changes in seasonal mean states of the upper-troposphere zonal wind and baroclinicity in the lower troposphere. Due to lack of 6-hourly outputs, we cannot apply the cyclone-tracking algorithm to the other eight CCSM3 realizations. Based on the linkage between the mean state change and the cyclone frequency anomalies, it is likely a common feature among the other ensemble members that cyclone activity is reduced on the East Coast and in Alaska as a result of global warming.

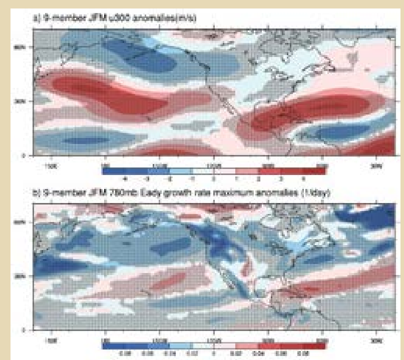

Figure 1.

High resolution figure

Figure caption: 9-member ensemble mean a) 300 hPa zonal wind anomalies and b) 780 hPa Eady growth rate maximum in JFM 2080-2099 relative to 1980-1999. Stippling indicates at least 6 out of the 9 members agree on the sign of the anomalies.

Deser, C., and H. Teng, 2008: Evolution of Arctic sea ice concentration trends and the role of atmospheric circulation forcing, 1979-2007. Geophys. Res. Lett., 35, L02504, doi:10.1029/2007GL032023.

Abstract: The retreat of Arctic sea ice in recent decades is a pre-eminent signal of climate change. What role has the atmospheric circulation played in driving the sea ice decline? To address this question, we document the evolution of Arctic sea ice concentration trends during the period January 1979-April 2007 in light of changing atmospheric circulation conditions, in particular an upward trend in the wintertime Northern Annular Mode during the first half of the record and a downward trend during the second half. The results indicate that concurrent atmospheric circulation trends contribute to forcing winter and summer sea ice concentration trends in many parts of the marginal ice zone during both periods. However, there is also an emerging signal of overall Arctic sea ice decline since 1979 in both winter and summer that is not directly attributable to a trend in the

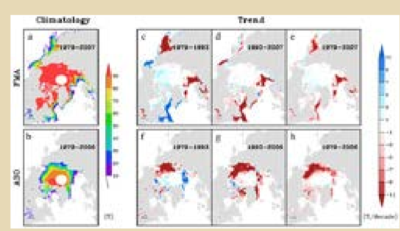

Figure 2.

overlying atmospheric circulation.

High resolution figure

Figure caption: (left) Long-term mean sea ice concentrations (%) for (a) winter (February-April) and (b) summer (August-October) based on the period January 1979 - April 2007. The white ellipse around the North Pole indicates missing data. (right) (c)-(e) Winter and(f)-(h) summer sea ice concentration trends (% per decade) during 1979-1993 (Figures 1c and 1f), 1993-2007 (Figures 1d and 1g) and 1979-2007 (Figure 1e and 1h). Note that 2006 is the last year of data in summer.

Knutti, R., M. R. Allen, P. Friedlingstein, J. M. Gregory, G. C. Hegerl, G. A. Meehl, M. Meinshausen, J. M. Murphy, G. K. Plattner, S. C. B. Raper, T. F. Stocker, P. A. Scott, H. Teng, and T. M. L. Wigley, 2008: A review of uncertainties in global temperature projections over the twenty-first century. Journal of Climate, 21, 2651-2663, doi:10.1175/2007JCLI2119.1

Abstract: Quantification of the uncertainties in future climate projections is crucial for the implementation of climate policies. Here a review of projections of global temperature change over the twenty-first century is provided for the six illustrative emission scenarios from the Special Report on Emissions Scenarios (SRES) that assume no policy intervention, based on the latest generation of coupled general circulation models, climate models of intermediate complexity, and simple models, and uncertainty ranges and probabilistic projections from various published methods and models are assessed. Despite substantial improvements in climate models, projections for given scenarios on average have not changed much in recent years. Recent progress has, however, increased the confidence in uncertainty estimates and now allows a better separation of the uncertainties introduced by scenarios, physical feedbacks, carbon cycle, and structural uncertainty. Projection uncertainties are now constrained by observations and therefore consistent with past observed trends and patterns. Future trends in global temperature resulting from anthropogenic forcing over the next few decades are found to be comparably well constrained. Uncertainties for projections on the century time scale, when accounting for structural and feedback uncertainties, are larger than captured in single models or methods. This is due to differences in the models, the sources of uncertainty taken into account, the type of observational constraints used, and the statistical assumptions made. It is shown that as an approximation, the relative uncertainty range for projected warming in 2100 is the same for all scenarios. Inclusion of uncertainties in carbon cycle-climate feedbacks extends the upper bound of the uncertainty range by more than the lower bound.

Meehl, G. A., C. Tebaldi, H. Teng, and T. C. Peterson, 2007: Current and future U.S. weather extremes and El Niño. Geophys. Res. Lett., 34, L20704, doi:10.1029/2007GL031027.

Abstract: A global coupled climate model representative of the current generation of models is shown to simulate most first order aspects of El Niño events, their teleconnections over North America, and the associated observed patterns of extremes in present-day climate. Future El Niño teleconnection patterns over the U.S. are projected to shift eastward and northward due in part to the different midlatitude base state atmospheric circulation in a warmer climate. Consequently, projections for the changes in the patterns of extremes over the U.S. during future El Niño events include: decreases of frost days over the southwestern U.S expand northward and eastward; increases in intense precipitation in the SW U.S. expands eastward and areas in the SE U.S. become stronger; and decreases of heat wave intensity over much of the southern tier of states turn to increases.

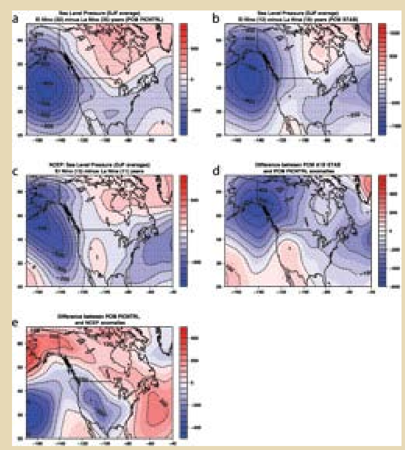

Figure 3.

High resolution figure

Figure caption: (a) Composite SLP anomalies (DJF), El Niño minus La Niña, for the model control run events, (b) same as Figure 1a except for the stabilized A1B future climate experiment, (c) same as Figure 1a except for observations, (d) differences, future minus control, for model-simulated El Niño event teleconnections, and (e) differences, model minus observations, of El Niño teleconnection patterns (all in Pa).

Meehl, G. A., and H. Teng, 2007: Multi-model changes in El Niño teleconnections over North America in a future warmer climate. Climate Dynamics, 29, 779-790, doi:10.1007/s00382-007-0268-3.

Abstract: Previous studies with single models have suggested that El Niño teleconnections over North America could be different in a future warmer climate due to factors involving changes of El Niño event amplitude and/or changes in the midlatitude base state circulation. Here we analyze a six-member multi-model ensemble, three models with increasing future El Niño amplitude, and three models with decreasing future El Niño amplitude, to determine characteristics and possible changes to El Niño teleconnections during northern winter over the North Pacific and North America in a future warmer climate. Compared to observed El Niño events, all the models qualitatively produce general features of the observed teleconnection pattern over the North Pacific and North America, with an

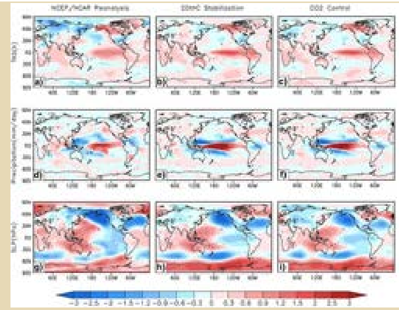

Figure 4.

High resolution figure

anomalously deepened Aleutian Low, a ridge over western North America, and anomalous low pressure over the southeastern United States. However, associated with systematic errors in the location of sea surface temperature and convective heating anomalies in the central and western equatorial Pacific (the models' anomaly patterns are shifted to the west), the anomalous low pressure center in the North Pacific is weaker and shifted somewhat south compared to the observations. For future El Niño events, two different stabilization experiments are analyzed, one with CO_2 held constant at year 2100 concentrations in the SRES A1B scenario (roughly doubled present-day CO_2), and another with CO2 concentrations held constant at $4XCO_2$. Consistent with the earlier single model results, the future El Niño teleconnections are changed in the models, with a weakened as well as an eastward- and northward-shifted anomalous low in the North Pacific. This is associated with weakened anomalous warming over northern North America, strengthened cooling over southern North America, and precipitation increases in the Pacific Northwest in future events compared to present-day El Niño event teleconnections. These changes are consistent with the altered base state upper tropospheric circulation with a wave-5 pattern noted in previous studies that is shown here to be consistent across all the models whether there are projected future increases or decreases in El Niño amplitude. The future teleconnection changes are most consistent with this anomalous wave-5 pattern in the models with future increases of El Niño amplitude, but less so for the models with future decreases of El Niño amplitude.

Figure caption: a Surface temperature anomalies (°C) for a composite of observed El Niño events, years 0 DJF minus long term mean, for the NCEP/NCAR reanalyses for events listed in the text; b same as a except for six-member multi-model composite of El Niño events from the 20th century stabilization reference experiment; c same as b except for the present day control experiment; d same as a except for precipitation (mm day-1); e same as b except for precipitation; f same as c except for precipitation; g same as a except for SLP (hPa); h same as b except for SLP; i same as c except for SLP.

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MUKUL TEWARI

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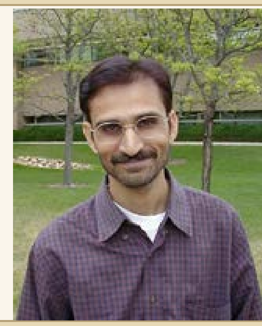

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Research Focus FY08:

IHOP_2002 data : WRF-ARW Comparison

In continuation of the earlier work (Lemone et al., 2008), we have compared the WRF (ARW) model simulation with the IHOP_2002 data. The model was initialized using land surface states from High Resolution Land Data assimilation system. We have used the 30 arcsec Modis Land use data instead of the old USGS landuse data for these simulations. The purpose of this work is to gain insight into how the surface influences convective boundary layer (CBL) fluxes and structure.

We find that the modeled sensible heat flux H is significantly larger than observed, while the latent heat flux LE is much closer to observed values. The fluxes follow the soil moisture largely because the input land use map does not capture the observed variation in vegetation. Because of the too-high H, the model overestimates the CBL depth, but the timing of cumulus cloudiness is reproduced for three of the four days we selected for our investigation.

WRF reproduces the cloud structure quite well and also the westward rise of the boundary layer depth. Further investigation for the roll generated cloud streets, their modulation is under progress.

Manitou Spring Bark Beetle Infestation : WRF Simulations

In order to assess the impact of landuse of mesoscale flow over the Manitou Spring (CO) region, the area where forest area is killed by bark beetle, we conducted high resolution WRF simulation introducing new landuse map for forest killed regions. The work is conducted in collaboration with Christine Wiedinmyer (ACD) and the analysis of the work is under progress.

Top view of adult Mountain Pine Beetle (actual size, 1/8 to 1/3 inch). Picture: Colorado State University)

Headwater - Noah Land Surface Model - SNODAS - WRF

In context with the Headwater Project, Livneh's formulation for the modification of albedo in Noah Land Surface Model (LSM) is implemented and tested for the 20 Nov 2003 snow case. The results are verified against SNOw Data Assimilation System (SNODAS - NOAA) and Modis data and coupled WRF simulations showed promising results.

Publications FY08:

Miao, S., F. Chen, M. A. LeMone, M. Tewari, Q. Li, Y. Wang, 2008: An observational and modeling study of characteristics of urban heat island and boundary layer structures in Beijing. *J. Appl. Meteor. Climat.*. (In Press)

LeMone, M. A., M. Tewari, F. Chen, J. G. Alfieri, D. Niyogi, 2008: Evaluation of the Noah land-surface model using data from a fair-weather IHOP_2002 day with heterogeneous surface fluxes. *Mon. Wea. Rev.*. (In Press)

Tewari M., F. Chen, W. Coirier, S. Kim, 2008: Impact of coupling a microscale computational fluid dynamics model with a mesoscale model on urban scale contaminant transport and dispersion. Submitted to *Geophysical Research Letters*.

Hong, S.,V. Lakshmi , E. E. Small, F. Chen, M. Tewari, and K. W. Manning, 2008: Simulation and validation of land surface variables using the Noah land and WRF Models compared to IHOP and MODIS observations. Submitted *to J. Hydro. Meteor.*

Mukul Tewari Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. PETER THORNTON

Peter Thornton

Publications

Stockli, R., D. M. Lawrence, G. Y. Niu, K. W. Oleson, P. E. Thornton, Z. L. Yang, G. B. Bonan, A. S. Denning, and S. W. Running. 2008. Use of FLUXNET in the community land model development. Journal of Geophysical Research-Biogeosciences, doi:10.1029/2007JG000562.

Abstract: The Community Land Model version 3 (CLM3.0) simulates land-atmosphere exchanges in response to climatic forcings. CLM3.0 has known biases in the surface energy partitioning as a result of deficiencies in its hydrological and biophysical parameterizations. Such models, however, need to be robust for multidecadal global climate simulations. FLUXNET now provides an extensive data source of carbon, water and energy exchanges for investigating land processes, and it encompasses a global range of ecosystem-climate interactions. Data from 15 FLUXNET sites are used to identify and improve model deficiencies. Including a prognostic aquifer, a bare soil evaporation resistance formulation and numerous other changes in the model result in a significantly improved soil hydrology and energy partitioning. Terrestrial water storage increased by up to 300 mm in warm climates and decreased in cold climates. Nitrogen control of photosynthesis is revealed as another missing process in the model. These improvements increase the correlation coefficient of hourly and monthly latent heat fluxes from a range of 0.5-0.6 to the range of 0.7-0.9. RMSE of the simulated sensible heat fluxes decrease by 20-50%. Primary production is overestimated during the wet season in mediterranean and tropical ecosystems. This might be related to missing carbon-nitrogen dynamics as well as to site-specific parameters. The new model (CLM3.5) with an improved terrestrial water cycle should lead to more realistic land-atmosphere exchanges in coupled simulations. FLUXNET is found to be a valuable tool to develop and validate land surface models prior to their application in computationally expensive global simulations.

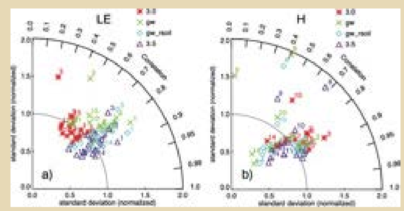

Figure 1.

High resolution figure

Figure caption: Performance of four model versions at 15 FLUXNET towers (numbers 1-15). Statistics in the Taylor diagram are derived from hourly simulated and observed LE and H fluxes. Legend: CLM3.0: red asterisks; CLMgw: green crosses; CLMgw_rsoil: cyan diamonds; CLM3.5: violet triangles. In CLM3.0 H is off-scale for the two tropical sites 8 and 9 (and therefore not shown).

Oleson, K. W., et al., 2008: Improvements to the Community Land Model and their impact on the hydrological cycle. J. Geophys. Res., 113, G01021, doi:10.1029/2007JG000563.

Abstract: The Community Land Model version 3 (CLM3) is the land component of the Community Climate System Model (CCSM). CLM3 has energy and water biases resulting from deficiencies in some of its canopy and soil parameterizations related to hydrological processes. Recent research by the community that utilizes CLM3 and the family of CCSM models has indicated several promising approaches to alleviating these biases. This paper describes the implementation of a selected set of these parameterizations and their effects on the simulated hydrological cycle. The modifications consist of surface data sets based on Moderate Resolution Imaging Spectroradiometer products, new parameterizations for canopy integration, canopy interception, frozen soil, soil water availability, and soil evaporation, a TOPMODEL-based model for surface and subsurface runoff, a groundwater model for determining water table depth, and the introduction of a

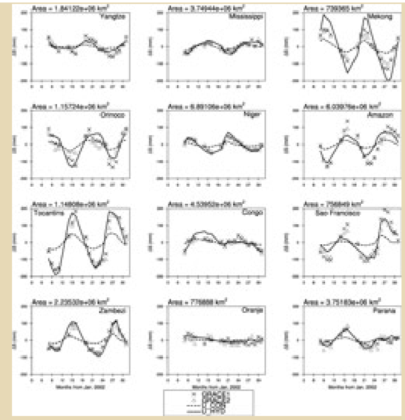

Figure 2.

[High resolution figure]

factor to simulate nitrogen limitation on plant productivity. The results from a set of offline simulations were compared with observed data for runoff, river discharge, soil moisture, and total water storage to assess the performance of the new model (referred to as CLM3.5). CLM3.5 exhibits significant improvements in its partitioning of global evapotranspiration (ET) which result in wetter soils, less plant water stress, increased transpiration and photosynthesis, and an improved annual cycle of total water storage. Phase and amplitude of the runoff annual cycle is generally improved. Dramatic improvements in vegetation biogeography result when CLM3.5 is coupled to a dynamic global vegetation model. Lower than observed soil moisture variability in the rooting zone is noted as a remaining deficiency.

Figure caption: Total water storage anomalies (mm) for U_HYD (CLM3.5) and U_CON (CLM3.0) compared to two sources of GRACE data (GRACE1 [Seo and Wilson, 2005] and GRACE2 [Chen et al., 2005]). Model total water storage anomalies are calculated from the sum of snow water, canopy water, total column soil water, and aquifer water. GRACE data were interpolated to the model resolution.

Thornton, P. E., J.-F. Lamarque, N. A. Rosenbloom, and N. M. Mahowald, 2007: Influence of carbon-nitrogen cycle coupling on land model response to CO2 fertilization and climate variability. Global Biogeochem. Cycles, 21, GB4018, doi:10.1029/2006GB002868.

Abstract: Nutrient cycling affects carbon uptake by the terrestrial biosphere and imposes controls on carbon cycle response to variation in temperature and precipitation, but nutrient cycling is ignored in most global coupled models of the carbon cycle and climate system. We demonstrate here that the inclusion of nutrient cycle dynamics, specifically the close coupling between carbon and nitrogen cycles, in a terrestrial biogeochemistry component of a global coupled climate system model leads to fundamentally altered behavior for several of the most critical feedback mechanisms operating between the land biosphere and the global climate system. Carbon-nitrogen cycle coupling reduces the simulated global terrestrial carbon uptake response to increasing atmospheric CO2 concentration by 74%, relative to a carbon-only counterpart model. Global integrated responses of net land carbon exchange to variation in temperature and precipitation are significantly damped by carbon-nitrogen cycle coupling. The carbon cycle responses to temperature and precipitation variation are reduced in magnitude as atmospheric CO2 concentration rises for the coupled carbon-nitrogen model, but increase in magnitude for the carbon-only counterpart. Our results suggest that previous carbon-only treatments of climate-carbon cycle coupling likely overestimate the terrestrial biosphere's capacity to ameliorate atmospheric CO2 increases through direct fertilization. The next generation of coupled climate-biogeochemistry model projections for future atmospheric CO2 concentration and climate change should include explicit, prognostic treatment of terrestrial carbon-nitrogen cycle coupling.

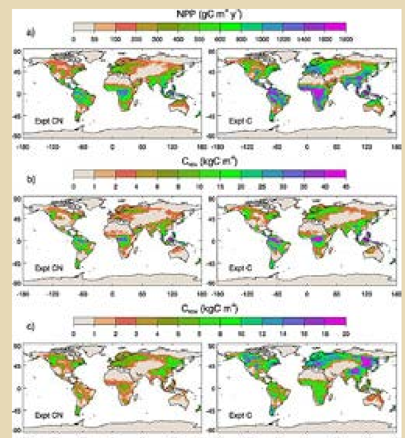

Figure 1.

[High resolution figure]

Figure caption: Example annual mean flux and state variables from final 25 a of control simulations for C-N (Experiment CN) and carbon-only (Experiment C) model configurations. (a) Net primary production (NPP). (b) Total vegetation carbon (C_{veg}). (c) Total soil organic matter carbon (C_{SOM}).

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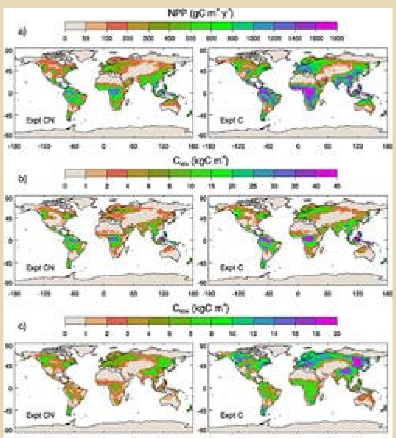
Research Focus FY08:



Example annual mean flux and state variables from final 25 a of control simulations for C-N (Experiment CN) and carbon-only (Experiment C) model configurations. (a) Net primary production (NPP). (b) Total vegetation carbon (Cveg). (c) Total soil organic matter carbon (CSOM).
High resolution figure

My research over the past year has continued to focus on the interactions between carbon and nitrogen cycles in terrestrial ecosystems, and how this coupling affects feedbacks within the climate system.

Publications FY08 (abstracts):

Oleson, K. W., G.-Y. Niu, Z.-L. Yang, D. M. Lawrence, P. Thornton, P. Lawrence, R. Stockli, R. Dickinson, G. Bonan, S. Levis, A. Dai, T. Qian, 2008: Improvements to the community land model and their impact on the hydrological cycle. *J. Geophys. Res.*, **113**, G01021, doi: 10.1029/2007JG000563.

Stockli, R., D. M. Lawrence, G. Y. Niu, K. W. Oleson, P. E. Thornton, Z. L. Yang, G. B. Bonan, A. S. Denning, and S. W. Running. 2008. Use of FLUXNET in the community land model development. Journal of Geophysical Research-Biogeosciences, doi:10.1029/2007JG000562.

Thornton, P. E., J.-F. Lamarque, N. A. Rosenbloom, N. M. Mahowald, 2007: Influence of carbon-nitrogen cycle coupling on land model response to CO2 fertilization and climate variability. *Global Biogeochemical Cycles*, **21**, GB4018, doi: 10.1029/2006GB002868.

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Research Focus FY08:

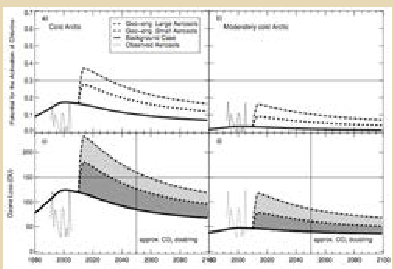


Figure 1: Impact of geo-engineered stratospheric aerosols on the potential for the activation of chlorine (PACl) and chemical ozone loss in the Northern Hemisphere polar vortex in winter and spring: *continued in the shaded box*

High resolution figure

Top panels: The temporal development of PACl taking into account the changing halogen burden in the stratosphere for two geo-engineering cases between 2010 and 2050, to counteract global warming in case of CO2 doubling (expected to occur around 2050), using observed temperatures for a very cold Arctic winter (panel a) and a moderately cold Arctic winter (panel b). The temporal evolution of PACl for background surface area densities (SAD) (solid line), is also shown. Finally, values of PACl based on observed SAD, temperature, and halogen burden, are shown (dotted lines).

Bottom panel: Chemical ozone loss versus time, derived from PACl (top panels) for the various SAD cases, is shown for meteorological conditions corresponding to a very cold Arctic winter (panel c) and a moderately cold Arctic winter (panel d). The ozone loss estimates are based on the linear relationship between chemical loss and PACl for the Arctic (Tilmes et al., Science, June 2, 2008).

Impact of Geo-engineered Aerosols on the Troposphere and Stratosphere

Geo-engineering schemes have been proposed to alleviate the consequences of global warming by continuous injection of sulfur into the stratosphere. Volcanic eruptions in the past have shown that strongly enhanced sulfate aerosols in the stratosphere result in a higher planetary albedo, leading to surface cooling. However, the increase of sulfate aerosol surface area enhances heterogeneous reactions in the stratosphere that lead to ozone loss. The potential for exceedingly high Arctic ozone depletion in the context of geo-engineering is known. On the other hand, decreasing halogen compounds in the atmosphere result in a recovery of the ozone layer and lessen the potential impact of aerosols.

Simone Tilmes investigated the sensitivity of polar ozone depletion to a proposed geo-engineering scheme for present and future halogen conditions. She used an empirical projection of past observations to future conditions. The deployment of a geo-engineering scheme to counteract global warming would result in a significant increase of polar stratospheric ozone depletion in the Northern Hemisphere up to the end of this century (Figure 1). Further, the recovery of the Antarctic ozone hole will be delayed by several decades in case geo-engineered aerosols would be applied to cool the climate (Tilmes et al, Science 2. June, 2008)

Further, Simone Tilmes used the NCAR, Whole Atmosphere Community Climate Model (WACCM), studying impact of Geo-engineering on the troposphere as well as on stratospheric chemistry and dynamics. Besides the cooling of the troposphere, local temperature changes and a decrease in precipitation in the Tropics is a possible result of geo-engineering. Further, changes in stratospheric chemistry and dynamics slow down the recovery of ozone for mid- and high latitudes in the Southern Hemisphere. A 200-300% increase of polar ozone

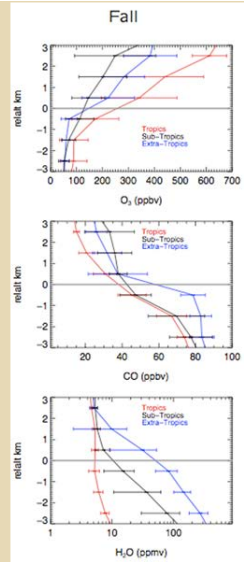


Figure 2: Relative altitudes (with regard to the thermal tropopause) of Ozone (top panel), CO (middle panel) and H2O (bottom panel) averaged for fall (September, October and November). Observations are grouped into different regions: Tropics (red), Sub-Tropics (black) and Extra-Tropics (blue) with the standard deviation shown as error bars.
High resolution figure

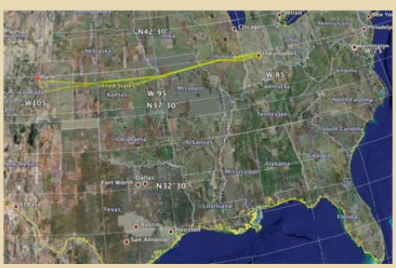
depletion in the Northern Hemisphere in winter spring was also simulated.

Evaluation of Chemistry Transport Models (CTMs) and Chemistry Climate Models (CCMs) using Aircraft observations

A good representation of the Upper Troposphere Lower Stratosphere (UTLS) processes in CCMs is an important component for the model's ability to predict climate changes. Currently, the international research community, led by SPARC, is working together on a process oriented validation project (CCMVal). As part of this project, diagnostics were proposed to quantify irreversible mixing processes in the UTLS region and the effect of Stratospheric Tropospheric Exchange (STE) on trace gas distribution using tracer-tracer correlations.

Depending on large-scale circulation and varying tropospheric weather systems, the signature of STE and mixing in the UTLS region varies with latitudes and season. Therefore, understanding the impact of transport and mixing for carefully separated regions based on dynamical and transport characteristics is important to localize shortcomings in the models.

Simone Tilmes uses aircraft observations of several campaigns that took place in the Northern Hemisphere to establish a climatology. Various trace gases are separated into seasons and regimes base on dynamical and transport characteristics (Figure 2). This aircraft serves as a reference for CTMs and CCMs, and can be used for satellite data validation. START08 data will be included into the climatology.



Google Earth flight path for START-08.
High resolution figure

START08

Simone Tilmes is Co-investigator of the Stratosphere-Troposphere Analyses of Regional Transport Experiment UTLS (START08) campaign, which took part between 21 April 2008 and 28 June 2008. Together with Bill Hall, she works on the data merging products for the campaign. Initial data comparisons show a very promising upcoming data product. START08 data will be used for a detailed model comparison using the NCAR WACCM model.

In the News:
- Stratospheric Injections to Counter Global Warming Could Damage Ozone Layer (NCAR)
- Staff Notes: A close look at one - geoengineering scheme
- NSF: Windows to the Universe: Injecting Sulfate Particles into Stratosphere Could Have Drastic Impact on Earth's Ozone Layer

Scientific Talks FY08:

- Impact of geo-engineered aerosols on stratospheric composition and dynamics (AGU, San Francisco, CA, December 2007)
- Impact of geo-engineered aerosols on stratospheric composition and dynamics (MPI, Mainz, Germany, January 2008)
- Impact of geo-engineered aerosols on stratospheric composition and dynamics (MPI, Hamburg, Germany, January 2008)
- Transport Characteristics of the UTLS region based on tracers with different lifetimes using the MOZART3 model (START08 Workshop, Boulder, CO January 2008)
- HIRDLS use with WACCM3 and MOZART (HIRDLS Science Team Meeting, Boulder, CO, January 2008)
- Impact of Geo-engineered Aerosols on Stratosphere composition and dynamics (EGU, Vienna, Austria, April 2008) - poster

- Method of model evaluation for the extra-tropical tropopause region and its application to NCAR WACCM models (EGU, Vienna, Austria, April 2008)
- Impact of Geo-engineered Aerosol Particles on Troposphere and Stratosphere (ACD-NCAR Seminar, Boulder, CO, September 2008)

Publications FY08:

Tilmes, S., R. Müller, R. Salawitch, 2008: The sensitivity of polar ozone depletion to proposed geoengineering schemes. *Science*, **320**, 1201-1204, doi: 10.1126/science.1153966.

Tilmes, S., R. Müller, R. J. Salawitch, U. Schmidt, C. R. Webster, H. Oelhaf, C. C. Camy-Peyret, J. M. Russell III, 2008: Chemical ozone loss in the Arctic winter 1991-1992. *Atmos. Chem. Phys.*, **8**, 1897-1910.

Tilmes, S., D. E. Kinnison, R. R. Garcia, R. Müller, F. Sassi, D. R. Marsh, B. A. Boville, 2007: Evaluation of heterogeneous processes in the polar lower stratosphere in the Whole Atmosphere Community Climate Model. *J. Geophys. Res.*, **112**, D24301, doi: 10.1029/2006JD008334.

Müller, R., S. Tilmes, J.-U. Grooss, A. Engel, H. Oelhaf, G. Wetzel, N. Huret, M. Pirre, V. Catoire, G. Toon, H. Nakajima, 2007: Impact of mesospheric intrusions on ozone-tracer relations in the stratospheric polar vortex. *J. Geophys. Res.*, **112**, D23307, doi: 10.1029/2006JD008315.

Rasch, P.J., S. Tilmes, R.P. Turco, A. Robock, L. Oman, C.-C. Chen, G. L. Stenchikov, R. R. Garcia, 2008: An overview of geoengineering of climate using stratospheric sulphate aerosols. *Philos Transact of the Royal Society*, **366**, 1882.

Müller, Rolf, Simone Tilmes, 2008: Comment on "Middle atmospheric O3, CO, N2O, HNO3, and temperature profiles during the warm Arctic winter 2001-2002" by Giovanni Muscari et al. *J. Geophys. Res.*, **113**, D18303, doi:10.1029/2007JD009709.

Simone Tilmes Research Catalog

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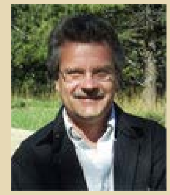
CGD 2008 PROFILES IN SCIENCE: DR. ROBERT TOMAS

Summary of achievements

Bob Tomas spends half his time with the Climate Analysis Section working with Clara Deser. Most of the projects that Bob works on with Clara diagnose the processes and mechanisms acting in the climate system, or in a broad sense, why is the climate the way it is? These studies are focused on changes to the climate that result from changes in a "forcing" such as changes in the sea-surface temperatures, sea-ice distribution and thickness, and land snow cover. Bob and Clara employ a suite of numerical models in their work including coupled climate system models (including CCSM3), atmospheric general circulation models (including CAM3), and linear models of the atmosphere. These studies broaden our understanding of how the climate system works and allow for a better understanding of what is happening in more complex situations, for example, when the green house gas concentration in the atmosphere changes.



Robert Tomas

In addition, Bob spends half time in the oceanography section, was previously half time with the paleoclimate section, and has been interacting the polar climate and land model working groups. Bob is investigating a behavior that has been noticed in many atmospheric general circulation modeling experiments but has not yet been completely explained: Why do warm mid-latitude SST anomalies produce a deeper and stronger atmospheric response than do cold anomalies of the same magnitude?

Publications

Deser, C., R. A. Tomas, and S. Peng, 2007: The Transient Atmospheric Circulation Response to North Atlantic SST and Sea Ice Anomalies. J. Climate, 20, 4751-4767.

Lawrence, D.M., A.G. Slater, R.A. Tomas, M.M. Holland, and C. Deser, 2008: Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. Geophys. Res. Lett., 35, L11506, doi:10.1029/2008GL033985.

Caspar M. Ammann, Fortunat Joos, David S. Schimel, Bette L. Otto-Bliesner, and Robert A. Tomas, 2007: Solar influence on climate during the past millennium: Results from transient simulations with the NCAR Climate System Model. PNAS 104:3713-3718; doi:10.1073/pnas.0605064103.

Bhatt, U. S., M.A Alexander, C. Deser, J.E.Walsh, J.S. Miller, M. Timlin, J.D. Scott, and R. Tomas, 2008: The Atmospheric Response to Realistic Reduced Summer Arctic Sea Ice Anomalies, to appear in AGU monograph: E. DeWeaver and C. Bitz, (ed.) Arctic Sea Ice Decline: Observations, Projections, Mechanisms, and Implications.

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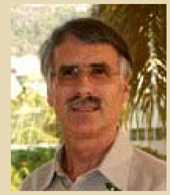
CGD 2008 PROFILES IN SCIENCE: DR. KEVIN TRENBERTH

Summary of achievements



Kevin Trenberth

Kevin Trenberth continues to be prominent in all aspects of climate variability and climate change research and is a leader in the Intergovernmental Panel on Climate Change assessments and in the World Climate Research Programme. In 2008 his primary research has focused on the global energy and water cycles and how they are changing, and his work mainly involves empirical studies and quantitative diagnostic calculations. Trenberth continues to be a primary advocate for the need to develop a climate information system that is an imperative for adaptation to climate change. In this vein, he has evaluated many datasets and been the primary promoter of the need to reanalyze global data into fields in ways that meet climate requirements for continuity and consistency. The climate information system framework developed by Trenberth is being used to help organize ocean observations and space-based observations, their processing, archival, and development into products. With John Fasullo, he has improved estimates of heat, energy and water transports within the atmosphere and ocean to a point where, when combined with top-of-atmosphere observed radiation, new estimates of ocean heat divergence and transports have become possible. This work is being used to validate coupled atmosphere-ocean climate models and understanding heat flows that are so important in climate change. He has continued to improve estimates of the global hydrological cycle. A particular focus is on changes in precipitation type, frequency, intensity and amount, and thus on how droughts and floods, and climate extremes change. In addition, with Aiguo Dai he has improved global estimates of runoff, streamflow, river discharge and the entire hydrological cycle, and how they change over time. He has also been to the fore in raising issues about how hurricanes change as the climate changes: in better determining the relation of hurricane to environmental variables, where the moisture that feeds the heavy rainfalls comes from, and the role of hurricanes in moving energy around.

Publications

Fasullo, J.T., and K.E. Trenberth, 2008: The Annual Cycle of the Energy Budget. Part I: Global Mean and Land-Ocean Exchanges. J. Climate, 21, 2297-2312.

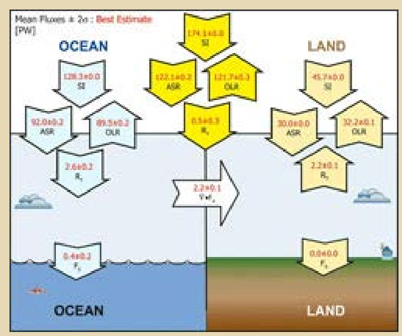


Figure 1.

High resolution figure

Abstract: The mean and annual cycle of energy flowing into the climate system and its storage, release, and transport in the atmosphere, ocean, and land surface are estimated with recent observations. An emphasis is placed on establishing internally consistent quantitative estimates with discussion and assessment of uncertainty. At the top of the atmosphere (TOA), adjusted radiances from the Earth Radiation Budget Experiment (ERBE) and Clouds and the Earth's Radiant Energy System (CERES) are used, while in the atmosphere the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis and 40-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40) estimates are used. The net upward surface flux (F_S) over ocean is derived as the residual of the TOA and atmospheric energy budgets, and is compared with direct calculations of ocean heat content (O_E) and its tendency (dO_E/dt) from several ocean temperature datasets. Over land, F_S from a stand-alone simulation of the Community Land Model forced by observed fields is used. A depiction of the full energy budget based on ERBE fluxes from 1985 to 1989 and CERES fluxes from 2000 to 2004 is constructed that matches estimates of the global, global ocean, and global land imbalances. In addition, the annual cycle of the energy budget during both periods is examined and compared with ocean heat content changes.

The near balance between the net TOA radiation (R_T) and F_S over ocean and thus with O_E, and between R_T and atmospheric total energy divergence over land, are documented both in the mean and for the annual cycle. However, there is an annual mean transport of energy by the atmosphere from ocean to land regions of 2.2 ± 0.1 PW (1 PW = 10^{15} W) primarily in the northern winter when the transport exceeds 5 PW. The global albedo is dominated by a semiannual cycle over the oceans, but combines with the large annual cycle in solar insolation to produce a peak in absorbed solar and net radiation in February, somewhat after the perihelion, and with the net radiation 4.3 PW higher than the annual mean, as it is enhanced by the annual cycle of outgoing longwave radiation that is dominated by land regions. In situ estimates of the annual variation of OE are found to be unrealistically large. Challenges in diagnosing the interannual variability in the energy budget and its relationship to climate change are identified in the context of the episodic and inconsistent nature of the observations.

Figure caption: CERES-period-mean best-estimate FM1 TOA fluxes (PW) globally and for the (right) global land and (left) global ocean regions.

Fasullo, J.T., and K.E. Trenberth, 2008: The Annual Cycle of the Energy Budget. Part II: Meridional Structures and Poleward Transports. J. Climate, 21, 2313-2325.

Abstract: Meridional structure and transports of energy in the atmosphere, ocean, and land are evaluated holistically for the mean and annual cycle zonal averages over the ocean, land, and global domains, with discussion and assessment of uncertainty. At the top of the atmosphere (TOA), adjusted radiances from the Earth Radiation Budget Experiment (ERBE) and Clouds and Earth's Radiant Energy System (CERES) are used along with estimates of energy storage and transport from two global reanalysis datasets for the atmosphere. Three ocean temperature datasets are used to assess changes in the ocean heat content (OE) and their relationship to the net upward surface energy flux over ocean (FoS), which is derived from the residual of the TOA and atmospheric energy budgets. The surface flux over land is from a stand-alone simulation of the Community Land Model forced by observed fields.

In the extratropics, absorbed solar radiation (ASR) achieves a maximum in summer with peak values near the solstices. Outgoing longwave radiation (OLR) maxima also occur in summer but lag ASR by 1-2 months, consistent with temperature maxima over land. In the tropics, however, OLR relates to high cloud variations and peaks late in the dry monsoon season, while the OLR minima in summer coincide with deep convection in the monsoon trough at the height of the rainy season. Most of the difference between the TOA radiation and atmospheric energy storage tendency is made up by a large heat flux into the ocean in summer and out of the ocean in winter. In the Northern Hemisphere, the transport of energy from ocean to land regions is substantial in winter, and modest in summer. In the Southern Hemisphere extratropics, land - ocean differences play only a small role and the main energy transport by the atmosphere and ocean is poleward. There is reasonably good agreement between FoS and observed changes in OE, except for south of 40°S, where differences among several ocean datasets point to that region as the main source of errors in achieving an overall energy balance. The winter hemisphere atmospheric circulation is the dominant contributor to poleward energy transports outside of the tropics [6-7 PW (1 petawatt = 10^{15} W)], with summer transports being relatively weak (~3 PW)—slightly more in the Southern Hemisphere and slightly less in the Northern Hemisphere. Ocean transports outside of the tropics are found to be small (<2 PW) for all months. Strong cross-equatorial heat transports in the ocean of up to 5 PW exhibit a large annual cycle in phase with poleward atmospheric transports of the winter hemisphere.

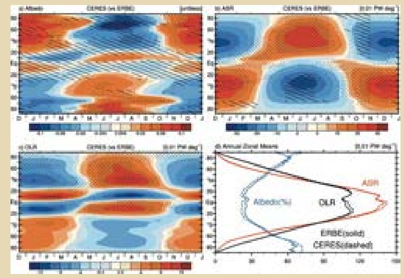


Figure 2.

High resolution figure

Figure caption: Zonal mean departures from the annual mean of (a) albedo (fraction), (b) ASR, and (c) OLR are shown based on CERES retrievals with positive (negative) differences from ERBE fields stippled (hatched) where they exceed ±2σI and ± W m^{-2} (or ±0.02 in the case of albedo). (d) The zonal annual mean terms as a function of latitude. The CERES values are based on averages from March 2000 to May 2004, the CERES period, while ERBE values are based on averages from February 1985 through April 1989, the ERBE period. For ASR and OLR the units are 0.01 PW $(°)^{-1}$.

Trenberth, K.E., and J.T. Fasullo, 2008: An Observational Estimate of Inferred Ocean Energy Divergence. J. Phys. Oceanogr., 38, 984-999.

Abstract: Monthly net surface energy fluxes (F_S) over the oceans are computed as residuals of the atmospheric energy budget using top-of-atmosphere (TOA) net radiation (R_T) and the complete atmospheric energy (A_E) budget tendency ($\delta A_E/\delta t$) and divergence (F_A). The focus is on TOA radiation from the Earth Radiation Budget Experiment (ERBE) (February 1985-April 1989) and the Clouds and Earth's Radiant Energy System (CERES) (March 2000-May 2004) satellite observations combined with results from two atmospheric reanalyses and three ocean datasets that enable a comprehensive estimate of uncertainties. Surface energy flux departures from the annual mean and the implied annual cycle in "equivalent ocean energy content" are compared with the directly observed ocean energy content (O_E) and tendency ($\delta O_E/\delta t$) to reveal the inferred annual cycle of divergence (F_O). In the extratropics, the surface flux dominates the ocean energy tendency, although it is supplemented by ocean Ekman transports that enhance the annual cycle in ocean heat content. In contrast, in the tropics, ocean dynamics dominate O_E variations throughout the year in association with the annual cycle in surface wind stress and the North Equatorial Current. An analysis of the regional characteristics of the first joint empirical orthogonal function (EOF) of F_S, $\delta O_E/\delta t$, and F_O is presented, and the largest sources of uncertainty are attributed to variations in O_E. The mean and annual cycle of zonal mean global ocean meridional heat transports are estimated. The annual cycle reveals the strongest poleward heat transports in each hemisphere in the cold season, from November to April in the north and from May to October in the south, with a substantial across-equatorial transport, exceeding 4 PW in some months. Annual mean results do not differ greatly from some earlier estimates,

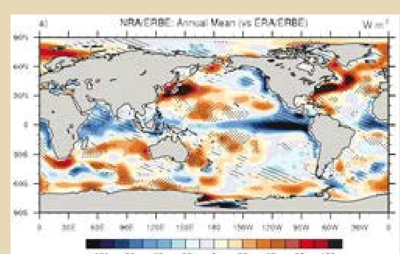


Figure 3.

High resolution figure

but the sources of uncertainty are exposed. Comparison of annual means with direct ocean observations gives reasonable agreement, except in the North Atlantic, where transports from the ocean transects are slightly greater than the estimates presented here.

Figure caption: (a) Annual mean F_S as computed by the residual from R_T and NRA atmospheric energy budgets for the ERBE period (W m^{-2}). Departure from the annual mean of the (b) JJA and (c) DJF surface flux out of the ocean (W m^{-2}). Stippling (hatching) denotes areas where NRA-based estimates exceed (fall below) those of ERA-40 by more than 10 W m^{-2} in (a) and by more than 30 W m^{-2} in (b) and (c).

Anthes, R. A., P. A. Bernhardt, Y. Chen, et al., 2008: The COSMOC/FORMOSAT-3 - Mission early results. Bulletin of the American Meteorological Society, 89, 313-+.

Abstract: The global positioning system (GPS) radio-occultation (RO) limb-sounding technique for sounding Earth's atmosphere was demonstrated by the proof-of-concept GPS Meteorology (GPS/MET) experiment in 1995-97 (Ware et al. 1996). Following GPS/MET, additional missions, that is, Challenging Minisatellite Payload (CHAMP); Wickert et al. 2001) and the Satellite de Aplicaciones Cientificas-C (SAC-C; Hajj et al. 2004), have confirmed the potential of RO sounding of the ionosphere, stratosphere, and troposphere.

Figure 4.

High resolution figure

At 0140 UTC 15 April 2006, six microsatellites were launched into a circular, 72° inclination orbit at an altitude of 512 km from Vandenberg Air Force Base, California (Cheng et al. 2006). The mission is a collaborative project of the National Space Organization (NSPO) in Taiwan and the University Corporation for Atmospheric Research (UCAR) in the United States. This mission is called the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) in the United States and the Formosa Satellite Mission 3 (FORMOSAT-3) in Taiwan. All satellites began delivering useful data within days after the launch (Anthes 2006). This paper summarizes the mission and the early scientific results, with emphasis on the radio-occultation part of the mission.

Figure caption: Schematic diagram illustrating radio occultation of GPS signals. [Figure courtesy of NSPO.]

Trenberth, K. E., 2008: Observational needs for climate prediction and adaptation. WMO Bulletin, 57 (1), 17-21.

Introduction: The climate is changing. In general, temperatures are increasing (Figure 1), owing to human-induced changes in the composition of the atmosphere, notably increased carbon dioxide from the burning of fossil fuels (IPCC, 2007). Land is mostly warming faster than the ocean. A close examination of Figure 1, however, shows that the temperatures actually declined from 1901 to 2005 in the south-eastern USA and the North Atlantic, changes in ocean currents clearly contribute. Over the south-eastern USA, changes in the atmospheric circulation that brought cloudier and much wetter conditions played a major role (Trenberth *et al., 2007*). This non-uniformity of change highlights the challenges of regional climate change that has considerable spatial structure and temporal variability.

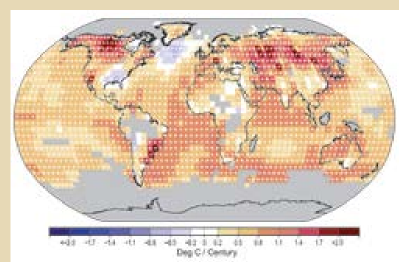


Figure 5.

High resolution figure

A foundation of climate research and future projections comes from the observations. These come from many and varied sources. Many are taken for weather forecasting purposes. Changes are common in instrumentation and siting, thereby disrupting the climate record, for which continuity and homogeneity are vitally important for assessing climate variations and change. Increasing volumes of observations come from space-based platforms, but satellites have a finite life time (typically five years or so), the orbit drifts and decays over time, the instruments degrade and, hence, the apparent climate record can become corrupted by spurious changes. An ongoing challenge is to create climate data records from the observations to serve many purposes.

Loss of Earth-observing satellites is also of concern, as documented in the recent National Research Council decadal survey (2007). Ground-based observations are not being adequately kept up in many countries. Calibration of climate records is critical. Small changes over a long time are characteristic of climate change but they occur in the midst of large variations associated with weather and natural climate variations, such as El Niño. Yet the climate is changing and it is imperative to track the changes and causes as they occur and identify what the prospects are for the future - to the extent that they are predictable. We need to build a system based on these observations to inform decision-makers about what is happening and why and what the predictions are for the future on several time horizons.

In this article, an outline is given a subset of activities related to the needs of decision-makers for climate information for adaptation purposes. It builds on some discussions held at a workshop on learning form the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC) (Sydney, Australia, 4-6 October 2007). The Workshop was sponsored by the Global Climate Observing System, the World Climate Research Programme of the International Council for Science. Within WCRP, the WCRP Observations and Assimilation Panel (WOAP), which the author chairs, attempts to highlight outstanding issues and ways forward in addressing them.

Figure caption: Linear trend of annual temperatures for 1901-2005 (° C century $^{-1}$. Areas in grey have insufficient data to produce reliable trends. Trends significant at the 5% level are indicated by white + marks. (From Trenberth *et al.*, *Climate Change 2007: The Physical Science Basis, Intergovernmental Panel on Climate Change).*

Trenberth, K. E., and J. Fasullo, 2008: The energy budgets of Atlantic hurricanes and changes from 1970. Geochemistry, Geophysics, Geosystems., in press.

Abstract: Based on the current observational record of tropical cyclones and sea surface temperatures (SSTs) in the Atlantic, estimates are made of changes in surface sensible and latent heat fluxes and hurricane precipitation form 1970 to 2006. The best track dataset of observed tropical cyclones is used to estimate the frequency that storms of a given strength occur after 1970. Empirical expressions for the surface fluxes and precipitation are based on simulations of hurricane Katrina in August 2005 with the advanced Weather and Research Forecasting (WRF) model at 4 km resolution without parameterized convection. The empirical relationships are computed for the surface fluxes and precipitation within 400 km of the eye of the storm for all categories of hurricanes based upon the maximum simulated wind and the observed sea surface temperature and saturation specific humidity. Strong trends are not linear but are better depicted as a step function increase from 1994 to 1995, and the large variability reflects changes in SSTs and precipitable water, modulated by El Niño events. The environmental variables of SST and water vapor are nonetheless accompanied by clear changes in tropical cyclone activity using several metrics.

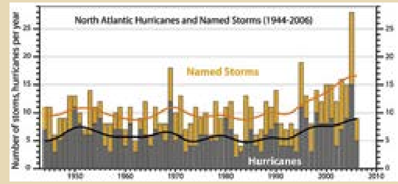


Figure 6.

High resolution figure

Figure caption: The record of numbers of named storms and hurricanes for the Atlantic from 1944 to 2006 based on the best track data. The smoothed curves show decadal variability using a 13 point filter with end values computed using reflected values.

Trenberth, K. E., and L. Smith, 2008: The three dimensional structure of the atmospheric energy budget: methodology and evaluation. Climate Dynamics, in press. doi:10.1007/s00382-008-0389-3.

Abstract: Studies of the vertically-integrated energy and moisture budgets of the atmosphere are expanded to three dimensions. The vertical integrals of the moisture, energy and heat budget equations computed analytically act as a very strong constraint on any local computational results of the vertical structure. This paper focuses on the methodology and difficulties in closing the budgets and satisfying constraints, given the need to use a pressure coordinate because model coordinates all differ. Vertical interpolation destroys delicate mass balances and can lead to inconsistencies, such as from how geopotential or vertical motion is computed. Using the advective rather than flux form of the equations greatly reduces the contamination from these effects. Results are documented for January 1989 using European Centre for Medium Range Weather Forecasts reanalysis (ERA-40) data. The moistening, diabatic heating and total energy forcing of the atmosphere are computed as a residual from the analyses using the moisture, dry energy (dry static energy plus kinetic energy) and total atmospheric (moist static plus kinetic) energy equations. The components from the monthly averaged flow and transients, as a function of layer in the atmosphere, and as quasi-horizontal and vertical fluxes of dry static, latent and kinetic energy are examined. Results show the moistening of the atmosphere at the surface, its release as latent heat in precipitation and transformation into dry static energy, and thus net radiative cooling as a function of height and location. The vertically integrated forcings computed from the model parameterizations are compared with available observations and budget-derived values, and large ERA-40 model biases are revealed in radiation and precipitation. The energy and moisture budget-derived quantities are more realistic, although results depend on the quality of the analyses which are not constructed to conserve mass, moisture or energy, owing to analysis increments.

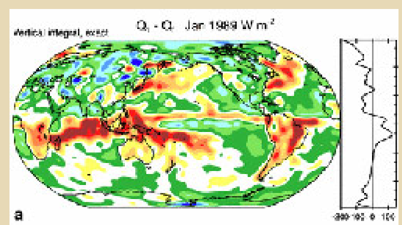


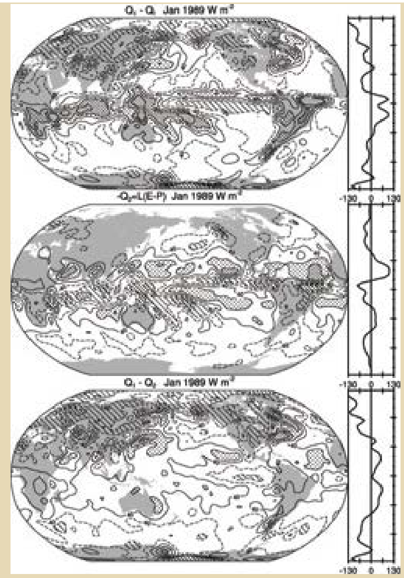
Figure 7.

High resolution figure

Figure caption: For Jan 1989 based on ERA-40 analyses, a) vertically integrated Q_1-Q_f truth versus b) results from the advective method, and c)differences between the two. The right hand side panels show the zonal averages. The plots are smoothed to T42 resolution and the units are Watts per square meter.

Trenberth, K. E., and L. Smith, 2008: Atmospheric energy budgets in the Japanese Reanalysis: Evaluation and variability. J. Meteor. Soc. Japan, in press.

Abstract: The vertically-integrated atmospheric energy and moisture budgets have been computed for all available months for the Japanese reanalysis (1979 to 2004), and results are described in detail for the month of January 1989 and compared with those of other reanalyses. Time series are also presented. The moistening, diabatic heating and total energy forcing of the atmosphere are computed as a residual from the analyses using the moisture, dry energy (dry static energy plus kinetic energy) and total atmospheric (moist static plus kinetic)



energy budget equations. These fields are also computed from the model output based on the assimilating model parameterizations. Moreover, some component fields can also be computed from observations to evaluate the results. In particular, when the vertically-integrated forcings computed from the model parameterizations are compared with available observations and the budget-derived values, significant JRA model biases are revealed in radiation and precipitation. The energy and moisture budget-derived quantities are more realistic than the model output and better depict the real atmosphere. However, low frequency decadal variability is spurious and is mainly associated with changes in the observing system. Results also depend on the quality of the analyses which are not constructed to conserve mass, moisture or energy, owing to analysis increments. By emphasizing the differences and the errors, there is a tendency to overlook the considerable progress in depicting diabatic components of the atmosphere, while also pointing to where research can make further improvements.

Figure caption: For Jan 1989 based on JRA analyses, vertically integrated Q_1, -Q_2 and Q_1 - Q_2. The right hand side panels show the zonal averages. The plots are smoothed to T42 resolution and the units are W m^{-2}. Contour interval is 80 W m^{-2}, and stipple and hatching begin at ±120 W m^{-2} and more densely at ±200 W m^{-2}.

Figure 8.

High resolution figure

Trenberth, K. E., T. Koike, and K. Onogi, 2008: Progress and prospects in reanalysis. EOS, 89, 26, 24 June 2008, 234-235.

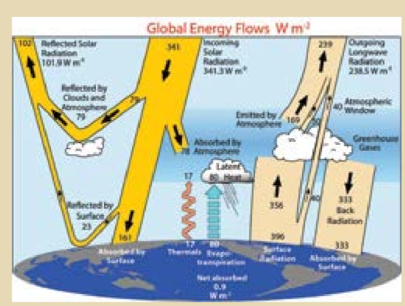
Abstract: Analyses of global atmospheric observations in real time for numerical weather prediction (NWP) lack continuity over time as the operational system evolves. Reanalysis of the observations - with more complete data, improved quality control, and a constatnt state-of-the-art assimilating model and analysis system - greatly improves the homogeneity of the record and makes it useful for examining climate variations. This whole endeavor is now referred to as "reanalysis".

However, even as atmospheric reanalysis of past observations has greatly improved our ability to determine climate variability, challenges still exist in depicting multidecadal changes. Moreover, although several reanalyses - from the U.S. National Oceanic and Atmospheric Administration's National Centers for Environmental Prediction (NCEP), NASA Goddard Space Flight Center (GSFC), the European Centre for Medium-Range Weather Forecasts (ECMWF), and the Japan Meteorological Agency (JMA) - now exist, the task is far from done. Further improvements to reanalysis - including expansion to encompass key trace constituents and the ocean, land, and sea ice domains - hold promise for extending their use in climate change studies, research, and the practical applications (such as how extremes of climate and their impacts on agriculture have changed).

Global gridded analyses of observations taken for many purposes - such as weather forecasting in the atmosphere or core oceanographic research - become part of the climate record but often display biases that mask long-term variations. Many climate data sets are inhomogeneous: The record length either is too short to provide decadal-scal information or is inconsistent owing to operational changes in instruments, their siting, and data transmission and processing and to the absence of adequate metadata. Hence, major effors have been required to homogenize the observed data for them to be useful for climate purposes. Reanalysis of atmospheric observations using a constant state-of-the-art assimilation model has helped enormously in making the historical record more homogeneous and useful for many studies. Indeed, in the 20 years since reanalysis was first proposed by *Trenberth and Olson* [1988] and *Bengtsson and Shukla* [1988], there have been great advances in our ability to generate high-quality temporally homogeneous estimates of the past climate.

Trenberth, K. E., J. T. Fasullo, and J. Kiehl, 2008: Earth's global energy budget. Bull. Amer. Meteor. Soc., in press.

Abstract: An update is provided on the Earth's global annual mean energy budget in the light of new observations and analyses. In 1997 Kiehl and Trenberth provided a review of past such estimates and performed a number of radiative computations to better establish the role of clouds and various greenhouse gases in the overall radiative energy flows, with top-of-atmosphere (TOA) values constrained by Earth Radiation Budget Experiment values form 1985 to 1989, when the TOA values were approximately in balance. The Clouds and the Earth's Radiant Energy System (CERES) measurements from March 2000 to May 2004 are used to TOA but adjusted to an estimated imbalance from the enhanced greenhouse effect of 0.9 W m^{-2}. Revised estimates of surface turbulent fluxes are made based on various sources. The partitioning of solar radiation in the atmosphere is based in part on the International Satellite Cloud Climatology



Project (ISCCP) ISCCP-FD computations that utilize the global ISCCP cloud data every 3 hours, and also accounts for increased atmospheric absorpton by water vapor and aerosols. Surface upwards longwave radiation is adjusted to account for spatial and temporal variability. A lack of closure in the energy balance at the surface is accommodated by making modest changes to surface fluxes, with the downward longwave radiation as the main residual to ensure a balance. Values are also presented for the land and ocean domains that include a net transport of energy from ocean to land of 2.2 Petawatts (PW) of which 3.2 PW is from moisture (latent energy) transport, while net dry static energy transport is from land to ocean. Evaluations of atmospheric reanalyses reveal substantial biases.

Figure 9.

High resolution figure

Figure caption: The global annual mean Earth's energy budget for the March 2000 to May 2004 period in W m^{-2}. The broad arrows indicate the schematic flow of energy in proportion to their importance.

Trenberth, K. E., C. A. Davis, and J. Fasullo, 2007: Water and energy budgets of hurricanes: Case studies of Ivan and Katrina. J. Geophys. Res., 112, D23106, doi:10.1029/2006JD008303.

Abstract: To explore the role of hurricanes in the climate system, a detailed analysis is made of the bulk atmospheric moisture budget of Ivan in September 2004 and Katrina in August 2005 from simulations with the Weather and Research Forecasting (WRF) model at 4 km resolution without parameterized convection. Heavy precipitation exceeding 20 mm h^{-1} in the storms greatly exceeds the surface flux of moisture through evaporation, and vertically integrated convergence of moisture in the lowest 1 km of the atmosphere from distances up to 1600 km is the dominant term in the moisture budget, highlighting the importance of the larger-scale environment. Simulations are also run for the Katrina case with sea surface temperatures (SSTs) increased by +1°C and decreased by -1°C as sensitivity studies. For hours 42 to 54 after the start of the simulation, maximum surface winds increased about 4.5 m s^{-1} (9%), and sea level pressure fell 11.5 hPa per 1°C increase in tropical SSTs. Overall, the hurricane expands in size as SSTs increase, the environmental atmospheric moisture increases at close to the Clausius-Clapeyron equation value of about 6% K-1 and the surface moisture flux also increases mainly from Clausius-Clapeyron effects and the changes in intensity of the storm. The environmental changes related to human influences on climate since 1970 have increased SSTs and water vapor, and the results suggest how this may have altered hurricanes and increased associated storm rainfalls, with the latter quantified to date to be of order 6 to 8%.

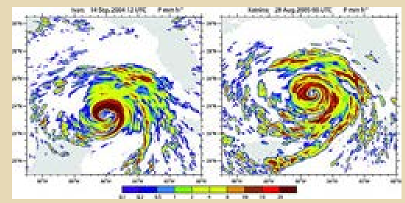


Figure 10.

High resolution figure

Figure caption: Precipitation (mm h^{-1}) fields for simulated hurricanes (left) Ivan at 1200 UTC 14 September 2004 and (right) Katrina at 0000 UTC 28 August 2005.

Trenberth, K. E., and J. Fasullo, 2007: Water and energy budgets of hurricanes and implications for climate change. J. Geophys. Res., 112, D23107, doi:10.1029/2006JD008304.

Abstract: On the basis of simulations of hurricane Katrina in August 2005 with the advanced Weather and Research Forecasting (WRF) model at 4 km resolution without parameterized convection, empirical relationships are computed between the maximum simulated wind and the surface fluxes and precipitation and provide a reasonable fit to the data. The best track data set of global observed tropical cyclones is used to estimate the frequency that storms of a given strength occur over the globe after 1970. For 1990-2005 the total surface heat loss by the tropical ocean in hurricanes category 1 to 5 within 400 km of the center of the storms is estimated to be about 0.53 x 10^{22} J a^{-1} (where a is year) (0.17 PW). The enthalpy loss due to hurricanes computed on the basis of precipitation is about a factor of 3.4 greater (0.58 PW), owing to the addition of the surface fluxes from outside 400 km radius and moisture convergence into the storms typically from as far from the eye as 1600 km. Globally these values correspond to 0.33 W m^{-2} for evaporation, or 1.13 W m^{-2} for precipitation. Changes over time reflect basin differences and a prominent role for El Niño, and the most active period globally was 1989 to 1997. Strong positive trends from 1970 to 2005 occur in these inferred surface fluxes and precipitation arising from increases in intensity of storms and also higher sea surface temperatures. Confidence in this result is limited by uncertainties in the best track tropical cyclone data. Nonetheless, the results highlight the importance of surface energy exchanges in global energetics of the climate system and are suggestive of the deficiencies in climate models owing to their inadequate representation of hurricanes.

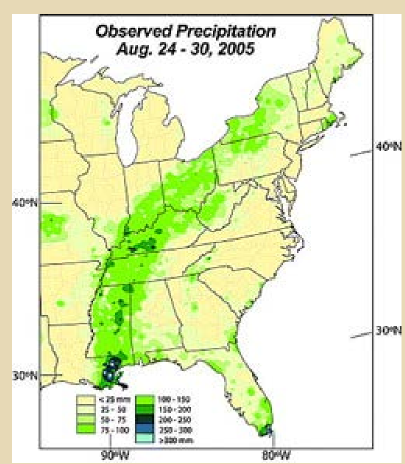


Figure 11.

High resolution figure

Figure caption: Estimate of observed precipitation based on surface gauges, adapted from a compilation by Climate Prediction Center, NOAA (printed with permission, courtesy Rich Tinker and Jay Lawrimore). These may be underestimates as many data were missing in the vicinity of New Orleans.

Trenberth, K. E., 2008: The Impact of Climate Change and Variability on Heavy Precipitation, Floods, and Droughts, The Encyclopedia of Hydrological Sciences. John Wiley & Sons, Ltd., Chichester, UK. DOI 10.1002/0470848944.hsa211.

Summary: There is a direct influence of global warming on changes in precipitation and heavy rains. Increased heating leads to greater evaporation and thus surface drying, thereby increasing intensity and duration of drought. However, the water-holding capacity of air increases by about 7% per 1 °C warming, which leads to increased water vapor in the atmosphere, and this probably provides the biggest influence on precipitation. Storms, whether individual thunderstorms, extratropical rain or snow storms, or tropical cyclones and hurricanes, supplied by increased moisture, produce more intense precipitation events that are widely observed to be occurring, even in places where total precipitation is decreasing. In turn, this increases the risk of flooding. Patterns of where it rains also have been observed to change, with dry areas becoming drier (generally throughout the subtropics) and wet areas becoming wetter, especially in mid to high latitudes. This pattern is simulated by climate models and is projected to continue into the future. Since more precipitation occurs as rain instead of snow with warming, and snow melts earlier, there is increased runoff and risk of flooding in early spring, but increased risk of drought in deep summer, especially over continental areas.

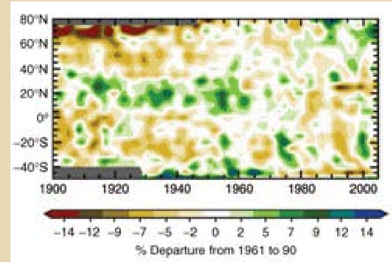


Figure 12.

High resolution figure

Figure caption: Latitude-time section of zonal average annual anomalies for precipitation (%) over land from 1900 to 2005, relative to their 1961-1990 means. The values are smoothed with a 1/12(1-3-4-3-1) filter to remove fluctuations less than about six years. The color scale is nonlinear and gray areas indicate missing data (From Trenberth et al. 2007) and reproduced by permission of IPCC).

Blogs, testimonies, other publications

Models can be useful tools for planning ahead: A response to Thomas Chase: 'A caution to policymakers: climate models fail key tests for accuracy', Ogmius, 22, summer 2008, pp 2-3.

An update on human-induced climate change. The U. S. Senate Committee on Environment and Public Works, The United States Senate, Room 406 of the Dirksen Senate Building, 10:00 a.m., July 22, 2008. Senate Testimony July 2008.

Are we good stewards of the planet Earth? Graduation address to Bridge School, Boulder, Friday May 30, 2008. Boulder Daily Camera.

Nations should act now to reduce carbon emissions, Denver Post, 16 March 2008, www.denverpost.com.

"Experts Debate Global Warming", Fort Collins Forum, February 19, 2008. Trenberth responds to Gray.

Atlantic hurricanes and global warming. Google News, 23 January, 2008.

CGD Research Catalog

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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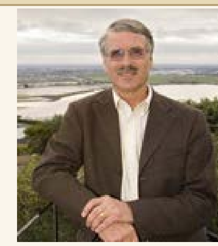
KEVIN E. TRENBERTH

General Information



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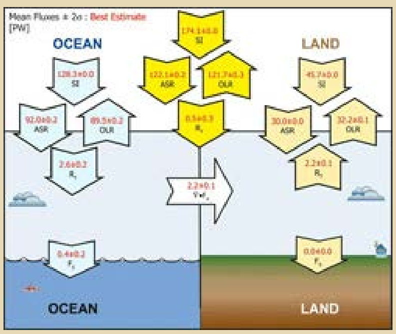


CERES-period-mean best-estimate FM1 TOA fluxes (PW) globally and for the (right) global land and (left) global ocean regions. The Annual Cycle of the Energy Budget. Part I: Global Mean and Land-Ocean Exchanges. J. Climate, 21, 2297-2312 - High resolution figure

Kevin Trenberth continues to be prominent in all aspects of climate variability and climate change research and is a leader in the Intergovernmental Panel on Climate Change assessments and in the World Climate Research Programme (additional information below).

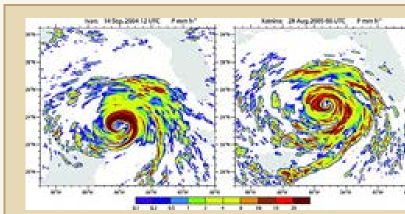
In 2008 his primary research has focused on the global energy and water cycles and how they are changing, and his work mainly involves empirical studies and quantitative diagnostic calculations. He continues to be a primary advocate for the need to develop a climate information system that is an imperative for adaptation to climate change. In this vein, he has evaluated many datasets and been the primary promoter of the need to reanalyze global data into fields in ways that meet climate requirements for continuity and consistency. The climate information system framework developed by Trenberth is being used to help organize ocean observations and space-based observations, their processing, archival, and development into products.

With John Fasullo, he has improved estimates of heat, energy and water transports within the atmosphere and ocean to a point where, when combined with top-of-atmosphere observed radiation, new estimates of ocean heat divergence and transports have become possible. This work is being used to validate coupled atmosphere-ocean climate models and understanding heat flows that are so important in climate change.

Work to improve estimates of the global hydrological cycle continues. A particular focus is on changes in precipitation type, frequency, intensity and amount, and thus on how droughts and floods, and climate extremes change.

In addition, with Aiguo Dai he has improved global estimates of runoff, streamflow, river discharge and the entire hydrological cycle, and how they change over time.

Trenberth has also been to the fore in raising issues about how hurricanes change as the climate changes: in better determining the relation of hurricane to environmental variables, where the moisture that feeds the heavy rainfalls comes from, and the role of hurricanes in moving energy around.



Precipitation (mm h-1) fields for simulated hurricanes (left) Ivan at 1200 UTC 14 September 2004 and (right) Katrina at 0000 UTC 28 August 2005. Water and energy budgets of hurricanes: Case studies of Ivan and Katrina. J. Geophys. Res., 112, D23106 - High resolution figure

In The News (a small sampling of Trenberth news coverage):

Nobel Peace Prize 2007: *IPCC Shares Nobel Peace Prize with Al Gore* (11 October 2007) - Guy Brasseur, William Collins, Elisabeth Holland, Reto Knutti, Linda Mearns, Gerald Meehl, Kevin Trenberth, additional NCAR authors: *"for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."* IPCC

Shares Nobel Peace Prize with Al Gore Congratulations to the United Nation's Intergovernmental Panel on Climate Change (IPCC) and Al Gore on their Nobel Peace Prize award. Since 1990, the IPCC has issued four reports highlighting the growing understanding of the climate change issue. Scientists both at NCAR and within our wider research community contributed significantly to these reports. Published this year, the IPCC's Fourth Assessment Report leverages computer modeling that depicts global climate with unprecedented detail. Through support of the U.S. Department of Energy and the National Science Foundation's supercomputing centers, and partnership with Japan's Central Research Institute of Electric Power Industry, the NCAR-based Parallel Climate Model and Community Climate System Model provided a wealth of scientific data to the IPCC report. Related: Article by the Associated Press, Thousands of Scientists Share Nobel....more

Nobel Peace Prize Press Release
Working Group I: Summary | NCAR Scientists & biographies who made major contributions
Working Group II: Summary | NCAR Scientists & biographies who made major contributions
General Information: Understanding Climate Change (UCAR)

Climate change expert to discuss grim global warming predictions

Bio-Medicine - October 28, 2008: On the day Americans elect a new president, one of the nation's leading climate change experts will speak at the University of Houston and outline the daunting global warming challenges awaiting the next administration. **Kevin Trenberth**, head of climate analysis at the National Center for Atmospheric Research (NCAR) in Boulder, Colo., will discuss evidence of manmade global warming at a colloquium Tuesday, Nov. 4. The event is free and open to the public ...more

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Grand Valley water outlook

The Grand Junction Daily Sentinel - November 2007: The future of Grand Junction's water system is hardly a subject of debate among Grand Valley water managers. The city's 1996 municipal water supply master plan projects the source of much of the Grand Valley's tap water, the snowpack on Grand Mesa, will be stable and water-rich through 2050......The effects of a changing climate on Colorado are quite the matter of educated guesswork, but the general consensus is that precipitation will more often fall as rain instead of snow, the snowpack will melt sooner each spring and, in parts of the West, warmer weather will desiccate soil once moist with the leftovers of soggy falls and snowy winters, [New Zealand native **Dr. Kevin Trenberth**] said... more

Community Service FY08:

- AGU Roger Revelle Medal Selection
- AGU panel on AGU position statement on data preservation and availability
- Science Advisor: Earth & Sky Radio
- Scientific Steering Group: GEWEX
- Coordinating Lead Author: Chapter 3, Working Group I, Fourth Assessment Report (AR4) for the IPCC
- CERES Climate Model and Analysis Advisory Group, NASA
- MERRA Advisory Board, NASA
- Climate Observing System Council, NOAA
- Science Advisory Panel for the Climate Change Data & Detection Program, NOAA
- Chair: Review Panel for Climate Observations and Analysis Program, NOAA
- Chair: Observations and Assimilation Panel (WOAP) for WCRP
- WCRP Modelling Panel, WCRP
- Third International Reanalysis Conference Committee (Tokyo, Japan January 2008), WCRP
- Graduate Address, Bridge School (Boulder, Colorado May 2008)
- Public Seminar: Global Warming: Ready or Not (Boulder, Colorado October 2007)

Scientific Talks FY08:

- A comparison of vertically-integrated water and energy cycle diagnostics from several reanalyses (Tokyo, JPN, 01/2008)

- An imperative: Building a climate information system to enable adaptation to regional climate change (Washington, DC USA, 10/2008)
- An imperative: Building a climate information system to enable adaptation to regional climate change (Boulder, CO USA, 10/2008)
- Broadcast Meteorologists "Ask the expert" Interview (Boulder, CO USA, 06/2008)
- Climate change and an imperative: building a climate information system to enable adaptation to regional climate change (Frascati, ITA, 08/2008)
- Climate change and extreme weather events (New York, NY USA, 06/2008)
- Climate change, coming ready or not (New York, NY USA, 06/2008)
- Discovery Channel Interview: Impossible Pictures series on alleviating climate change (Denver, CO USA, 06/2008)
- Earth's changing energy and water cycles (Ft. Lauderdale, FL USA, 05/2008)
- Exploiting and evaluating models with observations (Reading, GBR, 04/2008)
- Extremes in climate models (Buenos Aires, ARG, 02/2008)
- Facts about our changing climate (Denver, CO USA, 06/2008)
- Global warming (Denver, CO USA, 08/2008)
- Global warming affects us all; What must be done (Boulder, CO USA, 06/2008)
- Global warming is unequivocal (Daytona Beach, FL USA, 11/2007)
- Global warming is unequivocal (Longmont, CO USA, 01/2008)
- Global warming is unequivocal (Big Sky, MT USA, 03/2008)
- Global warming, coming ready or not (Boulder, CO USA, 10/2007)
- Global warming, coming ready or not (Tuscaloosa, AL USA, 12/2007)
- Global warming, coming ready or not (Denver, CO USA, 01/2008)
- Global warming, coming ready or not (Estes Park, CO USA, 04/2008)
- Global warming: Coming ready or not (Chicago, IL USA, 09/2008)
- Global warming: The physical science basis (Boulder, CO USA, 04/2008)
- How may the spatial and temporal characteristics of precipitation change under global warming, and what are the fundamental processes that will constrain those changes? (Totnes, GBR, 04/2008)
- How serious is climate change? How serious are we about addressing it? (Boulder, CO USA, 04/2008)
- Issues from IPCC AR4 WG 1, Atmospheric modeling and observations (Sydney, AUS, 10/2008)
- KGNU Radio 'Public Affair' Interview (Boulder, CO USA, 04/2008)
- KGNU radio interview on heat wave in Colorado (Boulder, CO USA, 08/2008)
- NBC Nightly News "Hurricanes and climate" (Denver, CO USA, 09/2008)
- NOAA strategic Plan for a National Climate Service (Vail, CO USA, 06/2008)
- Observations of climate (Boulder, CO USA, 10/2008)
- Schweizer Radio Interview (Zurich, CHE, 06/2008)
- Storage and movement of heat in the ocean (Washington, DC USA, 09/2008)
- Storage and movement of heat in the ocean (Washington, DC USA, 09/2008)
- Testimony to Colorado General Assembly: Hearing on House Bill 08-1164 (Denver, CO USA, 04/2008)
- Testimony to Colorado Public Utilities Commission: Docket No. 07A-447E (Denver, CO USA, 04/2008)
- Testimony to U.S. Senate Committee on Environment and Public Works: An update on human-induced climate change (Washington, DC USA, 07/2008)
- The facts about our changing climate (Denver, CO USA, 06/2008)
- The flow of energy through the Earth's climate system (Monte Verità, CHE, 06/2008)
- The flow of energy through the Earth's climate system (Frascati, ITA, 08/2008)
- The global water cycle and its changes (Frascati, ITA, 08/2008)
- The latest update on climate change and the 4th IPCC assessment (Parker, CO USA, 11/2007)

- TV interviews with Broadcast meteorologists at the AMS Broadcast Meteorologist Conference (Denver, CO USA, 06/2008)
- UNEP's online "Ask Today's Expert" (Boulder, CO USA, 09/2008)
- User requirements and applications: IPCC (Washington, DC USA, 09/2008)
- Vertical structure and variability of the flow of energy through the Earth's climate system (Boulder, CO USA, 09/2008)
- WCRP Observations and Assimilation Panel (Buenos Aires, ARG, 02/2008)
- Weather and climate in the 21st century: what do we know? And what don't we know? (Washington, DC USA, 03/2008)

Publications FY08 (abstracts):

Trenberth, K. E., J. Fasullo, 2008: Energy budgets of Atlantic hurricanes and changes from 1970. *Geochem. Geophys Geosys.*, **9**, Q09V08, doi: 10.1029/2007GC001847.

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Trenberth, K. E., 2008: Atlantic hurricanes and global warming. *Google News*.

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Fasullo, J., K. E. Trenberth, 2008: The annual cycle of the energy budget, Part I: Global mean and land-ocean exchanges. *J. Climate*, **21**, 2297-2312, doi: 10.1175/2007JCLI1935.1.

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Trenberth, K. E., 2008: Growing threats to climate. *Google News*.

Trenberth, K. E., 2007: Mike Rosen: Mostly wrong on warming. *Rocky Mountain News*.

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Models can be useful tools for planning ahead: A response to Thomas Chase: 'A caution to policymakers: climate models fail key tests for accuracy', Ogmius, 22, summer 2008, pp 2-3.

An update on human-induced climate change. The U. S. Senate Committee on Environment and Public Works, The United States Senate, Room 406 of the Dirksen Senate Building, 10:00 a.m., July 22, 2008. Senate Testimony July 2008.

Are we good stewards of the planet Earth? Graduation address to Bridge School, Boulder, Friday May 30, 2008. Boulder Daily Camera.

Nations should act now to reduce carbon emissions, Denver Post, 16 March 2008, www.denverpost.com.

"Experts Debate Global Warming", Fort Collins Forum, February 19, 2008. Trenberth responds to Gray.

Atlantic hurricanes and global warming. Google News, 23 January, 2008.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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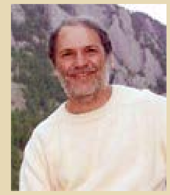
CGD 2008 PROFILES IN SCIENCE: DR. JOE TRIBBIA

Summary of achievements



Joe Tribbia

Over the past year four main scientific problems have dominated my research activities. The first, the analysis and prediction of forecast uncertainty, or more properly the prediction of the relevant aspects of the probability density of atmospheric states. My second main area of research has been in the development and diagnosis of the ENSO-decadal predictive skill of the NCAR CCSM. I am in the process of producing a number of experimental hindcasts demonstrating the skill of CCSM3. I also am involved in two projects which are examining numerical modeling on parallel machines. One activity has evolved to an effort to use the HOMME version of the spectral element model to be considered as a dycore option for CAM. Also in the area of computaional science, I am working with the Roger Temam on the problem of well-posed boundary conditions for limited-area hydrostatic numerical models.

Publications

Rousseau, A., R. Temam, and J. Tribbia, 2008: The 3D Primitive Equations in the absence of viscosity: Boundary conditions and well-posedness in the linearized case. Journal de Mathematiques Pures et Appliquees, 89, 297-319, doi:The 3D Primitive Equations in the absence of viscosity: Boundary conditions and well-posedness in the linearized case.

Abstract: In this article we consider the 3D Primitive Equations (PEs) of the ocean, without viscosity and linearized around a stratified flow. As recalled in the Introduction, the PEs without viscosity ought to be supplemented with boundary conditions of a totally new type which must be nonlocal. In this article a set of boundary conditions is proposed for which we show that the linearized PEs are well-posed. The proposed boundary conditions are based on a suitable spectral decomposition of the unknown functions. 116 Noteworthy is the rich structure of the Primitive Equations without viscosity. Our study is based on a modal decomposition in the vertical direction; in this decomposition, the first mode is essentially a (linearized) Euler flow, then a few modes correspond to a stationary problem partly elliptic and partly hyperbolic; finally all the other modes correspond to a stationary problem fully hyperbolic. (c) 2007 Elsevier Masson SAS. All rights reserved.

Wang, H., J.J. Tribbia, F. Baer, A. Fournier, and M.A. Taylor, 2007: A Spectral Element Version of CAM2. Mon. Wea. Rev., 135, 3825-3840.

Abstract: The authors describe a recent development and some applications of a spectral element dynamical core. The improvements and development include the following: (i) the code was converted from FORTRAN 77 to FORTRAN 90; (ii) the dynamical core was extended to the generalized terrain-following, or hybrid ?, vertical coordinates; (iii) a fourth-order Runge-Kutta (RK4) method for time integration was implemented; (iv) moisture effects were added in the dynamical system and a semi-Lagrangian method for moisture transport was implemented; and (v) the improved dynamical core was coupled with the Community Atmosphere Model version 2 (CAM2) physical parameterizations and Community Land Model version 2 (CLM2) in such a way that it can be used as an alternative dynamical core in CAM2. This spectral element version of CAM2 is denoted as CAM-SEM. A mass fixer as used in the Eulerian version of CAM2 (CAM-EUL) is also implemented in CAM-SEM. Results from multiyear simulations with CAM-SEM (coupled with CLM2) with climatology SST are also presented and compared with simulations from CAM-EUL. Close resemblances are shown in simulations from CAM-SEM and CAM-EUL. The authors found that contrary to what is suggested by some other studies, the high-order Lagrangian interpolation (with a limiter) using the spectral element basis functions may not be suitable for moisture and other strongly varying fields such as cloud and precipitation.

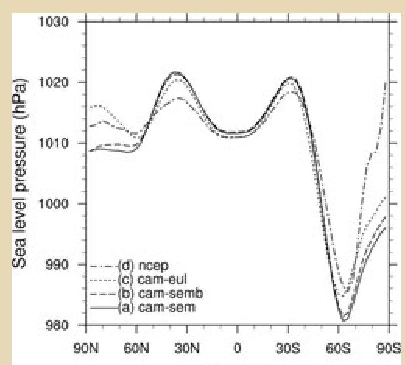


Figure 1.

High resolution figure

Figure caption: The zonally averaged annual mean PSL: CAM-SEM with mass fixer (a), CAM-SEM without mass fixer (b), CAM-EUL (with mass fixer) (c), and NCEP analysis (d).

CGD Research Catalog

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STAN TRIER

2008 Publications

Trier, S. B., F. Chen, K. W. Manning, M. A. Lemone, C. A. Davis, 2008: Sensitivity of the PBL and precipitation in 12-day simulations of warm-season convection using different land surface models and soil wetness conditions. Mon. Wea. Rev., 136, 2321-2343, doi: 10.1175/2007MWR2289.1.

ABSTRACT

A coupled land surface–atmospheric model that permits grid-resolved deep convection is used to examine linkages between land surface conditions, the planetary boundary layer (PBL), and precipitation during a 12-day warm-season period over the central United States. The period of study (9–21 June 2002) coincided with an extensive dry soil moisture anomaly over the western United States and adjacent high plains and wetter-than-normal soil conditions over parts of the Midwest. A range of possible atmospheric responses to soil wetness is diagnosed from a set of simulations that use land surface models (LSMs) of varying sophistication and initial land surface conditions of varying resolution and specificity to the period of study.

Results suggest that the choice of LSM [Noah or the less sophisticated simple slab soil model (SLAB)] significantly influences the diurnal cycle of near-surface potential temperature and water vapor mixing ratio. The initial soil wetness also has a major impact on these thermodynamic variables, particularly during and immediately following the most intense phase of daytime surface heating. The soil wetness influences the daytime PBL evolution through both local and upstream surface evaporation and sensible heat fluxes, and through differences in the mesoscale vertical circulation that develops in response to horizontal gradients of the latter. Resulting differences in late afternoon PBL moist static energy and stability near the PBL top are associated with differences in subsequent late afternoon and evening precipitation in locations where the initial soil wetness differs among simulations. In contrast to the initial soil wetness, soil moisture evolution has negligible effects on the mean regional-scale thermodynamic conditions and precipitation during the 12-day period.

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STANLEY TRIER

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Research Focus FY08:

During the past year I have participated in TIIMES research that has been co-sponsored by the NCAR Water System program. The work has focused on both land surface effects on the diurnal cycle of the planetary boundary layer and precipitation, and the role of the Rocky Mountain Cordillera on the diurnal cycle of propagating deep convection across the continental United States.

I have performed process studies of these effects using the Advanced Research Weather Forecast Model (ARW-WRF) at convection resolving resolutions for both retrospective periods and for more climatologically based environmental conditions.

Publications FY08 (abstracts):

Trier, S. B., R. Sharman, 2008: Convection-resolving simulations of the environment supporting widespread turbulence within the upper-level outflow of an MCS. *Mon. Wea. Rev.*. (Submitted)

Trier, S. B., F. Chen, K. W. Manning, M. A. Lemone, C. A. Davis, 2008: Sensitivity of the PBL and precipitation in 12-day simulations of warm-season convection using different land surface models and soil wetness conditions. *Mon. Wea. Rev.*, **136**, 2321-2343, doi: 10.1175/2007MWR2289.1.

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ANDREW TURNIPSEED

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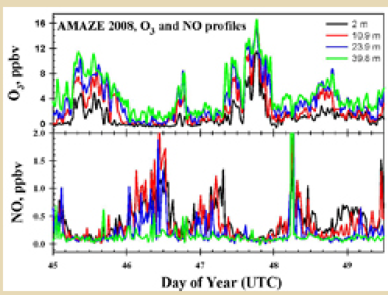
Research Focus FY08:



High resolution figure

My research has focused on understanding the interactions of several trace atmospheric species with the biosphere. Specifically, ozone (O3), oxides of nitrogen (NO, NOx, NOy), sulfur dioxide (SO2) and volatile organic carbon compounds (VOCs) are key species in understanding atmospheric chemical processing and aerosol formation in the atmosphere. These undergo a variety of processes with natural vegetation: (1) emission (e.g., VOCs) through stomatal, plant pores or from soils, and (2) uptake (e.g., O3), through plant stomata or deposition to soils and plant exteriors. For some species, both emission and uptake can be observed depending on the ambient concentration or the position within the plant canopy. Furthermore, the microclimate environment and turbulence within plant canopies can lead to unique atmospheric chemistry, either enhancing or retarding chemical transformations. To approach these questions, we have implemented a system designed to interface with a variety of trace gas sensors to measure concentration profiles through-out and above a plant canopy. When combined with turbulence data, these profiles can be used to infer fluxes as well as source and sink distributions of the species described above.

In FY07-08, I participated in two field campaigns (AMAZE08 and BEACHON-SRM08) aimed at looking at these interactions. In both experiments, a combination of eddy covariance and profiles were used to look at trace gas concentrations through the entire canopy. AMAZE08 took place during the wet season in the Amazonian rainforest with the aim of understanding aerosol formation in the tropics. O3 and NO, NOx and NOy profiles were measured to look at interactions and chemistry within the tropical forest canopy. The plot below shows an example of the data observed showing strong O3 deposition upon moving deeper into the canopy as well as soil emission of NO. This is also consistent with chemical transformations occurring within the canopy and modeling is currently underway to deduce the importance of each pathway. Currently at BEACHON-SRM08, similar measurements are underway in a water-limited ponderosa pine forest. SO2 profiles are also being measured in this campaign since this is a key species in understanding aerosol formation.

Finally, I have also remained involved in developing a simple Relaxed Eddy Accumulation (REA) system for VOC flux measurements. We currently have two of these systems in use; one at the Niwot Ridge AmeriFlux site in Colorado and one at the Duke Forest AmeriFlux site in Durham, NC in cooperation with Chris Geron of the Environmental Protection Agency. The goal of these studies is to have a simple flux system that be used for longer-term measurements to look at seasonal changes in emission. We also plan to reproduce this simple and relatively inexpensive system to enhance our VOC emission data base both spatially and temporally. This data base is necessary in order to validate and tune models such as MEGAN designed to simulate global VOC emissions. The results at Niwot Ridge may be particularly interesting as we now have two growing seasons of VOC flux data and it appears that a major infestation of pine bark beetles will be occurring over the next 2-3 years. This will have a large impact on the ecosystem and possibly changing emission characteristics which should be observable in the flux data.

Publications FY08:

Karl, T., A. B. Guenther, A. A. Turnipseed, E. G. Patton, K. Jardine, 2008: Chemical sensing of plant stress at the ecosystem scale. *Biogeosciences Discuss.*, 5, 2381-2399.

Yi, C., D. E. Anderson, A. A. Turnipseed, S. P. Burns, J. P. Sparks, D. I. Stannard, R. K. Monson, 2008: The contribution of advective fluxes to net ecosystem exchange in a high-elevation, subalpine forest. *Ecological Applications*, **18**, 1379-1390.

Patton, E. G., T. Horst, D. H. Lenschow, P. P. Sullivan, S. P. Oncley, S. P. Burns, A. B. Guenther, T. Karl, S. D. Mayor, S. M. Spuler, J. Sun, A. A. Turnipseed, E. Allwine, S. Edburg, B. Lamb, R. Avissar, H. Holder, R. Calhoun, J. Kleissl, W. Massman, K. Tha Paw U, J. Weil, L. Rizzo, A. Held, 2008: The Canopy Horizontal Array Turbulence Study (CHATS). , Stockholm, SE, AMS, American Meteorological Society, 18A.1.

Boy, M., T. Karl, A. Turnipseed, R. L. Mauldin, E. Kosciuch, J. Greenberg, J. Rathbone, J. Smith, A. Held, K. Barsanti, B. Wehner, S. Bauer, A. Wiedensohler, B. Bonn, M. Kulmala, A. Guenther, 2008: New particle formation in the Front Range of the Colorado Rocky Mountains. *Atmos. Chem. Phys.*, **8**, 1577-1590.

Sparks, J. P., J. T. Walker, A. A. Turnipseed, A. B. Guenther, 2008: Dry Nitrogen deposition estimates over a forest experiencing free air CO2 enrichment. *Global Change Biology*, **14**, 768-781, doi: 10.1111/j.1365-2486.2007.01526.x.

Andrew Turnipseed Research

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JOHN TUTTLE

2008 Publications

Carbone, R. E., J. D. Tuttle, 2008: Rainfall occurrence in the U.S. warm season: The diurnal cycle. J. Climate, 21, 4132-4146, doi: 10.1175/2008JCLI2275.1.

ABSTRACT

The diurnal occurrence of warm-season rainfall over the U.S. mainland is examined, particularly in light of forcings at multiple scales. The analysis is based on a radar dataset of 12-seasons duration covering the U.S. mainland from the Continental Divide eastward. The dataset resolves 2-km features at 15-min intervals, thus providing a detailed view of both large- and regional-scale diurnal patterns, as well as the statistics of events underlying these patterns. The results confirm recent findings with respect to the role of propagating rainfall systems and the high frequency at which these are excited by sensible heating over elevated terrain. Between the Rockies and the Appalachians, ~60% of midsummer rainfall occurs in this manner.

Most rainfall in the central United States is nocturnal and may be attributed to the following three main forcings: 1) the passage of eastward-propagating rainfall systems with origins near the Continental Divide at 105°W; 2) a nocturnal reversal of the mountain–plains solenoid, which is associated with widespread ascent over the plains; and 3) the transport of energetic air and moisture convergence by the Great Plains low-level jet.

Other features of interest include effects of the Appalachians, semidiurnal signals of regional significance, and the impact of breezes along the Gulf of Mexico. A modest effort was put forth to discern signals associated with El Niño and the Southern Oscillation. While tendencies in precipitation patterns are observed, the record is too short to draw conclusions of general significance.

Liu, C.-H., M. W. Moncrieff, J. D. Tuttle, 2008: A note on propagating rainfall episodes over the Bay of Bengal. Quart. J. Roy. Meteor. Soc., 134, 787-792.

Abstract

An observational analysis of precipitation episodes over the Bay of Bengal and the adjacent coastal region is conducted using the TRMM Real-Time Multi-Satellite Precipitation Analysis (MPA-RT) products for three warm seasons (i.e. May to September for 2002-2004). Time-distance diagrams (Hovmüller diagrams) of rainfall episodes reveal frequent travelling precipitation episodes having lifetimes greatly exceeding those of individual convective systems. The majority of the episodes translate southward and many do not appear to have a steering level (i.e. they propagate in a hydraulic-like manner), unlike those previously documented over midlatitude and tropical continents which usually have a steering level. On average, the coherent systems have a latitudinal span of 5 degrees and a 1-day duration and a meridional propagation speed of 8 m s-1, approximately. The episodes mostly initiate over the coastal land around midday and offshore around midnight.

Laing, A. G., R. E. Carbone, V. Levizzani, J. D. Tuttle, 2008: The propagation and diurnal cycles of deep convection in northern tropical Africa. Quart. J. Roy. Meteor. Soc., 134, 93-109, doi: 10.1002/qj.194.

Abstract

The propagation and diurnal cycle of organized convection in northern tropical Africa are examined using five years (1999-2003) of digital infrared imagery for May-August. Reduced-dimension techniques are used to document the properties of cold clouds - proxies for deep convection and precipitation. Large-scale environments are diagnosed from global analyses.

Organized convection in Africa consists of coherent sequences or episodes which span an average distance of about 1000 km and last about 25 h. A substantial fraction of events exhibits systematic propagation at regional to continental scales while undergoing decay and regeneration. Episodes with 36 h duration and 1472 km span recur at a one-per-day interval. Most episodes have phase speed of 10-20 m s-1, which is faster than most African easterly waves. Convective episodes tend to initiate in the lee of high terrain, consistent with thermal forcing from elevated heat sources. Average diurnal frequency maxima result from the superposition of local diurnal maximum with the delayed-phase arrival of systems propagating from the east. Propagation occurs with moderate low- to mid-tropospheric shear, which varies with the African easterly jet migration and West African monsoon phases. Frequent deep convection occurs with local shear maxima near high terrain. For the peak monsoon period and for 10°W-10°E, where easterly waves and convective systems are frequent, 35% of cold cloud episodes occur east of the wave trough compared with about 24% to the west. Based on the coherent behaviour of organized, propagating convection, inferences may be made regarding the prediction of precipitation beyond one or two days.

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Research Focus FY08:

Studies in the past several years have documented the climatology of warm season precipitation episode statistics (propagation speed, span and duration) over the United States using a national composited radar dataset. Recently these climatological studies have been extended to other continents including Asia, Africa, and Australia. Unfortunately continental regions outside of the United States have insufficient radar coverage and the newer studies have had to rely on geostationary satellite data at infrared (IR) frequencies as a proxy for rainfall. It is well known that the use of IR brightness temperatures to infer rainfall is subject to large errors. In work completed this year the statistics of warm season precipitation episodes derived from radar and satellite IR measurements over the U.S. were compared and biases introduced by the satellite data evaluated. It was found that the satellite span and duration statistics are highly dependent upon the brightness temperature threshold used, but with the appropriate choices of thresholds can be brought into good agreement to those based upon radar data. The propagation speed statistics of satellite events are on average ~4 m s-1 faster than radar events and are relatively insensitive to the brightness temperature threshold. A simple correction procedure based upon the difference between the steering winds for the precipitation core and the winds at the level of maximum anvil outflow was developed. Applying the correction to the satellite measurements brings them into close agreement to the radar statistics.

	Speed Difference (m s-1)			Span Difference (km)			Duration Difference (h)		
	0.02 mm h-1	0.05	0.1	0.02	0.05	0.1	0.02	0.05	0.1
235 K	4.1	4.0	3.8	51	68	97	-3.5	-3.0	-2.0
245	4.0	3.9	3.6	118	133	154	-2.2	-1.7	-1.2
255	3.7	3.7	3.4	164	177	198	-1.0	-0.4	0.3

Table 1. Mean satellite-radar differences in the zonal propagation speed, zonal span and event duration as a function of the brightness temperature and rainfall rate thresholds used to define the endpoints of satellite and radar events, respectively.

Publications FY08 (abstracts):

Tuttle, J. D., R. E. Carbone, P. A. Arkin, 2008: Comparison of ground-based radar and geosynchronous satellite climatologies of warm season precipitation over the United States. *J. Appl. Meteor. Climat.*, doi: 10.1175/2008JAMC2000.1. (In Press)

Carbone, R. E., J. D. Tuttle, 2008: Rainfall occurrence in the U.S. warm season: The diurnal cycle. *J. Climate*, **21**, 4132-4146, doi: 10.1175/2008JCLI2275.1.

Liu, C.-H., M. W. Moncrieff, J. D. Tuttle, 2008: A note on propagating rainfall episodes over the Bay of Bengal. *Quart. J. Roy. Meteor. Soc.*, **134**, 787-792.

Laing, A. G., R. E. Carbone, V. Levizzani, J. D. Tuttle, 2008: The propagation and diurnal cycles of deep convection in northern tropical Africa. *Quart. J. Roy. Meteor. Soc.*, **134**, 93-109, doi: 10.1002/qj.194.

John Tuttle Research Catalog

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Table of Contents

Strategic Goals: Science, Facilities & Technology

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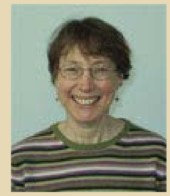
CGD 2008 Profiles in Science: Dr. Mariana Vertenstein



Mariana Vertenstein

Publications

Oleson, K.W., G.B. Bonan, J. Feddema, M. Vertenstein, and C.S.B. Grimmond, 2008: An urban parameterization for a global climate model. 1. Formulation and evaluation for two cities. J. Appl. Meteorol. Clim., 47, 1038-1060, doi:10.1175/2007JAMC1597.1.

Abstract: Urbanization, the expansion of built-up areas, is an important yet less studied aspect of land use/cover change in climate science. To date, most global climate models used to evaluate effects of land use/cover change on climate do not include an urban parameterization. Here, we describe the formulation and evaluation of a parameterization of urban areas that is incorporated into the Community Land Model, the land surface component of the Community Climate System Model. The model is designed to be simple enough to be compatible with structural and computational constraints of a land surface model coupled to a global climate model, yet complex enough to explore physically-based processes known to be important in determining urban climatology. The city representation is based upon the 'urban canyon' concept which consists of roofs, sunlit and shaded walls, and canyon floor. The canyon floor is divided into pervious (e.g., residential lawns, parks) and impervious (e.g., roads, parking lots, sidewalks) fractions. Trapping of longwave radiation by canyon surfaces and solar radiation absorption and reflection is determined by accounting for multiple reflections. Separate energy balances and surface temperatures are determined for each canyon facet. A one-dimensional heat conduction equation is solved numerically for a ten-layer column to determine conduction fluxes into and out of canyon surfaces. Model performance is evaluated against measured fluxes and temperatures from two urban sites. Results indicate the model does a reasonable job of simulating the energy balance of cities.

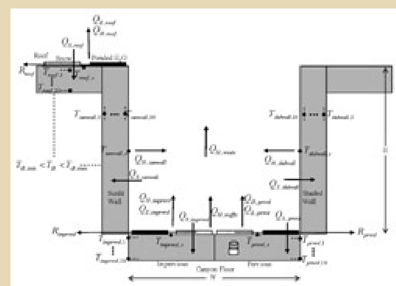


Figure 1.

High resolution figure

Figure caption: Schematic overview of the modeled urban land-unit. The canyon consists of roof, sunlit and shaded walls of height *H*, and a canyon floor of width *W* divided into pervious and impervious fractions. For each of these surfaces, temperatures (T), sensible (Q_H), latent (Q_E), and storage (Q_S) heat fluxes are simulated. Temperatures for each urban surface u include surface temperature ($T_{u,s}$) and internal temperatures for 10 layers ($T_{u,1...10}$). An internal building temperature (T_{iB}) is simulated that can be held at prescribed comfort levels, $T_{iB,min}$ and $T_{iB,\ max}$, thereby simulating heating and/or air conditioning. Hydrology on the roof and canyon floor is simulated, walls are hydrologically inactive. Snowpacks can form on the active surfaces. A certain amount of liquid water is allowed to pond on these surfaces which supports evaporation. Snow melt water or water in excess of the maximum ponding depth runs off (R_{roof}, $R_{imprvrd}$, R_{prvrd}). The pervious canyon floor has a soil moisture store to support evaporation. Anthropogenic fluxes from traffic ($Q_{H,traffic}$) or other sources such as heating and/or air conditioning waste heat ($Q_{H,waste}$) can be accommodated. Incident, reflected, and net solar and longwave radiation are calculated for each individual surface but are not shown for clarity.

Support: This research was supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402, the National Science Foundation grants ATM-0107404 and ATM-0413540, the National Center for Atmospheric Research Water Cycle Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives, and the University of Kansas, Center for Research.

Oleson, K.W., G.B. Bonan, J. Feddema, and M. Vertenstein, 2008: An urban parameterization for a global climate model. 2. Sensitivity to input parameters and the simulated urban heat island in offline simulations. J. Appl.

Meteorol. Clim., 47, 1061-1076, doi:10.1175/2007JAMC1598.1.

Abstract: In a companion paper (Oleson et al. 2007), we presented a formulation and evaluation of an urban parameterization designed to represent the urban energy balance in the Community Land Model. Here we test the robustness of the model through sensitivity studies and evaluate the model's ability to simulate urban heat islands in different environments. Findings show that heat storage and sensible heat flux are most sensitive to uncertainties in the input parameters within the atmospheric and surface conditions considered here. The sensitivity studies suggest that attention should be paid to not only accurately characterizing the structure of the urban area (e.g., height to width ratio), but also to the input data reflecting the thermal admittance properties of each of the city surfaces. Simulations of the urban heat island show that the urban model is able to capture typical observed characteristics of urban climates qualitatively. In particular, the model produces a significant heat island that increases with height to width ratio. In urban areas, daily minimum temperatures increase more than daily maximum temperatures resulting in a reduced diurnal temperature range compared to equivalent rural environments. The magnitude and timing of the heat island vary tremendously depending on the prevailing meteorological conditions and the characteristics of surrounding rural environments. The model also correctly increases the Bowen ratio and canopy air temperatures of urban systems as impervious fraction increases. In general, these findings are in agreement with those observed for real urban ecosystems. Thus, the model appears to be a useful tool for examining the nature of the urban climate within the framework of global climate models.

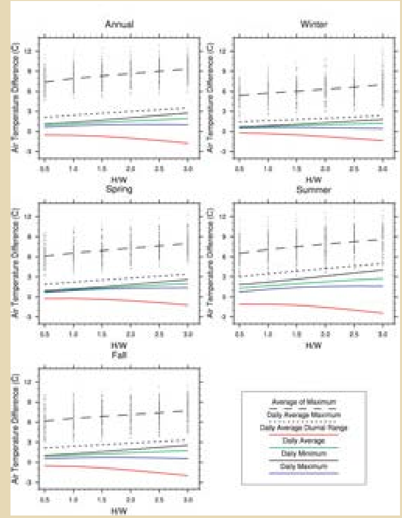


Figure 2.

High resolution figure

Figure caption: Annual and seasonal (winter-DJF, spring-MAM, summer-JJA, fall-SON) characteristics of urban and rural air temperature differences. Urban and rural air temperatures, T_{urban} and T_{rural}, are from hourly data as described in the text. The lines indicate air temperature differences averaged over all grid cells. The daily maximum (blue line) is $T_{urban, max}$ - $T_{rural, max}$ (with overbar) where $T_{urban, max}$ and $T_{rural, max}$ are the maximum urban and rural air temperature in a given day, and the overbar represents the average over the number of days in a given season. Similarly, the daily minimum (solid black line) is $T_{urban, min}$ - $T_{rural, min}$ (with overbar). The daily average (green line) is $T_{urban, avg}$ - $T_{rural, avg}$ (with overbar) where $T_{urban, avg}$ and $T_{rural, avg}$ are the daily average of the hourly urban and rural air temperatures. The daily average diurnal range (red line) is ($T_{urban, max}$ - $T_{urban, min}$) - ($T_{rural, max}$ - $T_{rural, min}$) (with overbar). The dots represent the maximum T_{urban} - T_{rural}at each grid cell for a given height to width ratio, while the long dashed line (average of maximum) represents the average of these at each height to width ratio.

Support: This research was supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402, the National Science Foundation grants ATM-0107404 and ATM-0413540, the National Center for Atmospheric Research Water Cycle Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives, and the University of Kansas, Center for Research.

CGD Research Catalog

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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JOSEPH KLEMP

2008 Publications

Klemp, J. B., J. Dudhia, A. D. Hassiotis, 2008: An upper gravity-wave absorbing layer for NWP applications. Mon. Wea. Rev., doi: 10.1175/2008MWR2596.1.

ABSTRACT

Although the use of a damping layer near the top of a computational model domain has proven effective in absorbing upward-propagating gravity-wave energy in idealized simulations, this technique has been less successful in real atmospheric applications. Here, a new technique is proposed for nonhydrostatic model equations that are solved using split-explicit time-integration techniques. In this method, an implicit Rayleigh damping term is applied only to the vertical velocity, as a final adjustment at the end of each small (acoustic) time step. The adjustment is equivalent to including an implicit Rayleigh damping term in the vertical momentum equation together with an implicit vertical diffusion of w, and could be applied in this manner in other time-integration schemes. This implicit damping for the vertical velocity is unconditionally stable and remains effective even for hydrostatic gravity waves. The good absorption characteristics of this layer across a wide range of horizontal scales are confirmed through analysis of the linear wave equation and numerical mountain-wave simulations, and through simulations of an idealized squall line and of mountain waves over the Colorado Rocky Mountains.

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. Mon. Wea. Rev., 136, 1990-2005, doi: 10.1175/2007MWR2085.1.4

ABSTRACT

Real-time forecasts of five landfalling Atlantic hurricanes during 2005 using the Advanced Research Weather Research and Forecasting (WRF) (ARW) Model at grid spacings of 12 and 4 km revealed performance generally competitive with, and occasionally superior to, other operational forecasts for storm position and intensity. Recurring errors include 1) excessive intensification prior to landfall, 2) insufficient momentum exchange with the surface, and 3) inability to capture rapid intensification when observed. To address these errors several augmentations of the basic community model have been designed and tested as part of what is termed the Advanced Hurricane WRF (AHW) model. Based on sensitivity simulations of Katrina, the inner-core structure, particularly the size of the eye, was found to be sensitive to model resolution and surface momentum exchange. The forecast of rapid intensification and the structure of convective bands in Katrina were not significantly improved until the grid spacing approached 1 km. Coupling the atmospheric model to a columnar, mixed layer ocean model eliminated much of the erroneous intensification of Katrina prior to landfall noted in the real-time forecast.

Skamarock, W. C., J. B. Klemp, 2008: A time-split non-hydrostatic atmospheric model for weather research and forecasting applications. J. Comput. Phys., 227, 3465-3485, doi: 10.1016/j.jcp.2007.01.037.1

Abstract

The sub-grid-scale parameterization of clouds is one of the weakest aspects of weather and climate modeling today, and the explicit simulation of clouds will be one of the next major achievements in numerical weather prediction. Research cloud models have been in development over the last 45 years and they continue to be an important tool for investigating clouds, cloud-systems, and other small-scale atmospheric dynamics. The latest generation are now being used for weather prediction. The Advanced Research WRF (ARW) model, representative of this generation and of a class of models using explicit time-splitting integration techniques to efficiently integrate the Euler equations, is described in this paper. It is the first fully compressible conservative-form nonhydrostatic atmospheric model suitable for both research and weather prediction applications. Results are presented demonstrating its ability to resolve strongly nonlinear small-scale phenomena, clouds, and cloud systems. Kinetic energy spectra and other statistics show that the model is simulating small scales in numerical weather prediction applications, while necessarily removing energy at the gridscale but minimizing artificial dissipation at the resolved scales. Filtering requirements for atmospheric models and filters used in the ARW model are discussed.

Klemp, J. B., W. C. Skamarock, J. Dudhia, 2007: Conservative split-explicit time integration methods for the compressible nonhydrostatic equations. Mon. Wea. Rev., 135, 2897-2913, doi: 10.1175/MWR3440.1.1

ABSTRACT

Historically, time-split schemes for numerically integrating the nonhydrostatic compressible equations of motion have not formally conserved mass and other first-order flux quantities. In this paper, split-explicit integration techniques are developed that numerically conserve these properties by integrating prognostic equations for conserved quantities represented in flux form. These procedures are presented for both terrain-following height and hydrostatic pressure (mass) vertical coordinates, two potentially attractive frameworks for which the equation sets and integration techniques differ significantly. For each set of equations, the linear dispersion equation for acoustic/gravity waves is derived and analyzed to determine which terms must be solved in the small (acoustic) time steps and how these terms are represented in the time integration to achieve stability. Efficient techniques for including numerical filters for acoustic and external modes are also presented. Simulations for several idealized test cases in both the height and mass coordinates are presented to demonstrate that these integration techniques appear robust over a wide range of scales, from subcloud to synoptic.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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JOANIE KLEYPAS

General Information

TIIMES - ISSE
Scientist III
Incubator

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Research Focus FY08:

Coral Reef Studies - Joanie Kleypas

Joanie Kleypas is a marine ecologist/geologist that focuses on how coral reefs and other marine ecosystems are affected by changes in the Earth's atmosphere and climate. Her work in TIIMES considers two aspects of increasing atmospheric CO_2 on coral reefs: ocean warming and ocean acidification. This work has revealed that the vulnerability of reef ecosystems to coral bleaching events (the loss of symbiotic algae from coral tissues) varies with not only regional differences in the exposure of reefs to increased temperature extremes, but with differences in coral sensitivity to those extremes. For example, while the western Pacific warm pool (WPWP) has experienced relatively minor increases in temperature, WPWP coral bleaching events have been triggered by smaller temperature increases than in other regions. These findings are being used with CCSM temperature projections to predict the frequency of future bleaching events. Kleypas also continues to lead planning efforts to conduct ocean acidification research at both national and international levels, and has just completed a pilot study to test various methods for augmenting NOAA's Integrated Coral Observing Network (ICON) stations with autonomous seawater carbonate chemistry measurements.

In the News:

Leopold Leadership Program (19 March 2008)

Based at Stanford University's Woods Institute for the Environment, the Leopold Leadership Program was founded in 1998 and is funded by the David and Lucile Packard Foundation. Each year the program selects up to 20 mid-career academic environmental scientists as fellows, who receive intensive communication and leadership training to help them deliver scientific information more effectively to journalists, policymakers, business leaders and the public. One of the 19 includes Joan Kleypas, scientist II, Institute for the Study of Society and Environment, National Center for Atmospheric Research (NCAR). Research: ocean acidification and the effects of climate change on coral reefs.... more

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East Pacific Coral Reefs Provide Insight into Ocean Acidification

Coral reefs in the Eastern Pacific are considered marginal in terms of the ability of the coral communities to build large wave-resistant coral structures. The strong upwelling in the region has always been thought to be a factor in their poor development, because the upwelled waters are cold, which slows coral growth, but also nutrient rich, which stimulates phytoplankton production and thus reduces water transparency. Joanie Kleypas (ISSE and RAL/TIIMES) was part of a team of researchers from NOAA, University of Miami, and the University of Colorado, to take a closer look at reef development in this area. Compared to well-developed reefs in the Bahamas, reefs of the Eastern Pacific, particularly those of the Galapagos Islands, are very poorly cemented. Furthermore, the degree of cementation correlates well with the carbonate chemistry of the upwelled water, which is enriched with CO_2 to levels equivalent to what is expected by the end of this century. This research indicates that if the high susceptibility of the Eastern Pacific reefs to bioerosion is indeed related the the naturally-high CO_2 upwelled waters, that reef growth of the future may be compromised by ocean acidification in yet another way.

Additional Articles:

Eastern Pacific reveals coral reefs' future - Envrionmental Research Web (July 29, 2008)
Pacific region may show the future of corals reefs in more acidic oceans - New York Times - Henry Fountain (July 29, 2008)
Study: High CO2 environment damages reefs - Science News (July 28, 2008)

NCAR Field Guide to: Climate's Impact on Coral & Reef Systems
Natural Ocean Thermostat Helps Protect Pacific Ocean Coral Reefs - National Science Foundation (NSF)
Ocean thermostat can save coral - BBC News (8 February 2008)
NCAR study: Coral reef may be spared - Daily Camera by Steve Graff (12 February 2008)
Coral Reefs May Be Protected By Natural Ocean Thermostat - Climate Shifts by OveHG (8 February 2008)
Coral reefs may be protected by natural ocean thermostat - Nature Comments (8 February 2008)
Ocean thermostat can save coral - Flickr - Environmental News (8 February 2008)
Coral Reefs May Be Protected By Natural Ocean Thermostat - LearnFreely.net (February 2008)
Ocean thermostat can save coral - Tehran Times (10 February 2008)

Community Service FY08:

- Editor - Climate Research
- International Advisory Panel, CARBOOCEAN - EU program on marine carbon sources and sinks
- Scientific Steering Committee, Ocean Carbon & Biogeochemistry, Inter-agency working group on ocean carbon
- Chair - Subcommittee on Ocean Acidification, Ocean Carbon & Biogeochemistry
- International Scientific Advisory Panel, EPOCA (European Program on Ocean Acidification)
- Graduate Advisor & Thesis Committee - Derek Manzello, PhD, Univ. Miami, Miami, FL USA
- Undergraduate Mentoring - Bridget Molloy, University of Colorado

Scientific Talks FY08:

- Ocean Acidification. Invited, EUR-OCEANS Open European Conference on "Global Change and Marine Ecosystems" Rome, Italy (25-27 Nov 2008)
- Poorly cemented coral reefs of the eastern tropical Pacific: possible insights into reef development in a high-CO2 world. (with Derek Manzello) The Ocean in a High-CO2 World, Monaco (6-9 Oct 2008)
- Coral reef vulnerability in light of the ocean thermostat and ocean acidifiation and implications for conservation. Invited, The Nature Conservancy workshop on ocean acidification, Kaneohe, HI (Aug 2007)
- Mission possible: Helping coral reefs through the climate crisis. (invited plenary) 11th Int. Coral Reef Symp., Ft. Lauderdale FL (Jul 2008) [view ISRS President Rich Aronson in Coral Reef Mission Impossible Video - about 2.5 minutes]
- New insights into the exposure and sensitivity of coral reefs to ocean warming. (with Patrick Boylan) 11th Int. Coral Reef Symp., Ft. Lauderdale FL (Jul 2008)
- Testimony on The Federal Ocean Acidification Reserch and Monitoring Act (FOARAM) before the U.S. House of Representatives Subcommittee on Energy and Environment (Science and Technology Committee), Washington DC (05 Jun 2008)
- Testimony on Global Warming's Impact on the Oceans before the U.S. House of Representatives Select Committee on Energy Independence and Global Warming, Washington DC (29 Apr 2008)
- Ocean acidification: Effects on marine ecosystems and research challenges for the coming decade. NCAR, Boulder CO (Mar 2008)
- The ocean thermostat and coral reef bleaching. NCAR, Boulder CO (Mar 2008)
- Ocean acidification and coral reefs -- why it matters. Invited public talk, Queensland Museum, Townsville, Australia (Mar 2008)
- Thoughts on a Great Barrier Reef ocean acidification program. Invited, Australian Inst. Mar. Sci., Townsville, Australia (Mar 2008)
- Potential role of thermostatic mechanisms in determining regional differences in coral reef bleaching events. (with Gokhan Danabasoblu and Janice Lough) Ocean Sciences, Orlando FL (Feb 2008)
- Doomsday (or not) for coral reefs. Invited informal seminar, NOAA, Boulder CO (Jan 2008)
- Coral reefs and the global CaCO3 budget. Invited, NOAA 4th Annual Combined Effects Think Tank to Support CREWS Modeling, Little Cayman Island (Dec 2007)
- How ocean acidification affects corals, coral communities, and reefs. Invited, Nat. Acad. Sci. Kavli Frontiers in Science, Irving CA (Nov 2007)

Publications FY08:

Boylan, P and J Kleypas, (submitted): New insights into the exposure and sensitivity of coral reefs to ocean warming. *Proc. 11th Int. Coral Reef Symp.*, Ft. Lauderdale, Florida, 7-11 July 2008.

Fortier, L, S Hawkins, J Kleypas, H-O Poertner, and Y Shirayama, Eds., (in press): Effects of Climate Change on Marine Ecosystems, Special Issue in *Climate Research*.

Feely RA, JC Orr, VJ Fabry, JA Kleypas, CL Sabine and C Langdon, (in press): Present and future changes in seawater chemistry due to ocean acidification. AGU Monograph on *The Science and Technology of Carbon Sequestration.*

Doney, SC, VJ Fabry, RA Feely, and JA Kleypas, (in press): Ocean acidification: The other CO2 problem. *Ann. Rev. Mar. Sci.* [link to online publication at *Annual Reviews*]

Dodge, RE, C Birkeland, M Hatziolos, J Kleypas, SR Palumbi, O Hoegh-Guldberg, R Van Woesik, JC Ogden, RB Aronson, BD Causey, and F Stuab, 2008: A call to action for coral reefs, *Science*, **322**, 189-190.

Manzello, DP, JA Kleypas, D Budd, CM Eakin, P.W. Glynn, and C Langdon, 2008: Poorly cemented coral reefs of the eastern tropical Pacific: Possible insights into reef development in a high-CO2 world, *Proc. Nat. Acad. Sci.*, **105**, 10450-10455 (doi:10.1073/pnas.0712167105).

Kleypas, JA, G Danabasoglu, and JM Lough, 2008: Potential role of the ocean thermostat in determining regional differences in coral reef bleaching events. *Geophys. Res. Lett.*, **35**:L03613, doi:10.1029/2007GL032257. PDF

Fabry, VJ, C Langdon, WM Balch, A Dickson, R Feely, B Hales, D Hutchins, J Kleypas, and C Sabine, 2008: Present and future impacts of ocean acidification on marine ecosystems and biogeochemical cycles (workshop report), *Eos Trans. Am. Geophys. Soc.*, **89**, 143-144.

Kleypas, JA, and O Hoegh-Guldberg, 2008: Coral reefs and global climate change, *Status of Caribbean Coral Reefs after Bleaching and Hurricanes in 2005*, C Wilkinson, Ed., Global Coral Reef Monitoring Network, pp. 19-29. PDF [link to full GCRMN Status Report]

Hendee, JC, L Gramer, JA Kleypas, D Manzello, M Jankulak, and C Langdon, 2007: The integrated coral observing network: Sensor solutions for sensitive sites, *ISSNIP 2007: Proc., 3rd Int. Conf., Intelligent Sensors, Sensor Networks, and Information Processing*, Melbourne, Australia, pp. 669-673. PDF

Caldeira K, D Archer, JP Barry, RGJ Bellerby, PG Brewer, L Cao, AG Dickson, SC Doney, H Elderfield, VJ Fabry, RA Feely, J-P Gattuso, PM Haugan, O. Hoegh-Guldberg, AK Jain, JA Kleypas, C Langdon, JC Orr, A Ridgwell, CL Sabine, BA Seibel, Y Shirayama, C Turley, AJ Watson, RE Zeebe, 2007: Comment on "Modern-age buildup of CO2 and its effects on seawater acidity and salinity" by Hugo A. Lo\'87iciga, *Geophys. Res. Lett.* **34**, L18608, doi:10.1029/2006GL027288.

Joanie Kleypas Research Catalog

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CHARLES KNIGHT

2008 Publications

Schlatter, P. T., T. W. Schlatter, C. A. Knight, 2008: An unusual hailstorm on 24 June 2006, Boulder, Colorado, Part I: Mesoscale setting and radar features. Mon. Wea. Rev., 136, 2813-2832, doi: 10.1175/2008MWR2337.1.

ABSTRACT

An unusual, isolated hailstorm descended on Boulder, Colorado, on the evening of 24 June 2006. Starting with scattered large, flattened, disk-shaped hailstones and ending with a deluge of slushy hail that was over 4 cm deep on the ground, the storm lasted no more than 20 min and did surprisingly little damage except to vegetation. Part I of this two-part paper examines the meteorological conditions preceding the storm and the signatures it exhibited on Weather Surveillance Radar-1988 Doppler (WSR-88D) displays. There was no obvious upper-tropospheric forcing for this storm, vertical shear of the low-level wind was minimal, the boundary layer air feeding the storm was not very moist (maximum dewpoint 8.5°C), and convective available potential energy calculated from a modified air parcel was at most 1550 J kg-1. Despite these handicaps, the hail-producing storm had low-level reflectivity exceeding 70 dBZ, produced copious low-density hail, exhibited strong rotation, and generated three extensive bounded weak-echo regions (BWERs) in succession. The earliest of these filled with high reflectivities as the second one to the south poked up through precipitation-filled air. This has implications for low-density hail growth, as discussed in Part II.

Knight, C. A., P. T. Schlatter, T. W. Schlatter, 2008: An unusual hailstorm on 24 June 2006, Boulder, Colorado, Part II: Low density growth of hail. Mon. Wea. Rev., 136, 2833-2848, doi: 10.1175/2008MWR2338.1.

ABSTRACT

The 24 June 2006 Boulder hailstorm produced very heavy precipitation including disc-like hailstones that grew with low density. These disc-like hailstones, 4 to 5 cm in diameter, are unusual, and some of them appear to have accumulated graupel while aloft. A large amount of very fine-grained slush was left on the ground along with the hail. The hail and the great amount of slush suggest that most of the hydrometeor growth in the cloud was by low or very low density riming. Consistent with that, the radar data suggest that the storm updraft had substantially depleted liquid water content. There is evidence that low-density hydrometeor growth within storms may be considerably more frequent than commonly suspected.

Knight, C. A., L. J. Miller, R. A. Rilling, 2008: Aspects of precipitation development in trade wind cumulus revealed by differentialreflectivity at S band. J. Atmos. Sci., 65, 2563-2580, doi: 10.1175/207JAS2569.1.

ABSTRACT

Early radar echo development in trade wind cumulus clouds is studied using the equivalent reflectivity factor, Ze, combined with the differential reflectivity, Zdr. The clouds studied are among the largest of trade wind cumulus, developing significantly positive values of Zdr and attaining at least about 30dBZ equivalent reflectivity factor. The measures used for analysis are values calculated for entire, constant elevation angle sweeps through the clouds and entire volume scans: not maximum, single pulse-volume values. The radar echo evolution follows fairly closely the Marshall-Palmer distribution with scatter towards higher values of Zdr especially in the earliest stages of echo intensification, where some of the scatter

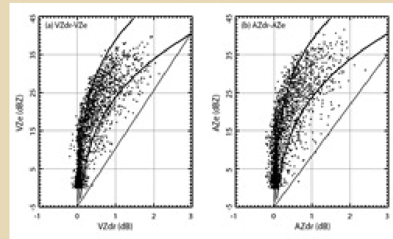

Figure 1: Scatter diagrams of S-band reflectivity factor (Ze) vs. differential reflectivity (Zdr) calculated for 2701 volume scans (V) and individual sweeps (A represents area) through precipitating, trade wind cumulus. The curved line to the left represents the traditional Marshall-Palmer distribution, and the one to the right represents the relationship for a single size of water drop. The straight line represents the limit of scatter, for comparison with other figures in the article.

High resolution figure

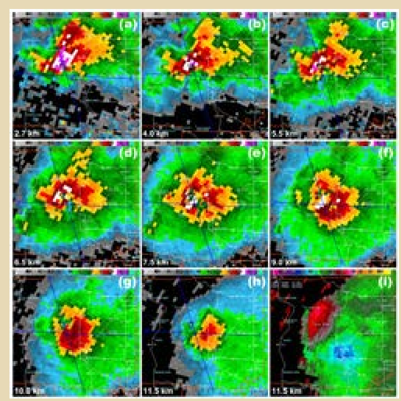

Figure 2: (a) through (h) are the PPI scans (approximately horizontal) through the Boulder storm, with the heights above sea level that indicated, and (i) is the 11.5 km radial velocity (the radar was SE of the storm) showing the upper level divergence. The two triangles mark the locations of two weak-echo vaults that formed within the storm and are related to the heavy precipitation of soft hail.

High resolution figure

in the whole-sweep values is caused by size sorting. The data provide no evidence for an important role of ultra-giant aerosols in initiating coalescence. They are in strong contrast with similar data from a cloud over northern Alabama, that do suggest a major role for UGA in producing several-mm-diameter raindrops that dominate its weak, early radar echo.

Rauber, R. M., B. Stevens, H. T. Ochs III, C. Knight, B. A. Albrecht, A. M. Blyth, C. W. Fairall, J. B. Jensen, S. G. Lasher-Trapp, O. L. Mayol-Bracero, G. Vali, J. R. Anderson, B. A. Baker, A. R. Bandy, F. Burnet, J.-L. Brenguier, W. A. Brewer, P. R. A. Brown, P. Chuang, W. R. Cotton, L. Di Girolamo, B. Geert, H. Gerber, S. Goeke, L. Gomes, B. G. Heikes, J. G. Hudson, P. Kollias, R. P. Lawson, P. Jonas, S. K. Krueger, D. H. Lenschow, L. Nuijens, D. W. O'Sullivan, R. A. Rilling, D. C. Rogers, A. P. Siebesma, E. Snodgrass, J. L. Stith, D. C. Thornton, S. Tucker, C. H. Twohy, P. Zuidema, 2007: Rain in (shallow) cumulus over the ocean - the RICO campaign. Bull. Amer. Meteor. Soc., 88, 1912-1928, doi: 10.1175/BAMS-88-12-1912.

Abstract

RICO studied the formation of rain in marine cumuli, and how rain modifies the structure and ensemble statistics of trade wind clouds.

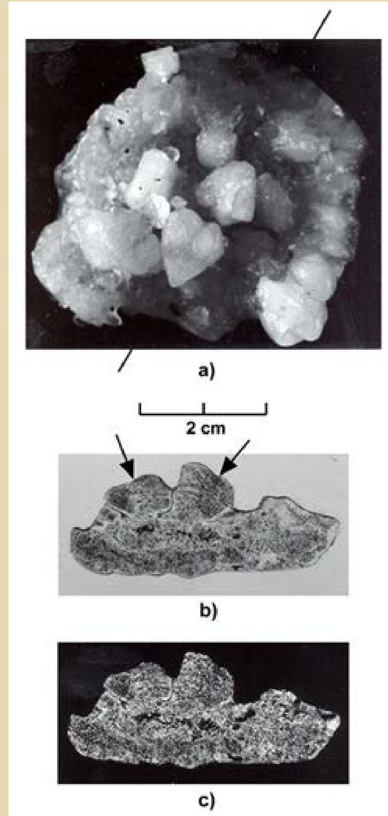

Figure 3: (a) shows a top view of one of the disc-like, soft hailstones from the Boulder storm, showing small, conical hail evidently collected by it, aloft. (b) and (c) are plain and polarized light views of a section through it (after freezing solid), showing very bubbly, very fine-grained ice that originated as low-density rime formed at a low temperature.

High resolution figure

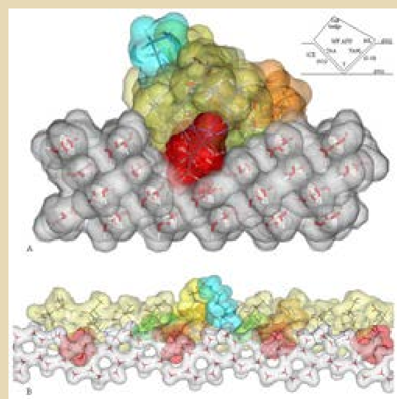

Figure 4: Proposed binding of the winter flounder HPLC6 antifreeze to ice.

High resolution figure

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KUBO, MASAHITO

Disintegration of Magnetic Flux In Decaying Sunspots. I.

Numerous small magnetic elements called moving magnetic features (MMFs) are generally observed in the moat region that surrounds a sunspot. MMFs appear around the outer boundary of the sunspot penumbra and then move almost radially outward in the moat region. It is widely believed that the formation of MMFs detached from the penumbra is important to understanding the process of sunspot decay. Continuous observations of sunspot penumbrae with the Solar Optical Telescope aboard the Hinode satellite clearly show that the outer boundary of the penumbra fluctuates around its averaged position. The penumbral outer boundary moves inward when granules appear in the outer penumbra. We discover that such granules appear one after another while MMFs are separating from the penumbral "spines" (penumbral features that have stronger and more vertical magnetic fields than those of their surroundings). These granules that appear in the outer penumbra often merge with bright features inside the penumbra that move with the spines as they elongate toward the moat region. This suggests that convective motions around the penumbral outer boundary are related to the disintegration of magnetic flux in the sunspot. Results of the research have been published in the Astrophysical Journal.

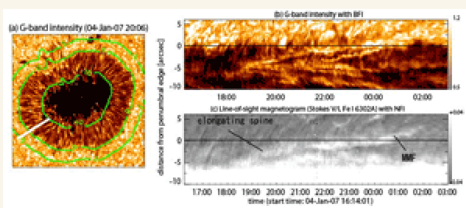

Figure 1 caption: *(a) Sunspot in NOAA AR 10933, observed with the Hinode/SOT in the G band on 2007 January 4 at 20:06. (b) Space vs. time plot along the white line in panel a for the G-band intensity. (c) Same as panel b, but for the line-of-sight magnetic field. The vertical axis in panels b and c represents the radial distance from the averaged penumbral outer boundary, and these figures present results of two consecutive observations, differing mainly by their cadence. The cadence is 2 minutes from 16:14 to 24:00 on 2007 January 4 and 7 minutes from 0:00 to 3:00 on 2007 January 5. The G-band intensity is normalized to the quiet-area intensity. White indicates positive polarity and black indicates negative polarity in panel c.*

Disintegration of Magnetic Flux In Decaying Sunspots. II.

This study attempts to address the basic question of how much magnetic flux is carried away from a sunspot to the outer boundary of the moat region and is subsequently removed from the photosphere. The mutual apparent loss of photospheric magnetic flux is often observed around the outer boundary of the moat region when one magnetic polarity element collides with another polarity magnetic element. This apparent flux loss is called "magnetic flux cancellation" as a descriptive term. We estimate the magnetic flux budget in a decaying sunspot and its surrounding moat region by using a time series of the spatial distribution of vector magnetic fields in the photosphere. A time series of spectropolarimetric measurements with the Solar Optical Telescope aboard the Hinode satellite allows us, for the first time, to estimate an accurate flux change without any effects of atmospheric seeing. The amount of magnetic flux that decreases in the sunspot and (inner) moat region is very similar to magnetic flux transported to the outer boundary of the moat region. The flux loss rates of magnetic elements with positive and negative polarities balance each other around the outer boundary of the moat region. These results suggest that most of the magnetic flux in the sunspot is transported to the outer boundary of the moat region as moving magnetic features, and then is removed from the photosphere by the "magnetic flux cancellation" around the outer boundary of the moat region. Results of the research were accepted for publication in the Astrophysical Journal.

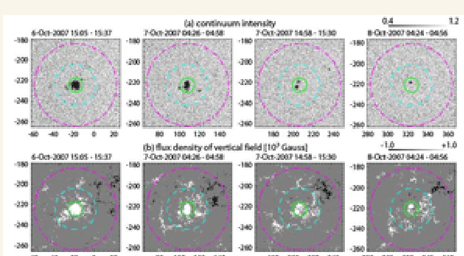

Figure 1 caption: *Time series of (a) continuum intensity and (b) magnetic flux density of vertical field for the following sunspot in NOAA AR 10972. The solid, dashed, and dash-dotted circles indicate the outer boundaries of regions called the sunspot region (7" from the sunspot center), the unipolar region (20" from the sunspot center), and the mixed polarity region (40" from the sunspot center), respectively. We compare a flux change rate in each region with a flux transport rate at it outer boundary. The vertical and horizontal axes show the positions with respect to the disk center in units of arcseconds.*

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YING-HWA (BILL) KUO

2008 Publications

Zeng, Z., A. Burns, W. Wang, J. Lei, S. C. Solomon, S. Syndergaard, L. Qian, Y.-H. Kuo, 2008: Ionospheric annual asymmetry observed by the COSMIC radio occultation measurements and simulated by the TIEGCM. J. Geophys. Res. - Atmos., 113, A07305, doi: 10.1029/2007JA012897.

Abstract

Average F2-layer electron densities at December solstice are higher than those at June solstice. This phenomenon, which is often called the F2-layer annual asymmetry, has been observed for several decades, but its causes are still not fully understood. This study investigates global variations of this annual asymmetry observed from one year of the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) ionospheric radio occultation (IRO) measurements. The IRO observations show that there is a strong NmF2 annual asymmetry that has significant longitudinal and local time variations. A strong peak of the asymmetry occurs at about noon and another one at midnight, both located at around 25° geomagnetic latitude. Numerical simulations using the Thermosphere-Ionosphere Electrodynamics Global Circulation Model (TIEGCM) are in very good agreement with these observations. The modeled NmF2 annual asymmetry has a similar magnitude, and similar semidiurnal and longitudinal variations as those in the observations. TIEGCM simulations show that changes in solar extreme ultraviolet (EUV) radiation between the December and June solstices and the displacement of the geomagnetic axis from the geographic axis are the two primary processes that cause the annual asymmetry and its associated longitudinal and local time variations. The tides propagating from lower altitudes also contribute to this asymmetry, but to a smaller extent.

Xiao, Q., E. Lim, D.-J. Won, J. Sun, W.-C. Lee, M.-S. Lee, W.-J. Lee, J.-Y. Cho, Y.-H. Kuo, D. M. Barker, D.-K. Lee, H. S. Lee, 2008: Doppler radar data assimilation in KMA's operational forecasting. Bull. Amer. Meteor. Soc., 89, 39-43, doi: 10.1175/BAMS-89-1-39.

Anthes, R. A., P. A. Bernhardt, Y. Chen, L. Cucurull, K. F. Dymond, D. Ector, S. B. Healy, S.-P. Ho, D. C. Hunt, Y.-H. Kuo, H. Liu, K. W. Manning, C. McCormick, T. K. Meehan, W. J. Randel, C. Rocken, W. S. Schreiner, S. V. Sokolovskiy, S. Syndergaard, D. C. Thompson, K. E. Trenberth, T.-K. Wee, N. L. Yen, Z. Zeng, 2008: The COSMIC/FORMOSAT-3 Mission: Early Results. Bull. Amer. Meteor. Soc., 89, 313-333, doi: 10.1175/BAMS-89-3-313.

Zeng, Z., W. Randel, S. Sokolovskiy, C. Deser, Y.-H. Kuo, M. Hagan, J. Du, W. Ward, 2008: Detection of migrating diurnal tide in the tropical upper troposphere and lower stratosphere using the Challenging Minisatellite Payload radio occultation data. J. Geophys. Res., 113, D03102, doi: 10.1029/2007JD008725.

Abstract

The atmospheric limb sounding technique making use of radio signals transmitted by the Global Positioning System (GPS) has already proven to be a promising approach for global atmospheric measurements. In this study, we assess for the first time the potential of GPS radio occultation soundings for detecting the migrating diurnal tide. Retrieved temperatures between 10 and 30 km in the tropics from the Challenging Minisatellite Payload (CHAMP) occultation observations during May 2001 to August 2005 are analyzed using space-time spectrum analysis to isolate diurnal waves. Because of incomplete local time (LT) coverage of the monthly CHAMP occultation data in any given year, data from all available years are merged to obtain complete 24-h LT coverage. The effects of aliasing associated with uneven data sampling and measurement noise are estimated using synthetic data. The results show the feasibility of determining tidal structures from the composite CHAMP occultation data, and the vertical, seasonal, and latitudinal structures of the diurnal tide are presented. The estimated diurnal amplitude generally increases with altitude, exhibiting a maximum of order 1 K at 30 km. The estimated phase indicates an upward propagating mode above 14 km with a vertical wavelength about 20 km. The observed diurnal tide at 30 km exhibits a distinct seasonal-latitudinal variation. Comparison of the observed diurnal tide to the simulated tide in the extended Canadian Middle Atmosphere Model (CMAM) and Global-Scale Wave Model Version 2 (GSWM02) indicates that CMAM overestimates the amplitude but reproduces the seasonal-latitudinal variation of the diurnal tide while GSWM02 simulates well the annual mean amplitude but lacks the seasonal-latitudinal variation of the diurnal tide.

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Bill Kuo Research Catalog

Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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YING-HWA 'BILL' KUO

General Information

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Research Focus FY08:

Bill is a meteorologist leading UCAR's effort to deploy an array of satellites that promises to provide a wealth of data about the atmosphere. COSMIC, which stands for the Constellation Observing System for Meteorology, Ionosphere and Climate, is a joint project between the United States and Taiwan (in Taiwan it's called FORMOSAT-3). The system is poised to transform weather forecasting, climate monitoring, and research on space weather.

Community Service FY08:

- Graduate Research Advisor: Chun-Sil Jin (Seoul National University, Korea)
- Thesis Committee: Xingpin Fang (Sun Yat-sen University, Guangzhou, China)
- Thesis Committee: Shu-Ya Chen (National Central University of Taiwan, Jhongli City, Taiwan)
- Thesis Committee: Na Liu (Ocean University of China, Qingdao, China)
- Thesis Committee: Lung-Yao Chang (National Taiwan University, Taipei City, Taiwan)

Publications FY08 (abstracts):

Xiao, Q., Y.-H. Kuo, Z. Ma, W. Huang, X.-Y. Huang, X. Zhang, D. M. Barker, J. Michalakes, 2008: Development of the WRF adjoint modeling system and its application to the investigation of the May 2004 McMurdo Antarctica severe wind event. *Mon. Wea. Rev.*, **136**, 3696-3713, doi: 10.1175/2008MWR2235.1.

Huang, X.-Y., Q. Xiao, D. M. Barker, X. Zhang, J. Michalakes, W. Huang, T. Henderson, J. Bray, Y. Chen, Z. Ma, J. Dudhia, Y.-R. Guo, X. Zhang, D.-J. Won, H.-C. Lin, Y.-H. Kuo, 2008: Four-dimensional variational data assimilation for WRF: Formulation and preliminary results. *Mon. Wea. Rev.*. (Submitted)

Kuo, Y.-H., H. Liu, Y.-R. Guo, C.-T. Terng, Y.-T. Lin, 2008: Impact of FORMOSAT-3/COSMIC data on typhoon and Mei-yu prediction. *National Taiwan University (NTU) Department of Atmospheric Sciences 50th Anniversary Book*, K.-N Liou, Ed., National Taiwan University (NTU) Department of Atmospheric Sciences 50th Anniversary book. (In Press)

Zeng, Z., A. Burns, W. Wang, J. Lei, S. C. Solomon, S. Syndergaard, L. Qian, Y.-H. Kuo, 2008: Ionospheric annual asymmetry observed by the COSMIC radio occultation measurements and simulated by the TIEGCM. *J. Geophys. Res. - Atmos.*, **113**, A07305, doi: 10.1029/2007JA012897.

Xiao, Q., E. Lim, D.-J. Won, J. Sun, W.-C. Lee, M.-S. Lee, W.-J. Lee, J.-Y. Cho, Y.-H. Kuo, D. M. Barker, D.-K. Lee, H. S. Lee, 2008: Doppler radar data assimilation in KMA's operational forecasting. *Bull. Amer. Meteor. Soc.*, **89**, 39-43, doi: 10.1175/BAMS-89-1-39.

Anthes, R. A., P. A. Bernhardt, Y. Chen, L. Cucurull, K. F. Dymond, D. Ector, S. B. Healy, S.-P. Ho, D. C. Hunt, Y.-H. Kuo, H. Liu, K. W. Manning, C. McCormick, T. K. Meehan, W. J. Randel, C. Rocken, W. S. Schreiner, S. V. Sokolovskiy, S. Syndergaard, D. C. Thompson, K. E. Trenberth, T.-K. Wee, N. L. Yen, Z. Zeng, 2008: The COSMIC/FORMOSAT-3 Mission: Early Results. *Bull. Amer. Meteor. Soc.*, **89**, 313-333, doi: 10.1175/BAMS-89-3-313.

Zeng, Z., W. Randel, S. Sokolovskiy, C. Deser, Y.-H. Kuo, M. Hagan, J. Du, W. Ward, 2008: Detection of migrating diurnal tide in the tropical upper troposphere and lower stratosphere using the Challenging Minisatellite Payload radio occultation data. *J. Geophys. Res.*, **113**, D03102, doi: 10.1029/2007JD008725.

Wu, Q., S. C. Solomon, Y.-H. Kuo, T. L. Killeen, 2008: Mesospheric effect on the ionosphere from the perspective of TIMED and COSMIC observations. *37th COSPAR Scientific Assembly*, Montreal, CA, COSPAR.

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ARLENE LAING

2008 Publications

Laing, A. G., R. E. Carbone, V. Levizzani, 2008: The propagation of deep convection in Africa: Implications for predictability of precipitation. Quantification and Reduction of Predictive Uncertainty for Sustainable Water Resources Management, E. Boegh, H. Kunstmann, T. Wagener, A. Hall, L. Bastidas, S. Franks, H. Gupta, D. Rosbjerg, J. Schaake, Eds., IAHS Press, 313, 24-32.3

LaJoie, M., A. G. Laing, 2008: The influence of El Nino-Southern oscillation on lightning in the Gulf coast of the United States, Part I: Lightning climatology. Mon. Wea. Rev., 136, 2523-2542, doi: 10.1175/2007MWR2227.1.

ABSTRACT

Cloud-to-ground (CG) lightning flashes from the National Lightning Detection Network are analyzed to determine if the El Niño–Southern Oscillation (ENSO) cycle influences lighting activity along the Gulf Coast region. First, an updated climatology of lightning was developed for the region. Flash density maps are constructed from an 8-yr dataset (1995–2002) and compared with past lightning climatologies. Second, lightning variability is compared with the phases of ENSO. Winter lightning distributions are compared with one published study of ENSO and lightning days in the Southeast.

Flash density patterns are, overall, consistent with past U.S. lightning climatology. However, the peak flash density for the annual mean was less than observed in previous climatologies, which could be due to the disproportionately large percentage of cool ENSO periods compared to previous lightning climatologies.

The highest annual lightning counts were observed in 1997, which consisted of mostly warm ENSO seasons; the 1997–98 El Niño was one of the strongest on record. The lowest lightning counts were observed in 2000, which had mostly cool or neutral phases of ENSO including the lowest Niño-3.4 anomaly of the study period. Analysis of winter season lightning flash densities substantiated the role of the ENSO cycle in winter season lightning fluctuations. Winter lightning activity increased dramatically during the 1997–98 El Niño. The lowest winter flash densities are associated with cool ENSO phases. Although 8 yr is inadequate to establish a long-term pattern, results indicate that ENSO influences lightning and that further study is warranted. As more years of lightning data are acquired, a more complete climatology can be developed.

Laing, A. G., M. LaJoie, S. Reader, K. Pfeiffer, 2008: The influence of El Nino-Southern oscillation on lightning in the Gulf coast of the United States, Part II: Monthly correlations. Mon. Wea. Rev., 136, 2544-2556, doi: 10.1175/2007MWR2228.1.

ABSTRACT

The El Niño–Southern Oscillation (ENSO) cycle is known to influence weather and climate along the Gulf Coast region, causing anomalously high precipitation during El Niño winters. This region is also known for having the highest lightning flash density in the United States. An 8-yr dataset (1995–2002) of cloud-to-ground (CG) lightning flashes was analyzed to determine if the ENSO cycle influences lighting activity along the Gulf Coast region. Simple Pearson's correlations were computed between concurrent monthly pairings of Niño-3.4 sea surface temperature (SST) and CG lightning flash deviation values from the study area. The correlation results are mapped and analyzed for links to meteorological features.

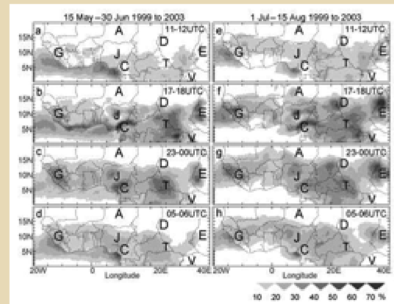

Figure 1: Percentage of cloud coverage with T_b < 253 K during the pre-monsoon (a)–(d) and peak monsoon (e)–(h) periods. Coverage is shown at six-hourly intervals. Bold capital letters identify the locations of mountain peaks.

High resolution figure

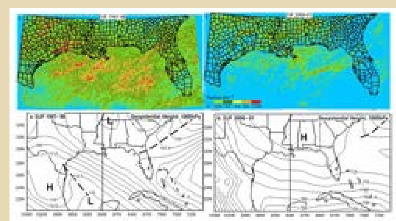

Figure 2: (Upper) December-February mean flash density for 1997-98, period of the warmest Ni�o 3.4 SST anomalies and 2000-01, period of the coolest Ni�o 3.4 SST anomalies. (Lower) Mean geopotential height of 1000 hPa level for the same periods, respectively.

High resolution figure

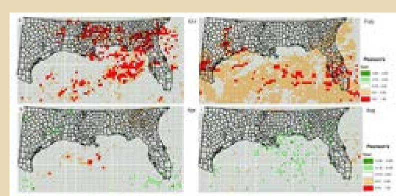

Figure 3: Correlations of Niño 3.4 SST anomalies and lightning flash deviation from monthly mean for October (largest area of maximum correlation), February (largest area of moderate positive correlation), April (minimum correlation), and August (largest area of negative correlation) 1995–2002.

High resolution figure

Statistically significant correlation values greater than 0.8 were noted over large swaths of the study area during each winter month. The highest correlations were arranged in banded swaths and associated with regions of low flash densities during December and February. In January, areas of high correlation were spatially coincident with areas of enhanced flash density. Both the enhanced CG flash regions and high correlation values and patterns are indicative of a southerly shift in the midlatitude storm track known to occur during warm ENSO events. During the spring and summer, most of the region has weak correlation with ENSO except for August, which has a large area of negative correlations. These findings indicate that lightning increases during La Niña summers. Correlation patterns in late fall are similar to those of winter. The ENSO–lightning relationship has implications for hazard assessment and can be a useful tool for long-term seasonal planning.

Laing, A. G., R. E. Carbone, V. Levizzani, J. D. Tuttle, 2008: The propagation and diurnal cycles of deep convection in northern tropical Africa. Quart. J. Roy. Meteor. Soc., 134, 93-109, doi: 10.1002/qj.194.

Abstract

The propagation and diurnal cycle of organized convection in northern tropical Africa are examined using five years (1999-2003) of digital infrared imagery for May-August. Reduced-dimension techniques are used to document the properties of cold clouds - proxies for deep convection and precipitation. Large-scale environments are diagnosed from global analyses.

Organized convection in Africa consists of coherent sequences or episodes which span an average distance of about 1000 km and last about 25 h. A substantial fraction of events exhibits systematic propagation at regional to continental scales while undergoing decay and regeneration. Episodes with 36 h duration and 1472 km span recur at a one-per-day interval. Most episodes have phase speed of 10-20 m s-1, which is faster than most African easterly waves. Convective episodes tend to initiate in the lee of high terrain, consistent with thermal forcing from elevated heat sources. Average diurnal frequency maxima result from the superposition of local diurnal maximum with the delayed-phase arrival of systems propagating from the east. Propagation occurs with moderate low- to mid-tropospheric shear, which varies with the African easterly jet migration and West African monsoon phases. Frequent deep convection occurs with local shear maxima near high terrain. For the peak monsoon period and for 10°W-10°E, where easterly waves and convective systems are frequent, 35% of cold cloud episodes occur east of the wave trough compared with about 24% to the west. Based on the coherent behaviour of organized, propagating convection, inferences may be made regarding the prediction of precipitation beyond one or two days.

MMM Research Catalog

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Research Focus FY08:

Arlene Laing has been studying the characteristics of convective precipitation over Africa — part of a global study of warm-season, continental precipitation endorsed by the *World Weather Research Programme* (WWRP) of the *World Meteorological Organization* (WMO). This work is also part of the NCAR Water Cycle Research Program and is being conducted in collaboration with Dr. Richard Carbone and Dr. Vincenzo Levizzani.

Community Service FY08:

- African Monsoon Multi-disciplinary Analysis (AMMA) US Steering Committee
- Thorpex Working Group (AMMA)
- Graduate Research Advisor: Robert Mera (North Carolina State University, Raleigh, NC)
- Thesis Committee: Felicia Whyte (University of West Indies, Kingston, Jamaica)
- Judge, SOARS-RESESS 2008

Scientific Talks FY08:

- Using GIS to relate the El Ni�o-Southern Oscillation (ENSO) and Cloud-to-Ground Lightning along the United States Gulf Coast (Boulder, CO USA, 01/2008)
- Cycles of deep convection and their propagation characteristics over central and southern Africa (New Orleans, LA USA, 01/2008)
- An online textbook: A rich resource for tropical meteorology education (New Orleans, LA USA, 01/2008)
- Cycles of deep convection over central and southern Africa (Orlando, FL USA, 04/2008)
- Using high-resolution numerical simulations to understand the role of East African mountains in the initiation of long-lived episodes of organized convection (Orlando, FL USA, 04/2008)
- An Online Textbook for Tropical Meteorology (Orlando, FL USA, 04/2008)
- Precipitation in Africa: Propagation and Diurnal Variability (Boulder, CO USA, 06/2008)

Publications FY08 (abstracts):

Laing, A. G., R. E. Carbone, V. Levizzani, 2008: The propagation of deep convection in Africa: Implications for predictability of precipitation. *Quantification and Reduction of Predictive Uncertainty for Sustainable Water Resources Management*, E. Boegh, H. Kunstmann, T. Wagener, A. Hall, L. Bastidas, S. Franks, H. Gupta, D. Rosbjerg, J. Schaake, Eds., IAHS Press, 313, 24-32.

LaJoie, M., A. G. Laing, 2008: The influence of El Nino-Southern oscillation on lightning in the Gulf coast of the United States, Part I: Lightning climatology. *Mon. Wea. Rev.*, **136**, 2523-2542, doi: 10.1175/2007MWR2227.1.

Laing, A. G., M. LaJoie, S. Reader, K. Pfeiffer, 2008: The influence of El Nino-Southern oscillation on lightning in the Gulf coast of the United States, Part II: Monthly correlations. *Mon. Wea. Rev.*, **136**, 2544-2556, doi: 10.1175/2007MWR2228.1.

Laing, A. G., R. E. Carbone, V. Levizzani, J. D. Tuttle, 2008: The propagation and diurnal cycles of deep convection in northern tropical Africa. *Quart. J. Roy. Meteor. Soc.*, **134**, 93-109, doi: 10.1002/qj.194.

Yoksas, T., R. Bruintjes, G. B. Foote, S. Heck, S. Herrmann, E. B. Hoswell, P. A. Kucera, A. G. Laing, B. Lamptey, M. Moncrieff, R. Pandya, M. Ramamurthy, R. Roberts, W. M. Spangler, T. T. Warner, M. Weingroff, 2008: The UCAR Africa Initiative - overview and update. *Conf. on Intl. Topics*, New Orleans, LA, US, American Meteorological Society.

Arlene Laing Research Catalog

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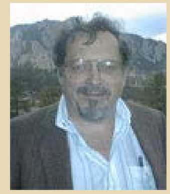
CGD 2008 PROFILES IN SCIENCE: DR. WILLIAM LARGE

Summary of achievements



William Large

The research interest that underlies my research is the physics of the upper ocean and feedbacks with the atmosphere. Of particular interest are low frequency, large scale phenomena, and the role of the upper ocean as a conduit between the interior ocean and the atmosphere. Therefore, upper ocean models for global climate modeling studies are a particular focus. I am involved in small scale experiments, both observational and numerical (LES), that are designed to determine important upper ocean processes, and the signatures of these processes, so that their large scale significance can be assessed and modeled. The atmosphere-ocean forcing functions are a very important aspect of the problem, and I continue to try to improve our knowledge of them.

Ocean and Sea-Ice Modeling for Coupled Climate Models: Major products are state of the art ocean and sea-ice model components for the NCAR Community Climate System Model (CCSM). These components are being tested extensively and exercised in studies of the global ocean and of the impacts of sea-ice and atmospheric boundary conditions. There is currently a concerted effort to force a coupled ocean, sea-ice system in as similar a manner as practical to when coupled to an atmospheric model. Growing activities are the assessment of component performance within a coupled CCSM integration, as well as analysis of the coupled model output. Objectives are to investigate the interaction of the atmosphere and ocean in decadal climate fluctuations and to identify possible sources of climate drift in coupled models.

Forcing Numerical Models: The goal here is to specify the frequency and wavenumber content of forcing functions required to force numerical ocean models. One task is to quantify the ocean model response to high wavenumber (25-500 km) winds. Since important responses have been found, a means of obtaining the needed high wavenumber information at the required frequency from satellite scatterometer measurements was developed. The product is an annual cycle (August 1996 through July 1997) of global scatterometer based winds. The resolution is one-half degree in both the zonal and meridional directions and every six hours in time.

Publications

Large, W.G. and S.G. Yeager, 2008: The Global Climatology of an Interannually Varying Air-Sea Flux Data Set. Climate Dynamics, doi:10.1007/s00382-008-0441-3.

Abstract: The air-sea fluxes of momentum, heat, freshwater and their components have been computed globally from 1948 at frequencies ranging from 6-hourly to monthly. All fluxes are computed over the 23 years from 1984 to 2006, but radiation prior to 1984 and precipitation before 1979 are given only as climatological mean annual cycles. The input data are based on NCEP reanalysis only for the near surface vector wind, temperature, specific humidity and density, and on a variety of satellite based radiation, sea surface temperature, sea-ice concentration and precipitation products. Some of these data are adjusted to agree in the mean with a variety of more reliable satellite and in sitmeasurements, that themselves are either too short a duration, or too regional in coverage. The major adjustments are a general increase in wind speed, decrease in humidity and reduction in tropical solar radiation. The climatological global mean air-sea heat and freshwater fluxes (1984-2006) then become 2 W/m^2 and -0.1 mg/m^2 per second, respectively, down from 30 W/m^2 and 3.4 mg/m^2 per second for the unaltered data. However, decadal means vary from 7.3 W/m^2 (1977-1986) to -0.3 W/m^2 (1997-2006). The spatial distributions of climatological fluxes display all the expected features. A comparison of zonally averaged wind stress components across ocean sub-basins reveals large differences between available products due both to winds and to the stress calculation. Regional comparisons of the heat and freshwater fluxes reveal an alarming range among alternatives; typically 40 W/m^2 and 10 mg/m^2 per second, respectively. The implied ocean heat transports are within the uncertainty of estimates from ocean observations in both the Atlantic and Indo-Pacific basins. They show about 2.4 PW of tropical heating, of which 80% is transported to the north, mostly in the Atlantic. There is similar good agreement in freshwater transport at many latitudes in both basins, but neither in the South Atlantic, nor at 35°N.

Chanut, J., B. Barnier, W.G. Large, L. Debreu, T. Penduff and J.M. Molines, 2008: Mesoscale eddies in the Labrador Sea and their contribution to convection and re-stratification. J. Phys. Oceanogr., doi:10.1175/2008JPO3485.1.

Abstract: The cycle of open-ocean deep convection in the Labrador Sea is studied in a realistic, high resolution (4km) regional model, embedded in a coarser (1/3 degree) North Atlantic. The configuration allows the simultaneous generation and evolution of three different eddy types that are distinguished by their source region, generation mechanism and dynamics. Very energetic

Irminger Rings (IRs) are generated by barotropic instability of the West Greenland and Irminger currents (WG/IC) off Cape Desolation and are characterized by a warm, salty sub-surface core. They densely populate the basin north of 58N, where their eddy kinetic energy EKE matches the signal observed by satellite altimetry in both magnitude and pattern. Levels of EKE also match offshore of the West Greenland and Labrador coasts, where Boundary Current Eddies (BCEs) are spawned by weakly energetic instabilities all along the Boundary Current System (BCS). Baroclinic instability of the steep isopycnal slopes that result from a deep convective overturning event, produces Convective Eddies (CEs) of diameter 20-30 km, as observed and produced in more idealized modeling, and a distinct seasonal cycle of EKE, with a peak in April. Sensitivity experiments show that each of these eddy types plays a unique role in the heat budget of the central Labrador Sea, and hence in the convection cycle. As observed in nature, deep convective mixing is limited to a small region in the south-western quadrant of the central basin, where adequate preconditioning can occur. To the east, west and south, BCEs flux heat from the BCS at a rate sufficient to counteract air-sea buoyancy loss. To the north, this eddy flux alone is not enough, but when combined with the effects of Irminger Rings preconditioning is effectively inhibited here too. Following a deep convective mixing event, the homogeneous convection patch reaches as deep as 2000m and a horizontal scale of order 1000km, as has been observed. Both CEs and BCEs are found to play critical roles in the lateral mixing phase, when the patch re-stratifies and transforms into Labrador Sea Water (LSW). The latter extract the necessary heat from the BCS and transport it to the deep convection site, where it is available for CEs to flux into convective patches during the initial phase. Later in the phase, BCE heat flux can maintain and even strengthen the re-stratification throughout the column, while solar heating establishes a near surface seasonal stratification. In contrast, IRs appear to have minimal impact on re-stratification, because they rarely enter the deep convection region. However, by virtue of their control on the surface area preconditioned for deep convection and the interannual variability of the associated barotroptic instability, they could have an important role in the variability of LSW.

Donner, L.J. and W.G. Large, 2008: Climate Modeling. Ann. Rev. of Environment and Resources, doi:10.1146/annurev.environ.33.020707.160752.

Abstract: Climate models simulate the atmosphere, given atmospheric composition and energy from the sun, and include explicit modeling of, and exchanges with, the underlying oceans, sea ice, and land. The models are based on physical principles governing momentum, thermodynamics, cloud microphysics, radiative transfer, and turbulence. Climate models are evolving into earth-system models which will also include chemical and biological processes and are the prospect of links to studies of human dimensions of climate and climate change.

Although the fundamental principles on which climate models are based are quite robust, computational limits preclude their numerical solution on scales which include many processes important for the determination of climate. Despite this limitation, many aspects of past and present climate and recent climate change have been successfully simulated using climate models, and climate models are used extensively to predict future climate change due to human activity.

Jochum, M., G. Danabasoglu, M. Holland, Y.-O. Kwon, and W. G. Large. 2008: Ocean viscosity and climate. J. Geophys. Res., 113, C06017, doi:10.1029/2007JC004515.

Abstract: The impacts of parameterized lateral ocean viscosity on climate are explored using three 120-year integrations of a fully coupled climate model. Reducing viscosity leads to a generally improved ocean circulation at the expense of increased numerical noise. Five domains are discussed in detail: the equatorial Pacific, where the emergence of tropical instability waves reduces the cold tongue bias; the Southern Ocean, where the Antarctic Circumpolar Current increases its kinetic energy but reduces its transport; the Arctic Ocean, where an improved representation of the Atlantic inflow leads to a better sea-ice distribution; the North Pacific, where the more realistic path of the Kuroshio leads to more realistic temperatures across the midlatitude Pacific; and the northern marginal seas, where stronger boundary currents lead to significantly less sea-ice. Although the ocean circulation and sea-ice distribution improve, the oceanic heat uptake, the poleward heat transport, and the large scale atmospheric circulation are not changed significantly. In particular, the improvements to the equatorial cold tongue did not lead to better representation of tropical precipitation or El Niño.

Figure caption: Anisotropic horizontal viscosity coefficients A and B at 100-m depth from (a-b) CONT, (c-d) NOSMAG, and (e-f) LOWVISC. Units are 1000 m^2 s^{-1}. All panels use the same color scale.

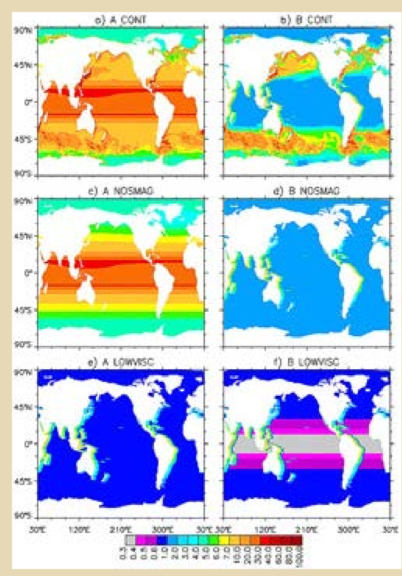


Figure 1.

High resolution figure

Yeager, S.G., and W.G. Large, 2007: Observational Evidence of Winter Spice Injection. J. Phys. Oceanogr., 37, 2895-2919.

Abstract: Temperature and salinity (T-S) profiles from the global array of Argo floats support the existence of spice-formation regions in the subtropics of each ocean basin where large, destabilizing vertical salinity gradients coincide with weak stratification in winter. In these characteristic regions, convective boundary layer mixing generates a strongly density-compensated (SDC) layer at the base of the well-mixed layer. The degree of density compensation of the T-S gradients of an upper-ocean water column is quantified using a bulk vertical Turner angle (Tub) between the surface and upper pycnocline. The winter generation of the SDC layer in spice-formation zones is clearly seen in Argo data as a large-amplitude seasonal cycle of Tub in regions of the subtropical oceans characterized by high mean Tub. In formation regions, Argo floats provide ample evidence of large, abrupt spice injection (T-S increase on subducted isopycnals due to vertical mixing) associated with the winter increase in Tub. A simple conceptual model of the spice-injection mechanism is presented that is based on known behavior of convective boundary layers and supported by numerical model results. It suggests that penetrative convective mixing of a partially density-compensated water column will enhance the Turner angle within a transition layer between the mixed layer and the upper pycnocline, generating seasonal T-S increases on density surfaces below the mixed layer. Observations are consistent with this hypothesis. In OGCMs, regions showing high Tub mean and seasonal amplitude are also the sources of significant interannual spice variability in the permanent pycnocline. Decadal changes in the North Pacific of a model hindcast simulation show qualitative resemblance to the observed multiyear time series from the Hawaii Ocean Time series (HOT) station ALOHA. Modeled pycnocline variations near Hawaii can be linked to high Tub seasonality and winter spice injection within a formation region upstream of ALOHA, suggesting that spice injection may explain the origins of observed large, interannual variations on isopycnals in the ocean interior.

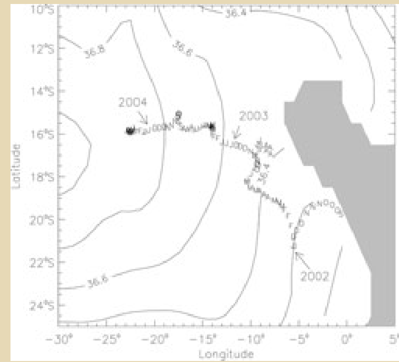


Figure 2.

High resolution figure

Figure caption: Trajectory of float WMO 5900117 after deployment near the Greenwich meridian in September 2001. Instantaneous profile locations (10 days apart) are indicated by the first letter of the month in which they were taken. The data extend through June 2004. The first January measurement of each year is indicated by the year labels. The contours show mean salinity on $\sigma o = 25.2$ kg m^{-3} computed from the WOA98 climatology (contour interval is 0.2; gray shade indicates outcropping of the isopycnal).

Griffies, S. M., A. Biastoch, C. Boning, F. Bryan, G. Danabasoglu, E. P. Chassignet, M. H. England, R. Gerdes, H. Haak, R. W. Hallberg, W. Hazeleger, J. Jungclaus, W. G. Large, G. Madec, A. Pirani, B. L. Samuels, M. Scheinert, A. S. Gupta, C. A. Severijns, H. L. Simmons, A. M. Treguier, M. Winton, S. Yeager, J. Yin, 2008: Coordinated Ocean-ice Reference Experiments (COREs). Ocean Modelling, in press.

Abstract: Coordinated Ocean-ice Reference Experiments (COREs) are presented as a tool to explore the behavior of global ocean-ice models under forcing from a common atmospheric dataset. We highlight issues arising when designing coupled global ocean and sea ice experiments, such as difficulties formulating a consistent forcing methodology and experimental protocol. Particular focus is given to the hydrological forcing, the details of which are key to realizing simulations with stable meridional overturning circulations.

The atmospheric forcing from Large and Yeager (2004) was developed for coupled ocean and sea ice models. We found it to be suitable for our purposes, even though its evaluation originally focused more on the ocean than on the sea-ice. Simulations with this atmospheric forcing are presented from seven global ocean-ice models using the CORE-I design (repeating annual cycle of atmospheric forcing for 500 years). These simulations test the hypothesis that global ocean-ice models run under the same atmospheric state produce qualitatively similar simulations. The validity of this hypothesis is shown to depend on the chosen diagnostic. The CORE simulations provide feedback to the fidelity of the atmospheric forcing, with identification of biases promoting avenues for model and/or forcing dataset development.

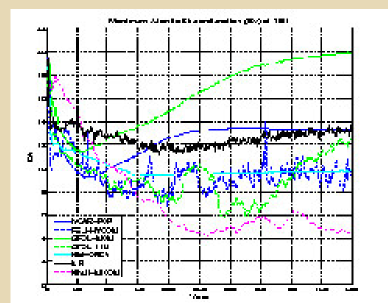


Figure 3.

High resolution figure

Figure caption: Time series of the annual mean Atlantic meridional overturning circulation (AMOC) index (vertical axis) for model years 1-500 (horizontal axis) in units of Sv from the seven participating models in this study. The index is computed as the maximum AMOC streamfunction at 45N in the region beneath the wind driven Ekman layer. Note that the GFDL-MOM simulation was extended to 600 years to verify that it was reaching a steady state for the overturning. An AMOC with realistic transport strength and structure is important for maintaining a realistic ocean climate. It is sometimes quite difficult to realize a stable overturning circulation, especially in ocean-ice models. The behavior of the ocean-ice models in this study indeed reflects on this sensitivity, with some models ``refusing'' to stabilize at a circulation reflecting observations (e.g., for North Atlantic Deep Water (NADW), about 15 Sv), whereas others appear to reach a stable value either with a very weak salinity restoring (NCAR-POP, FSU-HYCOM, and MPI), or stronger restoring (GFDL-MOM and Kiel-ORCA). It is notable that the two isopycnal models appear to have the most difficulty reaching a steady state, with the GFDL-HIM simulation showing large amplitude variations, whereas the KNMI-MICOM simulation settles into a very weak, nearly absent, overturning circulation in the NADW cell. We also note that the FSU-HYCOM simulation exhibits a nontrivial level of interannual variability relative to the simulations from NCAR-POP, GFDL-MOM, Kiel-ORCA, and MPI. Given the steady nature of the repeating annual forcing, the FSU-HYCOM variability is internally generated. The mechanism for variability has not been determined.

Support: NCAR is sponsored by the National Science Foundation.

Legg, S., B. Briegleb, Y. Chang, E. P. Chassignet, G. Danabasoglu, T. Ezer, A. L. Gordon, S. Griffies, R. Hallberg, L. Jackson, W. Large, T. M. Ozgokmen, H. Peters, J. Price, U. Riemenschneider, W. Wu, X. Xu, and J. Yang, 2008: Improving oceanic overflow representation in climate models: The Gravity Current Entrainment Climate Process Team. BAMS, in press.

Abstract: Oceanic overflows are bottom-trapped density currents originating in semi-enclosed basins such as the Nordic seas, or on continental shelves such as the Antarctic shelf. Overflows are the source of most of the abyssal waters, and so play an important role in the large-scale ocean circulation, forming a component of the sinking branch of the thermohaline circulation. As they descend the continental slope, overflows mix vigorously with the surrounding oceanic waters, changing their density and transport significantly. These mixing processes occur on spatial scales well below the resolution of ocean climate models, with the result that deep waters and deep western boundary currents are simulated poorly. The Gravity Current Entrainment Climate Process Team was established by US CLIVAR to accelerate the development and implementation of improved representations of overflows within large-scale climate models, bringing together climate model developers with those conducting observational, numerical and laboratory process studies of overflows. Here the organization of the Climate Process Team is described and a few of the successes and lessons learned during this collaboration are highlighted, with some emphasis on the well-observed Mediterranean overflow. The Climate Process Team has developed several different overflow parameterizations, which are examined in a hierarchy of ocean models, from comparatively well-resolved regional models to the largest-scale global climate models.

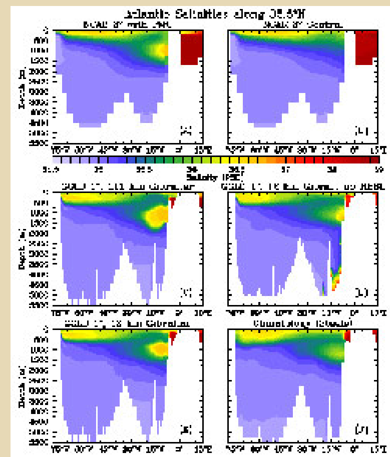


Figure 4.

High resolution figure

Figure caption: Salinity cross-sections in the Atlantic Ocean at the latitude of the Strait of Gibraltar. The top two panels compare the results after 30 years with the NCAR ocean-only simulations with the parameterized Mediterranean outflow (PMO) and a control experiment in which the Strait of Gibraltar is blocked. These simulations use the nominal 3-degree resolution version of the model. The improvements due to the PMO are obvious: The Mediterranean Salt Tongue is completely missing in the control integration, but clearly present in the PMO simulation. The next 3 panels show the results after 5 years in GFDL's 1-degree isopycnal coordinate model, GOLD, with Gibraltar open at 111 km (1 grid point) width, with Gibraltar restricted to 12 km but without the Hallberg Bottom Boundary Layer (HBBL) parameterization, and finally with both Turner-Ellison (TE) parameterization and HBBL parameterizations activated. With the inclusion of the HBBL parameterization in GOLD, the outflow plume now has a salinity, density, and volume much closer to that seen in observations. The final panel shows the salinity in the Steele ocean climatology; the data processing behind this climatology includes enough temporal and spatial smoothing that the "climatological" salinity of the plume is lower by several tenths of a PSU compared with raw profiles, but it should be reflective of the depth and extent of the plume.

Support: This study was supported by NSF Grant OCE-0336834 for the Climate Process Team on Gravity Current Entrainment. The computational resources were partially provided by the Scientific Computing Division of the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation.

Doney, S. C., S. Yeager, G. Danabasoglu, W. G. Large, and J. C. McWilliams, 2007: Mechanisms governing interannual variability of upper ocean temperature in a global ocean hindcast simulation. J. Phys. Oceanogr., 37, 1918-1938.

Abstract: The interannual variability in upper-ocean (0-400 m) temperature and governing mechanisms for the period 1968-97 are quantified from a global ocean hindcast simulation driven by atmospheric reanalysis and satellite data products. The unconstrained simulation exhibits considerable skill in replicating the observed interannual variability in vertically integrated heat content estimated from hydrographic data and monthly satellite sea surface temperature and sea surface height data. Globally, the most significant interannual variability modes arise from El Niño-Southern Oscillation and the Indian Ocean zonal mode, with substantial extension beyond the Tropics into the midlatitudes. In the well-stratified Tropics and subtropics, net annual heat storage variability is driven predominately by the convergence of the advective heat transport, mostly reflecting velocity anomalies times the mean temperature field. Vertical velocity variability is caused by remote wind forcing, and subsurface temperature anomalies are governed mostly by isopycnal displacements (heave). The dynamics at mid- to high latitudes are qualitatively different and vary regionally. Interannual temperature variability is more coherent with depth because of deep winter mixing and variations in western

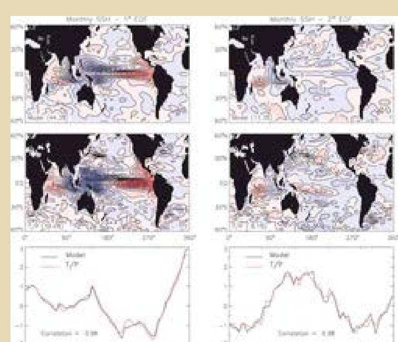


Figure 5.

boundary currents and the Antarctic Circumpolar Current that span the upper thermocline. Net annual heat storage variability is forced by a mixture of local air-sea heat fluxes and the convergence of the advective heat transport, the latter resulting from both velocity and temperature anomalies. Also, density-compensated temperature changes on isopycnal surfaces (spice) are quantitatively significant.

High resolution figure

Figure caption: Spatial maps of the (left) first and (right) second EOF (1993-97) for the (top) model and (middle) T/P monthly SSH anomalies after the removal of the average seasonal cycle for 1993-95. The contour interval is 1 cm, and the variances associated with each EOF are given as percentages of the respective total variances. (bottom) The time series of the TOPEX/Poseidon and model first-mode principal components.

CGD Research Catalog

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JOHN LATHAM

2008 Publications

Deierling, W., W. A. Petersen, J. Latham, S. Ellis, H. J. Christian, 2008: The relationship between lightning activity and ice fluxes in thunderstorms. J. Geophys. Res. - Atmos., 113, D15210, doi: 10.1029/2007JD009700, 2008.

Abstract

It is generally believed that a strong updraft in the mixed-phase region of thunderstorms is required to produce lightning. This is the region where the noninductive charging process is thought to generate most of the storm electrification. Analytic calculations and model results predict that the total lightning frequency is roughly proportional to the product of the downward mass flux of solid precipitation (graupel) and the upward mass flux of ice crystals. Thus far this flux hypothesis has only been tested in a very limited way. Herein we use dual-polarimetric and dual-Doppler radar observations in conjunction with total lightning data collected in Northern Alabama and also Colorado/Kansas during two field campaigns. These data are utilized to investigate total lightning activity as a function of precipitation and nonprecipitation ice masses and estimates of their fluxes for different storm types in different climate regions. A total of 11 storms, including single cell, multicell, and supercell storms, was analyzed in the two climatologically different regions. Time series of both precipitation and nonprecipitation ice mass estimates above the melting level show a good relationship with total lightning activity for the 11 storms analyzed (correlation coefficients exceed 0.9 and 0.8, respectively). Furthermore, the relationships are relatively invariant between the two climate regions. The correlations between total lightning and the associated product of ice mass fluxes are even higher. These observations provide strong support for the flux hypothesis.

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CGD Research Catalog

Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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CGD 2008 PROFILES IN SCIENCE: DR. PETER LAURITZEN

Summary of achievements

Peter Lauritzen

My science work is centered around numerical methods for dynamical cores, that is (roughly speaking), algorithms that approximate the solution to the adiabatic frictionless equations of motion for the atmosphere on resolved scales. For climate models and chemical transport models it is important that local and global balances dictated by physical principles are maintained in the numerical discretizations, for example, in the absence of sources and sinks mass should be conserved both locally and globally. At the same time the algorithm should be efficient on massively parallel supercomputers. Achieving a good balance between accuracy and efficiency is the overall goal of my research.

In an attempt to gather the global dynamical core research community I lead the 2008 NCAR ASP summer colloquium (http://www.cgd.ucar.edu/cms/pel/colloquium.html). The co-organizers were Dr. Christiane Jablonowski (University of Michigan), Dr. Mark Taylor (Sandia National Laboratories) and Dr. Ramachandran D. Nair (IMAGe, NCAR). The colloquium surveyed the latest developments in numerical methods for Atmospheric General Circulation Models and included an unprecedented student-run dynamical core inter-comparison project. The test case suite used for the inter-comparison was formulated by the colloquium organizers and 12 modeling groups (both US-based and international) participated in the colloquium by porting their model to NCAR computers, setting them up for the idealized test case suite formulated by the organizers and providing expert mentors to help the students run their models during the colloquium. The data produced by the students is currently being analyzed by the organizers. To facilitate the inter-comparison of the many models and test case data, meta-data describing the models and test case settings was put together and made available through the Earth System Grid portal by the Curator project (http://dycore.ucar.edu/browse/viewProject.htm?projectId=6ab23d33-b8c0-4317-b1ee-84ce236739b0). Also, the organizers are editing a book based on contributions from the colloquium lecturers that is going to be published in the Springer series Lecture Notes in Computational Science and Engineering.

Land, ocean and atmosphere components of coupled climate system models are often implemented on different spherical grids, individually designed to enhance the accuracy or capture features unique to their respective settings. Historically, the regular latitude-longitude (RLL) grid has been the predominant choice for global atmospheric models, but problems associated with the polar singularity persist, and hence this grid is not well-suited for highly scalable atmospheric models. Much interest in recent years has been instead directed towards the development of atmospheric solvers on more isotropic spherical grids. For example, the so-called cubed sphere grid, which divides the polar singularities among eight weaker singularities located at the corners of a cube, and is otherwise highly scalable on parallel architectures. For the land component, however, the RLL grid does not pose polar singularity problems as is the case for the atmosphere (with the current complexity of land models). Neither does the land model seem to be susceptible to scalability problems since most of the computation is in vertical columns rather than in the horizontal. Hence for the foreseeable future the RLL grid seems to be a viable and convenient grid for land model components. An intricate problem introduced by defining the model components on different spherical grids is that the exchange of information between the grids is non-trivial and requires a regridding algorithm. In a coupled climate system model it is paramount that the regridding process is not a spurious source or sink for first-order moment variables such as mass. Also, to prevent the generation of unphysical negative and/or large values, the regridding must also be shape-preserving/monotone for mixing-ratio related variables. Regridding with these constraints, conservation and monotonicity, is a non-trivial problem if higher than first order accuracy is desired. During the summer of 2008 I supervised the SIParCS (Summer Internships in Parallel Computational Science) student Paul Ullrich with whom I developed a new remapping algorithm to conservatively regrid scalars between the cubed-sphere and regular RLL grids.

Publications

Bennert Machenhauer, Eigil Kaas and Peter H. Lauritzen. 2008: Finite-Volume Methods in Meteorology. Chapter in Handbook of Numerical Analysis: Special Volume on Computational Methods for the Atmosphere and the Oceans: 120 pp., in press.

Abstract: Recent developments in finite volume methods provide the basis for new dynamical cores that conserve exactly integral invariants, globally as well as locally, and, especially, for the design of exact mass conserving tracer transport models. The new technologies are reviewed and the perspectives for the future are discussed.

Figure caption: The departure cell (shaded area) when using the scheme of (a)

RANCIC [1992], (b) MACHENHAUER and OLK [1998] scheme and (c) the cascade scheme of NAIR et al. [2002], respectively. The filled circles are the departure points, open circles the midpoints between the departure points, asterisks are the intermediate grid points which are used to define the intermediate cells in the cascade scheme (crosshatched area).

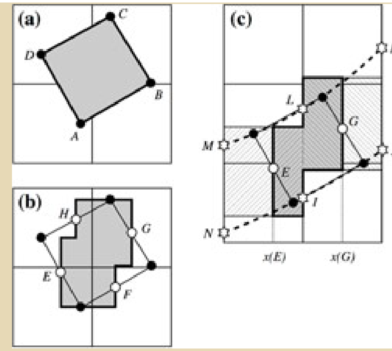


Figure 1.

High resolution figure

Peter H. Lauritzen, Eigil Kaas, Bennert Machenhauer and Karina Lindberg. 2008: A Mass-Conservative Version of the Semi-Implicit Semi-Lagrangian HIRLAM. Quart. J. Roy. Meteor. Soc.: in press.

Abstract: A mass-conservative version of the semi-implicit semi-Lagrangian High Resolution Limited Area Model (HIRLAM) is presented. The explicit continuity equation is solved with the so-called cell-integrated semi-Langrangian (CISL) method. To allow for the long time steps the CISL scheme is coupled with a recently developed semi-implicit time-stepping scheme that involves the same non-complicated elliptic equation as in HIRLAM. Contrarily to the tradition semi-Lagrangian method the trajectories are backward in the horizontal and forward in the vertical, that is, cells moving witht he flow depart from model layers and arrive in a regular column, and their vertical displacements are computed from continuity of mass and hydrostatic balance in the arrival column. This involves just two-dimensional upstream integrals and allows for a Lagrangian discretization of the energy conversion term in the thermodynamic equation.

Preliminary validation of the new model version is performed using an idealized baroclinic wave test case. The accuracy of the new formulation of HIRLAM is comparable to the reference version though it is slightly more diffusive. A main finding is that the new discretization of the energy conversion term leads to more accurate simulations compared to the traditional 'Eulerian' treatment.

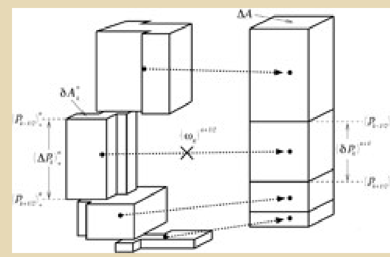


Figure 2.

High resolution figure

Figure caption: Schematic illustration of the departure and arrival cells, which make up the deformed column on the left and the regular column on the right, respectively, (in the special case where all cells in each model level have the same pressure thickness). The cells move with vertical walls and the horizontal extension is a polygon. In this Figure the polygon is as in the two-dimensional CISL scheme of Nair and Machenhauer (2002), but the general idea applies to all CISL schemes. $\Delta p_k{}^{n}{}_{*}$ is the integral mean value of the pressure-layer thickness over the irregular departure cell area $\delta A^n{}_k$, and $\delta p_k{}^{n+1}$ and is the mean value of the pressure-layer thickness over the regular arrival cell area ΔA. The average pressure at the bottom of the arrival cell is denoted $p_{k+1}{}^{n+1}$ and is given by the weight of the air above it (see (29)).

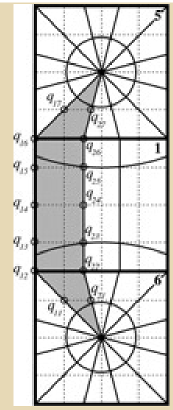
Peter H. Lauritzen and Ramachandran D. Nair, 2008: Monotone and conservative Cascade Remapping between Spherical grids (CaRS): Regular latitude-longitude and cubed-sphere grids Mon. Wea. Rev.: Vol. 136, No. 4, pp. 1416-1432.

Abstract: A high-order monotone and conservative cascade remapping algorithm between spherical grids (CaRS) is developed. This algorithm is specifically designed to remap between the cubed-sphere and regular latitude-longitude grids. The remapping approach is based on the conservative cascade method in which a two-dimensional remapping problem is split into two one-dimensional problems. This allows for easy implementation of high-order subgrid-cell reconstructions as well as the application of advanced monotone filters. The accuracy of CaRS is assessed by remapping analytic fields from the regular latitude-longitude grid to the cubed-sphere grid. In terms of standard error measures, CaRS is found to be competitive relative to an existing algorithm when regridding from a fine to a coarse grid and more accurate when regridding from a coarse to a fine grid.

Figure 3.

High resolution figure

Figure caption: A schematic illustration of the intermediate grid given the cubed-sphere grid (dashed lines) and regular latitude-longitude grid (thick solid lines) shown in local Cartesian coordinates centered on the surface of the cubed-sphere



faces (only one equatorial face is shown). The cubed-sphere face number is in the upper-right corner of each panel. Consider the first, i = 1, longitudinal belt (shaded area). The open circles encircle the intersections between the cubed-sphere latitudes and the regular longitudes for i = 1, 2. The intersections are denoted q_{il} where the subscripts i and l refer to the longitudinal belt and cubed-sphere latitude, respectively. The accumulated areas of the intermediate cells Δil along the longitudinal belt i are the areas of the spherical triangles with the South Pole, q_{il}, and $q_{(i+1)l}$ as edges.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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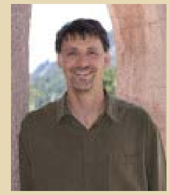
CGD 2008 PROFILES IN SCIENCE: DR. DAVID LAWRENCE

Summary of achievements



David Lawrence

Dave Lawrence continues to study climate feedbacks in the terrestrial high-latitude system. In collaboration with University colleagues, he has worked to improve permafrost dynamics in the Community Land Model (CLM) and has applied the new model to study the sensitivity of near-surface permafrost degradation to model parameterizations and to evaluate how changes in snow properties can affect soil temperature evolution. He has also used the model to study interactions between rapid sea ice loss, terrestrial warming, and permafrost degradation.

Dave also continues to serve as co-chair of the CCSM Land Model Working Group (LMWG) and in this role has helped coordinate the development of CLM4. He has led the Community Snow project, incorporating and evaluating an array of model improvements suggested by a number of LMWG members. In recognition of the cooperative work in producing CLM3.5, the LMWG was awarded the CCSM Distinguished Achievement Award at the 13th annual CCSM Workshop.

Publications

Lawrence, D. M., A. G. Slater, R. A. Tomas, M. M. Holland, and C. Deser, 2008: Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. Geophys. Res. Lett., 35, L11506, doi:10.1029/2008GL033985.

Abstract: Coupled climate models and recent observational evidence suggest that Arctic sea ice may undergo abrupt periods of loss during the next fifty years. Here, we evaluate how rapid sea ice loss affects terrestrial Arctic climate and ground thermal state in the Community Climate System Model. We find that simulated western Arctic land warming trends during rapid sea ice loss are 3.5 times greater than secular 21st century climate-change trends. The accelerated warming signal penetrates up to 1500 km inland and is apparent throughout most of the year, peaking in autumn. Idealized experiments using the Community Land Model, with improved permafrost dynamics, indicate that an accelerated warming period substantially increases ground heat accumulation. Enhanced heat accumulation leads to rapid degradation of warm permafrost and may increase the vulnerability of colder permafrost to degradation under continued warming. Taken together, these results imply a link between rapid sea ice loss and permafrost health.

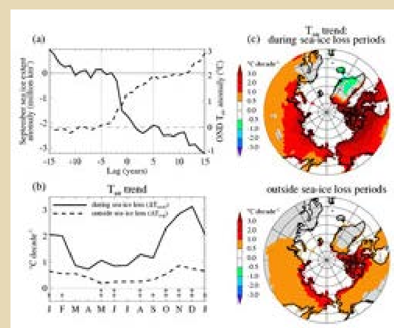


Figure 1.

High resolution figure

Figure caption: (a) Composite anomaly time series of September sea ice extent (solid line) and OND T_{air} (dashed line) over Arctic land area (65°-80°N, 60°-300°E). Composites are formed by nine 31-yr anomaly time series. Each of the nine time series are centered about the mid-point of a CCSM3 rapid sea ice loss event (lag 0 years) and are anomalies from the lag -10 to -5 year mean. (b) Average monthly Arctic land air temperature trends during rapid sea ice loss periods and outside sea ice loss periods. Trend is statistically significant at the 90% (*) and 95% (**) levels. (c) Maps of air temperature trends for OND during and outside abrupt sea ice loss periods.

Support: This research was supported by the Office of Science (BER), U. S. DOE, Cooperative Agreement No. DE-FC02-97ER62402 and NSF grants ARC-0229769 and ARC-0531040.

Lawrence, D. M., A. G. Slater, V. E. Romanovsky, and D. J. Nicolsky, 2008: Sensitivity of a model projection of near-surface permafrost degradation to soil column depth and representation of soil organic matter. J. Geophys. Res., 113, F02011, doi:10.1029/2007JF000883.

Abstract: The sensitivity of a global land-surface model projection of near-surface permafrost degradation is assessed with respect to explicit accounting of the thermal and hydrologic properties of soil organic matter and to a deepening of the soil column from 3.5 to 50 or more m. Together these modifications result in substantial improvements in the simulation of near-surface soil temperature in the Community Land Model (CLM). When forced off-line with archived data from a fully coupled Community Climate System Model (CCSM3) simulation of 20th

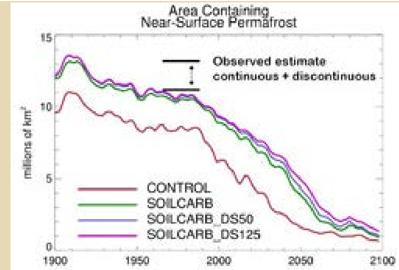


Figure 2.

High resolution figure

century climate, the revised version of CLM produces a near-surface permafrost extent of 10.7 × 10^6 km^2 (north of 45°N). This extent represents an improvement over the 8.5 × 10^6 km^2 simulated in the standard model and compares reasonably with observed estimates for continuous and discontinuous permafrost area (11.2-13.5 × 10^6 km^2). The total extent in the new model remains lower than observed because of biases in CCSM3 air temperature and/or snow depth. The rate of near-surface permafrost degradation, in response to strong simulated Arctic warming (~ +7.5°C over Arctic land from 1900 to 2100, A1B greenhouse gas emissions scenario), is slower inthe improved version of CLM, particularly during the early 21st century (81,000 versus 111,000 km^2 a^{-1}, where a is years). Even at the depressed rate, however, the warming is enough to drive near-surface permafrost extent sharply down by 2100. Experiments with a deep soil column exhibit a larger increase in ground heat flux than those without because of stronger near-surface vertical soil temperature gradients. This appears to lessen the sensitivity of soil temperature change to model soil depth.

Figure caption: Time series of total area containing near-surface permafrost (north of 45°N and excluding ground underneath glaciers) for CONTROL, SOILCARB (with organic soil), SOILCARB_DS50 (with organic soil and 50m-deep soil column) and SOILCARB_DS125 (with organic soil and 125m-deep soil column).

Support: This research was supported by the Office of Science (BER), U. S. Department of Energy, Cooperative Agreement No. DE-FC02-97ER62402. Additional support comes from the National Science Foundation grants OPP-0229769, OPP-0229651, ARC-0632400, ARC-0520578, ARC-0612533, and IARC-NSF CA: Project 3.1 Permafrost Research and NASA NNG04GJ39G and NNG06GH48G.

Stockli, R., D. M. Lawrence, G. Y. Niu, K. W. Oleson, P. E. Thornton, Z. L. Yang, G. B. Bonan, A. S. Denning, and S. W. Running. 2008. Use of FLUXNET in the community land model development. Journal of Geophysical Research-Biogeosciences, doi:10.1029/2007JG000562.

Abstract

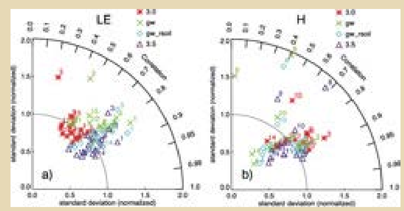


Figure 3.

High resolution figure

The Community Land Model version 3 (CLM3.0) simulates land-atmosphere exchanges in response to climatic forcings. CLM3.0 has known biases in the surface energy partitioning as a result of deficiencies in its hydrological and biophysical parameterizations. Such models, however, need to be robust for multidecadal global climate simulations. FLUXNET now provides an extensive data source of carbon, water and energy exchanges for investigating land processes, and it encompasses a global range of ecosystem-climate interactions. Data from 15 FLUXNET sites are used to identify and improve model deficiencies. Including a prognostic aquifer, a bare soil evaporation resistance formulation and numerous other changes in the model result in a significantly improved soil hydrology and energy partitioning. Terrestrial water storage increased by up to 300 mm in warm climates and decreased in cold climates. Nitrogen control of photosynthesis is revealed as another missing process in the model. These improvements increase the correlation coefficient of hourly and monthly latent heat fluxes from a range of 0.5-0.6 to the range of 0.7-0.9. RMSE of the simulated sensible heat fluxes decrease by 20-50%. Primary production is overestimated during the wet season in mediterranean and tropical ecosystems. This might be related to missing carbon-nitrogen dynamics as well as to site-specific parameters. The new model (CLM3.5) with an improved terrestrial water cycle should lead to more realistic land-atmosphere exchanges in coupled simulations. FLUXNET is found to be a valuable tool to develop and validate land surface models prior to their application in computationally expensive global simulations.

Figure caption: Performance of four model versions at 15 FLUXNET towers (numbers 1-15). Statistics in the Taylor diagram are derived from hourly simulated and observed LE and H fluxes. Legend: CLM3.0: red asterisks; CLMgw: green crosses; CLMgw_rsoil: cyan diamonds; CLM3.5: violet triangles. In CLM3.0 H is off-scale for the two tropical sites 8 and 9 (and therefore not shown).

Support: We acknowledge the NASA Energy and Water Cycle Study (NEWS) grant NNG06CG42G as the main funding source of this study.

Oleson, K. W., et al., 2008: Improvements to the Community Land Model and their impact on the hydrological cycle. J. Geophys. Res., 113, G01021, doi:10.1029/2007JG000563.

Abstract

The Community Land Model version 3 (CLM3) is the land component of the

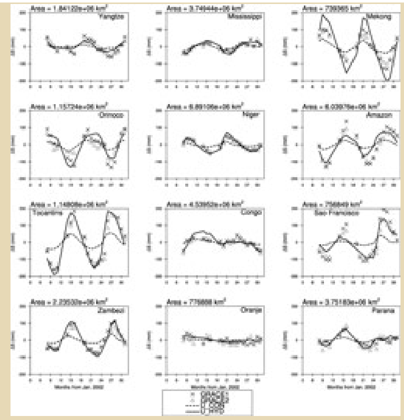


Figure 4.

High resolution figure

Community Climate System Model (CCSM). CLM3 has energy and water biases resulting from deficiencies in some of its canopy and soil parameterizations related to hydrological processes. Recent research by the community that utilizes CLM3 and the family of CCSM models has indicated several promising approaches to alleviating these biases. This paper describes the implementation of a selected set of these parameterizations and their effects on the simulated hydrological cycle. The modifications consist of surface data sets based on Moderate Resolution Imaging Spectroradiometer products, new parameterizations for canopy integration, canopy interception, frozen soil, soil water availability, and soil evaporation, a TOPMODEL-based model for surface and subsurface runoff, a groundwater model for determining water table depth, and the introduction of a factor to simulate nitrogen limitation on plant productivity. The results from a set of offline simulations were compared with observed data for runoff, river discharge, soil moisture, and total water storage to assess the performance of the new model (referred to as CLM3.5). CLM3.5 exhibits significant improvements in its partitioning of global evapotranspiration (ET) which result in wetter soils, less plant water stress, increased transpiration and photosynthesis, and an improved annual cycle of total water storage. Phase and amplitude of the runoff annual cycle is generally improved. Dramatic improvements in vegetation biogeography result when CLM3.5 is coupled to a dynamic global vegetation model. Lower than observed soil moisture variability in the rooting zone is noted as a remaining deficiency.

Figure caption: Total water storage anomalies (mm) for U_HYD (CLM3.5) and U_CON (CLM3.0) compared to two sources of GRACE data (GRACE1 [Seo and Wilson, 2005] and GRACE2 [Chen et al., 2005]). Model total water storage anomalies are calculated from the sum of snow water, canopy water, total column soil water, and aquifer water. GRACE data were interpolated to the model resolution.

Support: This work was supported by the NCAR Water Cycles Across Scales, Biogeosciences, and Weather and Climate Impacts Assessment Science Initiatives.

Lawrence, D. M. and A. G. Slater, 2008: Incorporating organic soil into a global climate model. Climate Dynamics, doi:10.1007/s00382-007-0278-1.

Abstract

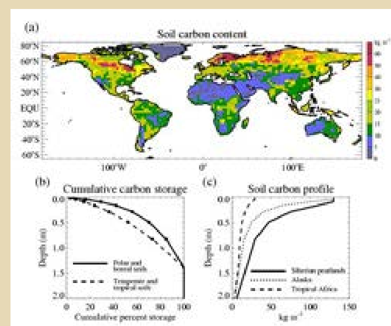


Figure 5.

High resolution figure

Organic matter significantly alters a soil's thermal and hydraulic properties but is not typically included in land-surface schemes used in global climate models. This omission has consequences for ground thermal and moisture regimes, particularly in the high-latitudes where soil carbon content is generally high. Global soil carbon data is used to build a geographically distributed, profiled soil carbon density dataset for the Community Land Model (CLM). CLM parameterizations for soil thermal and hydraulic properties are modified to accommodate both mineral and organic soil matter. Offline simulations including organic soil are characterized by cooler annual mean soil temperatures (up to ~2.5°C cooler for regions of high soil carbon content). Cooling is strong in summer due to modulation of early and mid-summer soil heat flux. Winter temperatures are slightly warmer as organic soils do not cool as efficiently during fall and winter. High porosity and hydraulic conductivity of organic soil leads to a wetter soil column but with comparatively low surface layer saturation levels and correspondingly low soil evaporation. When CLM is coupled to the Community Atmosphere Model, the reduced latent heat flux drives deeper boundary layers, associated reductions in low cloud fraction, and warmer summer air temperatures in the Arctic. Lastly, the insulative properties of organic soil reduce interannual soil temperature variability, but only marginally. This result suggests that, although the mean soil temperature cooling will delay the simulated date at which frozen soil begins to thaw, organic matter may provide only limited insulation from surface warming.

Figure caption: (a) Global Soil Data Task (2000) soil carbon content regridded onto CLM 2.8° x 2.8° grid. (b) Cumulative carbon storage with depth for the two major classes of soils identified in Zinke et al. (1986). These profiles are used to determine vertical soil carbon distribution in new CLM soil carbon dataset. (c) Sample derived soil carbon profiles for Siberian peatlands (60°-70°N, 70°-80°E), Alaska (60°-70°N, 140°-160°W), and Tropical Africa (Eq-10°N, 25°-35°E). Note that depth refers to the depth of the bottom boundary of each individual soil layer (solid circles in (b)).

Support: Funding support is provided by U.S. Department of Energy, Office of Biological and Environmental Research, cooperative agreement no. DE-FC03-97ER62402/A010 and National Science Foundation grants OPP-0229769 and OPP-0229651 and NASA NNG04GJ39G.

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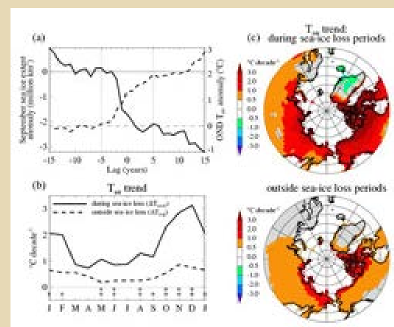
Research Focus FY08:

Dave Lawrence continues to study climate feedbacks in the terrestrial high-latitude system. In collaboration with University colleagues, he has worked to improve permafrost dynamics in the Community Land Model (CLM) and has applied the new model to study the sensitivity of near-surface permafrost degradation to model parameterizations and to evaluate how changes in snow properties can affect soil temperature evolution. He has also used the model to study interactions between rapid sea ice loss, terrestrial warming, and permafrost degradation.

Dave also continues to serve as co-chair of the CCSM Land Model Working Group (LMWG) and in this role has helped coordinate the development of CLM4. He has led the Community Snow project, incorporating and evaluating an array of model improvements suggested by a number of LMWG members. In recognition of the cooperative work in producing CLM3.5, the LMWG was awarded the CCSM Distinguished Achievement Award at the 13th annual CCSM Workshop.



(a) Composite anomaly time series of September sea ice extent (solid line) and OND Tair (dashed line) over Arctic land area (65°-80°N, 60°-300°E). Composites are formed by nine 31-yr anomaly time series. Each of the nine time series are centered about the mid-point of a CCSM3 rapid sea ice loss event (lag 0 years) and are anomalies from the lag -10 to -5 year mean. (b) Average monthly Arctic land air temperature trends during rapid sea ice loss periods and outside sea ice loss periods. Trend is statistically significant at the 90% (*) and 95% (**) levels. (c) Maps of air temperature trends for OND during and outside abrupt sea ice loss periods. - Lawrence, D. M., A. G. Slater, R. A. Tomas, M. M. Holland, and C. Deser, 2008: Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. Geophys. Res. Lett., 35, L11506, doi:10.1029/2008GL033985.

High resolution figure

Publications FY08 (abstracts):

Stockli, R., D. M. Lawrence, G.-Y. Niu, K. W. Oleson, P. Thornton, Z.-L. Yang, G. Bonan, A. Denning, S. Running, 2008: Use of FLUXNET in the community land model development. *J. Geophys. Res.*, **113**, G01025, doi: 10.1029/2007JG000562.

Oleson, K. W., G.-Y. Niu, Z.-L. Yang, D. M. Lawrence, P. Thornton, P. Lawrence, R. Stockli, R. Dickinson, G. Bonan, S. Levis, A. Dai, T. Qian, 2008: Improvements to the community land model and their impact on the hydrological cycle. *J. Geophys. Res.*, **113**, G01021, doi: 10.1029/2007JG000563.

Lawrence, D. M., A. Slater, V. Romanovsky, D. Nicolsky, 2008: The sensitivity of a model projection of near-surface permafrost degradation to soil column depth and inclusion of soil organic matter. *J. Geophys. Res.*, **113**, F02011, doi: 10.1029/2007JF000883.

Lawrence, D. M., A. G. Slater, R. Tomas, M. Holland, C. Deser, 2008: Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. *Geophys. Res. Lett.*, **35**, L11506, doi: 10.1029/2008GL033985.

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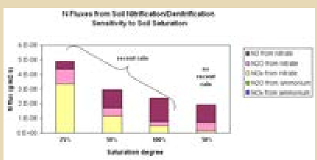
Research Focus FY08:



Nitrogen fluxes from soil nitrification/ denitrification. Sensitivity to soil saturation - High resolution figure

Julia Lee-Taylor is implementing a detailed empirically-based parameterization of soil nitrogen cycling in the CCSM. The action of nitrifying and denitrifying bacteria results in release to the atmosphere of nitrogen gases N2, N2O and NOx. The model includes factors such as rainfall timing, soil moisture regime and temperature, which influence the rates of nitrification and denitrification and, ultimately, the quantities and proportions of the evolved gases. The code is still in the troubleshooting stage. They plan to use the working model to assess the effects of soil nitrogen cycling on tropospheric oxidation chemistry and on soil carbon cycling.

Community Service FY08:

- Science Fair Judge, K-12, Lafayette, CO
- Girl Scout Day at NCAR, K-12, Boulder, CO

Scientific Talks FY08:

- Estimation of UV/Visible Absorption by Secondary Organic Aerosols from the Spectra of Condensable Gas Phase Precursors (San Francisco, CA, December 2007)

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MARGARET LEMONE

2008 Publications

Trier, S. B., F. Chen, K. W. Manning, M. A. Lemone, C. A. Davis, 2008: Sensitivity of the PBL and precipitation in 12-day simulations of warm-season convection using different land surface models and soil wetness conditions. Mon. Wea. Rev., 136, 2321-2343, doi: 10.1175/2007MWR2289.1.

ABSTRACT

A coupled land surface–atmospheric model that permits grid-resolved deep convection is used to examine linkages between land surface conditions, the planetary boundary layer (PBL), and precipitation during a 12-day warm-season period over the central United States. The period of study (9–21 June 2002) coincided with an extensive dry soil moisture anomaly over the western United States and adjacent high plains and wetter-than-normal soil conditions over parts of the Midwest. A range of possible atmospheric responses to soil wetness is diagnosed from a set of simulations that use land surface models (LSMs) of varying sophistication and initial land surface conditions of varying resolution and specificity to the period of study.

Results suggest that the choice of LSM [Noah or the less sophisticated simple slab soil model (SLAB)] significantly influences the diurnal cycle of near-surface potential temperature and water vapor mixing ratio. The initial soil wetness also has a major impact on these thermodynamic variables, particularly during and immediately following the most intense phase of daytime surface heating. The soil wetness influences the daytime PBL evolution through both local and upstream surface evaporation and sensible heat fluxes, and through differences in the mesoscale vertical circulation that develops in response to horizontal gradients of the latter. Resulting differences in late afternoon PBL moist static energy and stability near the PBL top are associated with differences in subsequent late afternoon and evening precipitation in locations where the initial soil wetness differs among simulations. In contrast to the initial soil wetness, soil moisture evolution has negligible effects on the mean regional-scale thermodynamic conditions and precipitation during the 12-day period.

Strassberg, D., M. A. LeMone, T. T. Warner, J. G. Alfieri, 2008: Comparison of observed 10-m wind speeds to those based on Monin-Obukhov similarity theory using IHOP_2002 aircraft and surface data. Mon. Wea. Rev., 136, 964-972, doi: 10.1175/2007MWR2203.1.

ABSTRACT

Comparisons of 10-m above ground level (AGL) wind speeds from numerical weather prediction (NWP) models to point observations consistently show that model daytime wind speeds are slow compared to observations, even after improving model physics and going to smaller grid spacing. Previous authors have attributed the discrepancy to differences between the areas represented by model and observations, and the small surface roughness upstream of wind vanes compared with the corresponding model grid value. Using daytime fair-weather data from the May–June 2002 International H2O Experiment (IHOP_2002), the effect of wind-vane exposure is explored by comparing observed 10-m winds from nine surface-flux towers in well-exposed locations to modeled 10-m winds found by applying Monin–Obukhov (MO) similarity for unstable conditions to flight-track-averaged data collected by the University of Wyoming King Air over flat to rolling terrain with occasional trees and buildings. In the calculations, King Air winds and fluxes are supplemented with thermodynamic means and fluxes from the surface-flux towers. After exercising considerable care in characterizing and reducing biases in aircraft winds and fluxes, the authors found that MO-based surface winds averaged 0.5–0.7 ± 0.2 m s-1 less than those measured—about the same as the smaller reported discrepancies between NWP models and observed winds.

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Director's Message
Table of Contents
Strategic Goals: Science, Facilities & Technology
Research Catalog

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Research Focus FY08:

Congratulations Peggy! She is president-elect in January 2009 and the new American Meteorological Society (AMS) President the following year.

My current research interests involve the atmospheric boundary layer and its interaction with the surface and clouds; and the structure of deep precipitating convection and its effect on momentum. In my early career, I combined numerical models and observations to study the structure of and transports through the fair weather planetary boundary layer and its interaction with clouds.

GLOBE Chief Scientist's Blog by Dr. Peggy LeMone

Cloud Image Gallery by Dr. Peggy LeMone

Publications FY08 (abstracts):

Alfieri, J., X. Xiao, D. Niyogi, R. A. Pielke, Sr., F. Chen, M. A. LeMone, 2008: Satellite-based modeling of transpiration and evaporation of grasslands and croplands in the Southern Great Plains, USA. *Global Planetary Changes*. (In Press)

Gorska, M., J. Vila-Guarau de Arellano, M. A. LeMone, C. van Heervaarden, 2008: Horizontal variability of heat, moisture, and carbon dioxide vertical flux profiles. *Mon. Wea. Rev.*. (In Press)

Miao, S., F. Chen, M. A. LeMone, M. Tewari, Q. Li, Y. Wang, 2008: An observational and modeling study of characteristics of urban heat island and boundary layer structures in Beijing. *J. Appl. Meteor. Climat.*. (In Press)

Carbone, R. E., J. Block, G. R. Carmichael, F. H. Carr, V. C. Chandrasekar, E. Gruntfest, R. M. Hoff, W. F. Krajewski, M. A. LeMone, T. W. Schlatter, E. S. Takle, J. Titlow, S. E. Boselly, J. F. Purdom, 2009: Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs. *Natl. Research Council of the Natl. Acad. Sci., BASC*, Richard E. Carbone, Ed., National Academies Press. (In Press)

Alfieri, J., D. Niyogi, P. Blanken, F. Chen, M. A. LeMone, K. Mitchell, M. Ek, A. Kumar, 2008: Estimation of the minimum canopy resistance for croplands and grasslands using data from the 2002 International H20 Project. *Mon. Wea. Rev.*. (In Press)

LeMone, M. A., M. Tewari, F. Chen, J. G. Alfieri, D. Niyogi, 2008: Evaluation of the Noah land-surface model using data from a fair-weather IHOP_2002 day with heterogeneous surface fluxes. *Mon. Wea. Rev.*. (In Press)

Trier, S. B., F. Chen, K. W. Manning, M. A. Lemone, C. A. Davis, 2008: Sensitivity of the PBL and precipitation in 12-day simulations of warm-season convection using different land surface models and soil wetness conditions. *Mon. Wea. Rev.*, **136**, 2321-2343, doi: 10.1175/2007MWR2289.1.

Strassberg, D., M. A. LeMone, T. T. Warner, J. G. Alfieri, 2008: Comparison of observed 10-m wind speeds to those based on Monin-Obukhov similarity theory using IHOP_2002 aircraft and surface data. *Mon. Wea. Rev.*, **136**, 964-972, doi: 10.1175/2007MWR2203.1.

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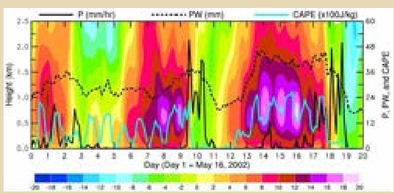
Research Focus FY08:



Time series of 3-hourly profiles of the meriodinal wind (m/s, color) and 3-hourly precipitation (mm/hr, black solid line), precipitable water (mm, dashed line), and total CAPE (x100 J/kg, blue line) from May 16 (Day 1) to June 14 (Day 20) in 2002. The wind profiles, PW, and CAPE are averages of radiosonde data at the five ARM stations, and the precipitation are mean values over the ARM site area.

High resolution figure

Understanding Warm-season Precipitation Diurnal Cycle over the Central U.S.

In contrast to late afternoon peaks over most land areas, warm-season precipitation over the central U. S. Great Plains (GP) is characterized by a maximum from midnight to early morning. The exact underlying processes leading to this nocturnal precipitation maximum (NPM) are not fully understood. Here we investigate the physical processes that suppress afternoon moist convection and those that lead to the NPM using data collected during the International H2O Project (IHOP) (May-June 2002) and the North American Regional Reanalysis (NARR). The diurnal cycles of convective available potential energy (CAPE) and convective inhibition (CIN) calculated from 3-hourly radiosonde data show that over the GP favorable conditions for convective initiation occur in the afternoon with maximum surface CAPE and minimum surface CIN. However, in the afternoon large-scale subsidence also exists in the free troposphere that suppresses the development of deep convection. In the early morning during rainy days over the GP, there exists a secondary CAPE maximum (CIN minimum) at a height of ~500m. Combined with nighttime large-scale upward motion in the free troposphere, this elevated instability produces deep convection and precipitation maximum at night over the GP.

Climate applications of a global, 2-hourly atmospheric precipitable water dataset from IGS ground-based GPS measurements.

A global, 2-hourly atmospheric precipitable water (PW) dataset is produced from ground-based GPS measurements of zenith tropospheric delay (ZTD) using the International GNSS (Global Navigation Satellite Systems) Service (IGS) tropospheric products (~80-370 stations, 1997-2006) and U.S. SuomiNet product (169 stations, 2003-2006). The climate applications of the GPS PW dataset are highlighted in this study. Firstly, the GPS PW dataset is used as a reference to validate radiosonde and atmospheric reanalysis data. Three types of systematic errors in global radiosonde PW data are quantified based on comparisons with the GPS PW data, including measurement biases for each of the fourteen radiosonde types along with their characteristics, long-term temporal inhomogeneity and diurnal sampling errors of once and twice daily radiosonde data. The comparisons between the GPS PW data and three reanalysis products, namely the NCEP-NCAR (NNR), ECMWF 40-year (ERA-40) and Japanese reanalyses (JRA), show that the elevation difference between the reanalysis grid box and the GPS station is the primary cause of the PW difference. Secondly, the PW diurnal variations are documented using the 2-hourly GPS PW dataset. The PW diurnal cycle has an annual-mean, peak-to-peak amplitude of 0.66, 0.53 and 1.11 mm for the globe, Northern Hemisphere, and Southern Hemisphere, respectively, with the time of the peak ranging from noon to late evening depending on the season and region. Preliminary analyses suggest that the PW diurnal cycle in Europe is poorly represented in the NNR and JRA products. Several recommendations are made for future improvements of IGS products for climate applications.

Community Service FY08:

- 2008-present: Member of NSF Facilities Assessment Editorial Board
- 2008-present: Co-conveners of "GNSS/GPS Observation Systems and their Utility in Climate and Meteorological Applications" session for AGU fall meeting in 2008
- 2008: Session co-chair of IGS Analysis Center Workshop 2008, 2-6 June 2008, Miami Beach, FL
- 2007: Co-chair of the surface-based remote sensing subcommittee for the NSF facilities assessment
- 2007: Co-chair of the "Data quality control and quality assurance" breakout session of NSF Facilities Users' Workshop, 24-26 September 2007, Boulder, CO
- 2007-2008: Member of the organizing committee for "Meeting on implementation of GCOS Reference Upper Air Network (GRUAN)", 25-28 February 2008, Lindenberg, Germany
- 2006-present: Member of the U.S. GCOS Reference Upper Air Network (GRUAN) team
- 2006-2008: Member of the surface-based remote sensing subcommittee for the NSF facilities assessment
- 2006-present: Member of WMO/GCOS working group on atmospheric reference observations of AOPC
- 2005-present: Editor for Journal of Atmospheric and Oceanic Technology

Scientific Talks FY08:

- Vertical air motion from T-REX dropsonde and radiosonde data, NCAR (2008)
- Climate applications of a global, 2-hourly atmospheric precipitable water dataset from IGS tropospheric products, NOAA (2008)
- Understanding warm-season precipitation diurnal cycle over the central U.S., Central Weather Bureau of Taiwan (2008)
- Validations of atmospheric precipitable water in three reanalysis products using ground-based GPS measurements , Tokyo University (2008)
- A global, 2-hourly atmospheric precipitable water dataset from ground-based GPS measurements and its scientific applications, Institute of Atmospheric Physics, Chinese Academy of Sciences, Invited. 2007
- Atmospheric Sounding: Basics, Research and Development, for the course "Measurements and Instruments", Invited. 2007
- Potential Unique Contributions of GPS RO (COSMIC) to Global Climate Observing System (GCOS), COSMIC 2006 retreat, Invited. 2007

Publications FY08:

Wang, J., A. Dai, 2008: Understanding warm-season precipitation diurnal cycle over the central U.S.. Geophys. Res. Lett.. (Revising)

Wang, J., J. Bian, W. O. Brown, H. Cole, V. Grubisic, and K. Young, 2008: Vertical air motion from T-REX radiosonde and dropsonde data. J. Atmos. Oceanic Technol., revising.

Ciesielski P. E., R. H. Johnson, and J. Wang, 2008: Correction of humidity biases in Vaisala RS80-H sondes during NAME. J. Atmos. Oceanic Technol., submitted.

Seidel, D.J., F.H. Berger, H.J. Diamond, J. Dykema, D. Goodrich, F. Immler, W. Murray, T. Peterson, D. Sisterson, M. Sommer, P. Thorne, H. Vömel, J. Wang, 2008: Reference Upper-Air Observations for Climate: Rationale, Progress and Plans. Bull. Amer. Meteorol. Soc., revised.

Wang, J., L. Zhang, 2008: Climate applications of a global, 2-hourly atmospheric precipitable water dataset from IGS ground-based GPS measurements. J. Geodesy. (In Press)Wang, J., L. Zhang, 2008: Systematic errors in global radiosonde precipitable water data from comparisons with ground-based GPS measurements. *J. Climate*, **21(10)**, 2218-2238, doi: 10.1175/2007JCLI1944.1.

Wang, J., L. Zhang, 2008: Validation of Atmospheric Precipitable Water in Three Reanalysis Products using Ground-based GPS Measurements. *3rd WCRP Intl. Conf. Reanalysis*, Tokyo, JP, JMA, NSF, NASA.

Gregory S. Poulos, Junhong Wang, Dean K. Lauritsen, and Harold L. Cole, 2007: A note on the use of targeted dropwindsondes in complex terrain. J. Atmos. Oceanic Technol, 24, 1489-1494. 10.1175/JTECH2065.1.

Wang, J., L. Zhang, A. Dai, T. VanHove, J. Van Baelen, 2007: A near-global, 2-hourly data set of atmospheric precipitable water from ground-based GPS measurements. *J. Geophys. Res.*, **112**, D11107, doi: 10.1029/2006JD007529.

Junhong Wang Research Catalog

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WEI WANG

2008 Publications

Weisman, M. L., C. A. Davis, W. Wang, K. Manning, 2008: Experiences with 0-36h explicit convective forecasts with the WRF-ARW model. Wea. Forecasting, 23, 407-437, doi: 10.1175/2007WAF2007005.1.

ABSTRACT

Herein, a summary of the authors’ experiences with 36-h real-time explicit (4 km) convective forecasts with the Advanced Research Weather Research and Forecasting Model (WRF-ARW) during the 2003–05 spring and summer seasons is presented. These forecasts are compared to guidance obtained from the 12-km operational Eta Model, which employed convective parameterization (e.g., Betts–Miller–Janjic). The results suggest significant value added for the high-resolution forecasts in representing the convective system mode (e.g., for squall lines, bow echoes, mesoscale convective vortices) as well as in representing the diurnal convective cycle. However, no improvement could be documented in the overall guidance as to the timing and location of significant convective outbreaks. Perhaps the most notable result is the overall strong correspondence between the Eta and WRF-ARW guidance, for both good and bad forecasts, suggesting the overriding influence of larger scales of forcing on convective development in the 24–36-h time frame. Sensitivities to PBL, land surface, microphysics, and resolution failed to account for the more significant forecast errors (e.g., completely missing or erroneous convective systems), suggesting that further research is needed to document the source of such errors at these time scales. A systematic bias is also noted with the Yonsei University (YSU) PBL scheme, emphasizing the continuing need to refine and improve physics packages for application to these forecast problems.

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. Mon. Wea. Rev., 136, 1990-2005, doi: 10.1175/2007MWR2085.1.

Abstract

Real-time forecasts of five landfalling Atlantic hurricanes during 2005 using the Advanced Research Weather Research and Forecasting (WRF) (ARW) Model at grid spacings of 12 and 4 km revealed performance generally competitive with, and occasionally superior to, other operational forecasts for storm position and intensity. Recurring errors include 1) excessive intensification prior to landfall, 2) insufficient momentum exchange with the surface, and 3) inability to capture rapid intensification when observed. To address these errors several augmentations of the basic community model have been designed and tested as part of what is termed the Advanced Hurricane WRF (AHW) model. Based on sensitivity simulations of Katrina, the inner-core structure, particularly the size of the eye, was found to be sensitive to model resolution and surface momentum exchange. The forecast of rapid intensification and the structure of convective bands in Katrina were not significantly improved until the grid spacing approached 1 km. Coupling the atmospheric model to a columnar, mixed layer ocean model eliminated much of the erroneous intensification of Katrina prior to landfall noted in the real-time forecast.

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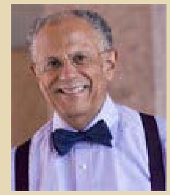
CGD 2008 PROFILES IN SCIENCE: DR. WARREN WASHINGTON

Summary of achievements



Warren Washington

During this last year, I have been working to help maintain the close collaboration between the NSF and DOE supported efforts on climate change and climate modeling. Scientists involved in the DOE-UCAR cooperative agreement are working toward having an improved the Community Climate System Model (CCSM) that can be used ongoing studies of climate change and for the next assessment of the IPCC. For example, we have worked on making large ensemble predictions to 30-40 years into the future to get some handle climate prediction limitations. The large set of IPCC scenario data will be made available to the world-wide climate science community. We are pleased to see that we have a growing number of scientists using this data set mostly through the DOE supported Earth System Grid. During this last year I have been collaborating with Haiyan Teng which has resulted in a publication on the changes in storm characteristics between present and the end of the century.

With respect to CGD program management I continue as a Section Head. The Climate Change Research Section has two main areas of research; one is performing climate change simulations and analysis of those simulations. The other is paleoclimate modeling and research. I continue my other NCAR/CGD management responsibilities as Co-PI for the DOE-UCAR cooperative agreement along with Jerry Meehl. The DOE management continues to be quite satisfied with the cooperative agreement research. The DOE management is continuing to be committed to partnership with NSF to support the CCSM support. I too strongly support this approach. The Climate End Station is a computational metaphor for equipment at the end of a nuclear accelerator where subatomic particles collide and generate interesting scientific results. My role is to help coordinate effective use of the DOE computers with Lawrence Buja's involvement DOE supported projects in the area climate research. The project works with CCSM and virtually all the DOE laboratorie to carry simulations and development of climate models in the areas of climate change, high resolution atmosphere and ocean modeling, and biogeochemical cycles. It is should be noted that all of these activities contribute to and are coordinated with the overall CCSM effort.

Also, during this last year I have been collaborating with Haiyan Teng which has resulted in a publication on the changes in storm characteristics between present and the end of the century.

Publications

Teng, H., W. M. Washington, and G. A. Meehl, 2008: Interannual variations and future change of wintertime extratropical cyclone activity over North America in CCSM3. Climate Dynamics, 30:673-686, doi:10.1007/s00382-007-0314-1.

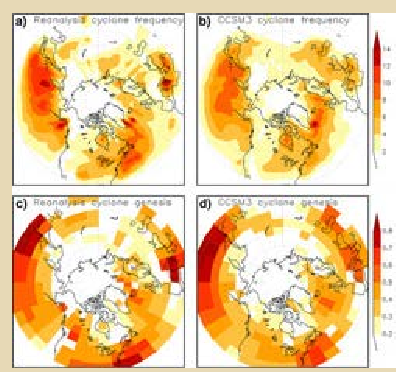


Figure 1.

High resolution figure

Abstract: Climatology and interannual variations of wintertime extratropical cyclone frequency in CCSM3 twentieth century simulation are compared with the NCEP/NCAR reanalysis during 1950-1999. CCSM3 can simulate the storm tracks reasonably well, although the model produces slightly less cyclones at the beginning of the Pacific and Atlantic storm tracks and weaker poleward deflection over the Pacific. As in the reanalysis, frequency of cyclones stronger than 980 hPa shows significant correlation with the Pacific/North America (PNA) teleconnection pattern over the Pacific region and with the North Atlantic Oscillation (NAO) in the Atlantic sector. Composite maps are constructed for opposite phases of El Nino-Southern Oscillation (ENSO) and the NAO and all anomalous patterns coincide with observed. One CCSM3 twenty-first century A1B scenario realization indicates there is significant increase in the extratropical cyclone frequency on the US west coast and decrease in Alaska. Meanwhile, cyclone frequency increases from the Great Lakes region to Quebec and decreases over the US east coast, suggesting a possible northward shift of the Atlantic storm tracks under the warmer climate. The cyclone frequency anomalies are closely linked to changes in seasonal mean states of the upper-troposphere zonal wind and baroclinicity in the lower troposphere. Due to lack of 6-hourly outputs, we cannot apply the cyclone-tracking algorithm to the other eight CCSM3 realizations. Based on the linkage between the mean state change and the cyclone frequency anomalies, it is likely a common feature among the other ensemble members that cyclone activity is reduced on the East Coast and in Alaska as a result of global warming.

Figure caption: a, b Climatological winter cyclone frequency (events/winter per 5° × 5° lat/lon degree) in the Reanalysis and the CCSM3 historical run, respectively. c, d Climatological winter frequency of cyclone generation (percent of the total number of cyclones) in the Reanalysis and CCSM3, respectively

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Santer, B.D., C. Mears, F.J. Wentz, K.E. Taylor, P.J. Gleckler, T.M.L. Wigley, T.P. Barnett, J.S. Boyle, W. Bruggemann, N.P. Gillett, S.A. Klein, G.A. Meehl, T. Nozawa, D.W. Pierce, P.A. Stott, W.M. Washington, and M.F. Wehner, 2007: Identification of human-induced changes in atmospheric moisture content. Proc. Nat. Acad. Sci., 104, 15248-15253.

Abstract: Data from the satellite-based Special Sensor Microwave Imager (SSM/I) show that the total atmospheric moisture content over oceans has increased by 0.41 kg/m2 per decade since 1988. Results from current climate models indicate that water vapor increases of this magnitude cannot be explained by climate noise alone. In a formal detection and attribution analysis using the pooled results from 22 different climate models, the simulated "fingerprint" pattern of anthropogenically caused changes in water vapor is identifiable with high statistical confidence in the SSM/I data. Experiments in which forcing factors are varied individually suggest that this fingerprint "match" is primarily due to human-caused increases in greenhouse gases and not to solar forcing or recovery from the eruption of Mount Pinatubo. Our findings provide preliminary evidence of an emerging anthropogenic signal in the moisture content of earth's atmosphere.

Figure caption: Simulated and observed spatial patterns of changes in W_o and estimation of detection time (10). Multimodel averages of the 20th century changes in W_o were used to calculate the ALL (A) and ANTHRO (B) fingerprints we search for in the observations. Also shown are the leading noise modes of the concatenated ALL (C) and ANTHRO (D) model control runs and the observed pattern of total linear changes in W_o over 1998-2006 (E). All calculations were performed on the common 10° × 10° latitude/longitude grid used for the fingerprint analysis.

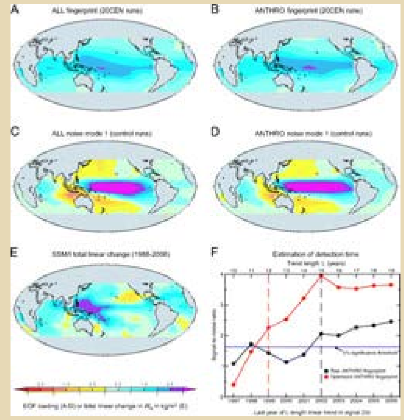

Figure 2.

High resolution figure

Washington, W.M., L. Buja and A. Craig, 2008: The computational future for climate and earth system models: On the path to petaflop and beyond. To be published in Philosophical Transactions of the Royal Society on Environmental eScience.

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Research Focus FY08:

Autonomous Robust CO2 Analyzer (AIRCOA)

High resolution figure

I am currently working for Dr. Britton Stephens measuring primarily oxygen and carbon dioxide in the atmosphere in support of projects seeking to understand links between oceanic and terrestrial carbon sinks and sources, in particular the influence of Rocky Mountain forests on these dynamics.

With NCAR engineering support, I am working on constructing an aircraft-worthy oxygen analyzer capable of measuring oxygen concentrations accurately to within 5 per meg. We currently have three compact rack-mountable boxes that will fit into a single aircraft rack. One carries a set of four calibration gases to ensure our measurements are NIST traceable. One carries the pump module, capable of introducing gas to the analyzer at appropriate pressures, despite moving from sea level to over 50,000 ft in elevation. The last module contains the vacuum ultraviolet absorption device which measures the oxygen absorption. While the engineering for this project has been in the works for months, the project now flying on HIAPER during the START08/Pre-HIPPO campaign. In the last year and a half, I have purchased, worked with vendors to get everything in place, designed, built-up and troubleshot the printed circuit boards and constructed the instrument. As flights commenced, additional challenges to precise measurements have cropped up and testing continues to improve on our measurements.

In October 2007, in cooperation with the Bureau of Indian Affairs and Marnie Carroll, the Dinè (Navajo) College Environmental Science Director, the Autonomous Robust CO2 Analyzer (AIRCOA, designed by Britt Stephens and Andy Watt, photos) was deployed at Roof Butte on the Navajo Nation in Northeastern Arizona in order to determine the regional carbon dioxide surface fluxes in this southwestern mountainous area. Dinè College Conference Report: Building a Successful Student Research Program Through Collaboration.

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Research Focus FY08:

Andy Weinheimer makes final adjustments to equipment for measuring active nitrogen in ozone during the ARCTAS field study (Photo by David McNew/Getty Images North America) - High resolution figure

Andy Weinheimer along with the Community Airborne Research Instrumentation (CARI) group is currently working on a NO-NOy Instrument - Two-channel instrument for the in situ measurement of NO (nitric oxide) and NOy (total reactive nitrogen). This two-channel chemiluminescence instrument will obtain ~1-sec in situ measurements of NO and NOy. Several components of the overall system have been built and tested. Plans for early FY2008 are to complete the development with (1) reconstruction of the main instrument module and modification of other existing components, (2) inlet design and fabrication, (3) CO containment vessel fabrication, (4) configuration into a GV rack, and (5) certification of the entire installation. This will be completed early in FY2008, in preparation for HEFT test flights, so that the instrument will be flight-tested and ready for deployment on the GV in START08.

In The News:

NASA's Flying Laboratory Studies Impact Of Air Pollution On Arctic: National Center for Atmospheric Research (NCAR) scientist Andy Weinheimer makes final adjustments to equipment for measuring active nitrogen in ozone aboard a DC-8 jet to be used by the National Aeronautics and Space Administration (NASA) as a flying laboratory in one of the largest environmental science campaigns ever conducted to study the impact of air pollution on the Arctic's atmospheric chemistry and changing climate, at NASA's Dryden Flight Research Center on March 31, 2008 in Palmdale, CA. For three weeks in April, NASA will use three research aircraft, satellites, weather balloons and more than 100 scientists based in Fairbanks, Alaska to study the "arctic haze" of air pollution that forms from sources across the Northern Hemisphere as part of the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) field campaign. In July a second phase of study is scheduled to be conducted out of Alberta and the Northwest Territories of Canada to focus on pollution from large boreal forest fires in northwest Canada. Additional Coverage: daylife.com, Jamd

Looking for Nitrogen (Discovery earthlive April 2008): Thule Airbase, Greenland, April 6, 2008 written by David Knapp about the ARCTAS Mission.

Scientific Talks FY08:

- NCAR NOxyO3 on the DC-8 in ARCTAS (Greenbelt, MD USA, 01/2008)
- START08 / pre-HIPPO In situ Measurements of NO, NOy, O3 from the GV (Broomfield, CO USA, 05/2008)

Publications FY08:

DeCarlo, P. F., E. J. Dunlea, J. R. Kimmel, A. C. Aiken, D. Sueper, J. Crounse, P. O. Wennberg, L. Emmons, Y. Shinozuka, A. Clarke, J. Zhou, J. Tomlinson, D. R. Collins, D. Knapp, A. Weinheimer, D. Montzka, T. Campos, J. L. Jimenez, 2008: Fast airborne aerosol size and chemistry measurements above Mexico City and Central Mexico during the MILAGRO campaign. *Atmos. Chem. Phys.*, **8**, 4027-4048.

Shim, C., Q. Li, M. Luo, S. Kulawik, H. Worden, J. Worden, A. Eldering, G. Diskin, G. Sachse, A. Weinheimer, D. Knapp, D. Montzca, T. Campos, 2007: Characterizing mega-city pollution with TES O3 and CO measurement. *Atmos. Chem. Phys. Discuss.*, 7, 15189-15212.

Andy Weinheimer Research

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MORRIS WEISMAN

2008 Publications

Weisman, M. L., C. A. Davis, W. Wang, K. Manning, 2008: Experiences with 0-36h explicit convective forecasts with the WRF-ARW model. Wea. Forecasting, 23, 407-437, doi: 10.1175/2007WAF2007005.1.

ABSTRACT

Herein, a summary of the authors' experiences with 36-h real-time explicit (4 km) convective forecasts with the Advanced Research Weather Research and Forecasting Model (WRF-ARW) during the 2003–05 spring and summer seasons is presented. These forecasts are compared to guidance obtained from the 12-km operational Eta Model, which employed convective parameterization (e.g., Betts–Miller–Janjic). The results suggest significant value added for the high-resolution forecasts in representing the convective system mode (e.g., for squall lines, bow echoes, mesoscale convective vortices) as well as in representing the diurnal convective cycle. However, no improvement could be documented in the overall guidance as to the timing and location of significant convective outbreaks. Perhaps the most notable result is the overall strong correspondence between the Eta and WRF-ARW guidance, for both good and bad forecasts, suggesting the overriding influence of larger scales of forcing on convective development in the 24–36-h time frame. Sensitivities to PBL, land surface, microphysics, and resolution failed to account for the more significant forecast errors (e.g., completely missing or erroneous convective systems), suggesting that further research is needed to document the source of such errors at these time scales. A systematic bias is also noted with the Yonsei University (YSU) PBL scheme, emphasizing the continuing need to refine and improve physics packages for application to these forecast problems.

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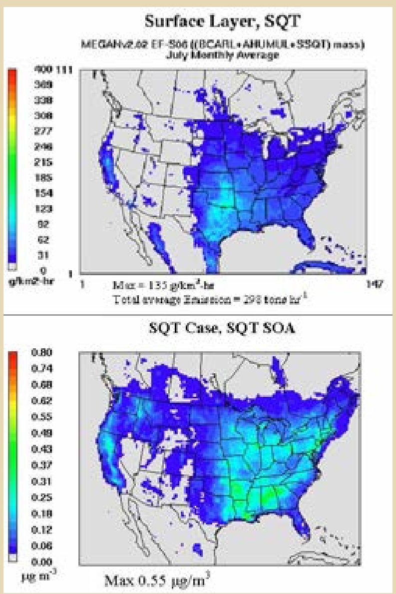
Research Focus FY08:



(A) Estimated biogenic sesquiterpene emissions estimated with MEGAN (July 2001 monthly average). (Sakulyanontvittaya et al., ES&T, 2008) and (B) Estimated secondary organic aerosol formed from biogenic sesquiterpene emissions (July 2001 monthly average) (Sakulyanontvittaya et al., ES&T, in review).
High resolution figure

Emissions of Particles & Gases from the Biosphere

Wiedinmyer's research focuses on the emissions of particles and gases from the biosphere, and how these impact atmospheric processes, specifically chemistry. In the recent past, she has led the development of a fire emissions model for North America for use by atmospheric modelers (Wiedinmyer et al., 2006) and contributed to the development of a new biogenic emissions model, Model of Emissions of Gases and Aerosols from Nature, MEGAN (Guenther et al., 2006). These emission estimates have been used with other models to evaluate the impact of these emissions on chemistry and meteorological processes.

In the past fiscal year, several advances have been made in terms of the ability to model emissions, chemistry and meteorology. Implementation of sesquiterpene emissions within MEGAN and chemical transport models has been completed, and the amount of secondary organic aerosol formed from these compounds in the US has been estimated (Sakulyanontvittaya et al., 2008; Sakulyanontvittaya et al., *in press*). The results of these studies are shown in Figure 1.

MEGAN has been included within the WRF-chem framework, so that biogenic emissions can be simulated online with atmospheric chemistry and meteorology. Preliminary studies have been performed to evaluate the direct impact of aerosols on clouds, and further, the impact on biogenic emissions (S. Chung (WSU), J. Fast (PNNL), and C. Wiedinmyer). Several modeling studies have been completed to investigate the impact of climate and land cover/land use change on future air quality. With X. Jiang (University of Texas) and F. Chen (RAL), the impact of future land cover change and climate on local meteorology and chemistry was investigated for Houston Texas with the use of the WRF-chem model (Jiang et al., in press). Investigations of future climate and land cover changes were performed for the continental US with collaborators from Washington State University, University of Washington and the US Forest Service (Chen et al., *Atmospheric Chemistry and Physics Discussions*, 2008; Avise et al., *Atmospheric Chemistry and Physics Discussions*, 2008).

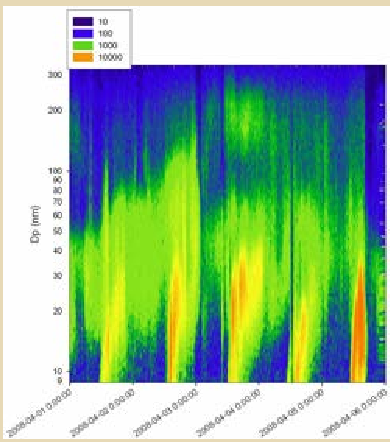
Emissions of Mercury & CO2 from Fires

Emissions of mercury (Wiedinmyer and Friedli, 2007) and CO2 (Wiedinmyer and Neff, 2007) from fires across the US have been estimated using the North American Fire Emissions Model. These emission estimates are addressed in terms of the policy implications of these emissions. An inter-comparison of fire emission estimates for the contiguous U.S. was completed with colleagues from other national agencies (Al-Saadi, *Journal of Applied Remote Sensing*, 2008). The results of this project highlighted the uncertainty associated with fire emission estimates and the need to better constrain the models.

Areal photo of the [Storm Peak Laboratory](#) in Steamboat Springs, CO.
[High resolution figure](#)

The Storm Peak Aerosol and Clouds Characterization Study 2008 (SPACCS08)

Wiedinmyer led an exploratory study at the Storm Peak Laboratory in April 2008. The Storm Peak Aerosol and Cloud Characterization Study (SPACCS2008) took place from March 23 through April 15, 2008 at the SPL (located at 10,200 ft ASL in Steamboat Springs, CO). Collaborators from over 10 different universities and organizations (including several graduate students) participated in an effort to characterize the biological and chemical composition of the ambient air, cloud water, and snow at the site. Analysis of the data is on-going.



PRELIMINARY Particle number concentrations (by particle size) measured during part of the SPACCS08 study at SPL. These data indicate daily particle formation events at the site.
High resolution figure

News Release & Background Information:
- U.S. Fires Release Large Amounts of Carbon Dioxide, New Study Shows
- Scientists Estimate Mercury Emissions from U.S. Fires; West Coast and Southeastern States are Major Emitters
- New Approaches to Understanding Wildfires
- NCAR Scientists Available to Discuss Wildfire Impacts and Behavior : Wildfire Animation
- Background: Wildfires
- Wildfire Research at MMM

In the News:
- Wildfires Spew Carbon, Re-Growth Absorbs It - (Discovery News by Larry O'Hanlon, 1 November 2007)
- California wildfires unleash CO2 (Environment Correspondent by Deborah Zabarenko, Reuters 1 November 2007)
- US Fires Release Large Amounts Of Carbon Dioxide (Science Daily, 1 November 2007)
- Wildfire smoke a culprit in mercury's toxic spread (The Denver Post by Steve Lipsher, 19 October 2007)
- Scientists estimate state-by-state mercury emissions from US fires (Science Codex, 17 October 2007)
- It Droppeth as the Gentle Rain (Colorado Confidential by Dan Whipple, 17 October 2007)
- Addional News Articles: links

Impact of Forest Mortality from the Mountain Pine Beetle

Top view of adult Mountain Pine Beetle (actual size, 1/8 to 1/3 inch). Picture: Colorado State University)

The beginning of a project investigating the impact of forest mortality in the western U.S. from the mountain pine beetle has begun. Work with F. Chen, M. Tewari, and M. Barlage has begun to determine the sensitivity of meteorological predictions to large forest mortality with the use of the WRF model. Further, the impact of these beetle-killed forests on biogenic volatile organic compound emissions and regional air quality is currently being investigated with a regional model framework (C. Wiedinmyer, T. Sakulyanontvittaya and R. Morris (ENVIRON), and others).

Future Work

Future work will continue to evaluate the impact of emissions from the biosphere (biogenic emissions and emissions from fires) on atmospheric processes. Improvements to the emissions models will be completed and the evaluation of the impacts of fires on atmospheric processes will continue. A review paper about of the isoprene secondary organic aerosol formation (co-authors AM. Carlton (U.S. EPA) and J. Kroll (MIT)) will be completed. With the use of WRF-chem, the interactions between the biosphere and the atmosphere will be more thoroughly investigated. Continued evaluation of land use and climate change on emissions and atmospheric processes on a regional scale will be completed.

References (*Specific to this write-up*):

Al-Saadi, J., A. Soja, R.B. Pierce, J. Szykman, C. Wiedinmyer, L. Emmons, S. Kondragunta, X. Zhang, C. Kittaka, T. Schaack, K. Bowman. (2008) Evaluation of Near-Real-Time Biomass Burning Emissions Estimates Constrained by Satellite Active Fire Detections. *Journal of Applied Remote Sensing*, v2, [DOI: 10.1117/1.2948785].

Avise, J., J. Chen, B. Lamb, C. Wiedinmyer, A. Guenther, E. Salathé, C. Mass. Attribution of projected changes in U.S. ozone and PM2.5 concentrations to global changes. Submitted to *Atmos. Chem. Phys. Discuss.*, June 2008.

Chen, J., J. Avise, B. Lamb, E. Salathé, C. Mass, A. Guenther, C. Wiedinmyer, J.-F. Lamarque, S. O'Neill, D. McKenzie, N. Larkin. The Effects of Global Changes upon Regional Ozone Pollution in the United States. Submitted to *Atmos. Chem. Phys. Discuss.*, June 2008.

Guenther, A., T. Karl, P. Harley, C. Wiedinmyer, P. I. Palmer, C. Geron (2006) Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature), *Atmospheric Chemistry and Physics*, 6, 3181-3210.

Jiang, X., C. Wiedinmyer, F. Chen, Z.-L. Yang, and J. C.-F. Lo (2008), Predicted impacts of climate and land use change on surface ozone in the Houston, Texas, area, *J. Geophys. Res.*, 113, D20312, doi:10.1029/2008JD009820.

Sakulyanontvittaya, T., A. Guenther, D. Helmig, J. Milford, C. Wiedinmyer. Secondary Organic Aerosol from Sesquiterpene and Monoterpene Emissions in the United States. Submitted *Environmental Science & Technology*, March 2008, in press.

Sakulyanontvittaya, T., T. Duhl, C. Wiedinmyer, D. Helmig, S. Matsunaga, M. Potosnak, J. Milford, A. Guenther (2008) Monoterpene and Sesquiterpene Emission Estimates for the United States. *Environmental Science & Technology*, *42* (5), 1623–1629.

Wiedinmyer, C. and H. Friedli. Mercury Emission Estimates from Fires: An Initial Inventory for the United States, in press, Environmental Science & Technology, October 17, 2007, DOI: 10.1021/es071289o.

Wiedinmyer, C. , B. Quayle, C. Geron, A. Belote, D. McKenzie, X. Zhang, S. O'Neill, and K.K. Wynne (2006) Estimating emissions from fires in North America for Air Quality Modeling. Atmospheric Environment , 40, 3419-3432.

Community Service FY08:

- Associate Editor: Journal of Geophysical Research- Atmospheres
- Member: Leadership Board, Earth Science Womens Network
- Graduate Advisor & Thesis Committee: Mike Feldman, University of Texas at Austin
- Graduate Advisor: Barron Henderson, University of North Carolina, Chapel Hill
- Graduate Advisor: Xiaoyan Jiang, University of Texas at Austin
- Graduate Advisor & Thesis Committee: Tanarit Sakulyanontvittaya, University of Colorado, Boulder

Scientific Talks FY08:

- Energy, Air Quality, and Water Systems in Colorado (Boulder, CO, October 2007)

Publications FY08:

Al-Saadi, J., A. J. Soja, R. B. Pierce, J. Szykman, C. Wiedinmyer, L. Emmons, S. Kondragunta, X. Zhang, C. Kittaka, T. Schaack, K. Bowman, 2008: Intercomparison of near-real-time biomass burning emissions estimates constrained by satellite fire data. *J. Appl. Remote Sens.*, **2**, 021504, doi: 10.1117/1.2948785.

Sakulyanontvittaya, T., T. Duhl, C. Wiedinmyer, D. Helmig, S. Matsunaga, M. Potosnak, J. Milford, A. Guenther, 2008: Monoterpene and Sesquiterpene Emission Estimates for the United States. *Environ. Sci. Technol.*, **42**, 1623-1629.

Wiedinmyer, C., H. Friedli, 2007: Mercury emission estimates from fires: An initial inventory for the United States. *Environ. Sci. Technol.*, **41**, 8092-8098, doi: 10.1021/es071289o.

Wiedinmyer, C., J. C. Neff, 2007: Estimates of CO2 from fires in the United States: implications for carbon management. *Carbon Balance and Mgmt.*, 2, 10, doi: 10.1186/1750-0680-2-10.

Christine Wiedinmyer Research

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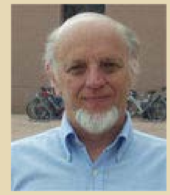
CGD 2008 PROFILES IN SCIENCE: DR. TOM WIGLEY



Tom Wigley

Publications

Bonfils, C., Duffy, P.B., Santer, B.D., Lobell, D.B., Phillips, T.J., Wigley, T.M.L., and Doutriaux, C., 2008: Identification of external influences on temperatures in California. Climatic Change, 87, 43-55, doi:10.1007/s10584-007-9374-9.

Abstract: We use nine different observational datasets to estimate California-average temperature trends during the periods 1950-1999 and 1915-2000. Observed results are compared to trends from a suite of climate model simulations of natural internal climate variability. On the longer (86-year) timescale, increases in annual-mean surface temperature in all observational datasets are consistently distinguishable from climate noise. On the shorter (50-year) timescale, results are sensitive to the choice of observational dataset. For both timescales, the most robust results are large positive trends in mean and maximum daily temperatures in late winter/early spring, as well as increases in minimum daily temperatures from January to September. These trends are inconsistent with model-based estimates of natural internal climate variability, and thus require one or more external forcing agents to be explained. Observational datasets with adjustments for urbanization effects do not yield markedly different results from unadjusted data. Our findings suggest that the warming of Californian winters over the twentieth century is associated with human-induced changes in large-scale atmospheric circulation. We hypothesize that the lack of a detectable increase in summertime maximum temperature arises from a cooling associated with large-scale irrigation. This cooling may have, until now, counteracted summertime warming induced by increasing greenhouse gases and urbanization effects.

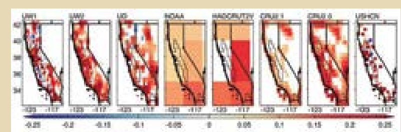


Figure 1.

High resolution figure

Figure caption: Spatial patterns of annual-mean temperature trends (°C/decade) in different observational datasets. At each grid-cell, trends were estimated by a least-squares linear fit to times series of temperature anomalies over 1950-1999. Trends that are not statistically different from zero at the 80% confidence level are in white. The 150-m contour roughly delineates California's Central Valley.

Knutti, R., M. R. Allen, P. Friedlingstein, J. M. Gregory, G. C. Hegerl, G. A. Meehl, M. Meinshausen, J. M. Murphy, G. K. Plattner, S. C. B. Raper, T. F. Stocker, P. A. Scott, H. Teng, and T. M. L. Wigley, 2008: A review of uncertainties in global temperature projections over the twenty-first century. Journal of Climate, 21, 2651-2663, doi:10.1175/2007JCLI2119.1

Abstract: Quantification of the uncertainties in future climate projections is crucial for the implementation of climate policies. Here a review of projections of global temperature change over the twenty-first century is provided for the six illustrative emission scenarios from the Special Report on Emissions Scenarios (SRES) that assume no policy intervention, based on the latest generation of coupled general circulation models, climate models of intermediate complexity, and simple models, and uncertainty ranges and probabilistic projections from various published methods and models are assessed. Despite substantial improvements in climate models, projections for given scenarios on average have not changed much in recent years. Recent progress has, however, increased the confidence in uncertainty estimates and now allows a better separation of the uncertainties introduced by scenarios, physical feedbacks, carbon cycle, and structural uncertainty. Projection uncertainties are now constrained by observations and therefore consistent with past observed trends and patterns. Future trends in global temperature resulting from anthropogenic forcing over the next few decades are found to be comparably well constrained. Uncertainties for projections on the century time scale, when accounting for structural and feedback uncertainties, are larger than captured in single models or methods. This is due to differences in the models, the sources of uncertainty taken into account, the type of observational constraints used, and the statistical assumptions made. It is shown that as an approximation, the relative uncertainty range for projected warming in 2100 is the same for all scenarios. Inclusion of uncertainties in carbon cycle-climate feedbacks extends the upper bound of the uncertainty range by more than the lower bound.

Pielke, R, T. Wigley, and C. Green, 2008: Dangerous Assumption. Nature, 452, 531-532, doi:10.1038/452531a.

Abstract: How big is the energy challenge of climate change? The technological advances needed to stabilize carbon-dioxide emissions may be greater than we think, argue Roger Pielke Jr, Tom Wigley and Christopher Green.

The United Nations Climate Conference in Bali in 2007 set the world on a two-year path to negotiate a successor to the 1997 Kyoto Protocol. Yet not even the most rosy-eyed delegate could fail to recognize that stabilizing atmospheric carbon-dioxide concentrations is an enormous undertaking. Here we address the magnitude of the technological changes required to meet that challenge. We argue that the size of this technology challenge has been seriously underestimated by the Intergovernmental Panel on Climate Change (IPCC), diverting attention from policies that could directly stimulate technological innovation.

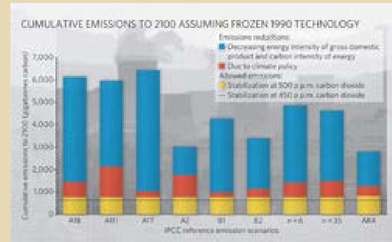


Figure 2.

High resolution figure

Figure caption: A range of 'built-in' emissions reductions (blue) in the scenarios used by the Intergovernmental Panel on Climate Change (IPCC). Total cumulative emissions to 2100 associated with a frozen-technology baseline are shown for: six individual scenarios, the means of these scenarios (n=6), and for all 35 IPCC scenarios, and the median of the scenario set (AR4). Additional reductions will have to be achieved by climate policy (red), assuming carbon-dioxide stabilization at about 500 parts per million (p.p.m.), leaving allowed emissions for this stabilization target (yellow).

Santer, B.D., C. Mears, F.J. Wentz, K.E. Taylor, P.J. Gleckler, T.M.L. Wigley, T.P. Barnett, J.S. Boyle, W. Bruggemann, N.P. Gillett, S.A. Klein, G.A. Meehl, T. Nozawa, D.W. Pierce, P.A. Stott, W.M. Washington, and M.F. Wehner, 2007: Identification of human-induced changes in atmospheric moisture content. Proc. Nat. Acad. Sci., 104, 15248-15253.

Abstract: Data from the satellite-based Special Sensor Microwave Imager (SSM/I) show that the total atmospheric moisture content over oceans has increased by 0.41 kg/m2 per decade since 1988. Results from current climate models indicate that water vapor increases of this magnitude cannot be explained by climate noise alone. In a formal detection and attribution analysis using the pooled results from 22 different climate models, the simulated "fingerprint" pattern of anthropogenically caused changes in water vapor is identifiable with high statistical confidence in the SSM/I data. Experiments in which forcing factors are varied individually suggest that this fingerprint "match" is primarily due to human-caused increases in greenhouse gases and not to solar forcing or recovery from the eruption of Mount Pinatubo. Our findings provide preliminary evidence of an emerging anthropogenic signal in the moisture content of earth's atmosphere.

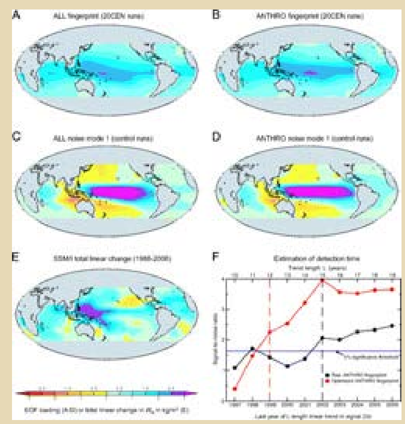


Figure 3.

High resolution figure

Figure caption: Simulated and observed spatial patterns of changes in W_o and estimation of detection time (10). Multimodel averages of the 20th century changes in W_o were used to calculate the ALL (A) and ANTHRO (B) fingerprints we search for in the observations. Also shown are the leading noise modes of the concatenated ALL (C) and ANTHRO (D) model control runs and the observed pattern of total linear changes in W_o over 1998-2006 (E). All calculations were performed on the common 10° × 10° latitude/longitude grid used for the fingerprint analysis.

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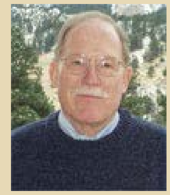
CGD 2008 PROFILES IN SCIENCE: DR. DAVID WILLIAMSON

Summary of achievements



David Williamson

I established the equivalent resolutions for the finite volume and spectral transform versions of CAM, and considered the question of convergence of simulations with increasing resolution, including what scales, if any, converge. These studies were based on aqua-planet simulations and consider free motions of the atmosphere only, not a forced component. Along with Mike Blackburn and Brian Hoskins (University of Reading, UK), I continue to organize the coordinated Aqua-Planet Experiment (APE) under the auspices of WGNE. I also continue to refine and apply the CCPP-ARM Parameterization Testbed (CAPT) method to examine parameterizations. This approach runs the CAM in a forecast mode using an ensemble of historical analyses from very recent years for periods during which high quality field program measurements exist, such as ARM IOPs. This allows direct comparison of the parameterized variables (e.g. clouds, precipitation) with observations from the field programs.

Publications

Williamson, D. L., 2008a: Convergence of aqua-planet simulations with increasing resolution in the Community Atmospheric Model, Version 3. Tellus, DOI:10.1111/j.1600-0870.2008.00339.x.

Abstract: The convergence of simulations from the Community Atmosphere Model with increasing resolution is determined in an aqua-planet context. Convergence as a function of scale is considered. Horizontal resolution (T42 to T340) and time step (40 to 5 minutes) are varied separately. The simulations are sensitive to both. Global averages do not necessarily converge with increasing resolution. The zonal average equatorial precipitation shows a strong sensitivity to time step. Parameterizations should be applied in a range of time steps where such sensitivity is not seen. The larger scales of the zonal average equatorial precipitation converge with increasing resolution. There is a mass shift from polar to equatorial regions with increasing resolution with no indication of convergence. The zonal average cloud fraction decreases with increasing resolution with no indication of convergence. Equatorial wave propagation characteristics converge with increasing resolution, however a relatively high truncation of T170 is required to capture wavenumbers less than 16. Extremes are studied in the form of the probability density functions of precipitation. The largest half of the scales of the model converge for resolutions above T85.

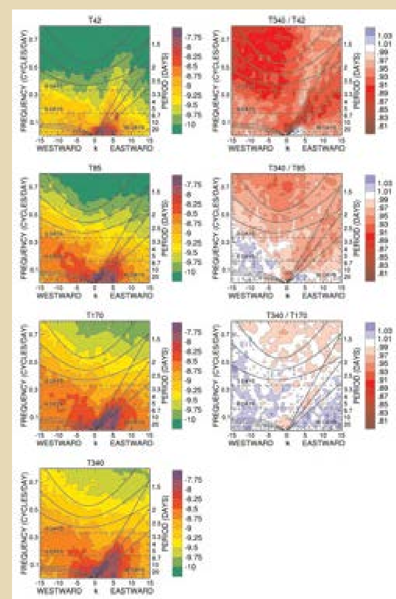


Figure 1.

High resolution figure

Figure caption: Wavenumber-frequency diagrams of log of power of equatorial precipitation for (left column) T42, T85, T170, and T340 with Δ t=5 minutes; and (right column) T42, T85, and T170 normalized by T340. Values less than 1 imply the lower resolution has less power than the T340. These diagrams indicate convergence with increasing resolution of the larger scale propagating wave characteristics, however a relatively high resolution of T170 is required to capture wavenumbers less than 16, the highest wavenumber plotted.

Williamson, D. L., 2008b: Equivalent Finite Volume and Spectral Transform Horizontal Resolutions Established from Aqua-planet Simulations. Tellus, DOI:10.1111/j.1600-0870.2008.00340.x.

Abstract: The equivalent resolutions for two different global dynamical cores are established when they are coupled to the sub-grid scale parameterization suite of the Community Atmosphere Model (CAM3). One core adopts the common Eulerian spectral transform formalism, the other adopts a finite volume approach. The equivalent resolutions are established over a range of resolutions employed today for climate models. The comparison is done in the context of the Aqua Planet Experiment. Thus it is based on the characteristics of free, unforced motions, due

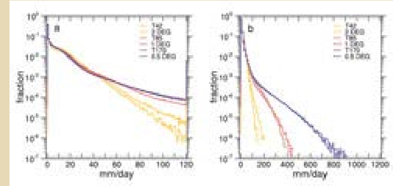


Figure 2.

High resolution figure

in large part to the dynamical component driven by the parameterized processes and explicit dissipation. The forced component arising from surface orography and land-ocean-sea-ice contrasts is not considered. The resolution equivalences are demonstrated for a number of model fields. These include selected time averaged, global and zonal averaged fields, the meridional structure of eddy kinetic energy and eddy temperature variance, the mean meridional eddy transports, the characteristics of tropical wave propagation, and probability density functions of precipitation. These fields indicate that the 2 degree finite volume model is equivalent to T42 spectral transform model, 1 degree is equivalent to T85, and 0.5 degree is equivalent to T170. This proportional relationship does not hold at lower resolutions.

Figure caption: Fraction of the time the precipitation is in 1 mm/day bins ranging from 0 to 120 mm/day (left) and in 10 mm/day bins ranging from 0 to 1200 mm/day (right), calculated from six-hour averages for all grid points between +-10 deg latitude for T42, T85, T170 and T340 spectral and 2 deg, 1 deg, and 0.5 deg finite volume model. This figure implies that for this quantity (2 deg, T42), (1 deg T85), and (0.5 deg, T170) are equivalent resolution pairs for these dynamical cores.

Medeiros, B., B. Stevens, I. M. Held, M. Zhao, D. L. Williamson, J. G. Olson, and C. S. Bretherton, 2008: Aquaplanets, climate sensitivity, and low clouds. J. of Climate, DOI:10.1175/2008JCLI1995.1.

Abstract: Cloud effects have repeatedly been pointed out as the leading source of uncertainty in projections of future climate, yet clouds remain poorly understood and simulated in climate models. Aquaplanets provide a simplified framework for comparing and understanding cloud effects, and how they are partitioned as function of regime, in large-scale models. This work uses two climate models to demonstrate that aquaplanets can successfully predict a climate model's sensitivity to an idealized climate change. For both models, aquaplanet climate sensitivity is similar to that of the realistic configuration. Tropical low clouds appear to play a leading role in determining the sensitivity. Regions of large-scale subsidence, which cover much of the tropics, are most directly responsible for the differences between the models. Although cloud effects and climate sensitivity are similar for aquaplanets and realistic configurations, the aquaplanets lack persistent stratocumulus in the tropical atmosphere. This, and an additional analysis of the cloud response in the realistically configured simulations, suggests the representation of shallow (trade-wind) cumulus convection, which is ubiquitous in the tropics, is largely responsible for differences in the simulated climate sensitivity of these two models.

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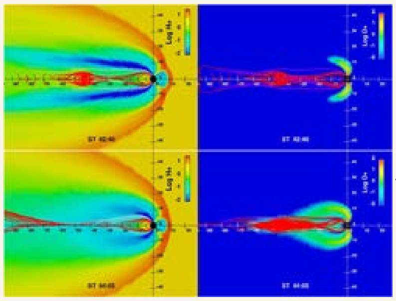
WILTBERGER, MIKE

Modeling of Ionospheric Outflows



Data from the Solar Extreme-ultraviolet Experiment (SEE) on the NASA TIMED satellite were used as input to the NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) for a simulation spanning the declining phase of solar cycle 23 from 2001-2007. Model simulations of the neutral thermospheric density at ~400 km were compared with density measurements obtained from observations of the atmospheric drag on five spherical satellites in low-Earth orbit. The solar observations greatly improve the model fidelity, and both solar-rotational and solar-cycle variations are accounted for. Additionally, the effects of impulsive geomagnetic storms can be can be seen in the model/data comparison (e.g., the "Halloween storms" in October-November 2003), and a surprisingly strong seasonal pattern is revealed, especially clear during solar minimum. These results are described in Qian et al., *J. Geophys. Res., in press, 2008.*

Figure caption: *A comparison of the magnetospheric configuration for a run without (left) and with (right) O+ outflow. The top panels show the configuration during the first substorm interval. In the lower panels a second substorm is only seen in the outflow simulation.*

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QINGNONG XIAO

2008 Publications

Liu, C.-H., Q. Xiao, B. Wang, 2008: An ensemble-based four-dimensional variational data assimilation scheme: Part I: Technical formulation and preliminary test. Mon. Wea. Rev., 136, 3363-3373, doi: 10.1175/2008MWR2312.1.

ABSTRACT

Applying a flow-dependent background error covariance (matrix) in variational data assimilation has been a topic of interest among researchers in recent years. In this paper, an ensemble-based four-dimensional variational (En4DVAR) algorithm, designed by the authors, is presented that uses a flow-dependent background error covariance matrix constructed by ensemble forecasts and performs 4DVAR optimization to produce a balanced analysis. A great advantage of this En4DVAR design over standard 4DVAR methods is that the tangent linear and adjoint models can be avoided in its formulation and implementation. In addition, it can be easily incorporated into variational data assimilation systems that are already in use at operational centers and among the research community.

A one-dimensional shallow water model was used for preliminary tests of the En4DVAR scheme. Compared with standard 4DVAR, the En4DVAR converges well and can produce results that are as good as those with 4DVAR but with far less computation cost in its minimization. In addition, a comparison of the results from En4DVAR with those from other data assimilation schemes [e.g., 3DVAR and ensemble Kalman filter (EnKF)] is made. The results show that the En4DVAR yields an analysis that is comparable to the widely used variational or ensemble data assimilation schemes and can be a promising approach for real-time applications.

In addition, experiments were carried out to test the sensitivities of EnKF and En4DVAR, whose background error covariance is estimated from the same ensemble forecasts. The experiments indicated that En4DVAR obtained reasonably sound analysis even with larger observation error, higher observation frequency, and more unbalanced background field.

Davis, C. A., W. Wang, S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, Q. Xiao, 2008: Prediction of landfalling hurricanes with the advanced hurricane WRF model. Mon. Wea. Rev., 136, 1990-2005, doi: 10.1175/2007MWR2085.1.

ABSTRACT

Real-time forecasts of five landfalling Atlantic hurricanes during 2005 using the Advanced Research Weather Research and Forecasting (WRF) (ARW) Model at grid spacings of 12 and 4 km revealed performance generally competitive with, and occasionally superior to, other operational forecasts for storm position and intensity. Recurring errors include 1) excessive intensification prior to landfall, 2) insufficient momentum exchange with the surface, and 3) inability to capture rapid intensification when observed. To address these errors several augmentations of the basic community model have been designed and tested as part of what is termed the Advanced Hurricane WRF (AHW) model. Based on sensitivity simulations of Katrina, the inner-core structure, particularly the size of the eye, was found to be sensitive to model resolution and surface momentum exchange. The forecast of rapid intensification and the structure of convective bands in Katrina were not significantly improved until the grid spacing approached 1 km. Coupling the atmospheric model to a columnar, mixed layer ocean model eliminated much of the erroneous intensification of Katrina prior to landfall noted in the real-time forecast.

Xiao, Q., E. Lim, D.-J. Won, J. Sun, W.-C. Lee, M.-S. Lee, W.-J. Lee, J.-Y. Cho, Y.-H. Kuo, D. M. Barker, D.-K. Lee, H. S. Lee, 2008: Doppler radar data assimilation in KMA's operational forecasting. Bull. Amer. Meteor. Soc., 89, 39-43, doi: 10.1175/BAMS-89-1-39.

Abstract

During 2001–03, the Mesoscale and Microscale Meteorology Division (MMM) at the National Center for Atmospheric Research (NCAR) partnered with the Korean Meteorological Administration (KMA) and Seoul National University (SNU) to use Doppler radar data in the MM5 with the Weather Research and Forecasting (WRF) 3-dimensional variational (3D-Var) data-assimilation system. After case studies and one-month comparison experiments with and without radar data assimilation in 2004, the system proceeded to semioperational testing in 2005 and was implemented for full operational production in 2006. The case studies showed benefits of radar data assimilation, and further tests indicated that Doppler radar data assimilation in WRF 3D-Var performed robustly and improved rainfall forecasting.

The procedure for KMA Doppler radar data assimilation is rather sophisticated: it includes data preprocessing (quality control,

error statistics, and formatting), assimilation with WRF 3D-Var, and analysis update cycling. The algorithms for direct assimilations of radial velocity and reflectivity are advanced and innovative. The transfer of the developed system from research mode at NCAR to operational mode at KMA has been very smooth and successful. With great efforts from all parties, KMA is running the advanced system operationally and benefiting Korea. The WRF 3D-Var Doppler radar data-assimilation system now resides in both NCAR and KMA and serves as a very useful tool for research.

Xiao, Q., J. Sun, 2007: Multiple radar data assimilation and short-range Quantitative Precipitation Forecasting of a squall line observed during IHOP 2002. Mon. Wea. Rev., 135, 3381-3404, doi: 10.1175/MWR3471.1.

ABSTRACT

The impact of multiple–Doppler radar data assimilation on quantitative precipitation forecasting (QPF) is examined in this study. The newly developed Weather Research and Forecasting (WRF) model Advanced Research WRF (ARW) and its three-dimensional variational data assimilation system (WRF 3DVAR) are used. In this study, multiple–Doppler radar data assimilation is applied in WRF 3DVAR cycling mode to initialize a squall-line convective system on 13 June 2002 during the International H2O Project (IHOP_2002) and the ARW QPF skills are evaluated for the case. Numerical experiments demonstrate that WRF 3DVAR can successfully assimilate Doppler radial velocity and reflectivity from multiple radar sites and extract useful information from the radar data to initiate the squall-line convective system. Assimilation of both radial velocity and reflectivity results in sound analyses that show adjustments in both the dynamical and thermodynamical fields that are consistent with the WRF 3DVAR balance constraint and background error correlation. The cycling of the Doppler radar data from the 12 radar sites at 2100 UTC 12 June and 0000 UTC 13 June produces a more detailed mesoscale structure of the squall-line convection in the model initial conditions at 0000 UTC 13 June. Evaluations of the ARW QPF skills with initialization via Doppler radar data assimilation demonstrate that the more radar data in the temporal and spatial dimensions are assimilated, the more positive is the impact on the QPF skill. Assimilation of both radial velocity and reflectivity has more positive impact on the QPF skill than does assimilation of either radial velocity or reflectivity only. The improvement of the QPF skill with multiple-radar data assimilation is more clearly observed in heavy rainfall than in light rainfall. In addition to the improvement of the QPF skill, the simulated structure of the squall line is also enhanced by the multiple–Doppler radar data assimilation in the WRF 3DVAR cycling experiment. The vertical airflow pattern shows typical characteristics of squall-line convection. The cold pool and its related squall-line convection triggering process are better initiated in the WRF 3DVAR analysis and simulated in the ARW forecast when multiple–Doppler radar data are assimilated.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

Research Catalog

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CGD 2008 PROFILES IN SCIENCE: STEPHEN YEAGER

Summary of achievements

Stephen Yeager

As the CCSM ocean model liason, I support the development, execution, and analysis of the ocean component of the Community Climate System Model, and provide assistance to community users of POP code and data. Some specific examples of my work in this role over the past year include: development of revision-controlled, publically-released ocean diagnostic routines which automate simulation analysis; development of POP modifications to enable vertical grid flexibility and multiyear interior restoring; and involvement in a project aimed at utilizing CCSM as a tool for decadal climate projections. An ongoing line of research with Bill Large has been the development of improved ocean surface boundary condition datasets--an effort which has facilitated the Common Ocean Reference Experiment (CORE) protocol of the CLIVAR Working Group for Ocean Model Development. In FY08, a second, extended version of this global, multiyear atmospheric state dataset was released to the ocean modelling community, along with a corresponding air-sea flux product which has been used to quantify the scales of interannual changes in ocean forcing components. Use of these multiyear datasets to generate high-fidelity ocean hindcast simulations has enabled studies of ocean multidecadal variability which would not be possible using observations alone. An example of this research is the identification of a generation mechanism for ocean spice variability, with a manuscript published this year, and ongoing exploration of the role that surface salinity variations play in driving change in the ocean interior. A new focus in the context of forced ocean experiments is understanding the sensitivities to high latitude thermohaline forcing, which is poorly constrained by observations. I'm also involved in research examining the possible coupling between ocean biology and ENSO variability.

Publications

Yeager, S.G., and W.G. Large, 2007: Observational Evidence of Winter Spice Injection. J. Phys. Oceanogr., 37, 2895-2919.

Abstract: Temperature and salinity (T-S) profiles from the global array of Argo floats support the existence of spice-formation regions in the subtropics of each ocean basin where large, destabilizing vertical salinity gradients coincide with weak stratification in winter. In these characteristic regions, convective boundary layer mixing generates a strongly density-compensated (SDC) layer at the base of the well-mixed layer. The degree of density compensation of the T-S gradients of an upper-ocean water column is quantified using a bulk vertical Turner angle (Tub) between the surface and upper pycnocline. The winter generation of the SDC layer in spice-formation zones is clearly seen in Argo data as a large-amplitude seasonal cycle of Tub in regions of the subtropical oceans characterized by high mean Tub. In formation regions, Argo floats provide ample evidence of large, abrupt spice injection (T-S increase on subducted isopycnals due to vertical mixing) associated with the winter increase in Tub. A simple conceptual model of the spice-injection mechanism is presented that is based on known behavior of convective boundary layers and supported by numerical model results. It suggests that penetrative convective mixing of a partially density-compensated water column will enhance the Turner angle within a transition layer between the mixed layer and the upper pycnocline, generating seasonal T-S increases on density surfaces below the mixed layer. Observations are consistent with this hypothesis. In OGCMs, regions showing high Tub mean and seasonal amplitude are also the sources of significant interannual spice variability in the permanent pycnocline. Decadal changes in the North Pacific of a model hindcast simulation show qualitative resemblance to the observed multiyear time series from the Hawaii Ocean Time series (HOT) station ALOHA. Modeled pycnocline variations near Hawaii can be linked to high Tub seasonality and winter spice injection within a formation region upstream of ALOHA, suggesting that spice injection may explain the origins of observed large, interannual variations on isopycnals in the ocean interior.

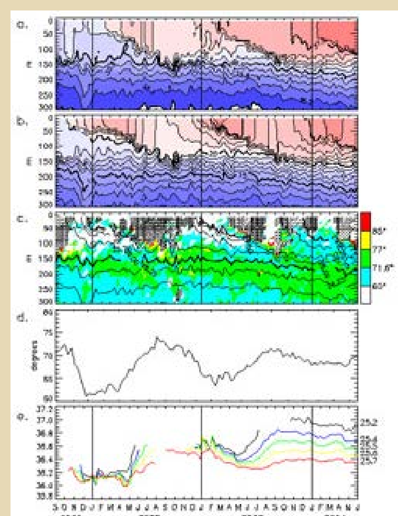

Figure 1.

High resolution figure

Figure caption: Multiyear time series from Argo profiler WMO 5900117 of South Atlantic upper ocean (a) salinity contoured at 0.2, (b) temperature contoured at 1°C, (c) Turner angle, Tu, with density overlaid (contoured at 0.25 kg/m^3), (d) bulk vertical Turner angle between the surface and 200m, and (e) isopycnal salinity on six σ surfaces: 25.2, 25.4, 25.5, 25.6, and 25.7

0

kg/m^3. In (c), Tu values of 60°, 71.6°, 77°, and 85° correspond approximately to R_ρ = 3.7, 2, 1.6, and 1.2, respectively, and cross-hatch indicates that vertical gradients are too small to compute Tu.

Large, W.G. and S.G. Yeager, 2008: The Global Climatology of an Interannually Varying Air-Sea Flux Data Set. Climate Dynamics, doi:10.1007/s00382-008-0441-3.

Abstract: The air-sea fluxes of momentum, heat, freshwater and their components have been computed globally from 1948 at frequencies ranging from 6-hourly to monthly. All fluxes are computed over the 23 years from 1984 to 2006, but radiation prior to 1984 and precipitation before 1979 are given only as climatological mean annual cycles. The input data are based on NCEP reanalysis only for the near surface vector wind, temperature, specific humidity and density, and on a variety of satellite based radiation, sea surface temperature, sea-ice concentration and precipitation products. Some of these data are adjusted to agree in the mean with a variety of more reliable satellite and in sitmeasurements, that themselves are either too short a duration, or too regional in coverage. The major adjustments are a general increase in wind speed, decrease in humidity and reduction in tropical solar radiation. The climatological global mean air-sea heat and freshwater fluxes (1984-2006) then become 2 W/m^2 and -0.1 mg/m^2 per second, respectively, down from 30 W/m^2 and 3.4 mg/m^2 per second for the unaltered data. However, decadal means vary from 7.3 W/m^2 (1977-1986) to -0.3 W/m^2 (1997-2006). The spatial distributions of climatological fluxes display all the expected features. A comparison of zonally averaged wind stress components across ocean sub-basins reveals large differences between available products due both to winds and to the stress calculation. Regional comparisons of the heat and freshwater fluxes reveal an alarming range among alternatives; typically 40 W/m^2 and 10 mg/m^2 per second, respectively. The implied ocean heat transports are within the uncertainty of estimates from ocean observations in both the Atlantic and Indo-Pacific basins. They show about 2.4 PW of tropical heating, of which 80% is transported to the north, mostly in the Atlantic. There is similar good agreement in freshwater transport at many latitudes in both basins, but neither in the South Atlantic, nor at 35°N.

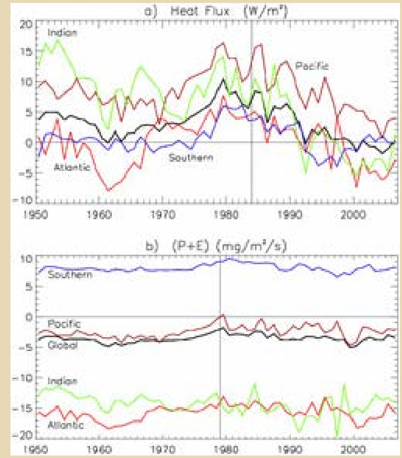

Figure 2.

High resolution figure

Figure caption: Time series over 57 years (1950 through 2006) of annual mean CORE.2 fluxes: a) air-sea heat flux in W/m^2, b) air-sea freshwater flux, excluding runoff, in mg/m^2/s, averaged over the global ocean and the Atlantic, Pacific, Indian and Southern, but not the Arctic basins.

Support:NOAA grant no. NA06GP0428 and by the National Science Foundation through its sponsorship of the National Center for Atmospheric Research.

Griffies, S. M., A. Biastoch, C. Boning, F. Bryan, G. Danabasoglu, E. P. Chassignet, M. H. England, R. Gerdes, H. Haak, R. W. Hallberg, W. Hazeleger, J. Jungclaus, W. G. Large, G. Madec, A. Pirani, B. L. Samuels, M. Scheinert, A. S. Gupta, C. A. Severijns, H. L. Simmons, A. M. Treguier, M. Winton, S. Yeager, J. Yin, 2008: Coordinated Ocean-ice Reference Experiments (COREs). Ocean Modelling, in press.

Abstract: Coordinated Ocean-ice Reference Experiments (COREs) are presented as a tool to explore the behavior of global ocean-ice models under forcing from a common atmospheric dataset. We highlight issues arising when designing coupled global ocean and sea ice experiments, such as difficulties formulating a consistent forcing methodology and experimental protocol. Particular focus is given to the hydrological forcing, the details of which are key to realizing simulations with stable meridional overturning circulations.

The atmospheric forcing from Large and Yeager (2004) was developed for coupled ocean and sea ice models. We found it to be suitable for our purposes, even though its evaluation originally focused more on the ocean than on the sea-ice. Simulations with this atmospheric forcing are presented from seven global ocean-ice models using the CORE-I design (repeating annual cycle of atmospheric forcing for 500 years). These simulations test the hypothesis that global ocean-ice models run under the same atmospheric state produce qualitatively similar simulations. The validity of this hypothesis is shown to depend on the chosen diagnostic. The CORE simulations provide feedback to the fidelity of the atmospheric forcing, with identification of biases promoting avenues for model and/or forcing dataset development.

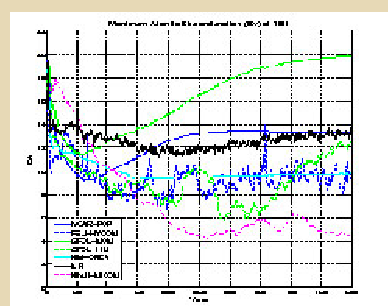

Figure 3.

High resolution figure

Figure caption: Time series of the annual mean Atlantic meridional overturning circulation (AMOC) index (vertical axis) for model years 1-500 (horizontal axis) in units of Sv from the seven participating models in this study. The index is computed as the maximum AMOC streamfunction at 45N in the region beneath the wind driven Ekman layer. Note that the GFDL-MOM simulation was extended to 600 years to verify that it was reaching a steady state for the overturning. An AMOC with realistic transport strength and structure is important for maintaining a realistic ocean climate. It is sometimes quite difficult to realize a stable overturning circulation, especially in ocean-ice models. The behavior of the ocean-ice models in this study indeed reflects on this sensitivity, with some models ``refusing'' to stabilize at a circulation reflecting observations (e.g., for North Atlantic Deep Water (NADW), about 15 Sv), whereas others appear to reach a stable value either with a very weak salinity restoring (NCAR-POP, FSU-HYCOM, and MPI), or stronger restoring (GFDL-MOM and Kiel-ORCA). It is notable that the two isopycnal models appear to have the most difficulty reaching a steady state, with the GFDL-HIM simulation showing large amplitude variations, whereas the KNMI-MICOM simulation settles into a very weak, nearly absent, overturning circulation in the NADW cell. We also note that the FSU-HYCOM simulation exhibits a nontrivial level of interannual variability relative to the simulations from NCAR-POP, GFDL-MOM, Kiel-ORCA, and MPI. Given the steady nature of the repeating annual forcing, the FSU-HYCOM variability is internally generated. The mechanism for variability has not been determined.

Support: NCAR is sponsored by the National Science Foundation.

Doney, S. C., S. Yeager, G. Danabasoglu, W. G. Large, and J. C. McWilliams, 2007: Mechanisms governing interannual variability of upper ocean temperature in a global ocean hindcast simulation. J. Phys. Oceanogr., 37, 1918-1938.

Abstract: The interannual variability in upper-ocean (0-400 m) temperature and governing mechanisms for the period 1968-97 are quantified from a global ocean hindcast simulation driven by atmospheric reanalysis and satellite data products. The unconstrained simulation exhibits considerable skill in replicating the observed interannual variability in vertically integrated heat content estimated from hydrographic data and monthly satellite sea surface temperature and sea surface height data. Globally, the most significant interannual variability modes arise from El Niño-Southern Oscillation and the Indian Ocean zonal mode, with substantial extension beyond the Tropics into the midlatitudes. In the well-stratified Tropics and subtropics, net annual heat storage variability is driven predominately by the convergence of the advective heat transport, mostly reflecting velocity anomalies times the mean temperature field. Vertical velocity variability is caused by remote wind forcing, and subsurface temperature anomalies are governed mostly by isopycnal displacements (heave). The dynamics at mid- to high latitudes are qualitatively different and vary regionally. Interannual temperature variability is more coherent with depth because of deep winter mixing and variations in western boundary currents and the Antarctic Circumpolar Current that span the upper thermocline. Net annual heat storage variability is forced by a mixture of local air-sea heat fluxes and the convergence of the advective heat transport, the latter resulting from both velocity and temperature anomalies. Also, density-compensated temperature changes on isopycnal surfaces (spice) are quantitatively significant.

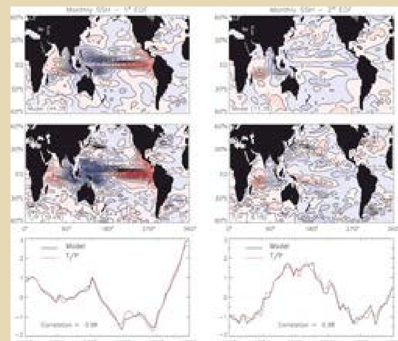

Figure 4.

High resolution figure

Figure caption: Spatial maps of the (left) first and (right) second EOF (1993-97) for the (top) model and (middle) T/P monthly SSH anomalies after the removal of the average seasonal cycle for 1993-95. The contour interval is 1 cm, and the variances associated with each EOF are given as percentages of the respective total variances. (bottom) The time series of the TOPEX/Poseidon and model first-mode principal components.

CGD Research Catalog

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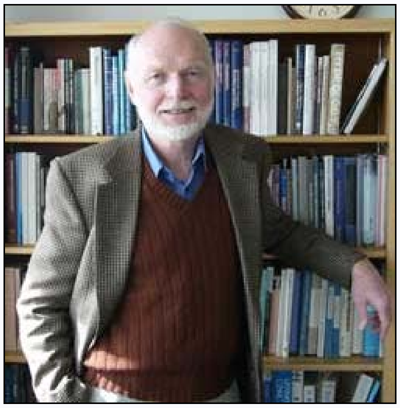
DIRECTOR'S MESSAGE


RAL Director - Brant Foote

Welcome to the Research Applications Laboratory's Annual Report for FY2008. Our mission is to conduct directed research that contributes to the depth of fundamental scientific understanding, to foster the transfer of knowledge and technology for the betterment of life on earth, and to support technology transfer that expands the reach of atmospheric science. We are, at present, an organization with an annual budget of more than $30M and a staff comprised of nearly 200 scientists, software engineers, and management/administration personnel. Although NCAR as a whole is largely funded by the National Science Foundation, RAL receives the vast majority of its funding from other sources such as domestic and international government agencies and private companies interested in exploiting the latest advanced weather technologies.

In 2005 we reorganized the Laboratory into five programs dealing with research and applications in topics related to aviation, homeland security, hydrometeorology, weather systems and assessments, and numerical testbeds. The activities within each of these programs are detailed on the RAL website. In this Annual Report, however, we present our program in a different way, highlighting the many areas in which our work supports and advances the NCAR Strategic Plan.

Given our focus on applied atmospheric research and technology transfer, it is natural that much of our work contributes to Strategic Goal 2, Priority 2: "Building capacity for coping with weather and climate hazards." It is also important to note, though, that many parts of our program map easily into other goals and priorities of NCAR's Strategic Plan. RAL scientists are engaged in fundamental investigations of earth-atmosphere interactions, in improving community models, in connecting science to decision making and public policy, in building scientific and technical capacity in developing countries, in creating new mathematical and statistical tools, and in improving instruments used to observe the atmosphere. In each of these activities, RAL works to bring science and technology to bear on problems that affect society.

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The National Center for Atmospheric Research
Research Applications Laboratory | RAL

2008 Lab Annual Report

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TABLE OF CONTENTS

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NCAR STRATEGIC GOALS

RAL focuses on all five of NCAR's strategic goals:

1. Understanding the Earth and Sun System
2. Resilience to Weather, Climate, and Atmospheric Hazards
3. Cultivating a Scientifically Engaged Citizenry
4. Providing Innovative Information Services
5. Providing World-Class Observational Facilities

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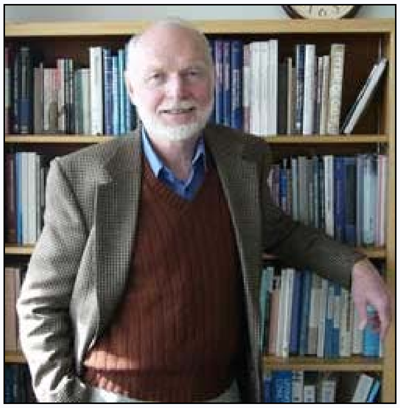

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GOAL 1: IMPROVE UNDERSTANDING OF THE ATMOSPHERE, EARTH SYSTEM, AND SUN

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GOAL 1: IMPROVE UNDERSTANDING OF THE ATMOSPHERE, EARTH SYSTEM, AND SUN

NCAR Strategic Priority 2: Investigating the Interactions of the Atmosphere, the Broader Earth System, and Human Society

Highlight: Aerosols and Precipitation

Over the past several years, the collection and analysis of data on aerosols, clouds, and storms has been an important element in the evaluation of rainfall enhancement programs that RAL conducts throughout the world. The primary objective of all these efforts is the better understanding of the natural variability of aerosols and clouds for the evaluation of the potential for rainfall enhancement in a region. Independently, the effects of aerosols as agents of significant climatic perturbations, particularly with respect to precipitation, have received increasing attention over the past decade or so. Understanding the potential for a direct or indirect aerosol effect, both processes involve changes in cloud microphysical processes, has become an additional factor to consider in documenting cloud and precipitation characteristics in regions proposed for weather modification activities. The feasibility studies on rainfall enhancement conducted by RAL examine both small-scale effects by direct weather modification and the large-scale impacts of indirect effects on the climate scale.

FY2008 Accomplishments:

Saudi Arabia
Using observations collected from two weather radar networks (see Figure 1 for the location of the seven radars in the two networks) and research aircraft, RAL scientists have gathered information that substantially aids in our understanding of the climatology of Saudi Arabia, as well as characterizing the variability of precipitating storms. The climatological distribution of annual rainfall observed by rain gauges across Saudi Arabia is shown in Figure 1 and 10-year climatology observed by satellite is shown in Figure 2. Dryness is the prevailing climatic characteristic of Saudi Arabia except in the Asir region (centered on Abha in Figure 1), which receives annual rainfall > 300 mm due to its unique geographical configuration and the local mountains, and a secondary peak located in northeast, which is associated with winter precipitation. Rainfall in most of Saudi Arabia is < 200 mm, highly irregular (i.e., large natural variability), and hence is not dependable. Analyses of the field data has continued into FY08. A second year of more extensive field studies of air chemistry, aerosol, cloud microphysics, precipitation, and storm characteristics was conducted for the period of December 2007 – May 2008 in the central region and June – September 2008 in the southwest (Asir) region of Saudi Arabia.

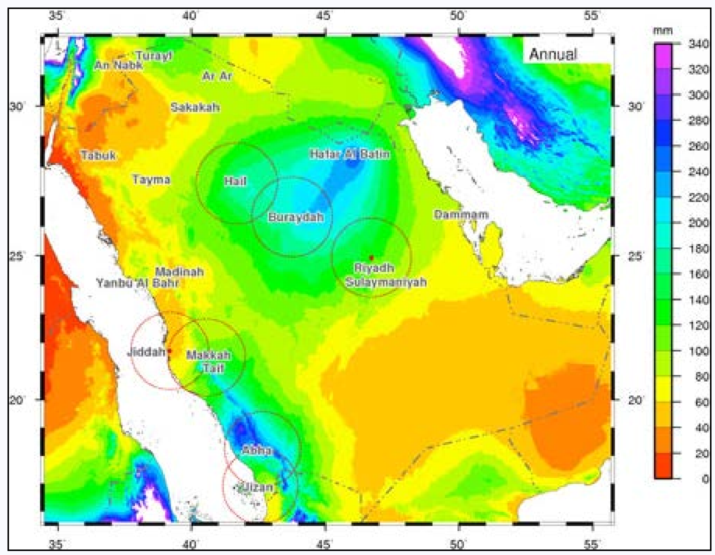


Figure 1: Map of Saudi Arabia showing the distribution of annual rainfall for a 50 year period (1950-2000) based on rain gauge observations. The circulations indicate the location radar observations winter study (November – May) in the central region and for the summer study in the southwestern region (June – September).

West Africa
A rainfall enhancement assessment study has been conducted in Mali, West Africa for the past three wet seasons (2006-2008). Aerosol and cloud microphysical measurements collected during the field program combined with NASA satellite and NRL aerosol model forecasts show that even though a major source of aerosols is related to dust transport from the Sahara, the Saharan dust is mostly confined to the northern areas of Mali (even during monsoon conditions) with only an occasional penetration of dust further south. Figure 3 shows an example aerosol distribution for a week starting on 8 Aug 2006, which is a typical distribution observed during the rainy season. These studies also showed that local variations in aerosols

embedded on the background levels may play an important role in the effects of aerosols on clouds. Storm trends have also been analyzed, improving our understanding of where, when, and how storms develop in this region. The diurnal distribution of the number of storms is shown in Figure 4 for the 2006 and 2007 wet seasons. Both years show a distinct afternoon peak. However, the 2007 season was much more active, which is likely related to the variability in large-scale dynamics and aerosols in the region. The 2008 field season focused on expanding the aerosol and microphysical observations for another season along with the initial implementation of a randomized cloud seeding study.

Istanbul, Turkey

A new program to assess the feasibility of rainfall enhancement in Turkey was conducted in the region near Istanbul during the winter and spring 2008. Airborne data were collected during this period to study the distribution of aerosols, cloud physical properties, and the development of precipitation.

Queensland, Australia

RAL has launched a new effort in Queensland this past year to scientifically investigate when and how well cloud seeding works to enhance rainfall from convective clouds near Brisbane, Australia. This was a unique field experiment because a network of advanced radars (dual-polarization and dual-wavelength) was implemented in the field in addition to well-instrumented research aircraft. In combination with the airborne measurements, the radar measurements make it possible to trace the physical chain of events from the natural or seeded small particles to droplet and ice crystal growth, subsequent precipitation development in clouds, and ultimately rain on the ground in both natural and seeding clouds.

North Dakota

A field campaign that utilized a C-Band polarimetric Doppler weather and an instrumented research aircraft was conducted in Eastern North Dakota for the period of 9 June – 11 July 2008, which coincides in the peak frequency of storms in the region. The objective of this field campaign is to better understand the effects of hygroscopic cloud seeding at cloud base on convective clouds in North Dakota. This project is a continuation of the original field program that was conducted in the summer of 2006, which indicated very positive results. Specifically, the project was conducted to determine if identifiable signatures of hygroscopic seeding in

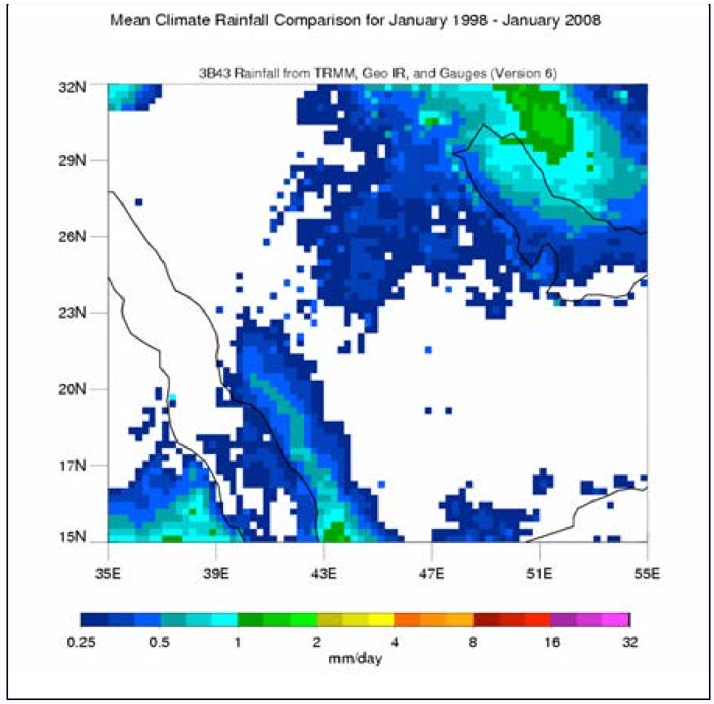


Figure 2: Map of rainfall observed by satellite (TRMM 3B43 product) over Saudi Arabia for a ten year period of January 1998 – January 2008. The rainfall pattern matches well with the long-term precipitation climatology shown in Figure 1.

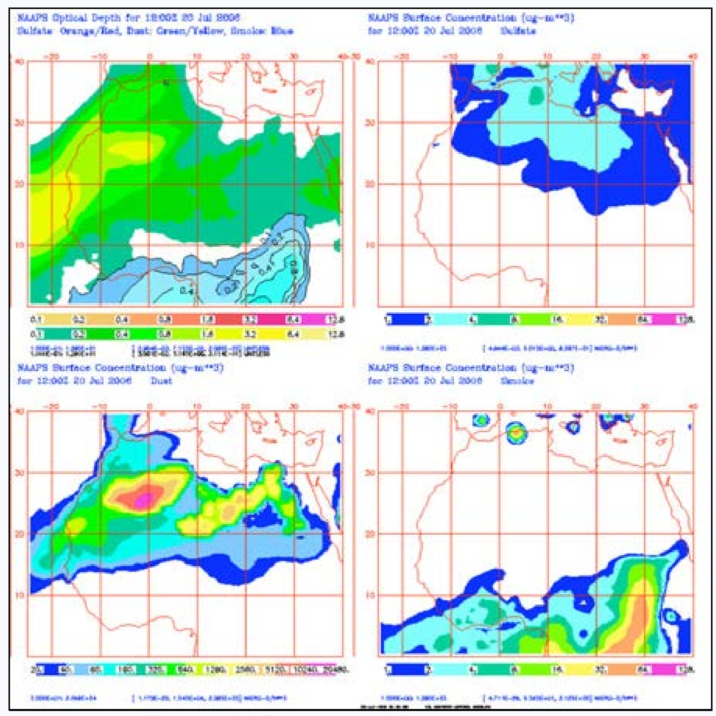


Figure 3: A weekly map of different aerosol characteristics over West Africa for the week of 8 August 2006. The different panels indicate different types of aerosols (top left corner – combined dust, sulfate and smoke aerosols; top right corner – sulfate aerosols; bottom left corner – dust aerosols; and bottom right corner – biomass smoke aerosols).

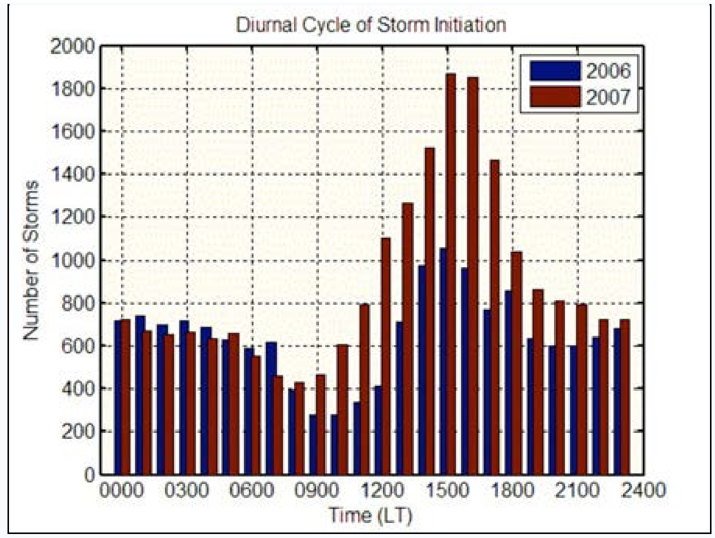


Figure 4: Diurnal cycle of storm initiation for the 2006 (blue) and 2007 (red) wet seasons in Mali

polarimetric observables or derived fields could be observed and to characterize hygroscopic seeding effects stratified by aerosol and CCN concentrations. The study was conducted randomly to understand cloud droplet distributions above cloud for seeded and non-seeded clouds to confirm inferences observed in the polarimetric fields.

FY2009 Plans:

Saudi Arabia
The 2006-2008 studies on aerosols, clouds, precipitation systems, and the feasibility of cloud seeding in central and southwestern Saudi Arabia was the first step in developing the infrastructure and collecting data aimed at understanding the physical processes in rainfall generation in Saudi Arabia. The plan is to continue the studies in the same areas, but have more focused measurement campaigns to address specific objectives of the project. The development of a randomized seeding program is also planned for 2009. A training program for visiting Saudi scientists at NCAR is also planned for this coming year.

West Africa
The next step for the 2008 Mali study is the analysis of the collected aircraft and radar data to better determine the natural aerosol and precipitation characteristics in Mali clouds, and the effect of cloud seeding on these processes and vice versa in the context of the randomized seeding cases. In addition, more training sessions for scientists and technicians in Mali are planned for FY09. An extensive randomized seeding program the will be conducted over the entire rainy season is being planned for June-September 2009.
Queensland, Australia
RAL has launched a second field campaign for 2008-2009 to continue to investigate when and how well cloud seeding works to enhance rainfall from convective clouds near Brisbane, Australia. At the same time, analysis will be conducted using the data from the first field season to investigate the physical chain of events from the natural or seeded small particles to droplet and ice crystal growth, subsequent precipitation development in clouds, and ultimately rain on the ground in both natural and seeding clouds.

North Dakota
The focus of the project for FY09 will be on radar data analyses which include: radar data quality control, statistical analyses of observed seeded and non-seeded cases, and the generation of liquid water content, particle shape, and rainfall estimates will be examined and compared with the previous study. Also, the NCAR polarimetric hydrometeor identification algorithm will be applied to the observed cases. For each case (13 cases, in total), seeded and non-seeded storms will be categorized. A statistical database along with a physical characterization will be developed for each case. A case study analysis of aircraft data will be conducted to stratify the results based on aerosol, CCN, and/or cloud droplet observations.

India
A new program to assess the feasibility of rainfall enhancement in India will be conducted throughout the country of India starting in June 2009, which coincides with the start of the monsoon season. Airborne data were collected during this period to study the distribution of aerosols, cloud physical properties, and the development of precipitation. The project is expected to be conducted over a five year period.

Highlight: Boundary Layer Processes

The atmospheric boundary layer (ABL) is characterized by strong energy exchanges between the atmosphere and the land surface. As such, it can be sensitive to land-surface heterogeneity and cloud shading, which modulate that exchange. A better understanding of the ABL should lead to improved prediction of ABL structure and evolution, in turn improving information provided to weather-forecast users affected by ABL circulations.

FY2008 Accomplishments:

In collaboration with Penn State University, we used a hierarchy of models to study the response of the convective atmospheric boundary layer (CABL) to land-surface heterogeneity and clouds. A study was completed with the WRF model to quantify temporal and spatial scales of predictability of CABL winds as it relates to uncertainty in soil moisture uncertainty. The

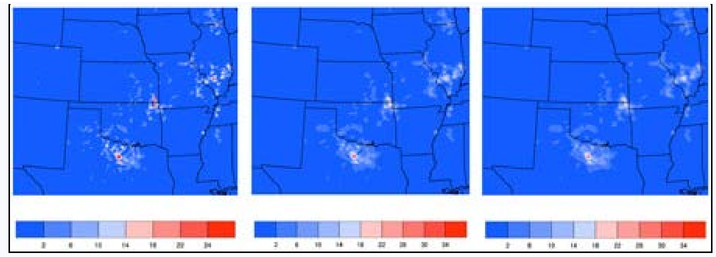


Figure 1: Band-passed error kinetic energy at 10-m above ground, with bands centered, from left, on 80, 200, and 600 km. Red colors show a loss of predictability, and together the panels show the upscale transfer of energy responding to small-magnitude soil moisture uncertainty, with known spatial covariance, prescribed at scales from 8-64 km. Results are valid 24 h after perturbation, at 1200 LST (Central) 28 May 2002.

key findings were (1) at short time scales (tens of minutes) the CABL wind response is locked to the soil moisture uncertainty, but at longer time scales (hours) the phase of the response decouples; (2) the magnitude of error growth in CABL winds is primarily a function of the dynamics of the coupled land-atmosphere system, and much less a function of the uncertainty scale or magnitude; (3) the presence of deep convection can act as a mechanism for upscale transfer of errors in CABL winds, and can also increase the magnitude of the error; and (4) regardless of the presence of convective instability, nonlinearity in error growth is present at time scales from minutes to hours. An example of up-scale transfer of error from small to large scales, in response to soil moisture uncertainty, is shown in Figure 1. The presence of nonlinear error growth in CABL winds under a wide range of atmospheric conditions has obvious implications for transport and dispersion predictions. CABL wind-speed errors less than 1 ms-1 (below current mesoscale weather analysis errors) can easily double or more on time scales of minutes to hours. In terms of transport, these results imply the predicted location of a contaminant can be in error by a kilometer in less than an hour.

A single-column model using the WRF land-surface and ABL physics was used to begin studying the response of the column to stochastic clouds. Experiments were designed to quantify the effects of cloud stochasticity on winds and stability within the CABL. Using cloud observations from the Atmospheric Radiation Measurement (ARM) Central Facility at Lamont, OK, stochastic models for cloud base height and liquid water path were designed in collaboration with statisticians at North Carolina State University. The stochastic models were used to generate hundreds of time series of clouds, which were then applied as a boundary condition in the single-column model. We ran ensembles daily for the period May-July 2003, and analysis of those experiments is ongoing.

The EULAG LES model was also improved in preparation for studying the CABL within mesoscale gradients and subject to land-surface heterogeneity. The EULAG was coupled to the WRF model. Testing to improve the EULAG LES subgrid-scale statistics and resolved-scale profiles for stable nighttime conditions was completed. A new Monin-Obukhov scheme was introduced for calculating surface heat and momentum fluxes (Z. Sorbjan, personal communication) and was generalized for both stable and convective conditions, in the absence of topographic features. The EULAG LES then was verified against the weakly stable conditions of the Beare et al. (2004) inter-comparison project.

One key problem is the lack of turbulence at LES inflow boundaries when periodic boundary conditions are not used. An investigation of methods to address this began in FY08, and will continue in FY09. A hierarchy of successively more complex and realistic tests has been prepared to evaluate the selected approach, culminating in the heterogeneous lower boundary-condition problem.

In the current phase of experiments new EULAG LBCs have been created. The model uses specific inflow LBC conditions (e.g. mesoscale wind and temperature) with turbulence input in the form of random noise below the inversion layer. Uniform surface heating within the whole domain provides forcing for the generation of turbulence. In the standard version, EULAG first used specified outflow LBCs, which caused an undesirable flow reversal at the height of the inversion layer. The outflow conditions were changed to open LBC conditions with zero gradient normal velocity components, which successfully eliminated the reverse-flow problem. Additionally, sensitivity studies involving different surface heating, surface drag coefficient, ambient wind and changes in turbulence inflow conditions have been completed. Other options currently being evaluated include linearly extrapolated outflow LBCs and gravity wave absorbers for the reduction of gravity waves trapped in the inversion layer, and for improving the downstream velocity profile.

As preparation for real-data simulations to be conducted later, the LES must also be extended to support irregular topographical features across multiple scales. We began this work by applying the EULAG model with a periodic complex-terrain lower boundary. The model was set up to simulate up-valley and down-valley thermally driven circulations with idealized complex terrain during weak synoptic forcing. This work was included in a model inter-comparison project for idealized daytime flows as part of the Terrain-induced Rotor Experiment (T-REX) (Rampanelli et al. 2004). The objective of the model inter-comparison was to quantify the uncertainty of thermally forced flows in idealized and real valleys over a full diurnal cycle. Metrics of concern included net radiation, surface sensible heat flux, the intensity and evolution of the along-valley and cross-valley circulations (along-valley flux and vertical flux at the top of the valley, maximum velocities near the slope and valley center, etc.), and the evolution of surface temperature and winds.

FY2009 Plans:

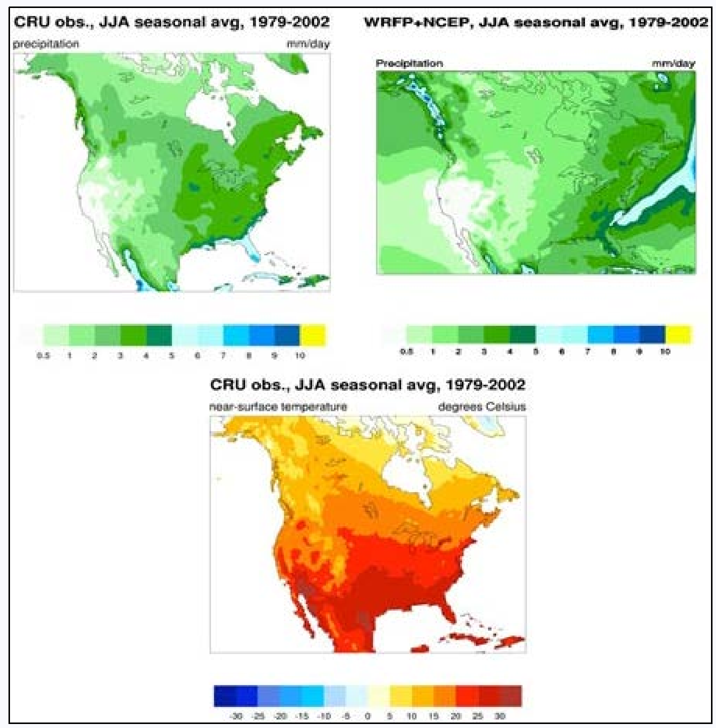
Analysis of the single-column response to stochastic cloud base height and liquid water path will continue. Evaluations focus on computing ensemble sensitivities that are analogous to adjoint calculations. This effort seeks to quantify the sensitivity of CABL stability to both instantaneous and time-integrated cloud-base height and liquid-water path from the imposed cloud time series. It is expected that the sensitivities of the responses will be functions of the time over which the sensitivities are computed, and also of the integration length scale of the cloud properties. The time scale of these sensitivities will reveal the CABL's memory of clouds, and which particular cloud parameters that can elicit a lasting response.

We plan to continue work to properly set up the EULAG LES to study the CABL with heterogeneous lower boundary conditions and mesoscale atmospheric gradients. Baseline simulations are being set up and run so that the method can be evaluated first against coupled mesoscale-LES simulations that ignore the explicit introduction of turbulence: (1) the initial baseline configuration will use WRF mesoscale initial and lateral boundary conditions, and homogeneous lower boundary conditions in the LES domain; (2) a second configuration will modify the surface fluxes in the LES in a simple way so that a spatially varying internal boundary layer develops.

To decrease the effects of transition from laminar to turbulent flow, establish fully developed turbulent flow as close as possible to the upstream boundary, and provide accurate downstream profiles, we propose implementing a variant of the perturbation recycling technique with rescaling. We will also consider a dynamic procedure to define the distance between the inflow boundary and the area with fully developed turbulence, with the goal of shortening that distance as the simulation progresses. Three problems that need to be addressed in this approach are the following: (1) dynamically define the downwind location in the plane from which the perturbations are copied (Liu and Pletcher 2006); (2) properly scale the perturbations to get the correct upwind turbulence inflow; (3) address the downscale TKE transfer from the mesoscale flow to the LES (Germano et al. 1991, Moeng et al. 2007). Work is ongoing to address these problems, and will continue in FY09.

North American Regional Climate Change Assessment Program (NARCCAP)

NARCCAP is the North American Regional Climate Change Assessment Program, an international program to generate high-resolution climate scenarios by nesting multiple regional climate models (RCMs) within multiple global coupled models (GCMs) over the coterminous United States, most of Canada, and northern Mexico. The resulting datasets will be highly valuable to climate change impacts assessment researchers because of their increased resolution and availability in GIS formats; and to investigators studying uncertainty in regional climate modeling by allowing the comparison of multiple models of the same future conditions. A large number of collaborators make up the project team: Within NCAR this includes scientists in IMAGe, CISL, CGD, and MMM. It also includes multiple university and national lab partners.



This figure represents sample results from Phase I of NARCCAP, wherein the regional models use boundary conditions from NCEP reanalyses. The top panel represents observed summer precipitation (CRU data set) and the lower panel displays the results of the simulation with the WRF model.

FY2008 Accomplishments:

It is expected that over 40 TB of quality-checked data will be submitted for archiving. During FY08, work at NCAR has included: development of an automated testing suite to ensure that data is correctly formatted and uncorrupted; coordinating plans with colleagues in CISL to archive data into the NCAR Mass Store and publishing these data through the Earth System Grid; development of a Data Archiving Protocol document; website and end-user support; discussions and testing to ensure that end-users' needs are met; and collaboration with the modeling groups and quality assurance team at Iowa State University. The NCEP-driven runs (1979-2004) with all six RCMs have been completed and archiving of much of the data from these runs is completed. The completion of the GFDL time-slice experiment occurred last year, and near completion of the (Community Atmospheric Model version 3 (CAM3) time slice experiment has occurred in FY08. The first two sets of RCM runs driven by global coupled models (GCMs) have been completed and data processing is underway. See the figure for sample results from Phase I (NCEP-driven run).

FY2009 Plans

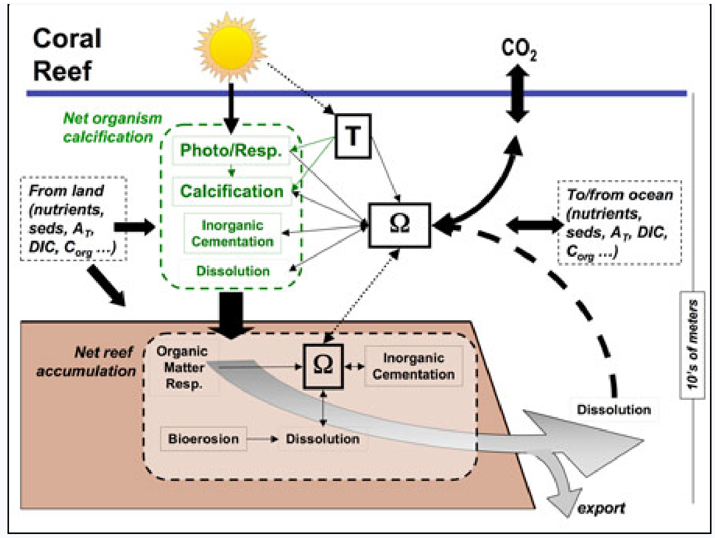
The program climate simulations will be completed in FY09. At that time a total of 14 high-resolution (50 km) simulations over North America will be available to the climate change community.

Ocean Acidification

The oceans have absorbed one-third to one-half of anthropogenic CO_2 from the atmosphere, which is causing a significant decrease in seawater pH. Called "ocean acidification," this process affects many ocean biogeochemical processes as well as many marine organisms and ecosystems from high-latitude planktonic systems to tropical coral reefs. Interest in ocean acidification has quickly become a major oceanographic research priority and has invoked strong political interest.

FY2008 Accomplishments

Work has continued at both the organizational level and in the field. NCAR interacts closely with NOAA researchers in leading a Subcommittee on Ocean Acidification within the Ocean Carbon and Biogeochemistry Program and recently completed a white paper calling for the formation of a U.S. National Research Program on Ocean Acidification, with specific recommendations toward its organizational structure. Much of this work builds on several U.S. congressional hearings highlighting ocean acidification as an important consequence of increasing atmospheric CO2 concentration. NCAR researchers also continue field work in Puerto Rico with NOAA and University of Miami, to establish a monitoring system for the carbonate system in seawater on the La Parquera coral reef. Work has also begun toward development of a numerical model that accounts for the interactions between seawater chemistry flowing over a coral reef, reef photosynthesis, and reef calcification.



Various processes that need to be accounted for in modeling changes both the changes in seawater chemistry in coral reef waters, as well as the responses of reef organisms.

FY 2009 Plans

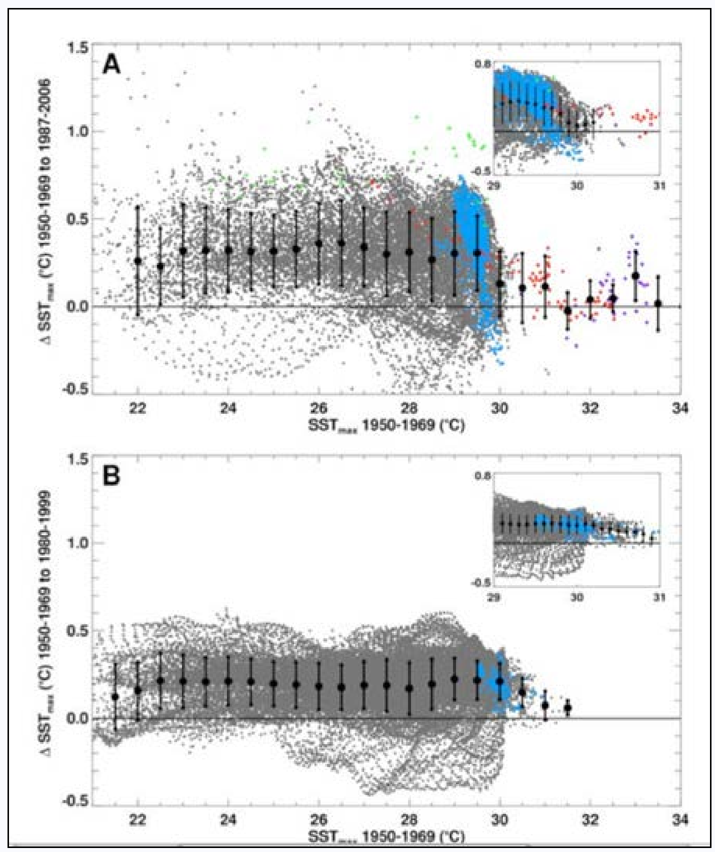
A joint NOAA/RSMAS/USGS/NCAR field exercise will be conducted in May 2009, to test various components of a seawater chemistry monitoring design on La Parquera Reef, Puerto Rico. At a larger scale, a collaborative project with researchers at CNRS, France, is underway, which attempts to synthesize the contribution of shelf calcium carbonate production rates on continental shelves. This synthesis is proving to be a critical to understanding the global carbon cycle as well as providing baseline data for ocean acidification studies. The modeling of coral reef chemistry continues, with the intent of improving our ability to predict how ocean acidification will affect coral reefs at regional to local scales. NCAR will also continue to play a leadership role in shaping US research on ocean acidification.

Temperature Extremes and Coral Bleaching

Coral bleaching, a phenomenon by which corals expel their symbiotic algae, has affected nearly 40% of reefs worldwide over the last 25 years, and has caused mass mortality of corals in about one-third of these events. Large-scale coral bleaching events are strongly correlated with extremes in sea surface temperature (SST). This project addresses the spatial variability in extreme events and how they determine coral reef bleaching patterns.

FY 2008 Accomplishments

A study that included analysis of both observations and model output examined the reasons for the regional differences in coral bleaching in the tropics. This study pointed to the potential for negative feedback mechanisms to keep temperatures in check in the western Pacific warm pool, an area that also has had a low incidence of coral bleaching. While both observational and model data illustrate the slower rate of warming in this region in the 20th century, model runs for the 21st century show that the rates of warming will increase at about the same rate as other tropical regions. Another study examined whether differences in coral bleaching rates are related to differences in the natural variability of sea surface temperature that in turn affects a corals tolerance of temperature change. This study illustrates that corals living in waters with naturally low temperature variability tend to bleach at lower temperature thresholds than corals from more variable environments.



(a) Warming of average maximum SSTs between 1950 – 69 and 1987 – 2006; mean (large black dots) and standard deviations (vertical lines) are shown for 0.5 deviation at 0.1 locations (based on HadISST). (b) As in (a), but comparing 1950 – 69 and 1980 – 1999, based on one member of the 20th Century CCSM3 integrations (from Kleypas, Danabasoglu, and Lough, 2008).

FY 2009 Plans

In a collaborative effort with the University of California, Berkeley and The Nature Conservancy, plans are underway to design a high-resolution modeling study of the Coral Triangle, the Australia-Indonesia region of high marine biodiversity. Pending funding, the goal is to use a Regional Ocean Modeling System adapted for the region to investigate the vulnerability of coral reefs to future changes in sea surface temperature. The factors determining susceptibility to bleaching will be assessed (e.g., exposure to temperature extremes, coral community composition), as well as the probability of reef recolonization by planktonic coral larvae following a coral mortality event. The goal of these work is to improve conservation efforts.

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GOAL 1: IMPROVE UNDERSTANDING OF THE ATMOSPHERE, EARTH SYSTEM, AND SUN

NCAR Strategic Priority 3: Improving Prediction of Weather, Climate, and Other Atmospheric Phenomena

Climate Downscaling

The Real Time Four-Dimensional Data Assimilation System developed at RAL generates a mesoscale re-analysis that is consistent with both observations and model dynamics. Even though it was originally developed for dynamic initialization of mesoscale forecasts with gridded data sets that contained fully developed mesoscale processes, the continuous data-assimilation process in RTFDDA is also ideal for generation of mesoscale climatologies. The RTFDDA technology, when applied in this way, is called the Climate-FDDA (C-FDDA) system.

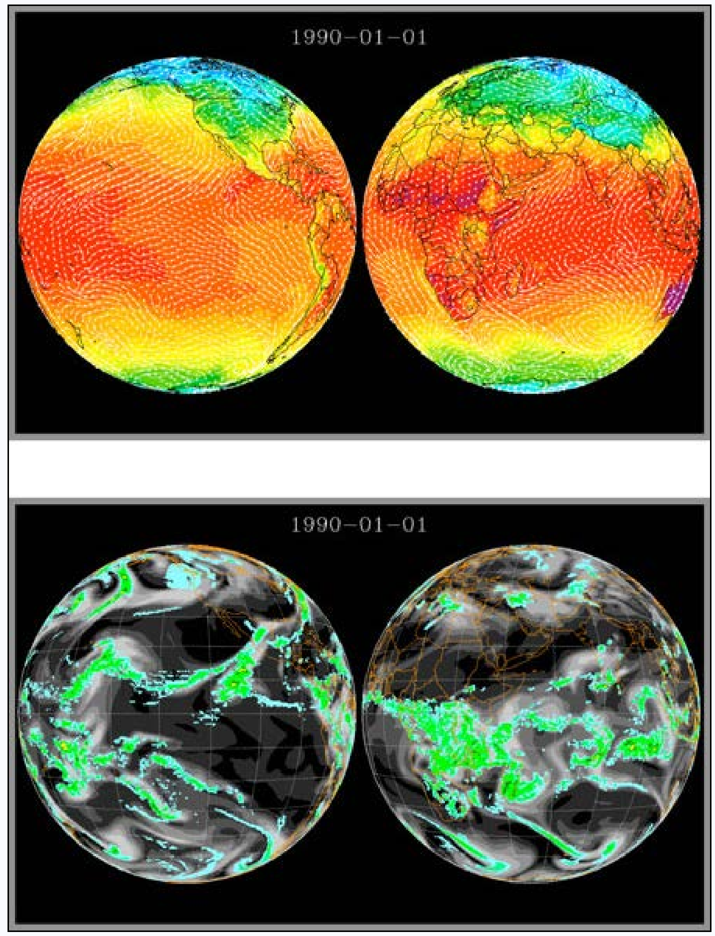

Figure A. Global surface air temperature and 10-m wind speeds (top) and relative humidity and hourly rain rate (green colors, bottom) produced from GLOBAL C-FDDA as part of the 21-year 40-km grid increment reanalysis.

FY2008 Accomplishments:

The current C-FDDA infrastructure, which involves performing observational data processing, model simulations with data assimilation, computation of statistical products, and model validation, is used in a number of applications:

- CFDDA has been used to create 60 months of hourly climatologies (2002-2006) at 25 sites spread across the world with 10 km grid size increment and over tiles ranging from 500x500 km2 to 1000x1000 km2 tiles. This project was carried out with an industrial partner in France: ARIA Technologies in support of the research activities conducted by Laboratoire de Recherche en Ballistique et Aérodynamique (LRBA), a French army lab developing unmanned aerial vehicle applications. The MM5-based C-FDDA technology has been transferred to LRBA with the permission of the US Department of State.
- A NEW global downscaled reanalysis product based on NNRP2 is being produced for the Defense Threat Reduction Agency (DTRA) for a 21-year period (Figure A). This product, which will have unprecedented spatial and temporal resolution (40 km and 1 hour, respectively) will be used by state, and local emergency managers for predicting the effects of accidental or intentional releases of hazardous material, as well as by military commanders for whom an understanding of “typical” atmospheric conditions in a given place on a given day will be useful in preparing strategic battle plans. The dataset, which is expected to be completed in early spring of 2009, is currently undergoing rigorous validation (Figure B).
- The Global Climatological Analysis Tool (GCAT, based on CFDDA technology) allows the U.S. National Ground Intelligence Center (NGIC) to generate a climatology for a region of interest, with typical boundary-layer conditions used to define likely directions and speeds of hazardous-material transport for different seasons and times of day. They have continued to use this tool throughout 2008 to generate high-resolution (grid spacing of 10 km) mesoscale climotologies for various

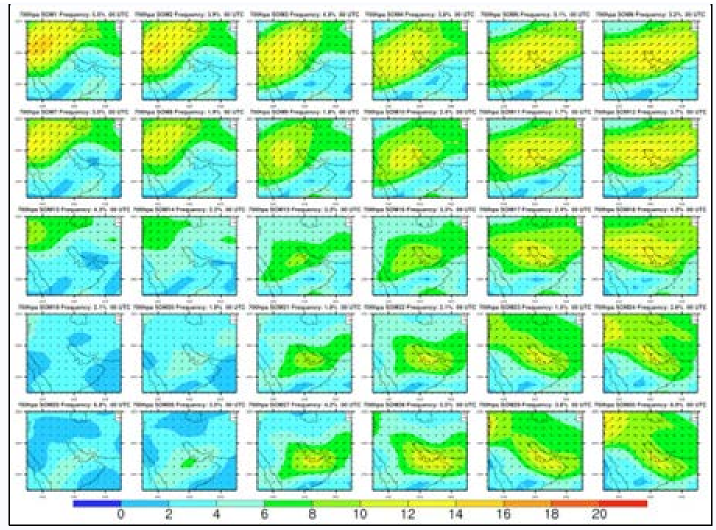

Figure B. Wind speed patterns from a 5x6 SOM mapping of 30 years of April 1-30, 0000 UTC GCAT analyses over the greater Persian Gulf region. Each tile shows the wind pattern associated with that node (coloring indicates speed in m/s) along with the frequency of occurrence for the pattern.

regions of the Earth.

FY2009 Plans:

Understanding the performance of our downscaling technologies in generating analyses is a crucial first step in understanding and representing climate variability on the mesoscale, and the application of these technologies to downscale future climates. With the size and number of climatological data sets continuing to grow, a number of post processing tools have been developed to organize and condense the data. Cluster-analysis techniques such as Self-Organizing Maps (SOM) allow us to identify weather or climate patterns and their associated frequencies (see Figure B). We can use clustering algorithms to define typical days for case studies and define climate-pattern-related climate statistics for hazardous-material transport and other applications.

Verification, evaluation and analysis of global reanalyses produced with C-FDDA system are ongoing, with current foci on the PBL structure, the 3D wind field and precipitation.

C-FDDA will also be employed to develop high-resolution regional-scale maps of cloud and precipitation mass profiles to be used to improve the specification of weather hazards and their impact on materials used in the manufacture of high-speed aero-vehicles.

C-FDDA technologies will continue to be transferred over to the WRF model which will soon replace the MM5 version.

Microphysical Observations and Modeling

It is widely recognized that uncertainties and approximations in the microphysics parameterizations within numerical models are a significant contributor to forecast error and that microphysics parameterization in models needs to be improved in order to significantly improve the skill of precipitation forecasts. An effort to develop multi-species microphysics schemes with accurate particle size distribution models and multiple moment schemes that are refined and verified with observations is progressing. The work involves coordinated system development with MMM through retrospective studies using operational and special field observations, and developing a new bulk microphysical parameterization for the Weather Research and Forecasting (WRF) model. Key areas for model improvement through upgraded microphysical schemes are: 1) quantitative precipitation forecasts and 2) cold pool and outflow formation and evolution.

FY2008 Accomplishments:

The microphysical parameterization described in Thompson et al (2008) was updated to include prediction of number concentration of rain. Previously, with prediction of rain mixing ratio only, the assumed rain size distribution was greatly constrained by the assumed y-intercept parameter. Predicting two rain variables produces more realistic representations of the rain size distribution and therefore should improve physical processes such as evaporation and rain fallout

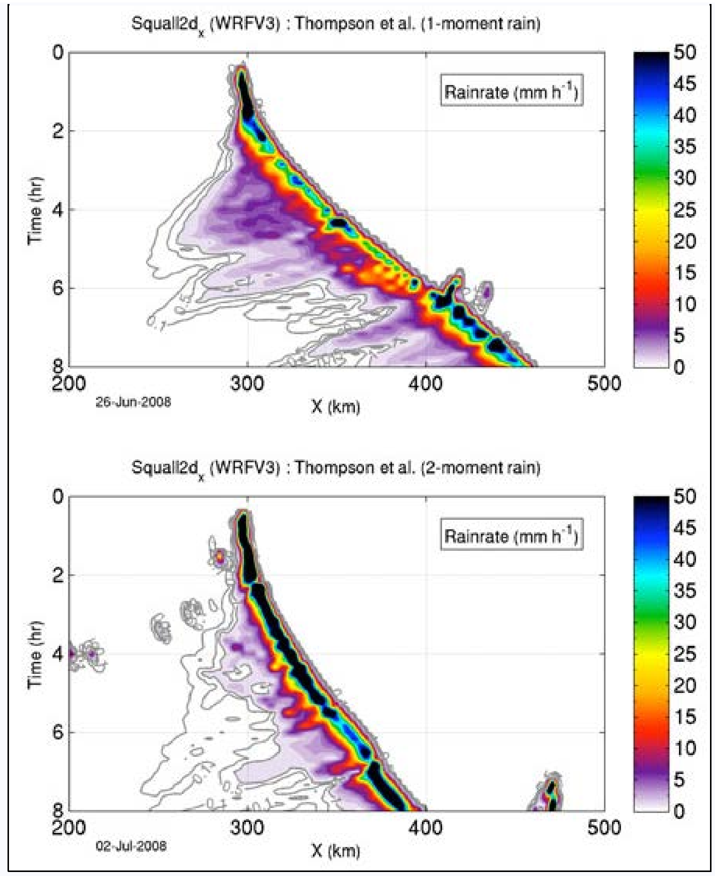

Figure 1. Time-distance plot of rain rate from a two dimensional squall line simulation. Upper panel provides the results from simulation with one moment of rain predicted (mixing ratio), and the lower panel two moments of rain predicted (mixing ratio and number concentration). Note the significantly slower propagation speed in the lower panel.

(see figure 1). The improved scheme was tested in idealized squall lines and supercells as well as events of freezing drizzle. Comparisons were also made to other WRF bulk microphysics schemes and more complex explicit/bin models. These comparisons were presented at the International Conference on Clouds and Precipitation (ICCP) in Cancun, Mexico and at the WMO International Cloud Modeling Workshop in Cozumel, Mexico during July.

A large dataset of aggregate terminal velocities obtained with a video disdrometer from winter storms along the Front Range in eastern Colorado was also examined. The data were stratified by temperature and power-law terminal velocity relations were computed for temperatures of –1º, –5º, and –10ºC (figure 2). Comparison with expressions found in the literature suggests that temperature-dependent relations may be surrogates for relations based on aggregate composition (e.g., plates, columns, or dendrites). The mean increase in terminal velocity with temperature for snowflakes of a specific size is attributed to increased riming.

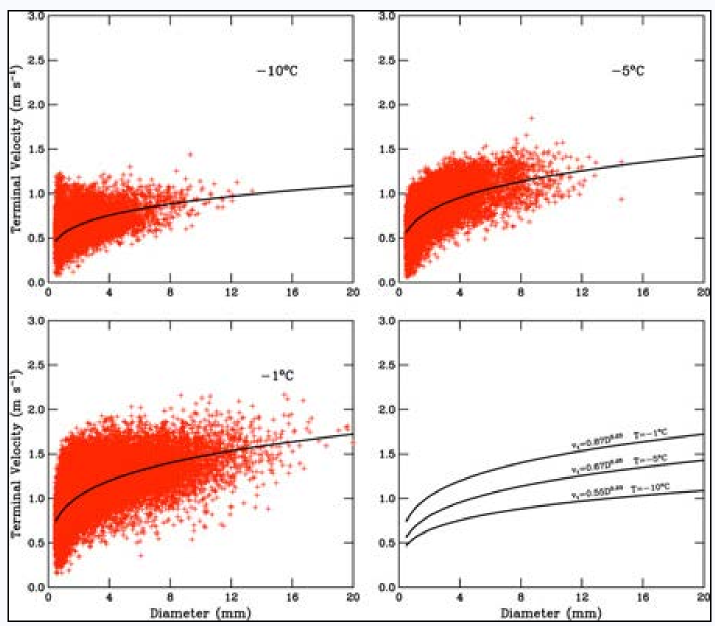

Figure 2. Snowflake terminal velocities plotted vs equivalent-volume diameter for various temperatures. Fitted relations are overlaid. Standard deviations are shown by vertical bars.

FY2009 Plans:

Expected activities for the coming year include:

- Collecting and analyzing observations that directly address key uncertainties in microphysical parameterization schemes in forecast models
- Improving the representation of processes in microphysical schemes based on observations
- Conducting additional case studies
- Verifying the storm simulations with observations
- Analyzing disdrometer data from a deployment in Oklahoma
- Adding treatment of aerosols, especially dust for ice initiation
- Applying the scheme in real-time WRF forecasts for use at the 2010 Winter Olympics in Vancouver, Canada

Pentagon and Urban Shield

The Pentagon, and its 25,000+ occupants, represents a potential target for a terrorist attack using chemical, biological, or radiological material released into the atmosphere. In response to this concern, the Department of Defense has engaged RAL to develop a building-protection system called Pentagon Shield (PS). The PS system assimilates meteorological and contaminant observations from remote and *in-situ* sensors into a complex linked system of models that operate together to represent processes from the mesoscale to the building scale. In the event of a hazardous-material release, the system calculates the properties of the contaminant source (e.g., location), the current characteristics of the contaminant plume, and the future path of the plume.

Caption

FY2008 Accomplishments:

Versions 1.2 and 1.3 of the building protection system were installed at the Pentagon during FY08. The system incorporates observational data feeds from Doppler radar and Doppler lidar, analyses of 3-dimensional wind fields from Doppler radial winds using NCAR's Variational Doppler Radar Assimilation System (VDRAS) and its Variational Lidar Assimilation System (VLAS), and numerical weather prediction capabilities from regional to metro scale using the Real-Time Four-Dimensional Data Assimilation System (RTFDDA). It blends observational and model data to provide redundant, continuous spatial and temporal coverage of non-building flow at a horizontal resolution on the order of 100 meters. Inclusion of building-flow effects through the use of two computational fluid dynamics (CFD) models provides characteristic flow fields at a scale of several meters within urban areas. By linking multiple, complex data-assimilation and forecast models to operate synchronously as a single system to depict the urban boundary layer from the mesoscale to the street-canyon/building scale, the building protection system provides a new ability to detect chemical and aerosol/particulate releases and predict the transport and dispersion of those releases.

The main task for v1.2 was the development and deployment of Urban Shield, an expansion of the modeling domain to cover a 144 km2 area of Washington, DC at 20 meter horizontal resolution. This has required the development of a distributed computing environment for the building flow diagnostic model, which consists of four 36 km2 tiles computing the flow effects of thousands of buildings. Urban Shield will be used to support emergency response efforts for both the DoD and Arlington County, Virginia.
The main tasks for v1.3 included moving point source terms and the ability to model dense gases.

FY2009 Plans:

Anticipated enhancements during FY09 involve inclusion of terminal Doppler weather radar data in the VDRAS system and porting the transport model to run on high-speed graphical processing unit (GPU) hardware.

River Flood Forecasting in Bangladesh

In 2000, the U.S. Agency for International Development (USAID) funded the Climate Forecasting Applications for Bangladesh (CFAB) project to provide advanced warning of severe flooding within the country of Bangladesh. This effort is based at the Georgia Institute of Technology, and involves an NCAR/RAL investigator, and colleagues at the Asian Disaster Preparedness Center (ADPC) in Bangkok, Thailand. While Bangladesh has its own well-developed river forecasting center, it has long been handicapped by very-limited and inconsistent river-discharge data-sharing between India and Bangladesh. As a result, two of its primary rivers, the Brahmaputra and the Ganges, were effectively ungauged basins above their entry point into Bangladesh from India, and advance warning of severe flooding events could only begin once observations were taken of the floodwaters crossing the India-Bangladesh border. To address this problem, CFAB issues operational forecasts designed to provide extended-lead-time information about the upper-catchment discharges of the Brahmaputra and Ganges Rivers before they enter Bangladesh. This is accomplished by utilizing ECMWF forecast products and NASA and NOAA precipitation estimates to produce short-range (1- to 10-day) and long-range (1- to 6-month) forecasts. Medium-range forecasts (20- to 25-day) use a statistical model to bridge these two time scales.

Caption

In addition to creating much improved forecasts, a good deal of effort was focused on disseminating those forecasts to the public. A pilot dissemination network was established in 2006 and a series of training workshops was conducted to teach people how to use the probabilistic discharge forecast information. The network was activated in 2007 in time to test the benefits of the short-range forecasting system for two severe flooding events. As a result of the advance forecasts, areas that would be hardest hit were evacuated in advance; other areas not forecast to be inundated by flood waters had the warning time they needed to mobilize food and safe drinking water for a week to 10 days, protect their rice seedlings and fishing nets, and raise and protect their fish pods. For the first time, 10-day advance official forecasts of significant chances of exceeding danger level in all the gauge stations along the Brahmaputra River were successfully communicated to the public. The dissemination network ultimately reached approximately 110,000 persons in five vulnerable regions within Bangladesh that have little access to advanced communication technology, let alone electricity.

FY2008 Accomplishments:

The existing forecast warning dissemination network is currently being expanded to include additional regions of Bangladesh, reaching more vulnerable citizens living primarily along the braided Brahmaputra River. This effort is being led by CARE-Bangladesh, the Asian Disaster Preparedeness Center (ADPC), and the Center for Geographic

The NCAR P.I., Tom Hopson, is working with Prof. Robert Brakenridge at the Dartmouth Flood Observatory (DFO) to assimilate satellite remotely-sensed estimated river discharges higher up in the Ganges and Brahmaputra watersheds to improve the forecast skill and accuracy of the CFAB forecast scheme. Because these river basins have essentially no operationally-available observations of river discharge higher up in the catchments, the DFO discharge estimates can provide beneficial estimates of the initial conditions of river channel flow within these large basins. By developing new data-assimilation approaches to assimilate these data, potential increases in useful forecast skill out to 15 days may be realized.

FY2009 Plans:

The researchers are also implementing a new pilot program to generate additional forecasting points within India so that citizens of that nation may also benefit from these long lead-time forecasts. This new initiative is also being expanded to the Awash River Basin in Ethiopia, in collaboration with Prof. MeKonnen Gebremichael at the Univ. of Connecticut.

Experience gained through the Bangladesh program will be applied in a new effort in the Northeast Highlands of Bangladesh, where severe flash floods early and late in the monsoon season have led to numerous deaths and extensive property damage. Hopson is working with the ADPC and the Bangladesh Institute for Water Modeling (IWM) to utilize WRF-produced 6- to 36-hr in-advance lead-time precipitation forecasts run at ADPC to drive multi-model hydrologic forecasts of severe flooding. The team is working to make the system operational by the start of the 2009 monsoon season.

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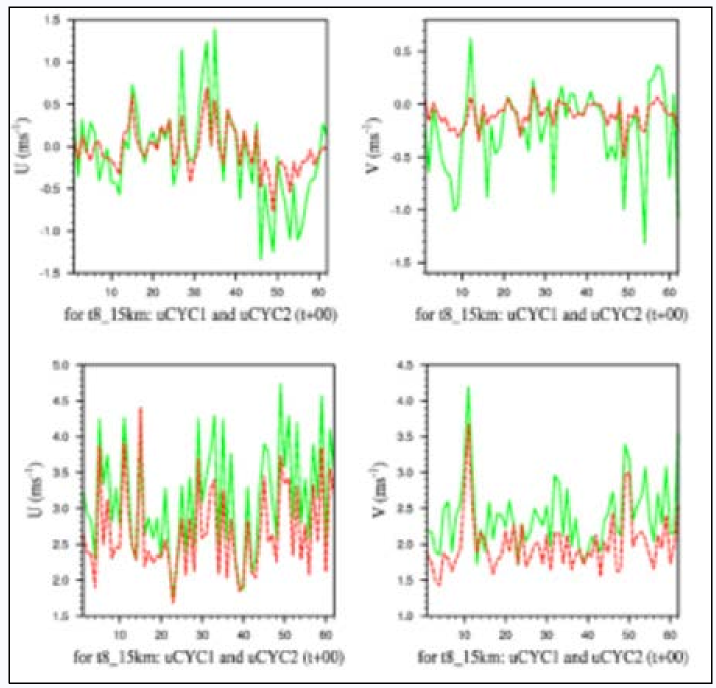
GOAL 1: IMPROVE UNDERSTANDING OF THE ATMOSPHERE, EARTH SYSTEM, AND SUN

NCAR Strategic Priority 4: Developing Community Models

Data Assimilation Testbed Center

In its second year, the DATC has performed detailed assessments of data assimilation capabilities in a number of testbeds and collaborated with other divisions in community support:

AFWA Testbed (Caribbean domain): One emphasis of the DATC is to ensure that its primary sponsor, the Air Force Weather Agency's (AFWA) data assimilation and forecasting systems are thoroughly tested to meet its unique set of requirements. In FY2008, the DATC conducted an extensive series of experiments to evaluate various data assimilation techniques, forecast impacts of various observations, observations error tuning, and multi-loop observation rejection schemes. All experiments were performed between August 15 and September 15, 2007 (hurricane season) for up to 24-hour forecasts four times per day. Case studies from the experiment were then analyzed, and results from the program were presented at the 9th WRF Users' Workshop in July 2008.



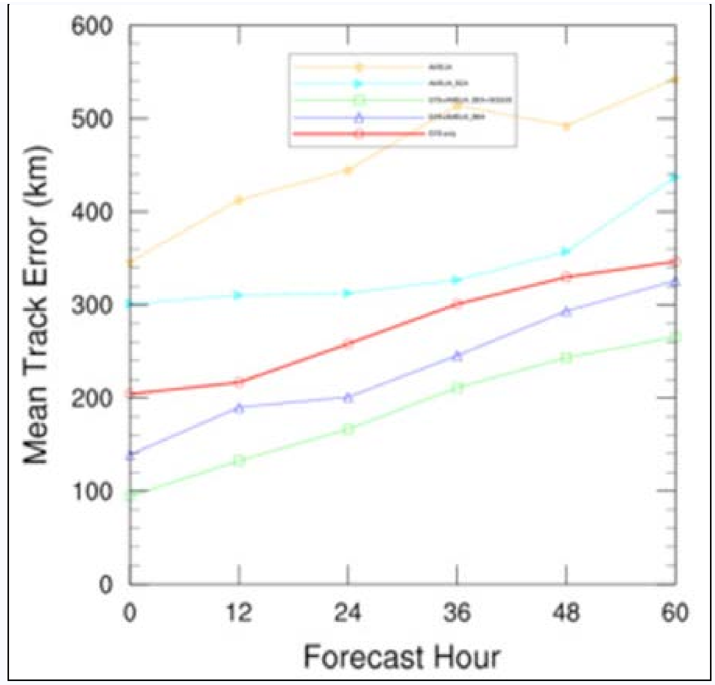
The time series of biases (upper panels) and root-mean-square errors (lower panels) of WRF-Var wind component analyses verified against surface synoptic observations: assimilation of Global Telecommunication System (GTS) observations only (green) and assimilation of GTS observations plus QSCAT sea wind observations (red). The x-axis units are number of twice daily verifications.

AMPS Testbed (South Polar domain): The DATC provides data assimilation support for the Antarctic Mesoscale Prediction System (AMPS) project. In 2008 this work included generation of background errors and investigation of impacts of Advanced Microwave Sounding Unit (AMSU-A) radiance data on Antarctic weather forecasts. The study found a positive impact of assimilating AMSU-A radiance data over the ocean with regard to wind and moisture forecasts. But significant biases at the model top destabilized the WRF model, especially when using analyses from assimilation of radiance data in WRF-VAR as the initial conditions. Results from AMPS WRF-Var work were presented at the 3nd Antarctic Meteorological Observation, Modeling, and Forecasting Workshop in June 2008.

CAA Testbed (East Asia domain): The Taiwanese Civil Aeronautics Administration (CAA) Testbed is a pre-operational testbed to evaluate the CAA's WRF-ARW and WRF-Var systems in Pacific applications. The DATC investigated AMSU-A radiance data impacts on typhoon forecasts. The study found a positive impact on hurricane intensity and track forecasts. One negative result appeared to be a degradation of hurricane forecasts due to assimilation of radiance data over land. This study provided a rational and scientific basis for the operational implementation of radiance data assimilation in Taiwan weather forecasting system.

KMA Testbed (East Asia domain): The Korean Meteorological Administration (KMA) Testbed features embedded domains with10-km and 3.3-km horizontal resolutions. The DATC evaluated impacts of radar data assimilation and model resolution on regional forecasts. The study found that radar (radial velocity) data assimilation improves intensity forecasts of precipitation while high-resolution data assimilation improves precipitation locations but degrades intensity forecasts.

Indian Testbed: The Indian Testbed explores the use of WRF NMM dynamic solver with both the NCEP's operational GSI data assimilation system and the NCAR's WRF-Var data assimilation system for the



The mean track errors of WRF-Var analysis and WRF forecasts for typhoon SEPAT during August 13-19, 2007 verified against the Joint Typhoon Warning Center (JTWC) best track: GTS data only (red), GTS plus AMSU-A radiance data over ocean (blue), GTS, AMSU-A radiance over ocean plus Typhoon bogus data (green), AMSU-A radiance data over ocean only (cyan) and AMSU-A radiance data over ocean and land (orange).

forecast of tropical cyclone track and intensity over the Bay of Bengal. This work is a collaborative effort with visitors to the DATC from India.

WRF-Var Tutorial: The DATC conducted a two-day joint WRF-Var Tutorial with ESSL/MMM in August 2008. It was the first WRF-Var tutorial held separately from the bi-annual WRF tutorials.

FY2009 Plans

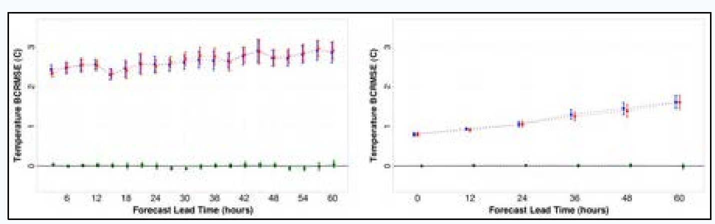
In 2009, the DATC will continue detailed testing of data assimilation capabilities in a variety of applications. The current AFWA, Antarctic and Taiwanese WRF data assimilation testbeds will be supplemented with the NCEP GSI data assimilation system, the ESSL/Data Assimilation Research Testbed (DART) ensemble data assimilation system, and enhanced WRF-ARW with polar physics.
The DATC will collaborate with the Developmental Testbed Center on the reference and operational configuration of data assimilation components of the WRF modeling system. It will also continue to work with ESSL/MMM on the WRF-Var tutorial and provide community support.

Developmental Testbed Center

The Developmental Testbed Center (DTC) is a national facility created in 2003 to facilitate the interaction of the operational and research communities in accelerating the improvement of Numerical Weather Prediction (NWP) for the U.S. The DTC effort at NCAR includes:

- A program for testing and evaluating various WRF model configurations. Results of this testing benefit both the operational and research communities.
- A visitor program that invites members from the operational and research communities to participate in the testing and evaluation of WRF.
- A user support system that provides documentation, tutorials, and helpdesk capabilities to aid users in accessing and using WRF codes.

FY2008 Accomplishments:



Annual median bias-corrected root-mean-square error for temperature as a function of lead time for 2-m (left panel) and 500 hPa for the ARW (blue), NMM (red) and ARW-NMM (green). Vertical bars represent the 99% confidence intervals.

WRF Testing and Evaluation: The current WRF Software Framework (WSF) supports two dynamic solvers: the Advanced Research WRF (ARW) developed by NCAR/MMM, and the Nonhydrostatic Mesoscale Model (NMM) developed by NCEP. In FY08, the DTC completed its extended Core Test for which intensive retrospective testing of the NMM and ARW was undertaken for lead times out to 60 hours. This testing showed that the errors for each core grow with lead time, whereas the inter-core differences, for the most part, did not grow with lead time.

High Resolution Hurricane Test Plan: In March 2008, the DTC hosted a workshop to design a test to evaluate the potential for high-resolution hurricane numerical prediction systems to impact NOAA services through improved hurricane forecasts. Workshop participants included representatives from seven modeling groups, hurricane and verification experts, and operational hurricane forecasters. DTC staff prepared a test plan reflecting the loose constraints agreed upon during the workshop. In addition to preparing the test plan, DTC staff began making preparations to evaluate the retrospective forecasts provided by the modeling groups. The focus of this testing activity is the impact of horizontal resolution on the forecast skill, and in particular on the intensity forecast.

WRF Code Management: During FY08, the DTC continued to develop the concept of WRF Reference Configurations. Feedback on

the document describing this concept was gathered from the DTC Technical Review panel members. The concept was also presented at the WRF Users Workshop in June 2008 and input from the general WRF community will be incorporated into the final version of the document.
WRF Tutorials: The DTC and MMM conducted two WRF Tutorials (January and July 2008). These tutorials include lectures on the pre-processor, model, and post-processing tools, as well as practical sessions that allow the participants to gain hands-on experience building and running each component of the end-to-end system. Lectures and hands-on exercises for the Model Evaluation Tools (MET) were added to the July tutorial, as well as moving from a 1-week to a 2-week format, where data assimilation and WRF-Chem were covered in the second week. The tutorial participants represented a broad cross-section of the national and international community.

DTC Verification System: During FY08, the DTC continued to work on the critical task of assembling a state-of-the-art verification toolkit, the Model Evaluation Tools (MET). This work is highlighted in a separate section of this RAL Annual Report.

DTC Visitor Program: The DTC released an "Announcement of Opportunity" for its 2008-2009 Visitor Program in February 2008. The DTC received 11 proposals and 5 of these proposals were selected for funding. These projects address much needed work in the areas of testing and evaluation, ensemble techniques, and new numerical techniques.

FY2009 Plans:

WRF Testing and Evaluation: During FY09, the DTC will implement the Reference Configuration process. Part of the process will include intensive retrospective testing of at least two WRF configurations.

High Resolution Hurricane Test Plan: During the first half of FY09, the DTC will complete preparations of its end-to-end evaluation system for this test plan and then process the retrospective forecasts provided by the participating modeling groups. Processing of these forecasts will be completed in early 2009 and a report will be prepared based on all the submitted forecasts. The results of this test will be presented at a workshop planned for March 2009.

WRF Code Management: The DTC will continue to further develop the concept of Reference Configurations by discussing the potential for Community-Contributed Reference Configurations with a panel of university professors. The Reference Configuration document will be updated to reflect the outcome of this discussion. The revised document will be distributed to the community for comment.

WRF Tutorials: Bi-annual WRF Tutorials are planned for FY09 (i.e., winter and summer offerings). The winter tutorial will continue the new two week format with the modification of moving the MET material to the second week and providing an opportunity for members of the community to register for this portion of the tutorial separately.

DTC Verification System: During FY08, work will continue to extend the capabilities of MET to include a broader spectrum of verification capabilities. Members of the verification community will be invited to join DTC staff for a workshop in Spring 2009 to discuss new capabilities for MET.

DTC Visitor Program: Another "Announcement of Opportunity" is expected to be issued in February 2009.

Land Surface Modeling

RAL scientists work to understand, through theoretical and observational studies, the complex interactions (biophysical, hydrological, and bio-geochemical) between the land-surface and the atmosphere at micro- and mesoscales. The ultimate goal is to integrate such knowledge into numerical mesoscale weather prediction and regional climate models to improve prediction of the impacts of land-surface processes on regional weather, climate, and hydrology. Land surface modeling efforts were funded in FY08 by NSF, the Air Force Weather Agency (AFWA), NOAA, NASA, DTRA, and the CFD Research Corporation.

FY2008 Accomplishments:

As part of a major collaborative effort among NCAR, NECP, NASA/GSFC, AFWA and several university groups, RAL scientists supported the development of the Unified Noah land surface model (LSM) for the numerical weather prediction community and its implementation in the Weather Research and Forecast (WRF) model. The Unified Noah LSM V3.0 was released in April 2008. The Noah LSM is enhanced for use in the Colorado Headwater project and for long-term Arctic simulations, and these enhancements include more and deeper soil layers, a zero-flux bottom boundary condition and a multi-layer snow model. A prototype has been developed to couple the Noah LSM, a multi-layer canopy model, a biogenic emission model (MEGAN), and a photosynthesis-based canopy resistance model (GEM).

To meet the need for accurate weather prediction over urban areas (especially important for the air-quality modeling community), an advanced single-layer urban canopy model (UCM) was coupled to Noah and released in WRF V2.2. In a new project started in FY07, supported by the Defense Threat Reduction Agency (DTRA), we are working towards improving the land-use data set in the DTRA Joint Effects Model/Hazard Prediction and Assessment Capability (JEM/HPAC) system and in WRF. A multi-layer urban canopy model has been implemented in WRF and tested for idealized cases and real cases for Houston. The coupled WRF/UCM was used to investigate the effects of

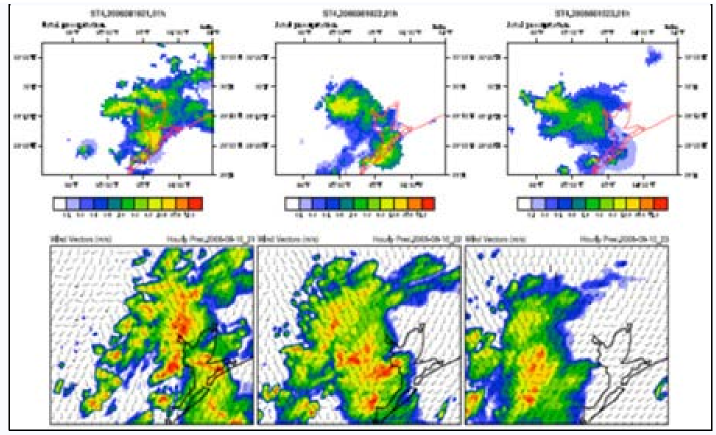


Figure 1: Hourly precipitation valid at 2100 UTC(left), 2200 UTC (middle), and 2300 UTC (right) on 10 August 2006. The Upper panels are WRF/UCM simulations and the lower panels are 4-km Stage-IV precipitation analyses.

urbanization on summer convective rainfall over the Houston, Texas region. We focused on evaluating the ability of the WRF model to simulate these fine-scale convective processes and investigating the impact of the urban area on the evolution and characteristics of such convective systems. As shown in Fig. 1, the WRF/UCM simulation reasonably captures the important characteristics of a heavy rainfall event on 10 August 2006.

The team also applied the Noah-urban modeling system, with 500-meter grid spacing, in WRF, where the resulting forecast fields were used to drive a LES-model-based transport and dispersion (T&D) model with grid spacing of a few meters for a case study during the Joint Urban 2003 field experiment conducted in Okalahoma City.

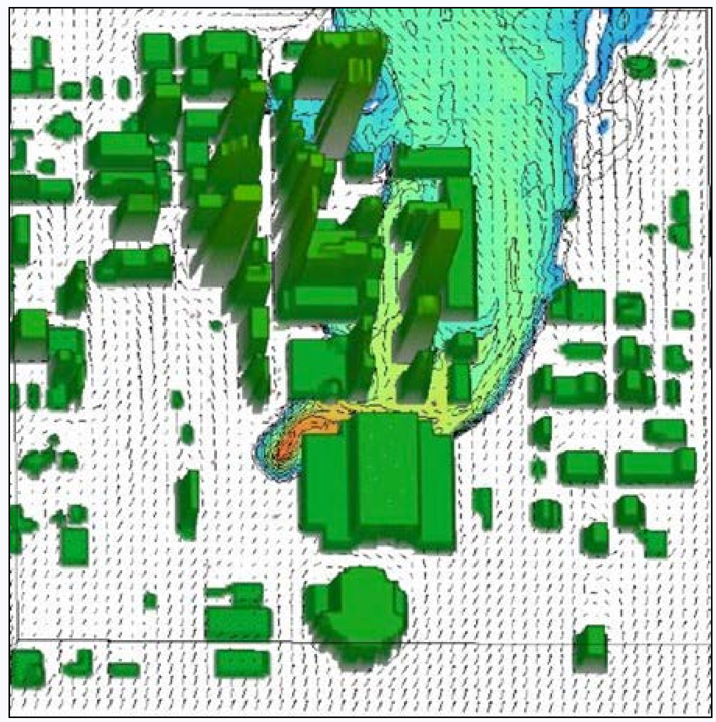


Figure 2: IOP6 dispersion footprint for SF6 passive tracer released from a source located at the Botanical Gardens, Oklahoma City.

Verification results indicate that the use of the WRF forecasts by the quasi-steady CFD-Urban model has resulted in a significant improvement (by four or five times) in the accuracy of T&D calculations, compared with input from a single sounding instead of WRF. We focus on the accuracy of both the mesoscale and LES wind field statistics and the LES T&D of a SF6 tracer gas in the convective daytime boundary layer (IOP6). See Fig 2. for an example of the near surface urban flow and dispersion footprint.

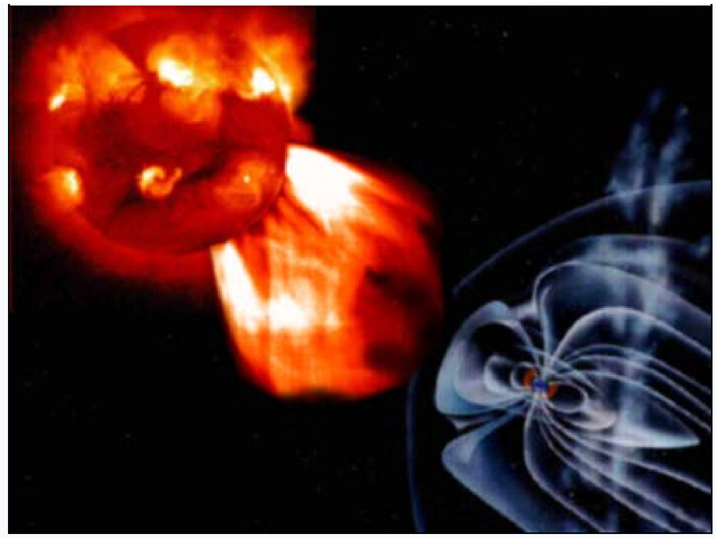
Although the important role of soil moisture in the development of deep convection has been recognized, it remains the most difficult variable to obtain because there is no routine high-resolution observation of soil moisture at the continental scale. Thus, a High-Resolution Land Data Assimilation System (HRLDAS) has been developed to support the WRF/Noah coupled land surface modeling system and ATEC range forecasts. It uses observed hourly precipitation, solar radiation derived from satellite, and analyzed surface wind and temperature to force a land-surface model to simulate the evolution of soil moisture. In this system, the NCEP/NOAA hourly 4-km rainfall analysis, based on NEXRAD and rain-gauge observations, is used so that errors in soil moisture caused by precipitation and radiation biases in coupled modeling systems could be avoided. HRLDAS has been extended to Asia and the Arctic to support real-time weather forecasting needs and long-term reanalysis of the Arctic land component. An infrastructure was developed for conducting ensemble Kalman filter data assimilation for soil moisture and temperature using SCAN observations.

FY2009 Plans:

- Further develop the ensemble Kalman filter approach and possibly interface HRLDAS with DART. Create interface so that WRF users can download and use MODIS 1-km tiles as input. Create a new climatology of MODIS-based products for Noah and HRLDAS.
- Test and evaluate the implementation of the Land Information System (LIS) developed at NASA in the coupled WRF/LIS framework.
- Test, evaluate, and release enhancements in the Noah LSM for the next WRF release in March 2009.
- Apply and evaluate the NUDAPT urban data in WRF/UCM for Houston region.
- Evaluate the coupled Noah-GEM/MEGAN model.

Space Weather Testbed Center

Space weather predictions describe the physical conditions in the geospace environment which are particularly important when they are disturbed by energetic events occurring on the Sun. These disturbances can affect human spaceflight, air travel satellite design, and the communication and navigation systems used throughout the globe.



FY 2008 Accomplishments:

The Space Weather Prediction Testbed (SWPT) was established within RAL's Joint Numerical Testbed program in 2008 in collaboration with ESSL/HAO, the Air Force Weather Agency, NOAA's Space Weather Prediction Center, and other members of the space weather community. Its goal is to serve as a center for testing and evaluating numerical models of the solar-terrestrial environment with the ultimate goal of facilitating their transition into operations at the Space Weather Prediction Center.

FY 2009 Plans

A management plan will be created for the Center, establishing a process for testing candidate space weather models and evaluating their potential for transfer to operational space weather organizations. A workshop will be held at NCAR in November 2008 to bring together stakeholders to discuss the management plan and to begin to draft a plan for testing candidate models.

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GOAL 2. INCREASE SOCIETAL RESILIENCE TO WEATHER, CLIMATE, AND ATMOSPHERIC HAZARDS

Strategic Priority: Investigating Weather and Climate Information Needs and Decision Making

ADAPTE: Adapting to Health Impacts of Air Pollution and Climate Extremes in Latin American Cities

This program, funded by the Inter-American Institute, seeks to investigate a crucial and not yet fully explored problem: the independent and combined effects of exposure to weather related stresses and air pollution on human health in four Latin American cities-- Buenos Aires, Argentina; Bogotá, Colombia; Mexico City, Mexico; and Santiago, Chile. The project will explore how patterns in human mortality/morbidity and vulnerability vary spatially, as well as how human and natural factors account for differential distribution of mortality/morbidity within the cities.

FY2008 Accomplishments

Efforts to find new ways to characterize uncertainty include development of new techniques for establishing probabilities for regional climate projections. An integrated project on uncertainty is also underway that embraces physical system impacts and decision making in the context of water resources. This project uses the probabilistic information developed from future climate model projections, and applies them within a water resources model to establish likelihoods of different water flow levels in several basins in California. The second area of research, extreme weather and climate events, is being explored through analyses of intense phenomena such as thunderstorms and tornadoes using climate models. A toolkit which allows for the easy application of extreme value methods to climate data has also been developed. This work is described in more detail under Goal 4 in this Annual Report. Accomplishments with regard to better understanding the role of climate in human health are explained in Goal 2 of this report.

A number of other projects have been conducted with funding from WCIASP. Highlights of these efforts can be found within the relevant Laboratory's Annual Report: Making inferences about climate and weather extremes (RAL); Spatial scaling of extreme events (CISL/IMAGe); Using the CCSM/CLM to improve climate impact assessment studies (ESSL/CGD, and U. Kansas): and Developing regional benchmarks to improve input data quality for impacts assessments (ESSL/CGD and NOAA).

FY2009 Plans

Efforts will focus on mapping and examining spatial patterns of heat/air pollution-related cases of mortality/morbidity. Based on outcomes of the mapping, we will identify vulnerability factors (e.g., age, socio-economic status, etc.) and conduct preliminary mapping of vulnerable areas (e.g., municipalities).

We will also hold a workshop on November 16-18 at NCAR. P.I.s and students will be trained on concepts and techniques relevant to our study. In particular, we will focus on comparing the four cities in terms of underlying factors of temperature, air pollution and vulnerability to extreme weather and air pollution; and planning the agenda for identifying the unique and common adaptive capacities and adaptation strategies in four Latin American cities. We also plan to write a paper presenting our initial results.

Climate and Health

Scientists are researching the complex interactions among climate processes, ecosystems, and human health in order to improve projections of climate impacts on human health and the health of the planet. This research will also help to 1) determine appropriate adaptations to potential threats to human health; 2) sort out the complex relationships between climate and ecosystems; and 3) help educate the next generation of researchers in these complex interwoven areas. Work has focused in four areas thus far:

Health Risks from Climate Change and Variability in Wisconsin. Started in FY06, this project concerns the analysis of the effect of extremes in temperature and precipitation on human health (morbidity) in Wisconsin and Chicago. Relationships between these extremes (heat waves as well as extreme run-off from extreme precipitation) and human morbidity are being examined. In 2007- 2008, observed temperature data and health data have been analyzed, and significant relationships obtained. In 2009, the relationships between observed conditions will be completed and potential changes in morbidity under conditions of climate changed determined. Potential adaptations (how we can cope with increased heat stress) to the new climate regime will also be explored.

Human-Environmental Interaction and Risk for Dengue Fever. Dengue is an emerging arboviral disease with worldwide impact. Increasing numbers of cases of this disease in both the Americas and Asia necessitate an examination of changing human and vector ecology in order to better understand the dynamics of dengue transmission. This transmission is especially important in geographic areas where dengue has more recently emerged. Research in these areas seeks to develop interventions to slow or halt the further expansion of dengue, and to efficiently focus preventive efforts. An outbreak investigation within the Lower Rio Grande was conducted in Brownsville, Texas and Matamoros, Mexico in 2005. This research revealed the highest prevalence of human anti-dengue antibodies in the continental United States in the last 50 years and the first case of classic dengue hemorrhagic fever acquired in the continental United States. The data indicate many more infections in Matamoros than in Brownsville and highlight the need to delineate the various influences, including climate, on dengue transmission dynamics.

Because dengue fever is transmitted by an urban, peridomestic mosquito, examination of waste tires and other water-holding containers in close proximity to households is critical to a clear understanding of the potential role that tires play in mosquito breeding sites. To better inform educational campaigns directed toward tire clean-up, it is necessary to ensure that household members understand the risk and are willing to engage in activities leading to tire removal/mosquito breeding site mitigation. Local government efforts to control tires must also be informed by careful evaluation to ensure efficient and effective quality control efforts.

Analysis and write-up of the 2007 field work is under way, and a poster has been accepted for presentation at the annual meeting of the American Society of Tropical Medicine and Hygiene in December 2008. Additional field work was undertaken in summer of 2008 to better define the ecology of *Aedes aegypti* and *Aedes albopictus* in this border region. Funding will be sought to expand the study to better understand the human-environmental interactions that contribute to disease transmission in the TX-MX border region.

Workshops on Climate and Health: The effects of climate on human health are a very sensitive and complex area of impacts research. It is also one that society is most concerned about when facing climate change. Careful training is necessary to perform high quality research in this area. Two very successful interdisciplinary workshops on Climate and Health were conducted by ISSE (FY04 and FY06), in which graduate students learned from a wide range of experts how to develop complex interdisciplinary health projects. These workshops form part of the Weather and Climate Impacts Assessment Science Program (WCIASP). The next biennial workshop will take place in FY09 and will focus on the individual and combined effects of heat stress and air pollution. This topic reflects the growing concern regarding these combined stresses on human health. The workshop will also link with on-going research efforts regarding heat stress, vulnerability and adaptive capacity in Phoenix, Arizona.

A prototype Earth-gauging system integrating weather and health data to manage meningitis. This project aims to build and implement a prototype decision-support system that integrates two- to 14-day weather forecasts and epidemiological data to provide actionable information that can be used to contain the spread of meningitis epidemics. In 2009 we intend to establish local partnerships in Ghana, demonstrate weather-meningitis links, and develop and verify ensemble derived forecasts for meningitis management.

Decision Support for Water Resource Management

RAL scientists are working on several fronts to help policy and other decision makers better understand the impact of climate change on water resources and to develop new tools to help them in their planning processes. At present, work is focused in the following areas:

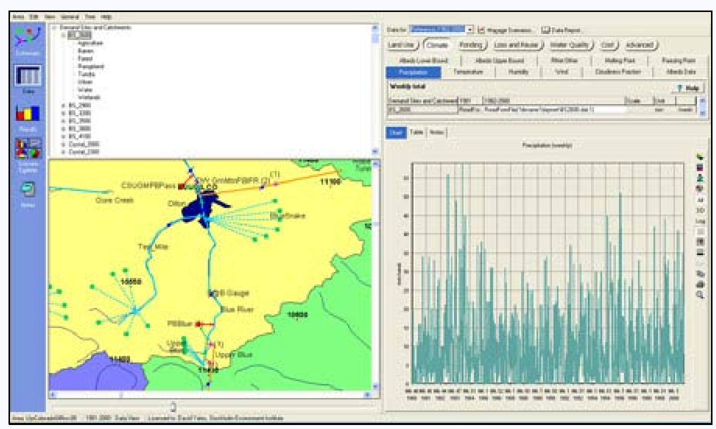


Fig 1. Representation of the Upper Blue River basin in the WEAP decision support system.

Incorporating climate change information in water utility planning: A collaborative, decision analytic approach: Working with five water utilities across the United States, this project builds upon a partnership with the American Water Works Association Research Foundation that produced an educational primer for the drinking water industry on global climate change and its potential impacts on municipal water utilities. The current project is taking the next step in this collaboration by engaging a select set of municipal water providers and related regional coordinating bodies in the development of decision support tools that will facilitate assessments of water utility vulnerabilities and response options to prospective climate changes. The project will focus, in particular, on the problem of planning in the context of uncertainties surrounding the local-scale hydrologic changes that will result from global climate change. A structured assessment process is being developed that includes decision support tools and decision analytic techniques such as risk and uncertainty analysis to help the drinking water industry conduct scientifically-sound and cost-effective assessments of utility vulnerabilities and adaptation options in the context of climate variability and change. Activities in FY09 will include the publication of a report that describes each of these utility collaborations and its climate goals and objectives.

In addition, Kathleen Miller has begun working with Rob Wilby (U. of Loughborough, UK) on a related project aimed at developing a compendium of resources, tools and information related to the analysis of climate change impacts. The target audience includes professionals in the water supply and wastewater industries. Both projects will be extended and concluded in FY09 with incorporation of insights from the work in guidance documents for industry professionals.

Sharpening Drought Plans by Considering Climate, the Watershed, the Regulatory Environment, and the Forces of Change. Drought is particularly unsettling for water utilities as it introduces a confounding financial conundrum: Revenues are generated by selling water, and yet during droughts utilities must encourage their customers to conserve, accepting the unwanted consequence of revenue reduction. This NOAA- supported project is motivated by a set of underlying questions: Can a utility develop a drought plan that minimizes costs borne by its customers, the environment, recreationalists, and even itself? What are the tools and techniques that should be brought-to-bear to develop such a robust plan?

To investigate these questions, we have partnered with the Stockholm Environment Institute, the University of California, Berkeley, and a set of water utilities in El Dorado County of Northern California. The utilities are currently in the midst of formulating drought plans, but believe they can use innovative tools and economic instruments to make their drought plan robust to their customer needs and their own financial interests. Through our interactions, the utilities have begun to wonder if their current analytical process leads to a "best" plan. Would adding more analytical rigor to their drought planning process via decision support (e.g. dynamic climate; alternative drought sequences; socio-economic factors; and other agents of change) lead to new insights? The decision support of interest is the Water Evaluation and Planning (WEAP) model that dynamically integrates climate, watershed hydrology, water management, and the financial dynamics of water utilities in one easy-to-use application.

Plans for FY09 include the continued development of the WEAP application and demand model for the utility, dialogue and interaction with EID, and the write-up and publication of a report and peer reviewed publication.

Decision Support for climate-responsive urban and agricultural water supply and demand. This NOAA- funded project is investigating the impact of water supply transfers on communities in the U.S. western states, particularly in the Arkansas River Valley of southern Colorado. Population growth and drought are already inducing substantial transfers of agricultural water to urban use, because other "new" water supplies are absent or very limited. Climate change may aggravate this. There are unfortunately large uncertainties about what water transfers will do to the areas from which water is removed, as well as limited knowledge about the interests which are not traditionally represented in the market because of the limits imposed by water law. Making socially beneficial changes in resource management will require considering all these factors.

For the past several years RAL researchers have been developing new applications for the WEAP model, described above, to more specifically address the needs of Western water decision makers. In FY2009 we plan to modify WEAP to support the implementation of new legal and institutional forms of water transfer that have recently been authorized or are under consideration in Colorado. The WEAP21 model has been tested for "demand side" uses, but not yet for "supply side" or transferor uses. The new forms would be radically more climate-responsive than the traditional forms of "buy-and-dry" transfer of agricultural water, in which lands are simply withdrawn from irrigation and local economies are often acutely impacted, but they are not easily examined or evaluated without modeling. The threat of cumulative impacts and unpleasant surprises in biological impacts must also be considered, although this is difficult because land and water resources in the area are both private, and there is almost no field study of the ecology of irrigation there.

Institutional Aspects of Vulnerability and Adaptation: Marine Fisheries

Rapid technological and socioeconomic changes have fueled explosive growth in global marine fish harvests. The resulting competitive harvesting race has often squandered the potential economic value of these resources while significantly damaging both targeted and non-targeted fish populations. International fishery governance institutions have often proven to be ineffective in avoiding such outcomes, and explanations for their ineffectiveness often point to the difficulty of enforcing agreements, maintaining cooperation and monitoring resource status in the context of climate-driven environmental variability. This situation suggests that scientific efforts to improve the ability to monitor and predict the status of marine fishery resources could contribute to more socially and environmentally responsible management, but it is also clear that such information may have little value in the absence of improvements in the design of the governance arrangements. Kathleen Miller (ISSE) has played a leading role in efforts to analyze how institutional factors and economic incentives affect efforts to sustainably manage internationally shared oceanic fishery resources in the presence of climate variability and other stresses.

FY2008 Accomplishments

In FY08, Dr. Miller worked with Dr. Peter Golubtsov (Moscow State Lomonosov University, Russia) and Dr. Robert McKelvey

(University of Montana, emeritus) on the analysis of a game theoretic model pertinent to the management of ENSO-affected tropical tuna stocks in the Western and Central Pacific. The project is making innovative contributions to the analysis of international fishery management problems by modeling the distinctly different roles and motivations of three different types of players. Dr. Miller presented a paper describing the project's findings at an international symposium sponsored by the UN's Food and Agriculture program in Rome. The paper was one of a small number of symposium papers selected for inclusion in an edited book to be published in FY09.

FY2009 Plans

Final revisions to the paper will be made in FY09. Also in FY09, Dr. Miller will organize a day-long workshop on "Socio-economic dynamics and ecosystems, governance implications" to be held in conjunction with the GLOBEC final Symposium. In addition, she will continue to contribute to international scientific planning through the U.S. Global Ocean Ecosystems Dynamics (GLOBEC) program.

Role of Institutions in the Use of Climate-Relevant Information

Cities are both significant emitters of carbon dioxide and centers of innovations that may contribute to de-carbonizing our societies. Local authorities should be included in mitigation efforts for addressing climate change; however, few studies have analyzed how local authorities use knowledge on climate in urban areas in middle- and low-income countries. P.I. Paty Romero Lankao is working to provide in-depth analysis of how local authorities use scientific information to formulate mitigation and related policies. Research undertaken in Latin American cities financed with grants from the Global Change Sys Tem for Analysis, Research and Training (START), the Inter-American Institute (IAI) and the National Science Foundation, suggests that a process of social learning regarding climate change has taken place. Although these urban centers are not big emitters of carbon dioxide, in comparison to cities in high-income nations, local authorities have developed a refined framework, strategies and institutional structures to target air quality, the main local concern, and to relate it to climate change. As in cities from high income countries, epistemic communities (academic groups), policy networks (e.g. International Council for Local Environmental Initiatives, ICLEI) and individuals have been key in launching a carbon and climate agenda at the urban level during the last several years.

Management is not only about framing an environmental problem; it also relates to what measures authorities design to actually deal with it in terms of one set of causes and effects instead of others. In short, it refers to whether policy makers can and want to go beyond declarations of good-will by introducing actions such as allocating resources to undertake the declared measures. Policy making on climate change is strongly constrained by the fact that environmental authorities in the region lack monies and influence over the key secretaries, ministries and offices that need to act for purpose of both mitigation and adaptation.

Romero Lankao has also joined with scientists in CGD, IMAGe, ACD, AIMES and the Global Carbon Project to establish the "Initiative to Attain Resilient and Sustainable Relationships among Carbon, Climate and Cities (RESUCCCITIES). RESUCCCITIES is bringing together groups with diverse expertise (carbon, atmospheric and climate modelers, urban science and policy, scenarios experts) to bridge the gap between global carbon and climate models on the one hand and urban case studies on the other. RESUCCCITIES seeks to bridge that gap by focusing on: a) measures and models of urban current contributions to regional carbon, atmospheric and human-energy-use budgets; b) understanding the socioeconomic, environmental and institutional drivers of cities' trajectories of change explaining their use of energy, atmospheric emissions, and "resilience" to climate relevant threats; and c) exploring and modeling the relationships and feedbacks between urban development, atmospheric emissions and climate change

FY2008 Accomplishments

Two papers have been written describing work to date:
Romero Lankao, P., Tribbia J. L. and Nychka, D. (forthcoming): "Development and greenhouse gas emissions deviate from the 'modernization' theory and 'convergence' hypothesis," Climate Research; and Romero Lankao, P., Tribbia J. L. and Nychka, D., "Testing theories to explore the drivers of cities' atmospheric emissions," Ambio, (submitted).

The ISSE P.I., P. Romero Lankao, is also participating in two initiatives to set the agenda on cities and climate change. A paper, "Cities and Climate Change: Review of Current Issues and Trends" on the current state of understanding of the relationships between cities and climate change has been written. This will serve as the basis for a "2011 Global Report on Human Settlements" which will focus on a "Cities and Climate Change" theme. Romero Lankao is also serving as contributing author in the development of the International Panel on Climate Change in Cities (IPC3) Assessment Report; this effort is led by the University of Colombia. This work addresses adaptation and mitigation responses, and the ways in which cities fit into the picture of national and global climate change strategies (i.e., how processes operating at the national and global level may constrain and/or enhance a city's ability to mitigate and adapt to climate change; what is the role of scientific knowledge in local climate policy decisions, and what other factors explain the huge gap between the rhetoric and reality of local climate policy

Societal Impacts Program

All aspects of the U.S. public and economy are directly and indirectly affected by weather. However, few definitive assessments of the use of weather information and weather impacts have been performed, and the information that has been generated from previous studies is hard to locate and synthesize. The Societal Impacts Program (SIP), funded by NOAA's U.S. Weather Research Program (USWRP) and NSF, addresses these gaps by developing and supporting a closer relationship between weather researchers, operational forecasters, relevant end-users, and social scientists concerned with the impacts of weather and weather information on society. SIP activities include primary research, outreach and education, and development and support for the weather impacts community. An important element of these outreach efforts is the Weather and Society * Integrated Studies (WAS*IS) program which is detailed separately in this report under Goal 3. SIP researchers at NCAR include participants from RAL, ISSE, and MMM, and from COMET in the UCAR Office of Programs.

FY2008 Accomplishments

Current research activities by SIP staff have focused on analyzing results from an internet-based survey of 1520 U.S. households nationwide that was conducted to elicit information on people's sources, perceptions, uses, and values for weather forecasts. People's understanding of, use of, and preferences for weather forecast uncertainty information were also elicited in the survey. Results indicate that the average individual accesses weather forecast information from various sources 115 times a month and these forecasts have a median value of at least $280 per U.S. household per year. Results also show that a majority of people are willing to receive forecasts that contain uncertainty information and that people have preferences for how uncertainty information is conveyed. A publication on the uncertainty communication results appeared in Weather and Forecasting in October 2008, and a paper on sources, uses, perceptions, and values for weather forecasts has been submitted to the Bulletin of the American Meteorological Society.

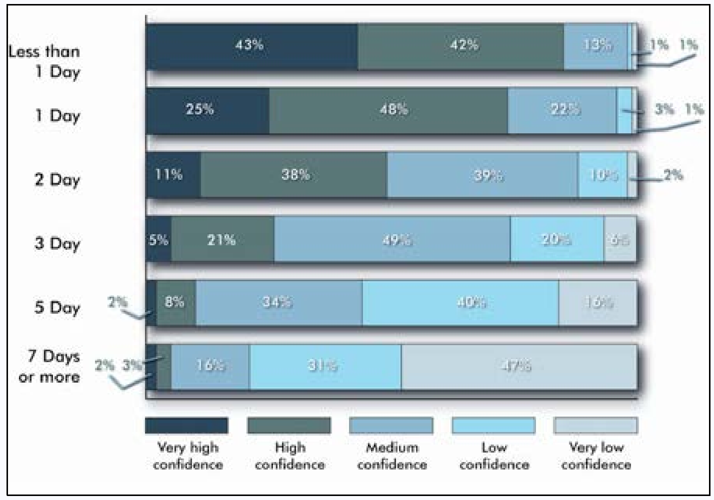


Figure: Respondents' confidence in weather forecasts of different lead times (n = 1,465 for each lead time)

SIP researchers are examining the processes involved in creating National Weather Service (NWS) hydrometeorological damage data presented in Storm Data through a survey distributed to NWS Warning Coordination Meteorologists (WCM) and other relevant employees. The first part of the survey focuses on NWS Weather Forecast Offices' (WFO) perceptions of the process as a whole and asks each WFO what changes they believe could be made to improve the quality of loss estimates. The second part of the survey elicits information from NWS personnel who have entered damage data into Storm Data for a specific weather event in the preceding year and asks about the source types and general process used to make a damage estimate. Ultimately the results of the survey would be used to facilitate better training for NWS employees entering Storm Data information and improve the accuracy of NWS-generated damage data

Funding from the U.S. Voluntary Cooperation Program Contribution managed by NOAA's NWS International Activities Office was used to develop the "Primer on Economics for National Meteorological and Hydrological Services". This Primer on economic theory, methods, and applications is primarily intended for members of the weather community with the goal of increasing their understanding of economic methods and their applicability in evaluating both the impacts of national meteorological and hydrological services (NMHS) and the associated benefits and costs of those services. Working with the World Meteorological Organization, SIP staff are implementing 3-day workshops to train personnel from a range of NMHS using the Primer. The first workshop was held in Sofia, Bulgaria in September 2007 and a second workshop is slated for Abu Dhabi, United Arab Emirates for 2009.

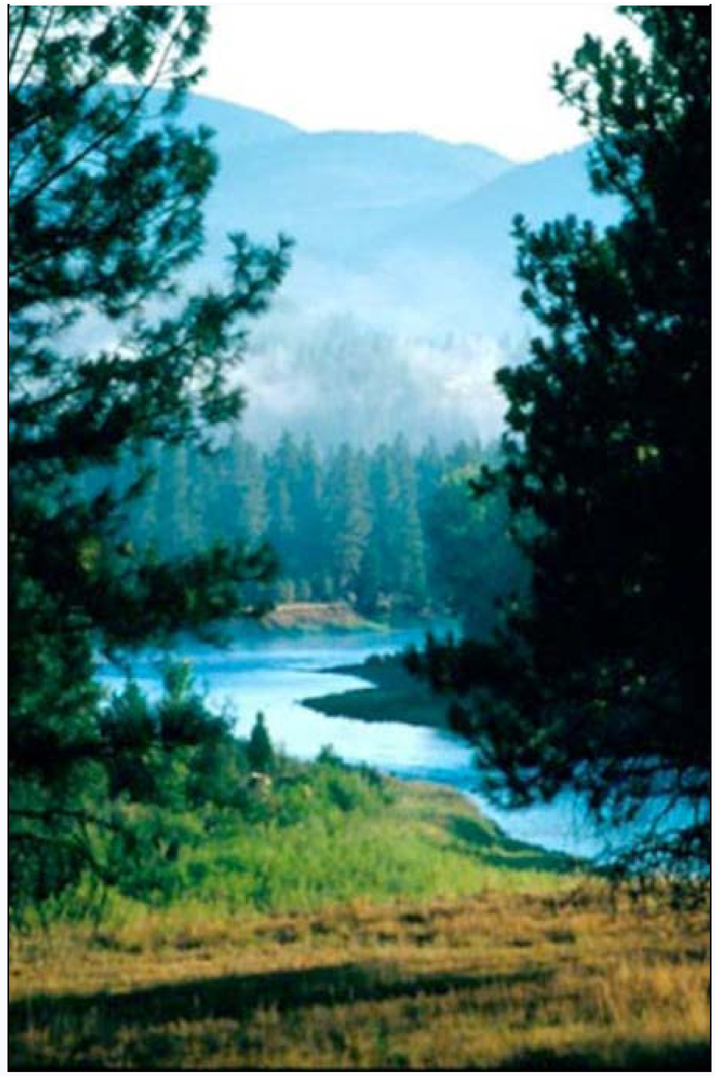
FY2009 Plans

SIP staff will focus on the following activities:

- Publish Weather and Society Watch quarterly newsletter
- Update the Extreme Weather Sourcebook to 2008 data
- Facilitate implementation of 3-day Integrated Warning Team workshop at NWS Kansas City/Pleasant Hill WFO
- Publication of BAMS article on basic forecast sources, perceptions, uses, and value results from the U.S. household survey.
- Complete statistical analysis and submit paper on geospatial analysis of data from the U.S. household survey on sources, uses, and preferences for weather forecasts and weather forecast uncertainty information.
- Analyze and report on use of uncertainty information in decision analysis scenarios from the U.S. household survey.
- Implement Part B of the Storm Data survey and analyze and report on results from Part A and Part B.
- Submit paper on societal impacts assessment component of NWS Service Assessment Team for the February 5-6, 2008 Super Tuesday tornado outbreak.
- Submit BAMS Inbox paper on an exploratory study with broadcast meteorologists on communication of weather forecast uncertainty
- Conduct research project on socio-economic impacts and benefits of the Hurricane Forecast Improvement Project.
- Initiate NSF-NOAA funded project on communicating hurricane information
- Develop work on NSF funded project on warning decisions in extreme weather events (flash floods and hurricanes) using an integrated interdisciplinary multi-method approach
- Initiate project on developing a prototype Earth-gauging system integrating weather and health data to manage meningitis in Africa

Society, Water, and Natural Systems (SWANS)

The multi-divisional SWANS program seeks to enhance the policy-relevance and usability of NCAR's water-



related research by coordinating and integrating work on the social, atmospheric, and other natural science aspects of critical water resource issues. SWANS encompasses a set of inter-related projects, all of which are contributing to building a strong core of research and expertise needed to link the atmospheric and related sciences more directly to the information needs of water resource managers and policy makers.

FY2008 Accomplishments

Scientists contributed to building the SWANS program through their work on the IPCC WG II report and IPCC Technical Paper on Water, and related presentations and published work. SWANS program participants also contributed to a number of external efforts to provide guidance on climate change impacts on water resources through presentations at several workshops and symposia. In addition, the program provided input on water and climate issues to the EPA, the Western Governors Association, the US Climate Change Science Program, the Western States Water Council, and the Western Water Assessment Report to the Colorado Water Conservation Board.

Also, in FY08 work began to assess the effects of climate change on snow processes in the Colorado Headwaters region, the resulting impacts on the volume and temporal distribution of runoff, and the ultimate implications for water management and water policy.

FY2009 Plans

Results of an initial high-resolution climate model experiment will be used to inform our collaborative work with Colorado Front Range urban water providers. Specifically, insights from the research on the range of potential future changes in water availability will be used to examine policy options for mitigating possible adverse socioeconomic and ecosystem impacts. Related research will continue on the broader socioeconomic and environmental effects of climate change on water resources. SWANS program participants are also exploring potential collaborative research on water-related climate change impacts in Latin America and on the U.S. High Plains.

Weather and Climate Impacts Assessment Science Program

Climate and weather create hazards and opportunities for society at multiple spatial and temporal scales. Assessment science seeks to examine and enhance the processes and methods for generating and communicating scientific knowledge to improve decision-making. The WCIASP focuses on critical gaps in the weather and climate arenas that are particularly challenging for decision-makers and scientists alike in the areas of (1) characterization of uncertainty; (2) extreme weather and climate events; and (3) the role of climate in human health. Since 2005 WCIASP has coordinated research by multi-disciplinary scientists throughout NCAR, at several universities, and at NOAA to address these gaps.

FY2008 Accomplishments

The research team focused on understanding the independent and combined effects of exposure to heat-cold stress and air pollution on human health in an urban environment. Major activities included development of common methodologies and tools for the implementation of the project and the treatment and analysis of data; review of available literature; development of common templates for the collection of three data bases on atmospheric/climate, health and vulnerability variables (making sure that the team works with the same/similar temporal and spatial units of analysis); and capacity building focused on training students on the most important concepts regarding air pollution, environmental health, and vulnerability assessment.

FY2009 Plans

FY09 will be the third and final year for the three-year cycle of current projects such as WCIASP that are funded through the NCAR Director's Office. The integrated uncertainty project will be expanded to include other water basins throughout the western US; the extremes project will expand to explore changes in extremes in high resolution future climate projections; and the third workshop on climate and health will be held in the summer of 2009.

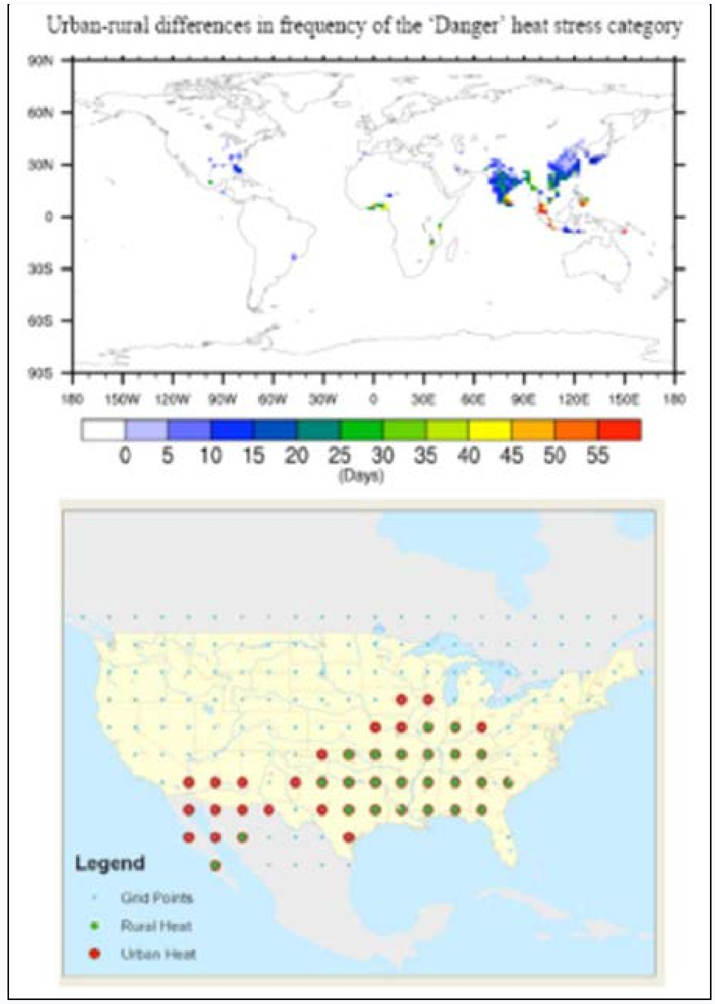


Figure 1 from Feddema, Bonan, and Wilhelmi WCIASP Project: Using the CCSM/CLM Urban Model to Improve Climate Impact Assessment Studies. The figure illustrates how the inclusion of the Urban Canyon Model in CLM allows for differentiating potential heat stress in urban areas compared to rural areas in climate models.

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Director's Message

Table of Contents

Strategic Goals: Science, Facilities & Technology

NCAR is sponsored by the National Science Foundation.

GOAL 2. INCREASE SOCIETAL RESILIENCE TO WEATHER, CLIMATE, AND ATMOSPHERIC HAZARDS

NCAR Strategic Priority: Building Capacity for Coping with Weather and Climate Hazards

Advanced Operational Aviation Weather System in Taiwan

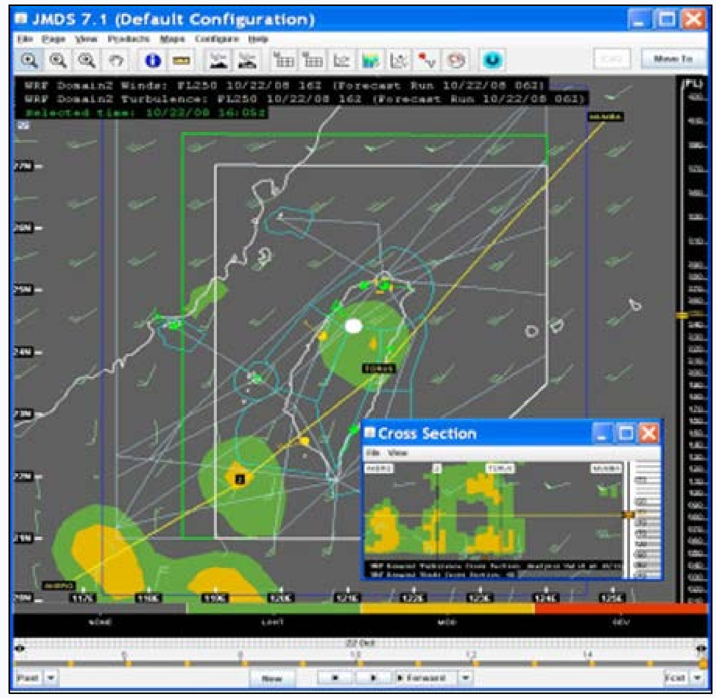


Figure 1: AOAWS Java based Multi-dimensional Display System (JMDS), which integrates all available aviation weather products (real-time and forecasts) and displays the information automatically in plan view or in vertical cross section form along user-defined flight routes. Image shows predicted clear-air turbulence at 25,000 ft and along a flight route.

Since 1998 RAL and MMM have collaborated in the development of an Advanced Operational Aviation Weather System (AOAWS) for the Civil Aeronautics Administration (CAA) of Taiwan. The initial AOAWS project (AOAWS-I) was completed and deployed for operational use in June 2002 and provides the CAA, the airlines, and the flying public with state-of-the-art aviation weather technology to detect and forecast hazardous weather phenomena that affect aviation operations, airspace efficiency, and capacity and safety at Taiwan's major hub airports. NCAR's local Taiwan research partner is the Institute for Information Industry (III).

In January 2005, the AOAWS Project entered a second five-year phase. This new phase focuses on the replacement of the MM5 model with the WRF model, advancing the data assimilation system (WRF-VAR) to incorporate new data types (e.g., COSMIC GPS, and other satellite data), upgrading the icing and turbulence products to incorporate the latest advancements developed as part of the FAA Aviation Weather Research Program, and developing and implementing new JAVA based display systems.

Major components of the AOAWS include: Low-Level Windshear Alert Systems (LLWAS Phase III) at Songshun and TTY International Airport (formerly known as Cheng Kai Shek International); the WRF model which provides regularly-updated forecasts on three domains with grid spacing of 5km, 15km, and 45km; the Multi-dimensional Display System (MDS), which integrates all available real-time observational data and displays the information automatically to aviation forecasters and flight planning specialists; a JAVA based version of the MDS; a web-based display system (WMDS) that displays most of the data available on the MDS on a CAA website for users (e.g., pilots and dispatchers) to view the AOAWS weather products remotely; and an AOAWS System Monitor Display (SMD) that provides system and networking activity information and alerts to the operators if any one of the sub-systems is not running smoothly.

FY08 Accomplishments

Several system upgrades were accomplished in 2008 including upgrades to the WRF model and the WRF-VAR data assimilation system to Version-3.0. New input datasets were explored including AMSU-A radiance data and parametric studies were performed to evaluate various physics packages to optimize WRF performance over Southeast Asia. A new AOAWS tropic cyclone bogus scheme was also developed and ported to the AOAWS. Testing of this new scheme began this year. Tests were also conducted to evaluate the performance of the system using boundary condition data from the NCEP's GFS model.

Enhancements were made to the MDS, model display, system monitor, and new Java-based display capabilities including convective storm warning capabilities. World Area Forecast System (WAFS) products were also successfully integrated into the AOAWS. Research was conducted to evaluate the performance of the in-flight icing and clear-air turbulence products operating on the WRF modeling system. Based on this research, enhancements to these products will be implemented in 2009.

Plans for FY2009

RAL, MMM, and our Taiwan technical partner, III, will continue to collaborate on the following research and development activities in 2009:

- Develop and evaluate enhancements to the WRF-VAR data assimilation system

- Evaluate new data input types and their contribution to WRF performance
- Implement enhancements to the in-flight icing algorithm and verify the performance
- Implement enhancements to the clear-air turbulence algorithm and verify the performance
- Continue to refine the Java-based Multi-dimensional Display System (JMDS)
- Begin redesign of the web-based Multi-dimensional Display System (WMDS)
- Continue to provide training of CAA personnel at NCAR and in Taiwan

Agricultural Weather

This NASA-funded project is focused on improving soil temperature and moisture forecasts and delivering those forecasts to agricultural end users through a decision support system operated by our commercial partners on this project, DTN-Meteorlogix. NCAR land-surface modelers are actively working to improve the scientific core of this project, the High Resolution Land Data Assimilation System (HRLDAS) and the Noah land-surface model. This research benefits a number of other land-surface modeling oriented projects.

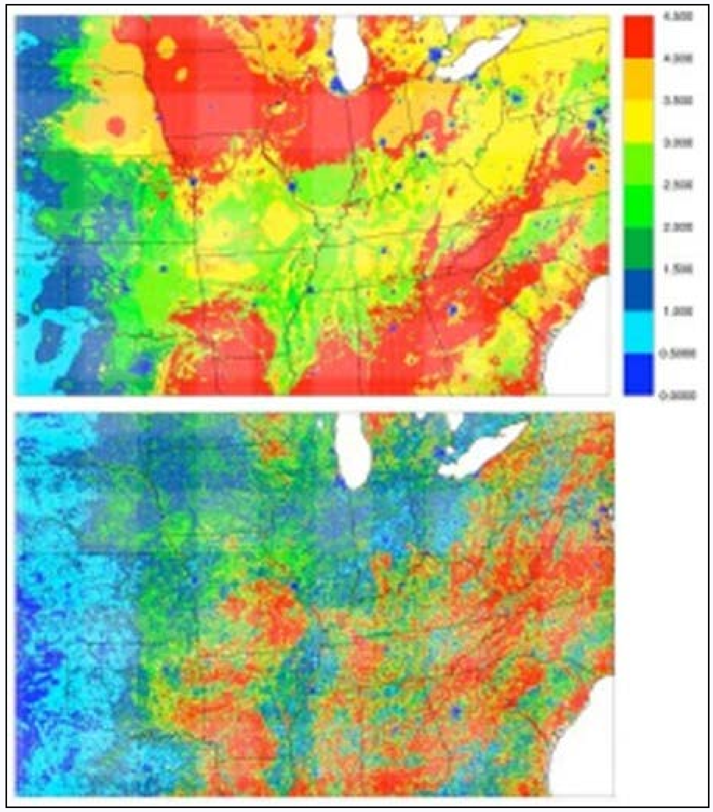


Figure 1: Climatological LAI (top) for July compared to MODIS remotely sensed LAI (bottom) for July 2006. The finer spatial resolution of the MODIS data is apparent (1 km vs 15 km for the climatological data). Also note how different the vegetation is in this particular month than normal. For example, the upper Midwest shows far less crop development than normal for July. Better estimates of the current vegetation state are critical to improving soil moisture and temperature predictions.

NCAR software engineers have developed an operational environment to run HRLDAS over the central and eastern United States at 4km resolution. The forecast data is delivered to DTN-Meteorlogix. During the growing season, DTN agricultural experts consult this data daily as part of their content generation for DTN Ag-Online, their agricultural web-based DSS with an established base of 80,000 customers.

The vegetation state and land use are key factors in the land-surface model. Prior to this project, HRLDAS has used static land use and climatological vegetation data sets developed in the 1970s by the USGS. This project is evaluating the use of MODIS satellite data sets to improve the initial conditions provided to HRLDAS. The MODIS land use data sets are static, but are of higher spatial resolution and are much newer than the USGS data sets. Rather than monthly climatological averages, the MODIS Leaf Area Index (LAI) and other products are updated weekly and better represent the current vegetation state. It is hoped that the use of these products will further improve the soil temperature and moisture forecasts.

FY2008 Accomplishments:

NCAR land-surface modelers have developed and tested improvements to HRLDAS. These include increasing the number of subsurface nodes, improved parameterization related to surface heat transfer, and the incorporation of MODIS LAI and Fraction of Photosynthetically Active Radiation (FPAR) data sets. Model runs covering 2005-2006 were compared to soil temperature and moisture observations. The soil temperature errors at 5 cm were reduced by roughly 10% and the 10 cm errors were reduced by approximately 50%. These are critical depths for agriculture.

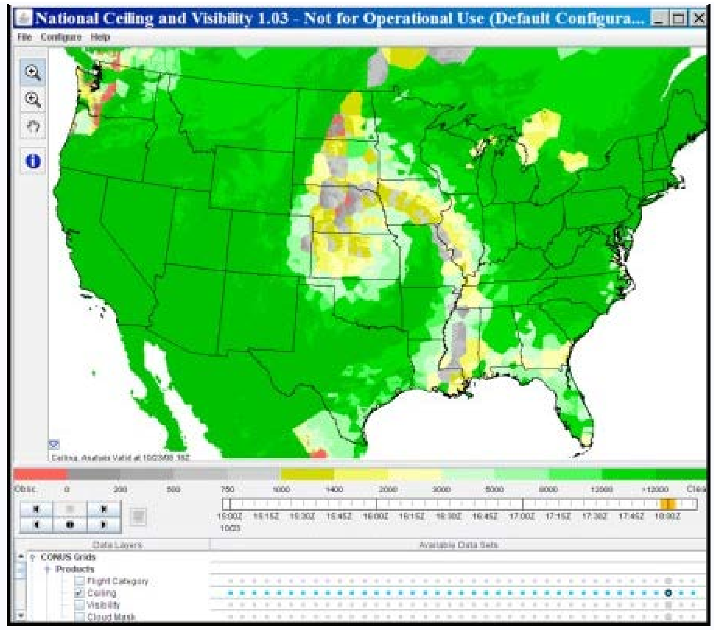
The software engineering team at RAL developed an operational forecasting environment which generates soil temperature and moisture predictions and delivers this data to DTN-Meteorlogix. This system has run continuously since early 2008, and its performance was evaluated during the growing season (April-June). Investigations have led to a better understanding of the complexities of land-surface model inputs. Notably, using land-use and vegetation data sets with different resolutions can lead to mismatches which negatively affect model performance. Also, there is some question as to whether the MODIS 1-km resolution is sufficient to accurately model areas of rapidly changing land use.

FY2009 Plans:

MODIS data, as well as enhancements made by the HRLDAS developers in 2008, will be incorporated into the operational system for use in the 2009 growing season. Continued land-surface model development will attempt to further improve the modeled heat transfer at the surface. DTN will again evaluate these data sets and possibly incorporate the results directly into their DSS. The results from retrospective studies and the 2009 growing season using these model improvements will be incorporated into an end-of-project report to NASA.

Ceiling and Visibility Research and Development

Impacted ceiling and surface visibility (C&V) conditions represent a costly source of flow



capacity reduction for air terminals servicing high-volume commercial traffic. Further, these conditions pose a major safety risk for general aviation (GA) operations, and critical operational limitations for helicopter-based emergency medical services and off-shore oil production facilities. RAL's work toward automated real-time C&V diagnoses and probabilistic forecasts will help address the human-based decisions made in these applications today, and will provide the quantitative forecast grids needed by the automated decision support systems that are critical to future operations within the NextGeneration Air Transportation System (NextGen).

FY2008 Accomplishments:

RAL's concept for a C&V diagnosis product takes the form of a real-time 'spacecast' in which current ceiling, visibility and flight category conditions at observing points are combined with accompanying probabilistic estimates of the conditions across the data-sparse regions between these points. A first-generation CONUS diagnosis product utilizing simpler representation of conditions between observing points was completed in FY08 (pictured above) and readied for independent evaluation by FAA prior to operational acceptance in FY09. A 2-level (low and normal) confidence field was formulated to aid user interpretation of the uncertainty of the analyzed fields in regions remote from observing points.

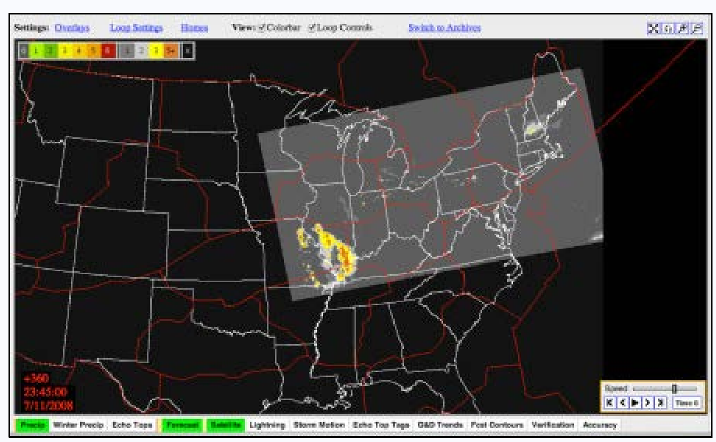
- RAL made a change of direction in its C&V forecast work, initiating effort toward a first-generation probabilistic 1-12 hr C&V forecast. This effort, which builds on past work toward a deterministic forecast, directly supports NextGen requirements for probabilistic information supporting aviation decision support systems. The approach taken is to maximize the use and synthesis of existing operational models, monthly output statistics (MOS)-based guidance and other winter and summer aviation forecast products such as the new Consolidated Storm Prediction Algorithm (CoSPA). FY08 work established tools for diagnostic play-back of the forecast integration process and used these for fundamental examination of automated forecast component scoring and selection procedures. Parallel work began to explore the use of existing forecast ensembles and probabilistic output of products such as LAMP. Early steps were taken to identify methodologies to capture, derive and integrate probabilistic information from the forecast products and models currently available. Work to advance the RAL-developed observations-based forecast method, which can significantly augment the forecast sources above, focused on the development of data filtering and processing tools needed for forecast method improvement.

FY2009 Plans:

The NCV CONUS analysis product will undergo independent evaluation by the FAA in FY2009 , and we anticipate that the analysis system will be approved for operational use. Forecast product work will focus on the exploration of techniques to formulate and verify probabilistic C&V forecast information from existing forecast sources, and on the development of the prototyping tools needed to accomplish this.

Consolidated Storm Prediction for Aviation

For more than two decades the Federal Aviation Administration (FAA) has funded research and development efforts aimed at improving short-term forecasting of storm hazards affecting aviation. In FY07, the FAA started integrating the wealth of different forecasting tools by focusing on the development of a single authoritative forecast system, the "Consolidated Storm Prediction for Aviation" (CoSPA). This effort brings together researchers from NCAR's Research Applications Laboratory, MIT Lincoln Laboratory, and NOAA's Global Systems Division to create a 0-8 hour forecast for both summer and winter storms. Forecast products from this system are designed to satisfy the current needs of Air Traffic Management (ATM), as well as the future demands of the Next Generation Air Transportation System (NextGen), in which much of the strategic air traffic decision-making will be made utilizing automated decision support tools based on gridded probabilistic forecasts.



Northeast CoSPA 6 hour forecast valid for 11 July 2008 at 23:45 UTC.

FY2008 Accomplishments:

CoSPA reached a major milestone during the summer 2008 with its first experimental real-time demonstration of a prototype CoSPA forecast system focused on the northeastern corridor of the United States (see figure). The initial 0-6 hour forecasts of vertically integrated liquid (VIL)—other parameters, such as echo tops and precipitation phase will be added in future versions—are generated utilizing an advanced blending technique that merges heuristic-based extrapolation forecasts with output from a high-resolution, mesoscale numerical weather prediction model (i.e., the High-Resolution Rapid Refresh model) that includes radar data assimilation. The blended forecast products are rapidly updating (every 15 minutes) so that the latest model and observational data can be incorporated.

Research and development (R&D) has continued on all aspects of the CoSPA forecast system, including the establishment of procedures for real-time, network-enabled data exchange and agreement on a common data format, working towards a system architecture with a modular design to foster ease of plug-and-play experimentation with new technologies, improvement of extrapolation techniques for longer lead times, utilization of statistical approaches for assessing the relevance of a myriad of predictor fields in predicting storm initiation and evolution, advancement of radar data assimilation techniques, implementation of sophisticated blending procedures that incorporate a phase correction of the model output, and advanced forecast verification methods.

FY2009 Plans:

The experimental real-time demonstration of the prototype CoSPA forecast system will continue and remain focused on the northeastern corridor of the United States for the next year. Thus far, only the developers and FAA sponsor have had access to these forecasts. However, the CoSPA forecast system has matured to the extent that we anticipate a broader distribution by 2009 through which selected users may receive access to the password-protected website. Work will continue on all of the R&D tasks outlined above.

Convective Weather Forecasting: Benefits of a "Forecaster over the Loop"

The Forecaster-Over-the-Loop (FOTL) thunderstorm nowcasting project is completing its fourth year of operational testing and evaluation at the Ft. Worth/Dallas Weather Forecast Office (WFO). The FOTL project is sponsored by the Aviation Weather Group of the National Weather Service and seeks to demonstrate the value-added enhancements to gridded, automated, thunderstorm nowcast products when forecasters are included in the forecast process. Validation statistics show that forecasters can increase the reliability and accuracy of thunderstorm nowcast products by entering the locations of surface convergence boundaries into the NCAR thunderstorm Auto-nowcaster (ANC) system running at the WFO. The FOTL ANC demonstration is a prototype for capabilities and applications incorporating forecaster input that may eventually exist within the automated aviation weather digital products (4-D Data Cube) being planned for the Next Generation (NexGen) Air Transportation System.

FY2008 Accomplishments

In previous years, the forecasters entered convergence boundaries on the NCAR stand-alone display system located next to the aviation forecast desk at the WFO. This year the boundary entry tools developed at RAL, as well as the gridded thunderstorm nowcast fields produced by the ANC, were installed on the NWS Advanced Weather Interactive Processing System (AWIPS) in the forecast office. This was a significant and successful step in formalizing forecaster involvement with an "automated" nowcasting system in an operational, real-time setting by incorporating the FOTL graphical interfaces, tools and fields into the NWS operational display system. In preparation for prototyping the complete ANC system on AWIPS, RAL transferred the software to the NWS Meteorological Development Laboratory and assisted staff there in the installation.

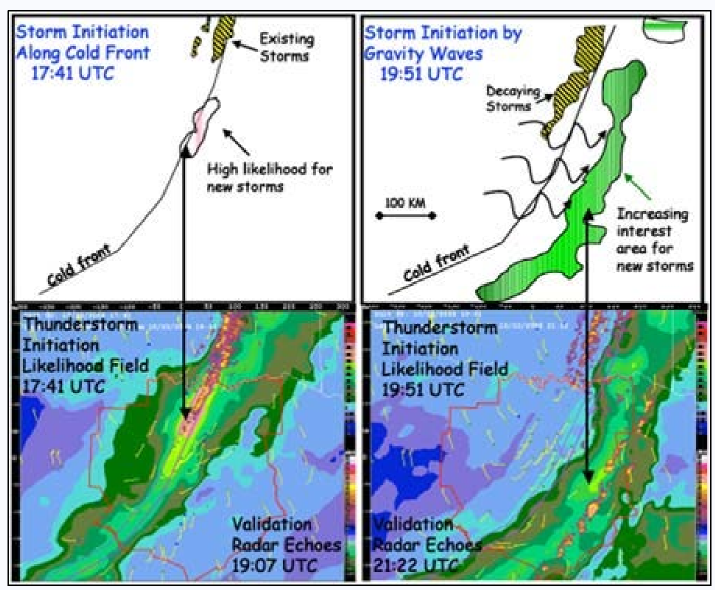


Figure 1: Forecaster-Over-the-Loop system used to nowcast thunderstorm initiation locations using input from the forecasters (i.e., the insertion of the cold front convergence boundary at 17:41 UTC and the automatically updated 60 min boundary location (parallel purple lines in the lower two panels). Note the very location-specific forecast (pink region) for new storm initiation (upper panel) that verifies well with the location of new convection ~90 min later.

Detailed statistical validation of the performance of the FOTL ANC's thunderstorm nowcasts are being conducted by RAL scientists for the 2008 real-time demonstration. Figure 1 illustrates the ability of the system to nowcast thunderstorm initiation locations using input from the forecasters (i.e., the insertion of the cold front convergence boundary at 17:41 UTC and the automatically updated 60 min boundary location (parallel purple lines in the lower two panels). Note the very location-specific forecast (pink region) for new storm initiation (upper panel) that verifies well with the location of new convection ~90 min later. No other storms form and no false alarm nowcasts are produced along the cold front during the subsequent time periods. Of particular interest in this case is the increasing likelihood area (green shades) for thunderstorm initiation 100 km to the east of the cold front being predicted by the FOTL ANC system two hours later (19:51 UTC). The forecast system shows increased interest for convection due possibly to the triggering of new convection ahead of the front by gravity waves; this is a frequently observed weather phenomena in the eastern U.S. but a particularly challenging forecast problem for identifying the location and onset for this squall convection. The lower right panel shows that a squall line develops 90 min later (21:22 UTC) along the N-S axis of highest thunderstorm likelihood interest values at 19:51 UTC. Note that there is no new convection occurring along the actual cold front location. This event on 22 October and others will be examined in more detail to determine the reliability and robustness of the system for nowcasting convection ahead of large scale synoptic fronts.

FY2009 Plans

Three enhancements to the ANC system initiated this year are in the nascent stages of development; research in these areas will continue in 2009.

- Exploration of methodologies for converting the deterministic FOTL ANC forecasts into probabilistic forecasts at the request of the forecasters and meteorologists at the WFO and the Ft. Worth CWSU.
- Development of a synoptic regime for nowcasting elevated convection, (i.e., convection not trigger by surface forcing). The ANC system has been set up to produce and display the preliminary interest fields showing the likelihood for elevated convection mid-way through the season enabling the scientists to assess these fields during real-time, elevated convection events.

Development of a new synoptic regime for low instability events to more appropriately handle situations when widespread convective outbreaks occur under weak environmental instability. Preliminary examination of nowcast performance when this regime is activated is showing encouraging results

DTRA Sensor Data Fusion

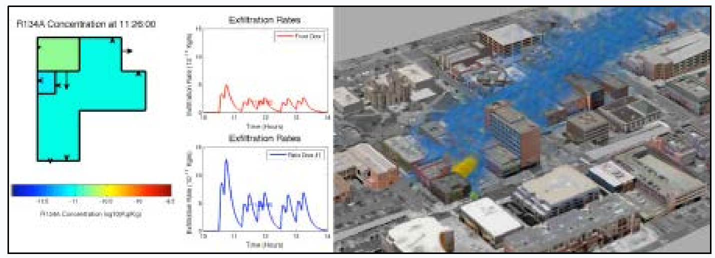


Figure 1. VTHREAT results illustrating coupled internal-external chemical transport and dispersion and building/room infiltration/exfiltration values for simulation of a chemical release inside a building.

Since late FY04, RAL has been sponsored by the Department of Defense's Defense Threat Reduction Agency (DTRA) to develop tailored meteorological decision-support applications for the military and domestic emergency-response communities. In particular, these applications are used to enhance DoD's Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) hazard-prediction toolsets such as the Hazard Prediction and Assessment Capability (HPAC) and more recently the Joint Effects Model (JEM). RAL's work has two primary objectives: 1) development of an operational algorithm which can both estimate an unknown CBRNE source and predict a refined downwind hazard from that source, using available CBRNE and meteorological sensor observations; and 2) integration of this algorithm into the HPAC/JEM hazard-prediction toolsets. To support testing and evaluation of this product, RAL is developing a virtual testing and evaluation environment (VTHREAT) which will enable simulation of a physically realistic CBRNE release scenario, placement of CBRNE and meteorological sensors, and extraction of the resulting synthetic sensor readings. These synthetic observations can then be used by the evolving algorithms to evaluate their ability to recreate the CBRNE event.

FY2008 Accomplishments:

During the early development of the VTHREAT prototype, DTRA requested that RAL use the VTHREAT concept to provide field test design guidance for DTRA's FUSION Field Test 2007 (FFT-07). VTHREAT was used to generate typical atmospheric conditions for the field test area, Dugway Proving Ground, Utah, and from these synthetic atmospheric datasets, myriad material releases were simulated using three different proposed sensor configurations. The synthetic sensor readings were then extracted and analyzed to determine the probability of detection under each of these configurations. The FFT07 field program was a resounding success. RAL received a preliminary indication from DTRA and the DPG test coordinator that the VTHREAT pre-experiment simulations were qualitatively consistent with their experience during the field program. In FY08, RAL continued the development of the prototype VTHREAT system. RAL completed modifications required to emulate the Automated Chemical Agent Detector Alarm (ACADA) system and now provides synthetic CBRNE readings to the Joint Warning and Reporting Network (JWARN) sensor signal emulation system. The National Institute of Science and Technology (NITST) CONTAM indoor chemical transport and dispersion model was also added to the VTHREAT environmental and transport and dispersion-modeling framework. (Figure 1)

FY08 also marked the continuing development of the Variational Sensor Data Fusion (SDF) prototype. Phase I of this effort used the existing L3-Titan SCIPUFF code (and adjoint) to calculate a source estimate, and then used that source estimate to run a single forward SCIPUFF simulation. Phase II of this algorithm is designed to improve upon the initial source estimate from Phase I, utilizing a recently developed Eulerian plume model (and adjoint), that iteratively refines the source estimates with variational data-assimilation techniques. The combined Phase I and II SDF prototypes were demonstrated using synthetic chemical and meteorological sensor data generated with the VTHREAT prototype. The Phase II algorithm has been shown to consistently improve the release location and mass estimates over Phase I algorithm based on the L-3 Titan system.

FY2009 Plans:

VTHREAT will be a key element of the CBRNE Contamination Avoidance System Evaluation Tool (CASET) being developed for DTRA. RAL plans to continue the refinement of the VTHREAT prototype application during FY09 to support this effort. Current plans call for the enhancement of the meteorological sensor (towers, rawinsonde, and LIDAR) and chemical/biological sensor emulation, the ability to dynamically place grids of chemical sensors, and an improved GUI application tailored for the CASET program.

The primary activity of the SDF program during FY09 will be the continued development of the variational sensor-data-fusion algorithm. The Phase II SDF algorithm will be enhanced to discriminate between and identify the source parameters of instantaneous, continuous, and limited-duration chemical and biological weapon releases. Current plans call for the development of the ability to include observations taken at multiple times, and the ability to identify the source locations from multiple release scenarios. RAL also plans to participate in a SDF algorithm evaluation, where source-term estimation techniques from various organizations will be scrutinized using the FFT07 field program observations.

DTRA Weather Services Research and Development

Since FY04, RAL has been sponsored by the Department of Defense's Defense Threat Reduction Agency (DTRA) to develop tailored meteorological decision support applications for the military and domestic emergency-response communities. In particular, these applications are used to enhance DoD's Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) hazard prediction toolsets such as the Hazard Prediction and Assessment Capability (HPAC) and more recently the Joint Effects Model (JEM) (Figure 1). The objectives of this particular effort are to:

1) Continue to develop and operational deploy enhancements to the DTRA Next Generation Meteorological Data Server (NexGen MDS) systems.

2) Continue to provide weather software enhancements and fixes to DTRA's hazard prediction toolsets, including HPAC and JEM.

The first official version (v1.0) of DTRA's NexGen MDS system, developed from the ground up by NCAR/RAL, became operational in late FY06. The purpose of this system is to provide one stop shopping for any and all meteorological products required by operational Transport and Dispersion (T&D) applications.

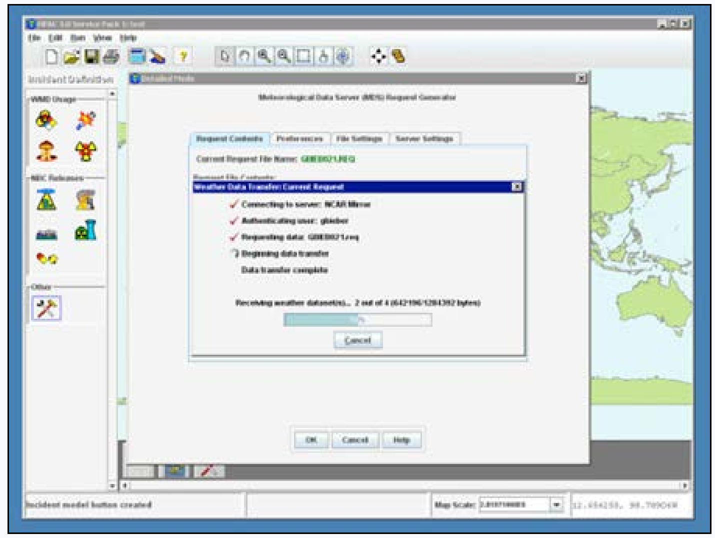


Figure 1. HPAC 5.0 SP1 snapshots showing improvements to NexGen MDS GUI. The new GUI provides the user with information on estimated download file size, download status, data source identity, plus NWP Data Generation (Analysis) time.

Special care was taken in developing the system interface, so that an external software development group could easily integrate this interface into their larger toolset. The first official release of the MDS system Application Programming Interface (API) occurred concurrently with the NexGen MDS release in late FY06. Since that time, the API has successfully been integrated into the HPAC and JEM toolsets and continues to be adopted in other T&D applications. A conceptual overview of the system architecture is shown in Figure 1. More details on FY08-related accomplishments and FY09 plans are listed below.

FY2008 Accomplishments:

FY08 was a productive year for the Environmental Sciences project. Over the course of the year, RAL developed and deployed one new release and four major patches to the operational NexGen MDS systems. These updates added a variety of new Web Based Toolsets, including a Data Status Monitor and Data Subscription Utility. The Data Status Monitor provides users with a real time status of the Numerical Weather Prediction (NWP) Forecast Product Inventory so they can determine the availability of certain products, before making data requests to the system. The Data Subscription Utility provides access to prepackaged MDS data products, in a variety of formats, for users to download directly through their web browser. In addition to these new toolsets, these updates provided a number of bug fixes and system-security patches, to enhance the system stability and ensure uninterrupted 24/7 service to all MDS customers.

In addition to providing major MDS upgrades in FY08, RAL also developed and delivered two major software upgrades to DTRA's HPAC toolset (v4.04 and v5.0 Service Pack 1). These updates provided a variety of MDS Client GUI enhancements, which provide more up-to-date status information, during the data request/retrieval process (Figure 1).

FY09 Plans

In FY09, RAL will begin the final transition of the NexGen MDS technology to the DTRA Operations Division, in preparation for the project completion in early FY10. The focus will be to develop and deliver a comprehensive set of documentation and associated training, which will allow DTRA to autonomously maintain and further refine the NexGen MDS systems. Additionally, RAL plans to develop tools which should substantially simplify the operation of the MDS.

Four-Dimensional Weather System: ATEC

Over the past 12 years, the U.S. Army Test and Evaluation Command (ATEC) has sponsored the research and development of the Four-Dimensional Weather (4DWX) system, a cutting-edge weather modeling system based on the MM5 and WRF models. 4DWX provides high-resolution mesoscale numerical weather prediction, short-term thunderstorm prediction, multi-dimensional integrated displays, and fine-scale climatological analysis tools, enabling the Army to test military hardware under precise conditions across the full spectrum of arctic, tropical, desert, and

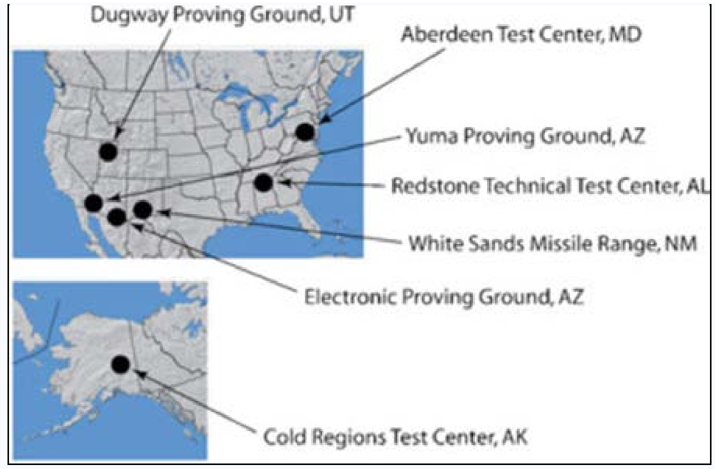


Figure 1: 4DWX is accredited for operational use at seven test ranges.

other natural and controlled environments. The WRF Model core was recently upgraded to version 2.2.1. 4DWX is accredited for operational use at seven test ranges.

FY2008 Accomplishments:

Global Meteorology on Demand (GMOD):
In its standard implementation, the 4DWX system operates automatically, generating forecasts according to an optimized model configuration on predetermined computational domains. The recently improved GMOD tool (Figure 2) allows a user on short notice to reconfigure the 4DWX system and apply it to domains virtually anywhere in the world in order to meet sudden and unusual forecast challenges.

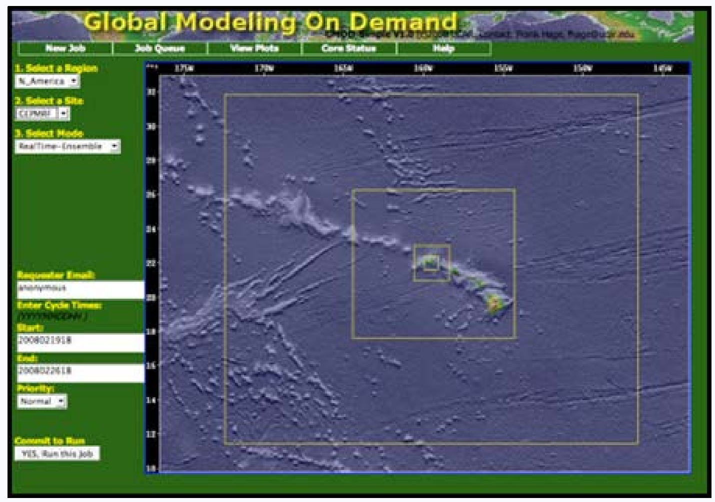


Figure 2: GMOD User Interface.

Real-Time Four-Dimensional Data Assimilation (RTFDDA):
This unique scheme assimilates observations from a variety of data feeds, preserving the data's temporal dimension during assimilation. New analyses and forecasts are made every one to three hours, depending on the range, providing the operational forecaster with very timely information. The latest version of RTFDDA permits more customization for each computation domain of a nested configuration, including resolution-dependent radii of influence and temporal windows for data assimilation.

3-Dimensional Variational Data Assimilation (3DVAR):
3DVAR techniques at the mesoscale are being evaluated, and a number of non-standard observations that cannot be included in RTFDDA's observation-nudging scheme, such as satellite radiance, GPS, and radar, are being incorporated. 3DVAR is currently being integrated into the RTFDDA system, yielding a model-based solution that will account for all available observations.

New Datasets:
This year RAL developed a unique method of creating global, spatial-temporal composites of real-time, high-resolution sea-surface temperatures derived from the MODIS instruments aboard polar-orbiting satellites operated by NOAA (Figure 3). RAL is in the process of including these improved data sets in the 4DWX system.

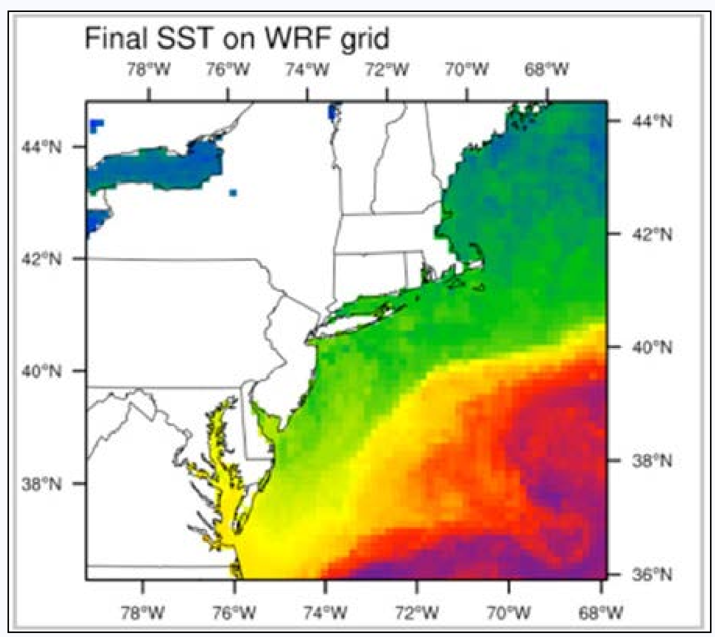


Figure 3: High-resolution sea-surface temperatures.

Ensemble Forecasting:
An ensemble forecast system (called E-RTFDDA) extends the pseudo-deterministic, single RTFDDA realizations by running a suite of RTFDDA forecasts, all valid at the same place and time (Figure 4). The ensemble comprises 30 members whose differences are induced by varying initial conditions, boundary conditions, model physics, and model cores. The system cycles every 6 h and produces four 48-h weather forecasts per day. RAL has recently developed and demonstrated an innovative technique for calibrating this ensemble based on quantile regression. Calibration will soon be applied operationally.

Coupled Applications: The direct NWP output from 4DWX is the essence of the forecast guidance used by staff at the ATEC ranges, but a great amount of added value is achieved by coupling this direct output to secondary models, also known as *coupled applications*. These include:

- Noise Assessment and Prediction System (NAPS)
- Second-order Closure Integrated Puff (SCIPUFF) model
- Lewis Rocket Trajectory Model
- Open Burn / Open Detonation Model (OBODM)

SCIPUFF is now coupled to the ensemble forecast system in order to produce automatically an ensemble of transport-and-dispersion simulations.

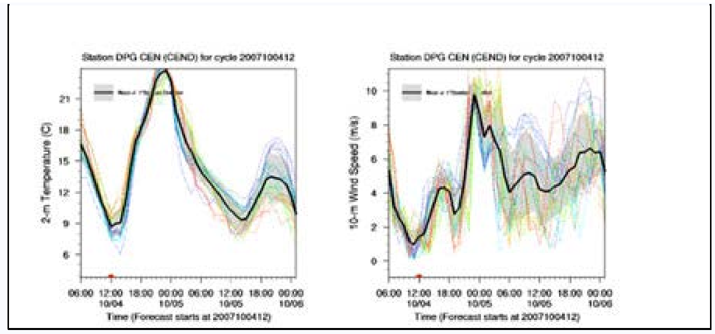


Figure 4: Ensemble Metograms.

Model Verification: In FY08, RAL continued development of approaches to model verification that go beyond traditional metrics such as root-mean-squared errors calculated at points. Among the newer approaches to verification are those that treat predicted and observed weather as one or more "events," or "objects"—a change in wind direction, or a coherent region of rainfall, for instance. Object-based approaches do not inherently handicap more resolved models and are often more consistent with the mental images that end-users have of forecasts and observations. RAL has extended some of these object-based techniques to produce prototypes of graphical forecast aids that intelligently combine into unified figures both model forecasts and statistics about recent model performance in order to better guide forecasters in how to interpret model output.

Web Portal: RAL made a series of preliminary releases to incorporate feedback from the ATEC staff, culminating in its formal release at all the ranges. The Web Portal provides a dramatically new look and feel to the 4DWX range Web pages using portal technology, which permits administrative and user customization. The portal's flexibility, accessibility, modularity, and extensibility make it ideal for serving as the new foundation for most 4DWX user interfaces.

MetVault: The first formal release of MetVault was made for all ATEC ranges. MetVault is a central data repository for observations and model output. It provides a sophisticated search engine, a suite of services that enable users to extract, interpolate, combine subsets of stored data, returning them in a variety of formats, and a quality control system for observations ingested into the 4DWX database.

MIR Database: A new database, the Meteorological Information Repository (MIR), was also deployed at the ATEC ranges as part of the Web Portal and MetVault releases. It stores all current and historical observational range data and works in tandem with ATEC's new ARMADA database. Its key improvements are enhanced performance from an improved table structure, extensiblity from a modular schema, and robustness from new data management and quality control fields designed in collaboration with ATEC.

Climate FDDA (C-FDDA): RAL is generating a test archive of mesoscale climatographies for use by ATEC ranges for long-range scheduling of the optimal time, day, season, and location for materiel testing under specific weather conditions.

FY2009 Plans:

- The 4DWX system will be upgraded to WRF Model v.3 and the Polar WRF Model will be incorporated into the system.
- MetVault's functionality will be expanded, including additional data formats for use in 3rd-party data exploration software, reusable queries to enable fast searching, and expanded data availability.
- Web Portal development will also continue and will emphasize making enhancements that are prioritized based on feedback received from range users.
- RAL will continue to explore methods for assimilating radar data into 4DWX. In FY09 we anticipate significant advances from an approach that is based on the coupled cycling of RTFDDA and the Variational Doppler Radar Assimilation System (VDRAS)
- RAL will release an interactive GUI that permits forecasters and other users of model output to customize reporting of verification statistics. Output will include two-dimensional maps and time series of verification statistics, both in terms of forecast hour and of diurnal cycle. Statistics for 4DWX will be compared with those of other operational models, such as those from the National Centers for Environmental Prediction (NCEP).
- RAL will complete installation of a unique method of dynamically correcting the WRF Model's bias in temperature, humidity, and possibly wind over full computational domains, even where observations are unavailable.

Future Combat Systems Modeling and Simulation

The Future Combat System (FCS) is the U.S. Army's program to modernize American war-fighting capabilities and achieve the ability to rapidly deploy a dominant ground force anywhere in the world within days. Because most weapons testing and military operations rely heavily on accurate weather information, the Army relies on tools such as the 4-Dimensional Weather Real-Time Four Dimensional Data Assimilation (4DWX-RTFDDA) system developed at RAL in collaboration with the Army Test and Evaluation Command (ATEC). This modeling system provides high-resolution 4-D synthetic weather analyses and forecasts by continuously merging all available observations with full-physics models. It has become a very valuable tool for providing weather modeling support for the FCS Modeling and Simulation (FCS M&S) program. Since 2004, RAL has been continuously adapting and refining this modeling system and providing realistic simulated battle-field-scale weather events for the FCS/MS applications.

FY2008 Accomplishments:

RAL produced model simulations of weather events for FCS with the 4DWX-RTFDDA system, for 1) events at the US Army Dugway Proving Ground (DPG), Utah, focusing on nocturnal mountain drainage flows; and 2) events at the Army Cold Region Test Center (CRTC), Alaska, involving an extreme cold-weather event.

The FY08 research has focused on studying and improving the 4DWX WRF-RTFDDA modeling capability for simulating wintertime severe cold-air events. A week-long period with large temperature variation and very cold weather during 20-27 January 2007 was selected to study the 4DWX model's capability. The case study identified many limitations in the community WRF model, which led to a large overestimation of temperature during the extreme cold-air weather situations. Research found that to accurately model the development of strong inversions and cold-air-pools that are associated with cold-air advection and drainage flows, the surface energy budgets, the boundary layer, and the near-surface mixing must be treated properly. Improved surface temperature prediction was obtained by modifying the WRF model snow depth and snowcover initialization, the snow emissivity and albedo, the clouds that affect downward long-wave radiation, the boundary layer and horizontal diffusion, and lake temperatures. These changes will be tested and applied for improving the 4DWX-WRF-RTFDDA system for general winter weather forecasting in regions with complex-terrain.

FY2009 Plans:

Several recent advances in the 4DWX WRF-RTFDDA capabilities will be applied to improve the weather support to FCS. The WRF LES model will be embedded in the WRF-RTFDDA system to provide continuous 4-D complete weather data at exceptionally high-resolution (with grid sizes of 100 – 200 m) for locations and weather scenarios selected by the FCS M&S program. The high-resolution 4D synthetic weather data will contain detailed weather circulations that are forced by fine-scale complex terrain, lower atmospheric turbulence, and ground soil moisture and temperature contrasts that can dramatically affect the performance and operation of the FCS manned and unmanned ground and aerial vehicles.

Another important area is to explore applying probabilistic weather information for FCS M&S. Uncertainties in the analyses and forecasts of weather variables that have important influences on FCS M&S components will be estimated using the ensemble-based probabilistic analysis and forecasting system (4DWX E-RTFDDA).

RAL will continue to work with the Army Dugway Proving Ground to explore applications of the 4DWX model for simulating ground-vehicle trafficability, cloud ceiling and visibility, and turbulence and aircraft icing parameters.

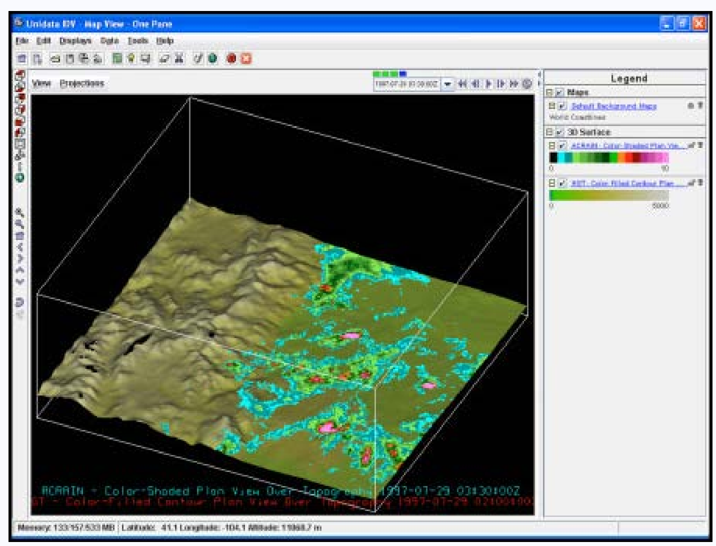
Hydrometeorological Processes

The hydrological impacts of significant weather and climate events often translate into staggering human, economic and environmental costs. Despite decades of research, significant gaps remain in how weather and climate information are used for reliable hydrological prediction. Additionally, it is now well-recognized that terrestrial hydrologic processes are not only influenced by weather and climate but also exert a significant feedback to the coupled Earth system. The nature of the relationship between terrestrial hydrologic processes and the atmospheric processes that simultaneously drive and respond to them are the focus of RAL's Hydrometeorological Processes efforts.

FY2008 Accomplishments:

Romania: RAL continued to provide hydrological modeling support for a World Bank-funded project for the country of Romania. Working in collaboration with scientists from Baron Advanced Meteorological Services (BAMS) we have finalized model development and full parallelization of the hydrological modeling system and are presently in a model implementation and evaluation phase for test basins within the U.S. and Romania.

Colorado Front Range: Operational flash flood forecasting for the Colorado Front Range region was conducted. Daily cloud-resolving model simulations using the WRF model as well as radar nowcasts generated from the NCAR-RAL TITAN system were developed and used to drive the Noah-distributed hydrological model. Despite being a drier than average summer, numerous heavy precipitation events and their hydrologic impacts were captured during the month of August. Work is proceeding with analysis of the real-time precipitation and streamflow forecasts.



Radar mosaic of Colorado Front Range thunderstorm activity. Radar estimated rainfall imagery is overlain on a digital elevation model of the flash flood forecasting domain. (Image created using Unidata IDV software.)

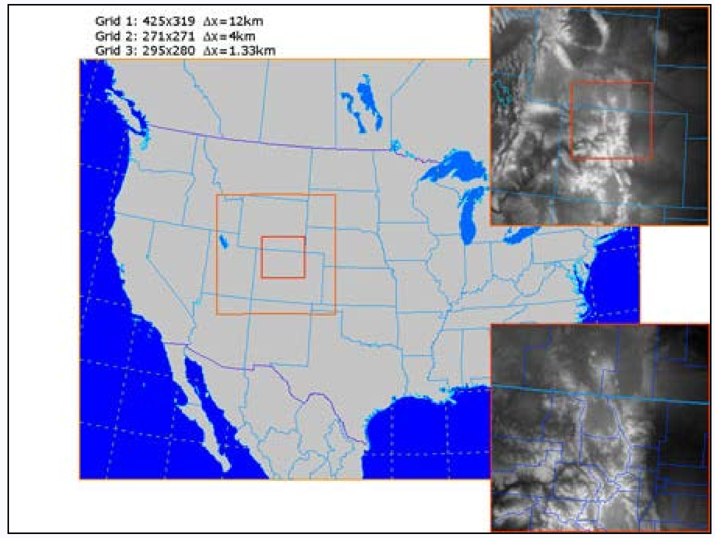
North American Monsoon research: Research into diagnosing the diurnal structure of rainfall and clouds over the North American Monsoon region of western Mexico continued during 2008. Using a network of surface rainfall and other meteorological measurements extensive work in evaluating remotely sensed quantitative precipitation estimates has been completed and is in press in both the *J. of Hydrometeorology* and *Atmosfera*. Combined, these works provide critical information on the structure of rainfall and cloud cover on the diurnal timescales across the complex terrain of western Mexico and is now being used to evaluate and improve operational hydrometeorological prediction models.

FY2009 Plans:

During FY2009, work will center on evaluating and improving the flash flood prediction system for the Colorado Front Range. Specifically, work is underway to tune NEXRAD estimated rainfall using the Colorado State CHILL research radar which was operating within our prediction domain during 2008. Work is also underway to improve the data assimilation aspect of the numerical weather prediction and hydrological prediction modeling components of the flash flood prediction system. In addition to the Front Range flood research and North American Monsoon precipitation research, we will expand our hydrometeorological modeling work to encompass a cool-season precipitation snowmelt effort for the new Colorado Headwaters project. Research on this project will center on evaluating the coupling of land surface-atmosphere processes in the formation of precipitation and in the evolution of seasonal snowpack and runoff.

In-Flight Icing

National Transportation Safety Board records indicate that in-flight icing causes more than 25 accidents annually, with over half of these resulting in fatalities and damaged aircraft. The cost of injuries, fatalities and aircraft damage is estimated to be $100M annually. The RAL In-Flight Icing Program addresses this problem by producing improved operationally -available, high-resolution, accurate diagnoses and forecasts of aircraft icing conditions. This work is funded by the FAA's Aviation Weather Research Program and the NASA Advanced Satellite Aviation Weather Program.



The figure shows the domain of the ICE-L version of the WRF, illustrating the increased resolution of the terrain.

FY2008 Accomplishments:

Progress was made in improving the microphysical parameterizations within the Weather Research and Forecast (WRF) model to provide better forecasts of potentially hazardous icing conditions. A high-resolution version of the WRF was run in real-time in support of the ICE-L field project. Project participants believed the model runs were beneficial to project planning and a number of flights were determined partly from the model's explicit forecasts of wave clouds. To improve the representation of supercooled large drop icing, the microphysical parameterization of Thompson et al (2008) was modified to predict the number concentration of rain in addition to the mass mixing ratio. Adding this new variable produced rain size distributions that matched observations more closely and improved the prediction of freezing drizzle aloft and at the surface. Icing algorithm research and development continued with a focus on examination of new input data sets and their potential for improving the Current and Forecast Icing Products (CIP and FIP). Preliminary results using NASA's advanced satellite products are very encouraging. Evaluation of the NSSL 3-D NEXRAD reflectivity mosaic suggests that vertical profiles of reflectivity and its spatial variations could help determine which clouds are and are not icing hazards. Additionally, freezing drizzle detection using NEXRAD data looks feasible, and RAL scientists are now engaged in determining a path to operations for the new detection algorithm.

FY2009 Plans:

- We will begin development of a warning tool for High Ice Water Content environments, most likely using a combination of global weather models and satellite data.
- Our Alaska icing products will take a new turn as we collaborate with the Model Development Lab of the National Center for Environmental Research on implementation and testing of the FIP and CIP on their Interactive Calibration in 4-D tool; we expect to install these products for evaluation at the Alaska Aviation Weather Unit in Anchorage.
- We anticipate that the FIP will be approved by the FAA for operational use in spring 2009.
- Work is underway to make the new WRF Rapid Refresh model the basis for our icing diagnosis and forecasting algorithms.
- New data sets (e.g., NEXRAD 3D mosaic and advanced satellite products) will be tested for use in the Current Icing Product.
- Further development of microphysical parameterizations in WRF will continue.
- A confidence field will be created for our icing algorithms to enable them to be incorporated into automated decision-making systems.

Juneau Terrain-Induced Turbulence

The Juneau, Alaska, environment is characterized by rugged terrain and adverse weather that combine on occasion to produce moderate to severe terrain-induced turbulence and wind shear for flights into and out of the Juneau International Airport. To address this problem, the FAA tasked RAL in FY97 with the development and implementation of a new wind hazard warning system for the airport. Over the last ten years, RAL engineers

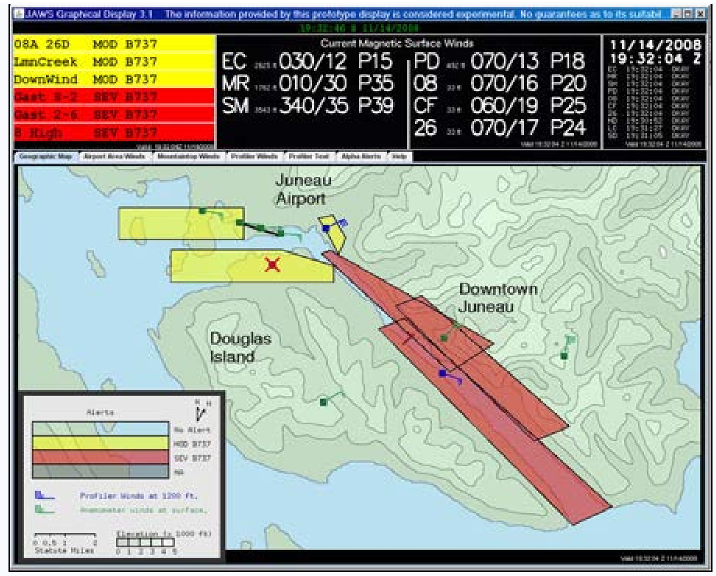


Figure 1. Geographic display of Juneau Airport Wind System. Hazard alert areas are outlined as boxes.

and scientists have built a prototype warning system that relies on statistical correlations between wind-related parameters observable by the system (i.e., speed, direction, shear, variance, etc.) and the location and severity of turbulence. Since terrain is fixed and there are distinct strong-wind scenarios, correlations are expected between winds and hazards. These correlations were established using the warning system's input measurements and hazards measured by research aircraft during three intensive field projects. The graphical display was designed for a variety of users including Automated Flight Service Station specialists, airline dispatchers, and pilots. It contains information that depicts current alerts and conditions as well as conditions during the past hour. The prototype warning system is used every day by airlines and pilots flying in and out of Juneau to assess the current turbulence hazards around the airport.

FY2008 Accomplishments:

RAL continued operation and maintenance of the warning system. Alaska Airlines is required to use the current Operational Specification (OpSpec); in addition they voluntarily included the use of our alerting system, specifically requiring their pilots to use our severe alerts as another go/no go decision point in addition to OpSpec mandated decisions. NCAR and the FAA evaluated several alternative possibilities for the end-state system design. We have now been directed to proceed with plans to complete the system as a "hybrid" turbulence alerting system using the FAA-developed communications with all sensor sites, integrated with NCAR's algorithm and display computers. Although final approval for this decision was not made in FY2008, it is expected early in FY2009.

FY2009 Plans:

RAL will continue to operate and maintain the prototype warning system to continue service for the Juneau community. A new version of alerts will be turned on in the first quarter so that Alaska Airlines pilots and the FAA can evaluate them during the winter season. The new hybrid "JAWS-H" system will be developed and installed in Juneau late in FY2009. Documentation of the system will commence to provide operations and maintenance information to the FAA for inclusion in their handbooks. The end-state JAWS Operational Ready Date is planned for the end of FY2011.

Nowcasting Technology Transfer to China and Beijing 2008 Forecast Demonstration

As part of the NCAR Short Term Explicit Prediction Program (STEP) RAL's Convective Weather Group participated in the Beijing 2008 Forecast Demonstration Project. The project was endorsed by the World Weather Research Program (WWRP). A goal of the Forecast Demonstration Project (FDP) was to use state-of-the-art nowcasting systems to support meteorological services to the Beijing 2008 Olympic Games. Forecast products included storm severity (e.g., hail, lightning, strong winds, and heavy rain). Most forecasts were for 3 hours or less with a few radar reflectivity and precipitation rate forecasts to 6 hours. Nowcasting systems participating in the FDP were from Hong Kong, Canada, Australia, China and the U.S. NCAR fielded its nowcasting system called "Niwot" which produces 1-6 hour forecasts of thunderstorms by blending radar extrapolation and a WRF numerical model. The Auto-nowcaster system, developed at NCAR and transferred to the Beijing Meteorological Bureau, was also fielded.

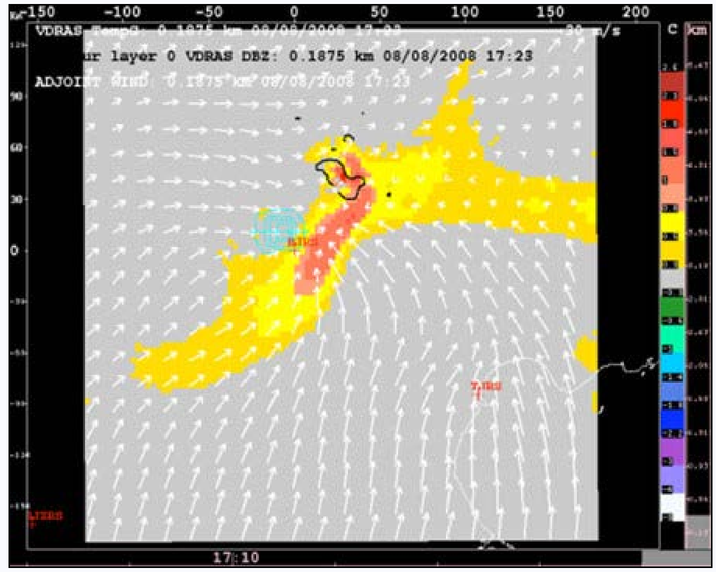
There were numerous days in the week before the Olympic Games began and during the games themselves when weather was a significant issue; this created a challenging test for the nowcasting systems. During the demonstration, a close working relationship developed between the Beijing Meteorological Bureau forecasters, who had the ultimate responsibility for issuing the forecasts for the games, and the representatives from the WWRP nowcasting systems.

FY2008 Accomplishments:

The FDP was the most comprehensive demonstration to date to assess the strengths and weaknesses of various systems' ability to make precipitation and thunderstorm forecasts for the 0-6 hour period. Also assessed was the quality of an automated consensus forecast of precipitation rate based on the forecasts from the individual systems.
There were two occasions where the forecasts had a particularly large potential impact on the Games. The first involved a full-scale rehearsal for the opening ceremony and the other was the opening ceremony itself. In both cases intense thunderstorms in the mountains were moving towards Beijing. In both cases the FDP the human-generated consensus forecast correctly forecast that the thunderstorms would dissipate before reaching the stadium. It should be noted, however, that in these two cases and on many other occasions it was the human forecaster overriding the forecasts from the automated systems that resulted in the correct forecast. There were three numerical weather prediction systems focused on the very short period. Even though one of these models assimilated radar data, they all had considerable difficulty in providing sufficient accuracy on the

time and space scale of the Olympic events. The NCAR Auto-nowcaster was the only system that had the ability to aggressively forecast initiation, growth and decay, but it had not been modified to account for the effect of terrain to the immediate north and west of Beijing on storm growth and dissipation. With the exception of large-scale synoptic events it was apparent that there is much to be done before numerical weather prediction models will be able to provide sufficient forecast skill on the scale of individual cities for residents to take appropriate actions to minimize the effect of adverse weather on their actions. Automated extrapolation techniques and blending techniques also have limited forecast skill, particularly in a region like Beijing where the mountains are a major influence on the evolution of the weather. For the foreseeable future, expert systems like the Auto-nowcaster, in conjunction with a human playing an oversight role, are the most promising means for the 0-6 hour forecast.

It was apparent that high resolution observations of the evolving wind and stability fields are critical for accurate 0-6 hr forecasting. The NCAR Variational Doppler Radar Analysis System (VDRAS) which fits a numerical model to high resolution observations was operating throughout the demonstration and was particularly useful to forecasters for identifying local regions of convergence and strong gradients in the temperature field. The figure shows a VDRAS wind analysis for a time period when thunderstorm initiation was taking place following the Opening Ceremony. The initiation is taking place along old outflow boundaries that are nicely depicted by the wind and temperature gradient fields.



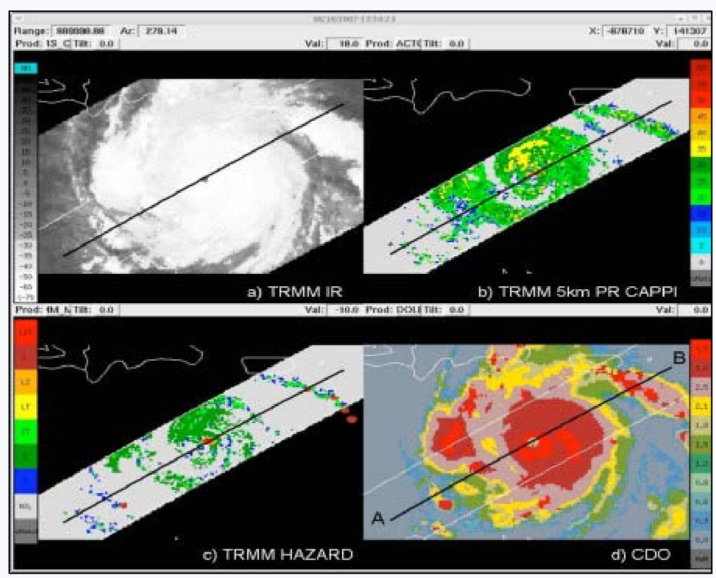
VDRAS wind vectors at height of 187 meters on opening day of the Olympic games in Beijing China. The ring roads of Beijing are shown by the cyan lines. The solid colors represent the temperature gradient and the black contours radar reflectivity greater 35 dBZ.

FY2009 Plans:

NCAR scientists will collaborate with other WWRP scientists to formally evaluate the FDP systems and analyze the strengths and weaknesses of the various forecast technologies. The results will be presented at conferences, particularly the next WWRP nowcasting conference in Canada, and written up as journal papers.

Oceanic Weather

Convection is an aviation hazard that can produce turbulence, icing, hail and lightning. Over the continental United States, the aviation community is well-served by the national Weather Surveillance Radar 1988 Doppler (WSR-88D) network that gives accurate and timely detections of the presence of hazardous convection. Over remote oceanic regions, however, the aviation community is hampered by the scarcity of available data that can be used to create products that detect and warn pilots, dispatchers and air traffic controllers of the current and future locations of hazardous convection. Unexpected convective development while en route can lead to costly re-routing and delays. Transmitting this critical information into the flight deck is difficult and further compounds the hazards faced by oceanic flights. The long duration of oceanic flights requires convective forecasts with longer lead times than those required for the continental United States. Under NASA Earth Observing System sponsorship, the Oceanic Convection Program at RAL is working to overcome these limitations through the use of geostationary and polar-orbiting satellite observations and global numerical model results within an intelligent system that generates 0-2 hour nowcasts of convection location. Collaborators in this research include the Naval Research Laboratory-Monterey (NRL), and the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL).



Four-panel analysis display showing the (a) TRMM infrared brightness temperature (°C), (b) TRMM radar reflectivity (dBZ) at 5 km altitude, (c) TRMM derived hazard product, and (d) CDO interest field of oceanic convective clouds associated with Hurricane Dean on 18 August 2007 at 13:44:11 UTC.. The TRMM derived product denotes regions where our criteria for hazard was observed based on the following designations: T – convective rain, Z – reflectivity ≥30 dBZ at 5 km altitude, L – lightning, or ZT, LT, LZ, and LZT – combination of the hazard classes. An interest threshold of 2.5 is applied to the CDO interest field to indicate the presence of convective clouds. A cross sectional view of the radar reflectivity and CDO interest values along the black line segment labeled A-B in (d) is illustrated in the second figure. The TRMM PR swath width is 243 km.

FY2008 Accomplishments:

This R&D effort is currently focused on the greater Gulf of Mexico region and includes the Caribbean and parts of the western Atlantic and eastern Pacific oceans. The Oceanic Convection system consists of two products: the convection diagnosis oceanic

(CDO) and the convective nowcasting oceanic (CNO). The CDO product detects the location of convection using a scaled combination of three satellite-based algorithms. The CNO tracks the location of convection as defined by the CDO using the thunderstorm initiation, tracking and nowcasting (TITAN) algorithm and provides 1-hour and 2-hour nowcasts of storm location.

Accomplishments in FY08 include an evaluation of the CDO product against mission products available from the NASA Tropical Rainfall Measuring Mission (TRMM) satellite by MIT LL. Data sets used in the evaluation of the CDO during Hurricane Dean (12-23 August 2007) are shown in the figure below. An evaluation of the CNO system was accomplished, using the CDO field for validation. Investigation into the use of a machine learning technique called Random Forrest for possible inclusion into the CNO are underway, and preliminary results look promising. An investigation into characterizing the environment of regions where convection initiation has occurred was completed. Use of geostationary cloud motion vectors for storm extrapolation is under investigation and will be completed in the following year. Expansion into the Pacific domain has begun with the testing of component algorithms to use meteorological satellite (MTSAT) imagery.

FY2009 Plans:

Expansion of the CDO/CNO system into the Pacific is underway. Development of the system will continue with further investigation into the use of the Random Forest technique. Evaluation of the CNO results with the TRMM mission products is expected.

Real-Time Modeling and Data Assimilation

Effective combination of mesoscale weather modeling systems with diverse weather observations is a reasonable approach for producing four-dimensional weather data sets that are useful for event reconstruction and model initialization. At RAL, such a system has been formulated by enhancing the MM5 and WRF models with a real-time four-dimensional data assimilation (RT-FDDA) capability. In the last few years, the RTFDDA system has been deployed to provide multi-scale (meso-gamma to meso-alpha), rapid-cycling (1–6 hour), high resolution (0.5–3 km grid intervals), real-time weather information for many US government agencies, industrial sponsors, and foreign governments. RTFDDA data assimilation technology is also the core engine for the RAL current-climate downscaling capabilities.

FY2008 Accomplishments:

RTFDDA capabilities have been significantly expanded in several key areas, including improvements to the WRF "observation-nudging" code, development of hybrid data-assimilation schemes, assimilation of radar radial wind and reflectivity, and advances in mesoscale ensemble analysis and forecasting.

RAL modelers led the "observation-nudging"-based FDDA scheme development in WRF, which improved RTFDDA operational applications for both sponsors and the broad community of WRF users. Many detailed case studies and real-time parallel-run experiments have been carried out to strengthen the data assimilation system's performance.

The WRF-3DVAR, the VDRAS (Variational Doppler Radar Assimilation System) and the WRF grid-nudging method were evaluated with respect to their ability to be used in the WRF RTFDDA system; they are being incorporated. An IHOP-2002 severe convective event was selected to demonstrate a hybrid data assimilation scheme that uses "grid-nudging" with intermittent 3D radar data analyses produced by WRF-3DVAR, along with the standard WRF-RTFDDA algorithm that assimilates observations. This hybrid data assimilation approach effectively reduces the serious "spin-up" problem associated with 3DVAR radar data assimilation, and it also improves WRF-RTFDDA analyses and predictions of convection (Figure 1).

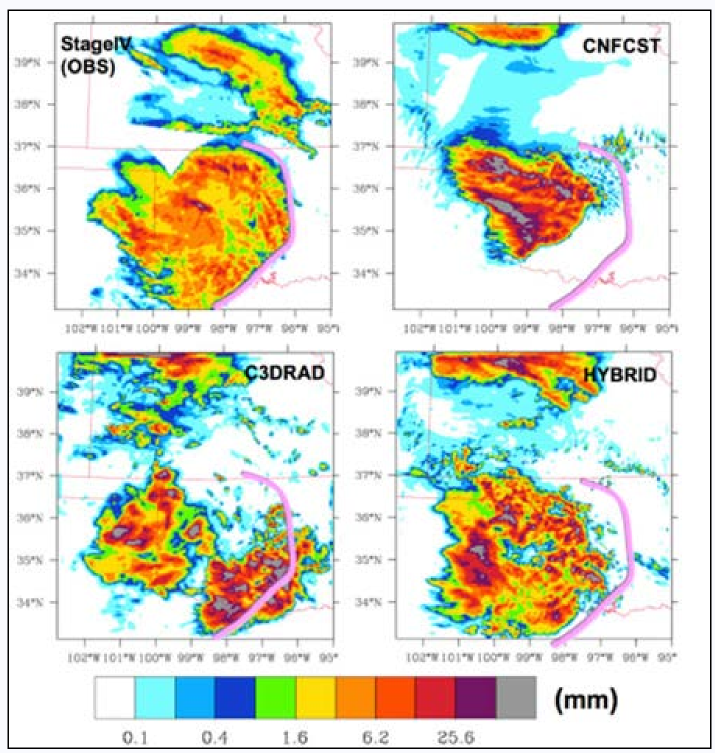


Figure 1. Observed and 0-6 h precipitation forecasts from WRF for a period during IHOP-2002. The "observations" in the upper left are based on the Stage-IV precipitation analysis, CNFCST is a forecast based on a cold-start initialization, C3DRAD is a forecast from a cold-start initialization that includes a 3DVAR analysis of radar data, and HYBRID uses the 3DVAR analysis with RTFDDA data assimilation.

In parallel with the 3DVAR-RTFDDA hybrid algorithm development, research was also carried out to employ VDRAS Doppler radar analyses in RTFDDA. As a first step, VDRAS was run to assimilate radar reflectivity and radial winds using WRF-RTFDDA short-range forecasts as the background. The VDRAS analyses were then used to initialize the WRF forecasts. The experiment results confirm that the VDRAS-RTFDDA hybrid data assimilation is another promising approach for incorporating radar data into WRF-RTFDDA.

Progress has also been made into Ensemble-RTFDDA. E-RTFDDA extends the single deterministic RTFDDA forecasting to probabilistic weather prediction by executing an ensemble of RTFDDA models. A 30-member E-RTFDDA system, which samples the uncertainties in the model components, has been operating at the Army Dugway Proving Ground (DPG) since August, 2007. Weather forecasters and decision makers at DPG have been productively exploiting the model products for supporting range tests. E-RTFDDA graphics displays were improved to better convey probabilistic forecast information to end-users. A module was also developed to use E-RTFDDA member output to drive a plume model directly in real-time. More than 20 terabytes of E-RTFDDA ensemble output have been stored, representing a valuable database for system verification and for pursuing ensemble calibration. Besides the operation at DPG, E-RTFDDA was also employed to optimize single deterministic WRF-RTFDDA systems and support other RAL projects.

Another RTFDDA research effort is the WRF LES (large eddy simulation) downscaling capability. A case study has been conducted to run WRF-RTFDDA-LES using 6 nested grids, with a fine mesh having a grid size of 123 m. Data assimilation was applied on the 4 coarsest meshes, while the LES modeling on the two finest meshes was realized through dynamical downscaling. The modeling experiment shows that the model is able to forecast many interesting kilometer- and sub-kilometer-scale complex flow features. Meanwhile, this work also indicates that real-data LES modeling can provide insight into the representativeness of in-situ surface and upper-air observations, and their impact on NWP model verification and data assimilation.

FY2009 Plans:

WRF-RTFDDA will be evaluated and further improved in terms of data assimilation and the basic WRF physics parameterizations. Development of accurate methods for modeling land-surface physics and planetary boundary layer mixing will be crucial for many applications, and for the effective assimilation of surface data. Scientific plans and procedures will be defined for customization and optimization of operational WRF-RTFDDA system in terms of the physics and data assimilation components. Work will be undertaken to further investigate the hybrid data assimilation approaches for incorporating radar data in WRF-RTFDDA. The results of case studies will be extended to a week-long IHOP re-forecasting period, and then deployed for operation and evaluation.

WRF-RTFDDA-LES will be explored to study the potential for supporting the applications that need very high-resolution weather, e.g. inter-turbine wind variation at wind farms. The representativeness errors of in-situ observations, and their impacts on NWP model verification and data assimilation, will be studied using the WRF-RTFDDA-LES framework.

E-RTFDDA will continue to be one of the main research foci in 4DWX model development. Major efforts will be invested in E-RTFDDA verification, calibration, perturbation-scheme optimization, and operational expansion. E-RTFDDA verification tasks include statistical evaluation of the general properties of the E-RTFDDA system running at DPG, using model-output archives, and real-time on-line verification statistics. A quartile-regression ensemble calibration procedure will be developed and implemented for the DPG operational E-RTFDDA, and applied for each of the DPG 19 surface stations. The calibrated probabilistic forecasts will be displayed along with the un-calibrated raw data. Finally, E-RTFDDA will be deployed for several new projects in FY09, including Xcel Energy wind power forecasting, winter weather forecasting at the Army Aberdeen Test Center (ATC), NASA Airspace Terminal Management (ATM) and others.

Besides operational application, E-RTFDDA also provides a development testbed for advancing the 4DWX core modeling technology toward an ensemble-based flow-dependent Kalman-filter data assimilation system. In FY09, research will continue on a 4-D EnKF scheme which is a hybrid FDDA method that makes use of “Kalman-Gain” to define the spatial weighting factors in “observation-nudging” data assimilation.

Spatial Patterns of Risk and Vulnerability in Extreme Precipitation Events: 1997 Fort Collins Case Study

Aftermath of Spring Creek flood in Fort Collins, CO (July 1997).

Between 1983 and 2003, in the United States, flash floods caused nearly $4.5 Billion in damage and 98 deaths. Along the Front Range of Colorado's Rocky Mountains, variable precipitation, steep terrain, and a growing population combine to enhance flash flood risk. Although significant research has been performed on impacts and mitigation of flash flood events, a methodology for assessing societal vulnerability and risk in the Colorado Front Range region has not been fully developed. Based on the work of a B. Edwards, a protégé with UCAR’s Significant Opportunities in Atmospheric Research and Science (SOARS) program, this study focuses on a spatial assessment of societal risk to extreme precipitation events and runoff. The 1997 extreme precipitation event, that caused a flood disaster in Fort Collins, Colorado, was used as a model event to assess societal risk and vulnerability to extreme precipitation events and flash flooding. The methodology developed in this study allowed for radar-derived precipitation data to be spatially integrated with socio-economic and demographic US Census-based data for spatial analysis. Spatial patterns of vulnerability were evaluated from both “during event” or “response” and “post-event” or “recovery” perspectives. The results provide a framework for a more in-depth study of flood risk utilizing near-real-time precipitation data, hydrological models and more detailed socio-economic geographic data. In FY08 we completed development of the methodology and used a data set of 911 calls from the flood to verify results. In FY09 we plan to submit a manuscript to a peer-reviewed journal describing the methodology and presenting results from the analysis to the research and practitioner community.

Collaborators: O. Wilhelmi (ISSE), R. Morss (MMM /ISSE) and B. Edwards (Oklahoma Department of Environmental Quality).

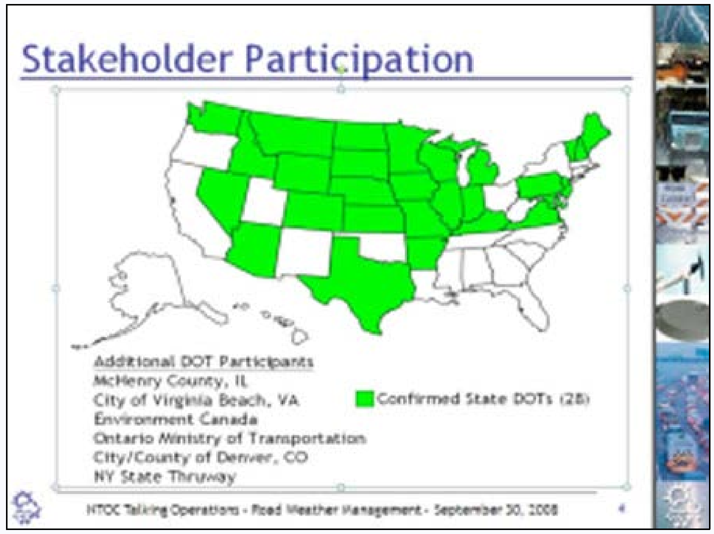
Surface Transportation Research and Development

RAL's commitment to build capacity for coping with weather hazards is demonstrated by its leadership role in the Road Weather Research and Development Program within the USDOT's, Federal Highway Administration (FHWA) and Research and Innovative Technology Administration (RITA). Approximately 1.57 million accidents occur each year in poor weather on the nation's roads and an estimated 713,000 injuries and 7,400 deaths per year (based on an 8-year average) occur, creating an annual economic toll of approximately $42B. Weather plays a role in about 28% of the total crashes and 19% of the total fatalities. Weather also reduces capacity and significantly impacts efficiency, triggering congestion, particularly on roads operating near capacity. Approximately 15% of all congestion is due to poor weather and related road conditions.

Since 1998, RAL has played a pivotal role in bringing the surface transportation and weather communities together to improve surface transportation safety and mobility. RAL continues to provide national leadership in surface transportation weather by organizing and participating in national and international surface transportation weather workshops, conferences, training programs, and committees.

FY2008 Accomplishments:

Maintenance Decision Support System (MDSS)



Since 1999, RAL has led a team of national laboratories in the development of the prototype winter Maintenance Decision Support System (MDSS), a unique decision support system that provides real-time snow and ice control guidance (e.g., treatment times, chemical choices, rates, and locations) for user-defined roadway segments. In FY08 the modeling, pavement (bridge and roadway) heat balance models, data fusion system, and rules of practice components of the MDSS were refined to improve the overall performance of the system. Other highlights included working with Environment Canada to improve the performance of their pavement heat balance model called METRo into the MDSS system; disseminate MDSS Version-5.0 software to over 60 road weather organizations (public and private); and successfully support the FHWA's annual MDSS stakeholder meeting, which included more than 80 participants from the surface transportation community including 28 State DOTs.

As part of the MDSS research and development project, the prototype MDSS was utilized in real-time by the City and County of Denver and the E-470 Public Highway Authority during the winter of 2007-2008. Commercial versions of the MDSS are being developed and demonstrated as part of a DOT Pooled Fund Research Program. The Pooled Fund MDSS was evaluated by 13 DOTs last winter.

Wireless Vehicle Technology

The USDOT has embarked on a relatively new program with the automotive and consumer electronics industries to develop a national capability to support wireless communications for vehicles. The Vehicle Infrastructure Integration (VII) Program is working toward deployment of advanced vehicle to vehicle and vehicle to infrastructure communications that will improve highway safety. RAL is working closely with the FHWA Road Weather Managements Program to develop concepts and assess the feasibility of utilizing vehicle data to enhance the diagnosis and prediction of weather and road conditions along our nation's roadway network. In 2007, RAL prepared and delivered to the FHWA a major vision document titled *Weather Applications and Products Enabled Through Vehicle Infrastructure Integration (VII)* and in 2008 NCAR participated in a VII proof of concept test in Detroit, Michigan. The VII program will provide vehicle probe data (including weather data) from millions of vehicles that will be available to the weather community to support the diagnosis and short-term prediction of

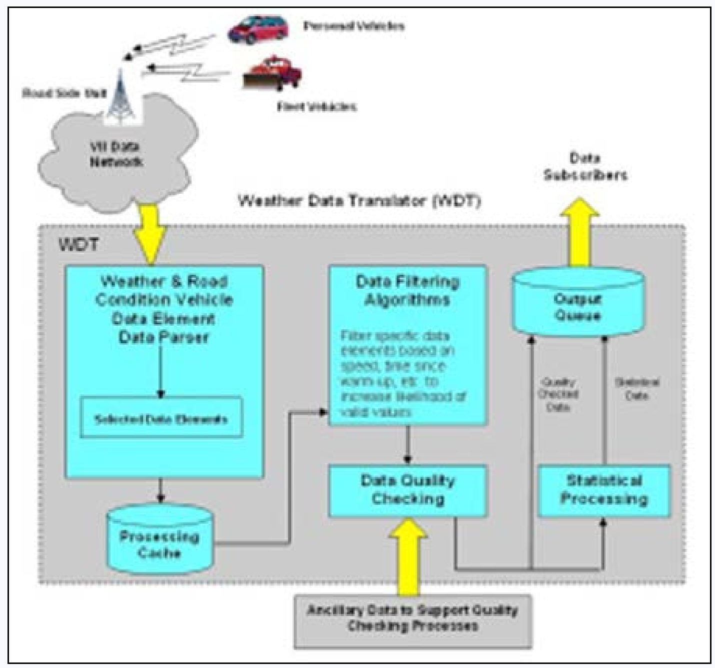
Example of a passenger vehicle traveling in Detroit wirelessly exporting weather measurements during a day with thunderstorms. Data courtesy of Daimler Chrysler

weather and road conditions.

FY2009 Plans:

Maintenance Decision Support System (MDSS): The MDSS system will continue to be developed and validated in 2009 using Colorado as a test bed. Prototype MDSS products will be provided to the E-470 Public Road Authority, the City and County of Denver, and new for 2009, we will provide MDSS data to Denver International Airport to support ground operations. A new release of the MDSS software to the weather and transportation communities is scheduled for spring 2009.

Clarus Initiative: RAL is participating in a national research and development effort to develop additional decision support systems for transportation specialists including traffic, emergency, and incident managers and summer maintenance personnel. RAL is teamed with Mixon-Hill on a project to: a) perform research to optimize numerical weather prediction modeling capabilities to support surface transportation weather, b) develop advanced quality checking algorithms for the Clarus System, and c) support the development of advanced decision support systems.

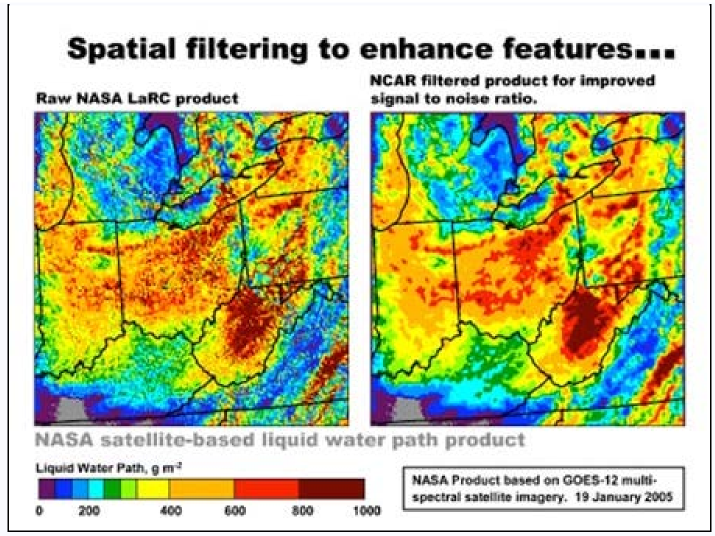


Conceptual illustration of the Weather Data Translator (EDT) that will be developed by RAL to process data from millions of vehicles and generate derived weather and road condition analyses.

Wireless Vehicle Technology: In FY2008, RAL participated in the VII testbed near Detroit, Michigan. In 2009, RAL will process and evaluate the quality of vehicle data and begin to analyze their characteristics including, density, and geographical and temporal distribution. RAL will continue the development of the Weather Data Translator (WDT) that will be used to parse, ingest, process, quality control, and generate advanced weather and road condition analyses utilizing vehicle probe data. This will be a significant scientific and engineering activity that will eventually facilitate the collection and processing of millions of new surface weather observations.

Transitioning Advanced Satellite Observations into Practical Applications

RAL scientists and engineers are continuing work on a number of projects that involve the acquisition and application of meteorological satellite data to enhance understanding of atmospheric processes and applications. Much of this work is being supported by NASA, through the Advanced Satellite Aviation Weather Products (ASAP) initiative and through a system of competitive grants awarded by NASA's Applied Sciences Program. The goal of ASAP is to enhance the transition



An example of an ASAP developed enhancement to a NASA liquid water path product for aviation applications, using spatial filtering techniques to improve the product signal-to-noise ratio and emphasize features critical to in route aircraft.

of new and existing satellite information and products into operational products by collaborating with the FAA's Aviation Weather Research Program (AWRP) Research Teams, many of which are based at NCAR. This effort is specifically addressing hazards such as in-flight icing, convective weather, turbulence (clear-air and cloud-induced), and the monitoring of weather in the data-sparse areas over oceans. RAL's role in ASAP is to coordinate the contributions from the participating universities and laboratories with the needs and requirements of the FAA's aviation weather Research Teams and to evaluate the accuracy and usefulness of these advanced satellite products.

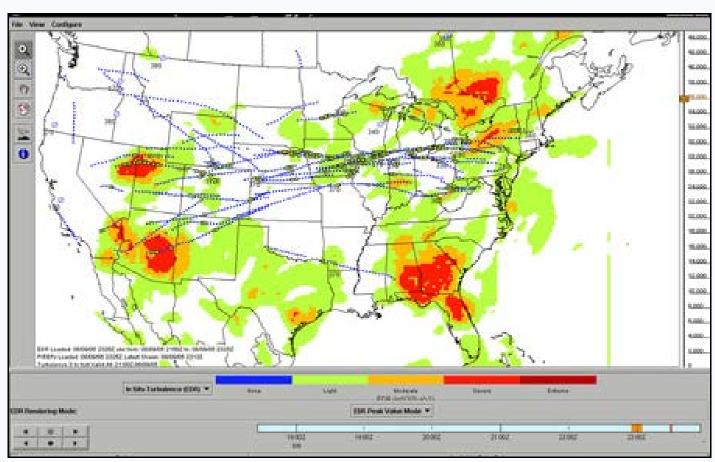
FY2008 Accomplishments:

- During 2008 the In-Flight Icing team continued to develop satellite-based cloud microphysical products produced by NASA Langley for incorporation into operational icing products such as the Current Icing Product (CIP).
- RAL scientists worked with scientists from the University of Alabama, Huntsville (UAH) and the University of Wisconsin's Cooperative Institute for Meteorological Satellite Studies (UW/CIMSS) to 1) test the utility of satellite-based, high-resolution, early cloud imagery for identifying favorable areas for convective development capable of growing into hazardous storms; and 2) to identify cloudy and clear-air features that may help identify areas of strong turbulence.
- RAL hosted a summer student from Christopher Newport University in Virginia, as part of the NASA DEVELOP Program. The student helped add space weather observations to the RAL-developed Aviation Digital Data Service (ADDS) experimental web page.
- Three projects aimed at enhancing the use of NASA Earth Science data sets in decision support systems continued. These projects include studies of oceanic aviation weather hazards (in collaboration with scientists at the Navy Research Laboratory Monterey and MIT/Lincoln Laboratory); aircraft avoidance of convectively-induced turbulence due to thunderstorms (in collaboration with scientists at UAH and UW/CIMSS); and improved monitoring and forecasting of soil moisture and temperature for agriculture (in collaboration with DTN/Meteorlogix).
- In 2008 RAL received an additional NASA ROSES award to develop a Global Atmospheric Turbulence Decision Support System for Aviation, based on a combination of satellite observations, in situ observations, and numerical models.
- The ASAP program received the NASA Langley Research Center's Holloway Award for Technology Transfer.

FY2009 Plans:

The RAL NASA ASAP effort will continue in 2008 with a gradual transition of the new satellite products into operational use through collaborations with the FAA Aviation Weather Research Teams. A key component of the transition to operations for these new products is their integration into the developing Next Generation Air Transportation System, NextGen.

Turbulence Research and Development



Experimental ADDS Web-based display showing in situ turbulence reports overlaid on contours of the Graphical Turbulence Guidance (GTG) turbulence forecast product.

Encounters with turbulence pose significant safety, efficiency and workload issues for commercial and general aviation. The number of pilot-reported encounters with turbulence is substantial, with moderate-or-greater turbulence pilot reports averaging about 65,000/year and severe-or-greater reports averaging about 5,500/year. More often than not, pilots will try to avoid or exit turbulent air, so turbulence significantly impacts national airspace (NAS) efficiency and air traffic controller workload. Fortunately, not every significant encounter with turbulence results in an injury; nevertheless, according to NTSB numbers, each year turbulence accounts for approximately 71% of all weather-related accidents and incidents. The cost to U.S. airlines due to injuries (medical attention and liability suits), cabin and aircraft damage, flight delays, and time lost to inspection and maintenance is substantial, with estimates in the $150-$500 million/year range. In order to help reduce the number and severity of turbulence encounters and the impact of turbulence on the NAS, RAL scientists are working on improving the detection, nowcasting and forecasting of turbulence and providing operationally useful products directly to users and as input to the automated decision support systems planned for the Next Generation Air Transportation System.

Aviation turbulence R&D at RAL is funded primarily through the FAA's Aviation Weather Research Program and is augmented by NASA's Applied Sciences Weather Program and the Boeing Corporation.

FY2008 Accomplishments:

- A new in situ turbulence detection and on-board quality control algorithm was developed. The software has been successfully deployed on the entire fleet of 70 Delta Airlines 737-800 aircraft.
- The NEXRAD Turbulence Detection Algorithm (NTDA) was deployed on all NEXRADs as part of the Open Radar Products Generator Build 10 upgrade.
- A real-time demonstration of the NTDA was expanded to use data from 133 NEXRADs covering the CONUS. A 3-D mosaic of in-cloud turbulence was provided to users via a web-based Java display, and archived for use in developing a comprehensive turbulence nowcast product.
- Case studies of near-cloud turbulence were performed using high resolution WRF simulations of turbulence observed near an MCS. This work has identified a new source of upper level turbulence in clear air and has been submitted and accepted for publication in the Monthly Weather Review.
- A prototype real-time diagnosis of convectively induced turbulence (DCIT) based on an empirical algorithm ran at 15-minute intervals during the summer of 2008, providing deterministic and probabilistic assessments of CIT. A comprehensive database associating in situ eddy dissipation rate (EDR) measurements with satellite, lightning, radar, and numerical weather prediction model data was assembled for use in refining the algorithm. DCIT will be a component of the GTG Nowcasting system.
- The Graphical Turbulence Guidance-2 (GTG2) algorithm continues to progress toward Aviation Weather Technology Transfer (AWTT) Board approval for operational status, which is expected in early 2009. Displays of the product are currently available on the Experimental ADDS web site (http://weather.aero). A still more updated experimental version that provides turbulence forecasts due to mountain waves and also provides probabilistic forecasts has been developed and is currently being evaluated by NOAA/ESRL/GSD
- A prototype GTG-Nowcasting (GTGN) system was developed and implemented in RAL. The system is intended to bring together all available explicit measurements of turbulence (e.g. from PIREPs, in situ EDR data, and NTDA) as well as inferences of turbulence from other remote sources such as satellite imagery.
- A comprehensive study regarding the use of airborne GPS receivers to measure turbulence was performed and delivered to the Boeing Corporation.

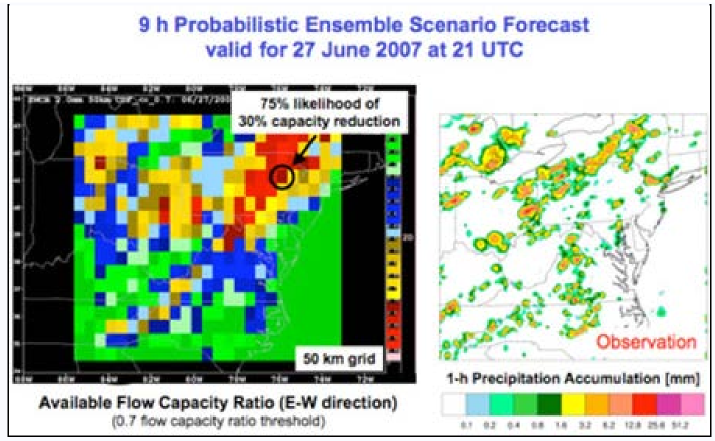
FY2009 Plans:

Work will be focused in the following areas:

- In situ measurements: Verification of the in situ EDR measurements against PIREPs will continue, and ICAO documentation on the algorithm will be completed. Fleet-wide implementation of the winds-based EDR algorithm on the approximately 400 aircraft in the Southwest Airlines 737 fleet will be completed. Further, implementation of the algorithm on 140 Northwest Airlines planes will begin. We are also in discussion with other airlines, both national and international, about implementation on their respective fleets.
- Development and implementation of NTDA-2 will continue to address recent changes to NEXRAD operational modes (super-resolution, phase coding, and new volume coverage patterns), providing improved accuracy and coverage. The real-time NTDA demonstration will continue. Refinement of DCIT will result in a finalized algorithm for use in the GTG Nowcasting system evaluation.
- Nowcasting/forecasting: GTG2 should become "operational" and available on NOAA's Operational ADDS web site in early CY09. This product produces forecasts of clear-air turbulence sources out to 12 hours, and is updated hourly at 1000 ft increments from 10,000 to 45,000 ft MSL. Work will continue to more efficiently use the high density of in situ EDR measurements within GTG3. Work will continue on the GTG-Nowcast, which combines all observations of turbulence (including NTDA-2, in situ EDR, pilot reports, and satellite-based diagnostics) with GTG3 analyses to produce a probabilistic nowcast product updated at 15 minute intervals. Work will also commence on a global turbulence nowcast and forecast (Global GTG) product that will provide rapid updates of oceanic convection and associated CIT, based mainly on satellite and Global Forecast System (GFS) model data, and GFS-based forecasts of upper-level turbulence globally out to 36 hours.

Weather Integration with Air Traffic Management

Weather, especially convective storms, continues to exert a disruptive influence on aviation, both in the terminal area and en-route air traffic flow. Aviation users need 0 – 6 hour forecasts that provide not only details about the likely weather outcome, but also information about storm structure, intensity, and organization, and associated forecast uncertainty. This emphasizes the need for short-range (0 – 2 days), high-resolution (<10 km spatial resolution) ensemble weather forecasting systems. Optimization of air traffic management, especially under future scenarios of



Probabilistic ensemble scenario forecast of expected reduction of the available flow capacity ratio in east-west direction due to inclining weather nine hours ahead.

anticipated much increased demand, requires automated decision support tools that integrate probabilistic weather information to estimate airspace capacity and provide guidance for managing air traffic flows under consideration of the associated prediction uncertainties. Under NASA sponsorship, RAL is defining and refining new concepts of how probabilistic weather forecasts can be tailored for aviation needs and integrated with automated decision support tools.

FY2008 Accomplishments:

A proof-of-concept has been demonstrated (see figure below) to show how ensemble weather forecasts in the not-too-distant future may be analyzed from an aviation user's point of view and packaged for integration with automated air traffic management decision support tools. The focus of this approach has been on convective storms primarily because of their disruptive influence on air traffic flows. However, we have also shown that the ensemble-based approach is applicable to other en-route weather hazards, such as turbulence and icing as well. Analyses carried out thus far include performance assessments of the ensemble-based probabilistic scenario forecasts as a function of lead-time, spatial scale, and magnitude of the weather event.

FY2009 Plans:

The concept, developed during FY07 and put to work during FY08, will be further refined. In particular, additional cases will be studied based on utilizing high-resolution ensemble model simulations to achieve a more substantial database for evaluation. Moreover, the impact of such probabilistic scenario forecasts on aviation users will be evaluated using NASA's FACET (Future ATM Concepts Evaluation Tool) software package.

Winter Weather Research and Development

Winter weather research and development at RAL has focused on developing a real-time nowcasting system called the Weather Support to Deicing Decision Making (WSDDM) system. Recent additions to the system included the Check Time system, and Liquid Water Equivalent (LWE) system. The Check Time system is a UCAR patented technology for aircraft ground deicing that determines when the fluid is close to failure (Check Time) of an applied aircraft deicing fluid based on temperature measurements and precipitation rates that update every minute. This check time is aircraft independent and only requires the end user to know the time that the aircraft was deiced. The Check Time system is based on the LWE system, which determines precipitation rate and type. The LWE system combines a Hotplate and GEONOR snow gauge, a Vaisala PWD-22 precipitation type sensor, a Campbell freezing rain sensor, and a Vaisala WXT wind, temperature, and humidity sensor to estimate a real-time liquid water equivalent precipitation rate in support of the determination of holdover times for de/anti-icing fluids.

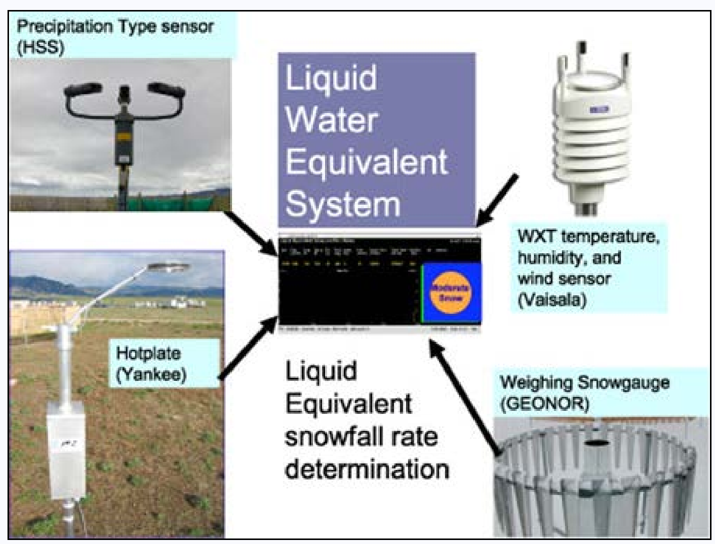


Figure 1 Schematic of Liquid Water Equivalent (LWE) system

FY2008 Accomplishments:

The key accomplishment for FY08 was the demonstration of the LWE system at four airports: Pittsburgh, Chicago O'Hare, Denver, and Minneapolis/St. Paul. An additional system was deployed at the Marshall Field site in Boulder, CO, for system verification. Manual snow pan observations (measuring the water equivalent of melted snow every 10-min) were collected at the Marshall site during most snow events last winter to serve as truth data for the verification. The FAA is using this data to develop a specification for approval of LWE and Check Time systems for operational use at airports in support of ground deicing. In addition, the NOAA Climate Reference Network group under Bruce Baker moved their Sterling, Virginia, test site to the Marshall Field site this summer to support testing of future snow gauge site designs for Western U.S. snow environments.

FY2009 Plans:

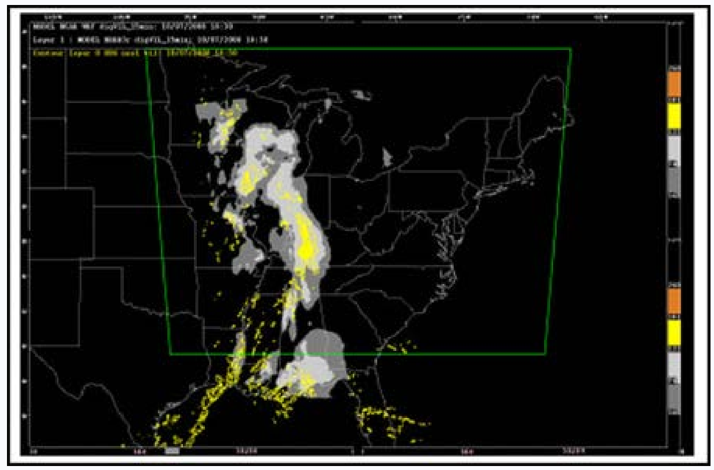
The demonstration of the LWE system at the four airport sites mentioned above will continue with an emphasis on freezing rain and freezing drizzle detection. Data from the LWE system will be provided to airlines, pilots and deicing users via a website and radio broadcast. A diagram of the LWE system is given below.

Zero to Six Hour Storm Forecasting

High-resolution data assimilation and numerical modeling are critical elements in the effort to improve short-term (0-6 h) forecasts of convective storms. Radar data assimilation using advanced techniques allows a model to start up with initial conditions that account for the presence of existing storms and can result in significant improvement in the timing and location of forecasting convective storms. Modeling efforts within RAL's Convective Weather Group emphasize the assimilation of radar reflectivity and radial velocity level II data from operational network into high-resolution cloud-resolving models. Although the long-term goal is to apply a WRF-based unified system that includes the advanced data assimilation techniques of 4DVAR (4-dimensional variational technique) and EnKF (Ensemble Kalman filter) for the convective-scale data assimilation and forecasting application, in the short term, our emphasis is on simpler techniques that can be run in real-time with the current computing power. Specific attention has abeen paid to the evaluation of the current real-time data assimilation systems and the development of methodologies to create a new hybrid system.

FY2008 Accomplishments:

In collaboration with NOAA/GSD, several cases documented during the FAA-supported summer 2007 forecasting demonstration period in the Indiana/Illinois domain have been selected to study the impact of high-resolution (3km) WRF initialization using RUC 13 km output that has radar reflectivity assimilation. The 0-12 hour forecasts from this study were compared with the conventional initialization using NCEP GFS (Global Forecast System) 40 km analysis and improvement was demonstrated. The WRF 3km forecast system based on the new initialization technique was demonstrated in real-time during summer 2008. The forecast system was run on a domain covering the southeastern region of the U.S. with an overlapping region of ~100 km with NOAA/GSD's HRRR (High Resolution Rapid Refresh) system, which runs in the northeastern U.S., thus extending HRRR's coverage of the WRF 3km forecasts. Fig. 1 shows an example of the merged forecast from the two domains.



Model runs on a northeast domain and a southeast domain. The observation of VIL from the NEXRAD network is overlaid by yellow contours.

With leveraged funds from STEP and the U.S. Army's Test and Evaluation Command, studies were conducted to examine the feasibility of combining data assimilation algorithms to improve the 0-6 hour storm prediction. Two methodologies were explored. One used VDRAS (Variational Doppler Radar Analysis System) analysis that was retrieved by assimilating radar observations with a 4DVAR technique to initialize WRF high-resolution model runs. Another was to assimilate WRF 3DVAR radar data analysis into WRF high-resolution model using the Newtonian nudging technique applied in RTFDDA. Both methodologies have shown promising results.

FY2009 Plans:

The methodologies for assimilating radar radial velocity and reflectivity for the initialization of high-resolution WRF model will be further developed and tested. The emphasis will be on the combination of the assimilation systems of RTFDDA, WRF 3DVAR, and VDRAS. The conduct of real-time demonstrations of the 0-6 hour forecasting with improved initial conditions will continue. In addition, WRF 3km forecasts from summer 2008 will be reexamined for convective weather events that significantly affected aviation, in an effort to understand the nature of forecast errors.

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GOAL 2. INCREASE SOCIETAL RESILIENCE TO WEATHER, CLIMATE, AND ATMOSPHERIC HAZARDS

NCAR Strategic Priority: Building New Connections with Researchers in Developing Nations

Building Capacity in Developing Countries

RAL staff participate in a variety of programs aimed at building capacity in developing countries. These are focused primarily in the following areas: improvement of radar networks and data-distribution systems in Africa; improvement of mesoscale modeling capabilities in Africa; and more recently in efforts to understand connections between weather, climate and health in Africa, Central America and South America.

FY2008 Accomplishments:

The effort to upgrade an operational network of weather radars in Burkina Faso, Mali, and Senegal continued. The RAL P.I. for this effort was the only American invited to the 8th EUMETSAT User Forum, held in September in Accra, Ghana. The conference, which included the heads of all of the African weather agencies, as well as representatives from the African Union and the European Union, focused on accessing and using satellite data to better meet the needs of African weather forecasting and environmental monitoring needs. Attention was also directed toward to strengthening links to African users through training, workshops, and joint research programs to ensure that the new products meet users' real needs. The conference generated a specific recommendation involving NCAR which is included in the 2009 plans below.

Currently, only a few African countries are running mesoscale models operationally. Most of these models, however, were developed for research, or have not been adapted for African weather. In 2007 we began an effort to adapt the WRF model to better meet local and regional needs. A WRF-based, high-resolution operational forecasting system centered on West Africa was established, and in 2008 forecasts from the model have been used for the training of forecasters in Africa. Dr. Benjamin Lamptey, a former NCAR ASP post-doctoral student, used the model output to train meteorologists in Ghana on the use of mesoscale models for forecasting. RAL scientists have also worked with university colleagues in Cairo, Egypt, under a small NSF grant to procure sufficient computing power to effectively run the WRF model

Figure 1. West Africa weather-radar coverage (circles). See text for details.

A number of weather, climate and health efforts are described in Section 2.1 of this Annual Report. It is clear that while their primary focus is indeed building societal resilience to extreme weather events and the impacts of climate change, each of them also has a capacity-building component as NCAR scientists work in close collaboration with local scientists and practitioners. In a similar vein, the success of our flood forecasting and warning work in Bangladesh (described in Section 1.3) is highly dependent on collaboration with local individuals and organizations.

FY2009 Plans:

The EUMETSAT conference described above produced concrete recommendations for moving its agenda forward. RAL intends to work with this organization to accomplish the following: "Noting how well radar imagery complements and validates satellite data, the Forum invites NCAR to consider expanding the scope of its initiative to establish a radar network in West Africa, to other regions of Africa and to organize and promote a workshop in 2009 on the applications possible from using African radar network data in combination with satellite data." This is meant to be a follow-up to the workshop NCAR organized in Burkina Faso in April 2007.

Work will begin on a new program funded by Google.org to develop and implement a prototype decision-support system that integrates 2 -14 day weather forecasts and epidemiological data to provide actionable information to contain the spread of meningitis epidemics. In 2009 we intend to establish local partnerships in Ghana, demonstrate weather-meningitis links, and develop and verify ensemble-derived forecasts for meningitis management in Africa.

Work is also expected to begin on a new effort for the InterAmerican Development Bank, establishing a science and technology transfer program between NCAR and the Caribbean and Latin American scientific communities. Climate modeling activities will be planned and conducted to assess current and future vulnerability to climate variability and climate change and expected impacts in the region. Local scientists and practitioners will work jointly with NCAR in defining the scope of the activities and their conduct, as well as in evaluating the results of their work.

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GOAL 3. CULTIVATE A SCIENTIFICALLY LITERATE AND ENGAGED CITIZENRY AND A DIVERSE AND CREATIVE WORKFORCE

NCAR Strategic Priority: Supporting and Enhancing Formal Science Education at All Levels

A Serious Game for Coastal Hazards and Sustainability

The Disaster Dynamics project was initated in 2003 with funding from the National Science Foundation to develop an educational computer game about the interactions between human decisions and natural hazards in a fictional Gulf Coast barrier island community. The game is targeted at undergraduates in hazard management or urban planning programs, but is suitable for any interested students or lay people at the high school level or above. Through role-based negotiation of the use of limited resources to deal with problems in the aftermath of extreme events affecting the town, players learn lessons about natural hazards, sustainability, complex systems, urban growth, and decision-making in the real world. This learning experience is widely praised by those who have experienced it.

Logo of the Disaster Dynamics project 2003-2008

FY2008 Accomplishments:

The NCAR P.I. for this effort, Seth McGinnis, continued to provide maintenance support for the game. He presented it to the National Science Teachers Association at their regional meeting in Denver in November 2008, where it was received very positively. He also worked with collaborators at the University of Maryland, University College, on an effort to port the game from Java to Flash, making it even more accessible to the user community.

FY2009 Plans:

McGinnis plans to continue to provide support for the game and promote it to educators to increase its use.

Weather and Society * Integrated Studies (WAS*IS)

Weather and Society * Integrated Studies (WAS*IS) is an innovative series of workshops, education and outreach activities, and community building efforts aimed at improving the integration of weather and social science. Organized and conducted by NCAR's Societal Impacts Program (SIP), WAS*IS works to enhance the societal value and impact of the work conducted within the meteorological community. Its goal is to empower practitioners, researchers, and stakeholders in all sectors of the weather enterprise to forge new relationships, and to develop and use new tools for more effective socio-economic applications and evaluations of weather products. Five WAS*IS workshops have been held since the program began in summer 2005, creating a cadre of more than 170 persons at present who are learning social science tools and concepts to more effectively address the impacts of weather and climate on society.

FY2008 Accomplishments:

WAS*IS activities were conducted on a variety of fronts in 2008. These included:
• Conducting a summer workshop in Boulder, Colorado. Presentations are available on the website
• Establishing a new Weather and Society Discussion Group on the web
• Creating a monthly seminar series in collaboration with NOAA's Earth System Research Lab
• Conducting an advanced workshop, "Beyond Storm-Based Warnings: Communication of Probabilistic Hazard Information" in Norman, Oklahoma
• Publishing an article about WAS*IS, "Building a Community for Integrating Meteorology and Social Science," in the November 2007 edition of the Bulletin of the American Meteorological Society
• Surveying those who have attended WAS*IS workshops to evaluate the effectiveness of the program and to glean new ideas for future events

FY2009 Plans:

• The SIP staff will evaluate the results of its recent survey of workshop participants. This information will be used to drive agendas for future workshops, and may serve as useful feedback to the program's NOAA and NSF sponsors.
• Planning is underway for a summer 2009 WAS*IS workshop in Boulder
• Work will continue on the creation of a web-based compendium, providing information and resources to those in the physical and social science communities interested in engaging in interdisciplinary work

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GOAL 4. PROVIDE ROBUST, ACCESSIBLE AND INNOVATIVE INFORMATION SERVICES AND TOOLS

NCAR Strategic Priority: Conducting Computer Science, Computational Science, Applied Mathematics, Statistics, and Numerical Methods R&D

Extreme Value Methods as an Integrative Element in Weather and Climate Impacts Assessment

Extreme events are the focus of much attention in assessments of the impacts of weather and climate. Yet the methods used still tend to be rather ad hoc, lacking any theoretical justification. This project calls for a more sustained effort to establish extreme value theory as the appropriate foundation on which to base statistical aspects of such assessments, thus playing an integrative role in impact assessment.

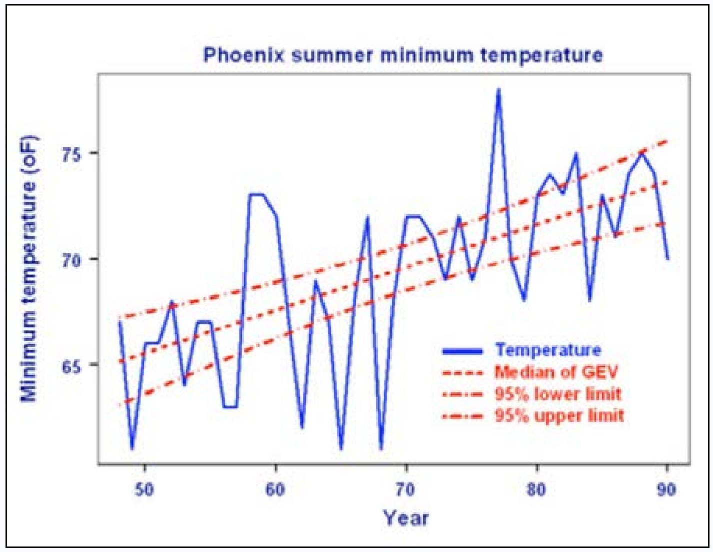


Figure Legend. Trend in lowest summer minimum temperature at Phoenix, AZ.

FY2008 Accomplishments

Work continued to address the question of how best to extend the concepts of "return period" and "return level," used to communicate the uncertainty about an extreme event, to a changing climate. Whether the extension was based on the expected waiting time or on the expected number of events did not necessarily have much effect on the actual return level. But either extension results in some rather undesirable features under climate change, suggesting that an entirely new concept is needed instead.

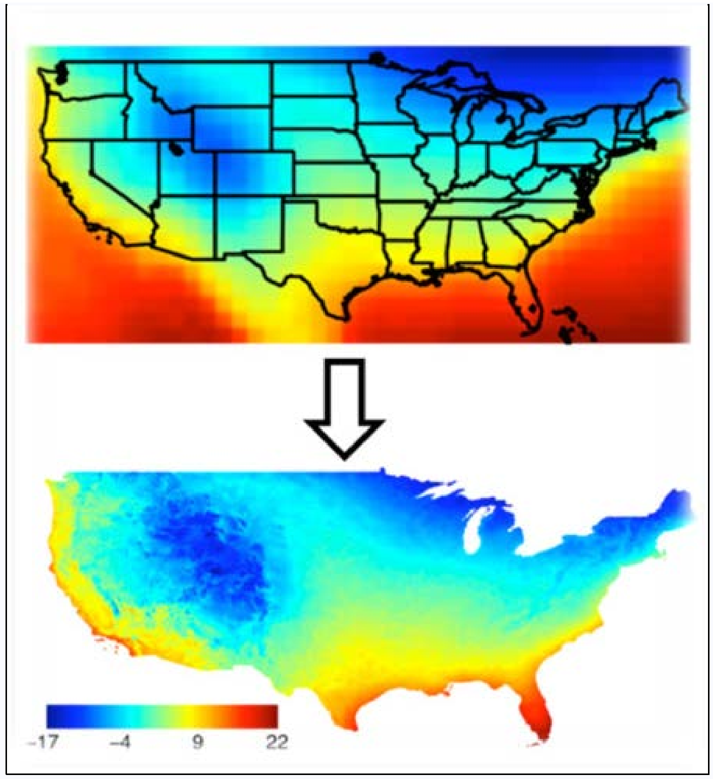
Work was initiated by SOARS protégé Marcus Walter to examine whether extreme value theory could be used to devise more appropriate methods for detecting trends in the characteristics of weather spells, such as heat waves. The statistical modeling of the frequency of occurrence, duration, and peak intensity of heat waves was essentially completed. As a test, the methods were applied to Phoenix, AZ, a city which has experienced marked trends in temperature extremes as part of the urban heat island. We learned that extreme value theory does provide a satisfactory statistical model for these characteristics of heat waves at Phoenix.

FY2009 Plans

Future work includes the completion of the development of better statistical methods for detecting trends in heat waves. It remains to develop a statistical model, based on extremal modeling with covariates, for the clustering of high temperatures within a hot spell. One constraint is that the methods be simple enough to implement within the Extremes Toolkit (www.isse.ucar.edu/extremevalues/evtk.html). The toolkit is currently used by researchers from a variety of disciplines, including atmospheric sciences and statistics, to detect trends in weather and climate extremes. But it can only treat simple extreme events, such as a single hot day, not more complex forms of extreme events such as heat waves whose societal impacts are potentially much greater.

Geographical Information Systems (GIS)

The Geographic Information Systems (GIS) Strategic Initiative at the National Center for Atmospheric Research (NCAR) is an interdisciplinary effort to foster collaborative science, spatial data interoperability, and knowledge sharing with GIS. Working toward the definition, standards and interoperability of atmospheric information for usable science, the GIS Initiative is: 1) Conducting research integrating the Earth system and social sciences through spatial analysis and interoperability of georeferenced information; 2) Supporting the use of GIS as both an analysis, and an infrastructure tool in atmospheric research; 3) Improving usable science and knowledge sharing between science groups, educators and stakeholders; and 4) Addressing broader issues of spatial data



Monthly mean temperature for January 1896 from the CCSM AR4 20th Century Experiment before and after statistical downscaling.

management, interoperability, and geoinformatics within the geosciences.

FY2008 Accomplishments

- Many NCAR research projects, where spatial analysis and accurate georeferenced data are important, benefited from GIS expertise provided by the initiative staff. With more than a hundred GIS users in all NCAR laboratories, the projects range from atmospheric chemistry to homeland security to societal impacts of climate change.
- The GIS Climate Change Scenarios project continues to provide access to global data sets of climate change scenarios generated for the Intergovernmental Panel on Climate Change, Assessment Report 4 (IPCC AR4) by the Community Climate System Model (CCSM-3). Near 3000 users from 108 countries have accessed the CCSM-3 climate predictions through the GIS data portal. In FY08 we developed a tutorial for portal users as a demonstration of appropriate use of the CCSM projections.
- Responding to users' needs, the GIS Initiative, in collaboration with CISL-IMAGe, added a downscaled product of CCSM climate change projections to the GIS portal. Statistically downscaled temperature and precipitation projections for the United States at 4.5 km spatial resolution are now available to a GIS community (see figure).
- The GIS Initiative continued to work towards improvement of compatibility, accessibility and accuracy of atmospheric data and models across scales with regard to the GIS environment. We investigated methods of conversion between sphere-based models and ellipsoid-based data for GIS analysis. This work will continue in FY09. In FY2008, the GIS Initiative, together with ESRI conducted a survey of GIS professionals about their uses of weather and climate information. A manuscript describing results of the survey is now in preparation.
- Collaboration with EPA, University of Wisconsin, Arizona State University and Stratus Consulting on exploring spatial patterns of societal vulnerability to extreme heat in Phoenix, AZ and Philadelphia, PA continues through preparation of a manuscript for submission to Environmental Health Perspectives. In FY08 we initiated a pilot project on improved assessment of societal vulnerability and adaptive capacity through integration of quantitative and qualitative data and information in a GIS. This Phoenix-based project will continue in FY09.
- The 5th Atmospheric Data Modeling workshop, conducted in January 2008, was focused on preparation of an edited volume on the Atmospheric Data Model. This compendium will demonstrate a range of GIS applications in the atmospheric and oceanographic sciences.
- The GIS Initiative continued to support Open Geospatial Consortium (OGC) standards-based developments with the goal to improve interoperability between atmospheric and GIS data and tools.

FY2009 Plans

The GIS Initiative will be working on: 1) integrating social and natural sciences through integration of quantitative and qualitative data in a GIS; 2) improving spatial accuracy and usability of atmospheric models for terrestrial and societal applications; and3) building capacity through GIS-focused education ladder for UCAR community, usable GIS lab, community workshops, conferences, joint publications and enabling interdisciplinary research.

The main focus in FY09 will be on the following tasks:
Integration of quantitative and qualitative data and information in a GIS. Societal vulnerability depends on local contexts and interests, including socio-economic, political and cultural factors. Quantitative vulnerability assessments are limited by available geocoded census data and cannot reflect individual conceptions and actions, interactions within neighborhoods, communities and places, and governance processes. Examples from the literature indicate that integration of quantitative and qualitative information can strengthen our understanding of societal vulnerability and provide a more nuanced analysis of the local environment and social processes. Through a pilot project, based in Phoenix, AZ and in collaboration with ASU and Arizona public health organizations, we will develop methods to integrate quantitative and qualitative data in a GIS framework and investigate how transferable this integration across locales and applicability of the method for integrated regional adaptation strategies.

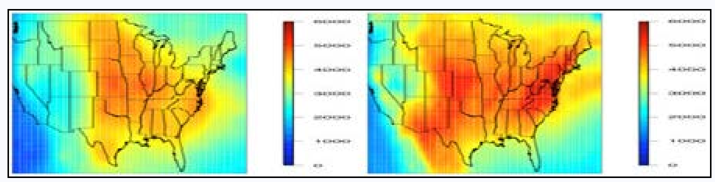
3rd Community Workshop on GIS in Weather, Climate and Impacts. The GIS Initiative will be hosting the 3rd community workshop on GIS in Weather, Climate and Impacts. The theme of this workshop will be "Integrating social and natural systems in GIS." The first two NCAR GIS workshops (http://www.gis.ucar.edu/workshops.jsp) were focused on integration of GIS with atmospheric data across scales, setting research directions for GIScience that are relevant for atmospheric, weather and climate research, and tackling spatial data management challenges. 3rd workshop will review the progress that has been made in AtmoGIS research, applications and data standards, and will add another dimension to the discussion: quantitative and qualitative social science data across scales. Topics of presentations and discussions will include: 1) atmospheric data needs for spatial societal research and applications; 2) Spatial data needs for integrative assessments and Earth System modeling; 3) methodologies for integration of natural and social science data (both quantitative and qualitative) for weather hazards preparedness and climate change adaptation.

WRF-GIS. Earlier work of the GIS initiative ensured compatibility of WRF model outputs, available in NetCDF CF format, with the GIS software. In FY09, the GIS Initiative will explore use of web services and web GIS technologies with regard to distribution of WRF model outputs in the context of societal impacts of weather. Methods of conversion between sphere-based models and ellipsoid-based data for GIS analysis will be investigated further to determine the full potential of the sphere-ellipsoidal shift and its impacts upon the output positional accuracy for numeric weather models as well as, the use of these models to determine impacts upon society, and infrastructure.

Atmospheric Data Model. Since 2003, the GIS Initiative has been leading a community effort in developing an Atmospheric Data Model for GIS. This effort enabled many research projects, NWS operations, national and international collaborations and adopting NetDCF data format by ESRI. Most recent activity of the atmospheric data modeling working group (participants from NOAA labs and NWS regional offices, NASA JPL, NCAR, Unidata, universities and private sector) focuses on preparation of an edited volume for publication through ESRI Press. This publication will summarize atmospheric data modeling concepts and use cases and provide GIS professional community with a number of cases illustrating GIS applications in meteorology, climatology, atmospheric remote sensing, and marine applications.

NCAR science support. Approximately, 150 scientific, engineering and educational NCAR/UCAR staff members use services and facilities provided by the GIS Initiative. GIS methods, tools and data have been used in a wide range of projects and contributed to a number of peer-reviewed publications. Interactions among the staff through the workshops, UCAR GIS User Group meetings and GIS seminars resulted in increased collaboration and knowledge transfer between research groups and divisions. In FY09 GIS initiative will continue supporting NCAR staff, being involved in interdisciplinary research projects, and identifying future directions that would most effectively contribute to NCAR's core mission and usability of NCAR's science.

Modeling Weather Extremes



Median (1980-1999) annual maximum Wmax (m/s) * shear (m/s) from the reanalysis (left) and CCSM3 (right). CAPE is the convective available potential energy and Shear is the magnitude of the vector difference between the surface and 6-km estimated wind.

In the third and fourth Assessment Reports of the Intergovernmental Panel on Climate Change, discussions of the impacts of climate change on severe thunderstorms have been limited to comments regarding the difficulty of using storm report databases to determine if changes have taken place historically. Because convective storms occur on very fine spatial scales, it is not possible to directly resolve such phenomena from coarse-scale global datasets. However, large-scale indicators can be employed to study trends in environments that are conducive to such severe weather. Initial work in this area has focused on identification of useful measures of large-scale environments that are relevant for severe thunderstorm formation based on NCAR global model reanalysis data. These data have been used to investigate trends in the large scale environmental characteristics, as well as spatial and extreme value distribution attributes. The approaches developed for the reanalysis data will be extended to Global Climate Model (GCM) projections of future climate, to determine the expected characteristics of severe weather environments associated with future climate change scenarios. Large-scale indicators of severe weather analyzed so far involve the product of 0-6 km wind shear (Shear) and Convective Available Potential Energy (CAPE).

This work has led to identification of several statistical challenges as well as new areas for research. Statistical challenges include methods for modeling extreme values in a spatial context; addressing the issue of multiple comparisons inherent in working with gridded data; and making inferences about changes in distribution parameters.

FY2008 Accomplishments

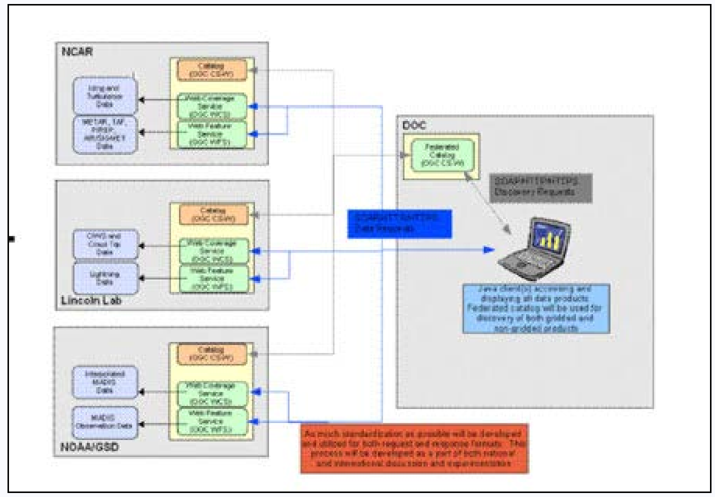
Initial analysis was started using the output of the NCAR Community Climate System Model (CCSM3), AB1 scenario being used to represent the current climate as well as comparison of results associated with the reanalysis data. Results to date were presented by Eric Gilleland at the annual Joint Statistical Meetings (JSM) of the American Statistical Association (ASA) in an invited session. Some important feedback about the analyses was gleaned from R. L. Smith and H. E. Brooks regarding (i) difficulties in estimating the parameters of the generalized extreme value (GEV) for these data, and (ii) the weak relationship between the product of CAPE and shear and severe weather. For the first issue, it was suggested that Bayesian estimation should be tried as the GEV-estimated return levels were everywhere severely under estimating the observed empirical return levels, though the empirical level estimates cannot be fully trusted. Although new to Bayesian estimation, Gilleland has begun to implement a Gibbs sampling procedure in order to estimate the parameters under the Bayesian paradigm. For the second point, Brooks very recently discovered a stronger connection between concurrently high values of shear and a transformation of

CAPE, Wmax, with severe weather. This new large-scale indicator will allow for stronger and more meaningful conclusions from the project. Results presented at the JSM were submitted to the conference proceedings, which was possible because the presentation session was an invited one. These analyses continue to be in collaboration with H. Brooks at the NOAA National Severe Storms Laboratory and P. Marsh at the University of Oklahoma.

FY2009 Plans

Bayesian estimation will be explored for finding reasonable estimates of the GEV parameter, and trend analysis for the CCSM3 will be performed to determine whether the characteristics of CAPE and Shear based on GCM output for an unchanged climate are consistent with the characteristics of these parameters in the reanalysis data. Initial diagnostics suggest that there are large discrepancies. However, these discrepancies are less pronounced after transformation of CAPE to Wmax, and the overall spatial structure of the two fields is similar (see Figure).

NextGeneration Network Enabled Weather (NNEW)



Since its inception in 1998, the Aviation Digital Data Service (ADDS) has emphasized user-friendly and intuitive weather graphics to provide users with enhanced weather situational awareness. Within the ADDS system, there exists a fundamental infrastructure for serving weather data in a network-centric manner. The ADDS Flight Path Tool (FPT), for example, enables human users to visualize specific portions from immense volumes of data using a highly interactive software application and an Internet browser.

While graphical presentations of weather data are useful to human users, there is also a need for machine-to-machine data dissemination to provide data to decision support tools and systems that manage air traffic. This need has been identified as a critical element in the U.S. Joint Planning and Development Office's drive to transform the nation's air transportation system by 2025. The research and development challenge here is to provide four-dimensional weather data using standard formats for the request and delivery of important weather information.

To address this problem, NCAR/RAL has teamed with MIT-Lincoln Labs and NOAA's Global Systems Division to explore and implement standards-based, net-centric data access. The goal of this effort is to create a virtual weather database spanning more than one physical location, organization, and data system. Starting in late 2007, each laboratory has been conducting research-to-operations work on open standards and technologies to provide uniform access to weather information.

FY2008 Accomplishments

Efforts in FY2008 focused on development of a standards-based implementation of a service to distribute traditional non-gridded products to aviation users. These new products, as well as gridded products from previous years, are now accessible via a single NNEW registry/repository that allows them all to be treated transparently as a virtual database. Additionally, the registry/repository includes ontological mappings and enhanced standards based metadata for service endpoints and data products.

FY2009 Plans

Future work will include the participation of all three labs in developing reference implementations for web services for these new four-dimensional weather capabilities. The NNEW labs will also continue to produce demonstrations of basic capabilities, including data retrieval, registry/repository utility, and flight hazard avoidance.

Each lab will also take responsibility for a portion of the data products included in the Initial Operating Capability (IOC) plan for the NextGeneration air transit system. They are also tasked with assisting in developing data formats and operational capabilities for the organizations that will be operationally providing these products. Additionally, the labs will participate in broad national and international collaborations to develop an extensible, flexible, and efficient non-gridded data model with associated formats.

Tools for Studying Biocomplexity in the Environment

The goal of this activity is to develop tools that facilitate end-to-end uncertainty analysis in assessments of the economic impacts of seasonal to decadal variations in climate on agriculture. It is part of two broader multidisciplinary projects, the first on "Climate, Agriculture, and Complexity in the Argentine Pampas" and the subsequent one on "Interactions between Changing Climate and Technological Innovations in Agricultural Decision-Making: Implications for Land use


Soybean field in Argentine Pampas

and Sustainability of Production Systems", involving collaboration among researchers from various institutions in the U.S. and Argentina from a wide range of disciplines including agronomy, economics, hydrology, political science, psychology, and statistics.

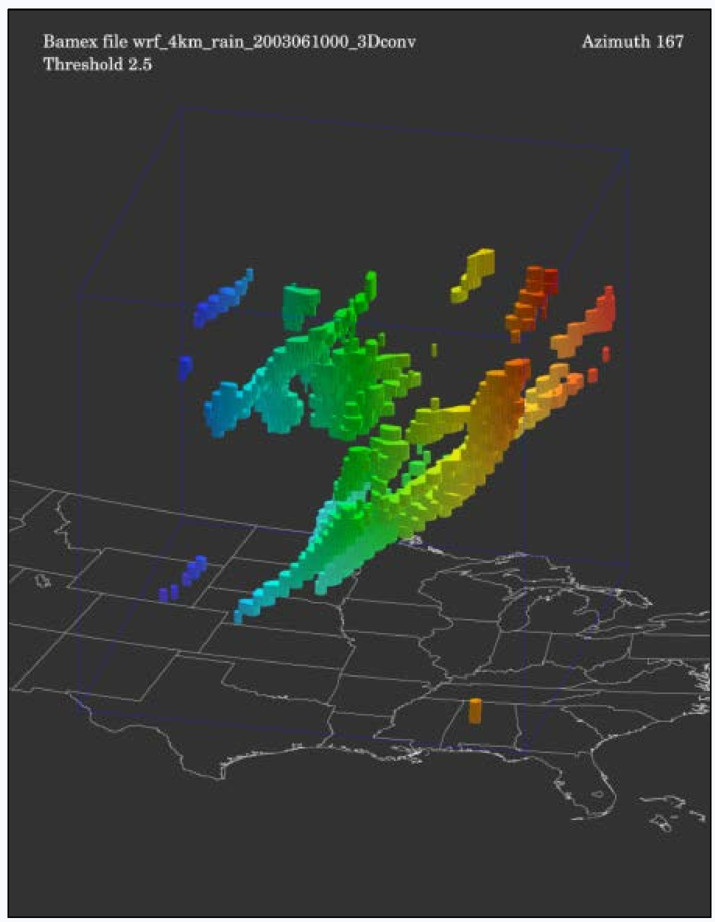
FY2008 Accomplishments

Previous work included the development of an improved stochastic weather generator for producing scenarios of daily weather, based on the statistical approach known as generalized linear modeling (GLM). During the past year, this framework was used to implement methods, consistent with the results of extreme value theory, to improve the simulation of extreme high precipitation amounts by stochastic weather generators. For more information on the GLM weather generator, see www.image.ucar.edu/~eva/GLMwgen/index.shtml.

FY2009 Plans

Future work will focus on the development of tools to produce scenarios of daily weather for input to agronomic models that reflect the variation in climate on annual to decadal time scales. These tools will be based in part on hidden Markov models to allow for persistent regime shifts in climate. Apparent regime shifts in climate have contributed to decisions by farmers to switch from one crop to another (e.g., corn to soybeans).

Verification Research and Development



Example of "3-dimensional" precipitation objects identified by the MODE forecast evaluation method. For this example, the time dimension is in the vertical. Colors change from West to East.

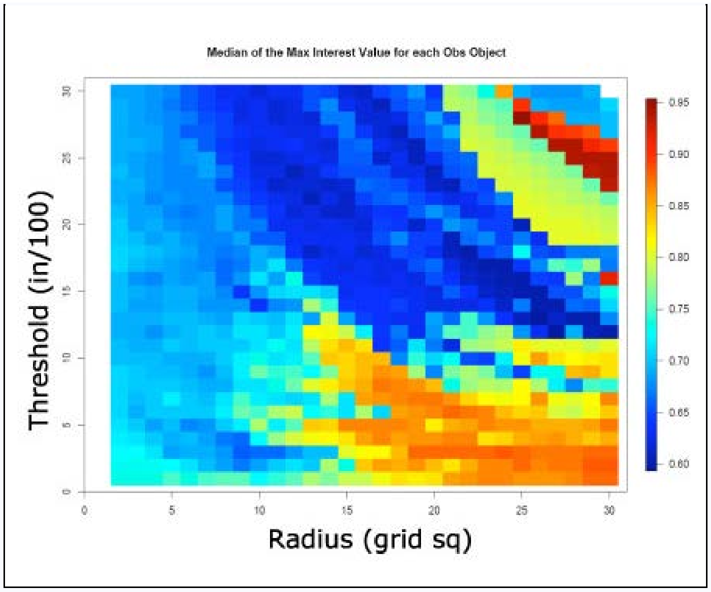
Forecast verification and evaluation activities typically are based on relatively simple metrics that measure the meteorological performance of forecasts and forecasting systems. Metrics such as the Probability of Detection, Root Mean Squared Error, and Equitable Threat Score provide information that is useful for monitoring changes in performance of single aspects of forecast performance with time. However, they generally do not provide information that can be used to improve the forecasts, or that can be used by end users (including forecasters) for decision making. Moreover, it is possible for forecasts that are quite useful – including high resolution forecasts – to have very poor scores when evaluated by using these standard metrics. In response to these limitations, the RAL Verification Group develops improved verification approaches and tools that provide more meaningful and relevant information about forecast performance. The focus of this effort is on diagnostic, statistically valid approaches, including object-based evaluation of precipitation and convective forecasts and other approaches (e.g., distribution-based) that can provide more useful information – for forecast developers as well as forecast users – about forecast performance; and the development and application of methods (e.g., confidence intervals) to estimate the uncertainty associated with verification measures. In addition, the RAL Verification Group develops forecast evaluation tools that are available for use by members of the operational, model development, and research communities.

Development and dissemination of new forecast verification approaches requires research and application in several areas, including statistical methods, exploratory data analysis, statistical inference, pattern recognition, and evaluation of user needs.

FY2008 Accomplishments

Versions 1.0 and 1.1 of the Model Evaluation Tools, developed by RAL's Developmental Testbed Center (DTC), were released to the community in January and July, respectively. This state-of-the-art set of model evaluation tools includes traditional verification methods as well as new methods that have been developed for spatial forecasts. MET has been widely implemented by the university community and by government and commercial users.

One of the new forecast evaluation methods included in MET is the Method for Object-based Diagnostic Evaluation (MODE), which was developed by NCAR scientists. MODE has recently been extended to examine forecast performance as a function of scale and to consider temporal attributes of forecasts (see figures).



Example of a "quilt" plot showing precipitation forecast performance as a function of scale – where the scale is represented by the convolution radius and threshold values used by MODE to define spatial objects. Warm colors indicate better performance. Values for Threshold-Radius combinations in the upper right are not meaningful due to small sample sizes. The plot suggests that performance is best for scales with objects defined using a radius greater than 10 grid squares and thresholds less than 0.15 inches.

The ongoing intercomparison project (ICP) for spatial forecast verification methods involves scientists from around the world who are developing new methods for evaluation of spatial forecasts. The ICP focuses on the evaluation of several real and idealized forecast cases, and was facilitated by a workshop among participants in April 2008. Results of the applications of each method will be described in papers to be included in an upcoming special collection of papers for the journal, *Weather and Forecasting*. The ICP is also expected to lead to discussions within the verification and NWP communities regarding development of a protocol for judging when new verification methods are ready to be applied in operational settings.

We also continued advocacy and outreach efforts through participation in, and leadership of the WMO's Joint Working Group on Verification, numerous conferences and workshops, statistical support for forecast evaluation studies undertaken by the RAL Developmental Testbed Center (DTC), and applications of MODE by various scientists at NCAR and in the wider atmospheric science community. The RAL Verification Group also organized and hosted a verification workshop on state-of-the-art verification methods in April 2008, with participation by international verification and numerical weather prediction experts.

FY2009 Plans

Version 2.0 of MET will be implemented in winter 2008. The new version will include methods for probabilistic forecasts, new data formats, and additional spatial verification approaches. A workshop will be held to identify new methods that should be included in future MET versions, for example, to facilitate the evaluation of ensemble forecasts.

Attributes of the MODE approach will be more thoroughly investigated, including extensive examination of the impacts of variations in spatial scale, as represented by the parameters used to define objects. New diagnostic methods will be developed to summarize object attribute comparisons, to provide greater understanding of model performance. The approach for incorporating the time dimension in MODE analyses will be further investigated and enhanced.

The results of the verification method intercomparison project (ICP) will be summarized in journal articles. A special collection of papers will be created for the journal, *Weather and Forecasting.* In addition, we will investigate the desirability of follow-on projects and possible establishment of a "verification method testbed."

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GOAL 5. PROVIDE WORLD-CLASS GROUND, AIRBORNE, AND SPACE-BORNE OBSERVATIONAL FACILITIES AND SERVICES

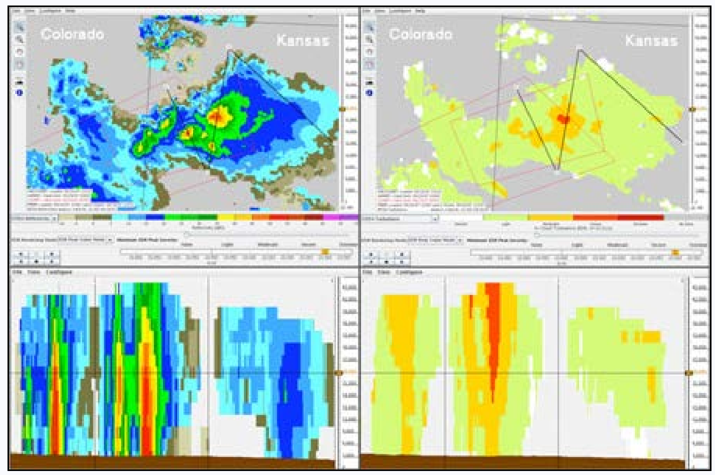
NCAR Strategic Priority: Developing New Instrumentation

Advanced Weather Radar Techniques for Aviation

RAL is working under the sponsorship of the FAA's Aviation Weather Research Program to develop technologies that utilize weather radar data to support the detection and prediction of aviation hazards. Current efforts are focused on two tasks: implementing and supporting operational deployment of new radar algorithms, and conducting research and development of radar products that will utilize future capabilities of weather radars.

FY2008 Accomplishments

RAL scientists have worked for more than 15 years to improve the detection of turbulence. Over the past several years they have developed the NEXRAD Turbulence Detection Algorithm (NTDA), a new approach to processing data from the national network of Next Generation Radars (NEXRADs, also called WSR-88Ds). While aviation users commonly use reflectivity from onboard radars or ground-based radar mosaics to gauge the intensity of a storm, the NTDA uses NEXRAD's Doppler data to detect the wind variations that can shake an aircraft. By directly measuring this in-cloud turbulence intensity, the NTDA will provide airline dispatchers, air traffic managers, and pilots an important new source of information for tactical turbulence avoidance.



Four views from the Experimental NTDA Java display on 2007-09-28 22:30Z: (upper left) reflectivity plan view of a storm at 24,000 ft. altitude, with overlaid convective SIGMET polygons and a user-drawn three-segment flight track; (upper right) NTDA eddy dissipation rate plan view; (lower left) reflectivity vertical cross-section along the flight track; (lower right) NTDA EDR cross-section. Moderate and severe turbulence is evident in and above the reflectivity cores, but moderate turbulence also appears in some low-reflectivity and anvil regions.

In FY08, NTDA was deployed on all NEXRAD's as part of a routine software upgrade. Work began on a new version of NTDA to accommodate NEXRAD changes and to improve the NTDA's spatial coverage and accuracy. RAL scientists and engineers also collaborated with National Severe Storms Laboratory staff to develop a prototype operational 3-D mosaic that will cover the contiguous U.S. RAL also continued development and evaluation of an improved spectrum width estimator that would substantially improve the quality of the NEXRAD measurements. The FAA has formally requested that the accuracy requirements for NEXRAD spectrum width be tightened and that the implementation of the RAL-developed technique be considered by the NEXRAD Technical Advisory Committee.

Techniques are also under development to determine whether precipitation detected with dual-polarization radars is rain, snow, mixed-phase, or freezing drizzle. The polarimetric Hydrometeor Classification Algorithm (HCA) being developed for the aviation community uses known physical properties of hydrometeors to determine habits and discriminate between liquid and frozen precipitation. The algorithm considers temperature observations as a check to prevent spurious hydrometeor designations such as rain layers above the melting layer in the atmosphere. During the past year the algorithm was improved by modifying the fuzzy logic interest fields for temperature. This was done by using National Weather Service reports in the central and eastern U.S. and computing the likelihood of snow or rain as a function of temperature. Results revealed that the transition from >50% probability of frozen precipitation to >50% liquid precipitation occurs as dry-bulb temperatures rise from 33 to 34F. There was a 95% probability of rain for temperatures > 33F and a 95% probability of snow for temperatures < 22F. Liquid precipitation is relatively rare but occurs at temperatures less than 20F. Only liquid precipitation occurred at temperatures > 38F.

FY2009 Plans:

Changes to the NEXRAD radar operational modes (particularly super-resolution, range-velocity mitigation techniques, and dual-polarization) will necessitate a maintenance upgrade, the NTDA-2. This product, which will also contain an improved data quality algorithm, will be implemented and, if all goes well, accepted for inclusion in the NEXRAD system. The NTDA 3 D mosaic will continue to undergo development and testing, and evaluation of the improved spectrum width estimator will continue.

RAL scientists and engineers, in conjunction with the In-Flight Icing team, will begin implementation of real-time versions of the freezing level and freezing drizzle algorithms. This will allow for the evaluation and ultimately inclusion of these products into icing hazard detection algorithms such as RAL's Current Icing Potential (CIP).

The national network of WSR-88Ds is targeted to be upgraded for dual-polarimetric capabilities beginning in FY11. Specific long-term project goals are to develop remote sensing capabilities for discriminating between rain and snow, designating icing conditions in the terminal area (freezing drizzle and rain) and in-cloud, quantifying winter precipitation in support of aircraft deicing operations, and estimating precipitation-impacted visibility.

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GOAL 1: IMPROVE UNDERSTANDING OF THE ATMOSPHERE, EARTH SYSTEM, AND SUN

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GOAL 2. INCREASE SOCIETAL RESILIENCE TO WEATHER, CLIMATE, AND ATMOSPHERIC HAZARDS

Strategic Priority: Investigating Weather and Climate Information Needs and Decision Making

NCAR Strategic Priority: Building Capacity for Coping with Weather and Climate Hazards

NCAR Strategic Priority: Building New Connections with Researchers in Developing Nations

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GOAL 3. CULTIVATE A SCIENTIFICALLY LITERATE AND ENGAGED CITIZENRY AND A DIVERSE AND CREATIVE WORKFORCE

NCAR Strategic Priority: Supporting and Enhancing Formal Science Education at All Levels

A Serious Game for Coastal Hazards and Sustainability

The Disaster Dynamics project was initated in 2003 with funding from the National Science Foundation to develop an educational computer game about the interactions between human decisions and natural hazards in a fictional Gulf Coast barrier island community. The game is targeted at undergraduates in hazard management or urban planning programs, but is suitable for any interested students or lay people at the high school level or above. Through role-based negotiation of the use of limited resources to deal with problems in the aftermath of extreme events affecting the town, players learn lessons about natural hazards, sustainability, complex systems, urban growth, and decision-making in the real world. This learning experience is widely praised by those who have experienced it.

Logo of the Disaster Dynamics project 2003-2008

FY2008 Accomplishments:

The NCAR P.I. for this effort, Seth McGinnis, continued to provide maintenance support for the game. He presented it to the National Science Teachers Association at their regional meeting in Denver in November 2008, where it was received very positively. He also worked with collaborators at the University of Maryland, University College, on an effort to port the game from Java to Flash, making it even more accessible to the user community.

FY2009 Plans:

McGinnis plans to continue to provide support for the game and promote it to educators to increase its use.

Weather and Society * Integrated Studies (WAS*IS)

Weather and Society * Integrated Studies (WAS*IS) is an innovative series of workshops, education and outreach activities, and community building efforts aimed at improving the integration of weather and social science. Organized and conducted by NCAR's Societal Impacts Program (SIP), WAS*IS works to enhance the societal value and impact of the work conducted within the meteorological community. Its goal is to empower practitioners, researchers, and stakeholders in all sectors of the weather enterprise to forge new relationships, and to develop and use new tools for more effective socio-economic applications and evaluations of weather products. Five WAS*IS workshops have been held since the program began in summer 2005, creating a cadre of more than 170 persons at present who are learning social science tools and concepts to more effectively address the impacts of weather and climate on society.

FY2008 Accomplishments:

WAS*IS activities were conducted on a variety of fronts in 2008. These included:
• Conducting a summer workshop in Boulder, Colorado. Presentations are available on the website
• Establishing a new Weather and Society Discussion Group on the web
• Creating a monthly seminar series in collaboration with NOAA's Earth System Research Lab
• Conducting an advanced workshop, "Beyond Storm-Based Warnings: Communication of Probabilistic Hazard Information" in Norman, Oklahoma
• Publishing an article about WAS*IS, "Building a Community for Integrating Meteorology and Social Science," in the November 2007 edition of the Bulletin of the American Meteorological Society
• Surveying those who have attended WAS*IS workshops to evaluate the effectiveness of the program and to glean new ideas for future events

FY2009 Plans:

• The SIP staff will evaluate the results of its recent survey of workshop participants. This information will be used to drive agendas for future workshops, and may serve as useful feedback to the program's NOAA and NSF sponsors.
• Planning is underway for a summer 2009 WAS*IS workshop in Boulder
• Work will continue on the creation of a web-based compendium, providing information and resources to those in the physical and social science communities interested in engaging in interdisciplinary work

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GOAL 4. PROVIDE ROBUST, ACCESSIBLE AND INNOVATIVE INFORMATION SERVICES AND TOOLS

NCAR Strategic Priority: Conducting Computer Science, Computational Science, Applied Mathematics, Statistics, and Numerical Methods R&D

Extreme Value Methods as an Integrative Element in Weather and Climate Impacts Assessment

Extreme events are the focus of much attention in assessments of the impacts of weather and climate. Yet the methods used still tend to be rather ad hoc, lacking any theoretical justification. This project calls for a more sustained effort to establish extreme value theory as the appropriate foundation on which to base statistical aspects of such assessments, thus playing an integrative role in impact assessment.

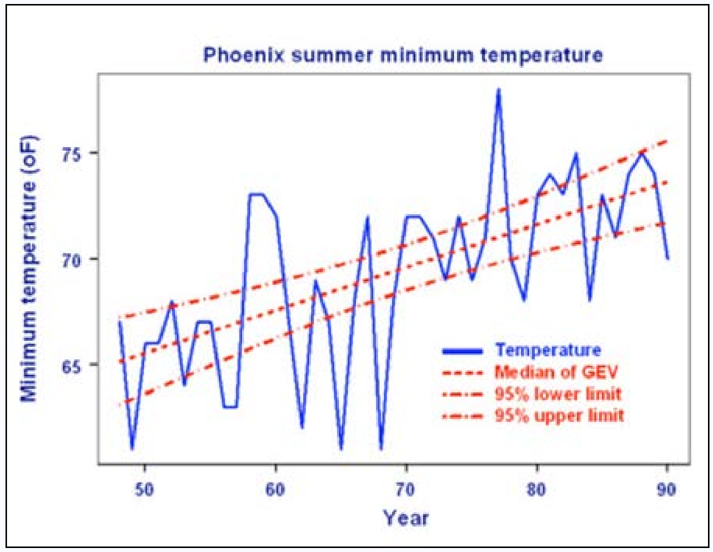


Figure Legend. Trend in lowest summer minimum temperature at Phoenix, AZ.

FY2008 Accomplishments

Work continued to address the question of how best to extend the concepts of “return period” and “return level,” used to communicate the uncertainty about an extreme event, to a changing climate. Whether the extension was based on the expected waiting time or on the expected number of events did not necessarily have much effect on the actual return level. But either extension results in some rather undesirable features under climate change, suggesting that an entirely new concept is needed instead.

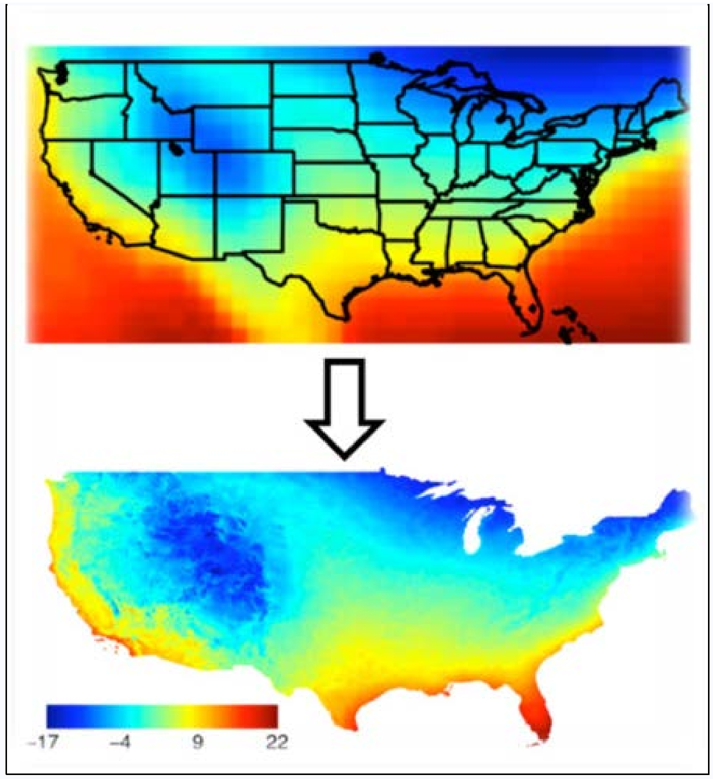
Work was initiated by SOARS protégé Marcus Walter to examine whether extreme value theory could be used to devise more appropriate methods for detecting trends in the characteristics of weather spells, such as heat waves. The statistical modeling of the frequency of occurrence, duration, and peak intensity of heat waves was essentially completed. As a test, the methods were applied to Phoenix, AZ, a city which has experienced marked trends in temperature extremes as part of the urban heat island. We learned that extreme value theory does provide a satisfactory statistical model for these characteristics of heat waves at Phoenix.

FY2009 Plans

Future work includes the completion of the development of better statistical methods for detecting trends in heat waves. It remains to develop a statistical model, based on extremal modeling with covariates, for the clustering of high temperatures within a hot spell. One constraint is that the methods be simple enough to implement within the Extremes Toolkit (www.isse.ucar.edu/extremevalues/evtk.html). The toolkit is currently used by researchers from a variety of disciplines, including atmospheric sciences and statistics, to detect trends in weather and climate extremes. But it can only treat simple extreme events, such as a single hot day, not more complex forms of extreme events such as heat waves whose societal impacts are potentially much greater.

Geographical Information Systems (GIS)

The Geographic Information Systems (GIS) Strategic Initiative at the National Center for Atmospheric Research (NCAR) is an interdisciplinary effort to foster collaborative science, spatial data interoperability, and knowledge sharing with GIS. Working toward the definition, standards and interoperability of atmospheric information for usable science, the GIS Initiative is: 1) Conducting research integrating the Earth system and social sciences through spatial analysis and interoperability of georeferenced information; 2) Supporting the use of GIS as both an analysis, and an infrastructure tool in atmospheric research; 3) Improving usable science and knowledge sharing between science groups, educators and stakeholders; and 4) Addressing broader issues of spatial data



Monthly mean temperature for January 1896 from the CCSM AR4 20th Century Experiment before and after statistical downscaling.

management, interoperability, and geoinformatics within the geosciences.

FY2008 Accomplishments

- Many NCAR research projects, where spatial analysis and accurate georeferenced data are important, benefited from GIS expertise provided by the initiative staff. With more than a hundred GIS users in all NCAR laboratories, the projects range from atmospheric chemistry to homeland security to societal impacts of climate change.
- The GIS Climate Change Scenarios project continues to provide access to global data sets of climate change scenarios generated for the Intergovernmental Panel on Climate Change, Assessment Report 4 (IPCC AR4) by the Community Climate System Model (CCSM-3). Near 3000 users from 108 countries have accessed the CCSM-3 climate predictions through the GIS data portal. In FY08 we developed a tutorial for portal users as a demonstration of appropriate use of the CCSM projections.
- Responding to users' needs, the GIS Initiative, in collaboration with CISL-IMAGe, added a downscaled product of CCSM climate change projections to the GIS portal. Statistically downscaled temperature and precipitation projections for the United States at 4.5 km spatial resolution are now available to a GIS community (see figure).
- The GIS Initiative continued to work towards improvement of compatibility, accessibility and accuracy of atmospheric data and models across scales with regard to the GIS environment. We investigated methods of conversion between sphere-based models and ellipsoid-based data for GIS analysis. This work will continue in FY09. In FY2008, the GIS Initiative, together with ESRI conducted a survey of GIS professionals about their uses of weather and climate information. A manuscript describing results of the survey is now in preparation.
- Collaboration with EPA, University of Wisconsin, Arizona State University and Stratus Consulting on exploring spatial patterns of societal vulnerability to extreme heat in Phoenix, AZ and Philadelphia, PA continues through preparation of a manuscript for submission to Environmental Health Perspectives. In FY08 we initiated a pilot project on improved assessment of societal vulnerability and adaptive capacity through integration of quantitative and qualitative data and information in a GIS. This Phoenix-based project will continue in FY09.
- The 5th Atmospheric Data Modeling workshop, conducted in January 2008, was focused on preparation of an edited volume on the Atmospheric Data Model. This compendium will demonstrate a range of GIS applications in the atmospheric and oceanographic sciences.
- The GIS Initiative continued to support Open Geospatial Consortium (OGC) standards-based developments with the goal to improve interoperability between atmospheric and GIS data and tools.

FY2009 Plans

The GIS Initiative will be working on: 1) integrating social and natural sciences through integration of quantitative and qualitative data in a GIS; 2) improving spatial accuracy and usability of atmospheric models for terrestrial and societal applications; and3) building capacity through GIS-focused education ladder for UCAR community, usable GIS lab, community workshops, conferences, joint publications and enabling interdisciplinary research.

The main focus in FY09 will be on the following tasks:
Integration of quantitative and qualitative data and information in a GIS. Societal vulnerability depends on local contexts and interests, including socio-economic, political and cultural factors. Quantitative vulnerability assessments are limited by available geocoded census data and cannot reflect individual conceptions and actions, interactions within neighborhoods, communities and places, and governance processes. Examples from the literature indicate that integration of quantitative and qualitative information can strengthen our understanding of societal vulnerability and provide a more nuanced analysis of the local environment and social processes. Through a pilot project, based in Phoenix, AZ and in collaboration with ASU and Arizona public health organizations, we will develop methods to integrate quantitative and qualitative data in a GIS framework and investigate how transferable this integration across locales and applicability of the method for integrated regional adaptation strategies.

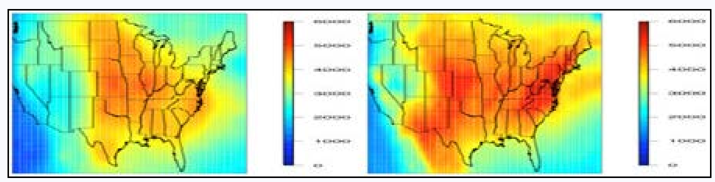
3rd Community Workshop on GIS in Weather, Climate and Impacts. The GIS Initiative will be hosting the 3rd community workshop on GIS in Weather, Climate and Impacts. The theme of this workshop will be "Integrating social and natural systems in GIS." The first two NCAR GIS workshops (http://www.gis.ucar.edu/workshops.jsp) were focused on integration of GIS with atmospheric data across scales, setting research directions for GIScience that are relevant for atmospheric, weather and climate research, and tackling spatial data management challenges. 3rd workshop will review the progress that has been made in AtmoGIS research, applications and data standards, and will add another dimension to the discussion: quantitative and qualitative social science data across scales. Topics of presentations and discussions will include: 1) atmospheric data needs for spatial societal research and applications; 2) Spatial data needs for integrative assessments and Earth System modeling; 3) methodologies for integration of natural and social science data (both quantitative and qualitative) for weather hazards preparedness and climate change adaptation.

WRF-GIS. Earlier work of the GIS initiative ensured compatibility of WRF model outputs, available in NetCDF CF format, with the GIS software. In FY09, the GIS Initiative will explore use of web services and web GIS technologies with regard to distribution of WRF model outputs in the context of societal impacts of weather. Methods of conversion between sphere-based models and ellipsoid-based data for GIS analysis will be investigated further to determine the full potential of the sphere-ellipsoidal shift and its impacts upon the output positional accuracy for numeric weather models as well as, the use of these models to determine impacts upon society, and infrastructure.

Atmospheric Data Model. Since 2003, the GIS Initiative has been leading a community effort in developing an Atmospheric Data Model for GIS. This effort enabled many research projects, NWS operations, national and international collaborations and adopting NetDCF data format by ESRI. Most recent activity of the atmospheric data modeling working group (participants from NOAA labs and NWS regional offices, NASA JPL, NCAR, Unidata, universities and private sector) focuses on preparation of an edited volume for publication through ESRI Press. This publication will summarize atmospheric data modeling concepts and use cases and provide GIS professional community with a number of cases illustrating GIS applications in meteorology, climatology, atmospheric remote sensing, and marine applications.

NCAR science support. Approximately, 150 scientific, engineering and educational NCAR/UCAR staff members use services and facilities provided by the GIS Initiative. GIS methods, tools and data have been used in a wide range of projects and contributed to a number of peer-reviewed publications. Interactions among the staff through the workshops, UCAR GIS User Group meetings and GIS seminars resulted in increased collaboration and knowledge transfer between research groups and divisions. In FY09 GIS initiative will continue supporting NCAR staff, being involved in interdisciplinary research projects, and identifying future directions that would most effectively contribute to NCAR's core mission and usability of NCAR's science.

Modeling Weather Extremes



Median (1980-1999) annual maximum Wmax (m/s) * shear (m/s) from the reanalysis (left) and CCSM3 (right). CAPE is the convective available potential energy and Shear is the magnitude of the vector difference between the surface and 6-km estimated wind.

In the third and fourth Assessment Reports of the Intergovernmental Panel on Climate Change, discussions of the impacts of climate change on severe thunderstorms have been limited to comments regarding the difficulty of using storm report databases to determine if changes have taken place historically. Because convective storms occur on very fine spatial scales, it is not possible to directly resolve such phenomena from coarse-scale global datasets. However, large-scale indicators can be employed to study trends in environments that are conducive to such severe weather. Initial work in this area has focused on identification of useful measures of large-scale environments that are relevant for severe thunderstorm formation based on NCAR global model reanalysis data. These data have been used to investigate trends in the large scale environmental characteristics, as well as spatial and extreme value distribution attributes. The approaches developed for the reanalysis data will be extended to Global Climate Model (GCM) projections of future climate, to determine the expected characteristics of severe weather environments associated with future climate change scenarios. Large-scale indicators of severe weather analyzed so far involve the product of 0-6 km wind shear (Shear) and Convective Available Potential Energy (CAPE).

This work has led to identification of several statistical challenges as well as new areas for research. Statistical challenges include methods for modeling extreme values in a spatial context; addressing the issue of multiple comparisons inherent in working with gridded data; and making inferences about changes in distribution parameters.

FY2008 Accomplishments

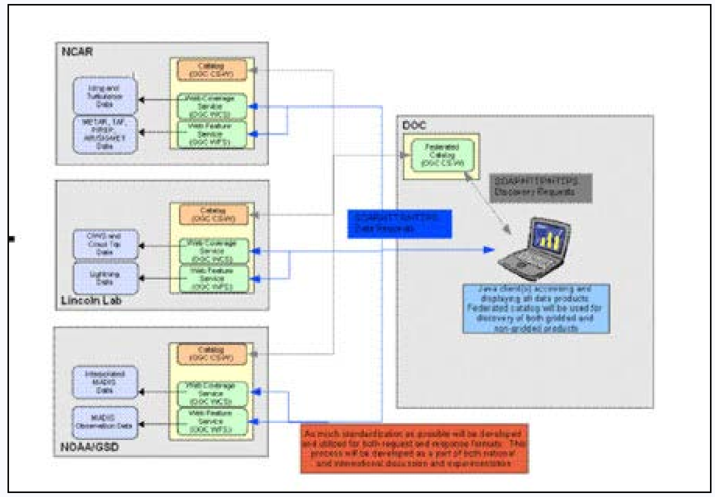
Initial analysis was started using the output of the NCAR Community Climate System Model (CCSM3), AB1 scenario being used to represent the current climate as well as comparison of results associated with the reanalysis data. Results to date were presented by Eric Gilleland at the annual Joint Statistical Meetings (JSM) of the American Statistical Association (ASA) in an invited session. Some important feedback about the analyses was gleaned from R. L. Smith and H. E. Brooks regarding (i) difficulties in estimating the parameters of the generalized extreme value (GEV) for these data, and (ii) the weak relationship between the product of CAPE and shear and severe weather. For the first issue, it was suggested that Bayesian estimation should be tried as the GEV-estimated return levels were everywhere severely under estimating the observed empirical return levels, though the empirical level estimates cannot be fully trusted. Although new to Bayesian estimation, Gilleland has begun to implement a Gibbs sampling procedure in order to estimate the parameters under the Bayesian paradigm. For the second point, Brooks very recently discovered a stronger connection between concurrently high values of shear and a transformation of

CAPE, Wmax, with severe weather. This new large-scale indicator will allow for stronger and more meaningful conclusions from the project. Results presented at the JSM were submitted to the conference proceedings, which was possible because the presentation session was an invited one. These analyses continue to be in collaboration with H. Brooks at the NOAA National Severe Storms Laboratory and P. Marsh at the University of Oklahoma.

FY2009 Plans

Bayesian estimation will be explored for finding reasonable estimates of the GEV parameter, and trend analysis for the CCSM3 will be performed to determine whether the characteristics of CAPE and Shear based on GCM output for an unchanged climate are consistent with the characteristics of these parameters in the reanalysis data. Initial diagnostics suggest that there are large discrepancies. However, these discrepancies are less pronounced after transformation of CAPE to Wmax, and the overall spatial structure of the two fields is similar (see Figure).

NextGeneration Network Enabled Weather (NNEW)



Since its inception in 1998, the Aviation Digital Data Service (ADDS) has emphasized user-friendly and intuitive weather graphics to provide users with enhanced weather situational awareness. Within the ADDS system, there exists a fundamental infrastructure for serving weather data in a network-centric manner. The ADDS Flight Path Tool (FPT), for example, enables human users to visualize specific portions from immense volumes of data using a highly interactive software application and an Internet browser.

While graphical presentations of weather data are useful to human users, there is also a need for machine-to-machine data dissemination to provide data to decision support tools and systems that manage air traffic. This need has been identified as a critical element in the U.S. Joint Planning and Development Office's drive to transform the nation's air transportation system by 2025. The research and development challenge here is to provide four-dimensional weather data using standard formats for the request and delivery of important weather information.

To address this problem, NCAR/RAL has teamed with MIT-Lincoln Labs and NOAA's Global Systems Division to explore and implement standards-based, net-centric data access. The goal of this effort is to create a virtual weather database spanning more than one physical location, organization, and data system. Starting in late 2007, each laboratory has been conducting research-to-operations work on open standards and technologies to provide uniform access to weather information.

FY2008 Accomplishments

Efforts in FY2008 focused on development of a standards-based implementation of a service to distribute traditional non-gridded products to aviation users. These new products, as well as gridded products from previous years, are now accessible via a single NNEW registry/repository that allows them all to be treated transparently as a virtual database. Additionally, the registry/repository includes ontological mappings and enhanced standards based metadata for service endpoints and data products.

FY2009 Plans

Future work will include the participation of all three labs in developing reference implementations for web services for these new four-dimensional weather capabilities. The NNEW labs will also continue to produce demonstrations of basic capabilities, including data retrieval, registry/repository utility, and flight hazard avoidance.

Each lab will also take responsibility for a portion of the data products included in the Initial Operating Capability (IOC) plan for the NextGeneration air transit system. They are also tasked with assisting in developing data formats and operational capabilities for the organizations that will be operationally providing these products. Additionally, the labs will participate in broad national and international collaborations to develop an extensible, flexible, and efficient non-gridded data model with associated formats.

Tools for Studying Biocomplexity in the Environment

The goal of this activity is to develop tools that facilitate end-to-end uncertainty analysis in assessments of the economic impacts of seasonal to decadal variations in climate on agriculture. It is part of two broader multidisciplinary projects, the first on "Climate, Agriculture, and Complexity in the Argentine Pampas" and the subsequent one on "Interactions between Changing Climate and Technological Innovations in Agricultural Decision-Making: Implications for Land use


Soybean field in Argentine Pampas

and Sustainability of Production Systems", involving collaboration among researchers from various institutions in the U.S. and Argentina from a wide range of disciplines including agronomy, economics, hydrology, political science, psychology, and statistics.

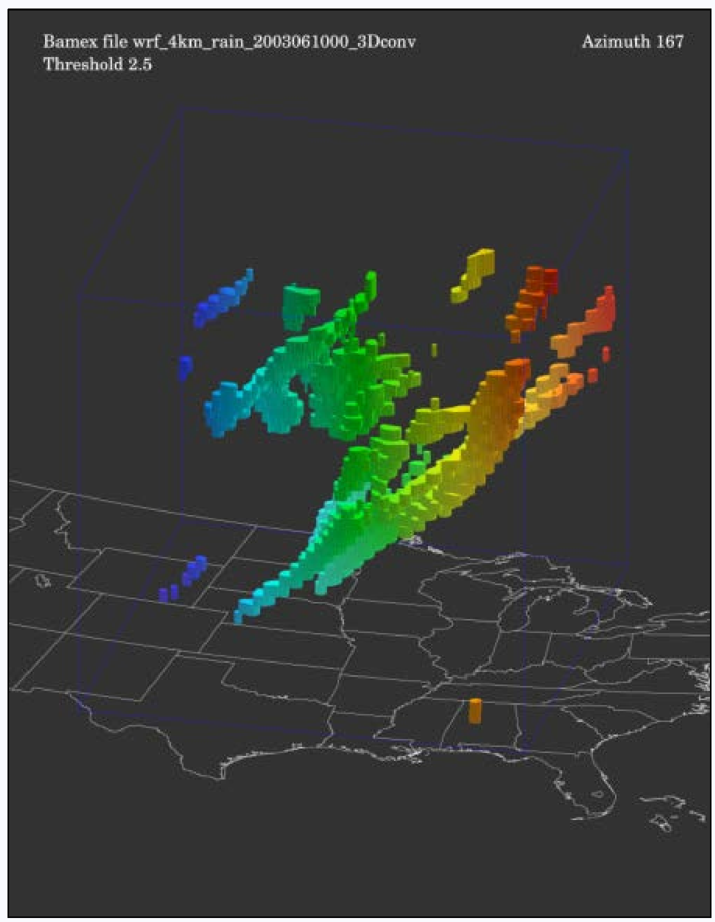
FY2008 Accomplishments

Previous work included the development of an improved stochastic weather generator for producing scenarios of daily weather, based on the statistical approach known as generalized linear modeling (GLM). During the past year, this framework was used to implement methods, consistent with the results of extreme value theory, to improve the simulation of extreme high precipitation amounts by stochastic weather generators. For more information on the GLM weather generator, see www.image.ucar.edu/~eva/GLMwgen/index.shtml.

FY2009 Plans

Future work will focus on the development of tools to produce scenarios of daily weather for input to agronomic models that reflect the variation in climate on annual to decadal time scales. These tools will be based in part on hidden Markov models to allow for persistent regime shifts in climate. Apparent regime shifts in climate have contributed to decisions by farmers to switch from one crop to another (e.g., corn to soybeans).

Verification Research and Development



Example of "3-dimensional" precipitation objects identified by the MODE forecast evaluation method. For this example, the time dimension is in the vertical. Colors change from West to East.

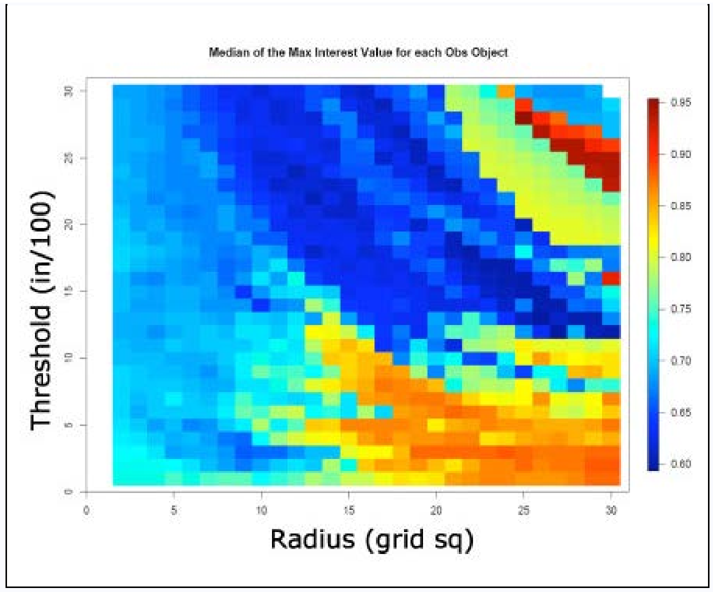
Forecast verification and evaluation activities typically are based on relatively simple metrics that measure the meteorological performance of forecasts and forecasting systems. Metrics such as the Probability of Detection, Root Mean Squared Error, and Equitable Threat Score provide information that is useful for monitoring changes in performance of single aspects of forecast performance with time. However, they generally do not provide information that can be used to improve the forecasts, or that can be used by end users (including forecasters) for decision making. Moreover, it is possible for forecasts that are quite useful – including high resolution forecasts – to have very poor scores when evaluated by using these standard metrics. In response to these limitations, the RAL Verification Group develops improved verification approaches and tools that provide more meaningful and relevant information about forecast performance. The focus of this effort is on diagnostic, statistically valid approaches, including object-based evaluation of precipitation and convective forecasts and other approaches (e.g., distribution-based) that can provide more useful information – for forecast developers as well as forecast users – about forecast performance; and the development and application of methods (e.g., confidence intervals) to estimate the uncertainty associated with verification measures. In addition, the RAL Verification Group develops forecast evaluation tools that are available for use by members of the operational, model development, and research communities.

Development and dissemination of new forecast verification approaches requires research and application in several areas, including statistical methods, exploratory data analysis, statistical inference, pattern recognition, and evaluation of user needs.

FY2008 Accomplishments

Versions 1.0 and 1.1 of the Model Evaluation Tools, developed by RAL's Developmental Testbed Center (DTC), were released to the community in January and July, respectively. This state-of-the-art set of model evaluation tools includes traditional verification methods as well as new methods that have been developed for spatial forecasts. MET has been widely implemented by the university community and by government and commercial users.

One of the new forecast evaluation methods included in MET is the Method for Object-based Diagnostic Evaluation (MODE), which was developed by NCAR scientists. MODE has recently been extended to examine forecast performance as a function of scale and to consider temporal attributes of forecasts (see figures).



Example of a "quilt" plot showing precipitation forecast performance as a function of scale – where the scale is represented by the convolution radius and threshold values used by MODE to define spatial objects. Warm colors indicate better performance. Values for Threshold-Radius combinations in the upper right are not meaningful due to small sample sizes. The plot suggests that performance is best for scales with objects defined using a radius greater than 10 grid squares and thresholds less than 0.15 inches.

The ongoing intercomparison project (ICP) for spatial forecast verification methods involves scientists from around the world who are developing new methods for evaluation of spatial forecasts. The ICP focuses on the evaluation of several real and idealized forecast cases, and was facilitated by a workshop among participants in April 2008. Results of the applications of each method will be described in papers to be included in an upcoming special collection of papers for the journal, *Weather and Forecasting*. The ICP is also expected to lead to discussions within the verification and NWP communities regarding development of a protocol for judging when new verification methods are ready to be applied in operational settings.

We also continued advocacy and outreach efforts through participation in, and leadership of the WMO's Joint Working Group on Verification, numerous conferences and workshops, statistical support for forecast evaluation studies undertaken by the RAL Developmental Testbed Center (DTC), and applications of MODE by various scientists at NCAR and in the wider atmospheric science community. The RAL Verification Group also organized and hosted a verification workshop on state-of-the-art verification methods in April 2008, with participation by international verification and numerical weather prediction experts.

FY2009 Plans

Version 2.0 of MET will be implemented in winter 2008. The new version will include methods for probabilistic forecasts, new data formats, and additional spatial verification approaches. A workshop will be held to identify new methods that should be included in future MET versions, for example, to facilitate the evaluation of ensemble forecasts.

Attributes of the MODE approach will be more thoroughly investigated, including extensive examination of the impacts of variations in spatial scale, as represented by the parameters used to define objects. New diagnostic methods will be developed to summarize object attribute comparisons, to provide greater understanding of model performance. The approach for incorporating the time dimension in MODE analyses will be further investigated and enhanced.

The results of the verification method intercomparison project (ICP) will be summarized in journal articles. A special collection of papers will be created for the journal, *Weather and Forecasting.* In addition, we will investigate the desirability of follow-on projects and possible establishment of a "verification method testbed."

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GOAL 5. PROVIDE WORLD-CLASS GROUND, AIRBORNE, AND SPACE-BORNE OBSERVATIONAL FACILITIES AND SERVICES

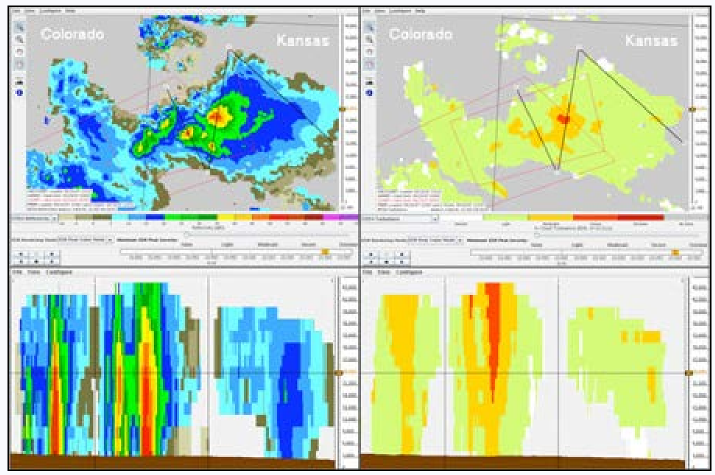
NCAR Strategic Priority: Developing New Instrumentation

Advanced Weather Radar Techniques for Aviation

RAL is working under the sponsorship of the FAA's Aviation Weather Research Program to develop technologies that utilize weather radar data to support the detection and prediction of aviation hazards. Current efforts are focused on two tasks: implementing and supporting operational deployment of new radar algorithms, and conducting research and development of radar products that will utilize future capabilities of weather radars.

FY2008 Accomplishments

RAL scientists have worked for more than 15 years to improve the detection of turbulence. Over the past several years they have developed the NEXRAD Turbulence Detection Algorithm (NTDA), a new approach to processing data from the national network of Next Generation Radars (NEXRADs, also called WSR-88Ds). While aviation users commonly use reflectivity from onboard radars or ground-based radar mosaics to gauge the intensity of a storm, the NTDA uses NEXRAD’s Doppler data to detect the wind variations that can shake an aircraft. By directly measuring this in-cloud turbulence intensity, the NTDA will provide airline dispatchers, air traffic managers, and pilots an important new source of information for tactical turbulence avoidance.



Four views from the Experimental NTDA Java display on 2007-09-28 22:30Z: (upper left) reflectivity plan view of a storm at 24,000 ft. altitude, with overlaid convective SIGMET polygons and a user-drawn three-segment flight track; (upper right) NTDA eddy dissipation rate plan view; (lower left) reflectivity vertical cross-section along the flight track; (lower right) NTDA EDR cross-section. Moderate and severe turbulence is evident in and above the reflectivity cores, but moderate turbulence also appears in some low-reflectivity and anvil regions.

In FY08, NTDA was deployed on all NEXRAD’s as part of a routine software upgrade. Work began on a new version of NTDA to accommodate NEXRAD changes and to improve the NTDA’s spatial coverage and accuracy. RAL scientists and engineers also collaborated with National Severe Storms Laboratory staff to develop a prototype operational 3-D mosaic that will cover the contiguous U.S. RAL also continued development and evaluation of an improved spectrum width estimator that would substantially improve the quality of the NEXRAD measurements. The FAA has formally requested that the accuracy requirements for NEXRAD spectrum width be tightened and that the implementation of the RAL-developed technique be considered by the NEXRAD Technical Advisory Committee.

Techniques are also under development to determine whether precipitation detected with dual-polarization radars is rain, snow, mixed-phase, or freezing drizzle. The polarimetric Hydrometeor Classification Algorithm (HCA) being developed for the aviation community uses known physical properties of hydrometeors to determine habits and discriminate between liquid and frozen precipitation. The algorithm considers temperature observations as a check to prevent spurious hydrometeor designations such as rain layers above the melting layer in the atmosphere. During the past year the algorithm was improved by modifying the fuzzy logic interest fields for temperature. This was done by using National Weather Service reports in the central and eastern U.S. and computing the likelihood of snow or rain as a function of temperature. Results revealed that the transition from >50% probability of frozen precipitation to >50% liquid precipitation occurs as dry-bulb temperatures rise from 33 to 34F. There was a 95% probability of rain for temperatures > 33F and a 95% probability of snow for temperatures < 22F. Liquid precipitation is relatively rare but occurs at temperatures less than 20F. Only liquid precipitation occurred at temperatures > 38F.

FY2009 Plans:

Changes to the NEXRAD radar operational modes (particularly super-resolution, range-velocity mitigation techniques, and dual-polarization) will necessitate a maintenance upgrade, the NTDA-2. This product, which will also contain an improved data quality algorithm, will be implemented and, if all goes well, accepted for inclusion in the NEXRAD system. The NTDA 3 D mosaic will continue to undergo development and testing, and evaluation of the improved spectrum width estimator will continue.

RAL scientists and engineers, in conjunction with the In-Flight Icing team, will begin implementation of real-time versions of the freezing level and freezing drizzle algorithms. This will allow for the evaluation and ultimately inclusion of these products into icing hazard detection algorithms such as RAL's Current Icing Potential (CIP).

The national network of WSR-88Ds is targeted to be upgraded for dual-polarimetric capabilities beginning in FY11. Specific long-term project goals are to develop remote sensing capabilities for discriminating between rain and snow, designating icing conditions in the terminal area (freezing drizzle and rain) and in-cloud, quantifying winter precipitation in support of aircraft deicing operations, and estimating precipitation-impacted visibility.

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