NCAR Annual Scientific Report -- FY 1994

National Center for Atmospheric Research

NCAR's Mission Statement
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The Annual Scientific Report

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NCAR's Mission:

The National Center for Atmospheric Research focuses on important atmospheric research problems that require major commitments of resources and a wide range of scientific talent over extended periods of time. By housing scientific programs and providing a wide variety of research facilities, facilities support, and related services, NCAR serves the specialized needs of the university research community.

Science

Science programs are carried out by four scientific divisions:

- Atmospheric Chemistry,
- Climate and Global Dy namics,
- Mesoscale and Microscale Meteorology , and the
- High Altitude Observatory.

Facilities

Facilities are developed, operated, and maintained by two other divisions:

- Atmospheric Technology and
- Scientific Computing.

Programs

There are three additional **programs**.

- The Research Applications Program is working to improve predictions of a variety of weather hazards that affect aviation, and to develop forecasting and visualization products for the aviation indust ry.
- The Environmental and Societal Impacts Group is made up of scientists who research the impacts of climate change, bot h naturally occurring and man-made.
- The Advanced Study Program selects and appoints graduate and postdoctoral fellows fr om numerous disciplines who wish to broaden their research experience du ring a two year visit at NCAR.

The center is dedicated, in partnership with the universities, to excellence in the atmospheric and related sciences to the benefit of humankind.

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A Message from NCAR's Director

Robert J. Serafin

... The **National Center for Atmospheric Research** is a federally funded research and development center which conducts research in the atmospheric and related sciences. NCAR focuses on important long-term atmospheric problems requiring major resource commitments and a wide range of scientific talent. NCAR additionally provides the scientific research community with major research facilities such as supercomputers, aircraft and ground based observing systems.

In collaboration with university researchers, other federal laboratories and international scientists, NCAR conducts research in the areas of global climate change, atmospheric dynamics, solar-terrestrial interactions, ozone depletion and other important atmospheric chemical processes, mesoscale meteorology and weather hazards, and the societal impacts of climate and weather related events.

Two major facility goals reached near-completion this year: restructuring of our research aviation aircraft fleet and enhancing our supercomputing capabilities. Our research aircraft fleet has been modernized with the acquisition of a C-130 aircraft capable of flying large instrument payloads for long distances and flight times. The C-130 became operational in September, 1994. A second research aircraft, the WB-57F, is undergoing modifications and will be placed in service in the near future. These two aircraft will make possible a series of observations previously unavailable to us. In supercomputing, we have established a Climate Simulation Laboratory, a suite of dedicated resources for long term simulations of climate and other highly complex numerical models. This laboratory will be available to the broadly-based climate research community in 1995.

NCAR has initiated and participates in a spectrum of educational activities that encompasses K-12 and secondary education, through postdoctoral appointments. We have a vigorous and popular tour and exhibits program, and have developed innovative teacher training programs in the atmospheric sciences. Our commitment to improving science, mathematics and technology education forms the third of our four mission areas.

Technology transfer and improved competitiveness are issues of strategic national importance. In 1994, NCAR began a collaboration with the new Hong Kong airport project. NCAR and other team members will utilize the latest research results and technologies to develop methods for predicting and mitigating aviation weather hazards at that site. Other national and international projects outlined in this report exemplify our ongoing efforts in this, our fourth mission area.

This year marks the debut of the National Center for Atmospheric Research on the World Wide Web. We are happy to present our Annual Scientific Report for fiscal year 1994 through Mosaic. Complete, downloadable text is available for those who would like a shelf copy of the report.

We invite you to explore some of the highlights of our accomplishments in Fiscal Year 1994. We hope you will also take the opportunity to read the written report and "visit" some of the other NCAR websites. NCAR's "homepage" will direct you to more information on the many aspects of the research, facility, education and outreach programs at NCAR.

Significant Accomplishments

- Experiments during ICECOLORS suggested that CO, OCS, and DMS concentrations in natural seawater could respond to ozone-induced changes in UV radiation in Antarctic marine ecosystems.
- Model calculations show that changes in stratospheric circulation can significantly impact temporal trends in tropospheric trace gases.
- Techniques were developed to use whole air tracer measurements to determine the age of stratospheric air and to further evaluate halogen partitioning in the polar stratosphere.
- Oscillatory solutions were identified in models of the tropospheric oxidizing chemical system.
- Estimations were made of ground-level UV-B increases due to stratospheric ozone reductions.
- Numerous model developments including a new three-dimensional chemical-transport model (CTM) of the troposphere and lower stratosphere, a telescoping resolution regional chemical model, integration of the carbon cycle into the CCM2, and the implementation of 3-D chemical code on a parallel processor computer.
- Assessment of the radiative effects of several trace gases were made, including CO_2, CH_4, N_2O, methane, and several CFC's and HCFC's.
- The High Resolution Dynamics Limb Sounder (HIRDLS) completed its Instrument Technical Specification and selected Lockheed as its prime subcontractor as this EOS project prepares to enter the Execution Phase of instrument construction.
- An OH intercomparison yielded good agreement between both long path absorption and ion assisted OH measurement methods.

http://www.ncar.ucar.edu/archives/asr/ASR94/ACD/ACDStaff.html Go

Staff, Visitors, and Collaborators

Staff

Division Director's Office

- Guy Brasseur (director)
- Michael Coffey
- Teresa Rivas
- Donna Sanerib
- Paul Sperry
- Sharon Vieyra

Analytical Measurements

- Eric Apel
- Timothy Gilpin
- James Greenberg
- Gary Hampton
- Patrick Zimmerman (leader)

Ecosystem Studies

- Alex Guenther (leader)
- Elisabeth Holland
- Lee Klinger

Atmospheric Odd Nitrogen

- Frank Grahek
- Brian Ridley (leader)
- James Walega
- Andrew Weinheimer

HO_x Measurements

- Christopher Cantrell
- Fred Eisele (leader)
- Richard Shetter
- David Tanner

Laboratory Kinetics

- John Orlando
- Geoffrey Tyndall (leader)

UARS

- Charles Cavanaugh
- Cheryl Craig
- John Gille (leader)
- Lawrence Lyjak
- Steven Massie
- Daniel Packman
- William Randel

MOPPITT

- Paul Bailey
- David Edwards
- John Gille (leader)
- Liwen Pan

HIRDLS

- Philip Arter
- Michael Dials
- Selena Drum
- John Gille (leader)
- Chris Halvorson
- Karl Kneisel
- Joanne Loh
- Judy Oeltjenbruns
- David Wilson
- Douglas Woodard

Stratospheric/Tropospheric Measurements

- Elliot Atlas (leader)
- Richard Lueb
- Walter Pollock
- Sue Schauffler

Regional and Process Studies

- Chris Fischer
- Claire Granier
- Peter Hess
- Sasha Madronich (leader)

Global and Stratospheric Studies

- Guy Brasseur (leader)
- Brian Eaton
- David Erickson
- Rolando Garcia
- Anne Smith
- XueXi Tie

Stacy Walters

Optical Techniques

- Michael Coffey
- James Hannigan
- William Mankin (leader)

Tunable Diode Lasers

- Alan Fried (leader)
- Bruce Henry

Technical Support

- William Bradley
- Edward Ellert
- Timothy Fredrick
- Kathleen Mosher
- Paul Sperry (leader)

Administrative Support

- Trinh Dean
- Janice Powell
- Teresa Rivas (leader)
- Donna Sanerib
- Marilena Stone
- Sharon Vieyra
- Jack Wainwright

Affiliate Scientists

- Aaron Goldman, University of Denver
- Susan Solomon, NOAA Aeronomy Laboratory
- Halvore Westberg, Washington State University

ACD Publications

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Ecosystem Studies

The Ecosystem studies group conducts research in collaboration with the Analytical Measurements group to characterize ecosystem structure and function with respect to trace gas emissions. Their focus is on the characterization and modeling of biological controls over trace gas fluxes. Significant accomplishments in FY 94 include the following:

Non-Methane Hydrocarbon Emission Modeling

Non-methane hydrocarbons can play a major role in the chemistry of the atmosphere, especially in continental regions of the earth. The oxidation products of NMHC's include many chemical species which can have regional and global consequences. NMHC emission modeling techniques are being developed to estimate the impact of biogenic emissions on photochemical oxidant production. A global emissions model was developed as part of the International Global Atmospheric Chemistry (IGAC) project. For an example of the global emission maps produced by this model click here. This model has been incorporated into the global three-dimensional chemistry and transport models developed at NCAR and used to assess the global impact of isoprene emissions. A regional NMHC emissions model has been developed for use by the U.S. Environmental Protection Agency (EPA) in regulatory and research applications. NMHC emissions modeling efforts are led by Alex Guenther and involve collaboration with Nicholas Hewitt (University of Lancaster), Brian Lamb and Halvore Westberg (Washington State University), Christopher Geron and Thomas Pierce (EPA), and Raymond Fall and Russell Monson (University of Colorado).

Biogenic Hydrocarbon and Nitrogen Fluxes from a Subtropical Shrub Land (La Copita, Texas)

Biogenic hydrocarbon fluxes were measured at leaf, branch, canopy and landscape scales at a site in southern Texas by Alex Guenther, Patrick Zimmerman, Lee Klinger, Lee Vierling, James Greenberg, and Detlev Helmig. Nitrogen oxide fluxes from soils were measured by Elisabeth Holland in collaboration with Robin Martin (Colorado State University) and Mary Scholes (University of Wittwattersand) in collaboration with Steve Archer (Texas A and M University). The La Copita, Texas site is representative of subtropical shrub lands that are important globally and are a major focus of the planned EXPRESSO study. Ecological, meteorological and remote sensing measurements were made to provide a detailed description of the site. These data will be used to understand the factors controlling trace gas fluxes at this site. An Integrated Sounding System (ISS), including continuous wind and temperature profilers and LORAN release sonde system (developed by NCAR-ATD) was deployed at the site to characterize the atmospheric boundary layer meteorology. In addition, the Tethered Atmospheric Observation System (TAOS) developed jointly by ACD and ATD (Ned Chamberlain and Dean Lauritsen) was used to characterize meteorological conditions. Leaf-level measurements were made with a portable environmentally controlled cuvette system. Canopy flux measurements were made using a tower gradient-flux system. Landscape-level fluxes were estimated using vertical profiles of ambient hydrocarbon concentrations collected with samplers deployed on a balloon tether line.

Phytotron Studies

Final setup of the automated environmental controls for the NCAR Phytotron (greenhouse/environmental chamber) was completed. An experiment examining the isoprene emissions of the dominant species of oaks and other plants from around the world is currently underway. This effort is led by Peter Harley in collaboration with James Greenberg, Alex Guenther, Lee Klinger, and Patrick Zimmerman. Investigations of oxygenated hydrocarbon emissions are being initiated by this group using Phytotron-grown plants in collaboration with Raymond Fall (University of Colorado). These data are being used to assign emission factors in biogenic emission models and to better understand relationships between emissions and plant taxonomy.

Successional Theory

Ecosystems change with time. It is important to understand the processes which lead to this change in order to be able to develop accurate predictive global change models. NCAR efforts to relate succession to trace gas emissions are led by Lee Klinger. Progress was made in the development of a peatland succession model during a visit to Lawrence Livermore Laboratory by Lee Klinger. This was a collaborative effort with Norman Miller (Lawrence Livermore Laboratory). Collaborative ecosystem characterization research was conducted by Klinger at the Cheeka Peak study site in the Olympic Peninsula, Washington as part of CACHE (Cloud-Atmosphere Chemistry Experiment) headed by Richard Vong (Oregon State University). Assisting in this effort was Susan Canney (visiting scientist, Green College Centre, Oxford). Anthony Delany (ATD) was also a collaborator in this experiment, which involved the use of the ASTER facility.

Refinements were made in the ecosystem characterization methodology allowing for relatively quick and precise measurements of forest composition, leaf area index, and biomass along with environmental variables. In conjunction with our new remote sensing capabilities, these measurements allow for landscape-level ecological characterization. In collaboration with James White and Vera Markgraf (Institute for Arctic and Alpine Research), a field and laboratory experiment is being conducted by Klinger to examine the role of methane and other variables in controlling the delta^{13}C of Sphagnum tissue in bogs. These results will help to further the development of techniques to use the delta^{13}C of Sphagnum tissue in bogs as a proxy for past atmospheric CO_2 concentrations.

Linkages between Carbon and Nitrogen Cycling

Fertilization of the biosphere by nitrogen deposition represents an important connection between atmospheric chemistry and the global carbon cycle. An estimate of terrestrial carbon storage that accounts for spatial distributions in nitrogen deposition and vegetation types, turnover of plant and soil carbon pools, and the cumulative effects of prior deposition was developed by Elisabeth Holland and co-workers.

Vegetation type has a pronounced effect on C uptake; the combination of high C:N ratios and the long lifetime of wood may create a significant sink in forests, but much of the nitrogen falls on cultivated areas and grasslands where there is limited capacity for long-term carbon storage. Estimated 1990 net uptake due to deposition of fossil fuel N was calculated to be between 0.2-1.2 PgC/yr (1Pg=10^{15}g), depending on the fraction allocated to wood, with a best estimate of 0.64 PgC/yr. Thus, nitrogen deposition may account for a substantial fraction of the hypothesized terrestrial sink for anthropogenic CO_2.

Nitric oxide (NO) fluxes from tropical ecosystems represent a significant portion of the global NO budget. In the past year we focused on soil fluxes associated with biomass burning. Following burning and associated NO volatilization, NO fluxes from soil are enhanced for months following the burn. The flux is controlled by biological supply of the needed substrates which are also enhanced for months following the burn.

Community Service

A workshop on biogenic hydrocarbon emissions measurements and modeling was held at Estes Park, Colorado on May 12 and 13. The workshop was organized by Alex Guenther (NCAR) and Chris Geron (EPA) and designed to focus U.S. research efforts in biogenic hydrocarbon emissions studies and foster collaboration between NCAR, EPA, and universities. Recent results were presented, research priorities were set, and collaborative studies were planned. Workshop attendees included Robert Arnts, Chris Geron, Dalin Nye and Tom Pierce (EPA), Dennis Baldocchi (NOAA), Cari Furiness (North Carolina State University), Jud Isebrandes (U. S. Forest Service), Brian Lamb and Halvore Westberg (Washington State University), Frank Marsik (University of Michigan), Russell Monson, Carol Wessman and Mary Wildermuth (University of Colorado), Fred Mowry (Duke University), Tom Sharkey (University of Wisconsin), plus Zimmerman, Greenberg, Guenther, Klinger, Peter Harley, Detlev Helmig, Elisabeth Holland, Kenneth Davis, andTony Delany (all NCAR).

Atmospheric Odd Nitrogen (AON)

The group's interest is in the measurement of trace constituents which are influential players in determining the photochemical production and destruction of ozone in the troposphere and stratosphere and the oxidizing capacity of the troposphere. AON emphasizes (a) the development of instrumentation for measurements especially in, but not limited to, the remote atmosphere, (b) the development of aircraft and ground-based measurement programs to test our understanding of the chemistry and transport within the atmosphere, and (c) through collaboration, the analysis and interpretation of observations through modeling exercises.

Accomplishments

The principle effort of the group this past year was on the analysis, interpretation, and manuscript preparation concerning past field programs. These programs include the Mauna Loa Observatory Photochemistry Experiment (MLOPEX II), the Airborne Arctic Stratospheric Expedition (AASE II), the Rural Oxidants in the Southern Environment (ROSE) aircraft studies, and the aircraft program over New Mexico designed to investigate the production of active nitrogen by thunderstorms. Andrew Weinheimer prepared several manuscripts which were accepted for publication detailing results on the distribution of $NO_{x,y}$ and ratios of species from the AASE II flights. Collaborators in this work were James Collins (Science and Technology Corporation), Glen Sachse and Bruce Anderson (NASA Langley Research Center), Bruce Gary (Jet Propulsion Laboratory), and Donald Blake, Nicola Blake, and F. Sherwood Rowland (University of California, Irvine). Ian Folkins (Dalhousie University) is leading the preparation of another manuscript in which data from the AASE II flights to and from Tahiti are used in combination with a three-dimensional model to detail dynamical influences on the distribution of $NO_{x,y}$ and O_3 between tropical and mid-latitudes in the upper troposphere. Anna Zheng (visitor, NOAA Aeronomy Laboratory [NOAA AL]) in collaboration with Shaw Liu (NOAA AL) completed a detailed analysis and had a manuscript accepted investigating the emissions from aircraft in the upper troposphere and lower stratosphere during the AASE II flights. In collaboration with James Dye (MMM), an overall summary of the thunderstorm flights was accepted for publication. We are in the process of preparing several manuscripts that discuss the influence of long range transport to the mid-Pacific (Mauna Loa region) as determined by the aircraft flights in the spring intensive of MLOPEX II and which discuss the seasonal variation of measured species at the Observatory. Collaborations in this effort are the entire MLOPEX team as listed in the 1993 Annual Scientific Report. Michael Trainer and Xing Lin (NOAA AL) led the preparation of two manuscripts that use aircraft data acquired during ROSE. One discusses the chemistry and dynamics of urban plumes in the area around Birmingham, Alabama. The second uses the many vertical profiles measured during the flights to improve the convective parameterization in the NOAA regional model.

Improvements to the aircraft instrumentation is ongoing and led by Frank Grahek. We also designed a smaller detector for NO_y measurements that may prove to be useful on small aircraft.

Community Service

The group supplied detailed engineering drawings of their four-channel instrument for aircraft based measurements of NO, NO_2, NO_y, and O_3 to colleagues interested in acquiring similar measurement capabilities. In some cases, the basic detectors were reproduced in the NCAR machine shop. These colleagues include Mary Anne Carroll and George Alber (University of Michigan), Franz Rohrer and Dieter Ehhalt (Institute 3 for Chemistry, Juelich, Germany), Bernard Bonsang, Joseph Sanak, and Daniel Martin (Centre des Faibles Radioactivities, France), David Parrish (NOAA AL), and Greg Kok (ATD). The group also supplied parts of instrumentation to Fred Fehsenfeld's group (NOAA AL) and Carroll's group for their P-3 aircraft program conducted this last summer. James Walega and Denise Montzka developed, maintain, and update the MLOPEX data archive for ACD and outside colleagues. Walega participated in the development of software for working with the archive and the different time-bases of the data.

Ridley served as the American editor of the *Journal of Atmospheric Chemistry* (European editors are Paul Crutzen and Dieter Ehhalt). He also collaborated with David Fahey (NOAA AL) and Elliot Atlas in writing a chapter for the Committee on Atmospheric Chemistry, National Research Council dealing with instrumentation and platform needs for $NO_{x,y}$ measurements in the next decade. Ridley was also co-lead author with Andreas Volz-Thomas (Institute 2 for Chemistry, Juelich, Germany) of chapter 5, entitled *Tropospheric Ozone*, for the 1994 WMO/UNEP Scientific Assessment of Ozone Depletion.

Laboratory Kinetics

Photolysis Quantum Yields and Reaction Kinetics of Chlorine Nitrate

Chlorine nitrate, $ClONO_2$, is an important reservoir for chlorine throughout the stratosphere. The major loss processes for chlorine nitrate in the stratosphere are photolysis and reaction with $O(^3P)$ atoms, and a quantitative understanding of these processes is required to determine the effectiveness of chlorine nitrate as a reservoir species. Experiments have shown that photolysis of $ClONO_2$ at 308 nm leads to production of both Cl-atoms (quantum yield ~ 0.7) and ClO radicals (quantum yield ~ 0.3). The quantum yield for O-atom production has also been shown to be < 0.05. In addition, the rate coefficient for the reaction of $O(^3P)$ with $ClONO_2$ has been measured to assess the impact of this reaction on the partitioning of chlorine in the stratosphere. This work was sponsored by the NASA Upper Atmospheric Research Program.

UV/Visible Absorption Spectrum of Hypobromous Acid, HOBr

The production and subsequent photolysis of HOBr in the lower stratosphere leads to an important catalytic cycle for the destruction of ozone. While photolysis of HOBr was assumed in atmospheric models to be quite rapid, quantification of this process has until now been impossible due to difficulty in synthesizing HOBr in the gas phase so that its UV/visible absorption spectrum could be measured. In collaboration with James Burkholder (NOAA Aeronomy Lab), HOBr was synthesized from the reaction of Br_2O and H_2O and its UV/visible spectrum was measured. These data were used to show that photolysis of HOBr is not as rapid as previously assumed and that HOBr levels in the stratosphere are higher than those indicated by previous model calculations. This work was partially supported by the NASA Upper Atmospheric Research Program.

Reaction Rate Coefficients for $O(^3P)$ with Biogenic Hydrocarbons

Hydrocarbons of biogenic origin, such as isoprene (C_5H_8) and the terpenes ($C_{10}H_{16}$) are oxidized in the atmosphere mainly by their reaction with OH and NO_3 radicals. However, reactions of $O(^3P)$ atoms with these compounds can also be of some significance particularly near sunrise or sunset. These reactions also occur in smog chamber studies of alkene oxidation where $O(^3P)$ concentrations are higher than those found in the atmosphere. Thus, rate constant data for these reactions are of importance in fully understanding the atmospheric oxidation of these biogenic compounds. We have determined the rate constant for reaction of $O(^3P)$ with isoprene, alpha-pinene, and $Delta^3$-carene. The reaction of alpha-pinene with $O(^3P)$ is faster than expected when compared with its reaction with OH and will represent a non-negligible atmospheric loss for this molecule.

Reactions of Alkoxy Radicals

Alkoxy radicals (RO^*, where R is an alkyl group) are reactive intermediates formed in the atmospheric oxidation of all hydrocarbons. The alkoxy radicals are very short-lived, typically less than one microsecond, and enjoy a very rich chemistry. They can react with O_2 to produce stable carbonyl compounds, or can undergo a number of different types of unimolecular reactions. The branching ratios for these various reaction pathways will ultimately determine the products obtained from the oxidation of the parent hydrocarbon. During this fiscal year, we studied the reactivity of a number of alkoxy radicals:

1) The $CH_3(C{=}O)CH_2^*$ radical, which is obtained from acetone oxidation, was shown to decompose to CH_3CO and CH_2O even at low temperatures, contrary to theoretical predictions.

2) Analysis of organic nitrate yields was carried to determine the chemistry of the numerous alkoxy radicals obtained from the OH-initiated oxidation of isopentane (C_5H_{12}).

3) The CH_2ClO^* radical, obtained in the atmospheric oxidation of methyl chloride (CH_3Cl), was shown to react with O_2 to form formyl chloride (HCOCl) or to undergo a novel unimolecular decomposition to HCl and HCO. A study of this chemistry as a function of temperature and pressure shows that the reaction with O_2 will be dominant under conditions of relevance to the troposphere and lower stratosphere.

Collaborations

Carla Kegley-Owen (graduate student, University of Colorado) has been working in our laboratory studying the photochemistry of $ClONO_2$. Collaboration on the measurement of the UV/visible absorption spectra of HOBr and Br_2O continues with James Burkholder (NOAA Aeronomy Laboratory and University of Colorado). Suzanne Paulson (University of California, Los Angeles) is collaborating with us on the study of the rate coefficients for reaction of $O(^3P)$ with the biogenic compounds isoprene, alpha-pinene, and $Delta^3$-carene. Jonathan Williams (graduate student, University of East Anglia, England) is working with us on a study of acetone oxidation as a function of temperature. Collaborations with Timothy Wallington (Ford Motor Company, Dearborn, MI) continue with a study of the atmospheric oxidation mechanism of CH_3Cl as a function of temperature, and on the study of the rate coefficients for the reaction of Cl-atoms with CH_3OH and CH_3CHO. Frank Flocke (KFA, Juelich, Germany) is working with us on a study of the production of organic nitrates in the oxidation of branched-chain alkanes of importance in the atmosphere.

Measurement of Pollution in the Troposphere (MOPITT)

Measurements Of Pollution In The Troposphere (MOPITT) is a satellite-borne gas filter correlation radiometer that will measure carbon monoxide and methane on a global basis. It will fly on the AM1 platform, now scheduled for mid-1998 launch as the initial component of NASA's Earth Observing System (EOS). Work at NCAR on the Canadian-built MOPITT is proceeding in close collaboration with the principal investigator, James Drummond (University of Toronto). Additional collaborators include Brasseur, Gary Davis (University of Saskatchewan), John McConnel (York University), Guy Peskett (Oxford University), Henry Reichle (NASA Langley Research Center), and Nigel Roulet (York University).

Mark Smith (ASP) continues construction at NCAR of a gas filter correlation radiometer based on technology similar to that of MOPITT, but simplified and capable of ground-based or airborne operation. This instrument will incorporate a length modulator cell, a critical element provided by the University of Toronto. The NCAR instrument will aid the development of the data retrieval algorithm by providing insight into the operation of MOPITT and by providing limited data sets in advance of satellite launch. A study to optimize the spectral band passes of the various measurement channels showed that a shift in the CH_4 channel would reduce interference by water vapor. This change is now being considered for implementation on the flight instrument.

Liwen Pan continued work on the development of retrieval algorithms and studies with the constrained linear inversion developed earlier. As an example, one study showed that changing the pressure or length of the highest altitude channel would not provide as much information as the baseline. An Algorithm Theoretical Basis Document (ATBD) that describes the physics and mathematics of the retrieval was written by Gille, Pan, Edwards, Smith and Bailey. This is now in being revised to incorporate present thinking on the way to identify and deal with broken clouds, improvements in the retrieval, and sensitivities to weaknesses in the spectral data base. Additional MOPITT information may be obtained by clicking here.

Tunable Diode Lasers

Caribou Peak Photochemistry Experiment Data Analysis

The newly developed field TDL system was successfully employed for six weeks during the Caribou Peak Photochemistry Experiment to measure the important intermediate product of hydrocarbon oxidation, formaldehyde. This represented the first field test of this instrument and provided an excellent opportunity to compare results with long path ultraviolet measurements of this gas acquired by Jerry Harder (NOAA Aeronomy Laboratory, Fritz Peak Observatory). Both techniques not only employed different spectral regions but also widely different methods of sampling, calibration, and spatial coverage.

The first phase of this analysis comprised of an instrument intercomparison. Time coincident results of the TDL and long path systems were first tabulated and intercompared. Since each technique samples vastly different spatial scales, the first task was to identify time periods where different air masses were clearly being sampled by the two techniques. Ancillary data such as wind speed and wind direction as well as the concentrations of other gases that were measured over both spatial scales (water vapor, nitrogen dioxide, ozone, and the hydroxyl radical) were used in this analysis. The first pass revealed excellent agreement: a scatter plot revealed that both techniques agreed to within 17% and produced no statistically significant intercept. Both time coincident data sets were binned into 20 minute averages for the entire six week campaign. This serves as a low pass filter to smooth out instantaneous differences due to air mass variations. Not only were the resulting diurnal profiles nearly identical, the resulting absolute values of the profiles were very close in almost all instances. Both techniques measured an average daily formaldehyde concentration of 1.5 ppbv and a maximum value of 2 ppbv around 6 PM.

Improvements to the Field TDL System

The field TDL system was improved to enable 24 hour unattended operation of two laser channels allowing complete diurnal measurements of two species to be carried out simultaneously. A novel digital signal processing (DSP) data acquisition unit designed and built by James Drummond (University of Toronto) was installed in the field system. Sewell and Henry were also involved in this endeavor. A new host data acquisition program, based on the National Instruments Lab View Graphical System, was installed to run both the DSP and TDL systems.

Southern Oxidant Study (SOS) Formaldehyde Intercomparison

As part of the SOS study, the TDLAS group has been collaborating with Timothy Gilpin, Eric Apel and Jack Calvert (retired) to host a formaldehyde intercomparison that will take place in Boulder in 1995. Activities to date in this project include: the development of a field portable formaldehyde calibration system based on permeation devices and verified using three independent methods; establishment of a sampling protocol for the intercomparison; the initiation of procedures to characterize both a glass inlet and sample spiking system; and the initiation of the necessary logistics for this intercomparison.

Laboratory Heterogeneous Studies on Sulfuric Acid Aerosols

In collaboration with Michael Mozurkewich (York University, Toronto), the TDLAS group continued the second phase of heterogeneous studies focusing on chlorine nitrate on sulfuric acid aerosols. Both reactions are extremely important in effecting the depletion of stratospheric ozone on a global scale. The aerosol generation system was also recently used in carrying out tests with Charles Brock and Charles Wilson at the University of Denver to determine the extent of volatilization of sulfuric acid aerosols in their airborne particle counting system.

Completion of a Study of Carbonyl Sulfide (OCS) Standards

The first detailed study of the time dependence of OCS permeation standards was completed. Fried quantified the resulting errors that may arise when carrying out ambient measurements of this gas when only gravimetry is used as the basis of calibration. The results of this study have importance in ascertaining temporal trends of OCS, a gas that may play a role in the earth's radiation balance.

Involvement with the International Community of TDL Users

Fried was actively involved with the international community of TDL users in an effort to advance this technique through collaborations and international symposia. Fried was co-editor of proceedings for the International Society of Photo-Optical Instrumentation Engineers (SPIE); served on the organizing committee for the 1994 and 1996 Optical Society's Laser Applications for Chemical Analysis Symposia; served on the organizing committee for the 1994 International Freiburg Conference on TDLs; and served on the organizing committee for the 1995 Russian High Resolution Spectroscopy Conference. The TDL group along with Harder are working with modelers Stuart Mckeen and Michael Trainer (NOAA Aeronomy Laboratory) to fit the data into a photochemical model. The TDLAS group also collaborated with John Birks and Daniel Rodier (University of Colorado) in carrying out the ambient measurements of formaldehyde during the Caribou campaign.

The Climate and Global Dynamics Division at NCAR

OVERVIEW

The goals of research in the **Climate and Global Dynamics (CGD) Division** are to promote further understanding of the physical causes of present and past climates and of large-scale atmospheric and oceanic dynamics, thus contributing to the basis for the scientific prediction of weather and climate. To fulfill its mission, CGD supports a staff of 130, including visitors and collaborators, and is divided into several research areas (see division organizational chart). Our research activities in fiscal year 1994 (FY 94) included the following: (1) making available to the scientific community the latest version of the community climate model (CCM2) on the Internet via anonymous file transfer protocol (ftp); (2) investigating, with the CCM and other models, the mechanisms of global climate change and exploration of the basis for long-range prediction of weather and climate; (3) studying the dynamics of global oceans and interactions with the atmosphere; (4) analyzing global observational data sets for the study of climate variability; (5) incorporating clouds, their radiative properties, and their effects on global energy balance into the global geosciences through satellite observations; (6) describing and modeling the interface between the atmosphere and the oceans, cryosphere, chemosphere, and land--biosphere within the concept of coupled climate systems (see schematic); (7) examining the mesoscale implications of large-scale climate changes; and (8) studying the relationship between ecosystem processes and the atmosphere.

In our commitment to the U.S. Global Change Research Program, we are continuing to participate in the Climate Modeling, Analysis, and Prediction (CMAP) program, the Global Tropospheric Chemistry Program (GTCP), Tropical Ocean and Global Atmosphere (TOGA) and Coupled Ocean--Atmosphere Response Experiment (COARE), World Ocean Circulation Experiment (WOCE), Geosystems Databases, North Atlantic Climate Change Program, and International Satellite Cloud Climatology Project (ISCCP). CMAP, the study of earth system processes and feedbacks that affect climate and its systematic changes, continued into its third year. Within CMAP, we began development of the new-generation Climate System Model (CSM). Initial emphasis for this coupled model involved the upper ocean, lower atmosphere, and basic land-surface processes; we are developing a flux coupler to integrate these climate components. We coupled the Equilibrium Vegetation Ecology (EVE) model into the Global ENvironmental and Ecological Simulation of Interactive Systems (GENESIS) model. We, together with staff from the Environmental and Societal Impacts Group (ESIG), launched the Geophysical Statistics Project, supported by NSF's Division of Mathematical and Physical Sciences. This program encourages collaborations in the statistical, mathematical, and geophysical sciences to analyze and interpret data from the climate system and its models. We continued research on GTCP (including a CCM-based transport model), TOGA, the

Comprehensive Ocean--Atmosphere Data Set, the North Atlantic Ocean experiments as part of the WOCE Community Modeling Effort (CME), the Global Energy and Water Cycle Experiment (GEWEX), and the Paleoclimate from Arctic Lakes and Estuaries (PALE) program. In Geosystems Databases, we are continuing to document, analyze, verify, and distribute data sets to university and NCAR users. We are involved with the multiagency-funded High Performance Computing and Communications program with support from both NSF and the Department of Energy (DOE). Our activities in this area include improving the parallel algorithms for climate modeling to increase the speed of our models, improving the representation of moist and radiative processes in highly parallel atmospheric general circulation models (GCMs) to better represent the climate process, and enhancing computational algorithms through expansion of multitasking capabilities in the CCM. Through the Computer Hardware, Advanced Mathematics and Model Physics (CHAMMP) program, our goal is to improve the modeling of physical processes and the development of improved numerical techniques to integrate components of the earth's climate system on advanced supercomputers. This program also contributes to improved computational formulation to stimulate the climate coupling process and it takes advantage of multiple parallel-processing computers. We are involved with several Earth Observing System (EOS) interdisciplinary investigations addressing the coupled climate system and the role of terrestrial ecosystems in the earth system. Activities in EOS include improving climate and ecosystem models and developing algorithms for assimilating satellite observations in atmospheric and ecosystem simulations. We participated in the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) by providing climatological information processes in forms compatible with ecosystem models for a major intercomparison of ecosystem model sensitivity to climate change. VEMAP is supported by the Electric Power Research Institute (EPRI), NASA, NSF, and the U.S. Forest Service.

In addition to NSF, funding from the following agencies supported important research projects in CGD and contributed to the program goals of NSF in FY 94: DOE (2 projects), DOE CHAMMP program (3 projects); NASA's EOS (2 projects); DOE's Atmospheric Radiation Measurements program (1 project); the Environmental Protection Agency (EPA) (2 projects); NOAA Climate and Global Change (3 projects); NASA (4 projects); the Italian Commission for Research and Development of Nuclear and Alternative Energy (1 project); the Central Research Institute of Electric Power Industry (CRIEPI) (1 project); and the National Institute for Global Environmental Change (NIGEC) (1 project).

SIGNIFICANT ACCOMPLISHMENTS

- New observations of enhanced cloud absorption which indicate that clouds absorb substantially more shortwave radiation, 25 to 30 watts per square meter, than indicated by previous model simulations. A significant change occurred in the CCM distribution of shortwave radiation between the surface and atmosphere (see image). The enhanced cloud absorption leads to an important reinterpretation of the energetics of the climate system [Veerabhadran Ramanathan (Scripps Institution of Oceanography), Robert Cess (State University of New York, or SUNY, Stony Brook), Jeffrey Kiehl, James Hack, Ming-Hua Zhang (SUNY)].

- Examination of the effect of cloud-albedo feedback on global climate with a global coupled ocean--atmosphere GCM. Decreasing the sea-surface temperature (SST) threshold for the specified cloud-albedo feedback scheme causes globally cooler conditions (see image). Precipitation decreases over the tropical western Pacific and is associated with changes in large-scale upper-level divergence that result in increased precipitation over tropical land areas, thus intensifying the monsoonal circulations and affecting global climate sensitivity [Gerald Meehl, Warren Washington].

- Availability of the CCM2 on the Internet via anonymous ftp. The distribution package contains the CCM2 source code, boundary and initial data sets, and execution scripts. All CCM2 technical documentation was made available on the Internet in postscript format [Hack, Lawrence Buja, Linda Bath, James Rosinski]. CCM2 climate simulations reveal the response of many atmospheric variables, such as precipitable water (see image), to experimental changes to the dynamical system.

- Geophysical Statistics Project colloquium, ``Applications of Statistics to Modeling the Earth's Climate System,'' for graduate students in statistics, atmospheric sciences, and related fields. The forum included tutorials on climate, objective analysis, scaling and spatial processes, and statistical problems; practice sessions to familiarize the students with data sets available at NCAR; and some statistical routines coded to analyze these data [Richard Katz (ESIG), Roland Madden, Linda Mearns, Kevin Trenberth, Joseph Tribbia, David Williamson]. (See image .)

- Computation of the heat budget locally (see image) over the entire globe for each month of 1988. Compatible top-of-the-atmosphere radiation data from the Earth Radiation Budget Experiment (ERBE), combined with European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric data, produced new estimates of ocean heat transports [Kevin Trenberth, Amy Solomon (Massachusetts Institute of Technology, or MIT)].

- First incarnation of a coupled atmosphere--ocean--sea-ice CSM, under the direction of co-chairs Byron Boville and William Holland. A unique flux-coupler concept controls the integration and distributes the fluxes between component models so that they can run as separate executables. Staff members have produced a 2-degree-by-2-degree ocean model for the next incarnation of the CSM, making significant improvements to the physical parameterizations and numerical techniques [William Large, Peter Gent, Frank Bryan, Kathryn Holcomb, Brian Kauffman].

- Integration to equilibrium of global ocean model solutions with 3-degree-by-4-degree resolution for 8 cases with different horizontal and isopycnal mixing coefficients. The new parameterization of subgrid-scale eddies greatly improves deep-water temperatures, thermocline sharpness, tracer transport (see figure) in the Southern Ocean, poleward and surface heat fluxes, and deep-water formation regions. The approach to equilibrium has also been documented [Gokhan Danabasoglu (visitor funded by NOAA), James McWilliams].

- Elucidation of links between anomalous eddy forcing and long-lived planetary-scale patterns by combining a stationary wave model with a model to represent stormtrack structure. This combination of models explains the geographical structure of both planetary waves and stormtracks [Grant Branstator].

- Empirical correction of the systematic errors of the CCM2 with the budget tendency method. This method can isolate error sources in the model [Ramalingam Saravanan, David Baumhefner]. (See image .)

- Coupling of EVE into the GENESIS v1.02 global climate model. (See images one , two , and three). The coupled model was used in a pair of long-term simulations (1x and 2x present carbon dioxide) with fully interactive vegetation--climate biophysical feedbacks. These simulations allowed vegetation distribution to change in response to climate change and are the first of their kind using a complex life-form-based model of natural vegetation [Jon Bergengren, David Pollard, Starley Thompson].

- Initiation of modeling outreach with a poster outlining the many division-wide modeling efforts. A CGD models node on the Internet gopher also facilitates updates of this information. Inquiries and collaborations cover all continents [Patrick Kennedy]. An example of scientific visualization is the image from the GENESIS model, which includes submodels for the oceans, vegetation, topography, land ice, sea ice, and the atmosphere. In the image, jet stream winds (greater than 40 meters per second) appear in blue above the planet.

- Analysis of the steady-state and transient temperature sensitivity of terrestrial carbon storage with the CENTURY ecosystem model (see image). The steady-state analysis made use of standard climatological analyses and showed a global sensitivity of 11--15 Gt C per degree warming. The transient analysis used temperature anomalies from the microwave sounding unit instrument and is being compared with changes in the growth rate of carbon dioxide in the atmosphere and with changes in atmospheric isotopes [David Schimel, Bobby Braswell, Thomas Painter, Rebecca McKeown, Elisabeth Holland (Atmospheric Chemistry Division, or ACD), Alan Townsend (Stanford University), Philippe Ciais (ACD), James White (University of Colorado), Pieter Tans and Michael Trolier (both of NOAA), Joseph Berry and James Collatz (both of Carnegie Institution of Washington), David Randall (Colorado State University), Piers Sellers (NASA), and Roger Francey (Commonwealth Scientific and Industrial Research Organization, or CSIRO)].

- Development of the VEMAP data base (see image). Intercomparison of simulations of terrestrial carbon storage and productivity required development of current and doubled carbon-dioxide climatologies with spatial and temporal resolution compatible with the input requirements of extant terrestrial ecosystem models. The VEMAP data base is a model for the use of GCM results in assessing the impacts of climate change on terrestrial ecosystems. [Timothy Kittel, Schimel, Nan Rosenbloom, Henry Fisher].

CLIMATE SENSITIVITY AND CARBON DIOXIDE RESEARCH

Climate Sensitivity and Albedo

Research in the Climate Sensitivity and Carbon Dioxide Research Group is partially supported by the DOE. Meehl and Washington, together with Thomas Bettge and Gary Strand, have addressed the effect of cloud albedo on global climate. Results from a model sensitivity experiment with the latest version of the global coupled ocean--atmosphere GCM indicate that decreasing the SST threshold for the specified cloud-albedo scheme (coincident with warm SSTs and deep convection) causes globally cooler conditions than in the control integration with the specified cloud-albedo scheme, as in a previous experiment. Precipitation decreases over the tropical western Pacific and is associated with changes in the large-scale upper-level divergence that cause increased precipitation over tropical land areas. The monsoonal circulations are intensified as a consequence. Such perturbations are reminiscent of those evident during cold events in the Southern Oscillation. These changes combine to rapidly increase planetary albedo, decrease absorbed solar radiation at the surface, cool the entire troposphere, and change the global atmospheric circulation. This study points to the importance of the cloud-albedo feedback in global climate and climate sensitivity.

El Nino--Southern Oscillation (ENSO)

Meehl began collaborative work with Esther Brady, Gent, and Tribbia to study the different variations of the El-Nino-event evolution in several coupled model simulations. Preliminary results indicate that conditions in the ocean prior to an event can dictate its evolution. For example, a deep thermocline in the western equatorial Pacific and a shallow thermocline in the equatorial eastern Pacific appear to contribute to a subsequent set of SST anomalies that form in both the east and west and propagate toward the center of the basin, as in the 1972--73 event. However, a deep thermocline in both the east and west results in SST anomalies that appear only in the west and propagate eastward, as in the 1982--83 event.

Intergovernmental Panel on Climate Change (IPCC)

Meehl became a lead author of Chapter 10 of the 1995 IPCC Scientific Assessment that will summarize recent findings of transient climate change due to increased carbon dioxide and trace gases. Meehl will summarize the effects of possible changes in climate variability as a result of increased carbon dioxide.

Ocean-Circulation Dependence on Wind-Stress Forcing

Robert Chervin and Albert Semtner (NCAR affiliate scientist from the Naval Postgraduate School) completed a set of experiments with different wind-stress prescriptions with the parallel ocean climate model using the Cray Y-MP/2 of the Model Evaluation Consortium for Climate Assessment. The three decadal integrations featured forcing by (1) ECMWF monthly climatological winds for the time span of 1980--89, (2) individual monthly mean winds for the same time span, and (3) daily winds. The simulations have shown considerable sensitivity in both first- and second-moment climatic quantities to the details of the wind-stress prescription. Furthermore, some traditional assumptions about the steadiness of deep transport and the degrees of seasonal and interannual change in total heat transport are questionable. Detailed analyses of these experiments are under way.

Global Ocean Model Development and Application

Supported by the DOE CHAMMP program, Chervin, in collaboration with Semtner, Anthony Craig, and investigators at Los Alamos National Laboratory (Robert Malone, Richard Smith, and John Dukowicz), continued model development by including additional physical processes, more accurate prescription of bottom topography and islands, higher-resolution, and massively parallel application, They performed integrations with a 1/4-degree average grid spacing on the Cray Y-MP/8 and a 1/6-degree average spacing on the CM-5 at the Los Alamos Advanced Computing Laboratory. Key features of the revised models are a free-surface formulation replacing the rigid-lid approximation and the use of a Mercator grid to more closely match the decreasing radius of deformation with latitude to permit better eddy resolution. Major results of the new 1/4-degree simulation include greater meridional overturning in both hemispheres, continuous flow through a complex Indonesian Archipelago, quite vigorous Agulhas eddies extending well toward South America, a Gulf Stream that tends to separate mainly at Cape Hatteras, and much increased eddy kinetic energy in the Southern Hemisphere.

Freon Tracer Studies

Craig and Chervin, in collaboration with Edward Harrison and John Bullister (NOAA Pacific Marine Environmental Laboratory), initiated a series of studies on the distribution of F11 and F12 in the global ocean. They based these studies on the known solubility of these tracers in the surface waters and the atmospheric concentration as a function of time, and they used a 1-degree version of the Parallel Ocean Program developed at Los Alamos. Integrations were performed on the 32-processor CM-5 at NCAR. Analysis of these experiments is ongoing and should assess the accuracy and limitations of the dynamics in the model as comparisons are made of the model-determined distributions of these passive tracers and the observed distributions.

CLIMATE MODELING

Research in the Climate Modeling Section (CMS) encompasses a variety of modeling studies of the physical mechanisms governing the global climate system and the numerical techniques required to represent these mechanisms. Scientists carry out observational studies, particularly in comparing models with observations; they develop and test new versions of the CCM and validate them; and they use the CCM to study atmospheric circulation. These studies include two-dimensional and shallow-water models, zonally averaged chemical--dynamical models, and one-dimensional column-radiation models. The CCM Core Group develops and maintains the standard versions of the CCM and its ancillary postprocessing code.

CCM2

This past year, CMS scientists made available the latest version of the CCM2 on the Internet via anonymous ftp. Instructions for acquiring the code were widely distributed via the UCAR Newsletter and other NCAR publications. All who acquired the CCM2 distribution package are strongly encouraged to register. To date, over 40 groups from 10 countries have done so. The distribution package, assembled by the CCM Core Group (Bath, Buja, Rosinski, and Gloria Williamson) along with John Truesdale and Hack, contains the CCM2 source code, boundary and initial data sets, and execution scripts. The Core Group has also made all CCM2 technical documentation available on the Internet in postscript format with plain gopher (gopher -p1/processor/doc isis.cgd.ucar.edu 70), xgopher (xgopher isis.cgd.ucar.edu 70 in subdirectories Processor/Downloadable CCM2 Documention/*), and xmosaic (at Hypertext Markup Language address: gopher://isis.cgd.ucar.edu/11/processor/doc). A CCM-users discussion group was established as an open e-mail forum for rapid exchange of information, ideas, and topics relating to the versions of the NCAR CCM and the CCM modular processor. (To subscribe, send mail to MajorDomo@ncar.ucar.edu with the words ``subscribe CCM-users" as the mail text.) As of this time, 108 individuals have joined the group.

Intercomparison and Analysis of CCM Simulations

In FY 94, CMS scientists continued to study the performance of the CCM2. Here, they describe their diagnostic work with the frozen model aimed at understanding the simulated climates. In later sections, they discuss studies to improve future versions.

Williamson, Kiehl, Hack, and Truesdale continued to participate in the Atmospheric Model Intercomparison Project (AMIP) sponsored by the Environmental Sciences Division of the DOE. Some 30 modeling groups around the world are involved, all using the same 10-year observed monthly average sea-surface data set for the lower boundary condition to drive the atmospheric models. Computer time was provided by the DOE at the Lawrence Livermore National Laboratory (LLNL) for one 10-year AMIP simulation. Two other 10-year AMIP simulations were carried out at NCAR. All 3 simulations have been extended for an additional 5 years. Analysis of the simulations continues at NCAR and in the 25 official AMIP diagnostic subprojects. Analyses of the CCM2 simulations show that it exhibits a realistic response to tropical boundary forcing. This is easily observed in the outgoing longwave radiation (OLR) and precipitation fields in the tropics. A signal can also be detected in some midlatitude regions.

James Hurrell, Hack, and Baumhefner completed a formal intercomparison of various versions of the CCM. This intercomparison, the first comprehensive examination of the many atmospheric GCMs used within CGD, clearly illustrates the various strengths and weaknesses of these models and the evolutionary nature of improvements in the CCM.

Williamson, Kiehl, and Hack completed a series of simulations with the CCM2 at different horizonal resolutions. The truncations included were rhomboidal (R15) and triangular (T21, T31, T41, T63, and T106). Although many global climate statistics in these simulations show little variation with increased resolution above T42, the physical processes that produce those climates show significant variation up to at least T106 when examined at the regional scales on which the processes act. Finer scales of motion (those resolved by T63 to T106) are required to capture the nonlinear processes that force the medium (T42) scales. Global atmospheric GCMs are complex forced-fluid dynamical systems. A large component of the forcing occurs via parameterizations of subgrid-scale processes. These parameterizations are highly nonlinear and depend on the predicted grid-scale atmospheric-state variables. The forcing can, but does not necessarily, enter the system on the grid scale. This feedback on the finest scales may be responsible for the lack of convergence evident in atmospheric models. Williamson and Jerry Olson began developing a version of the CCM2 in which the fluid dynamical and physical parameterization components are calculated at different resolutions. They will use this version to examine the numerical convergence with increasing resolution of the fluid dynamical component of simulations when the scales of the forcing from the parameterizations are held fixed.

Hack, in collaboration with Kiehl and Zhang, completed an investigation of water vapor, temperature lapse rate, and cloud feedbacks in the CCM2. This study, making use of a diagnostic procedure developed by Zhang, has (1) quantified the large compensation that occurs between the water vapor and lapse-rate feedbacks in GCMs, and (2) examined the nature of the sensitivity in the simulated CCM2 climate to cumulus convection and boundary-layer processes.

Kiehl, in collaboration with Zhang and Cess, studied cloud-absorption effects in the CCM2. Two recent studies by Cess et al. and Ramanathan et al. indicate that clouds absorb far more shortwave radiation (roughly 40 watts per square meter) than models predict. Based on these studies, Kiehl carried out a series of simulations in the CCM2 that included this additional cloud absorption. The initial effect was to increase the top-of-the-atmosphere shortwave absorption by 12 watts per square meter. The model response to the additional cloud absorption was to warm the atmosphere by up to 6 K. The additional heating in the upper tropics led to a 20-percent reduction in the strength of the Hadley circulation. Associated with this slower Hadley cell was a reduction in tropical surface wind speeds (by roughly a factor of 2). This reduction caused a significant reduction in the latent heat flux in the tropical Pacific (30 watts per square meter). The net effect of this enhanced cloud absorption was to reduce shortwave surface fluxes by 40 watts per square meter and increase the atmospheric shortwave flux by a similar amount.

Kiehl, in collaboration with Ramanathan, compared the CCM2 tropical Pacific surface energy budget with data from the Central Equatorial Pacific Experiment (CEPEX). They paid particular attention to clear-sky longwave and shortwave fluxes and compared the CCM2 results with those from more detailed radiative-transfer models. The CCM2 net clear-sky longwave surface fluxes agreed well with the observations, whereas the clear-sky shortwave fluxes differed by more than 20 watts per square meter. The source of this bias is thought to be aerosol-related. Comparisons with the TOGA--Tropical Atmosphere Ocean array of latent heat-flux measurements indicated that the model fluxes were 40--60 watts per square meter too large in the western equatorial Pacific region. Rosinski and Williamson studied the growth of machine rounding-sized initial errors in the CCM2. The growth is faster than the predictability error growth that results from turbulent flow. They showed that rounding accumulation dominates the growth when temperature differences are below the order of 0.001 K. Discontinuous code branches are not a source of growth when the differences are less than 0.001 K. They argued that the fast growth of differences is caused by the physical parameterizations as they respond to the evolving states produced by the dynamical flow. Based on a careful examination of this growth of small differences, Rosinski and Williamson developed a two-part validation strategy for codes ported to new computing environments. (1) The difference between simulations from the ported and original codes should grow no faster than does a minimal perturbation with the original code. (2) January averages, simulated by the ported versions, must fall within the natural variability of the long control simulations produced by the original code. The first phase of the strategy is also useful to ensure that operating system, library, and compiler changes do not adversely affect the CCM in a normal NCAR production environment.

Augmentations of CCM2

Williamson and Hack have been involved in a DOE CHAMMP-sponsored project with Paul Swarztrauber, Steven Hammond, Richard Sato, and John Dennis (all of Scientific Computing Division, or SCD), Richard Loft (Thinking Machines Corporation), and members of Oak Ridge National Laboratory and Argonne National Laboratory to port the CCM2 to a variety of distributed-memory, massively parallel computers. The group has ported and validated a data-parallel version on the Thinking Machines CM-5 and a message-passing version on the Intel Paragon. In both cases, the strategy described above was invoked to validate the ports. Both versions of the code will be made available to the community in the future.

In addition to standard maintenance support for the CCM1, CCM2, and the CCM modular processor, the Core Group has been active in performance and functional enhancements to the CCM2 and the CCM modular processor. Many of the prototype functional enhancements to the CCM2 and associated land-surface model facilitate future coupled modeling activities in CSM described elsewhere in this report.

CCM Development and Applications

Gordon Bonan developed and applied a new land-surface process model for use with the CCM2. The model is similar in concept to most land-surface models, but it differs in parameterizations for turbulent transfer, surface fluxes, soil temperature, and hydrology. An intercomparison with another NCAR land-surface model, using prescribed atmospheric forcings, identified important differences and similarities among models. Despite vastly different parameterizations of canopy processes, especially turbulent transfer, most differences between models were related to soil hydrology and stomatal resistance. Other important features of the new model are multiple surface types, the inclusion of lakes within a GCM land-grid box, and land--atmosphere carbon dioxide exchange.

CMS scientists coupled the model to a modified version of the CCM2 and used it in a variety of studies: (1) land--atmosphere carbon dioxide exchange, which validated the carbon dioxide flux model and confirmed that land-surface process models are a convenient means to add terrestrial carbon dioxide fluxes to a climate system model; (2) effects of lakes on climate that showed their climatic importance in high lake areas; and (3) reconstruction of past climates, in collaboration with John Kutzbach (University of Wisconsin). In this study, the coupled land--atmosphere model is being used in preliminary studies of the climate 6,000 years before present.

Kiehl and Hack implemented improvements to the cloud-prediction scheme in the CCM2. These included the distinction between continental and maritime effective cloud-drop size and a diagnostic liquid-water scale height. Kiehl has shown that the drop-size effect has a significant impact on the model climate. The shortwave cloud forcing increases by 60 watts per square meter over land which, in turn, lowers surface temperatures by up to 3.5 K. Associated with this decrease in surface temperature is a decrease in precipitation.

Hack generalized the liquid-water-path diagnostic procedure in the CCM. The two approaches to improving the diagnosis of cloud optical properties are complementary. Their incorporation into the CCM2 results in the elimination of a large component of the Northern Hemisphere summer surface temperature warm bias and a significant improvement in wintertime anomalies in the midlatitude circulation.

Kiehl has developed efficient parameterizations for the radiative effects of methane, nitrous oxide, and chlorofluorocarbons 11 and 12. These parameterizations are being incorporated into the latest CCM.

Hack continued to analyze diabatic forcing in the CCM2. Budget studies suggest an unrealistic nonlinear interaction between boundary-layer and convective processes that contributes to unrealistic features in precipitation and surface latent-heat-flux fields. Preliminary techniques to constrain the diagnosis of atmospheric boundary-layer height have been explored; these limit excessive water-vapor transport and improve precipitation and latent-heat-flux distribution. The constrained boundary-layer formulations also result in an undesirable systematic cooling and drying of the simulated atmosphere, which apparently was linked to the additional removal of water vapor by convection in the lower troposphere. Work by Kiehl and Cess on short-wave absorption by clouds suggests that slight enhancements in solar absorption can offset the undesirable effects. Alternative boundary-layer formulations are also being pursued in collaboration with Albertus Holtslag (NCAR affiliate scientist from the Royal Netherlands Meteorological Institute).

Rasch, with Jon Kristjansson (University of Oslo), developed a parameterization utilizing an explicit representation of cloud water for the CCM2. The partitioning of cloud water between liquid and ice phases is diagnosed from temperature. Following the ideas of Sundqvist, they developed a simple microphysics package to model the conversion of cloud water to rain and snow and their evaporation. The parameterization includes processes for conversion to precipitation for both pure and mixed phases of the condensate. The parameterization improved the model simulation in the extratropics and revealed new problems in the tropics connected with very strong convection over tropical land masses. Rasch is exploring the use of a Tiedtke-like convective parameterization in ameliorating some of these problems.

Williamson and Olson continued the development of a semi-Lagrangian version of the CCM2. Their previous results showed that the semi-Lagrangian method is a viable approach for climate modeling, and studies this year unveiled additional advantages of this approach. Spectral transform, semi-Lagrangian, and semi-implicit atmospheric models do not require conventional quadratically unaliased Gaussian grids because advection is no longer expressed as an Eulerian quadratic product. The conventional T42 spectral model actually supports a T63 spectral truncation but is truncated at T42 for stability reasons. (Similarly for other resolutions.) In a comparison of long climate simulations, Williamson and Olson showed that the spectral truncation of the top third of the spectrum is not necessary with semi-Lagrangian models. The simulation with T63 spectral truncation or a T42 grid looks like that from a normal T63 model rather than that from a normal T42 model. Thus, the linear grids provide a 50-percent increase in resolution at negligible additional cost.

Kiehl and Bruce Briegleb completed development of a slab mixed-layer ocean model and a thermodynamic sea-ice model and coupled them to the CCM2. The ocean model employs the net surface fluxes from the control simulation of the CCM2 to obtain implied ocean heat fluxes as a function of latitude, longitude, and month. These data are then used in conjunction with observed mixed-layer-depth data to determine the SST. The model ensures that the present spatial and temporal distribution of SSTs is realistically reproduced, while adding an interactive ocean surface to the CCM2.

Other Model Applications and Development

Kiehl, in collaboration with Hack, Wojciech Grabowski and Mitchell Moncrieff (both of Mesoscale and Microscale Meteorology Division, or MMM), and Gregory Tripoli (University of Wisconsin) carried out a 25-day simulation of a tropical deep convective cloud system with a cumulus ensemble model. The model is two-dimensional (horizontal versus vertical) with a total horizontal domain size of 1000 km. The model was forced with steady large-scale conditions from the tropical western Pacific. After 10 days, the model reached an equilibrium with this large-scale forcing. Kiehl and Charles Zender (visitor, University of Colorado) are using the convective mass fluxes and anvil outflow liquid ice-water paths to develop a parameterization of anvil ice water for the CCM2. Analysis of these data indicates a strong correlation between the 200-mb convective mass flux and the upper-tropospheric ice water.

With support from the DOE CHAMMP program, Hack, Kiehl, and Michael Hoswell, in collaboration with Bruce Albrecht and William Frank (both of Pennsylvania State University, or PSU), have continued research on a simplified workstation-based, numerical framework for parameterization development. A single-column version of the CCM2 physics package was the central component around which dynamical forcing and analysis components were developed. The target platforms were SUN workstations. Scientists adopted a netCDF data format, along with filters for transparently converting between netCDF and the CCM2 history-tape formats (for which a substantial ECMWF analysis data base currently exists). They developed a sophisticated X-Windows graphical user interface (GUI), which requires integration of the FORTRAN-based CCM2 physics with the C-based GUI. Model namelist parameters are specifiable as command-line data or via X-Defaults. The point-and-click graphical interface streamlines the control of code flow including data-set selection; column-location (latitude/longitude) selection; modification of control variables (such as termination conditions, update frequencies, specification of history data, etc.); modification of initial data and the associated large-scale forcing (e.g., modification of vertical structures, amplitudes, etc.); and the visualization of output data (vertical profiles, time series, etc.). The adoption of a semi-Lagrangian approach to handle vertical advection allows for the accurate solution of vertical-advection terms for an arbitrary number of model variables (including the standard-state variables).

Bonan collaborated with Terry Chapin (University of California, Berkeley) on an NSF-sponsored Arctic System Science Land--Atmosphere--Ice Interactions flux study to measure and model terrestrial surface fluxes in Arctic regions. Bonan is also principal investigator in NASA's Boreal Ecosystem Atmosphere Study to measure and model land--atmosphere interactions in boreal forests.

Aerosols, Chemistry, and the CCM2

Kiehl and Briegleb, in collaboration with Joyce Penner and Cathy Chuang (both of LLNL) and Mai Pham (visitor, ACD), compared forcing from new sulfate aerosol calculations. The Penner and Chuang data yield a global annual average sulfate forcing of -0.33 watts per square meter, in agreement with the data published by Kiehl and Briegleb. The Pham data yield a global forcing of -0.66 watts per square meter. The difference is a result of different chemical reaction rates. This study indicates the current range in estimated direct sulfate aerosol forcing due to differing chemistry schemes.

Study continued on the role of transport processes in controlling trace-species distributions in the stratosphere and troposphere. These studies are taking place in both the CCM2 and a matching offline transport model. Philip Rasch, Boville, and Guy Brasseur (ACD) coupled the CCM2 to a comprehensive middle-atmosphere ozone chemistry model, coupled this chemistry model to the offline transport model, and generated the data sets required to drive the offline model in its middle-atmosphere configuration. They added to the photochemistry package the reactions required to describe the chemistry taking place in sulfate stratospheric aerosols and are looking at the model sensitivity to these reactions. They are exploring the model sensitivity to stratospheric dynamics by driving the offline model with model runs using Boville's new gravity-wave-drag formulation. They are also examining the potential impact of stratospheric-aircraft emissions on the distribution of chemical tracers in the lower stratosphere.

Rasch, with David Erickson (ACD) and Pieter Tans (Cooperative Institute for Research in the Environmental Sciences, or CIRES), documented the development of a version of the CCM2 for carbon-cycle studies. Rasch worked with Tans on the use of a transport model to infer carbon sources.

In FY94, emphasis has increased on modeling the transport and removing short-lived trace species in the troposphere. With Natalie Mahowald (MIT), Rasch developed parameterizations of in-cloud scavenging processes and dry deposition and ported all relevant parameterizations from the CCM2 to the offline model. They have begun to investigate the properties of the CCM2 convective transport algorithms in moving tracers and to compare the model with the observed evolution and distribution of short-lived trace species controlled by convection. Alternative parameterizations of convective transports have been implemented and used to transport trace species in order to compare the solution sensitivity to convection. The offline model has been substantially modified for portability and computational efficiency. Rasch is driving this model with analyzed data from the ECMWF and the National Meteorological Center (NMC), in addition to model results. The offline model has also been merged with a tropospheric chemistry module developed by Paul Crutzen and Mark Lawrence (both of Max Planck Institute, or MPI). Scientists will use this model to understand the extremely low ozone amounts evident in the upper troposphere during the CEPEX.

CLIMATE ANALYSIS

Research in the Climate Analysis Section (CAS) is cosponsored by by NOAA, NASA, and the Division of Mathematical and Physical Sciences at NSF.

The goals of CAS research are to increase understanding of the atmosphere by exploring climate, climate variability, and climate change through development and analysis of observational and assimilated data sets and by using the data sets for empirical studies, diagnostic analyses, and model validation.

CAS studies focus on the atmosphere and its interactions with the surface of the earth and oceans on a wide range of time scales. Blocking events, 40- to 50-day tropical oscillations, interannual variations such as the ENSO, the North American 1988 drought and 1993 floods, solar-weather relationships, interdecadal variations, and longer-period trends are some of the phenomena studied.

A central ongoing thrust of importance to the community involves data sets and includes acquisition of data; evaluation, improvement, and restructuring of data sets; development of climatologies; and the use of the data sets in diagnostic studies. CAS scientists are also pursuing several theoretical and modeling studies.

A new thrust, and NCAR-wide activity, is the geophysical statistics project established to (1) encourage the development and application of statistical techniques to the problems faced by the research community, (2) involve many others throughout NCAR, and (3) entrain a cadre of much needed statistical experts in the study of atmospheric and climate problems of importance to the science and to society.

CAS research spans many topics and includes several studies that are part of national and international programs, such as TOGA, ISCCP, ERBE, GEWEX, Climate Variability and Predictability, Global Ocean--Atmosphere--Land System, the Solar Terrestrial Energy Program, and Global Change. CAS scientists interact with other sections within CGD, especially through the analysis and validation of all CGD climate models.

Data Sets

CAS scientists (Dennis Shea, Christian Guillemot, and Jeffery Berry in particular) continue to collaborate with NCAR's Data Support Section to acquire and evaluate data. Ongoing efforts are devoted to conventional meteorological data and analyses, but model and satellite data are increasingly included as well. Shea led the development of an NCAR instructional aid, ``An Introduction to Atmospheric and Oceanographic Data." As a data primer for students and those in other fields of research, it describes the general characteristics of atmospheric and oceanographic data sets, commonly used data sets and storage formats, and how to find what data are available and where. Shea and Roy Jenne and Wilbur Spengler (both of SCD) have described NCAR's daily data base and provided several examples of how the data are used. Berry continues to develop an on-line catalog with a point-and-click interface of all global data sets in CCM history-tape format [now available through gopher and the World-Wide Web (Mosaic)]. Trenberth and Guillemot are continuing their evaluation of global analyses from ECMWF and NMC for 1979--1993.

Climate Analysis

Using temperature fields simulated by the CCM, Rudolf Weber (Paul Scherrer Institute, Switzerland) and Roland Madden extended their analysis of the optimal averaging method for estimating the global mean temperature. They tested isotropic and homogeneous assumptions, found them to be reasonable, and compared the optimal average with averages determined by linear regression. A screening procedure to select the gridpoints with the highest correlation with the global average can do better than the optimal average, but observations may not be available where these correlations are highest.

Ralph Milliff and Madden, along with Timothy Hoar, have continued their study of fast-moving 30--40 meters-per-second-pressure waves observed in the eastern Pacific. They are now including scatterometer surface wind data from the Earth Remote-Sensing Satellite (ERS-1).

In their documentation of the temporal and spatial variability of the tropical semi-annual oscillation (TSAO) in the upper troposphere, Shea, Harry van Loon, and Hurrell demonstrated that TSAO is most conspicuous over the Indian and Pacific Oceans.

Shea, Madden, and Neelima Sontakke (Indian Institute for Tropical Meteorology) are studying the potential for prediction of monthly precipitation over India. Shea and Sontakke are preparing an NCAR technical note to describe the daily annual cycle of precipitation over India. Both conventional and robust statistical descriptions are used.

Guillemot has developed a new graphics package for presentation-quality graphics for use especially with CCM history-tape output. A manual documenting this package has been published as a technical note.

Conservation of mass in the global analyses on pressure coordinates is violated in ECMWF analyses and yet is required for budget studies of all kinds. The imbalances arise from postprocessing the variables onto pressure surfaces, from problems of dealing with the lower boundary and substituting an artificial atmosphere below ground, and from diurnal pressure tendencies associated with the semidiurnal tide and the timing and distribution of observations. Trenberth, Hurrell, and Solomon have devised methods for adjusting the global ECMWF analyses in three dimensions so that mass balance is achieved. Rather than any universal single-correction technique, a four-step process proves to be necessary to produce reasonable results. The diagnostic results are a warning to users of the analyses of potential substantial problems for certain applications. The results also indicate how operational centers could desirably alter their postprocessing procedures to ensure that the velocity field archived on constant-pressure surfaces in below-ground regions satisfies the constraint of conservation of mass.

Meehl continued to collaborate with George Kiladis and Matthew Wheeler (both of CIRES) and Klaus Weickmann and David Gutzler (both of NOAA) to document the composite evolution of synoptic-scale systems that produce westerly wind bursts in the equatorial western Pacific. In addition, they are studying the large-scale atmospheric circulation in relation to a November 1989 westerly wind-burst event and a large westerly wind-burst event in December 1992 during the TOGA COARE field phase. Results of this comparison suggest that simultaneous pressure surges from the midlatitudes in both hemispheres may combine to produce optimal conditions for triggering equatorial convection and the subsequent westerly wind burst. Observations from Integrated Sounding Systems and the operational analyses are being analyzed for documentation.

Meehl continued his research to identify the role of the south Asian monsoon in the tropospheric biennial oscillation. Results indicate that the monsoon plays an active role in the biennial mechanism via land--atmosphere--ocean interaction. He analyzed observations and results from the global coupled model to elucidate how the monsoon functions in the biennial oscillation as well as in the Southern Oscillation.

ENSO Madden--Julian Oscillation

Madden, Hoar, and Milliff have begun a study of the surface winds in the eastern tropical Pacific that are associated with the eastward-moving clouds of the 40- to 50-day oscillation. To date, data have been sparse in this region, but the ERS-1 scatterometer provides very good coverage of surface winds, the basis of this study.

Climate Diagnostics

Trenberth and Solomon completed their study of the heat budget locally over the entire globe for each month of 1988 using compatible top-of-the-atmosphere radiation from the ERBE combined with ECMWF atmospheric data. Combination of the effective heat sources and sinks (diabatic heating) and effective moisture sources and sinks for the atmosphere produced overall estimates of the atmospheric energy divergence and the net flux through the earth's surface. On an annual mean basis, this is directly related to the divergence of the ocean heat transport, and new computations of the ocean heat transport are made for the ocean basins.

Trenberth and Guillemot have derived accurate but approximate formulae for determining the mass of the atmosphere in terms of the surface pressure and applied them to globally analyzed data from the ECMWF for 1985 through 1993. The formulae factor affects the shape of the earth and variations in gravity with latitude and height. Variations in total mass occur because of changes in the water-vapor loading of the atmosphere. Using the ECMWF analyses of specific humidity, Trenberth and Guillemot made independent computations of the surface pressure due to water vapor, which is proportional to the precipitable water. Spurious trends in both the mass of dry air and atmospheric moisture arise from changes in the analysis system at ECMWF and confound attempts to seek real trends associated with climate change. New estimates are made of the total mass of the atmosphere and its water-vapor component.

Trenberth and Guillemot examined the accuracy of the moisture budget in the atmosphere by comparing precipitable water from two algorithms using Special Sensor Microwave/Imager data and ECMWF- and NMC-derived fields. The former are quite similar but differ substantially from the global analyses, which also differ from each other; moreover, the differences are not diminishing in time. Trenberth and Guillemot are also computing evaporation--precipitation from NMC and ECMWF analyses, and the discrepancies are huge, typically 75 percent or so in a root-mean-square sense.

Hurrell is examining the transient eddy forcing of the rotational flow using 11 years of ECMWF analyses. Contrary to general perceptions, results indicate that the convergence of the vorticity flux by the transient divergent flow is comparable on large scales with the equivalent rotational term. Furthermore, a widespread approximation of the direct transient eddy forcing of the mean flow by only the vorticity-flux convergence can be misleading when planetary scales of motion are considered.

Meehl collaborated with Branstator to study the role of convective heating anomalies in the tropics associated with the air--sea biennial mechanism in forcing alterations of the midlatitude longwaves. These circulation changes appear to cause persistent surface temperature anomalies over south Asia that set up anomalous land--sea temperature contrast and affect monsoon development. Thus, south Asian snow cover contributes to subsequent monsoon strength, but it is mainly symptomatic of fundamental changes in the midlatitude longwave pattern associated with tropical convective heating anomalies.

Madden and Meehl demonstrated that the present surface-observing-station network is adequate to capture the globally averaged surface-air-temperature increase associated with a pattern of carbon dioxide warming from a global coupled GCM. The absolute value of the associated bias is generally less than 2 percent.

Decadal Variability

Van Loon and Hurrell have further analyzed notable decadal time-scale changes after the late 1970s in atmospheric circulation over the Southern Hemisphere, especially in the semiannual cycle and including a delayed breakdown of the polar vortex in the troposphere and lower stratosphere during the 1980s. The changes may be linked to concomitant changes in the tropics. In further work with John Kidson (National Institute for Water and Atmospheric Research, New Zealand), van Loon examined the relationship between latitudinal temperature gradient and eddy heat transports in the Southern Hemisphere.

Hurrell and van Loon continued their study of interdecadal variations over the North Atlantic during winter. Hurrell is examining atmospheric circulation changes associated with recent extreme events of the North Atlantic Oscillation using ECMWF global analyses. Van Loon is studying the atmospheric circulation associated with sea-ice variability around Greenland and Iceland.

Van Loon and Karin Labitzke (NCAR affiliate scientist from the Free University of Berlin) are continuing to define the decadal-period (10- to 12-year) oscillation in the stratosphere. The effects of three volcanic eruptions (Mt. Agung, El Chichon, and Mt. Pinatubo) on the stratosphere have been analyzed with account taken of the phase of the Quasibiennial Oscillation. They have analyzed the trends of temperatures and geopotential height over the Northern Hemisphere in the lower stratosphere and noted the difficulty of distinguishing trends in the presence of marked decadal variations that are correlated with the sunspot cycle.

Climate Modeling and Validation

Trenberth, Berry, and Buja have documented new algorithms implemented in the CCM modular processor for deriving pressure-level data from model-level (hybrid or sigma) data. They have explored issues associated with vertical interpolation and horizontal truncation or change in resolution of model-coordinate data. This work has substantial implications for postprocessing globally analyzed data onto coarse grids (such as planned for reanalysis data sets). In addition, they have developed a new algorithm for deriving sea-level pressure fields below high topography that has now been implemented in the CCM postprocessor along with the algorithms for other variables from ECMWF. In the course of this work, they discovered that the basic omega fields put into the original archive at ECMWF are not correct (in the sense that they are consistent with their model).

Hurrell completed documentation of the climate records of four versions of the CCM (standard versions of the CCM1 and CCM2 and recent versions of the Climate Sensitivity and Carbon Dioxide Research Group and GENESIS models). The validation and comparison involved many different fields, and common strengths and deficiencies and evolutionary improvements have been highlighted.

Geophysical Statistics Project

Principal investigators Katz and Madden, along with coinvestigators Mearns, Trenberth, Tribbia, and Williamson, have dedicated time to the geophysical statistics project (funded by the Division of Mathematical and Physical Sciences of NSF) whose mission is to encourage the development and application of modern statistical techniques to problems faced by NCAR scientists. Hoar was the first hire of the project, and Steve Cherry, from the statistics department at Montana State University, is the project's first postdoctoral scientist.

A major activity of the statistics project was sponsorship of a two-week colloquium, ``Applications of Statistics to Modeling the Earth's Climate System," in the summer of 1994. Besides encouraging interactions between scientists and statisticians onsite, two important goals of the colloquium were to facilitate an exchange of ideas beyond UCAR and to interest young persons in problems involving statistics, modeling, and analysis of the climate system. Thirty-two graduate students who expressed an interest in applying statistics to the geophysical sciences attended the colloquium. Tutorials focused on climate, objective analysis, scaling, and spatial autoregressive-moving average processes. Other more specialized talks on a wide variety of statistical problems in atmospheric and ocean sciences were presented by 18 visiting experts and 10 NCAR scientists. The colloquium made progress in facilitating the exchange of ideas between statisticians and geoscientists and in interesting young persons in problems involving statistics and the climate system.

During the past year, Chester Newton reviewed the historical development of the ``Bergen School" of meteorology and how the associated polar front theory was established in the United States.

OCEANOGRAPHY

Oceanography Section (OS) scientists focus on understanding the large-scale ocean circulation and the dynamics of climate through studies of the important processes in the ocean, air--sea interaction, and coupled systems. Emphasis is on numerical modeling of global and regional ocean circulation, development of coupled models, idealized process studies in geophysical fluid dynamics, and analysis and interpretation of observational data.

Coupled Atmosphere--Ocean Models

The first incarnation of a coupled atmosphere--ocean--sea-ice coupled model for the CSM research has been completed and is now running in coupled mode. These models are running as separate executables being driven by, and passing information to and from, the flux coupler, another separately executing program. This coupler also computes the interfacial fluxes that are then used to drive the component models and ensures that there is exact conservation of properties across the interface. The components of this first CSM are the CCM2 and land model at R15, a 4-degree-by-3-degree global ocean model, and a simple 4-degree-by-3-degree sea-ice model that is very similar to the default sea-ice model in the standard version of the CCM2. With guidance from Bryan, Gent, and Large, Holcomb (funded by NASA) and Kauffman have programmed the flux coupler. To allow testing of the CCM with the flux coupler in a stand-alone mode and to facilitate research on the sensitivity of the atmospheric circulation to the resolution of sea-surface features, they developed small ``dummy'' ocean and sea-ice models that read gridded data sets.

Other ocean models to be coupled with the CCM2 plus the land model at higher T42 resolution are (1) a finer-resolution Geophysical Fluid Dynamics Laboratory (GFDL) modular ocean model (MOM), a 2.4-degree-by-2-degree global ocean model version developed this year, (2) the upper-tropical Pacific Ocean model of Gent and Mark Cane (Lamont-Doherty Geological Observatory) to be used for ENSO studies, and (3) a high-resolution CME North Atlantic model to be used for studies of decadal variability in the North Atlantic. A description of work with these models in ocean-alone simulations follows.

McWilliams, with Saravanan and Olivier Thual (Centre Europeen de Recherche et de Formation Avancee en Calcul Scientifique), is investigating multiple equilibria and climate transitions in a coupled model of the oceanic thermohaline convection and the atmosphere.

Coupled Ocean--Biogeochemistry Models

Bryan, with Jorge Sarmiento (Princeton University), completed initial integrations of the coupled circulation--biogeochemical cycling model of the North Atlantic. While the results appear promising in many ways, the inadequacy of the present advection scheme in the CME model was exacerbated by very strong gradients in the biologically active tracers of the simulation. The experiment will be repeated with one or more of the monotonic advection schemes developed by William Holland and Matthew Hecht (visitor, funded by the Italian Commission for Research and Development of Nuclear and Alternative Energy Sources, or ENEA) for use in the global ocean model.

Aspects of biological--physical coupling were explored by Scott Doney, along with Raymond Najjar (PSU) and David Glover (Woods Hole Oceanographic Institution, or WHOI), in a one-dimensional numerical model with the planetary boundary-layer (PBL) mixing scheme developed for the global upper-ocean model. The initial coupled-model work has focused on the Sargasso Sea where the model can be validated with the extensive physical, chemical, and biological data set for the Bermuda time-series site. To understand the role of different biological interactions (variable chlorophyll to nitrogen ratios and dissolved organic nitrogen production), they carried out extensive process and sensitivity studies.

Global Ocean Models

OS scientists have been working together on a 2.4-degree-by-2-degree-resolution version of the global GFDL MOM. This model will soon be used as the ocean component of the next incarnation of the CSM. Improvements in physical parameterizations and numerical techniques have been significant. OS scientists are currently exploring sensitivity to the values of several parameters. When a final configuration has been chosen, they will run the model until an equilibrium solution is reached. Because this is the adjustment time of the deep ocean, this requires an integration time of several thousand years.

Using this new model, Bryan undertook an analysis of the angular momentum budget of the ocean that is quite different from that of the atmosphere. The seasonal rate of change of angular momentum is a small fraction of the applied torques, so that the ocean contributes little to changes in length of day. Wind-stress torques at the sea surface are balanced almost entirely by ``mountain torques'' at the same latitude. Frictional torques on the ocean bottom and meridional transports play a very small role in the budget. Bryan is investigating the sensitivity of the angular momentum distribution to a number of model factors, such as topographic roughness, wind-stress distribution, and various parameter choices.

Danabasoglu, McWilliams, and Gent implemented the isopycnal transport parameterization of Gent and McWilliams in the GFDL ocean GCM, replacing the physically unjustifiable horizontal mixing of tracers. They investigated the effects of this parameterization in a global domain with a resolution of 3 degrees by 4 degrees. Comparison of the results with those of the conventional horizontal diffusion reveals substantial and significant improvements in the simulation of several climatically important aspects of the ocean circulation. These improvements include a sharper main thermocline, cooler abyssal ocean, elimination of the Deacon cell as a tracer transport agent, zonally integrated meridional heat transport and surface heat fluxes in better agreement with observations, and better confinement of the locations of convection.

Large, McWilliams, and Doney (funded by NOAA) completed the development and validation of a nonlocal parameterization of vertical mixing in the oceanic boundary layer. It is comprised of a scheme for diagnosing the boundary-layer depth and prescriptions for the turbulent mixing within this layer. Simulations of several annual cycles at Ocean Weather Station Papa demonstrated that this model exchanged properties between the mixed layer and thermocline in a manner consistent with observations and at least as well as, or better than, alternatives. The parameterization was specifically developed and tested at resolutions feasible for the ocean component of CSMs and has been incorporated into both global and regional ocean GCMs.

Regional Ocean Models

OS scientists continue to analyze the CME model data generated in past years and to provide data sets to users in the university community. The University of Miami ocean modeling group (Eric Chassignet, Rainer Bleck, and Linda Smith) is undertaking a follow-on calculation to the CME using their isopycnal coordinate model. OS scientists are providing them with data sets from the original CME integrations as part of a model intercomparison. With Ilana Wainer (visitor, Cidade Universitaria), Bryan is evaluating the momentum budget of the equatorial undercurrent of the model. Previous analyses of this type, undertaken on lower-resolution models of the tropical circulation of the Atlantic, revealed that parameterized horizontal dissipation plays a dominant role in the zonal momentum budget over a large part of the domain. In contrast, horizontal viscosity is negligible in the CME model with vertical friction and inertial terms becoming more important.

Antonietta Capotondi (Advanced Study Program, or ASP) has completed a spectral analysis of 15 years of CME outputs. This study was directed toward identifying the characteristics of the model variability at periods longer than annual. She is continuing this study in order to develop a dynamical framework to explain the model's low-frequency variability.

The upper-ocean mixing scheme of Large, McWilliams, and Doney has now been implemented in the upper Pacific Ocean primitive-equation model of Gent and Cane. Initial runs look very promising in that the amplitude and phase of the annual cycle of SST in the eastern tropical Pacific are now much more in line with observations. Future tasks are to test the sensitivity of the upper-ocean mixing scheme to (1) the vertical discretization of the numerical model, (2) the critical value of the bulk Richardson number used, and (3) the introduction of shorter-time-scale variability into the wind-stress forcing, which at present is the monthly climatology provided by Florida State University.

Through a suite of numerical experiments, Milliff (funded by NASA) and Large have demonstrated the effects of realistic high-wavenumber wind forcing on the general circulation of a high-resolution, quasigeostrophic North Atlantic ocean model. A 15-year synthesis of hydrographic observations in the eastern basin of the North Atlantic compares well with 20-year average upper-level streamfunction fields from the North Atlantic ocean model, driven by the ECMWF daily winds that were augmented to contain energy at finer spatial scales, consistent with upcoming scatterometer observations from satellites. The effect is largest in the eastern basin (Azores Current), associated with strong wind-stress-curl features oriented alongshore.

Milliff has continued his collaboration with Dale Haidvogel (NCAR affiliate scientist from Rutgers University), Mohamed Iskandarani (Rutgers University), and Nadia Pinardi (Istituto per lo Studio Delle Metodologie Geofisiche Ambientali) on a numerical study of the abyssal circulation of the Eastern Mediterranean Sea. They have completed preliminary experiments using the spectral finite-element shallow-water-equation model developed by Iskandarani and Haidvogel. They impose a deep-water source to mimic the formation process at the mouth of the Adriatic Sea. Near-equilibrium solutions over a flat bottom and over a realistic representation of the bathymetry can be compared to indicate the importance of the local geometry. Later experiments will be run to quantify subbasin-scale residence times and to identify characteristic particle pathways in the abyssal Eastern Mediterranean.

Hecht and Holland, with collaborators Pinardi and Vincenzo Artale (visitor, ENEA), continued research to understand the role of the input of very salty water from the Mediterranean Sea into the North Atlantic Ocean. They accomplished a high-quality simulation of the circulation of the Mediterranean Sea and assessed the output of heat and salt through the Gibraltar Strait. In addition, they conducted North Atlantic experiments with and without Mediterranean sources to examine the sensitivity of the North Atlantic ``conveyor belt'' to these inputs. Results indicate that the North Atlantic circulation is far more vulnerable to thermohaline collapse in the absence of Mediterranean waters.

Large and Gregory Crawford (visitor, ASP and Oregon State University) completed their study of the upper-ocean's response to midlatitude storm forcing. They found that the nonlocal K-profile parameterization of vertical mixing in the oceanic boundary layer was able to predict observed ocean responses and changes in kinetic energy, potential energy, and mixed-layer temperature. The key to this success was a superior diagnosis of the depth to which wind- and buoyancy-driven mixing penetrates the stably stratified thermocline. Extraordinarily large responses, especially in mixed-layer temperature, were due to a resonant response with inertially rotating winds. A numerical investigation showed how such a response depends on wind strength, duration, and rotation, as well as on initial ocean currents and stratification.

Ocean Chemistry Models

Doney completed research on the exchange of gases from the atmosphere and ocean, in particular carbon dioxide. He carried out theoretical studies of the relevant thermodynamic equations for air--sea exchange with emphasis on irreversible thermodynamic phenomena. Calculations for both idealized gas--liquid and air--water interfaces demonstrated that irreversible thermodynamic effects play a smaller role than previously suggested and do not influence global carbon dioxide budget calculations.

Doney and Najar initiated a project to look at the interaction of photochemistry and turbulent mixing in the ocean boundary layer. They developed appropriate scaling arguments and completed initial numerical simulations of the diurnal cycle. The physical processes underlying the formation and destruction of the diurnal thermocline enhanced the diurnal signal and near-surface gradient for photochemical species. Work is continuing on application of these results to the interpretation of field data and global ocean source calculations.

Studies in Geophysical Fluid Dynamics

In the field of dynamics of geophysical vortices, McWilliams has conducted research in the following areas: life cycles of atmospheric cyclones and Gulf Stream rings with Andrew Bush and Richard Peltier (both of University of Toronto); finite-amplitude equilibration of baroclinically unstable vortices with Xavier Carton (Toulouse); evolution of eddies with Alain Colin de Verdiere (visitor, Oceanographic Center of Brittany) and Yves Morel (visitor, Laboratoire des Ecoulements Geophysiques et Industriels Institut de Mecanique de Grenoble); cyclostrophic adjustment with Pascale LeLong (NWRA Consultants); and instability of monopole vortices in a rotating, stratified fluid with William Smyth (Oregon State University). McWilliams is also investigating cumulus cloud parameterizations and self-organized convection and its fractality in the tropical atmosphere with Jin-Ichi Yano (visitor, Monash University), Moncrieff, and Kerry Emanuel (MIT). McWilliams has developed a theory of Lagrangian accelerations in quasigeostrophic flows with Lien Hua (Oceanographic Center of Brittany). He has investigated geophysical turbulence in the following situations: rotating convection with Joseph Werne (ASP) and Keith Julien and Sonya Legg (both of University of Colorado); rotating, stably stratified turbulence with Jeffrey Weiss (visitor, University of Colorado) and Irad Yavneh (visitor, Israel Institute of Technology); turbulence in the shallow-water equations with Lorenzo Polvani (Columbia University) and Michael Spall (WHOI); breakdown of the slow manifold in shallow-water turbulence with Yavneh; and magnetohydrodynamic turbulence with Toshiki Tajima (University of Texas) and Rodney Kinney (ASP). Other projects include PBL surface-layer fluxes and intermittency with Chin-Hoh

Moeng and Peter Sullivan (both of MMM); Langmuir circulations in the ocean boundary layer with Sullivan and Sidney Leibovich (Cornell University); PBL modeling with a K-profile parameterization with Large and Doney; modeling the PBL over a non-uniform surface with Stuart Marlatt (visitor, University of Colorado) and Sedat Biringen (University of Colorado); and an evaluation of PBL parameterizations with Large, Doney, Moeng, Sullivan, Keith Ayotte (MMM), and John Wyngaard (PSU).

Milliff has collaborated with Yavneh to develop a multigrid elliptic solver for the nonseparable equation that arises in a rigid-lid, shallow-water model formulation over steep topography. Milliff will employ this new model in numerical experiments to extend the linear theory of McWilliams and Atsushi Kubokawa (visitor, Hokkaido University). This theory describes the dynamical control of a western boundary current by the bathymetry rather than by the artificial lateral boundary conditions that are usual in ocean modeling.

Hecht and Holland have studied alternatives to the highly dispersive centered-in-space leapfrog differencing with which ocean-tracer advection is generally treated. Several upwind-weighted, forward-in-time algorithms have been identified as promising candidates based on the results of passive-tracer advection in two-dimensional ocean-basin circulation. One of these advection schemes, the MPDATA algorithm of Piotr Smolarkiewicz (MMM), has been implemented and evaluated in the GFDL model.

Capotondi and Saravanan are completing a study to test the performance of different surface boundary conditions for heat and salt in a two-dimensional Boussinesq model of the ocean thermohaline circulation. Their approach consists of comparing the characteristics of the model thermohaline circulation equilibria and their stability obtained by using different surface boundary conditions with the results obtained by Saravanan and McWilliams by coupling the same ocean model with a two-layer atmospheric model.

Capotondi and Holland have undertaken a study of the variability of the ocean thermohaline circulation. Variability at decadal time scales has been found in observations of oceanic and atmospheric quantities in the North Atlantic. An important scientific question is associated with the nature of this variability---whether it is an ocean-only phenomenon driven by atmospheric forcing or a mode of behavior of the coupled ocean--atmosphere--ice system. Four different boundary conditions for temperature, corresponding to different representations of the atmospheric behavior, are considered.

Ocean Observations

Milliff, Large, Holland, and McWilliams continue to serve on the NASA/Jet Propulsion Laboratory Science Working Team for the NSCAT (NASA Scatterometer) program. They have received scatterometer data from the European Space Agency's ERS-1 mission. These data are maintained at NCAR in cooperation with Steven Worley (SCD). Milliff has collaborated with Madden and Hoar and other Geophysical Statistics Project staff to detect in the ERS-1 derived zonal winds, a fast eastward-propagating, surface-pressure signal associated with the 40- to 50-day oscillation. Milliff and Madden have recently demonstrated the existence of this fast surface-pressure signal.

In collaboration with Rik Wanninkhof and John Bullister (both of NOAA), Doney completed preliminary analysis of the discrete bottle data from the 1993 NOAA CO2 cruise in the eastern equatorial and North Atlantic. The purposes of the cruise were to (1) make simultaneous measurements of the full suite of parameters for the carbon dioxide system (pH, alkalinity, total carbon dioxide, and pCO2), (2) provide a baseline for future studies of the ocean uptake of greenhouse carbon dioxide, (3) examine the interactions between biological processes and pCO2 in the surface water, and (4) study the rates of ventilation of the eastern basin using transient tracers (Carbon 14, chlorofluorocarbons).

Large, Jan Morzel, and Crawford were able to reconcile the differences in observed marine wind speeds of 10 meters per second and greater, as measured by anemometers at 3.0, 4.5, and 5.0 m. They postulated that all the measurements could be correct, but that neglect of the surface wave distortion of the wind profile resulted in different 10-m wind speeds. These differences and those with winds from ECMWF analyses were used to construct general correction functions. The corrections were serious (40 percent in stress for 20 meters-per-second wind speeds) and essential for credible performance of numerical simulations.

GLOBAL DYNAMICS

The scientific objective of the Global Dynamics Section (GDS) is to increase understanding of the mechanisms and theoretical predictability of large-scale atmospheric variability on time scales of days to years. This objective will contribute to the scientific basis of predicting transient, global circulations in the atmosphere beyond present practical limits. GDS scientists take three approaches to their research: (1) numerical and theoretical studies using a hierarchy of physical models that range from the nondivergent vorticity equation to coupled atmosphere--ocean models, (2) investigation of the cause of low-frequency variability and experimentation with the CCM to explore the practical skill of predicting low-frequency variability, and (3) sensitivity analysis of numerical prediction to atmospheric initial conditions and design of improved data assimilation for nongeostrophic flows, particularly for tropical and mesoscale forecasting.

Predictability Studies and Determinism of Climate

Over the past several years, GDS scientists have been investigating the theoretical predictability of atmospheric variations of increasingly longer time scales. Studies are continuing on both ends of the temporal spectrum---short-term predictability of the atmosphere and climate determinism and almost-intransitive behavior of the climate system. With respect to climate determinism and (almost) intransitivity, one of most exciting developments in ocean modeling in recent years has been the discovery of the multiple-equilibrium structure of the thermohaline circulation. This multiple-equilibrium structure has been studied extensively in ocean models of varying degrees of complexity, from box models to global GCMs. Understanding the multiple-equilibrium structure of the thermohaline circulation in the ocean--atmosphere system may be crucial to explaining long-term climate variability, both natural and anthropogenic.

Saravanan and McWilliams have been investigating the properties of the thermohaline circulation in an idealized coupled ocean--atmosphere model. The atmospheric component of this coupled system is a two-level global primitive-equation model, using the moist primitive equations and incorporating simplified parameterizations of radiation, precipitation, and albedo. The oceanic component is a two-dimensional zonally averaged model of the thermohaline circulation, wherein all small-scale processes are represented by eddy diffusion coefficients. Integrations of the coupled ocean--atmosphere model were carried out at T21 resolution for the atmosphere and 3 degrees meridional resolution for the ocean, with a 1-h time step.

Numerical experiments with this idealized coupled model have led to several interesting conclusions. The multiple-equilibrium structure in the ocean-only context seems to persist in the coupled ocean--atmosphere system. Although coupling to the atmosphere changes important details of the ocean circulation, there seems to be a one-to-one correspondence between the coupled equilibria and the ocean-only equilibria. Coupled integrations with negative, high-latitude salinity anomalies indicate that the mixed boundary conditions traditionally used in ocean models tend to destabilize unrealistically the thermohaline circulation. Capotondi and Saravanan are investigating the use of more realistic boundary conditions for ocean models to better capture the atmospheric feedback processes. Also, the atmospheric meridional heat transport compensates very rapidly for changes in the oceanic meridional heat transport, so the sum of the atmospheric and oceanic meridional heat transports remains nearly constant. This appears to be due to the relative efficiency of the dynamical processes, as compared to the radiative--thermodynamic processes, in responding to changes in the equator-to-pole SST gradient.

In recent years, it has been suggested that one may not need a coupled climate system to produce the type of flip behavior indicative of almost intransitivity; the atmosphere alone in its nonlinear behavior may exhibit such variations. For example, before the significance of signals of climate change can be accurately tested, it is necessary to characterize the low-frequency variability that can occur in the climate system in the absence of external changes to the system. One facet of this characterization is whether the system has more than one equilibrium. Some investigations of the CCM have suggested that an atmosphere with fixed boundary conditions can have two equilibria, but recent work has indicated that the data used in these studies were insufficient from which to draw definitive conclusions. Branstator and Anthony Hansen (visitor, Augsburg College) have begun a new investigation to settle this question. Using very long integrations of CCM0B, they are calculating probability density functions of various indices of planetary-wave amplitude to determine whether multiple equilibria are detectable when sampling problems are not an issue. To date, only unimodal distributions have been produced.

There also remain some issues in short-range predictability of the atmosphere where, in particular, the question of mesoscale predictability remains controversial. To shed some light on the subtleties involved, Ronald Errico and Martin Ehrendorfer (visitor, University of Vienna) estimated the numbers of growing singular vectors in a model for forecasts up to 24 h. These are the numbers of independent, orthogonal perturbations that increase the value of a norm, expressed in terms of the perturbations, during a specified period. They determined that only approximately one quarter of one percent of the possible modes were growing ones if gravitational modes were excluded from consideration. These results help explain the lack of perturbation error growth observed in either mesoscale or global predictability studies for short time ranges.

Ehrendorfer and Tribbia investigated the intrinsic predictability of the El Nino phenomenon. They are studying the compatibility of a nonlinear dynamical model and a linear statistical forecast method that attributes loss of predictability to stochastic forcing. Some progress has been made in statistical modeling of the synthetic time series (simulated El Nino, Tziperman model). Embedding a time series generated by a nonlinear model in a higher-dimensional phase space may allow the description of the process in a linear framework. More and systematic experiments, as well as some form of hypothesis testing, are necessary.

Over the past year, Philip Thompson has been investigating the dynamical significance of a previously unrecognized invariant of two-dimensional nondivergent flow. This invariant, which Thompson discovered by examining the triad interactions in Fourier space, is not a quadratic form like the familiar invariants of energy and enstrophy and thus may be important in modifying the view and relevance of statistical equilibrium, equipartition spectral distribution which utilizes energy and enstrophy to define the effective "Boltzman temperature" of the distribution. This new, as yet unnamed, invariant will also be useful in the construction of analytic solutions to low-order spectral models with greater than three degrees of freedom.

Tropical and Mesoscale Analysis and Ensemble Forecasting

A rigorous test of the understanding of phenomena in the atmosphere, as embodied by a formulation of comprehensive models, is the accuracy of such models in the forecast arena. This is especially true in the tropics and at extended range where the influences of the diabatic terms can be of paramount importance. In the tropics, efforts to validate and improve forecast performance have been hindered by the delay in the generation of diabatic forcing in atmospheric models when initiated with analyses of the atmosphere.

Akira Kasahara, Arthur Mizzi, and Leo Donner (NCAR affiliate scientist from GFDL) are conducting research on a unified scheme of diabatic initialization to improve the analysis of temperature, horizontal divergence, and moisture in the tropics. The unified scheme is a combination of the cumulus initialization and the traditional diabatic nonlinear normal mode initialization. The objective of the cumulus initialization is to adjust the distributions of temperature, moisture, and horizontal divergence through the inversion of a convective precipitation parameterization with additional dynamical and physical constraints such that the calculated convective precipitation agrees very closely with observed precipitation rates. Forecast experiments using the CCM1 with the Kuo cumulus parameterization indicate that the application of this cumulus-initialization scheme can ameliorate the problem of precipitation spin-up.

Kasahara has begun to investigate adaptation of the present methodology of diabatic initialization to a forecasting model that adopts a type of cumulus parameterization different from the Kuo scheme. The current cumulus initialization scheme for CCM2 uses a stability-dependent mass-flux parameterization for cumulus convection designed by Hack. Although this scheme adjusts only the moisture field at present, the inversion method is flexible enough to be applied to a different type of cumulus parameterization as long as it is written in a subroutine form. The need for temperature adjustment will be examined after testing this scheme in forecasting mode with the CCM2.

There are interesting similarities between the large-scale motions in the tropics and the mesoscale motions in general. One commonality is that the effect of diabatic heating is important in supporting the vertical circulation. Also, both scales of motion are ageostrophic and divergent. It is well known that the problem of spin-up in precipitation forecasts with mesoscale models is severe if only a conventional initialization is used. The mesoscale modeling community has made various efforts to introduce a special procedure of initialization to overcome the spin-up problem. Kasahara, with Hiromaru Hirakuchi and Jun-Ichi Tsutsui (both visitors, CRIEPI), is developing a unified diabatic initialization for the NCAR/PSU mesoscale model (MM4). One area of focus is the problem of diabatic initialization for tropical cyclones to which very little attention has been paid so far. Preliminary results with MM4 forecasting a dual system of typhoons Nos. 18 and 19 in September 1990 in the western Pacific show that the lack of diabatic initialization gives rise to a severe precipitation spin-up problem. Since latent heat of condensation is the major source of energy in tropical cyclones, the precipitation spin-up problem significantly affects the analysis and prediction of tropical cyclones.

Two additional efforts involve examining issues in mesoscale analysis. Errico and Jian-Wen Bao (ASP) investigated the information content of observations used in analyses produced by nudging. They determined that, in the ways normally applied, nudging effectively discards prior observations and effectively retains only observations at the final analysis time. They performed this study by directly computing sensitivities of the analysis fit to observations with respect to the observations themselves and by using a version of the NCAR Mesoscale Adjoint Modeling System Version 1 (MAMS1) incorporating the adjoint of the nudging terms. The results indicate that the so-called four-dimensional data assimilation using nudging has more in common with other three-dimensional procedures than the statistical dynamical four-dimensional techniques, such as Kalman smoothing and variational assimilation using adjoints. By incorporating diabatic physics and small-scale information on the mesoscale, Vukicevic is examining the possibilities and limitations of the use of the MAMS1 for assimilation of cloud-related data. Specific issues are (1) evaluation of the tangent linear and adjoint model errors associated with discontinuities due to cloud parameterizations, and (2) possibilities for minimizing these errors through a four-dimensional data-assimilation procedure that uses constraints on these parameterizations.

The second important testing ground for atmospheric models is the monthly forecast. Because deterministic forecasting over such an extended range is impossible owing to the intrinsic loss of predictability in the atmospheric system, a stochastic dynamic prediction method is needed and studies investigating the efficacy of ensemble prediction have continued. Prior to an ensemble forecast, an estimate of analysis uncertainty is necessary. Baumhefner calculated differences from a five-year sample analysis between the NMC and ECMWF products to determine the global geographical distribution of analysis error. Not surprisingly, the largest differences were in the storm-track regions of the world with values exceeding 100 m at 500 mb.

With respect to ensemble construction using a small number of realizations, Ehrendorfer and Tribbia investigated the prediction of forecast skill or, more generally, predicting moments of the phase-space probability density function (pdf) of the model state. The Liouville equation provides the conceptual framework. However, in view of the large dimensionality of the model phase space for operational models, direct solution of the Liouville equation is inefficient, and estimating moments can be achieved (approximately) by simulating the method of characteristics through ensemble prediction, thus avoiding questions of closure (as in stochastic--dynamic prediction). In this context, efficient sampling of the initial pdf becomes important. The relationship between dynamical orthogonal patterns and the eigenfunctions of the covariance structure of the pdf provides a means to design efficient sampling strategies. Results of some experiments performed for a low-dimensional Lorenz system indicate that considerable savings over random sampling are possible.

The proof of any scientific endeavor lies in the ability to forecast future events, and Baumhefner has documented the success of the GDS effort to date in extended-range forecasting. He completed a study of a direct comparison of eight 30-day forecast ensembles with a low-resolution climate model to forecast ensembles with a much-higher-resolution model. The climate-model forecasts on average were slightly better, especially late in the period. The systematic error was reduced considerably, and the spread of the ensemble skill was as large as the high-resolution cases. He has begun documentation of the sensitivity of these results to model physics changes and seasonal variations. He recently conducted an extensive comparison of 6- to 10-day forecast skill from a T31 version of CCM1 with the operational NMC model during the winters of 1990--93. Twenty-two samples showed that the forecast error was slightly worse when the 2 control forecasts were compared; however, when the 10-member T31 ensembles were used, the CCM1 averaged forecasts were better. All comparisons to date strongly indicate the superiority in forecast skill of relatively low-resolution ensemble forecasts for periods beyond the deterministic daily limit of predictability

Theoretical Studies of Atmospheric Flows

The dynamics of long-lived, low-frequency flow regimes remain of great interest, since a satisfactory theoretical explanation of their manifestations has been elusive. Branstator has examined three aspects of this variability---eddy forcing, modal behavior, and external diabatic forcing.

An outstanding question in the theory of intra-annual to interannual atmospheric variability has to do with why fluctuations that occur on these time scales tend to be concentrated over the North Pacific and North Atlantic and what processes affect their structure. One process that should affect such variability is the feedback from momentum fluxes by higher-frequency synoptic disturbances, since the distribution and structure of synoptic disturbances are influenced by lower-frequency perturbations. Branstator has been able to isolate the eddy feedback by using a model of the storm tracks that he recently developed. Among other things, this model indicates the time-averaged momentum fluxes produced by the synoptic disturbances that occur in reaction to a specified low-frequency anomaly. The feedback is especially strong and positive over the North Pacific and North Atlantic and, thus, is apparently one reason that low-frequency variability is concentrated in these regions. Further experiments with the storm-track model suggest that the feedback is strong enough to change the structure of a low-frequency anomaly and helps to determine which low-frequency anomalies are especially prominent. Work along these lines is being used to diagnose the low-frequency behavior of the CCM.

Modal behavior is also a cause for persistence in the atmosphere and continues to be a topic of investigation. Branstator and Isaac Held (Princeton University) extended their investigation of the influence of stationary waves on the frequency and structure of Rossby--Haurwitz modes. Their new calculations indicate that some modes that are sometimes thought to exist in nature (in particular, the 16-day wave) cannot be unambiguously followed; for these modes, the results of tracking depend on the path taken through basic-state phase space. Thus, when it is influenced by stationary waves of significant amplitude, it is not meaningful to refer to the structure of such a Rossby--Haurwitz mode.

Frequently, specialized model algorithms can elucidate dynamical aspects of geophysical flows not easily observed using conventional algorithms. Saravanan used one such technique---contour dynamics---to study tropospheric and stratospheric dynamical processes. One of the advantages of using contour dynamics to solve fluid equations is that it allows one to focus attention exclusively on the dynamically active regions of the flow. In the modeling of the life cycle of baroclinic waves, the dynamically most active regions are the planetary surface and the tropopause, regions of discontinuity in potential vorticity. Saravanan used a three-dimensional quasigeostrophic contour dynamics algorithm to construct a model of baroclinic wave evolution that confines all the dynamics to the tropopause and to the surface. This model is able to capture some of the important qualitative features of baroclinic-wave life cycles seen in high-resolution primitive-equation integrations, such as the sensitivity of wave breaking to the background jet shear.

Diagnostic and Development Activities

Comparison of a model with observations is the first step in deductive improvement of scientific theories and models. Such studies have been proceeding with various NCAR CCMs.

One of the most important tests for validating an atmospheric GCM is to compare its mean simulated climate to the mean observed climate. The difference between the two is often referred to as the systematic error. One would like to reduce this systematic error because it is a symptom of the inadequacies and errors in the formulation of the GCM. The traditional approach to improving a GCM is to use one's limited and sketchy physical understanding of the atmosphere to guess the source of the systematic error, use that guess to modify the model, and determine whether the modification reduces the systematic error. This approach, although physically motivated, is more of an art than a science. It is also computationally intensive, requiring long climate integrations to test the effect of each modification.

An alternative approach is to use statistical techniques to identify the sources of systematic error. Although the techniques themselves may not be physically motivated, it may be possible to find a physical interpretation for spatial error patterns resulting from such an approach. Saravanan and Baumhefner carried out a statistical study of the systematic error in a recent version of the CCM2. In terms of applicability to long-range forecasting, one of the most important deficiencies of the CCM2 is the large systematic error in the 500-mb height field. One approach to identifying and isolating the source of this error is to estimate the systematic bias in initial tendencies when starting forecasts from initialized analyses. Because there are many potential sources of noise in computing the true initial-tendency bias from analyses, the only way to ascertain whether any estimates of initial-tendency bias contain useful information is to use the estimated error patterns to correct for initial-tendency bias in CCM2 itself and determine whether this attempt actually leads to a decrease in the systematic error.

GDS scientists used two independent sets of analyses (NMC and ECMWF) for the winter of 1988--89 to obtain estimates of the systematic initial-tendency error. Although there was broad agreement in the spatial patterns of the initial-tendency bias obtained from both sets of analyses, the magnitude of the bias in the thermodynamic variables (T,q) was quite different. Since the ECMWF analyses were available four times daily (considerably reducing the possibility of aliasing of the diurnal cycle), GDS scientists used the initial-tendency bias estimates from those analyses in attempts at bias correction in CCM2. Since the initial bias in thermodynamic terms is strongly affected by the model spin-up, it was necessary to reduce the amplitude of the correction by 50 percent for these terms. The ensemble average of five winter (December, January, February) runs with the bias-corrected version of the CCM2 shows a significant reduction in the systematic error in the 500-mb height field and also some improvements in the variability of the model, such as in the simulation of blocking. It seems to virtually eliminate the large negative bias in the zonally averaged temperature in the summer high-latitude lower stratosphere. Work is in progress to isolate those parts of the initial-tendency bias that are primarily responsible for these ``improvements" and to study the effects of tendency correction on 30-day ensemble forecasts.

In addition to statistically derived modifications, Baumhefner conducted several more traditional sensitivity experiments to reduce the bias of the stationary waves in the model. He tested the sensitivity of the lower boundary conditions (mountains, snow, ice, land type) by modifying these fields to more closely fit the observations. The overall effect was small and slightly negative. For many climate interactions, precipitation is a key variable, so the validation of precipitation in climate integrations through comparisons with observations is a critical activity. Mizzi, with the aid of Merra Asres (student, 1993 Summer Employment Program) and Lana Stillwell, developed a nonlinear multiple-regression relationship between pentad Global Precipitation Climatology Project (GPCP) precipitation and pentad average OLR and albedo observations. They applied a univariate nonlinear model to 5 years of daily OLR observations for January, April, July, and October to obtain estimates of the daily tropical precipitation. Comparison of temporal, spatial, and ensemble statistics from the GPCP, OLR-based, CCM1, and CCM2 tropical precipitation showed that the OLR-based climatology is approximately 20 percent larger than the GPCP results, while the spatial variance is approximately 7 percent smaller. For both CCMs, the terrestrial precipitation exceeds the maritime precipitation throughout the year. The CCM tropical precipitation is approximately 9 percent smaller than the OLR results, and the spatial variance is approximately 160 percent larger. Similar results are found by examining the precipitation-frequency distribution for the OLR, CCM1, and CCM2 distributions. GDS scientists estimated observed-frequency distributions from 5 years of Climate Analysis Center tropical station data. This comparison suggests that the CCMs have too much spatial and temporal variance for tropical precipitation.

Recent attention has focused on model development of parameterized physical processes, but some investigators are reexamining the numerical aspects of climate models. Mizzi collaborated with Tribbia and James Curry (visitor, University of Colorado) to apply the spectral transform method to the vertical coordinate of low-resolution primitive-equation models. They placed these models on tropical f- and equatorial beta-planes. The appropriate normal modes were the horizontal basis functions, and the vertical normal modes of Staniforth et al. were the vertical basis functions. To avoid the use of artificial constraints to control velocity near the upper boundary, these models were based on geopotential, and the hydrostatic equation was used to calculate temperature from geopotential, ensuring that temperature went to zero when pressure was zero. This is the first time that the spectral transform method has been applied to the vertical coordinate of a primitive-equation model without artificial constraints on velocity or temperature.

The experiments showed that the upper-level velocities are sensitive to mass and velocity field imbalances present in the initial conditions or introduced during the integration. GDS scientists suggested that vertical spectral truncation introduces mass and velocity imbalances during the integration. These imbalances manifest themselves as oscillations in the upper-level velocity field. Scientists are studying the role of each of these explanations, as well as the use of alternative vertical basis functions.

Filippo Giorgi and Tomislava Vukicevic are examining use of the adjoint method for the assimilation of global fields into a regional climate model. These global fields are provided either by the CCM2 integration or by the ECMWF or NMC analysis. They use the variational method for parameter estimation to determine an optimal three-dimensional nudging coefficient for each model field for large scales only. Consequently, the regional model solution and the global fields are filtered for this purpose. This approach will be used to improve representation of the one-way interacting lateral boundary forcing for the regional climate model developed in the Interdisciplinary Climate Systems (ICS) Section.

INTERDISCIPLINARY CLIMATE SYSTEMS

ICS scientists conduct research on the relationships between climate change and global environmental systems. Emphasis is on the regional and global interactive coupling of the atmosphere with other climate systems, such as the terrestrial biosphere and oceans. They develop and analyze mesoscale and global earth system model components with the overall goal of studying climate changes of the past, present, and future on decadal or longer time scales.

GENESIS Climate Model

Thompson, Pollard, and others continued development of the comprehensive global earth system model, GENESIS. This project is supported by funding from the EPA. The current climate model version 1.02 of GENESIS has been in use by a number of groups within and outside since NCAR January 1992, and much of the development effort this year was focused on the next version 2 (v2), planned for release to current users in FY 95.

During FY 94, the GENESIS development team incorporated new physical processes into v2. These included the explicit representation of trace gases in the infrared radiation code (methane, nitrous oxide, chlorofluorocarbons) by Wei-Chyung Wang and colleagues (SUNY, Albany). They included background aerosols in both the solar and infrared radiation codes and replaced the single-effective cloud-layer approximation used in the earlier model's solar code with multilayer clouds assuming random overlap between layers. They improved the soil model physics by including the effects of vertical pressure gradients in saturated soils, a prerequisite for predicting regional water tables. They also added a ponding reservoir and macro-pores to improve the realism of the model's surface runoff. With the aid of Jon Foley and Michael Cox (both of University of Wisconsin), the development team added a large-scale river-basin accounting that gathers the model runoff and drainage for comparison with major river-discharge data. Pollard substantially improved the snow model which now includes snow-moisture content, percolation, and refreezing of meltwater.

The GENESIS model is a part of several intermodel comparison programs: Wang and collaborators have run an AMIP simulation with an experimental version of GENESIS; Lisa Sloan (University of California, Santa Cruz) has used GENESIS version 1.02 to perform simulations for the Paleoclimate Modeling Intercomparison Project; and the GENESIS land-surface-transfer module (LSX) continues to participate in the Project for Intercomparison of Landsurface Parameterization Schemes.

In collaboration with Christopher Wold (GEOMAR Institute, Kiel) and Michael Schulz (University of Kiel), Pollard continued to develop proxy-formation models that form links between paleoclimatic GCM results and geologic records. They developed a model of evaporite lakes and saline deposits that includes two-dimensional (vertical, horizontal) lake dynamics and the aqueous chemistry of halite and gypsum precipitation.

Stillwell collaborated with Thompson, Pollard, and Lee Klinger (ACD) to generate a set of global maps of present-day wetlands and related fields. These maps are at 1-degree-by-1-degree resolution, combine data from several sources, and include distributions of fens, bogs, swamps, marshes, seasonal flood plains, lakes, and seasonal rice paddies. These data will be useful as the sophistication of the GENESIS model's surface hydrology increases.

In January, Brady joined the GENESIS project to work on the development of the ocean GCM in preparation for coupling to the atmospheric GCM. The ocean GCM (a Semtner and Chervin version) was obtained from the Climate Sensitivity and Carbon Dioxide Research Group and adapted for GENESIS input and output. Brady began extensive work that included the development of oceanic data sets, validation against oceanic climatologies, the identification of areas of potential model improvement, and the exploration of distorted physics techniques to spin up the model to equilibrium. Brady also began a series of experiments to test the model's sensitivity to different surface forcings.

Elizabeth Law-Evans (postdoctoral visitor, Metropolitan State College of Denver) continued as the liaison between the NSF PALE program principal investigators and ICS climate modelers. The long-term goals of the PALE--ICS interaction are to reconstruct late-Quaternary Arctic climate variations and to understand the interactions of those variations within the global climate system. Law-Evans assembled global observed climate data sets for the validation of GENESIS v.2, in addition to participating in the design of late-Quaternary Arctic climate simulations.

Modeling Biosphere--Climate Interactions

Bergengren, Pollard, and Thompson fully coupled EVE into GENESIS v1.02 and completed a pair of long-term simulations (1x and 2x present carbon dioxide) with fully interactive vegetation--climate biophysical feedbacks. The results are now being compared with a pair of 1x and 2x carbon dioxide runs without vegetation feedback completed earlier in 1994. The interactive runs are the first of their kind using a complex life-form-based model of natural vegetation. Both doubled carbon dioxide simulations had significant poleward migration of the boreal forest and arctic tundra zones, with some decrease of tree cover in tropical savannas. However, initial analysis indicates that the biophysical feedbacks (i.e., excluding carbon-cycle feedbacks) from the terrestrial biosphere did not have a significant effect on the equilibrium state of the climate. The predicted climate and vegetation for the 1x and 2x carbon dioxide cases of the interactive simulations are very similar to the analogous cases of the noninteractive prescribed vegetation simulations.

Larry McDaniel and Terry Root (visitor, University of Michigan) continued their collaboration on the study of the influence of climatic change on the distribution and abundances of birds wintering in North America. The preliminary findings were that bird abundances at a northern site (Reelfoot, Tennessee) were negatively correlated with ambient temperature (e.g., number of days with the minimum temperature below -4 degrees C) while a more southerly site (Jackson, Mississippi) exhibited a positive correlation. Consequently, colder weather seems to be forcing the birds south. These results have prompted the design of a larger-scale (continent-wide) study, which necessitates obtaining 30 years of weather-station data across North America. Because other NCAR employees need these data, McDaniel may collaborate to build this data base. A second study has been the examination of population changes in 51 species of birds from the winter of 1959--1960 to 1988--89. This study has shown many species exhibiting dramatic declines. A few species show increases and these are primarily species that benefit from human habitation (e.g., Cedar Waxwings). Root and McDaniel are expanding this study to include all passerines (e.g., sparrows, robins, etc.) and waterfowl.

Analysis continued with Robert Dickinson (University of Arizona), Ann Henderson-Sellers (NCAR affiliate scientist from Macquarie University, New South Wales), and Kennedy on a flux coupler for the CCM2 and the Biosphere--Atmosphere Transfer Scheme (BATS). Emphasis has been on the BATS-specific fields (snow cover, surface and deep runoff, and interception--reevaporation).

Regional Climate Modeling

Giorgi, in collaboration with Gary Bates, Christine Shields, Rosaria Marinucci (University of L'Aquila), and Hirakuchi, extensively tested the new version of RegCM (RegCM2) over a number of regions, using different resolutions, and driven by ECMWF and GCM data.

Completed validation experiments with the model driven by ECMWF analyses of observations for simulation periods between 1982 and 1992 include (1) 1-year runs at resolutions from 50 to 200 km over Europe. This run is being intercompared with similar runs performed by other European groups; (2) a 4-year run at 50-km resolution over the entire United States. ICS scientists identified and corrected several errors in the model code during these validation experiments. The main biases revealed by these runs occur during the summer periods, when the model tends to overestimate precipitation and to be relatively dry and cool in the lower boundary layer. To improve these biases, ICS scientists are testing different cumulus parameterizations, as well as modifications to the boundary-layer scheme and the BATS.

ICS scientists also completed RegCM2 climate simulations using GCM-derived boundary conditions. These included (1) two 5-year runs, one for present-day conditions and one for 2x carbon dioxide conditions over Eastern Asia at a resolution of 50 km, with the model driven by the Washington--Meehl version of the CCM, (2) samples of month-long (January and July) simulations over the Alpine region at a resolution of 20 km, with RegCM nested within the MPI GCM (ECHAM). They have carried out a detailed analysis of high-resolution effects simulated by the nested model. Among the relevant results of these experiments for the 20-km European runs---the highest RegCM resolution used to date---the model did not show a deterioration in performance compared to lower-resolution runs. In the Eastern Asia runs, the model reproduced several features of monsoon climatology over the region, although it substantially overestimated precipitation amounts mostly due to errors in the CCM-driving fields.

Giorgi continued development of a new land-surface package that will replace BATS in the regional climate model. The scheme combines elements of the big-leaf and statistical approach to surface modeling and it includes (1) soil and snow modules from the GENESIS LSX surface model, (2) a one-layer vegetation model (with some parameterizations taken from BATS), (3) representation of nonlinear effects associated with continuous subgrid-scale distribution of soil moisture and surface temperatures, (4) inclusion of fractional urban and inland water cover, and (5) a prognostic equation for surface water including production via surface-runoff mechanisms, water routing, and exchanges between surface water and soil water. Giorgi has coded a stand-alone version of the scheme, and testing of the numerical schemes employed in the model is under way.

Giorgi continued his collaboration with Anji Seth (visitor, University of Michigan) on the possible effects of dynamical circulations induced by surface inhomogeneities. For the first time, they are studying these effects using observed rather than idealized meteorological conditions. They performed several summertime simulations with the model running in multiple nesting mode (a 10-km run driven by output from a 60-km run) with various surface-vegetation geometries.

Supported by NOAA's Global Change Program, Bates completed a two-year simulation with the RegCM2 at 60-km resolution over the Great Lakes basin from 1 September 1990 to 1 September 1992. In that simulation, the one-dimensional thermal lake model of Steven Hostetler (visitor, U.S. Geological Survey) provided time-varying lake-surface temperatures, evaporation rates, and lake-ice thicknesses. Results from this simulation indicate that this coupled modeling system generally captures quite well the annual cycle of precipitation, surface temperatures, and lake-ice formation.

With Melanie Wetzel (Desert Research Institute), Bates has also completed a study into the ability of the regional modeling system to capture the distribution of cloud fraction. Generally, the model simulated well the total cloud fraction during a cool-season period (late September) but under-predicted clouds during July. Convective clouds, in particular, are specified quite simply in the current version of the model. This study points to the need for improvements in this area.

Climate Model Analysis and Impacts of Climate Variability

Mearns, Leslie Mayer, and Hoar developed a statistical package for analysis of daily climatic variability in models and observations. This package performs a suite of statistical tests on daily temperature and precipitation time series across a model or observational spatial domain. Eventually, the package will be built up to a point where problems of multiplicity and multicollinearity will be resolved. Part of this work is within the context of the Statistics and Atmospheric Sciences Program.

Mearns continued her sensitivity analysis of the effect of changed daily climate variability on the deterministic wheat model (CERES). She modified a variant of an existing daily weather generator for use in this study. This year, she focused on detailed sensitivity analyses and compared these results with earlier results in which a simplified method was used to change only the interannual variability. The results of the current study wherein both interannual and daily variability are changed show larger changes in simulated wheat yields. The tentative conclusion is that changes in climatic variability have a more significant effect on crop yields than indicated by the earlier study.

With Barbara Brown (Research Applications Program), Katz, and the assistance of McDaniel, Mearns investigated the scaling properties of hourly precipitation over space in point observations (NOAA hourly precipitation data set) and climate models (nested regional model). From a test case with data from Iowa, the spatial scaling characteristics of observations and model output exhibit multiscaling rather than simple scaling characteristics. This demonstrates that the precipitation intensities are best represented by a random cascade and that the spatial organization of the model precipitation is not dissimilar from the observations.

Mearns, Giorgi, Shields, and Bates also worked on developing a regional climate model scenario application to crop models. This NIGEC-supported project involves regional modeling with RegCM2 by Giorgi, Shields, and Bates, and detailed model evaluation and application to crop models by Mearns and colleagues at the University of Nebraska. A goal of the project is to appropriately integrate climate modeling work, model analysis, climate-change scenario formation, and application to impacts models.

Modeling Outreach

With Washington, Kennedy initiated modeling outreach with a published poster outlining the dozen ICS and division-wide modeling efforts. To facilitate updates of this information, Kennedy also established a CGD models node on the Internet gopher. His experience with biosphere and atmosphere models enables him to be a mentor to the prospective and current modeling community outside NCAR. Inquiries and collaboration cover all continents and have ranged from the University of Lapland to the Bangladesh Center for Advanced Studies, from the White House in Washington to the Weather Bureau in South Africa, and from Swiss designers of coal-fired power plants in China to grain farmers in northern Alberta.

ECOSYSTEM DYNAMICS AND THE ATMOSPHERE

Scientists in the Ecosystem Dynamics and the Atmosphere Section (EDAS) study the linkage of terrestrial biogeochemical and physiological processes to the atmosphere through modeling efforts, data-base development, and field studies. A key effort was reconfiguration of the CENTURY ecosystem model, originally developed at Colorado State University, for use in global applications and coupled earth system modeling of the carbon cycle. EDAS scientists were involved in field studies to test ecosystem models, engage in international ecosystem model intercomparisons, and develop geographic data bases for the continental and global implementation of CENTURY. They used simple and highly parameterized models of the global carbon cycle to evaluate the sensitivity of global carbon-cycle projections to uncertainties in terrestrial feedbacks. In addition to NSF funds, EDAS received support from EOS, EPRI, NASA, and the U.S. Forest Service for VEMAP.

Modeling of Ecosystem Interactions with the Earth System

Ecosystems interact with the atmosphere and climate system through physical and biogeochemical processes. EDAS scientists and university collaborators use modeling and remote-sensing tools to understand the coupling of ecosystems to the atmosphere at regional-to-global scales. Work over the past year has focused on understanding the negative feedbacks to changing atmospheric carbon dioxide and climate that arise from the coupling of terrestrial carbon and nitrogen (N) cycles. As soils warm, N is released, fertilizing vegetation and reducing overall carbon losses. If carbon stocks increase with increasing carbon dioxide, this sequesters N, eventually constraining the positive effects of carbon dioxide. However, when the two effects occur simultaneously, the feedback becomes positive, as the stimulation of plant growth by release of soil N allows a larger response to carbon dioxide. EDAS scientists are now seeking to quantify these feedbacks using a global model.

In studies conducted as part of the EPRI/NCAR/U.S. Forest Service VEMAP project, EDAS scientists, along with other modeling groups (Marine Biological Laboratory, University of Montana, University of Sheffield, University of Virginia, U.S Forest Service, and Colorado State University), used the CENTURY model to examine scenarios of climate change, carbon-dioxide enrichment, and changes in vegetation for the conterminous United States. The models were run using common boundary conditions for climate, soils and vegetation, developed by Kittel and students Thomas Painter, Rosenbloom, and Fisher. Results from the intercomparison are nearly final, and a data workshop in the fall of 1994 will be held prior to publication.

The early 1990s saw a large reduction in the growth rate of atmospheric carbon dioxide. In examining the preliminary evidence from collaborative studies of atmospheric 13C with NOAA, Ciais and Tans suggested a role for the terrestrial biosphere. Schimel, together with Tans, Braswell, and Dennis Ojima (Colorado State University) used global temperature anomalies measured with the microwave temperature sounder from NOAA polar orbiters as input into the CENTURY terrestrial ecosystem model. This record shows the global cooling produced by the Mt. Pinatubo aerosols. CENTURY simulations show that cooling reduced respiration and increased carbon storage in many ecosystems. In others, cooling reduced plant productivity, leaving carbon storage unchanged or reduced. The global integral suggests a role for the terrestrial biosphere in the reduced carbon-dioxide growth rate during the early 1990s. Models of the carbon cycle are very sensitive to the isotopic difference between photosynthesis. This effect has rarely been measured. Recently, NSF funded a joint proposal to Colorado State University and NCAR to develop a facility for the measurement of this and other isotopic changes between the atmosphere and terrestrial biosphere. Schimel and Eugene Kelly (Colorado State University) are the principal investigators.

IPCC

Schimel was the convening lead author for the IPCC Carbon Cycle group, along with Ian Enting (CSIRO), Martin Heimann (Germany), Diogenes Alves (Brazil), Thomas Wigley, Dominique Raynaud (France), and Ulrich Siegenthaler (Switzerland). The 1994 assessment, based on contributions from approximately 30 authors, has taken a fresh look at the carbon cycle and commissioned a wide range of model analyses, including a suite of sensitivity studies for terrestrial ecosystems and a set of carbon-cycle model calculations of industrial emissions consistent with eventual stabilization of atmospheric carbon-dioxide concentrations.

New calculations for the lifetime of excess carbon dioxide were performed, using models that included simple representations of the biosphere. They resulted in a significant shortening of the lifetime of carbon dioxide used in greenhouse warming potential (GWP) calculations, developed jointly with GWP chapter authors Susan Solomon and Daniel Albritton (both of NOAA) and Donald Wuebbles (DOE). This increased the GWP for the other trace gases, most notably methane. The sensitivity of the global carbon cycle to the terrestrial biosphere was also evident in projections of future atmospheric carbon-dioxide concentrations, where varying the assumptions about biospheric uptake or release substantially affected the projected concentrations. The activities developed for the IPCC carbon-cycle chapter have drawn major interest and stimulated a significant number of new research activities in the carbon cycle. Sadly, lead author Ulrich Siegenthaler died after a long illness as the chapter was being completed. The 1994 assessment will be dedicated to Siegenthaler, whose modeling forms the foundation of current understanding.

STAFF, VISITORS, AND COLLABORATORS

Staff

Division Director's Office

```
Susan Henry (to 8 June 1994)
Holly Howard
Kathy Kramer
Ann Modahl
Michael Moran
Stephen Schneider
Kevin Trenberth (deputy director)
Barbara Vlasity
Warren Washington (director)
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Division Office Systems Programmers

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Steven Carson
Elizabeth Coolbaugh
Lisa Giedt (to 22 December 1993)
JoAnne Mann
Lee Melvin
Colleen O'Toole
Matthew Rice (to 27 May 1994)
Allan Walker
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Climate Sensitivity and Carbon Dioxide Research Group

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Gregory Bean (to 13 May 1994)
Thomas Bettge
Garrett Campbell (long-term visitor)
Robert Chervin
Anthony Craig
Randy Cubrilovic
Kent Larson
Gerald Meehl (joint with CAS)
Gary Strand
Warren Washington (leader)
Suzanne Whitman
David Younghans
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Climate Modeling Section

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Gordon Bonan
Byron Boville
Bruce Briegleb
Joseph Doetzl
Paula Drager
Brian Eaton (joint with ACD)
James Hack
Michael Hoswell
Jeffrey Kiehl (deputy head)
Natalie Maholwald (long-term visitor)
Jerry Olson
Philippe Peylin (long-term visitor)
Philip Rasch
Janet Rodina (to 29 July 1994)
John Truesdale
Mariana Vertenstein
David Williamson (head)
Michael Zecca
Charles Zender (long-term visitor)
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CCM Core Group

Linda Bath
Lawrence Buja
James Hack (leader)
James Rosinski
Gloria Williamson

Climate Analysis Section

Jeffery Berry
Steve Cherry (long-term visitor)
Stephanie Gaddis (to 18 March 1994)
Christian Guillemot
Timothy Hoar
James Hurrell
Roland Madden (deputy head)
Gerald Meehl (joint with CSCORG)
Chester Newton (senior research associate)
Dennis Shea
Elizabeth Stephens
Kevin Trenberth (head)
Harry van Loon (senior research associate)
Tom Wigley (joint with UCAR and ASP)

Oceanography Section

Barbara Ballard (joint with GDS)
Frank Bryan
Antonietta Capotondi (ASP long-term visitor)
Julianna Chow
Gokhan Danabasoglu (long-term visitor)
Scott Doney
Peter Gent (head)
Lydia Harper (joint with GDS)
Matthew Hecht (long-term visitor)
Katherine Holcomb
William Holland
Brian Kauffman
Rodney Kinney (ASP long-term visitor)
William Large (deputy head)
Sonya Legg (long-term visitor)
James McWilliams
Ralph Milliff
Jan Morzel
Nancy Norton

Global Dynamics Section

Barbara Ballard (joint with OS)
David Baumhefner
Grant Branstator
Martin Ehrendorfer (long-term visitor)
Ronald Errico (deputy head)
Lydia Harper (joint with OS)
Sue Ellen Haupt (long-term visitor)
Akira Kasahara
Yen-Huei Lee
Andrew Mai
Thomas Mayer
Arthur Mizzi
Kevin Raeder
Ramalingam Saravanan
Lana Stillwell
Mark Taylor (long-term vistor)
Francois Thibaud (long-term visitor)
Philip Thompson (senior research associate; deceased 3 September 1994)
Joseph Tribbia (head)
Jun-Ichi Tsutsui (long-term visitor)
Tomislava Vukicevic

Interdisciplinary Climate Systems Section

James Adams
Gary Bates
Jon Bergengren (long-term visitor)
Esther Brady
Charles D'Ambra
Carter Emmart (long-term visitor)
Filippo Giorgi
Steven Hostetler (long-term visitor)
Patrick Kennedy
Elizabeth Law-Evans (long-term visitor)
Rosaria Marinucci (long-term visitor)
Renaud Mathieu (long-term visitor)
Leslie Mayer
Larry McDaniel
Linda Mearns
David Pollard
Anji Seth (long-term visitor)
Stephanie Shearer
Christine Shields
Starley Thompson (head)
Steve Welch (long-term visitor)

Ecosystem Dynamics and the Atmosphere Section

Bobby Braswell (long-term visitor)
Susan Chavez
Henry Fisher
Timothy Kittel (long-term visitor)
Rebecca McKeown
Nan Rosenbloom
David Schimel (head)
Elizabeth Sulzman

Affiliate Scientists

Leo Donner, Geophysical Fluid Dynamics Laboratory
Dale Haidvogel, Rutgers University
Ann Henderson-Sellers, Macquarie University
Albertus Holtslag, Royal Netherlands Meteorological Institute
Karin Labitzke, Free University of Berlin
Albert Semtner, Naval Postgraduate School

Visitors and Collaborators

Dates refer to visitor's stay at NCAR during FY 94. No dates are given for collaborators who did not visit NCAR.

Henry Abarbanel; University of California, San Diego; chaotic behavior of atmospheric data

Bruce Albrecht; Pennsylvania State University; parameterization of moist convection

James Alexander; University of Maryland; parallel ocean climate model and mass variations

Robert Allan; Commonwealth Scientific and Industrial Research Organization, Hobart; 15--19 June 1994; Climate Sensitivity and Carbon Dioxide Research Group

John Allen; Oregon State University; 26 May 1994; Oceanography Section

Diogenes Alves; INPE, Brazil; 31 October 1993--2 November 1993; Ecosystem Dynamics and the Atmosphere Section

Todd Arbetter; University of Colorado; 1 October 1993--30 September 1994; Oceanography Section

Steven Archer; Texas A&M University; 18 February 1994; Ecosystem Dynamics and the Atmosphere Section

Vincenzo Artale; Italian Commission for Research and Development of Nuclear and Alternative Energy Sources; 16 July 1993--17 January 1994; Oceanography Section

Eric Barron; Pennsylvania State University; paleoclimatic modeling with GENESIS GCM

Donna Beller; Hebrew University; 7 March 1994--1 April 1994; Ecosystem Dynamics and the Atmosphere Section

Martin Beniston; Polytechnic Institute of Zurich; development of a high-resolution regional climate model for the western alpine region and coupling of model to the Hamburg GCM

Kathy Bero; Lake Michigan Federation; water resources and environmental policy

Joseph Berry; Carnegie Institution of Washington; plant physiology

Sedat Biringin; University of Colorado; large eddy simulation of the planetary boundary layer

Robert Black; Georgia Institute of Technology; diagnosis of low-frequency flow in CCM2

Rainer Bleck; University of Miami; ocean modeling

Claus Boening; University of Kiel; 26 February--3 March 1994; Oceanography Section

Ben Bolker; Princeton University; 24 February 1994; Ecosystem Dynamics and the Atmosphere Section

Jeff Borchers; Oregon State University; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

W. John Boscardin; University of California, Berkeley; 5--20 July 1994; Statistics Colloquium

Penelope Boston; Complex Systems Research Incorporated; 1 April 1993--31 March 1994; Interdisciplinary Climate Systems Section

Lee Botts: Lake Michigan Federation; water resources and environmental policy

Esther Brady; Woods Hole Oceanographic Institution; 26 February--17 December 1993; Oceanography Section

Achi Brandt; Weizmann Institute; multigrid algorithms

Aaron Brasket; University of Colorado; 1 October 1993--30 September 1994; Oceanography Section

Peter Briggs; Macquarie University; 5--20 July 1994; Statistics Colloquium

Waltraud Brinkmann; University of Wisconsin; water resources and climate change

Michael Brklacich; Carlton University; water resources and climate change

William Bua; University of Maryland; 5--20 July 1994; Statistics Colloquium

Roberto Buizza; European Centre for Medium-Range Weather Forecasts; dynamics of perturbation growth in primitive equations

John Bullister; Pacific Marine Environmental Laboratory; freon tracer studies in the global ocean

Andrew Bush; University of Toronto; Gulf Stream rings

Mark Cane; Lamont-Doherty Geological Observatory; regional equatorial ocean modeling

Debbie Carlson; Montana State University; 5--20 July 1994; Statistics Colloquium

Edward Carmona; Parallel Software Investments; 5--8 April 1994; Climate Modeling Section

Xavier Carton; Naval Hydrographic and Oceanographic Service, Toulouse; baroclinic unstable vortices

Paolo Cecchella; Universita Degli Studi di Pisa; 29 March 1994; Global Dynamics Section

Robert Cess; State University of New York, Stony Brook; clouds and radiation

Stanley Changnon; Illinois State Water Survey; water resources and climate change

Terry Chapin; University of California, Berkeley; Arctic terrestrial surface fluxes

Robert Charlson; University of Washington; aerosols and climate

Eric Chassignet; University of Miami; ocean modeling

Tsing-Chang Chen; Iowa State University; 18--22 July 1994; Global Dynamics Section

Ping Cheng; University of Colorado; atmospheric dynamics

Toshio Mike Chin; University of Miami; 5--20 July 1994; Statistics Colloquium

John Christy; University of Alabama; surface temperatures and microwave sounding unit data

Ching-Sang Chu; Naval Postgraduate School; ocean sound transmission

Philippe Ciais; LMCE/DSM; 24 February 1994; Ecosystem Dynamics and the Atmosphere Section

Josef Cihlar; Canada Centre for Remote Sensing; forest dynamics and carbon cycle

Lisa Cirbus-Sloan; University of California; paleoclimatic modeling with GENESIS global climate model

Julie Cole; University of Colorado; GENESIS global climate model

Alain Colin de Verdiere; Oceanographic Center of Brittany; 11--12 October 1994; Oceanography Section

William Collins; Scripps Institution of Oceanography; 8--11 August 1994; clouds and radiation

Stephen Colucci; Cornell University; analysis and prediction of extended-range forecast skill

Curt Covey; Lawrence Livermore National Laboratory; 18--22 October 1993; Interdisciplinary Climate Systems Section

Gregory Crawford; University of British Columbia, 1 August--31 October 1993; Oceanography Section

Thomas Croley; NOAA Great Lakes Environmental Research Laboratory; lake modeling and hydrology

Thomas Crowley; Texas A&M University; paleoclimatic modeling with GENESIS global climate model

Ulrich Cubasch; Max Planck Institute for Meteorology; coupled ocean--atmosphere models, observed data

James Curry; University of Colorado; 1 June 1994--1 August 1995; Oceanography Section

William Dannevik; Lawrence Livermore National Laboratory; massively parallel ocean modeling

Russ Davis; University of California, San Diego; 10--18 September 1994; Climate Sensitivity and Carbon Dioxide Research Group

Gerardo DeCanio; Italian Commission for Research and Development of Nuclear and Alternative Energy Sources; 16 July

1993--15 July 1994; Global Dynamics Section

Robert DeConto; University of Colorado; paleoclimate modeling and GENESIS global climate model

Laurel DeHaan; Cooperative Institute for Research in the Environmental Sciences; model validation

Arthur Dempster; Harvard University; continuing visits; Statistics Project and Climate Analysis Section

John Derber; National Meteorological Center; 4--8 April 1994; Global Dynamics Section

Richard DeVeaux; Princeton University; 6--13 July 1994; Statistics Project and Climate Analysis Section

Robert Dickinson; University of Arizona; Biosphere--Atmosphere Transfer Scheme, Earth Observing System

Min Dong; University of Oklahoma; 13 December 1993--5 January 1994; Global Dynamics Section

Leo Donner; Geophysical Fluid Dynamics Laboratory; 14--18 February 1994; Global Dynamics Section

John Drake; Oak Ridge National Laboratory; parallel algorithms and parallel programming tools

William Easterling; University of Nebraska; crop climate modeling and climate change

Paul Edwards; Stanford University; 26--30 September 1994; Division Office

Kerry Emanuel; Massachusetts Institute of Technology; cumulus cloud parameterizations

William Emanuel; Oak Ridge National Laboratory; 16 May 1994; Ecosystem Dynamics and the Atmosphere Section

Ian Enting; Commonwealth Scientific and Industrial Research Organization, 31 October--2 November 1993; Ecosystem Dynamics and the Atmosphere Section

James Evans; University of South Carolina; ocean observations

James Famiglietti; University of Texas, Austin; 11 July--31 August 1994; Ecosystem Dynamics and the Atmosphere Section

Johannes Feddema; University of California, Los Angeles; 18 July 1994--17 January 1995; Division Office and Interdisciplinary Climate Systems Section

Susan Ferguson; United States Department of Agriculture, Forestry; effects of climate on United States forestry and climate-change scenario

Michael Fosberg; United States Department of Agriculture, Forestry; climate change and forestry

Ian Foster; Argonne National Laboratory; parallel algorithms and parallel programming tools

Douglas Fox; United States Department of Agriculture, Forestry; effects of climate on biophysical systems and climate change

Roger Francey; Commonwealth Scientific and Industrial Research Organization; isotope geochemistry

William Frank; Pennsylvania State University; parameterization of moist convection

Congbin Fu; Chinese Academy of Sciences; regional modeling for eastern Asia

Lee Fu; Jet Propulsion Laboratory; ocean observational analyses and model studies

Kenneth Gage; National Oceanic and Atmospheric Administration; coupled ocean--atmosphere models, observed data

Boris Galperin; University of South Florida; parallel ocean climate model and eddy viscosity parameterization

John Gallimore; University of Wisconsin; paleoclimatic modeling with GENESIS global climate model

Lev Gandin; National Meteorological Center; 5--20 July 1994; Statistics Colloquium

Zulema Garraffo; Columbia University; parallel ocean climate model data analysis

Sylvia Garzoli; Columbia University; parallel ocean climate model data analysis

W. Lawrence Gates; Lawrence Livermore National Laboratory; coupled ocean--atmosphere models, observed data

Sarah Gille; Woods Hole Oceanographic Institution; 27--30 December 1993 and 30 May--4 June 1994; Climate Sensitivity and Carbon Dioxide Research Group

David Glover; Woods Hole Oceanographic Institution; 25--28 July 1994; Oceanography Section

J. Stewart Godfrey; Commonwealth Scientific Industrial Research Organization; parallel ocean climate model data analysis

Richard Goldberg; Goddard Institute for Space Studies; agriculture, crop climate modeling, and climate-change scenarios

Jianjian Gong; University of Wisconsin; 5--20 July 1994; Statistics Colloquium

Richard Grotjahn; University of California, Davis; 2--4 May 1994; Global Dynamics Section

Richard Gunst; Southern Methodist University; 5--20 July 1994; Statistics Colloquium

Vijay Gupta; Cooperative Institute for Research in Environmental Sciences; 5--20 July 1994; Statistics Colloquium

Peter Guttorp; University of Washington; 5--20 July 1994; Statistics Colloquium

David Gutzler; National Oceanic and Atmospheric Administration; coupled ocean--atmosphere models, observed data

Terri Hagelberg; National Oceanic and Atmospheric Administration; 20 October--31 December 1993; Interdisciplinary Climate Systems Section

Dale Haidvogel; Rutgers University; 30 December 1993--7 January 1994 and 15 June--15 August 1994; Oceanography Section

Anthony Hansen; Augsburg College; 8 April 1994; Global Dynamics Section

Michael Hantel; Institute for Meteorology and Geophysics, Austria; 28--30 March 1994; Global Dynamics Section

Edward Harrison; Pacific Marine Environmental Laboratory; freon tracer studies in the global ocean

Dana Hartley; Georgia Institute of Technology; chemical transport

Alex Haxeltine; University of Lund, Sweden; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

William Hay; University of Colorado; paleoclimatic modeling with GENESIS global climate model

Xinyu He; University of Warwick, Coventry; 20 April--2 July 1994; Oceanography Section and Geophysical Turbulence Program

Gabriele Hegerl; Max Planck Institute for Meteorology; 22--26 August 1994; Climate Sensitivity and Carbon Dioxide Research Group

Martin Heimann; Max Planck Institute for Meteorology; 31 October--2 November 1993; Ecosystem Dynamics and the

Atmosphere Section

Isaac Held; Geophysical Fluid Dynamics Laboratory; low-frequency dynamics

Ann Henderson-Sellers; Macquarie University; MECCA impacts of tropical deforestation, sea-ice modeling, and cloud--cryosphere interaction

Scott Herod; University of Colorado; 1 June 1994--1 August 1995; Oceanography Section

Kathy Hibbard; Texas A&M University; 18 February 1994; Ecosystem Dynamics and the Atmosphere Section

Hiromaru Hirakuchi; Central Research Institute Electric Power Industry, Japan; regional climate modeling over eastern Asia

Justin Hnilo; University of Alabama; 27 June--29 July 1994; Climate Analysis Section

Martin Hoerling; Cooperative Institute for Research in the Atmospheric Sciences; atmospheric model data analysis

David Holland; McGill University; 9--12 October 1993; Oceanography Section

Marika Holland; University of Colorado; 1 October 1993--30 September 1994; Oceanography Section

Greg Holloway; Institute of Ocean Sciences, British Columbia; 5--20 July 1994; Statistics Colloquium

James Holton; University of Washington; stratospheric dynamics

Lien Hua; Oceanographic Center of Brittany; quasigeostrophic flows

E. Raymond Hunt, Jr.; University of Montana; ecosystem dynamics and climate change

Akio Ishida; Kansai Environmental Engineering Center; 25 October 1993; Oceanography Section

Mohamed Iskandarani; Rutgers University; ocean modeling

Gregory Jenkins; Pennsylvania State University; 22 August--2 September 1994; Interdisciplinary Climate Systems Section

William Jenkins; Woods Hole Oceanographic Institution; ocean-tracer distributions

Yanli Jia; Chilworth Research Centre, Southampton; 23--30 September 1994; Oceanography Section

Richard Jones; University of Colorado Health Sciences Center; continuing visits; Statistics Project and Climate Analysis Section

Paul Julian; National Meteorological Center; 5--20 July 1994; Statistics Colloquium

Keith Julien; University of Colorado; convection

Eigil Kaas; Danish Meteorological Institute; blocking

Eugenia Kalnay; National Meteorological Center; 12 October 1993; Global Dynamics Section

Jack Katzfey; Commonwealth Scientific and Industrial Research Organization; 12 July 1994; Interdisciplinary Climate Systems Section

Ralph Keeling; Scripps Institution of Oceanography; 8 August--2 September 1994; Ecosystem Dynamics and the Atmosphere Section

Michael Keller; U.S. Forest Service, Puerto Rico; 8--12 August 1994; Ecosystem Dynamics and the Atmosphere Section

William Kellogg; Boulder; 1 February--30 September 1994; Division Office

Karen Kelly; University of Virginia; 5--20 July 1994; Statistics Colloquium

Barbara Kess; University of Nebraska, Lincoln; 5--20 July 1994; Statistics Colloquium

David Kicklighter; Marine Biological Laboratory; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

John Kidson; National Institute for Water and Atmosphere Research, New Zealand; Southern Hemisphere climate change

George Kiladis; National Oceanic and Atmospheric Administration; coupled ocean--atmosphere models, observed data

Gabor Kis-Kovacs; Eotvos Lorand University, 5--20 July 1994; Statistics Colloquium

Eric Kluzek; Utah State University; high-resolution climate runs over Utah

Steven Koonin; California Institute of Technology; chaotic behavior of atmospheric data

David Krauel; Royal Roads; WOCE/TOGA Surface Velocity Project

Rob Kremer; University of Montana; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

Atsushi Kubokawa; Kyushu University; 19 May 1993--15 March 1994; Oceanography Section

John Kutzbach; University of Wisconsin; 1--21 August 1994; Division Office

Rolf Langland; Naval Research Laboratory; adjoint sensitivity analysis of marine cyclogenesis

Vitaly Larichev; Geophysical Fluid Dynamics Laboratory; geophysical fluid dynamics

Ray Lassiter; United States Environmental Protection Agency; GENESIS global climate model

Mojib Latif; Max Planck Institute for Meteorology; 10--12 August 1994; Global Dynamics Section

Barry Law; University of Aberdeen; 5--20 July 1994; Statistics Colloquium

Paul LeBlond; University of British Columbia; large eddy simulation modeling

Tsengdar John Lee; Colorado State University; regional atmosphere--ecosystem interactions

Harald Lejenas; Stockholm University; atmospheric angular momentum

Sidney Leibovich; Cornell University; Langmuir circulations

Cecil Leith; Lawrence Livermore National Laboratory; 10--22 October 1993, 26 June--5 July 1994, and 5--20 July 1994; Global Dynamics Section and Statistics Colloquium

Pascale Lelong; NWRA Consultants; stratified turbulence

B.P. Leonard; University of Akron; 9--10 May 1994; Climate Modeling Section

Richard Levine; Cornell University; 5--20 July 1994; Statistics Colloquium

John Lewis; National Severe Storms Laboratory; adjoint sensitivity analysis of moisture transport

Luning Li; University of Indiana; 5--20 July 1994; Statistics Colloquium

Zhengyu Liu; University of Wisconsin; 17 July--10 August 1994; Oceanography Section

Robert Livezey; National Meteorological Center; 5--20 July 1994; Statistics Colloquium

David Long; Brigham Young University; 22 July 1994; Oceanography Section

Edward Lorenz; Massachusetts Institute of Technology; 5--20 July 1994; Statistics Colloquium

Roger Lukas; University of Hawaii; parallel ocean climate model data analysis

Manda Lynch; University of Alaska; development of a coupled atmosphere/ocean/sea-ice regional model for the Alaskan--Northern Pacific region

Bennert Machenauer; Max Planck Institute for Meteorology; regional climate modeling interactions

Rajasri Machiraju; Michigan Technological University; 5--20 July 1994; Statistics Colloquium

Paola Malanotte-Rizzoli; Massachusetts Institute of Technology; ocean observations

George Malanson; University of Iowa; forest dynamics and carbon cycle

Robert Malone; Los Alamos National Laboratory; massively parallel ocean modeling

Michael Mann; Yale University; 5--20 July 1994; Statistics Colloquium

Eliza Manzini; Max Planck Institute for Meteorology; 8--13 July 1994; Division Office

Jianping Mao; University of Maryland; 5--20 July 1994; Statistics Colloquium

Stuart Marlatt; University of Colorado; 8 July--7 November 1993; Oceanography Section

Hal Marshall; University of Michigan; GENESIS global climate model

Susan Marshall; University of North Carolina; modeling of snow albedo

Philippe Martin; Joint Research Centre, Italy; development of a coupled surface physics/biosphere/hydrology model

James Maslanik; University of Colorado; GENESIS global climate model

Simon Mason; University of Witwatersrand; 5--20 July 1994; Statistics Colloquium

David Matthews; Bureau of Reclamation; 1 October 1993--30 September 1994; Interdisciplinary Climate Systems Section

David McGinnis; Pennsylvania State University; GENESIS global climate model

David McGuire; Marine Biological Laboratory; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

Vikram Mehta; Goddard Space Flight Center; 6--8 June 1994; Climate Sensitivity and Carbon Dioxide Research Group

Wendy Meiring; University of Washington; 5--20 July 1994; Statistics Colloquium

Jerry Melillo; Marine Biological Laboratory; 19--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

Gary Meyers; Commonwealth Scientific Industrial Research Organization; parallel ocean climate model data analysis

John Mitchell; Hadley Centre; coupled ocean--atmosphere models, observed data

David Montroy; University of Oklahoma; 5--20 July 1994; Statistics Colloquium

Yves Morel; Laboratoire de Ecoulements Geophysiques et Industriels Institut de Mecanique de Grenoble; 9 May--12

September 1944; Oceanography Section

Philip Mote; University of Edinburgh; troposphere/stratosphere exchange

Bret Mullan; National Institute for Water and Atmosphere Research, New Zealand; Southern Hemisphere climate change

Steven Mullen; University of Arizona; regional modeling of Arizona monsoon

Katrin Muller; Free University of Berlin; 5--20 July 1994; Statistics Colloquium

Walter Munk; Scripps Institution of Oceanography; parallel ocean climate model data and acoustic scattering

Allan Murphy; Max Planck Institute for Meteorology; 5--20 July 1994; Statistics Colloquium

Ray Najjar; Pennsylvania State University; biogeochemical cycles

Antonio Navarra; Istituto per lo Studio Delle Metodologie Geofisiche Ambientali; large-scale dynamics

Ronald Neilson; United States Forest Service; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

Neville Nicholls; Bureau of Meteorology Research Center; coupled ocean--atmosphere models, observed data

Viovy Nicolas; LMCE/CEA; 10--22 October 1993; Ecosystem Dynamics and the Atmosphere Section

Karla Nobrega; University of Alberta; 5--20 July 1994; Statistics Colloquium

Gerald North; Texas A&M University; statistical structure of atmospheric data

Warwick Norton; Oxford University; 1 September--30 November 1994; Climate Modeling Section

Atsumu Ohmura; Polytechnic Institute of Zurich; development of a high-resolution regional climate model for the western Alpine region and coupling of model to the Hamburg GCM

Dennis Ojima; Colorado State University; global carbon-cycle modeling

Iggy O'Muircheartaigh; University College, Galway; 5--20 July 1994; Statistics Colloquium

Jean Opsomer; Cornell University; 5--20 July 1994; Statistics Colloquium

J.D. Opsteegh; Royal Netherlands Meteorological Institute; 23--30 October 1993; Global Dynamics Section

Bette Otto-Bliesner; University of Texas, Arlington; paleoclimate modeling with GENESIS global climate model

W. Brechner Owens; Woods Hole Oceanographic Institution; 24--28 February 1994 and 4--5 May 1994; Oceanography Section

Steve Pacala; Princeton University; 24 February 1994; Ecosystem Dynamics and the Atmosphere Section

Theresa Paluszkiewicz; Pacific Northwest Laboratory; parallel ocean climate model and deep convection parameterization

Yude Pan; Marine Biological Laboratory, Woods Hole; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

Lee Panetta; Texas A&M University; 7 June--19 August 1994; Oceanography Section

William Parton; Colorado State University; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

Harry Pavlopoulos; University of the Aegean; 5--20 July 1994; Statistics Colloquium

Richard Peltier; University of Toronto; dynamics of geophysical vortices

Cecile Penland; Cooperative Institute for Research in the Environmental Sciences; 5--20 July 1994; Statistics Colloquium

Joyce Penner; Lawrence Livermore National Laboratory; 7--8 July 1994; Climate Modeling Section

Igor Perisic; Harvard University; 5--20 July 1994; Statistics Colloquium

Roger Pielke; Colorado State University; regional atmosphere--ecosystem interactions

Lars Pierce; University of Montana; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

Nadia Pinardi; Istituto per lo Studio Delle Metodologie Geofisiche Ambientali; ocean modeling and Mediterranean climate

Karen Poiani; Cornell University; 29 June 1994; Ecosystem Dynamics and the Atmosphere Section

Peter Pokrandt; University of Wisconsin; 9--12 February 1994; Climate Modeling Section

Lorenzo Polvani; Columbia University; 25 July--23 August 1994; Global Dynamics Section

Rui Ponte; Atmospheric Environment Research, Inc.; parallel ocean climate model data analysis

David Porter; Army High Performance Computing Research Center; 1 March 1994--28 February 1995; Oceanography Section

German Poveda; Cooperative Institute for Research in the Environmental Sciences; 5--20 July 1994; Statistics Colloquium

Scott Power; Bureau of Meteorology Research Centre; 31 January-- 4 February 1994; Climate Sensitivity and Carbon Dioxide Research Group

Colin Prentice; SAGES, Sweden; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

Ronald Prinn; Massachusetts Institute of Technology; role of convection in transport of trace species

Xiaowei Quan; University of Colorado; regional climate modeling over China

Peihua Qui; University of Wisconsin; 5--20 July 1994; Statistics Colloquium

Stefan Rahmstorf; University of Kiel; 28 February--1 March 1994; Oceanography Section

Veerabhadran Ramanathan; Scripps Institution of Oceanography; clouds and radiation

David Randall; Colorado State University; atmospheric sciences

Marilyn Raphael; University of California, Los Angeles; 12 April--30 September 1994; Climate Analysis Section

Dominique Raynaud; National Research Center, France; carbon cycle

William Reiners; University of Wyoming; ecosystem dynamics and climate change

Richard Reynolds; National Meteorological Center; sea-surface temperatures

Peter Rhines; University of Washington; 26--28 December 1993; Climate Sensitivity and Carbon Dioxide Research Group

Jonathan Rich; Northwestern University; 14 January--15 August 1994; Interdisciplinary Climate Systems Section

Kelvin Richards; Chilworth Research Centre, Southampton; 23--30 September 1994; Oceanography Section

Todd Ringler; Cornell University; 5--20 July 1994; Statistics Colloquium

Franklin Robertson; Marshall Space Flight Center; GENESIS global climate model

Peter Rogers; Harvard University; hydrology and climate change

Terry Root; University of Michigan; 1 October 1993--30 September 1994; Interdisciplinary Climate Systems Section

Chet Ropelewski; National Meteorological Center; temperature data sets

Richard Rosen; Atmospheric Environment Research, Inc.; parallel ocean climate model angular momentum

Cynthia Rosenzweig; Goddard Institute for Space Studies; agriculture, crop climate modeling, and climate-change scenarios

Steve Running; University of Montana; 20--22 April 1994; Ecosystem Dynamics and the Atmosphere Section

Rande Ruttenburg; Lamont-Doherty Geological Observatory; 1 August--30 November 1994; Ecosystem Dynamics and the Atmosphere Section

Benjamin Santer; Lawrence Livermore National Laboratory; 5--20 July 1994; Statistics Colloquium

Jorge Sarmiento; Princeton University; ocean biogeochemical cycles

Joseph Schelling; Sandia National Laboratories; regional climate modeling

John Schultz; Florida State University; 8 December 1993--30 March 1994; Oceanography Section

Michael Schulz; University of Kiel; 27 April--15 June 1994; Interdisciplinary Climate Systems Section

Steven Scott; Harvard University; 5--20 July 1994; Statistics Colloquium

Joseph Sela; National Meteorological Center; 12--14 October 1993; Climate Modeling Section

Piers Sellers; Goddard Space Flight Center; biosphere--atmosphere interactions

Frederick Semazzi; North Carolina State University; GENESIS global climate model and regional modeling for the Sahelian region

Simon Shackley; Lancaster University; 9--16 April 1994; Division Office

Pedro Silva Dias; University of Sao Paulo; 19--22 January 1994; Global Dynamics Section

Yuri Skiba; City University, Mexico City; 15--17 December 1993; Global Dynamics Section

Julia Slingo; University of Reading; 40- to 50-day tropical oscillation in CCM2

Richard Smith; Los Alamos National Laboratory; massively parallel ocean modeling

Richard Smith; University of North Carolina; 5--20 July 1994; Statistics Colloquium

Thomas Smith; University of Virginia; ecological effects of climate change

William Smyth; Oregon State University; monopole vortices

Gary Sneddon; Dalhousie University; 5--20 July 1994; Statistics Colloquium

Amy Solomon; Massachusetts Institute of Technology; 13 July--21 September 1994; Climate Analysis Section

Neelima Sontakke; Indian Institute of Tropical Meteorology; 1 September--24 December 1993; Climate Analysis Section

Michael Spall; Woods Hole Oceanographic Institution; geophysical fluid dynamics

Peter Speth; University of Cologne; angular momentum budget from ECMWF data

Detlef Stammer; Massachusetts Institute of Technology; parallel ocean climate model sea-surface height analysis

J. Scott Stewart; University of Colorado; 1 October 1993--30 September 1994; Oceanography Section

Robert Stewart; Texas A&M University; parallel ocean climate model momentum fluxes

Brian Stocks; Great Lakes Forestry Centre; regional climate modeling over the Great Lakes

Ronald Stouffer; Geophysical Fluid Dynamics Laboratory; coupled ocean--atmosphere models, observed data

Ted Strub; Oregon State University; parallel ocean climate model eastern boundary currents

Luis Suarez; United States Environmental Protection Agency; GENESIS global climate model

Dezheng Sun; Princeton University; 19--20 September 1994; Climate Analysis Section

Georgi Sutyrin; Institute of Oceanology; 26 December 1993--8 April 1994; and 15 August--15 November 1994; Oceanography Section

Gordon Swaters; University of Alberta; WOCE/TOGA Surface Velocity Project

Paul Switzer; Stanford University; 5--20 July 1994; Statistics Colloquium

Toshiki Tajima; University of Texas, Austin; 6--8 April 1994; Oceanography Section

Yukari Takayabu; Goddard Space Flight Center; 27--28 June 1994; Statistics Project and Climate Analysis Section

Eugene Takle; Iowa State University; climate variability, extreme events, and validation of climate models

Raja Tallamraju; Boulder; 1 August 1994--31 January 1995; Global Dynamics Section

Gregory Taylor; California State University, Chico; moist convection and transport

John Taylor; Australian National University; climate modeling chemistry of the urban environment

Simon Tett; Meteorological Office, Bracknell; 31 January--1 February 1994; Climate Sensitivity and Carbon Dioxide Research Group

Jean Thiebaux; National Science Foundation; 5--20 July 1994; Statistics Colloquium

Richard Thomson; Institute of Ocean Sciences; WOCE/TOGA Surface Velocity Project

Olivier Thual; Centre Europeen de Recherche et de Formation Avancee en Calcul Scientifique; 7--12 December 1993; Oceanography Section

Edward Tollerud; National Oceanic and Atmospheric Administration; precipitation processes, precipitation data management

Juri Toomre; University of Colorado; 8 December 1993--7 December 1994; Oceanography Section

Steven Tracton; National Meteorological Center; 11 April 1994; Global Dynamics Section

Gregory Tripoli; University of Wisconsin; 10--12 February 1994; Climate Modeling Section

Michael Trolier; University of Colorado; carbon cycle

Peter Tschuck; Polytechnic Institute of Zurich; development of a high-resolution regional climate model for the western alpine region and coupling of model to the Hamburg GCM

Elena Tsvetsinskaya; University of Nebraska; 18 March 1994 and 8--19 August 1994; Interdisciplinary Climate Systems Section

Jun-Ichi Tsutsui; Central Research Institute of Electric Power Industry, Japan; 1 April 1994--31 March 1996; Global Dynamics Section

Peter Tyson; University of the Witwatersrand; 21--27 February 1994; Division Office

Garland Upchurch; Southwest Texas State University; GENESIS global climate model

David Valentine; Colorado State University; trace-gas emissions

Geoffrey Vallis; University of California, Santa Cruz; geophysical fluid dynamics

Keith van Cleve; University of Alaska; ecological effects of climate change

Marco Verdecchia; University of L'Aquila; development of regional climate model for the European region

Shashi Verma; University of Nebraska; trace-gas emissions

Michel Verstraete; Joint Research Centre, Italy; development of a coupled surface physics/biosphere/hydrology model

Guido Visconti; University of L'Aquila; development of regional climate model for the European region

Hans von Storch; Max Planck Institute for Meteorology; 17--21 January 1994; Division Office

Jinsong von Storch; Max Planck Institute for Meteorology; 17--21 January 1994; Division Office

Grace Wahba; University of Wisconsin; 5--20 July 1994; Statistics Colloquium

Ilana Wainer; City University, Sao Paulo; 15 June--19 August 1994; Oceanography Section

Roxana Wajsowicz; Goddard Space Flight Center; parallel ocean climate model and Indonesian throughflow

Greg Walker; Oregon State University; 5--20 July 1994; Statistics Colloquium

Kevin Walsh; Commonwealth Scientific and Industrial Research Organization; 5--20 July 1994; Statistics Colloquium

Huaxiao Wang; University of South Carolina; GENESIS global climate model

Wei-Chyung Wang; State University of New York, Albany; GENESIS global climate model

Rik Wanninkhof; National Oceanic and Atmospheric Administration; ocean carbon dioxide system

Edward Waymire; Oregon State University; 5--20 July 1994; Statistics Colloquium

Rudolf Weber; Paul Scherrer Institute, Switzerland; 5--20 July 1994; Statistics Colloquium

Klaus Weickmann; University of Colorado; coupled ocean--atmosphere models, observed data

Albert Weiss; University of Nebraska; crop climate modeling, climate change

Jeffrey Weiss; University of Colorado; 1 September 1993--31 August 1994; Global Dynamics and Oceanography Sections

Christian Werner; Macquarie University; GENESIS global climate model

Carol Wessman; University of Colorado; terrestrial ecosystem modeling

Melanie Wetzel; Desert Research Institute; use of satellite data for validation of model cloudiness

Matthew Wheeler; Macquarie University; 1 October--7 December 1993; Climate Sensitivity and Carbon Dioxide Research Group

James White; University of Colorado; carbon cycle

Christopher Wikle; Iowa State University; 5--20 July 1994; Statistics Colloquium

Martin Wild; Polytechnic Institute of Zurich; development of a high-resolution regional climate model for the western alpine region and coupling of model to the Hamburg GCM

John Wilkin; Commonwealth Scientific Industrial Research Organization; parallel ocean climate model data analysis

Clark Wilson; University of Texas; solid earth geophysics, primarily changes in length of day and polar wander

Kevin Wilson; University of Colorado; paleoclimatic modeling with GENESIS global climate model

Chris Wold; GEOMAR; 1 January--30 June 1994; Interdisciplinary Climate Systems Section

Ian Woodward; University of Sheffield; vegetation distribution modeling

Paul Woodward; Army High Performance Computing Research Center; 1 March 1994--28 February 1995; Oceanography Section

Hulin Wu; Florida State University; 5--20 July 1994; Statistics Colloquium

Carl Wunsch; Massachusetts Institute of Technology; parallel ocean climate model sea-surface height analysis

John Wyngaard; Pennsylvania State University; large eddy simulation of the planetary boundary layer

Michio Yanai; University of California, Los Angeles; Asian monsoon

Jun-Ichi Yano; Boulder; 1 February 1993--30 June 1994; Global Dynamics and Oceanography Sections

Irad Yavneh; Israel Institute of Technology; 23 March--4 April 1994; Oceanography Section

Lisan Yu; Massachusetts Institute of Technology; 10--28 February 1994; Oceanography Section

Lizin Zeng; University of Washington; 5--20 July 1994; Statistics Colloquium

Weizong Zeng; Nanjing University; regional climate modeling

Ming-Hua Zhang, State University of New York, Stony Brook; cloud radiation interactions

Victor Zlotnicki; Jet Propulsion Laboratory; ocean observational analyses and model studies

Dusanka Zupanski; National Meteorological Center; 28 February--2 March 1994; Global Dynamics Section

Francis Zwiers; Canadian Climate Centre; 11 March 1994 and 5--20 July 1994; Statistics Colloquium and Climate Analysis Section

PUBLICATIONS

(*non-NCAR collaborator)

Refereed

BONAN, G.B., 1993: Physiological derivation of the observed relationship between net primary production and mean annual air temperature. *Tellus* **45B,** 397--408.

BONAN, G.B., 1994: Comparison of the land surface climatology of the National Center for Atmospheric Research Community Climate Model 2 at R15 and T42 resolutions. *Journal of Geophysical Research* **99D,** 10,357--10,364.

*CESS, R.D. *M.-H. ZHANG, *G.L. POTTER, *H. BARKER, *R.A. COLEMAN, *D.A. DAZLICH, *A.D. DelGENIO, *M. ESCH, *J.R. FRASER, *V. GALIN, *W.L. GATES, J.J. HACK, *W.J. INGRAM, J.T. KIEHL, *A.A. LACIS, *H. LeTREUT, *Z.-X. LI, *X.-Z. LIANG, *J.-F. MAHFOUF, *B.J. McAVANEY, *V.P. MELESHKO, *J.J. MORCRETTE, *D.A. RANDALL, *E. ROECKNER, *J.-F. ROYER, *A.P. SOKOLOV, *P.V. SPORYSHEV, *K.E. TAYLOR, *W.-C. WANG, and *R.T. WEATHERALD, 1993: Uncertainties in carbon dioxide radiative forcing in atmospheric general circulation models. *Science* **262,** 1252--1255.

*COURTIER, P., *J. DERBER, R.M. ERRICO, *J.-F. LOUIS, and T. VUKICEVIC, 1993: Review of the use of adjoint, variational methods and Kalman filters in meteorology. *Tellus* **45A,** 343--357.

DANABASOGLU, G., J.C. McWILLIAMS, and P.R. GENT, 1994: The role of mesoscale tracer transports in the global ocean circulation. *Science* **264,** 1123--1126.

DONEY, S.C., 1994: Irreversible thermodynamic coupling between heat and mass fluxes across a gas/liquid interface. *Journal of the Chemical Society, Faraday Transactions* **90,** 1865--1874.

DONEY, S.C., and *W.J. JENKINS, 1994: Ventilation of the deep western boundary current and the abyssal western North Atlantic: Estimates from tritium and He-3 distributions. *Journal of Physical Oceanography* **27,** 638--659.

EHRENDORFER, M., 1994: The Liouville equation and its potential usefulness for the prediction of forecast skill. Part I: Theory. *Monthly Weather Review* **122,** 703--713.

EHRENDORFER, M., 1994: The Liouville equation and its potential usefulness for the prediction of forecast skill. Part II: Applications. *Monthly Weather Review* **122,** 714--728.

EHRENDORFER, M., 1994: The Liouville equation and prediction of forecast skill. In *Predictability and Nonlinear Modeling in Natural Sciences and Economics* (J. Grasman and G. van Straten, Eds.), Kluwer, 29--44.

EHRENDORFER, M., *M. HANTEL, and *Y. WANG, 1994: A variational modification algorithm for three-dimensional mass flux non-divergence. *Quarterly Journal of the Royal Meteorological Society* **120,** 655--698.

ERRICO, R.M., T. VUKICEVIC, and K. RAEDER, 1993: Comparison of initial and lateral boundary condition sensitivity for a limited-area model. *Tellus* **45A,** 539--557.

ERRICO, R., T. VUKICEVIC, and K. RAEDER, 1994: Examination of the accuracy of a tangent linear model. *Tellus* **45A,** 462--477.

*FRIEDL, M.A., *J. MICHAELSEN, *F.W. DAVIS, *H. WALKER, and D.S. SCHIMEL, 1994. Estimating grassland biomass and leaf area index using ground and satellite data. *International Journal of Remote Sensing* **15,** 1401--1420.

GARCIA, R.R., and B.A. BOVILLE, 1994: ``Downward control'' of the mean meridional circulation and the temperature of the polar winter stratosphere. *Journal of the Atmospheric Sciences* **51,** 2238--2245.

GENT, P.R., J.C. McWILLIAMS, and *C. SNYDER, 1994: Scaling analysis of curved fronts: Validity of the balance equations and semigeostrophy. *Journal of the Atmospheric Sciences* **51,** 160--163.

GIORGI, F., C.S. BRODEUR, and G.T. BATES, 1994: Regional climate change scenarios over the United States produced with a nested regional climate model: Spatial and seasonal characteristics. *Journal of Climate* **7,** 375--399.

GIORGI, F., S.W. HOSTETLER, and C.S. BRODEUR, 1994: Analysis of the surface hydrology in a regional climate model. *Quarterly Journal of the Royal Meteorological Society* **120,** 161--184.

*GUTZLER, D.S., *G.N. KILADIS, G.A. MEEHL, *K.M. WEICKMANN, and *M. WHEELER, 1994: The global climate of December 1992--February 1993. Part II. Large-scale variability across the tropical western Pacific during TOGA COARE. *Journal of Climate* **7,** 1606--1622.

HACK, J.J., 1993: Climate system simulation: basic numerical and computational concepts. In *Climate System Modeling* (K. Trenberth, Ed.), Cambridge University Press, 283--318.

HACK, J.J., 1994: Parameterization of moist convection in the National Center for Atmospheric Research Community Climate Model (CCM2). *Journal of Geophysical Research* **99D,** 5551--5568.

*HARTLEY, D.E., D.L. WILLIAMSON, P.J. RASCH, and *R. PRINN, 1994: Examination of tracer transport in the NCAR CCM2 by comparison of CFCl3 simulations with ALE/GAGE observations. *Journal of Geophysical Research* **99D,** 12,885--12,896.

*HESS, P.G., *D.S. BATTISTI, and P.J. RASCH, 1993: Maintenance of the Intertropical Convergence Zone on a water covered earth. *Journal of the Atmospheric Sciences* **50,** 691--713.

*HOLTSLAG, A.A.M., and B.A. BOVILLE, 1993: Local versus nonlocal boundary-layer diffusion in a global climate model. *Journal of Climate* **6,** 1825--1842.

HOSTETLER, S.W., and F. GIORGI, 1993: One-way coupling of landscape-scale hydrologic models with a regional climate model: An assessment. *Water Resources Research* **29,** 1685--1695.

HOSTETLER, S.W., F. GIORGI, G.T. BATES, and *P.J. BARTLEIN, 1994: The role of lake--atmosphere feedbacks in sustaining paleolakes Bonneville and Lahontan 18,000 years ago. *Science* **263,** 665--668.

HURRELL, J.W., and H. VAN LOON, 1994: A modulation of the atmospheric annual cycle in the Southern Hemisphere. *Tellus* **46A,** 325--338.

*KAROLY, D.J., *J.A. COHEN, G.A. MEEHL, *J.F.B. MITCHELL, *A.H. OORT, *R.J. STOUFFER, and *R.T. WETHERALD, 1994: An example of fingerprint detection of greenhouse climate change. *Climate Dynamics* **10,** 97--105.

KASAHARA, A., A.P. MIZZI, and *L.J. DONNER, 1994: Diabatic initialization for improvement in the tropical analysis of divergence and moisture using satellite radiometric imagery data. *Tellus* **46A,**242--264.

KIEHL, J.T., 1994: On the observed near cancellation between longwave and shortwave cloud forcing in tropical regions. *Journal of Climate* **7,** 559--565.

*KINNEY, R., *T. TAJIMA, J.C. McWILLIAMS, and *N. PETVIASHVILLI, 1994: Filamentary magnetohydrodynamic plasmas. *Physics of Plasmas* **1,** 260--280.

*LABITZKE, K., and H. VAN LOON, 1993: Some recent studies of probable connections between solar and atmospheric variability. *Annales Geophysicae* **11,** 1084--1094.

*LABITZKE, K., and H. VAN LOON, 1994: A note on trends in the stratosphere: 1958--1992. *COSPAR Colloquia Series* **5,**, Pergamon Press, 537--546.

LAW-EVANS, E., and *P.A. KAY, 1994: Quantifying the effect of technology and management on wheat yields in the western great plains. *Great Plains Research* **4,** 133--146.

*LIEBERMAN, R.S., *C.B. LEOVY, B.A. BOVILLE, and B.P. BRIEGLEB, 1994: Diurnal heating and cloudiness in the NCAR Community Climate Model. *Journal of Climate* **7,** 869--889.

MADDEN, R.A., and G.A. MEEHL, 1993: Bias in the global mean temperature estimated from sampling a greenhouse warming pattern with the current surface observing network. *Journal of Climate* **6,** 2486--2489.

MADDEN, R.A., and *P.R. JULIAN, 1994: Observations of the 40--50 Day Tropical Oscillation---A Review. *Monthly Weather Review* **122,** 814--837.

*McCANN, M.P., *A.J. SEMTNER, and R.M. CHERVIN, 1994: Transports and budgets of volume, heat and salt from a global eddy-resolving ocean model. *Climate Dynamics* **10,** 59--80.

McWILLIAMS, J.C., and P.R. GENT, 1994: The wind-driven ocean circulation with an isopycnal-thickness mixing parameterization. *Journal of Physical Oceanography* **24,** 46--65.

McWILLIAMS, J.C., and *J.B. WEISS, 1994: Anisotropic geophysical vortices. *Chaos* **4,** 305--311.

McWILLIAMS, J.C., *J.B. WEISS, and *I. YAVNEH, 1994: Anisotropy and coherent vortex structures in planetary turbulence. *Science* **264,** 410--413.

MEEHL, G.A., 1994: Influence of the land surface in the Asian summer monsoon: External conditions versus internal feedbacks. *Journal of Climate* **7,** 1033--1049.

MEEHL, G.A., *M. WHEELER, and W.M. WASHINGTON, 1994: Low-frequency variability and CO2 transient climate change. Part 3. Intermonthly and interannual variability. *Climate Dynamics* **10,** 277--303.

MILLIFF, R.F., and J.C. McWILLIAMS, 1994: The evolution of boundary pressure in ocean basins. *Journal of Physical Oceanography* **24,** 1317--1338.

*MULLEN, S., and D.P. BAUMHEFNER, 1994: Monte Carlo simulations of explosive cyclogenesis. *Monthly Weather Review* **122,** 1548--1567.

*MURPHY, A.H., and M. EHRENDORFER, 1994: Evaluation of forecasts. In *Predictability and Nonlinear Modeling in Natural Sciences and Economics* (J. Grasman and G. van Straten, Eds.), Kluwer, 11--28.

*OJIMA, D.S., D.S. SCHIMEL, *W.J. PARTON, and *C.E. OWENSBY, 1994: Long- and short-term effects of fire on nitrogen cycling in tallgrass prairie. *Biogeochemistry* **24,** 67--84.

*PARTON, W.J., *J.M.O. SCURLOCK, *D.S. OJIMA, *T.G. GILMANOV, *R.J. SCHOLES, D.S. SCHIMEL, *T. KIRCHNER, *J.-C. MENAUT, *T. SEASTEDT, *E.G. MOYA, *A. KAMNALRUT, and *J.L. KINYAMARIO, 1993: Observations and modeling of biomass and soil organic matter dynamics for the grassland biome worldwide. *Global Biogeochemical Cycles* **7,** 785--809.

POLLARD, D., and S.L. THOMPSON, 1994: Sea-ice dynamics and CO2 sensitivity in a global climate model. *Atmosphere--Ocean* **32,** 449--467.

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RASCH, P.J., X.-X. TIE, B.A. BOVILLE, and D.L. WILLIAMSON, 1994: A three-dimensional transport model for the middle atmosphere. *Journal of Geophysical Research* **99D,** 999--1017.

*ROOT, T.L., and *J.D. WECKSTEIN, 1994: Changes in distribution patterns of select wintering North American birds from 1901 to 1989. *Studies in Avian Biology* **15,** 191--201.

SCHIMEL, D.S., 1994: Introduction. In *Integrated Regional Models* (P.M. Groffman and G.E. Likens, Eds.), Chapman and Hall, 3--10.

SCHIMEL, D.S., T.G.F. KITTEL, and *W.J. PARTON, 1994: Transect biomass and nitrogen data. In *Collected Data of the First ISLSCP Field Experiment. Vol. 1: Surface Observations and None-Image Data Sets* (D.E. Strebel, D.R. Landis, K.F. Huemmrich, and B.W. Meeson, Eds.), NASA Goddard Space flight Center, Greenbelt, Md., CD-ROM.

*SEMAZZI, F., *Y.W. LIN, and F. GIORGI, 1994: Effects of SST anomalies on Sahelian climate as simulated with a regional climate model. *Geophysical Research Letters* **20,** 2897--2900.

*SIROIS, L., G.B. BONAN, and *H.H. SHUGART, 1994: Development of a simulation model of the forest-tundra transition zone of northeastern Canada. *Canadian Journal of Forest Research* **24,** 697--706.

TIE, X.-X., *G.P. BRASSEUR, *P. FRIEDLINGSTEIN, *C. GRANIER, and P.J. RASCH, 1994: The impact of high altitude aircraft on the ozone layer in the stratosphere. *Journal of Atmospheric Chemistry* **18,** 103--128.

TRENBERTH, K.E., 1993: Review of "The nature and causes of climate change: Assessing the long-term future," by C.M. Goodess, J.P. Palutikif, and T.D. Davies, Belhaven Press, London, 1992, *Bulletin of the American Meteorological Society* **74,** 2399--2400.

TRENBERTH, K.E., and J.W. HURRELL, 1994: Decadal atmosphere-ocean variations in the Pacific. *Climate Dynamics* **9,** 303--319.

TRENBERTH, K.E., and *A. SOLOMON, 1994: The global heat balance: Heat transports in the atmosphere and ocean. *Climate Dynamics* **10,** 107--134.

*TURNER, C.L., and T.G.F. KITTEL, 1994: 1989 FIFE site burn map. In *Collected Data of the First ISLSCP Field Experiment. Volume 1: Surface Observations and None-image Data Sets* (D.E. Strebel, D.R. Landis, K.F. Huemmrich, and B.W. Meeson, eds), NASA Goddard Space Flight Center, Greenbelt, Md., CD-ROM and accompanying documentation.

*VALENTINE, D., E.A. HOLLAND, and D.S. SCHIMEL, 1994: Ecosystem and physiological controls over methane production in northern wetlands. *Journal of Geophysical Research* **99D,** 1563--1571.

*VERDECCHIA, M, *G. VISCONTI, F. GIORGI, and M.R. MARINUCCI, 1994: Diurnal temperature range for a doubled carbon dioxide concentration experiment: Analysis of possible physical mechanisms. *Geophysical Research Letters* **21,** 1527--1530.

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http://www.ncar.ucar.edu/archives/asr/ASR94/ESIG/homepage.html Go

Environmental and Societal Impacts Group

The research activities of the Environmental and Societal Impacts Group (ESIG) are geared toward providing insights into how societies might better understand and cope with the interactions between human activities and changes in atmospheric processes on various time scales.

During fiscal year 1994, ESIG activities involved *research, linkage*, and *outreach*. **These are not mutually exclusive categories.**

- *Research* is undertaken by ESIG group members individually, with others in the group (including ESIG visitors and adjunct scientists), and with those in other NCAR divisions;
- *linkage* refers to collaboration with researchers at universities and in government organizations in the United States and elsewhere;
- *outreach* pertains to ESIG-sponsored lectures, workshops, symposia, publications, and studentships.

ESIG's research and outreach activities focused on interactions between climate and society, regional scenarios of responses to climate variability and change, global change, and the value and use of meteorological information. Such activities foster research on topics considered by ESIG researchers as neglected or in need of scientific consideration.

In addition to its NSF support, ESIG has received additional funding from several outside agencies, including the United Nations Environment Programme (UNEP) for ESIG's climate-related impacts *Network Newsletter*.

- UNEP and the US Agency for International Development (AID) Office of Foreign Disaster Assistance (OFDA) provided complementary funding for an international ESIG workshop on El Niño/Southern Oscillation (ENSO) events as they relate to famine early warning systems (FEWS) in Africa.
- UNEP also provided support for an Informal Planning Meeting on ENSO events as they relate to early warning systems in Southeast Asia, and for a workshop on Creeping Environmental Phenomena.
- The National Oceanic and Atmospheric Administration (NOAA) Office of Global Change (OGP) provided support for a study of precipitation variability (begun in FY 92); for a workshop on North American applications of ENSO information, to be held early in FY 95; and for an Institute on the Economics of the Climate Resource, to be convened in the summer of FY 95.
- The NSF Division of Atmospheric Sciences provided special funds for a two-year research assessment of extreme mesoscale events and their impacts during 1992-94.
- The NSF Division of Mathematical Sciences continued to provide special funds for a five-year grant to foster collaboration between the statistical and atmospheric sciences (joint with CGD).

Significant Accomplishments

- Two major research projects focusing on water resources were completed during FY 94. Kathleen Miller completed work on a project analyzing water banking as a tool for promoting flexible management of variable water supplies. Lynne Bennett (ASP graduate research assistant) completed her research on water allocation under interstate compacts in the western United States.
- ESIG identified and collaborated with new agencies (e.g., AID/OFDA, UNEP's desertification unit, NOAA/OGP). It

has also made initial contacts with NASA's Mission to Planet Earth to develop possible support for climate-related impact assessment research.

- Michael Glantz completed a multiyear research project on *Drought Follows the Plow,* which draws on specific examples provided by researchers from around the globe. Each case study raises concern about how we might respond to droughts in the future. An edited book published by Cambridge University Press appeared in September 1994.
- Michael Glantz convened a UNEP- and USAID/OFDA-sponsored international workshop in Budapest, Hungary, to focus research across disciplines and agencies on ENSO events as they relate to famine early warning systems (FEWS). The workshop brought together experts from research and policy communities that do not often interact (ENSO researchers, famine early warning personnel, food security agencies and climate impacts specialists).
- Richard Katz and Roland Madden (CGD) organized a two-week colloquium, "Applications of Statistics to Modeling the Earth's Climate System," as part of a five-year grant from the NSF Division of Mathematical Sciences to promote collaboration between the statistical and atmospheric sciences. The lecturers and the graduate students attending the colloquium were equally divided between statistical and atmospheric (or related) sciences. This is a significant addition to NCAR's research agenda.
- Michael Glantz prepared a manuscript for the UNEP/GEMS Climate Series on *The Impacts of Climate on Fisheries.* It was published by UNEP in June for widespread distribution to policymakers.
- ESIG received funding from NOAA/OGP for a workshop on North American Applications of ENSO events to help agencies identify the uses of research findings of the ENSO research and impacts community.
- ESIG received funding from the NSF Division of Atmospheric Science to begin work on a two-year research project to examine extreme mesoscale events and impacts during the 1992-94 time frame. This is a significant addition to ESIG's research activities.
- Glantz convened a UNEP-sponsored workshop in Boulder on the notion of Creeping Environmental Phenomena. This has led to the application of the notion to assess CEP in the Aral Sea Basin. The workshop was sponsored by UNEP's Climate Unit and its Desertification Unit.
- During FY 94 ESIG involved several students in climate-related environmental change assessments. Through the judicious use of its very limited visitor resources, the group has enabled these visitors to participate on-site in ESIG projects.
- Glantz convened a UNEP-supported Informal Planning Meeting in Bangkok, with participants drawn from physical science, social science, and policymaking communities, in order to evaluate the need for a Usable Science: ENSO/Early Warning System Workshop in Southeast Asia. Researchers supported such a meeting, which will be funded by UNEP and USAID/OFDA.

Although ESIG is a small group, its researchers are involved in numerous ongoing multidisciplinary studies. The following outline provides detailed information on each of the FY 94 activities. The name of the ESIG researcher(s) involved in the activity appears in parenthesis.

Climate Change and Water Institutions

- Water banking in the West (Miller)
- Climate Change and Water Law (Miller, Rhodes)
- Urban Drought (Glantz, Mason-ASP)
- An Evaluation of Interstate Water Sharing in the Western United States under Conditions of Climatic Uncertainty (Bennett-ASP)

- Colorado-Amudarya Rivers Project (Glantz)
- Changes and Variability in Climate and River Deltas (Smith-ASP)
- Economics, Lake Levels, and Conflict (Miller)

Policy Aspects of Climate Change

- Climate-Induced Sea Level Rise and Toxic Waste Sites Along the Louisiana Gulf Coast (Rhodes)
- Aluminum Production, Greenhouse Gases, and Sustainable Development in the Brazilian Rainforest (Mason-ASP)
- Global Change and Usable Information (Pielke)

Regional Scenarios Project: Forecasting by Analogy

- Russian Case Studies (Glantz)
- Drought Follows the Plow (Glantz)
- Impacts of Climate on Fisheries (Glantz)
- Climate-Related Impacts Assessment in Vietnam (Glantz)
- Assessing the Use and Value of ENSO Information for Food Security in Southern Africa (Glantz)

Societal Adjustment to Perceived Climatic Risks

- Great Plains Rural Electrification and Groundwater Depletion (Rhodes)

Use and Value of Weather and Climate Information

- Stochastic Hydrology (Katz)
- Climate Scenario Generation (Katz)
- ENSO/Famine Early Warning Systems(Africa) (Glantz)
- ENSO/Famine Early Warning Systems (Southeast Asia) (Glantz)
- Creeping Environmental Phenomena (CEP) (Glantz)
- ENSO/North American Applications Workshop (Glantz)
- Usable Science IV: The Use of Remote Sensing and Other Scientific Information Related to ENSO and Its Impacts (Glantz)

Rates and Processes of Environmental Change

- Overview
- Methods of Measuring Tropical Deforestation (Downton)

Mesoscale Events and Impacts

- Mesoscale Weather Assessment (Rhodes)
- STORM/USWRP History (Pielke)
- Extreme Mesoscale Events and Impacts 1992-94 (Pielke)

Multidisciplinary Collaboration

- Geophysical Statistical Project (Katz, Madden-CGD)

Networking

- Network Newsletter (Glantz, Stewart)

Community Involvement

Staff, Visitors and Collaborators

Publications

Return to ASR Home Page

Staff, Visitors, and Collaborators

Staff

Michael Glantz (head)
Richard Katz (deputy head)

Mary Downton (80%)
Victoria Holzhauer
Kathleen Miller
Roger Pielke, Jr. (as of 9/5/94)
Steven Rhodes
Jan Stewart

Visitors and Collaborators

Dates refer to the visitor's stay at NCAR during FY 94. No dates are given for collaborators who did not visit NCAR.

Len Ackland; Center for Environmental Journalism, University of Colorado at Boulder; 7- 10 February 1994; Creeping Environmental Phenomena Workshop

Alex Alusa; United Nations Environment Programme, Nairobi, Kenya; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Gopal Arulselvi; Tamil Nadu, India; 31 August to 2 September 1994; international development

Melaku Ayalew; Food Security Project, Relief & Rehabilitation Commission, Addis Ababa, Ethiopia; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Sarah Bates; Natural Resources Law Center, University of Colorado at Boulder; water banking in the west

Dan Bedford; University of Colorado at Boulder; 1 April to 30 May 1994; effects of climate change on water resources in the Aral Sea basin

Fekadu Bekele; National Meteorological Services Agency, Addis Ababa, Ethiopia; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Abdellatif Bencherifa; Faculti des Lettres et des Sciences Humaines, Mohammed V University, Rabat, Morocco; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Michele M. Betsill; Department of Political Science, University of Colorado at Boulder; 31 May to 30 September 1994; value of ENSO information

Forrest Briscoe; Harvard College, Cambridge, Massachusetts; 13 June to 2 September 1994; rates and processes of climate change

Margaret Buchanan-Smith; Institute of Development Studies, University of Sussex, Brighton, UK; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Roger Buckland; Food Security Technical & Administrative Unit, Southern Africa Development Community, Harare, Zimbabwe; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Diana Callear; Land & Agriculture Policy Centre; Johannesburg, South Africa; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

David Campbell; Department of Geography, Michigan State University, East Lansing, Michigan; severe food deficits in rural Africa

Mark Cane; Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Stanley Changnon; Illinois State Water Survey, Champaign, Illinois; 25-26 May and 8-9 September 1994; water resources and climate change

Pao-Shin Chu; University of Hawaii, Honolulu, Hawaii; ENSO teleconnections with drought

Kristine Crandall; Department of Agricultural Economics, University of Arizona, Tucson; 1 August to 30 September 1994; economic impacts of droughts in southern Africa

John Currelly; US Agency for International Development, Port-au-Prince, Haiti; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Margaret Davidson; South Carolina Sea Grant Consortium, Charleston, South Carolina; 7-10 February 1994; Creeping Environmental Phenomena Workshop

William T. Davoren; Aral Sea Information Committee, Sausalito, California; 25-26 April 1994; environmental degradation and the Aral Sea

Maxx Dilley; Office of US Foreign Disaster Assistance, Agency for International Development, Washington, DC; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Carolina Burle Schmidt Dubeux; Coordenação do Programa de Despoluição da Baia de Guanabara, Rio de Janeiro, Brazil; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Timothy C. Earle; Psychology Department, Western Washington University, Bellingham, Washington; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Tibor Farago; Ministry of Environment, Department of International Relations, Budapest, Hungary; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Graham Farmer; Agency for International Development, Famine Early Warning System Project, Arlington, Virginia; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Brian Fisher; Australian Bureau of Agricultural Research and Economics (ABARE); 16 June 1994; climate change policy

Kevin Gallagher; Regis College, Denver, Colorado; 19-30 September 1994; use of ENSO information

Juan Garrido Acero; University of Extremadura, Badajoz, Spain; 27 June to 16 September 1994; teleconnections, stochastic hydrology

Cecilia Girz; NOAA/Forecast Systems Laboratory, Boulder; spatial and temporal variability of precipitation

Graeme Hammer; Agricultural Production Systems Research Unit, Toowoomba, Queensland, Australia; 29-30 August 1994; impacts of climate on agriculture

J.R.E. (Robin) Harger; Regional Office for Science and Technology for Southeast Asia, UNESCO, Jakarta, Indonesia; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Les Heathcote; Flinders University of South Australia, Adelaide; 6-11 February 1994; Creeping Environmental Phenomena Workshop

Charles Howe; Department of Economics, University of Colorado at Boulder; water banking in the west

Rebecca Huss-Ashmore; Department of Anthropology, University of Pennsylvania, Philadelphia; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Jeffrey W. Jacobs; National University of Singapore, Singapore; 24-25 January 1994; ENSO forecasts in Southeast Asia

Dale Jamieson; University of Colorado at Boulder; 24-25 January 1994 and 31 May to 30 September 1994; ENSO forecasts in Southeast Asia, environmental philosophy and policy implications of climate change

Yusup Kamalov; Union for the Defense of the Aral and Amudarya, Nukus, Karakalpakstan, Uzbekistan; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Joseph H. Kinuthia; Kenya Meteorological Department, Nairobi, Kenya; 25-28 October 1993; famine early warning systems and value of ENSO information

Tran Viet Lien; Institute of Meteorology and Hydrology, Hanoi, Vietnam; 24-25 January 1994; ENSO forecasts in Southeast Asia

Lawrence MacDonnell; Natural Resources Law Center, University of Colorado at Boulder; water banking in the west, climate change and water law

Antonio Magalhães; Fundacao Grupo Esquel Brasil, Brasilia, Brazil; drought, desertification, and climate change

Melanie Mason; University of Colorado at Boulder; 1 October 1993 to 7 November 1994; sustainable industrial development, climate change, deforestation

James McCann; African Studies Center, Boston University, Boston, Massachusetts; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Mack McFarland; DuPont Fluoroproducts, Wilmington, Delaware; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Gordon McKay; Canadian Climate Centre, Downsview, Ontario, Canada; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Adams Miller; Office of Global Programs, NOAA, Silver Spring, Maryland; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Ana Maria Molina; San Salvador, El Salvador; 1-31 October 1993; economics of climate impacts and waste management

Mikiyasu Murakami; School of Political Science and Economics, Tokyo, Japan; 22-23 June 1994; UN University Conference on Inland Seas

Mikiyasu Nakayama; Utsunomiya University, Tochigi, Japan; 7-10 February 1994; Creeping Environmental Phenomena Workshop, UN University Conference on Inland Seas

Neville Nicholls; Bureau of Meteorology Research Centre, Melbourne, Victoria, Australia; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Nguyen Huu Ninh; Center for Environment Research, Education, and Development, Hanoi, Vietnam; 24-25 January 1994;

ENSO forecasts in Southeast Asia

Laban Ogallo; Department of Meteorology, University of Nairobi, Kenya; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Stella C. Ogbuagu; Department of Sociology, University of Calabar, Nigeria; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Patricia Parisi; University of Colorado at Boulder; 1 October 1993 to 30 September 1994; rates and processes of tropical deforestation

Robert K. Parkin; University of Colorado at Boulder; 17 May to 11 August 1994; economics of climate variability and change

Suwanna Panturat; Srinakharinwirot University, Bangkok, Thailand; 24-25 January 1994; ENSO forecasts in Southeast Asia

Marc Parlange; University of California at Davis; 15 August to 9 September 1994; stochastic modeling of precipitation

Roger Pielke, Jr.; Department of Political Science, University of Colorado at Boulder; 11 February to 2 September 1994; atmospheric science policy

Mahesh Pradham; UNEP/Regional Office for Asia & Pacific, Bangkok, Thailand; 24-25 January 1994; ENSO forecasts in Southeast Asia

Carl Rebstock; US Naval Observatory, Washington, DC; 11-15 October 1993; rates and processes of environmental change

Carlos Quesada; University of Costa Rica, San Jose, Costa Rica; sustainable development in the Osa Peninsula

Teresa Rice; Natural Resources Law Center, University of Colorado at Boulder; water banking in the west

Jennifer Robinson; Department of Geography, State University of New York at Buffalo; 4-10 August 1994; rates and processes of tropical deforestation

John Rook; UN Food & Agriculture Organization, Southern Africa Development Community, Harare, Zimbabwe; 25-28 October 1993; famine early warning systems and value of ENSO information

Alvin Z. Rubinstein; University of Pennsylvania, Philadelphia, Pennsylvania; policy aspects of the Area Sea decline

Deborah Saidy; Drought Emergency in Southern Africa Programme, UN Department of Humanitarian Affairs, Geneva, Switzerland; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Hoang Thi San; Mangrove Ecosystems Research Centre, Hanoi National Pedagogical University, Hanoi, Vietnam; mangrove deforestation in Vietnam

Megumi Seki; UNEP/SIDA Project on CFCs, Bangkok, Thailand; 24-25 January 1994; ENSO forecasts in Southeast Asia

Ronaldo Serôa da Motta; Instituto de Pesquisa Econômica Aplicada, Rio de Janeiro, Brazil; 7- 10 February 1994; Creeping Environmental Phenomena Workshop

Gary Sharp; NOAA Center for Ocean Analysis and Prediction, Monterey, California; climate impacts on Indian Ocean fisheries

Thomas Stewart; State University of New York, Albany, New York; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Dusadee Sukawat; Weather Forecast Divison, Meteorological Department, Bangkok, Thailand; 24-25 January 1994; ENSO forecasts in southeast asia

Will Swearingen; Earth Sciences Department, Montana State University, Bozeman; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Christopher Tapscott; Social Sciences Division, University of Namibia, Windhoek, Namibia; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Lesley Tarleton; NOAA/NWS, Silver Spring, Maryland; urban heat islands and extremes

Ed Tollerud; NOAA/Forecast Systems Laboratory, Boulder; spatial and temporal variability of precipitation

Asiya Tureniazova; Aral Centre Academy of Sciences, Nukus, Karakalpakstan, Uzbekistan; attended Budapest workshop 25-28 October 1993; famine early warning systems and value of ENSO information

Peter D. Tyson; Department of Environmental Sciences, University of Virginia at Charlottesville; rates and processes of environmental change

Peter Usher; UN Environment Programme, Nairobi, Kenya; 19-22 November 1993, 24-25 January 1994, and 7-10 July 1994; climate-related impact assessment networking, ENSO forecasts in Southeast Asia

Klasina VanderWerf; Department of Philosophy, University of Colorado at Boulder; 7-10 February 1994; Creeping Environmental Phenomena Workshop

Celso Vargas; Costa Rica Institute of Technology, San Jose, Costa Rica; sustainable development in the Osa Peninsula

Sergei Vinogradov; Russian Academy of Sciences, Institute of State and Law, Moscow, Russia; 22-30 July 1994; transboundary water resource problems and laws in Central Asia

Coleen Vogel; Climatology Research Group, University of the Witswatersrand, Johannesburg, South Africa; 25 January to 11 February 1994; Creeping Environmental Phenomena Workshop, climate impact methodologies

Benjamin Webster; Bates College, Lewiston, Maine; 13 June to 19 August 1994; history of STORM and USWRP

Samuel Wheeler; RCG/Hagler, Bailly, Inc., Boulder, Colorado; rural electrification and Great Plains aquifer depletion

Karen Wiley; Colorado School of Mines, Golden, Colorado; climate change and sea level rise

Donald Wilhite; University of Nebraska, Lincoln, Nebraska; 25-28 October 1993 and 7-10 February 1994; famine early warning systems and value of ENSO information, Creeping Environmental Phenomena Workshop

Karin Wisiol; Karin Wisiol & Associates, Glenview, Illinois; mathematical analysis and ecological models

Igor Zonn; VO Soyuzvodproyect, Moscow, Russia; 7-10 February 1994; creeping environmental phenomena on the Aral Sea and Kalmykia, Creeping Environmental Phenomena Workshop http://www.ncar.ucar.edu/archives/asr/ASR94/ESIG/12pubs.html Go

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High Altitude Observatory

Research at the High Altitude Observatory is focused on understanding the sun and heliosphere and the earth's upper atmosphere, ionosphere, and magnetosphere as an integral physical system. Although there are astrophysical and planetary components in HAO's research program, the principal efforts are directed toward understanding the physical processes underlying the variability of the solar-terrestrial system and the impacts of this variability on the earth's lower atmosphere.

The combined action of convection and rotation in the solar interior generates the solar magnetic field in cycles of approximately 22 years, and it is this magnetic field that leads to the variability of the solar output of radiation, magnetized plasma, and energetic particles on time scales ranging from minutes to millennia, including the most familiar solar activity time scale of approximately 11 years. In the solar interior, the magnetic field alters the outward flow of energy: directly, by transforming fluid energy into magnetic energy and by providing additional modes of energy transport to the outer layers; and, indirectly, by altering the convective and the radiative transport efficiencies. In the solar atmosphere, the magnetic field controls the thermal and dynamical properties of the plasma which, in turn, give rise to the wealth of physical phenomena associated with the variable outputs of the sun. Understanding the physics of these phenomena is both inherently interesting and essential to our desire eventually to have a predictive capability for the variability of solar outputs that have a significant impact on the terrestrial environment.

The sun, of course, is the principal forcing agent of the terrestrial environment. Solar radiation in the visible, infrared, and near-ultraviolet spectral ranges directly impacts the terrestrial lower atmosphere, while the shorter wavelength radiation directly impacts the upper atmosphere. The solar magnetized plasma and energetic particle outputs couple through the inner heliosphere and the terrestrial magnetosphere to impact primarily the high-latitude terrestrial upper atmosphere. The variability associated with the short-wavelength radiation, magnetized plasma, and energetic particles is coupled downward into the lower atmospheric layers, just as the variability in the lower atmosphere associated with anthropogenic effects is coupled upward into the upper atmospheric layers. Hence, studies of the anthropogenic effects in the upper atmosphere (where they are frequently much larger than in the lower atmosphere) can provide important information on the magnitude of anthropogenically induced global change at lower levels in the atmosphere, while studies of the downward transport of solar variability effects through the atmosphere provide a basis for understanding the relative importance of solar and anthropogenic variability effects on biospheric global change.

The unusual breadth of the HAO research program (which includes the region from the interior of the sun to the terrestrial atmosphere, as well as related astrophysical and planetary systems) strains the available resources, but it is necessary for a coherent approach to the study of solar variability and its impact on the terrestrial environment. Fortunately, the unifying theme of solar-terrestrial research produces strongly overlapping interests over all of HAO's research efforts and leads to a healthy level of interaction and cooperation.

Support for HAO's research program comes primarily through NCAR's base NSF funding, but as is appropriate to the breadth and nature of the HAO program, funding also comes from the NSF Global Change programs of CEDAR, GEM, and SunRISE, from NASA's Mission to Planet Earth Office for space experiments on the UARS and EOS missions, and from NASA's Office of Space Science for a space experiment on the TIMED mission and for various theoretical and observational research projects.

Significant Accomplishments

· During 1994, Steve Tomczyk and the HAO Instrumentation Group completed, deployed, and began operations of the Low Degree Oscillations Experiment (LOWL), which measures oscillations of low degree (spatial frequency) in the velocity field of the solar photosphere. These measurements allow the inference of the structure and rotation rate of the deep solar interior with much greater precision than has been possible with currently available data.

· Paul Charbonneau, Tom Bogdan, and Keith MacGregor have constructed and are studying a class of axisymmetric numerical mean-field dynamos characterized by the propagation of a dynamo surface wave at the interface between the solar radiative core and overlying convective envelope. These interface dynamos lead naturally to the storage and amplification of the toroidal magnetic field in a thin, stable stratified layer located below the core-envelope interface, even though the helicity is assumed to vanish there.

· A longstanding problem of solar physics has been the nature of the decay and dispersal of sunspots and active regions. For the first time, Andy Skumanich, Bruce Lites, and Valentin Martínez Pillet (Instituto de Astrofisica de Canarias) have used measurements from the HAO/NSO Advanced Stokes Polarimeter (ASP) to observe the magnetic flux of sunspots as they traverse the entire solar disk with a precision that allows one to measure their actual decay rates.

· Eijiro Hiei (Mesei University), Art Hundhausen, and David Sime have studied observations in white-light and soft X-rays of the reformation of a coronal helmet streamer at the solar west limb on January 24-26, 1992. This study has provided the first persuasive observational evidence of the helmet streamer being formed as a closed magnetic structure in the corona by resistive reconnection of a magnetic field after the field has been pulled open by a coronal mass ejection.

· Don Hassler and Tom Moran (NASA/GSFC) have obtained profiles of the visible Fe X coronal emission line out to 1.16 solar radii in a coronal hole. Analysis of the line widths suggests a large component of nonthermal broadening that increases with height which is consistent with the presence of hydromagnetic waves of a sufficiently large amplitude to play an important role in coronal heating and solar wind acceleration.

· Gary Rottman (Principal Investigator) and Co-Investigators from the University of Colorado have made use of UARS/SOLSTICE data to study solar ultraviolet radiative variability on all time scales, including very rapid solar flare activity, the dominant 27-day variability associated with the appearance and disappearance of active regions on the solar disk modulated by solar rotation, and an initial determination of the eleven year solar cycle variations. The UARS instruments are the first to incorporate in-flight calibration schemes to correct for long-term instrumental drift.

· Tom Woods (Principal Investigator) and Co-Investigators from the university of Colorado, the Naval Research Laboratory, the Jet Propulsion Laboratory, and HAO began development of a solar irradiance experiment, the Solar Extreme-ultraviolet Experiment (SEE), to be flown on the TIMED (Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics) mission, which is scheduled for launch by NASA in 1999. The HAO Instrumentation Group is near completion of the conceptual design for the SEE instrument.

· Tom Woods and collaborators from the University of Colorado, Boston University, the Jet Propulsion Laboratory, and HAO conducted a highly successful sounding rocket experiment on October 4, 1993. This is the fourth in a series of experiments extending back to 1988 that are now beginning to provide a reliable estimate of the solar cycle variability of the solar extreme ultraviolet irradiance.

· Nikolai Gavrilov (University of Saint Petersburg) and Ray Roble have used a global mean model of the upper atmosphere and gravity wave and turbulence theory to develop gravity wave heating and turbulent cooling formalisms to guide the use of these effects in the NCAR TIME-GCM (Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model), which they then applied to the energetics of the Mesopause Region. Their study showed a near balance between gravity-wave (dissipative) heating and turbulent cooling for a wide range of conditions, suggesting that the globally averaged middle atmosphere is in near radiative equilibrium.

· Maura Hagan, with collaborators from the University of Colorado, CNRS (France), and Trinity University continued development of a model for tidal and planetary wave studies, including new specifications for effective Rayleigh friction and monthly variability in eddy diffusivity and tidal forcing. Together with collaborators from the University of Colorado, the University of Michigan, the University of Saskatoon, the University of New Hampshire, RASC-Japan, and TYPHOON/Obninsk-Russia, Hagan carried out model and observational studies of global-scale quasi 2-day wave signatures in the mesosphere-lower-thermosphere region during winter conditions. One result of these studies was the confirmation of the interhemispheric asymmetry in the response of the quasi 2-day wave during winter.

· Paul Song and Chris Russell (University of California, Los Angeles) developed the nonlinear MHD dispersion relation for a high beta plasma for application particularly to studies of the magnetosheath downstream of quasi-parallel or high-Mach number shocks. The most surprising and interesting result of this calculation is that fast mode waves are either damped or unstable, which is consistent with observations that the fast mode is unimportant in the magnetosheath.

· Gang Lu, Art Richmond, Barbara Emery, and Ray Roble have investigated magnetosphere-ionosphere-thermosphere coupling processes by incorporating realistic time-dependent patterns of ionospheric convection and particle precipitation derived from AMIE (Assimilative Mapping of Ionospheric Electrodynamics) into the NCAR TIGCM (Thermosphere-Ionosphere General Circulation Model) to study the effect of magnetospheric energy dissipation on the ionosphere and thermosphere. They found that the major part of magnetospheric electromagnetic energy dissipated in the high-latitude ionosphere goes into Joule heating, while only a small part of the energy goes to accelerate the neutral winds.

Solar Physics

The Solar Physics Section of HAO embraces a broad range of research topics connected by a common theme: to understand the physical processes which describe the sun from its interior to its extended atmosphere and the interplanetary medium, and the specific observed phenomena which arise from these processes. Particular emphasis is placed upon those mechanisms which cause the sun to vary its output of radiation, fields, and energetic particles; and, in concert with the Terrestrial Interactions Section, investigation of the influence of these processes on the earth's upper atmosphere.

Solar magnetic activity is the driver for the known variability of the sun on time scales ranging from seconds to decades (and perhaps longer). The source of solar activity lies in the interior of the sun, and it is believed to result from the interaction of convection and rotation in the outer one-third of the solar envelope: the solar dynamo. It manifests itself at the surface of the sun and above in a variety of fascinating phenomena including sunspots, solar flares, prominences, and coronal mass ejections.

These phenomena are interesting subjects of study in their own right as they represent the physical behavior of magnetized plasmas in regimes unattainable in terrestrial laboratories, and as they occur in perhaps the only physical system where we have a reasonable hope of understanding in detail those processes responsible for a wide variety of astrophysical phenomena. Therefore, understanding of solar variability and its terrestrial influences necessarily begins with study of the solar interior. Accordingly, this summary of solar physics research at HAO during FY 94 is organized by domain of study, starting with the deep interior of the sun, and progressing outward through the solar atmosphere into the solar corona, and the solar wind. While emphasis is given to investigation of phenomena related to the solar magnetic activity cycle, this goal is broadly interpreted to encompass the study of the "quiet" solar atmosphere which also participates in the solar activity cycle and whose phenomena are important components of the larger problems of solar magnetic activity and variability.

Research within this section is not limited to the context of the sun alone. Study of the sun provides us with details of magnetic activity in one star at one particular moment of its evolutionary history. Through observation of other stars at different evolutionary states, and whose rotation rates, masses, and chemical compositions differ from those of the sun, we may be able to further constrain the physical processes causing magnetic activity. This research is not only directly related to the overall goal of understanding the physical basis of solar variability, but it also helps scientists at HAO keep abreast of the larger astrophysics community.

Solar Physics at HAO takes a broad-based approach which integrates observations from instrumentation developed and operated in-house, utilization of national and international observing facilities, participation in space programs, and maintenance of a vigorous theoretical program. HAO is therefore maintaining its long history of diversity and excellence in its scientific approach. The following excerpts summarize research activity during FY 1994.

The Solar Interior

Research is ongoing at HAO in both theoretical and observational studies of the solar interior, including the study of solar and stellar oscillations, the evolution of the rotation of solar-type stars, and the physics of convection within the solar interior and its relationship to the solar magnetic activity cycle.

Solar Oscillations. The nonradial acoustic oscillation modes of the sun provide the best available information about the structure and dynamics of the solar interior via measurements at the solar surface of frequencies, amplitudes, and phases of the millions of oscillatory modes.

During 1994 Steven Tomczyk and the HAO Instrumentation Group completed and began operating a new instrument which promises to greatly sharpen our understanding of the deep solar interior. The Low Degree Oscillations Experiment (LOWL) observes oscillations of low degree (spatial frequency) in the velocity field of the solar photosphere. These measurements allow one to infer the structure and rotation rate of the deep solar interior with much greater precision than was possible using prior data. A significant milestone was achieved during FY 94 when the LOWL instrument was installed on Mauna Loa in Hawaii, and began taking routine observations on February 26, 1994. Tomczyk has completed the preliminary analysis of the first 3 months of LOWL data Along with collaborators Jesper Schou (Stanford) and Michael J. Thompson (Queen Mary and Westfield Colleges, U.K.), Tomczyk has completed the preliminary analysis of the first 3 months of LOWL data. They have been able for the first time to constrain the solar rotation rate as deep as 0.2 solar radii. They find that the core of the sun rotates rigidly at a rate not much different from the rotation rate at the surface. This finding is in contradiction to some predictions based upon the expectation that the solar core would retain a significant fraction of its primordial angular momentum. The analysis of longer data sets in the future will result in increasingly more accurate rotation measurements at greater depths into the sun.

For more than a decade, it has been recognized that the observed amplitudes of p-modes are suppressed in regions where the solar magnetic field is even moderately strong; there has, however, been no commonly accepted explanation for this behavior. This year, Timothy Brown suggested that the origin of the effect lies in a distortion of the p-mode eigenfunctions caused by an increase in the effective sound speed just below the solar photosphere. Evidence for such an eigenfunction distortion is found in the frequency dependence of the surface amplitude suppression. Indeed, the observed frequency dependence allows one to estimate the depth variation of the sound speed perturbation at each point on the sun's surface where the p-modes are observed. Combining the depth dependence inferred from the surface amplitudes with magnetogram data, one may estimate the corresponding changes in global p-mode frequencies resulting from the solar activity cycle. These turn out to be in agreement with the observed frequency shifts. A reasonably consistent picture can therefore be drawn relating the magnetic field at and just below the solar surface to the amplitudes and frequencies of the p-modes. Brown is continuing work to test for observable consequences of this picture, and (assuming the picture is correct) to sharpen the inferences that may be made concerning subsurface conditions, based upon observed surface amplitudes.

Theoretical Models of the Evolution of Internal Rotation and Magnetic Fields for the Sun and Solar-Type Stars. Paul Charbonneau and Keith MacGregor have begun the extension of their solar spin-down calculations to the case of non-axisymmetric internal magnetic fields. One interesting novelty, as compared to axisymmetric magnetic fields, is the possibility of destroying, by wrapping and reconnecting, the non-axisymmetric part of an initial magnetic field, leaving behind only its axisymmetric component. Rough estimates for solar parameters indicate that this process of symmetrization may occur for field strengths as high as a few Gauss, and so may well be an important factor in the magnetic and rotational evolution of the deep solar interior. As a first step toward the solar problem, the symmetrization mechanism is being studied (in collaboration with Fran Bagenal and Nick Schneider, APAS/University of Colorado in Boulder) in the kinematic regime, with a first application to the evolution of the internal magnetic field of Saturn. Solutions computed thus far indicate that the symmetrization process can operate rather efficiently in the Saturnian interior, despite the relatively low electrical conductivity.

Rony Keppens (visiting graduate student, Katholieke Universiteit, Leuwen, Belgium), MacGregor, and Charbonneau have completed an extensive parameter study of the evolution of rotation rate distributions of solar-type stars. The simulations highlight the difficulty of producing, at early evolutionary epochs, both a large population of slow rotators *and* a small group of rapid rotators. Their computations suggest that dynamo saturation plays an essential role in producing rapid rotators, and that magnetohydrodynamic coupling between a protostar and its surrounding accretion disk during the late pre-main sequence evolutionary phase may well be the only way to produce a population of slow rotators on the early main sequence. However, at least within the simple star-disk coupling model used for this study, a relatively fine tuning of parameters appears required to achieve the desired effect. Detailed investigations of the star-disk coupling mechanism must be carried out if further progress is to be made along this line. In parallel with this effort, postdoctoral visitor, Jianke Li (University of Sydney, Australia) has undertaken the study of a number of closely related MHD problems, with the hope of further clarifying the physical nature of the star-disk coupling.

The Solar Dynamo. Charbonneau and MacGregor have begun a systematic study of two-dimensional, axisymmetric, mean-field dynamos, including explicit treatment of flows driven by the large-scale Lorentz force. These calculations have three principal goals: (1) to investigate how the growth of the dynamo-generated field is affected by the inclusion of flow dynamics, particularly in the supercritical regime; (2) to model the torsional oscillation pattern observed at the solar surface; and (3), to investigate the possibility that the nonlinear interaction between the field and flow can modulate the operation of the dynamo, thereby leading to Maunder minimum-like periods of reduced magnetic activity. In an effort to better understand how the physical behavior of a nonlinear, dynamical, $\alpha\omega$-dynamo differs from that of its kinematical counterpart, several simplified models have been studied. In these models, the dynamo is situated in a Cartesian slab rather than a spherical shell, in such a way that the radial, azimuthal, and meridional directions approximately correspond to the *z*, *y*, and *x* coordinate axes, respectively. Solutions to the momentum and mean-field induction equations are sought in which the depth (*i.e.*, *z*) dependence of the fields is separable from their dependences on time and latitude (*x*). The models are further simplified by specifying the functional form of the dependence on vertical position so that physically derived boundary conditions on the top and bottom surfaces of the domain are automatically satisfied. In the kinematical limit for which the vertical extent of the domain is much greater than its horizontal extent, the equations describing the frequently studied "one-dimensional" -dynamo are recovered. These equations have been used to study how the operation of the dynamo is modified when provision is made for a dependence of the α-effect on the magnitude of the generated field. In particular, Charbonneau and MacGregor are studying the amplitude asymmetries and multiple periodicities that arise when an external source of a non-dynamo generated toroidal magnetic field is present in the domain. Such a situation might arise in the sun if an internal, primordial magnetic field was sheared by differential rotation, and subsequently diffused into the region occupied by the dynamo.

Two-dimensional models in pseudo-spherical geometry are also studied. In the supercritical regime, the models often exhibit multiple periodicities, and the relative phases between the toroidal, poloidal and velocity fields usually depend rather sensitively on the magnitude of magnetic and viscous dissipation, while the dynamo period typically does not. By detailed comparison of the spatial distribution and temporal evolution of the field components, velocity field, Lorentz force and dissipation, Charbonneau and MacGregor are currently investigating whether or not such effects can limit the growth of a solar dynamo operating in a thin layer at the base of the solar convection zone, and drive large-scale, small amplitude toroidal oscillations throughout the bulk of the solar convection zone.

(Dynamo Snapshot)

Charbonneau, Thomas Bogdan and MacGregor have constructed and are studying a class of axisymmetric numerical mean-field dynamos characterized by the propagation of a dynamo surface wave at the interface between the solar radiative core and overlying convective envelope. These interface dynamos lead rather naturally to the storage and amplification the toroidal magnetic field in a thin, stably stratified layer located *below* the core-envelope interface, even though the helicity is assumed to strictly vanish there.

(Dynamo Video)

This occurs in part because of a abrupt change in magnetic diffusivity, typically by many orders of magnitude across the interface. These models complement rather nicely recent calculations of the formation of bipolar active regions; the eruption of bipolar active regions at the solar surface is thought to be due the rise through the convection zone and subsequent emergence of intense toroidal magnetic flux loop stored below the convection zone. Numerical simulations of this process usually begin with the suppositions that near-equipartition strength toroidal magnetic flux tubes already exist below the convection zone, that the interface dynamo provides an attractive way to build up this field, *and* that it leads to the usual cyclic regeneration of a more diffuse magnetic field component throughout the solar convection zone, including both a toroidal and poloidal part. Computations carried out thus far indicate that the dipolar mode of operation is most easily excited for dynamo numbers that are critical and/or only weakly supercritical, and that the poloidal field reverses sign very rapidly between successive cycles.

Peter Fox and Peter Gilman (NCAR) continued their investigation of kinematic and dynamic solar dynamos. An axisymmetric dynamical model of differential rotation, meridional circulation and thermodynamic variations at the base of the convection zone has been constructed for a variety of boundary forcings and parameter values. These calculations provide a framework for studying the induction of a magnetic field in that region; an important step for understanding the behavior of the solar dynamo.

Solar Convection. Bogdan and Michael Knölker (Kiepenheuer Institut für Sonnenphysik, Freiburg, FRG) continue their collaboration with Fausto Cattaneo and Andrea Malagoli (University of Chicago) to create a low-viscosity hydrodynamic code for studying compressible convection at the highest attainable Rayleigh and Reynolds numbers. The program involves modification of the existing convection code developed by Cattaneo and Malagoli to incorporate the transport of energy by radiation. In its present form, the transport of energy is effected entirely through thermal conduction characterized by a constant thermal conductivity. The present code and its successor are both based upon a time splitting algorithm, wherein the dependent variables are first advanced by integrating along the characteristics neglecting diffusivities, and then the temperature is subsequently updated by taking account of the nonadiabatic transport of energy. In the advanced version of the code, this latter step requires the subsidiary task of computing the divergence of the radiative flux from the solution of the frequency-integrated (grey) equation of radiative transfer under the assumption of local thermodynamic equilibrium. This modification will be implemented using numerical techniques developed by the group at the Kiepenheuer Institut fur Sonnenphysik, which has been simulating the structure of solar surface magnetic flux concentrations.

Fox, with Yong-Cheol Kim (Yale University) completed an investigation of convective overshoot into a stably stratified layer--in this case, the interface between the solar convection and interior radiation zones. Previous calculations in two-dimensions were analyzed and augmented with three dimensional simulations. Both calculations encorporate a more realistic equation of state and opacities, as well as radiative transport by diffusion. The flows in the stable layer are small scale--less than 1/4 of the local scale height--with considerable spatial and temporal variation in the local super-adiabatic temperature gradient, which nominally delineates stable and unstable regions.

Fox, with Thomas Lydon and Sabatino Sofia (Yale University) calculated solar structure models of high precision and fine time resolution (1 month). These models were subjected to perturbations in convective energy transport and magnetic pressure contributions, then were compared to the most recent study of this type by Endal, Sofia and Twigg (in 1985). The results of this work has implications for global solar variability, specifically the correspondence between radius and luminosity changes on decadal and longer time scales.

Fox and Vittorio Canuto (NASA/GISS) have completed some tests of new formulations of Subgrid-Scale (SGS) turbulence models (developed by Canuto and associates) using large eddy simulations of compressible, stratified convection. These SGS models incorporate the physical effects of unstable and stable stratifications, rotation, anisotropy, temperature variance, and buoyancy effects in the expressions for the Reynolds stress and turbulent heat flux. An important effect was found when buoyancy terms are included: namely that since regions of high buoyancy do not coincide with those of high shear, the SGS formulation provides a much better description of small scale dissipation in both upflow and downflow regions.

Stellar Oscillations and Modeling. Brown, in collaboration with Robert Noyes, Peter Nisenson, and Sylvain Korzennik (all from the Harvard/Smithsonian Center for Astrophysics) and Scott Horner (Pennsylvania State University) has continued to improve the performance of and to observe with the Advanced Fiber Optic Echelle (AFOE), a spectrograph that is being used to study the pulsations of sun-like stars. Detection of oscillations in such stars would sharpen the diagnostic potential of the p-modes seen in the sun, by clarifying the physical processes relevant to stellar structure and pulsation. Significant improvements have been achieved during FY 94 in several aspects of the AFOE's performance. Mechanical stability has been brought nearly to the desired level by implementation of a vastly improved thermal control system; a new stellar fiber system and correction of a long-standing telescope problem have increased the system transmission by a factor of about six; installation of a new slit assembly has substantially increased the spectrograph's versatility; refinements in analysis algorithms have brought systematic Doppler errors down to the 5-10 m/s level; and the first release of source-controlled analysis software for the AFOE took place. In addition to instrument development activity, there were six observing runs in FY 94, concentrating primarily on pulsations in the sun-like star Procyon, with lesser amounts of time devoted to observations of pulsations in rapidly-rotating δ Scuti stars (υ UMa and ε Cep), and in a number of Cepheid variables. In collaboration with S. Tripathy (Udaipur Solar Observatory, India) and the rest of the AFOE team, a search for pulsations in the peculiar A star β CrB is nearing completion.

Brown and Jorgen Christensen-Dalsgaard (NCAR Affiliate Scientist, University of Aarhus, Denmark) are collaborating on a study of the utility of p-mode frequencies in constraining stellar structure models, when applied to main-sequence stars in open clusters (the Hyades, for instance). This work is an extension of a just-completed project that asked similar questions about the usefulness of p-mode data in constraining models of visual binary stars. The most difficult underlying problem in the current study is how to assess the agreement (or lack thereof) between observed color-magnitude diagrams and theoretical isochrones. This problem has apparently been solved, and work on other aspects of the study is continuing.

The Solar Photosphere

The region just above the visible surface of the sun is known as the photosphere. It represents the interface at which the transport of energy suddenly changes from dominantly convective in the interior to dominantly radiative in the lower solar atmosphere, and above. The nature of the stability and thermodynamics of magnetic concentrations in the photosphere, occurring on both large scales (sunspots) and very small scales ("flux tubes"), both with field strengths in the kiloGauss range, is one of the major puzzles for solar physics. Quantitative understanding of their structure is a major goal of the section.

Solar Granulation. During FY 1994 Mark Rast (postdoctoral visitor) continued studies into the dynamics of solar granulation, focusing particularly on the nature of "exploding" granules and granule fragmentation. Of particular interest are the dynamical effects of partial hydrogen ionization and photospheric radiative losses, and their role in new downflow plume formation. Numerical simulations indicate that descent velocities in plumes formed during granule fragmentation can become supersonic with depth, and this suggests that these sites are potentially ones of significant acoustic emission. To investigate this possibility, Brown and Rast in collaboration with Ted Tarbell (Lockheed) have begun to look at high spatial and temporal resolution Doppler and continuum images of the sun. Localized sites of particularly high high-frequency acoustic power have been identified, and a number of these may be associated with discrete sources. Rast in collaboration with Douglas Gough (Institute of Astronomy, Cambridge) has also investigated the properties of very high-frequency acoustic oscillations in a simplified analytic model of a driven polytrope overlain with an isothermal atmosphere. Variations in the frequency spacing and linewidth of oscillations well above the atmospheric acoustic cutoff frequency reflect the depth of the driving and damping layer.

Fox with Sabatino Sofia, Yong-Cheol Kim and Thomas Lydon (Yale University), and Kwing Chan (formerly of NASA/GSFC, now at National University of Science and Technology, Hong Kong) improved the physical description of convective energy transport using results from high resolution three-dimensional simulations of solar and stellar granulation and photospheric convection which encorporate a realistic equation of state and opacities (from LASL, OPAL, and Kurucz). An improved formulation of radiative transfer was developed and tested. Existing simulations, with the radiative diffusion approximation were analyzed to study the mean convective energy transport in regions of partial ionization and in the presence of radiative losses. They compared the previous results of Chan and Sofia for ideal gases with the new simulations, focusing on partial ionization and radiation effects, i.e. the difference between deep, efficient and shallow, inefficient compressible convection. They also investigated relationships for mean and fluctuating quantities suggested by Mixing Length Theory (MLT), using the aforementioned numerical simulations. In shallow photospheric layers, i.e. when the superadiabaticity exceeds 0.01, the inefficient nature of the convection significantly alters the linear relations that MLT suggests. In addition, the mixing length was found not to be proportional to the local scale height in those shallow layers.

Sunspots and Flux Tubes. The Advanced Stokes Polarimeter (ASP), a joint program between HAO and the National Solar Observatory (NSO), is now providing polarimetric data of unprecedented angular resolution and polarimetric accuracy. During FY94 observations using the ASP continued, and significant scientific results began to emerge from analysis of the data. Valentin Martínez Pillet (Visitor, Instituto de Astrofísica de Canarias, Spain), Lites, Skumanich, and Detlev Degenhardt (Freiburg University, FRG) identified a highly localized but substantially supersonic flow at the polarity inversion line of a "delta" sunspot (one which comprises magnetic fields of both polarities). This is the highest velocity flow yet identified in the solar photosphere.

Lites, Low, Martínez Pillet, Skumanich, and Seagraves continued investigation of the vector magnetic field structure of this delta-type spot. The high quality vector magnetograms from the ASP (one example is shown in the accompanying image) were combined with high resolution continuum and $H\alpha$ imaging of the same region obtained at the Swedish Solar Observatory on La Palma (Richard Shine and Zoe Frank, Lochkeed Palo Alto Research Laboratories) and X-ray images from the Yohkoh spacecraft (Saku Tsuneta, Tokyo University) to form a rather complete picture of the evolution of this region.

(ASP Image)

All of the observational data point to the novel interpretation for a nearly closed magnetic structure rising buoyantly through the photosphere into the corona. Reexamination of the observational literature indicates that the evolution of previously observed delta-type sunspots may be similarly interpreted. This new concept is greatly strengthened by Low's development of a three-dimensional analytic solution of the MHD equations for a gravitationally-stratified, closed torroidal magnetic flux system. This model agrees remarkably well with the field topology implied by the observed development of the vector magnetic field in the photosphere. It also suggests the formation of prominence-like structures in the chromosphere once the magnetic system has largely emerged into the solar atmosphere. The high velocity downflows observed at the polarity inversion line could be interpreted in this picture as points where the plasma contained in the rising magnetic system finds a route to drain downward. The scenario developed for the evolution of this delta-type sunspot might also be relevant to the emergence and evolution of large-scale structures in the quiet sun associated with polar-crown filaments and coronal mass ejections (see discussion below on the solar corona). It is yet too early to ascertain if this one event is representative of a primary means for the sun to shed magnetic flux and magnetic helicity, but if this interpretation survives further scrutiny, it will represent a major advance in our understanding of solar activity.

A longstanding problem of solar physics has been the nature of the decay and dispersal of sunspots and active regions. For the first time, the ASP has provided measurements of the magnetic flux of sunspots as they traverse the entire solar disk with a precision that allows one to measure their actual decay rates. For some time it has been suspected that "moving magnetic features" (MMFs)--small magnetic elements which appear to drift away from the outer edges of sunspots--represent the decay of sunspots. Pillet has used sequences of vector magnetic field maps from several sunspots observed in June 1992 to measure the net flux of the MMFs. He finds that the apparent decay rate represented by the MMFs is at least four times the actual observed decay rate of the sunspots. Thus, the MMFs do not represent the direct removal of flux from the sunspot: they must arise from from some other physical process. A short animation sequence showing the MMF phenomenon accompanies this document.

(ASP Video)

In a continuing study of sunspots, Skumanich, Lites, and Martínez Pillet have inferred the thermodynamic structure from the Stokes polarization profiles of small size sunspots observed with the Advanced Stokes Polarimeter (ASP). This is the first such use of Stokes profiles to derive the thermodynamic state for each observed magnetic elemental area. Their results for spot umbrae are in good agreement with extant thermal models inferred by other means whereas their penumbral results--which are not dependent on any assumptions regarding hydrostatic equilibrium--are significantly different from extant models predicated on hydrostatic equilibrium. They have also conclusively demonstrated that, in the mean, the penumbral Evershed velocity field is more inclined from the local solar vertical than the magnetic field by approximately 15 degrees and is not, contrary to popular assumptions, horizontal throughout the penumbra. This velocity field is found to extend out into the magnetic canopy beyond the penumbral edge.

The precise, high resolution polarization measurements obtained with the ASP permit one to assess the accuracy of more approximate observational and interpretive techniques commonly used to measure vector magnetic fields. Lites, Low, Martínez Pillet, and Skumanich carried out extensive simulations of vector magnetograph data based on imaging (instead of spectral, as with the ASP) polarimeters operating at fixed positions in the wing of solar spectral lines. They showed that serious errors in both the strength and orientation of the inferred magnetic field are commonplace, especially in active regions outside of sunspots. However, within sunspots, even though the vector field can be substantially in error, the imaging technique at least provides a reliable visual impression of the field orientation.

Fox completed an investigation of magnetic flux expulsion from a submerged horizontal flux concentration based on both two and three-dimensional models. It was found that many aspects of the flux emergence (omega-loops) are similar in two and three dimensions, however the submergence (u-loops) is distinctly different. He also completed a study of the convective collapse of a magnetic flux tube using a fully three-dimensional, stratified MHD simulation. The collapse process was compared to linear stability calculations (i.e. the onset of convective instability, represented by the local Brunt Vaisala frequency) and found to agree extremely well in the onset phase of the collapse. The calculation also confirmed the prediction of Spruit, that the tube could "blow up" due to both upward and downward flows.

(Sun 1 Image)

(Sun 2 Image)

MacGregor and Victor Pizzo (NOAA/SEL) continue to develop and refine their model for magnetostatic flux tubes in the solar atmosphere. The model is based on an efficient numerical procedure for solving the coupled equations describing force and energy balance in static, two-dimensional, magnetic structures including radiative transfer effects in two dimensions. Recently they have refined their model to treat the ionization equilibrium of a gas composed of hydrogen and helium in a more physically realistic manner, applicable to the conditions within a region extending roughly 500 km above and below the visible photosphere. They have also replaced the assumed adiabatic stratification of the subphotospheric layers by a one dimensional, mixing length formulation of convective energy transport. Pizzo and MacGregor are presently conducting a systematic comparison between the properties of flux tubes obtained using the current and previous versions of the model. They are also studying how flux tube characteristics are modified by the use of different specifications for the way in which vertical convective transport is inhibited by magnetic fields.

The Solar Chromosphere

In the chromosphere, which overlies the photosphere and is transparent to the bulk of the photospheric radiation, the nature of the energy supply changes. It appears that the dissipation of mechanical energy from waves and/or the dissipation of electric currents induced via horizontal motions of field footpoints provide the main energy source. Whether this energy is released in situ or propagates to this region from below (via waves) or from the corona above (via either energetic particles or conduction), or both, is poorly understood. Also poorly understood is the "transition region" between the solar chromosphere and the hot corona. Here again, magnetic fields must frequently play a dominant role in separating the plasma in these two temperature regimes. Even though the solar chromosphere and corona contribute only a tiny fraction of the total solar radiative output, these layers give rise to most of the variability the ultraviolet radiation from the sun, which in turn has a strong influence on the upper terrestrial atmosphere, as discussed later in this report. Significant advances in understanding of the energetics and dynamics of the solar chromosphere will depend upon the development of better diagnostics of the chromospheric plasma. Much of the current work on the chromosphere at HAO is in the direction of exploring these diagnostics.

Spectral Diagnostics of Chromospheres of the Sun and Stars. Not only are the spectral lines of hydrogen important diagnostics of the upper atmospheric layers of solar-type stars, they also play important roles in setting the structure and energetics of their atmospheres. In FY 94 Ivan Hubeny (visitor, NASA Goddard Space Flight Center) and Lites completed a method to treat in a general way the radiative transport within the resonance lines, including the effects of "partial redistribution" (PRD) of line photons over the frequency range of the spectral lines. They carried out the first computations of the hydrogen line transfer in one-dimensional model solar chromospheres in which all of the physics important to the PRD process in a stellar atmosphere, including resonant Raman scattering among the transitions, was treated in a general way for a multilevel model atom. They illustrated the effects of this multilevel, multi-transition interaction on the formation of the wings of the $L\beta$ line, indicating only rather small changes in the intensities of the line wings. Perhaps more importantly, their general and robust method for computation of the multilevel PRD transfer was demonstrated, and this development paves the way for physically complete treatments of PRD in other contexts, and including the effects of atmospheric dynamics and horizontal structure.

Frederic Paletou (Visitor, Institut d'Astrophysique Spatiale, University of Paris) and Lawrence Auer (Los Alamos National Laboratory) also worked on methods for solutions of the equations of transfer incorporating PRD effects. Their aim is toward development of computationally efficient means of solution of equations so that the PRD transfer problem may be solved in two- and three-dimensional geometry. They perfected an approximate operator technique which retains the essence of the PRD effects, thus producing rapid convergence of the iterative scheme even for lines such as hydrogen $L\alpha$ which have a very high degree of coherent scattering in the line wings, hence are greatly affected by PRD.

Philip Judge has continued to develop the "HAO Spectral Diagnostics Package" (SDP). The SDP can be used for calculations ranging from LTE calculations of photospheric lines, through NLTE calculations of coronal emission lines. It can be used to determine line emissivities for application to studies of emission lines formed in a variety of astrophysical sources. It contains packages for the computation of approximate atomic data and it will also contain interfaces to other atomic databases. A crucial component of the SDP is the careful compilation and documentation of the atomic data in the models. Thus, the user will easily be able to judge whether the existing atomic model contains sufficient data of sufficient quality to meet his/her needs. Furthermore, the user will also be able to modify existing models easily. A public release of this package is anticipated within the coming year.

With summer undergraduate student Veronika Hubeny, Judge has developed a promising simple method for the inversion of intensity integrals (for optically thin emission lines) with the aim of determining the distribution of material within an observed plasma as a function of temperature *and* density. This is potentially very valuable since, recognizing that unresolved plasma structures always exist in solar and stellar data, this method allows one to derive additional constraints on the distribution of plasma as a function of temperature and density and thus provide more detailed quantitative information on the nature of the unresolved structure. Thus one can anticipate making some major strides in the analysis of high quality data from new instruments, e.g. on the SOHO spacecraft.

In collaboration with Carpenter, Robinson (both NASA-Goddard), Judge has analyzed Goddard High Resolution Spectrograph (GHRS) observations of the anomalously weak resonance lines of OI and CI in the UV spectrum of the prototypical red supergiant α Ori. From a comparison of observational and theoretical data of various stars, Judge argues that their weakness in α Ori results from background opacity sources which become optically thick in the chromospheres of the most luminous stars. This work provides vital clues to the physical cause of the infamous "Wilson-Bappu" effect and its limitations, and has prompted re-analysis of radiative transfer problems including partial redistribution in the presence of background absorbers. They have also analyzed GHRS spectra of the M giant γ Cru. The observed line profiles indicate complex kinematics in the chromosphere which provide strong observational constraints on dynamical models for the expanding stellar wind.

Judge (with T. Brage, NASA-GSFC and C. Froese-Fisher, Vanderbilt University), using the HAO Spectral Diagnostics Package, has studied in detail observed emission lines of doubly ionized nitrogen in a variety of objects with the aim of determining the quality of atomic data and the potential of these lines as diagnostics of electron pressures in optically thin plasmas. Existing solar data are not of sufficient quality to determine whether recent experimental or theoretical oscillator strengths, calculated by the authors, are in error. Data from low density astrophysical plasmas indicate potential problems with collision cross sections thereby bringing into question previous determinations of electron pressures in a variety of objects.

Observations of the Chromosphere-Corona Transition Region. From the perspective of astrophysics and cosmology, the abundance ratio of helium to hydrogen is an extremely important observable quantity. The abundance ratio may however be strongly affected by physical processes such as thermal diffusion in the solar chromosphere and transition region. Hassler, Rottman, and Woods along with Egil Leer and Viggo Hansteen (both at Institute for Theoretical Astrophysics, University of Oslo, Norway) are preparing an experiment to fly with Tom Woods' sounding rocket experiment on November 3, 1994 to measure the helium abundance in the corona.

Hassler has been active in preparation of the SUMER (Solar Ultraviolet Measurements of Emitted Radiation) instrument which will fly on the joint ESA-NASA satellite SOHO (Solar and Heliospheric Observatory), scheduled for launch in July 1995. The SUMER instrument is a normal incidence spectrometer to study plasma flows, temperatures, densities, and wave motions in the upper chromosphere, transition region and lower corona with high spatial (one arcsecond) and spectral resolution by measuring line profiles and intensities of ultraviolet lines in the wavelength range 500-1600 angstroms. During FY 94 he spent several months at the Institut d'Astrophysique Spatiale (IAS) in Orsay, France working on the development and characterization of the SUMER instrument. Once launched, this instrument is expected to provide new insight into the processes which heat the chromosphere and corona.

The Solar Corona/Solar Wind

With its million degree temperature, the solar corona is so hot that it cannot be everywhere confined by solar gravity. It extends out to several solar radii where it blends into the solar wind flowing at supersonic speeds into interplanetary space. The magnetic field competes with the solar-wind expansion, forming isolated, closed-field regions where near-static plasmas are trapped. This dynamical competition determines the state of the large-scale corona in terms of open and closed magnetic regions, as exemplified by the coronal holes and helmet streamers.

The corona contributes significantly to the variability of the solar influence on the earth. The solar flares and intensely heated magnetic structures at the base of the corona produce short-wavelength electromagnetic radiation, as well as energetic particles, which influence the dynamics and chemistry of the earth's upper atmosphere. The sporadic ejections of magnetized plasmas, called coronal mass ejections, strongly perturb the background solar wind to impinge and interact with the earth's magnetosphere, causing geomagnetic storms and changing the earth's space environment. The understanding of the corona as a component in the solar-terrestrial chain of coupled systems must start with a physical description of the corona as an electrically highly conducting atmosphere in terms of its response to the solar dynamo below and its influence on the interplanetary space.

Interpretation of Coronal Observations. The HAO archives of white-light coronagraph images obtained on the ground at Mauna Loa over the past 30 years and obtained from space during the Skylab (1972 - 1977) and Solar Maximum (1980-1989) Missions are a unique data set which documents sporadic events of coronal mass ejections as well as the evolutionary changes of the corona over solar-cycle time scales. The value of this data set has been greatly enhanced by combining Mauna Loa white-light observations with simultaneous observations of the corona in soft X-rays by the Japan-NASA YohKoh satellite, through the collaborative works of Arthur Hundhausen, David Sime and Eijiro Hiei (Mesei University, Japan and Tokyo National Astronomical Observatory).

Hundhausen, David Elmore, Alice Lecinski, Joan Burkepile, Sime, Andrew Stanger, and Fran Bagenal (University of Colorado) continue with the upgrade of the white-light observations made with the existing Mark III coronameter at Mauna Loa. The field of view has been extended out to 2.74 solar radii, calibration has been improved significantly, and preparation has been made to render the data set available to outside users, in particular, to provide information on the global corona in support of experiments on the Ulysses spacecraft.

Hiei, Hundhausen, and Sime reported the simultaneous observations in white-light and soft X-rays of the reformation of a coronal helmet streamer at the solar west limb on January 24-26, 1992. The white-light and $H\alpha$ data indicate that a prominence eruption and coronal mass ejection occurred before the reformation event. This is the first persuasive observational evidence of the helmet streamer being formed as a closed magnetic structure in the corona by resistive reconnection of a magnetic field after the field has been pulled open by a coronal mass ejection.

(White Light/YOHKOH Image)

The complex relationship between coronal mass ejections and solar flares is a subject of considerable current interest; see the previous annual reports. Joan Feynman (Jet Propulsion Laboratory) and Hundhausen studied the flares and mass ejections associated with the large March 1989 active region. The study concluded that while mass ejections are associated with flares and prominence eruptions, neither of the latter is required for the occurrence of a mass ejection. It was proposed that the coronal mass ejections are related more directly to the evolution of the large scale magnetic field of the active region, a result consistent with the earlier study of the relationship between mass ejections and large-scale coronal magnetic fields by Sime.

Hundhausen, Burkepile and St. Cyr (now at Allied Signal Technical Services) reported on the statistical and general speed properties of coronal mass ejections observed by the SMM coronagraph in the periods 1980 and 1984-1989. In a set of 673 mass ejections observed, the speeds range from below 100 to about 1000 $km\ s^{-1}$, with an average speed of about 350 $km\ s^{-1}$. While there are variations in the distribution of speeds as a function of other physical quantities, the variations are not significant, notably, with respect to the phase of the activity cycle, widths of mass ejections, and latitude occurrence. This work is a part of an ongoing comprehensive program to interpret the SMM and Mark III data sets. The results of this program are not only useful scientific information provided to the external community, but they also serve as the starting point to go beyond the SMM era to explore the large-scale corona and its dynamics in the next decade with the prospects of the LASCO coronagraph to be flown on the ESA/NASA SOHO satellite, and HAO's current and future coronagraph observations from the ground.

Hassler and Tom Moran (GSFC) are continuing their ground-based observing program at NSO/Sac Peak to measure line profiles of the visible coronal emission lines as a function of height above the limb. Profiles of the visible Fe X coronal emission line were obtained out to 1.16 solar radii in a coronal hole. Analysis of the line widths suggests a large component of nonthermal broadening which increases with height ranging from 40 to 60 km/s, depending on the assumed temperature or thermal component of the profile. These results are in agreement with previous UV line profile measurements from sounding rockets and may suggest the presence of hydromagnetic waves, which are thought to play an important role in heating the corona and accelerating the solar wind.

Hassler is working with Lyman-alpha and white light observations of a coronal mass ejection (CME) ovserved with the White Light (WLC) and Ultraviolet (UVCS) Coronagraphs on the SPARTAN 201 satellite flown on the Space Shuttle in April 1993. From the measured velocity and electron density of the CME inferred from the pB images, these Lyman-alpha observations provide constraints on the ionization ratio of neutral to ionized Hydrogen and, thus, the electron temperature in the CME. The results suggest that the electron temperature in the CME can be as much as a factor of two lower than the surrounding plasma.

Sime reported his collaboration with a team led by S. Koutchmy (Institut d'Astrophysique, France) to observe the corona during the July 1991 eclipse at Hawaii using the Canada-France-Hawaii telescope. Fine-scale coronal features were observed for the first time suggestive of plasmoid-like activity and sheet-like voids above a filament channel.

The problem of how the coronal polar magnetic fields are reversed at the end of a solar cycle was addressed by Fox, Peter Wilson (University of Sydney), Pat McIntosh (NOAA/ERL/SEL), and Herschel Snodgrass (Lewis and Clark College), using Mt. Wilson magnetograms and $H\alpha / He$ 10830 synoptic charts together with models of magnetic field evolution. They found a systematic reversal process which fits all of the solar cycles for which magnetic polarity data exist. In this process, the weakening polar coronal hole drifts in latitude down and through a gap in the belt of high-latitude dark filaments drifting poleward in the opposite direction. Eventually, the gap closes and a new coronal hole of the opposite magnetic polarity moves into the pole from the lower latitudes.

In the theoretical study of coronal magnetic fields, Boon Chye Low proposed a global view of the solar activity in the corona. This view physically relates flares of various varieties, the formation of large-scale long-lived structures, and the daily events of coronal mass ejections; treating them as direct manifestations of the continual injection of fresh magnetic flux from below with the effect of the complete reversal of the large scale coronal magnetic field at the end of a solar cycle. In this view, the approximate conservation of magnetic helicity, suitably modified for the open coronal system, is a central concept dictating complementary roles for MHD energy releases by disspative and ideal processes. Based on observations and the physics of this view, it is also pointed out that a largely disengaged magnetic flux system may bodily enter the low corona to be eventually ejected out into the interplanetary space. This idea draws support from the recent interpretation of a delta-sunspot observed by the Advanced Stokes Polarimeter reported elsewhere in this report.

Joan Hundhausen (Colorado School of Mines) and Low developed a versatile magnetostatic model to demonstrate the basic structural and stability properties of the helmet-cavity-prominence system. Graduate student Yung-Ping Chou (ASP Graduate Fellow, Ph.D. 1994, Columbia University), Amitva Bhattacharjee (Iowa State University), and Low demonstrated the ideal MHD stability of highly sheared magnetic structures with three-dimensional variations suggested by the fine-scale structures in the penumbra of a sunspot observed by Alan Title (Lockheed Palo Alto Research Laboratories) and collaborators. In both works, it was shown that the forces associated with magnetic curvature and gravitational stratification may, under suitable solar circumstances, counteract to promote overall stability.

Chou and Charbonneau constructed numerical models of an axisymmetric magnetostatic corona in which a plasma depletion region is created and kept in equilibrium by a localized strong magnetic field associated with an azimuthal electric current. Parametric analysis of the models shows that successive states of increasingly enhanced depletion leads to a point characterized by an absence of neighboring equilibrium solutions. This result identifies these terminal equilibrium states to be initial states for a time-dependent MHD numerical calculation to study the onset of a coronal mass ejection. This work is motivated by observations that mass ejections originate from the destabilization of a helmet streamer by the prominence cavity; see the reports of the earlier years.

Solar and Stellar Winds. Charbonneau and Hundhausen suggest that the competition between the hot corona to expand into the solar wind and the tendency for a magnetic field to close upon itself may be governed by a variational principle which constrains the large-scale corona to seek a state of minimum total energy composed of the gravitational potential energy, internal energy, magnetic energy, and kinetic energy. This variational principle is difficult to formulate because the corona is an open system subject to an unknown heating mechanism. To explore the idea, a sequence of hybrid corona and wind models were used to simulate the global corona for a dipole-like magnetic field. It was found that with reasonable inputs of physical parameters, the member of the sequence with the minimum total energy is the one which best fits the morphology of the corona at activity minimum.

In an ongoing study of dynamical processes in expanding stellar atmospheres, MacGregor and Charbonneau studied the effect of the force produced by Alfvén waves on steady winds without the traditional simplifying restrictions on the wavelengths relative to length scales of the windflow. For physical conditions relevant to the corona, it was found that partial reflection of both high and low frequency waves and the interaction between inward and outward going waves can produce dynamical structures in the wind not found in the traditional WKB approximation. The theory has been extended to cool, evolved stars which do not have adequate thermal pressures to drive their outflows. Recent computational results suggest that, while undamped WKB Alfvén waves may accelerate low-temperature steady winds from such stars, non-WKB waves cannot, although this conclusion may not carry over to a time-dependent situation.

Solar Variability

Observations of Solar Variability

UARS SOLSTICE. The Upper Atmosphere Research Satellite was launched in September 1991. The High Altitude Obseravtory has responsibility for the Solar/Stellar Irradiance Comparison Experiment (SOLSTICE), one of ten scientific instruments aboard the satellite. The SOLSTICE is a three channel spectrometer and measures the solar irradiance at ultraviolet wavelengths between 120 and 420 nm. Three of the other UARS instruments also measure the energy input to the earth's atmosphere, and the remaining seven measure atmospheric composition and dynamics.

The SOLSTICE has now provided over three years of irradiance data and the resulting time series clearly show solar variability on all time scales. The amount of variation differs significantly as a function of wavelength, from a small fraction of one percent at the longest (visible) wavelengths, increasing toward shorter wavelengths, and becoming as large as a factor of two near 120 nm.

(Time Series Figure)

The "Time Series" figure is the SOLSTICE measurement of the solar irradiance near 200 nm, radiation important to both the production and distruction of ozone in the earth's middle atmosphere. Modulation at the 27-day period of solar rotation is especially obvious. One of the principal finding is the apparent rapid decline of Solar Cycle 22 in a series of steps following the last strong outburst of solar activity in January of 1992. These data plus measurements provided by Jack and Karen Harvey of the National Solar Observatory suggest a short, strong cycle with a length near 10 years.

Precise photometry accurate to better than 1% over long time periods is extremely difficult, especially in the ultraviolet where the harsh radiation coupled with the space environment have notoriously degraded the optics and compromised the stability of past instruments. However, SOLSTICE is uniquely suited to this challenge and incorporates its own internal, long-term calibration technique. During night portions of each orbit, it observes bright, blue stars with the very same optics and detectors used for the solar observations. The key assumption for this calibration technique is that these young stars, of spectral classification O, B, and A are inherently stable and, in fact, the theory of stellar evolution postulates that these stars should be stable to far better than 1% over time periods of thousands of years. Moreover, a collection of more than twenty stars is used, and it is the ensemble average flux from these stars that, first, provides a mechanism for identifying and removing any pathological stars from the selection, and then yields an average stellar flux level that should be absolutely unvarying in time. Apparent changes in this stellar flux level, therefore, are immediately and unambiguously recognized as changes in the SOLSTICE sensitivity. HAO scientists continue to validate and analyze the SOLSTICE results, now confident that the stellar comparison technique is working well and that the final solar data set will provide a relative accuracy exceeding 1% througout the UARS Mission.

Hopefully the UARS SOLSTICE will be the first of many devices using stars as a calibration standard to monitor solar irradiance over extremely long time periods. The technique is not limited by the characteristics and accuracy of an individual instrument. At any time in the future, other instruments, with similar or even quite different design, can monitor the sun, and by comparing the solar output to the same ensemble of stars used by the UARS SOLSTICE, it can directly relate solar conditions at that future time to the conditions between 1992 and 1994. The SOLSTICE concept has been proposed and accepted by NASA as the ultraviolet irradiance instrument for the Earth Observing System (EOS) to be implemented over the next twenty or so years. At the present time the EOS SOLSTICE is included as one of the five instruments on the EOS Chemistry Mission, scheduled for launch perhaps in 2002.

Gary Rottman of HAO is the Principal Investigator for the SOLSTICE investigation, and the Co-investigators include Thomas N. Woods and Oran R. (Dick) White of HAO and Julius London and Tom Ayres of the University of Colorado. In addition to the UARS Science Team, collaborations include Paul Simon, Lucien Bossy and Gaston Kockarts (Institute for Aeronomy in Brussels), Judith Lean (Naval Research Laboratory), Lon Hood (University of Arizona), W. Kent Tobiska (Jet Propulsion Laboratory - Telos System Group), Charles Barth (University of Colorado), and Paal Brekke (University of Oslo). The first three years of UARS SOLSTICE data have now been released and they are available to the science community through the EOS Distributed Active Archive Center (DAAC).

TIMED SEE Program. In 1993 the Solar EUV Experiment (SEE) was selected by NASA for the Thermospheric, Ionosphere, Mesosphere, Energetics, and Dynamics (TIMED) mission. The science objectives for SEE are (1) to accurately and precisely determine the time-dependent solar vacuum ultraviolet ( ) spectral irradiance, (2) to study the solar-terrestrial relationships utilizing atmospheric models, (3) to determine the thermospheric neutral densities from solar occultations, (4) to study the mechanisms and sources of solar VUV variability, and (5) to improve proxy models of the solar irradiance. These objectives will be pursued using solar irradiance and solar occultation measurements, coupled with modeling of both solar variability and atmospheric response to solar radiation. The instruments now being designed for the TIMED SEE program are enhanced versions of instrumentation successfully flown on HAO sounding rockets during the past few years. The HAO SEE program will involve the design, fabrication and test of the new instruments, their operation during the TIMED satellite mission, and the analysis of data and modeling solar variability and solar-terrestrial interactions. The current plan for the TIMED project is to start fabricating the flight instruments in 1996, ready for launch in 1999. The scientific team consists of Woods (Principal Investigator), Rottman, Raymond Roble, and White (HAO), Stan Solomon and George Lawrence (University of Colorado), Lean, and Tobiska. The SEE Definition Study (Phase B) is currently being carried out within the HAO Instrumentation Group.

Irradiance Rocket Program. The main science objective of the HAO rocket experiment is to study the solar EUV spectral irradiance with special emphasis on comparing results from different types of instrumentation. A second objective is to study the solar-thermosphere interactions by comparing the solar EUV and airglow measurements to predictions from atmospheric models. Woods leads the science team for this rocket program that includes Rottman, Solomon and Scott Bailey (University of Colorado), Supriya Chakrabarti and Dan Cotton (Boston University), and Tobiska. We have had two successful rocket launches at the White Sands Missile Range, one on October 27, 1992 and the other on October 4, 1993. This later flight also supported the moon albedo study using the EUV Explorer (EUVE), calibration for the Voyager UVS solar measurements, and a rocket experiment of Barth. We now have a total of four rocket measurements of the solar EUV irradiance extending back to 1988, and we are able to provide estimates of the solar cycle variation. NASA has approved an additional three flights to study the solar output during solar minimum, 1995 through 1997. The expanded science objectives include the development of new solar EUV proxy models and calibrations for the SOHO solar EUV measurements. During the past year the rocket payload has been refurbished and recalibrated and is now scheduled for a next launch on November 3, 1994.

EUVE Measurements Using Lunar Scattered Light. Philip Judge, Woods, Rottman, Roble, Alexander Brown (JILA, University of Colorado), and Jeremy Drake (University of California, Berkeley) have continued to obtain data from NASA's EUVE satellite to observe EUV light scattered from the moon. The aim of this project is to obtain regular (twice per month) solar EUV irradiance measurements at a time when they are sorely needed for input to models of the earth's upper atmosphere. The investigators have obtained simultaneous measurements of the solar EUV irradiance using spectrometers on the HAO sounding rocket flown October 4, 1993. Data reduction and analysis are nearing completion, and preliminary results are extremely promising. The first accurate lunar albedo in the EUV will be published soon.

Global Changes in the Sun. Peter Fox continued his involvement with the Solar Disk Sextant (SDS) experiment with Sabatino Sofia (PI - Yale University), Thomas Lydon (Yale), Williams Heaps, Kenneth Schatten (both NASA/GSFC), and Lawrence Twigg (ARC)) which makes very accurate measurements of the solar diameter - one of the important global solar parameters. In September (1994) another balloon-borne experiment was performed using the identical instrument from the 1992 flight. Once reduced, these data will further constrain the solar oblateness and give information on the possible time variation of the solar diameter, at the mili-arc-second level.

EUV Observations from the San Marco Satellite. This program studies the solar irradiance variability as measured in 1988 by the ASSI instrument on the San Marco 5 satellite. One major effort for this program has been to determine the absolute photometric calibration of the ASSI EUV and FUV spectrometers. A second major effort is to develop a proxy model for the solar EUV irradiance based on the solar magnetic fields measured in the photosphere. Woods, John Worden, (graduate student at the University of Colorado), and Gerhard Schmidtke (Fraunhofer-Institut für Physikalische Mebtechnik) have completed the ASSI calibration effort and have distributed their results to the ASSI science team. Worden and Woods, interacting with scientists at HAO and the University of Colorado, are developing a solar EUV proxy model using the San Marco data and ground-based measurements of solar magnetic fields.

CaII Ground Based Observing Program. This project has continued on a monthly basis since October 1974 and has generated a basic, high precision line profile series to define the variability of the CaII H and K lines ($\lambda = 390nm$) for the Sun when observed as a Star. White and William Livingston (National Solar Observatory) will continue the observations into the minimum of solar activity between Cycles 22 and 23, which will probably occur between 1996 and 1999. These Kitt Peak data are routinely combined with independent daily measurements from Sac Peak to generate as accurate and complete a database as possible. These measurements of chromospheric activity form the basis of a comparison between the sun and stars of the same mass but slightly different age.

The Kitt Peak and Sac Peak measurements are the basis of a backward extrapolation in time to determine the state of the sun during the Maunder Minimum, 1640 to 1715 AD. This extrapolation provides an estimate of the total irradiance of the sun for the same epoch. These data plus 10.7 cm radio flux observations and relative irradiances in the MgII doublet at 280 nm provide the most reliable surrogates for estimating solar irradiances at other wavelengths.

Theory and Modeling of Solar Variability

SunRISE program at HAO. Variations in the total radiative output of the Sun as well as the underlying spectral irradiance are of interest to the terrestrial and solar-stellar atmosphere communities. In the terrestrial case, the need is for an accurate specification of the input radiation field as a function of time and wavelength; whereas, for the Sun, we are more interested in the time history of the radiative loss from particular surface structures in different spectral lines and continuum bands. The link between these two interests is the accurate measurement of the solar radiation field.

From detailed observation of solar surface structure a small set of solar structures are identified--sunspots, plages, active and quiet network, and a basal atmosphere--as a practical subdivision into "solar atmospheres" for detailed study. Given a set of accurate physical models of these surface structures and their statistical spread, the intensity as a function of wavelength for each type of structure can be computed and then properly weighted to estimate the Sun's irradiance at any particular time.

As part of HAO's participation in the NSF SunRISE project, White, Fox, Juan Fontenla (all from HAO), Eugene Avrett and Robert Kurucz (both at the Center for Astrophysics) computed the first series of synthetic solar images in wavelengths representing Calcium IIK, Magnesium IIk, Helium I 10830, Lyman α. They also computed a synthetic spectral irradiance for Calcium IIK and compared it to observations made by White and Livingston.

(SunRISE Image)

In addition, databases have been established for solar atmosphere models representing sunspots, dark network, quiet network, bright network, faculae and plage. These databases, when combined with a surface distribution of magnetic features (which is presently derived from a combination of magnetograms, continuum intensity and Calcium II K images), can be used to produce synthetic images, irradiance spectra or total irradiance of the Sun at any stage during the solar cycle.

Influence of Convection. Fox, with Sofia (Yale University) and Kwing Chan (NASA/GSFC) are continuing their work on modeling aspects of solar convection related to irradiance variations. Time dependent, three dimensional numerical simulations, are used to establish how perturbations in the emerging flux of energy from the interior are either redistributed over the Sun, or stored within the Sun. Lydon with Fox and Sofia, have resumed a study of the perturbations to a standard model of the Sun which would be associated with time dependent changes in convective efficiency or variations in magnetic field strength and location. The aim is to determine what changes in solar radius and luminosity may occur on timescale of decades to centuries.

The Connection of Solar Radiation to Photospheric Magnetic Fields. Since the emergence of magnetic flux on the solar surface increases the thermal window to the solar interior, the relationship between surface brightness and magnetic field pattern is important in estimating the thermodynamic effects of flux emergence on the radiative output of the sun. To better understand the variability of different types of magnetic surface structure, White and Harvey developed a numerical procedure for decomposing full-disk solar magnetograms into 7 structure classes ranging from active regions to quiet atmosphere. Such a decomposition provides a tool for studying the variability of each structure class separately. An important question underlying the UV flux output of the sun is the contribution of the chromospheric network over the solar cycle. This work specifies the variability of the various magnetic structures and also the corresponding variability from the same regions measured in the HeI 1083 nm and CaII K 393 nm lines. This project contributes directly to the issue of solar image analysis and efficient extraction of information from time series of solar images. The research yields a scheme for carrying the spatial distribution of the seven structure types in a single solar image in byte format.

Solar Variation 1991 to 1994 and its Terrestrial Effects. The recent UARS/SOLSTICE UV measurements show the decline of solar radiation from a maximum period in early 1992 to the anticipated solar minimum beginning in early 1995. This decreased UV input to the upper atmosphere gives the opportunity to study the sensitivity of the atmosphere to solar variation as solar activity continues to decrease toward minimum conditions. A dramatic decrease in solar UV between January 1992 and July 1993 has produced thermospheric effects reported in White, et al, (1994) where the density is estimated to have decreased by 3X while the exospheric temperature decreased by 300 deg K. White (1994) also discussed the corresponding change in the total irradiance and pointed out the possibility that we see both thermal shadowing by subsurface magnetic fields and subsequent thermal advection as these magnetic aggregates emerge in the photosphere. This work extends to lower levels of solar variation in Cycle 22 with particular emphasis on the relationship between solar flux changes and secular ozone changes due to both anthropogenic and natural causes (volcanism and solar). The quantitative values for solar irradiances and their surrogates have been provided for use by the External Influences Working Group (EIWG) of the UARS project.

Solar-Terrestrial Coupling And Global Change. Lean, White and Andrew Skumanich (HAO) continued their studies of the Sun's radiative output and its climatic effect during the Maunder minimum (hereafter MM). With David Rind (Goddard Institute for Space Studies, GISS) they found that if one uses their estimate of an irradiance reduction of approximately 0.25 percent during the MM relative to contemporary mean values (refer Annual Report 1992) in the GISS-GCM, one finds that the global mean temperature is reduced by 0.46 degrees C. However, as a result of differential heating of the lands and oceans, some regions may cool and others may warm by as much as 1 degree C, in response to the reduced solar irradiance.

Lean, White & Skumanich have also estimated the reduction in the important ultraviolet (UV) irradiance between 115 nm and 300 nm. This part of the UV spectrum determines ozone composition in the stratosphere; thus, their study bears on the historical variability of ozone and its effects on climate. They estimate the reduction at various wavelengths, e.g. they find 64% at Lyman alpha (121.6 nm), 8% at 200 nm, and 4% in the range from 210 nm to 250 nm. The reduction in the entire band between 120 nm and 300 nm is 6% of the change in the total irradiance. This diminished UV output due to very low solar activity may result in a MM ozone level 4% to 8% below the 1986 level. The climatic consequences of such a change has yet to be determined.

Terrestrial Interactions Section

Studies of the response of the earth's environment to the variable nature of the sun encompass a wide range of topics, from solar wind magnetosphere coupling to the modulation of the middle and upper atmosphere by solar radiation and energetic particles. Understanding the chain of events involved in the coupling of solar radiative and solar plasma energy to the terrestrial environment is a major goal of the Terrestrial Interactions Section. Studies are also underway to understand the effects of global change on the structure of the upper atmosphere, ionosphere and magnetosphere and possible changes in solar-terrestrial couplings.

Raymond Roble, Arthur Richmond, Paul Song, Maura Hagan, and Rolando Garcia (Atmospheric Chemistry Division) are a team that is participating in the NASA Space Physics Theory Program. The management and scientific use of the NCAR Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) data base also occur within the section.

Thermosphere-Ionosphere Interactions

TIGCM. During the past year, the thermosphere-ionosphere general circulation model (TIGCM) continued to be used by the scientific community for a wide variety of geophysical studies. This model is continuing to be used to study the upward propagation of tides from the middle atmosphere to the thermosphere and ionosphere and the modification of tidal amplitudes and phases by solar and geomagnetic activity. Both the diurnal and semi-diurnal tidal components have been studied and model predictions compared with data.

It has also been used in various campaign studies in support of the NSF CEDAR program, for comparison of model predictions with data obtained during the campaign and also for the interpretation of data. These studies done, mainly in collaboration with Cassandra Fesen (Dartmouth College), have shown that tidal structures can be altered considerably during geomagnetic storms introducing variability into both thermosphere and ionosphere structure and dynamics.

The TIGCM has also been used by Jeffrey Forbes (University of Colorado) and Frank Marcos (Air Force Phillips Laboratory) to study the equatorial penetration of magnetic disturbance effects on the density distribution of the low latitude thermosphere.

The model has been used by Geoffrey Crowley (Johns Hopkins University) and Jacqueline Schoendorf (University of Massachusetts, Lowell) to study the formation of density cells in the polar regions that develop with enhanced ionospheric convection during geomagnetic storms. These density cells were first identified in TIGCM simulations and then later verified using data from an Air Force satellite. Schoendorf has determined that these density cells are similar to an anomolous low that develops occasionally in the lower atmosphere, but in the thermosphere it is forced by auroral processes between 120-300 km altitude. She is also a graduate student assistant at HAO.

The TIGCM is being used by Alan Burns, Timothy Killeen, and Roberta Johnson (all of the University of Michigan), and Roble to do a series of model runs that are being used to construct a numerically fast empirical model for operational prediction of satellite drag for the U.S. Air Force. This empirical model is currently being tested by the U.S. Air Force for possible operational use.

The TIGCM is also being used by Gonzalo Hernandez (University of Washington), and Roble to study thermospheric temperatures and winds over the Fritz Peak Observatory in Colorado. The model is being used to compare model predictions of winds and temperatures over a solar cycle and also for extremely high solar EUV conditions when the solar F10.7 radio emission reached 364, the highest value observed during solar cycle 21 with data. The results indicate that the model can reproduce the observed winds and temperature over this wide range of solar EUV and UV output.

The TIGCM is a community model, that in addition to the above studies, is being used by various other scientists for CEDAR and Geospace Environment Modeling (GEM) campaign studies as well as for analyzing data from NASA satellite missions, such as the Atmosphere Explorer, Solar Mesospheric Explorer, Dynamics Explorer, and the Upper Atmosphere Research Satellite (UARS).

TIE-GCM. The thermosphere-ionosphere-electrodynamics general circulation model (TIE-GCM) is a simulation model that computes self-consistently the coupled thermosphere and ionosphere dynamics, the associated dynamo electric fields and currents, and the electrodynamic feedback on the neutral and plasma motion and thermodynamics. During the past year the model is being used to evaluate model performance and determine its capability to model various geophysical events. The results of TIE-GCM simulations have been compared with similar simulations using the TIGCM to determine the importance of electrodynamic feedbacks between the neutral thermosphere and ionospheric plasma and also for comparisons with data obtained from various NASA satellite programs and CEDAR and GEM campaigns. Overall, the model is performing well and it will eventually replace the TIGCM as a new community model for scientific research.

The TIE-GCM has been used by Edward Szuszczewicz (SAIC) and Roble to study the formation and dynamics of intermediate and descending layers of ionospheric E-region ionization driven by tides and the resulting electrodynamic interactions. The model predicted ionization descents were in generally good agreement with observations made by a global network of ionosondes indicating that tides and the resulting electrodynamic interactions have an important influence on the formation of these metallic ion ionospheric structures.

The TIE-GCM has been used by Hernandez, Roger Smith (University of Alaska) and Roble to predict the wind structure over the south pole and various high latitude southern hemisphere stations for comparison with thermospheric wind and temperature measurements made from those stations. The results were in general agreement but there were discrepancies that are probably related to the complex magnetic field structure at high southern latitudes. Numerical experiments are continuing to better understand the factors controlling time-dependent dynamics over the south pole region.

The TIE-GCM has been used to support studies in the CEDAR coordinated analysis of the thermosphere (CAT) campaigns by providing stations predictions of winds and temperatures for various Fabry Perot interferometer and incoherent scatter radar locations. This new model achieves generally better agreement with data than the older TIGCM. The TIE-GCM has now replaced the older TIGCM as the basic model that the scientific community can use for studies of upper atmosphere and ionosphere dynamics and for investigations of solar-terrestrial couplings.

Thermosphere-Ionosphere-Mesosphere Interactions

Global Mean Structure. The global mean model of the thermosphere-ionosphere-mesosphere and upper stratosphere between 30 and 500 km has been used to study the important physical processes that maintain the global mean structure of these regions and to develop and test parameterizations for eventual incorporation into the new thermosphere-ionosphere-mesosphere electrodynamics general circulation model (TIME-GCM). During the past year the model was used to investigate the difference of upper atmosphere and ionosphere structure between solar cycle minimum and maximum conditions and the response of atmospheric regions to auroral electron particle precipitation and solar proton events. These simulations were used to help interpret the important physical and chemical processes that perturb the basic structure in advance of performing similar simulations with the new TIME-GCM. The results of these studies indicate a strong solar and particle control of upper atmosphere and ionosphere structure throughout the thermosphere, ionosphere and mesosphere.

Nikolai Gavrilov (University of Saint Petersburg, Russia) and Roble used the global mean model of the upper atmosphere and gravity wave and turbulence theory to develop gravity wave heating and turbulent cooling formalisms to guide the use of these quantities in the TIME-GCM. This model and parameterization was used to study the energetics of the mesopause region. Their study showed that heating caused by gravity wave dissipation is nearly balanced by turbulent cooling for a wide range on conditions suggesting that the globally averaged middle atmosphere is in near radiative equilibrium. This result is consistent with other studies that suggest that the upper mesosphere Prandtl number is large. This conclusion was verified using results from the TIME-GCM indicating that heating from gravity wave dissipation is small and that the temperature is established primarily by radiative balance and large scale dynamical heating and cooling.

The global mean model was also used to calculate changes in atmospheric thermal and compositional structure for conditions when the concentrations of CO_2 and CH_4 are doubled from their present day concentrations. The results are strongly dependent upon the magnitude of the $O-CO_2$ vibrational exchange rate used in the calculation. Roble and Robert Dickinson (University of Arizona) used a rate coefficient of $1x10^{-12} cm^3/s$ in their initial study but new laboratory and satellite studies suggest a rate as high as $6x10^{-12}$. If the higher rate coefficient is used the global mean temperature of the mesosphere will cool -15 K and the thermosphere -100 K. This compares with the previous values of -10 K and -50 K calculated by Roble and Dickinson. This suggests that the cooling of the upper atmosphere in the CO_2 and CH_4 doubled scenario will be much larger than previously thought and that the changes in compositional structure and dynamics will be much larger than in previous studies. The model was also used to determine the atmospheric response to variations in solar EUV and UV over a solar cycle and during geomagnetic storms under doubled CO_2 and CH_4 conditions. These simulations were done in advance of similar calculations to be made with the TIME-GCM.

TIME-GCM. The TIME-GCM is a new simulation model of the mesosphere, thermosphere and ionosphere with coupled electrodynamics that has been developed to calculate the global circulation, temperature and compositional structure of the upper atmosphere between 30 km (10 mb) and 500 km altitude. The model incorporates all of the features of the TIE-GCM but the lower boundary has been extended into the upper stratosphere and it includes physical and chemical processes appropriate for the mesosphere and upper stratosphere. The scientific motivation for the development of a new model that couples the mesosphere and upper stratosphere with the thermosphere and ionosphere is threefold: (1) to determine how deep into the atmosphere do the effects of solar and auroral variability penetrate; (2) to determine how physical, chemical and dynamical processes in the lower atmosphere affect the structure, dynamics and electrodynamics of the thermosphere and ionosphere; and (3) to determine how the upper atmosphere will respond to impending global change. The new model solves for global distributions of neutral gas temperature and winds, the heights of constant pressure surfaces and global compositional distributions of O, O_2, N_2, He, Ar, CO_2, CO, CH_4, H_2, H_2O, H, OH, HO_2, NO, $N(^4S)$, $N(^2D)$, NO_2, $O_2(^1\Sigma_g)$, $O_2(^1\Delta_g)$, O_3, $O(^1D)$ and properties of the ionosphere including the electron and ion temperatures and the electron and ion number densities including: $O^+(^2D)$, $O^+(^2P)$, $O^+(^4S)$, O_2^+, N_2^+, N^+, NO^+ and D-region positive and negative cluster ions. The model includes the CO_2 LTE and non-LTE radiation and gravity wave parameterizations and about 50 chemical reactions that are calculated at every grid point and time step.

The initial TIME-GCM has been used for various mechanistic studies to determine the sensitivity of the model to various input parameters and parameterizations. This version of the model has been run for two hypothetical geophysical conditions: perpetual equinox and December solstice solar cycle minimum, geomagnetic quiet conditions in order to compare the calculated structure and circulation with mean climatological conditions and also to determine the parameters that provide the best match to the climatological structure. It was found that weak gravity wave forcing is needed during equinox conditions and the level of forcing was sufficient to allow the diurnal tide to propagate to 100 km in the equatorial region with amplitudes in agreement with data from the UARS satellite. This level of forcing weakened but did not reverse the mesospheric jets. For solstice conditions it was found that 3 times more gravity wave flux was required in the winter hemisphere whereas the summer hemisphere gravity wave flux was slightly larger than for equinox. This level of gravity wave flux reversed the mesosphere jets in agreement with climatology for solstice conditions and was sufficiently strong to damp the diurnal tide to small amplitudes near 90 km in agreement with UARS observations.

Comparisons with Data. The model has been used by William Sharp (University of Michigan) for comparisons of middle atmosphere chemical composition and temperature profiles with measurements made by a rocket at Wind Sand Missile range and by John Wise (Boston College) to study the lower thermosphere IR cooling and for comparisons with IR measurements made by an Air Force rocket from the Poker Flats range and from the CIRRUS experiment on the NASA space shuttle. The model has also been used by Paul Hays and Dong Wu (both of the University of Michigan) for comparison of TIME-GCM winds with measurements made by the High Resolution Doppler Imager (HRDI) instrument on-board the UARS satellite, by Joe She (Colorado State University) for comparison with ground-based lidar observations and by Crowley and Sam Yee (Johns Hopkins University) for comparison with airglow emissions measure by the UARS satellite. As with the TIGCM and TIE-GCM this new simulation model is a community model and it will be used for CEDAR campaigns, and analyzing satellite and rocket data.

Boundary Forcings. The initial model used tidal theory to incorporate atmosphere structure at the lower boundary of the model. This model can introduce tidal components at the diurnal, semi-diurnal and annual frequency for mechanistic studies. Recently the lower boundary solver of the model has been modified so that arbitrary boundary conditions can be used. In particular, the TIME-GCM now uses NMC daily geopotential and temperature data along the 10 mb surface to specify lower atmosphere forcings imposing seasonal, planetary wave and other large-scale variations into the forcing of the model. The TIME-GCM has been run to simulate upper atmosphere and ionosphere structure between September 21, 1985 to February 15, 1986. The results of these simulations are now being analyzed but it is clear from the results that the lower atmosphere forcings introduce significant variability into the structure and dynamics of the lower thermosphere that must be included in any realistic simulation of thermospheric and ionospheric properties.

Work is also underway to couple the TIME-GCM to the NCAR Community Climate model, CCM2, using a flux coupler along the 10 mb constant pressure surface. This modeling effort in part of the NCAR Climate System Modeling (CSM) project.

Assimilative Modeling.

Rashid Akmaev (visitor from the University of Saint Petersberg, Russia) has developed a new assimilative middle atmospheric diagnostic scheme. The scheme is based on a global spectral model extending approximately from 15 up to 120 km which is used in both diagnostics and simulations of the observed monthly middle atmospheric climatology as represented in the CIRA-86 empirical model. First, the model in a two-dimensional mode is initialized with the empirical temperature and wind distributions for each month. An analog of the nudging data assimilation technique is then applied to retrieve zonal mean zonal momentum deposition rates necessary to keep the model's state in the vicinity of the observed climatology. This is combined with a straightforward procedure for estimating the global mean vertical diffusion coefficient from the thermodynamic equation averaged globally for each month. These estimates agree surprisingly well with recent observations in the mesosphere and lower thermosphere. At the second stage the inferred eddy diffusivities and zonal accelerations that are commonly believed to be produced by dissipating and breaking atmospheric waves of different scales are used as input in annual cycle integrations of the model. For the first time quantitative comparisons of the simulated and initial diagnosed climatologies have been made. The simulation results obtained using the diagnosed zonal forcing and vertical diffusion coefficients compare favorably with the empirical model on the one hand and with simulations using a gravity wave parameterization on the other. In particular, the empirical temperature model is reproduced with an annual global rms temperature deviation of 3.2 K or about 2% in the 15- to 110-km layer.

A modified version of the diagnostic scheme has been applied to the CIRA-86 climatology in conjunction with standard optimization procedures. It has been suggested that estimates of the zonal drag could be improved by introducing a nudging, or Newtonian-cooling type term into the thermodynamic equation at the diagnostic stage. A proper adjustment, optimization, of the strength of this term makes it possible to further reduce the rms temperature deviation down to approximately 2.7 K. These results suggest that direct optimization can successfully be applied to atmospheric model parameter identification problems of moderate dimensionality.

The above ideas on using quantitative criteria and optimization procedures are being used in assimilative optimization of the model itself (model parameter identification) including "free" parameters of current middle atmospheric gravity wave parameterizations.

Tidal and Planetary Wave (PW) Model Studies.

Hagan continued the development of the linearized tidal model with collaborators Forbes and Francois Vial (Centre National de la Recherche Scientifique, France). HAO summer student visitor, Julie Lundquist (undergraduate student at Trinity University) assisted with model runs to test the implementation of new specifications for effective Rayleigh friction, and monthly variability in eddy diffusivity and tidal forcing in the model.

The fully-developed PW version of the model was used to pursue additional investigation of global-scale quasi 2-day wave signatures in the mesosphere-lower thermosphere during winter conditions. Hagan discussed results for the 10-day January 1993 period during the CEDAR Coupling and Dynamics of Regions Equatorial (CADRE) workshop. Additional results confirmed experimental evidence of interhemispheric asymmetry in the response of the quasi 2-day wave during winter. Collaborators in the CADRE and Mesosphere-LTCS efforts in this area included David Fritts (University of Colorado), Alan Manson and Chris Meek (both of the University of Saskatoon, Canada), Ronald Clark (University of New Hampshire), Toshitaka Tsuda (RASC-Japan), and Yuri Portnyagin (TYPHOON/Obninsk-Russia). Complementary collaborations to investigate quasi 2-day wave signatures were also carried out by Hagan and members of the UARS HRDI team; Wu, Hays, and Ruth Lieberman (University of Michigan).

Comparative Terrestrial Planetary Thermospheres.

Stephen Bougher and Donald Hunten (both of the University of Arizona) and Roble have continued their study of comparative atmospheres of the terrestrial planets. They are currently incorporating their findings of energetics completed using globally averaged models into the thermospheric general circulation models of Earth, Venus, and Mars. Work is also progressing on the development of a TGCM for Jupiter.

Sodium Nightglow Measurements.

Over the past year, graduate student Bifford Williams (University of Colorado), under the supervision of Tomczyk and in collaboration with Hays, continued work on the sodium nightglow Magneto-Optical Doppler Analyzer (MODA). The MODA will measure the Doppler shift of the Sodium D-line emission from a thin atmospheric layer at about 100 km altitude. Earlier this year MODA was installed at a good dark-sky site at the CU Mountain Research Station. Preliminary observations of mesopause winds were obtained this spring. Hardware upgrades were made this summer and the instrument is now operating automatically every night. Williams will obtain and analyze data over the winter for his dissertation.

CEDAR Activities

Analysis and Interpretation of Measurements. Hagan collaborated with Joseph Salah (MIT Haystack Observatory) to investigate the role of upward propagating tides in interpreting variability observed in the thermosphere over Millstone Hill Observatory during two CEDAR campaign periods. Their analysis of the lower thermosphere coupling study (LTCS)-2 and LTCS-6 campaigns suggests that tidal sources in the lower atmosphere do not significantly affect the energy and momentum budgets of the middle latitude thermosphere during solar maximum winter conditions. Some of these experimental results were subsequently used as inputs to numerical models of the upper atmosphere in collaborative attempts to deconvolve local ion-neutral coupling effects, as well as global-scale dynamic and electrodynamic signatures. Additional collaborators involved in this effort included Roble, Richmond, and Cicely Ridley (HAO), Fesen, Phil Richards and Douglas Torr (both of the University of Alabama, Huntsville) and Michael Buonsanto (MIT Haystack Observatory). Hagan and Forbes co-convened a special session at the 1993 Fall American Geophysical Union (AGU) meeting wherein initial reports of all of these investigations were presented.

Hagan continued to coordinate the efforts of the CEDAR CAT project. She organized a half-day workshop for this group during the annual CEDAR meeting. The major scientific achievement of the CAT community during FY94 was publication of a collaborative report by Alan Hedin (NASA/Goddard Space Flight Center), Buonsanto and Dwight Sipler (MIT Haystack Observatory), Mihail Codrescu (NOAA/SEL), Marie-Louise Duboin (Centre National de la Recherche Scientifique, France), Fesen, Hagan, and Kent Miller (Utah State University), on similarities and differences in seasonal and solar cycle variability of magnetically undisturbed winds at a series of middle latitude locations. In general, they found that the diurnal mean wind was only weakly dependent on increased EUV forcing in good agreement with the predictions of both numerical and empirical models. Observational evidence contradicted the predicted behavior of diurnal wind amplitudes to varying degrees dependent upon the model in question. CAT results were characterized by amplitude increases with increased solar activity. The mechanisms responsible for these trends continue to be investigated.

CEDAR Data Base and Workshop. The major accomplishment of the CEDAR Data Base in FY 94 was the creation of a simple user interface called cmenu, which facilitates online access to data, documentation, and models. Through collaboration with MIT Haystack Observatory, the Data Base catalogue has been put online via MOSAIC at http://hyperion.haystack.edu/madrigal/catalogue.front.html. There are now data from 32 instruments in the Data Base, and output from 4 large models. Significant additions this year were data sets from 3 new instruments and TIGCM model output for several seasons and levels of solar and magnetic activity. There are about 125 outside logins on the cedar computer from about 50 institutions, of whom two-thirds are students. About 25 requests were filled by Data Base personnel, while 17 login users transferred data. Two students, David Machuga (Pennsylvania State University) and Judy Mirick (Clemson University), were funded to visit the Data Base just prior to and after the CEDAR Workshop to work on specific research projects.

The 1994 CEDAR Workshop was held June 20-25. A total of 348 persons, including 155 students, came from 37 universities and 34 other research institutes in 9 countries. Emery was the local organizer. The CEDAR Prize Lecture was given by Roble.

Jovian IO Torus (Planetary Magnetospheres)

Jianke Li (HAO), Song, and Thomas Holzer proposed a dynamical model of the Jovian magnetosphere associated with the mass release from its moon Io. Previous models were based on an assumption of static equilibrium, which ignores mass loss along the magnetic field to the Jovian ionosphere. In those models the released mass had to be transported by radial diffusion outward across the magnetic field, which proved difficult to achieve. The new model is based on the fact that the Io orbital speed is lower than the magnetospheric corotation speed so that the released particles cause a drag on magnetospheric corotation and hence a differential rotation along the field lines. A field-aligned flow is an inevitable consequence of such a differential rotation and the Jovian magnetosphere reaches its equilibrium dynamically. The difficulty encountered by radial diffusion models is not an issue in the new model. An important prediction of the model is an enhanced aurora associated with the field-aligned flow.

Solar-Wind/Magnetosphere Interactions

Song and Christopher Russell (University of California, Los Angeles) developed the nonlinear MHD dispersion relation for a high beta plasma (large ratio of thermal to magnetic pressures). It should be applicable to conditions in the magnetosheath downstream of quasi-parallel or high-Mach-number shocks, and in many solar and astrophysical processes. The density fluctuation and 1/beta are taken as small parameters, while nonlinear terms of other perturbations are retained. The results yield a correction to the linear dispersion relations for the Alfven and slow modes. The most surprising and interesting result is that the fast mode becomes either damped or unstable. This is different from conventional wisdom, which says that the waves in a high beta plasma are not far from what they are in an unmagnetized plasma, the sound or fast mode. Observations have shown that the fast mode is unimportant in the magnetosheath.

Song, Holzer, Russell and Zhi Wang (University of California, Los Angeles) further formulated the model of the Low Latitude Boundary Layer proposed by Song and Russell. In a dipole geometry, three solutions are found from the equations. One of the solutions is unphysical because the flow velocity goes to infinity with distance. The boundary flow velocity of the second solution reaches a constant in the distant tail. This physically describes the solar wind and is the open-magnetosphere solution. The other solution, in which the flow decelerates to a halt at a distance, represents a closed magnetosphere. This is the first model in which the flow could be stopped, thereby enabling the plasma to participate in magnetospheric convection.

Magnetosphere/Ionosphere Interactions

Gang Lu (HAO), Richmond, and Barbara Emery (HAO) have been actively involved in GEM campaign studies. They have used the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure to derive the global distributions of the ionospheric conductance, plasma convection, field-aligned current density, and other electrodynamic fields. Three GEM periods have been studied in detail: January 27-29, 1992; March 28-29, 1992; and July 20-21, 1992. The AMIE patterns at a 5-min time interval for these three periods are now available on microfiche. These patterns have been provided to many scientists in the GEM and CEDAR communities through scientific collaborations.

For the period of January 27-29, 1992, the ionospheric convection patterns were derived simultaneously for both the northern and southern hemispheres. Examination of these patterns revealed that there can be significant inter-hemispherical differences. By comparing the convection patterns with the corresponding energy spectrograms of the precipitating particles, Lu and her collaborators were able to identify the different magnetospheric drivers of the convection flow and to estimate quantitatively their contributions to the total cross-polar-cap potential drop.

Lu also collaborated with Lawrence Lyons (The Aerospace Corporation) to investigate the ionospheric signatures of the magnetic separatrix and boundary layers. For each selected time interval of relatively stable IMF, snapshots of the ionospheric convection configuration were derived based on data from the polar-orbiting DMSP and NOAA satellites as well as from radars and ground magnetometers. The polar cap boundary was identified from the observations of particle precipitation. The results were then compared with magnetospheric models.

The cusp is a region where intense solar wind plasma can be directly injected into the ionosphere. Therefore observations of the cusp can provide important information on the solar wind-magnetosphere interaction. Studies of ionospheric cusp signatures have been traditionally conducted through spatially-limited observations. By using the AMIE procedure, Lu and coworkers were able to combine various observations and to extend their study of the cusp over a broad area. They found that the cusp/mantle currents near local noon are coincident with the cusp or mantle particle precipitations; in contrast, the normal region 1 current on the dawn and dusk sides of the polar cap are usually associated with plasma-sheet precipitations. This implies that the cusp/mantle currents are generated through different mechanisms from the region 1 currents. On the other hand, the cusp/mantle currents are topologically connected with the region 1 currents. In this respect, they may be considered as one current system.

Lu, Richmond, Emery, and Roble have investigated the magnetosphere-ionosphere-thermosphere coupling processes. They incorporated the realistic time-dependent patterns of ionospheric convection and particle precipitation derived from AMIE into the TIGCM model to study the effect of magnetospheric energy dissipation on the ionosphere and thermosphere. They found that the major part of magnetospheric electromagnetic energy dissipated in the high-latitude ionosphere goes into Joule heating, while only small part of the energy goes to accelerate the neutral winds. The thermospheric winds can have a significant influence on the ionospheric electrodynamics: during active geomagnetic periods, these winds may have approximately a 25% effect on Joule heating and a 15% effect on field-aligned currents.

During a summer visit, Christophe Peymirat (University of Versailles, France), in collaboration with Richmond and Roble, converted his model of magnetospheric convection into a computer subroutine that can be dynamically coupled with the TIE-GCM. The goal of this project is to have a combined model with self-consistent magnetosphere-ionosphere coupling.

Richmond developed a theoretical formalism and a computer code for analyzing ionospheric electrodynamics in coordinate systems based on Magnetic Apex Coordinates, which allow use of a realistic (non-dipolar) model of the geomagnetic field. As compared with previous formulations using dipole coordinates, changes of the order of 10-50% are introduced into the electrodynamic equations due to non-dipolar distortions of the geomagnetic field. The formalism and computer code will facilitate an improved means of organizing three-dimensional observations of electric fields, currents, and magnetic perturbations, as done in the AMIE procedure. The formalism is currently used in the TIE-GCM for calculating electric fields, and it is being incorporated in the TIE-GCM for calculating electric currents and magnetic perturbations, in order to permit direct comparison between simulations and observations. The computer code is being made available to other researchers through the CEDAR Data Base.

Staff, Visitors, and Collaborators

Staff

Administrative Services

Louise Beierle

Liz Boyd

Wendy Edwards (to 16 September 1994)

Veda Emmett

Allison Gillespie

Thomas Holzer (Director)

Raymond Roble (Deputy Director)

Gary Rottman (Associate Director)

Peggy Searcy

Kathryn Strand (Manager) (to 24 November 1993)

Cindy Worster (from 1 June 1994)

Computing and Research Support

Peter Bandurian

Ray Bovet

Roy Barnes (85%)

Joan Burkepile

Robert Campbell (Student Assistant)

Duc Chu

Melissa Dixon (Student Visitor) (to 17 May 1994)

Robert Ferguson (to 17 May 1994)

Benjamin Foster

Janine Goldstein (Student Assistant) (to 11 January 1994)

Christopher Haggerty (Student Visitor) (to 17 May 1994)

Barry Knapp

Alice Lecinski

Robert Montgomery

Christopher Nielson (Student Assistant) (to 4 March 1994)

Matthew Oetting (Student Assistant) (to 16 May 1994)

Steven Pawlish (Student Visitor) (to 12 May 1994)

William Roberts

Paul Seagraves

Joshua Seiden

Stefan Serbicki

David Shafter

Leonard Sitongia

Thomas Sparn (Manager)

Andrew Stanger

Victor Tisone

Joylene Walsh

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Kitty Weaver

Instrumentation Group

Gregory Card

Clarke Chambellan

David Elmore

Howard Hull

Terry Leach

Ron Lull

Paula Rubin

Kim Streander (Manager)

Gregory Ucker

Ray Wrigley

Solar Physics Section

Thomas Bogdan

Timothy Brown

Paul Charbonneau

Katia Ferrière (to 18 August 1994)

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Donald Hassler

Thomas Holzer (50%)

Arthur Hundhausen

Philip Judge

Darryl Koon

Bruce Lites (Section Head)

Boon-Chye Low

Keith MacGregor

David Sime (to 29 March 1994)

Andrew Skumanich

Steven Tomczyk

Eric Yasukawa

Terrestrial Interactions Section

Brian Boyle (from 31 January 1994)

Barbara Emery

Daniel Gablehouse

Maura Hagan

Thomas Holzer (50%)

Gang Lu (from 1 October 1993)

Christopher Pankratz

Arthur Richmond

Cicely Ridley

Raymond Roble (Section Head)

Gary Rottman

Paul Song

Paul Willis

Thomas Woods

John Worden (Graduate Student)

Senior Research Associates

Oran R. White

Affiliate Scientists

Jørgen Christensen-Dalsgård, University of Århus,

Denmark

Timothy L. Killeen, University of Michigan

Egil Leer, Institute of Theoretical Astrophysics,

University of Oslo, Norway

Robert M. MacQueen, Rhodes College

Dimitri Mihalas, University of Illinois

Robert Rosner, University of Chicago

John H.Thomas, University of Rochester

Postdoctoral Fellowships

Jianke Li, The University of Sydney, Australia

Alan McAllister, Space Environment Laboratory, Boulder

Frederic Paletou, Institut d' Astrophysique Spatiale, Paris

Valentin Martinez Pillet, Instituto de Astrofisica de

Canarias, Spain

Newkirk Graduate Research Assistants

Christopher Balch, Space Environment Lab and

University of Colorado

Graham Barnes, Cornell University,

Yung-Ping Chou, Columbia University

(to 31 January 1994)

Janine Goldstein, University of Colorado (to 11 January

1994)

Farzad Kamalabadi, Boston University

Rony Keppens, Katholieke Universiteit, Leuven, Belgium

Jacqueline Schoendorf, University of Massachusetts at

Lowell

Seth Veitzer, University of Colorado (to 21 August 1994)

Bifford Williams, University of Colorado

John Worden, University of Colorado

Summer Undergraduate Student Visitors

Catherine Andrulis, University of Colorado

Robert Campbell, University of Colorado

Beth Clem, University of Colorado

Frank DiPentino, University of Colorado

Melissa Dixon, University of Colorado (to 17 May 1994)

Ana Escarcega-Macaya, University of Colorado, Denver

Robert Ferguson, University of Colorado

William Golesorkhi, University of Colorado

Christopher Haggerty, University of Colorado (to 17 May 1994)

Kristin Hotaling, University of Colorado

Veronika Hubeny, University of Maryland

Susanne Jordan, University of Colorado

Mike Kosenski, University of Colorado

Julie Lundquist, Trinity University

Randle Meisner, University of Colorado

Christopher Nielsen, University of Colorado

Matthew Oetting, University of Colorado

Vincent Palumbo, University of Colorado

Steve Pawlish, University of Colorado (to 12 May 1994)

Edward Schrader, University of Colorado

Joshua Seiden, University of Colorado

Stefan Serbicki, University of Colorado

David Shafter, University of Colorado

Zijin Shen, St. Michael's College, VT

Joylene Walsh, University of Colorado

Yu R. Wang, University of Colorado

Greg Wilson, University of Colorado

Young Kook Yoo, University of Chicago

Visitors and Collaborators

Dates refer to visitor's stay at NCAR during FY 93. No dates are given for collaborators who did not visit NCAR

Byung-Ho Ahn; Kyungpook National Observatory, Korea; 27 July - 20 August 1994; Auroral ionospheric electrodynamics

Rashid Akmaev; University of St. Petersburg, Russia; 7;September 1992 to 6 September 1994; Mesosphere, lower thermosphere

Tahar Amari; Ministere de L'Educational Nationale, Paris, France; 5-12 August 1994; Solar coronal MHD problems

Christine Amory-Mazaudier; Centre d'etude des Environnements Terrestre et Planetaires, France; CEDAR Data Base

David Anderson; Air Force Phillips Lab; Terrestrial Interactions Section

Catherine Andrulis; JILA, University of Colorado; Solar Physics Section

Steve Arendt; University of Chicago; 1 September 1992 to 31;August 1994; Solar Physics Section

Susan Avery; University of Colorado; CEDAR Data Base

Eugene H. Avrett; Smithsonian Astrophysical Observatory; Terrestrial Interactions Section

Thomas Ayres; University of Colorado; Terrestrial Interactions Section

Scott Bailey; University of Colorado; Terrestrial Interactions Section

Fran Bagenal; University of Colorado; Solar Physics Section

K. S. Balasubramanian; National Solar Observatory, Sacramento Peak; Solar Physics Section

Charles Barth; University of Colorado; Terrestrial Interactions Section

Jürg Beer; Swiss Federal Institute for Environmental Science & Technology; 1 August 1994 - 1 August 1995; Solar terrestrial relationship

Mitch Berger; University College of London; Solor Physics Section

Amitava Bhattacharjee; Iowa State University; Solar Physics Section

Manfred Biondi; University of Pittsburgh; CEDAR Data Base

Lucien Bossy; Institute for Aeronomy, Brussels; Terrestrial Interactions Section

Stephen Bougher; University of Arizona; Terrestrial Interactions Section

Axel Brandenburg; Nordita, Denmark; 1 December 1992 to 30 November 1994; Dynamics of solar convection zone

Guy Brasseur; NCAR, ACD; Terrestrial Interactions Section

Paal Brekke; University of Oslo, Norway; Terrestrial Interactions Section

Alexander Brown; JILA, University of Colorado; Terrestrial Interactions Section

Michael Buonsanto; MIT Haystack Observatory; Terrestrial Interactions Section

Alan Burns; University of Michigan; Terrestrial Interactions Section

Gary Burns; Australia Antarctic Division; Terrestrial Interactions Section

Mark Burrage; University of Michigan; Terrestrial Interactions Section

Allesandro Cacciani; University La Sapienza, Italy; 7-15;January 1993; Solar Physics Section

Paul Cally; Monash University, Clayton, Australia; Solar Physics Section

Vittorio Canuto; NASA/Goddard Institute for Space Studies; Solar Physics Section

Supriya Chakrabarti; Center for Space Physics, Boston University; Terrestrial Interactions Section

Kwing Chan; Goddard Space Flight Center; Terrestrial Interactions Section

Jih Kwin Chao; National Central University, Taiwan; Terrestrial Interactions Section

Jean-Pierre Chauvineau; Institut d'Optique, Orsay, France; Solar Physics Section

John Cho; Arecibo Observatory; Arecibo Observatory; CEDAR Data Base

Yung-Ping Chou; Columbia University; Solar Physics Section

Ronald Clark; University of New Hampshire; CEDAR Data Base

Mihail Codrescu; NOAA/SEL; Terrestrial Interactions Section

Peter Collis; EISCAT Scientific Association, Sweden; CEDAR Data Base

Daniel Cotton; Center for Space Physics, Boston University; Terrestrial Interactions Section

Roger Crickmore; British Antarctic Survey, United Kingdom; CEDAR Data Base

Geoffrey Crowley; Johns Hopkins University; Terrestrial Interactions Section

Manfred Cuntz; Joint Institute for Laboratory Astrophysics, University of Colorado; 1 January 1992 to 30;June 1994; Stochastic radiation hydrodynamics in cool star atmospheres

Jean-Pierre de la Boudiniere; Institut d'Astrophysique Spatiale, Orsay, France; Solar Physics Section

Odile de la Beaujardière; SRI International; Terrestrial Interactions Section

William Denig; Air Force Phillips Lab; Terrestrial Interactions Section

S. Dennis; Australian Geological Survey Organization, Australia; Terrestrial Interactions Section

Jeremy Drake; University of California at Berkeley; Terrestrial Interactions Section

Marie-Louise Duboin; Centre de Recherches en Phisique de l'Environnement, France; Terrestrial Interactions Section

Bela Fejer; Utah State University; Terrestrial Interactions Section

Katia Ferrière; Observatoire Midi-Pyrenees, Toulouse; 20 July - 17 August 1994; Galactic dynamo

Cassandra Fesen; Dartmouth College; 15-22 April 1994 and 13-24 June 1994; TGCM studies

Boris Fidel; Tel-Aviv University, Israel; Terrestrial Interactions Section

Richard R. Fisher; NASA Goddard Space Flight Center; Solar Physics Section

Juan Fontenla; University of Alabama; 1 January 1994 to

1 January 1995; Synthetic models of solar spectrum

Jeffrey Forbes; University of Colorado; Terrestrial Interactions Section

Victor Formichev; St. Petersburg University, Russia; Terrestrial Interactions Section

John C. Foster; MIT Haystack Observatory; CEDAR Data Base

Zoe Frank; Lockheed Palo Alto Research Laboratory; Solar Physics Section

Steven Franke; University of Illinois; Terrestrial Interactions Section

Grahame Fraser; University of Canterbury, New Zealand; CEDAR Data Base

Bernd Freytag; Christian-Albrechts-Universitat zu Kiel; 2-18 May 1994; Convection in A-type stars

Eigil Friis-Christensen; Danish Meteorological Institute, Denmark; Terrestrial Interactions Section

David Fritts, University of Colorado; Terrestrial Interactions Section

Timothy Fuller-Rowell; NOAA/SEL; Terrestrial Interactions Section

Alan Gabriel; Institut d' Astrophysique Spatiale, Orsay, France; Solar Physics Section

Chester Gardner; University of Illinois; CEDAR Data Base

Larry D. Gardner; Harvard-Smithsonian Center for Astrophysics

Nikolai Gavrilov; St. Petersburg University, Russia; Terrestrial Interactions Section

Ken Gayley; Bartol Research Institute; 8-24 November 1994; Radiative transfer

Ronald Gilliland; Space Telescope Science Institute; Solar Physics Section

Peter Gilman; NCAR; Solar Physics Section

Marcel Goossens; Katholieke Universiteit, Leuven, Belgium; 6-21 August 1994; MBD waves

Jack Gosling; Los Alamos National Laboratory; 31 July - 1 August 1994; Solar wind

Lika Guhathakurta; NASA Goddard Space Flight Center; Solar Physics Section

Chris Hall; University of Tromso, Norway; CEDAR Data Base

Viggo Hansteen; Institute of Theoretical Astrophysics, University of Oslo, Norway; 8-12 August 1994; Solar wind

Jack Harvey; National Solar Observatory; Terrestrial Interactions Section

Karen Harvey; National Solar Observatory; Terrestrial Interactions Section

Paul Hays; University of Michigan; Solar Physics Section

William Heams; Goddard Space Flight Center; Terrestrial Interactions Section

Williams Heaps; NASA/Goddard Space Flight Center; Solar Physics Section

Alan Hedin; NASA/Goddard Space Flight Center; Terrestrial Interactions Section

Gonzalo Hernandez; University of Washington; Terrestrial Interactions Section

Petr Heinzel; Academy of Sciences, Czech Republic; 8-25 September 1994; Radiative transfer problems

Eijiro Hiei; Meisei University, Japan; 13 March - 9 April 1994; Coronal structure and evolution, YOHKOH data

Peter Hoeflich; Harvard-Smithsonian Center for Astrophysics; 11-18 December 1993; Radiation hydrodynamics in stellar atmospheres

Lon Hood; University of Arizona; Terrestrial Interactions Section

Ivan Hubeny; NASA Goddard Space Flight Center; 18-25 November 1993; NLTE PRD Coda

Terence Hughes; Herzberg Institute of Astrophysics, Canada; Terrestrial Interactions Section

Joan Hundhausen; Colorado School of Mines; Solar Physics Section

Donald Hunten; University of Arizona; Terrestrial Interactions Section

Paul Hunter; Monash University, Clayton, Australia; 13 June - 13 December 1994; Modelling of absorption of p-modes by sunspots

Darrell L. Judge; Space Science Center, University of Southern California; Terrestrial Interactions Section

Yosuke Kamide; Nagoya University, Japan; Terrestrial Interactions Section

John Kelly; SRI International; CEDAR Data Base

Timothy Killeen; University of Michigan; Terrestrial Interactions Section

Yong-Cheol Kim; Yale University; Solar Physics Section

Delores Knipp; U.S. Air Force Academy; Terrestrial Interactions Section

Michael Knöelker; Kiepenheuer Institute, Germany; Solar Physics Section

Gaston Kockarts; Institute for Aeronomy, Brussels; Terrestrial Interactions Section

John L. Kohl; Harvard-Smithsonian Center for Astrophysics; Solar Physics Section

Herbert Kroehl; NOAA National Geophysical Data Center; Terrestrial Interactions Section

Robert Kurucz; Center for Astrophysics; Terrestrial Interactions Section

Egidio Landi; University of Florence, Italy; 1 August - 15 September 1994; ASP analysis

George Lawrence; University of Colorado; Terrestrial Interactions Section

Guan Le; University of California, Los Angeles; Terrestrial Interactions Section

Judith Lean; Naval Research Laboratory; Terrestrial Interactions Section

Egil Leer; University of Oslo, Norway; 9 May - 8 June 1994 and 19 July - 20 August 1994; Solar wind

Philippe Lemaire; Institut d'Astrophysique Spatiale, Orsay, France; Solar Physics Section

Ronald P. Lepping; NASA Goddard Space Flight Center; Terrestrial Interactions Section

Jianke Li; The University of Sydney, Australia; 23 October 1993 to 25 October 1995; MHD problems and pulsar wind problems

Ruth Lieberman; University of Michigan; 18-22 October 1993; Tidal signatures

Jeffrey Linsky; JILA, University of Colorado; Solar Physics Section

William Livingston; National Solar Observatory; Terrestrial Interactions Section

Julius London; University of Colorado; Terrestrial Interactions Section

Julie Lundquist; Trinity University; Terrestrial Interactions Section

Thomas Lydon; Yale University; Solar Physics Section

Lawrence Lyons; The Aerospace Corporation; Terrestrial Interactions Section

Carol G. Maclennan; AT&T Bell Laboratories; Terrestrial Interactions Section

Alan Manson; University of Saskatoon, Canada; CEDAR Data Base

Sara Martin; California Institute of Technology; Solar Physics Section

Alan McAllister; Space Environment Laboratory; 1 September 1994 to 1 September 1995; YOHKOH data

Angus McEwin; Australian Geological Survey Organisation, Australia; Terrestrial Interactions Section

Pat McIntosh; National Oceanagraphic and Atmospheric Administration/Environment Laboratory/Space Environment Laboratory; Solar Physics Section

Chris Meek; University of Saskatoon, Canada; Terrestrial Interactions Section

Michael Mendillo; Boston University; CEDAR Data Base

Kent Miller; Utah State University; Terrestrial Interactions Section

Thomas G. Moran; NASA Goddard Space Flight Center; Solar Physics Section

Raymond Morris; Australia Antarctic Division, Australia; Terrestrial Interactions Section

Rick Niciejewski; University of Michigan; CEDAR Data Base

Aake Nordlund; Copenhagen University Observatory; 1-30 July 1994; Solar convection and the solar dynamo

Espen Olsen; University of Oslo; 1 September - 15 December 1994; Neutral hydrogen in the innter solar wind

Hermann Opgenoorth; Swedish Institute of Space Physics, Sweden; Terrestrial Interactions Section

Frederic Paletou; Institut d'Astrophysique, University of Paris, France; 1 October 1992 to 12 August 1994; Plasma physics, radiative transfer

Maths L. Persson; Swedish Institute of Space Physics, Sweden; Terrestrial Interactions Section

Harry Petschek; MHP, Inc., Boston; 12-16 September 1994; Fast reconnection

Christophe Peymirat; Centre de Recherches en Physique de L'Environnement Terrestre et Planetaire, France;

1 July - 30 August 1994; TIEGCM

Valentin Martínez Pillet; Institute de Astrofísica de Canarias; 11;January 1993 to 10 January 1995; Advanced Stokes Polarimeter

Yuri Portnyagin; TYPHOON/Obninsk, Russia; Terrestrial Interactions Section

Diane Prinz; Naval Research Laboratory; Terrestrial Interactions Section

Mark Rast; University of Colorado, JILA; 27 October 1993 to 26 October 1994; Equation-of-state changes and convection flow dynamics

Manfred Rees; University of Alaska; Terrestrial Interactions Section

Patricia Reiff; Rice University; Terrestrial Interactions Section

Frederick Rich; Air Force Phillips Laboratory; Terrestrial Interactions Section

Phil Richards; University of Alabama, Huntsville; Terrestrial Interactions Section

Anthony Riddle; NOAA Aeronomy Laboratory; CEDAR Data Base.

David Rind; Goddard Institute for Space Studies; Terrestrial Interactions Section

Richard Robinson; Goddard Space Flight Senter; Solar Physics Section

Alan S. Rodger; British Antarctic Survey, United Kingdom; Terrestrial Interactions Section

Robert G. Roper; Georgia Institute of Technology; CEDAR Data Base

Günther Rudiger; Astrophysikalisches Institut, Germany; 5-14 August 1994; Galactic dynamo

J. Michael Ruohoniemi; Johns Hopkins University; CEDAR Data Base

Christopher Russell; University of California, Los Angeles; Terrestrial Interactions Section

Rob Rutten; Sterrekundig Instituut, Utrecht, The Netherlands; 8 March - 8 April 1994; Oscillations of the quiet chromosphere

Joseph Salah; MIT Haystack Observatory; Terrestrial Interactions Section

Ornulf Sandbaek; Institute of Theoretical Physics, Oslo, Norway; 20;July to 20;December 1993; Solar wind physics

Mariko Sato; University of Nagoya, Japan; Terrestrial Interactions Section

Kenneth Schatten; Goddard Space Flight Center; Terrestrial Interactions Section

Gerhard Schmidtke; Fraunhofer-Institut für Physikalische Meßtechnik, Germany; Terrestrial Interactions Section

Rudolf Schminder; University of Leipzig, Germany; CEDAR Data Base

Jesper Schou; Stanford University; Solar Physics Section

William Sharp; University of Michigan; Terrestrial Interactions Section

Joseph She; Colorado State University; Terrestrial Interactions Section

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Dwight Sipler; MIT Haystack Observatory; CEDAR Data Base

Steven Smith; University of California, Los Angeles; 1;October 1991 to 31;October 1993; Solar Physics Section

Herschel Snodgrass; Lewis and Clark College; Solar Physics Section

Sabatino Sofia; Yale University; Solar Physics Section

Stan C. Solomon; University of Colorado; Terrestrial Interactions Section

John Spreiter; Stanford University; Terrestrial Interactions Section

O. C. St. Cyr; Allied Signal Technical Services Corporation; Solar Physics Section

Richard Steinolfson; Southwest Research Institute; SMM data analysis

Robert Stening; University of New South Wales, Australia; 14;August to 14;October 1993; Modelling lunar tidal effects in the upper atmosphere

Jim Stone; University of Maryland; 1-10 August 1994; MHD turbulence

Leonard Strachan; Harvard-Smithsonian Center for Astrophysics; Solar Physics Section

Keith Strong; Lockheed Palo Alto Research Laboratory; Solar Physics Section

Wesley Swartz; Cornell University; CEDAR Data Base

Craig Tepley; Arecibo Observatory, Puerto Rico; CEDAR Data Base

John H. Thomas; University of Rochester; Solar Physics Section

Michael J. Thompson; Queen Mary and Westfield College; Solar Physics Section

W. Kent Tobiska; Telos Systems Group, NASA Jet Propulsion Laboratory; 29 August - 2 September 1994; UARS SOLSTICE data

Lester Tomlinson; Institute of Geological and Nuclear Sciences, New Zealand; Terrestrial Interactions Section

Douglas Torr; University of Alabama, Huntsville; Terrestrial Interactions Section

Ulf Torkelsson; University of Lund, Sweden; 10 January - 5 February 1994; Accretion disks, dynamo theory, turbulence

S. C. Tripathy; Udaipur Solar Observatory, India; 21 March - 1 April 1994; GONG efforts

Oleg Troshichev; Arctic and Antarctic Research Institute, Russia; Terrestrial Interactions Section

Saku Tsuneta; University of Japan; Solar Physics Section

Lawrence Twigg; Applied Research Corp.; Terrestrial Interactions Section

Michael van Hoosier; Naval Research Laboratory; Terrestrial Interactions Section

Francois Vial; Laboratoire de Metiorologie Dynamique du Centre Nationale de Recherche Atmospherique, France; 13-19 March 1994; Atmospheric dynamics

Jean-Claude Vial; Institut d' Astrophysique Spatiale, Paris; 12-16 September 1994; Solar prominences

Robert Vincent; University of Adelaide, Australia; Terrestrial Interactions Section

Zhi Wang; University of California, Los Angeles; Terrestrial Interactions Section

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Peter Wilson; University of Sydney; Solar Physics Section

David Winningham; Southwest Research Institute; Terrestrial Interactions Section

John Wise; Boston College; Terrestrial Interactions Section

Dong Wu; University of Michigan; Terrestrial Interactions Section

Ming Yan; Universiyt of Alaska; 2 May - 2 August 1994 Magnetosheath wave data analysis

Sam Yee; Johns Hopkins University; Terrestrial Interactions Section

Xiaoxin Zhang; Chinese Academy of Science, China; Terrestrial Interactions Section

Qihou Zhou; Arecibo Observatory, Puerto Rico; CEDAR Data Base

Ellen Zweibel; University of Colorado; Solar Physics Section

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Mesoscale and Microscale Meteorology (MMM) Division

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Significant Accomplishments FY 94

- The development mechanism for the ERICA IOP4 storm using balanced diagnostics was examined by Christopher Davis (joint appointment with RAP), and Melvyn Shapiro and Evelyn Grell (both of NOAA). They showed that the development strongly resembles the transient behavior seen in idealized models of cyclogenesis in which there is pronounced along-flow variation in the basic state, combined with a finite-amplitude initial disturbance.

- Mesoscale Convective Systems (MCSs) evolving in a balanced environment that exhibits horizontal variability in convective potential were modeled by William Skamarock, Morris Weisman, C. Davis, and Joseph Klemp. These simulations demonstrate that although the along-line variability can significantly modulate the detailed MCS structure, previous results obtained in a homogeneous environment capture the fundamental dynamics that govern system evolution.

- Large-scale tropical cloud systems in an idealized model driven by radiative cooling, fixed sea surface temperature, and a relaxation of the surface wind toward a specified value were studied by Jun-Ichi Yano (visitor, UCAR Visiting Scientist Program), James McWilliams (CGD), Mitchell Moncrieff, and Kerry Emanuel (affiliate scientist, Massachusetts Institute of Technology (MIT)). An eastward-propagating low-wavenumber disturbance containing a hierarchy of superclusters and cloud clusters was spontaneously generated from a random initial state using archetypes of different cumulus parameterizations which also radically affected the cluster regimes.

- Collaboration focusing on interactions among cloud dynamics, cloud microphysics, radiation and large-scale forcing on time scales of order weeks and spatial scales of order 1000 km using a cloud-resolving model continued among Wojciech Grabowski and Moncrieff, James Hack and Jeffrey Kiehl (both of CGD), and Gregory Tropoli (University of Wisconsin, Madison). A meso-beta-scale cloud system hierarchy was demonstrated and the surface energy balance was found to be strongly negative, a model demonstration of the "thermostat hypothesis."

- The dominance of radiative cooling and evaporation of orographic precipitation in producing flow reversal on the windward side of Hawaii, given a steady background flow as described by Smolarkiewicz et al., 1987, was demonstrated by Richard Carbone, William Cooper (joint appointment with ATD), and Wen-Chau Lee (ATD).

- Convection and Precipitation/Electrification Experiment (CaPE) data were used by L. Jay Miller, with Neil Laird, David Kristovich, and Harry Oches (all three of the Illinois State Water Survey) and Robert Rauber (University of Illinois), to show how the coastline and river altered the sea breeze structure to create areas favorable for convection.

- The theoretical differences between gravity currents and classical hydraulic jumps and bores were reconciled by Klemp, Richard Rotunno, and Skamarock. A more general front condition was derived for gravity currents and bores in atmospheric flows.

- A collaborative study of gravity wave activity in the middle atmosphere continued among Joseph Prusa (Iowa State University), Piotr Smolarkiewicz, and Rolando Garcia (ACD). Dispersion effects cause waves of comparable vertical and horizontal wavenumbers to dominate as initiators of wave breaking at mesopause altitudes, a result which contrasts with traditional ideas.

- Terrain-induced turbulence in the lee of Lantau Island as part of the Hong Kong project was simulated by Hsiao-Ming Hsu (visitor, Woods Hole Oceanographic Institution; joint appointment with RAP), Teddie Keller (joint appointment with RAP), and Terry Clark .

A major field campaign as part of the Winter Icing and Storms Project (WISP)was conducted by several MMM, RAP, and university scientists. They documented patterns of ice formation in winter clouds and related them to aerosol concentrations and other characteristics of the air masses in which ice formed.

- Studies of ice formation in cold clouds were conducted by Andrew Heymsfield and Larry Miloshevich. These studies strengthened the evidence for homogeneous nucleation of solution droplets as the predominant ice-forming mechanism in those clouds by showing that ice formation occurs only above a temperature-dependent critical humidity.
- A new instrument for the measurement of particle size, concentration, and index of refraction was developed by James Dye (joint appointment with ATD) and colleagues. They operated this instrument on the NASA ER-2 to determine critical conditions for the formation of polar stratospheric clouds.
- The variation of temperature, humidity, carbon dioxide, and ozone fluxes across the boreal forest of Canada from the prairies (on the South) to the sub-Arctic tundra (on the North) throughout the summer s measured by Donald Lenschow (joint appointment with ATD), Steven Oncley (ATD), Jakob Mann (visitor, Riso National Laboratory, Denmark), Kenneth Davis (ASP visitor, University of Colorado), and Qing Wang (ASP visitor, Pennsylvania State University). These data will, when combined with other aircraft and tower measurements, permit estimates of variations in air-surface exchange over the different ecosystems making up this region and are essential for developing parameterizations for and validating global and regional scale models. An extensive data set was collected which will also be used to study the structure of the convective boundary layer.
- A new two-part subgrid scale model for large-eddy simulation that yields significantly better correspondences with Monin-Obukhov similarity theory than prior models was developed by Peter Sullivan, McWilliams, and Chin-Hoh Moeng. The new model was found to be relatively independent of grid resolution.
- The MM5 was released for community use in February 1994. Jimy Dudhia, David Gill, and Sue Chen developed a more flexible modeling system than the previous version (MM4) with significant contribution from Georg Grell (NOAA) and David Stauffer (Pennsylvania State University).
- A series of observing system simulation experiments using the adiabatic MM5 adjoint model to assess the impact of global positioning system (GPS)-derived atmospheric refractivity data was conducted by Xiaolei Zou, Kuo, and Yong-Run Guo. They found that the assimilation of atmospheric refractivity is highly effective in recovering the vertical profiles of water vapor, which can be very valuable for short-range numerical weather prediction.
- The adjoint technique and thermodynamic retrieval to accurately retrieve the microphysical cloud fields were extended further by Juanzhen Sun and N. Andrew Crook (joint appointment with RAP).
- An evaluation of five techniques to derive the complete wind field using single-Doppler techniques was jointly conducted by John Tuttle (joint appointment with RAP) joined Alan Shapiro and Tzvi Gal-Chen (both of Center for the Analysis and Prediction of Storms (CAPS), University of Oklahoma), Qin Xu (Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), University of Oklahoma) and Isztar Zawadski (McGill University). Applied to a microburst case, all five techniques did a good job of retrieving features five to ten times the radar sampling volume.

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Larry Mahrt (Oregon State University)
Richard Reed (University of Washington)

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MMM Visitors and Collaborators , FY 94

Dates refer to visitor's stay at NCAR during FY 94. No dates are given for collaborators who did not visit NCAR.

Ishfaq Ahmad, Hong Kong Institute of Science and Technology, 10-13 August 1994, Cloud Scale Modeling Group

John Aiken, Laboratoire de Recherches en Vol, Canada, 13-14 January 1994, Boundary Layer and Turbulence Group

Anders Andren, Uppsala University, 24 May to 11 June 1994, Boundary Layer and Turbulence Group

David Atlas, NASA, Physical Meteorology Group

Keith Ayotte, Atmospheric Environment Service, Canada, 25 January 1993 to 25 January 1995, Boundary Layer and Turbulence Group

Peter Bakwin, NOAA, Boundary Layer and Turbulence Group

Jian-Wen Bao, University of Colorado, 24 August to 1 September 1994, Mesoscale Prediction Group

Gillis Barbier, L'Ecole Polytechnique, France, 9 May to 16 August 1994, Boundary Layer and Turbulence Group

Albert Barcilon, Florida State University, 1 June 1994 to 1 June 1995, Mesoscale Dynamics Group

Richard Barhydt, University of Colorado, 16 July 1993 to 16 July 1995, Mesoscale Analysis Group

Gary Barnes, University of Hawaii, Mesoscale Analysis Group

Mary Barth, University of Washington, 15 August 1992 to 14 August 1994, joint appointment with ACD, Physical Meteorology Group, Mesoscale Dynamics Group

Peter Bechtold, University of Paul Sabatier, France, 16-18 August 1994, Boundary Layer and Turbulence Group

Eric Betterton, University of Arizona, Cloud Scale Modeling Group

Warren Blier, University of California, Los Angeles, 24 August to 1 September 1994, Mesoscale Prediction Group

Howard Bluestein, University of Oklahoma, 11 June to 18 August 1994, Mesoscale Dynamics Group

William Blumen, University of Colorado, Mesoscale Analysis Group

Reinout Boers, CSIRO, Australia, 16-18 August 1994, Boundary Layer and

Turbulence Group

Michael Booth, University of Sydney, Australia, 6 June to 25 July 1994, Physical Meteorology Group

Mark Branson, Colorado State University, 16-18 August 1994, Boundary Layer and Turbulence Group

Jean-Louis Brenguier, Affiliate Scientist, Direction de la Meteteorlogie Nationale, France, 1-4 December 1993, Cloud Scale Modeling Group

James Bresch, Colorado State University, 1 May 1994 to 1 May 1995, Mesoscale Prediction Group

John Brown, NOAA, Cloud Systems Group and Mesoscale Prediction Group

Kathy Caesar, Texas A&M University, Mesoscale Analysis Group

Varaprasad Calmidi, University of Colorado, 15 May to 15 August 1994, Cloud Systems Group

Elizabeth Carter, Desert Research Institute, 6-17 June 1994, Cloud Scale Modeling Group

Tae Young Chang, University of Colorado, 1 March to 31 December 1994, Boundary Layer and Turbulence Group

Chaing Chen, NASA, 24 August to 1 September 1994, Mesoscale Prediction Group

Jay-Chung Chen, Hong Kong Institute of Science and Technology, 13-15 September 1994, Mesoscale Prediction Group

Fang-Ching Chien, University of Washington, 4 July 1994 to 5 July 1995, Mesoscale Prediction Group

Andreas Chlond, Max-Planck Institut fur Meteorologie, Germany, 16-18 August 1994, Boundary Layer and Turbulence Group

Janice Coen, University of Chicago, 1 September 1992 to 1 February 1994, Physical Meteorology Group

Brian Colle, University of Washington, 24 August to 1 September 1994, Mesoscale Prediction Group

William Cotton, Colorado State University, 16-18 August 1994, Boundary Layer and Turbulence Group

Timothy Crawford, NOAA, 13-14 January 1994, Boundary Layer and Turbulence Group

Hans Cuijperrs, Universite Paul Sabatier, France, 16-18 August 1994, Boundary Layer and Turbulence Group

Paul DeMott, Colorado State University, Physical Meteorology Group

David Dempsey, San Francisco State University, 24 August to 1 September

1994, Mesoscale Prediction Group

John Derber, National Meteorological Center, Washington D.C., 3-8 April 1994, Boundary Layer and Turbulence Group

Arthur DeVries, University of Illinois, Physical Meteorology Group

Sanjay Dixit, University of Colorado, 24 August to 1 September 1994, Mesoscale Prediction Group

Andrzej Domaradzki, University of Southern California, Boundary Layer and Turbulence Group

Jimy Dudhia, Pennsylvania State University, 1 July 1989 to 31 January 1994, Mesoscale Prediction Group

John Duman, Notre Dame University, Physical Meteorology Group

Michael Ek, Oregon State University, 16-18 August 1994, Boundary Layer and Turbulence Group

Kerry Emanuel, Affiliate Scientist, Massachusetts Institute of Technology, Cloud Systems Group and Mesoscale Dynamics Group

Chien-Hui Fang, National Taiwan University, 14 October to 31 December 1993 and 24 August to 1 September 1994, Mesoscale Prediction Group

Richard Farley, South Dakota School of Mines and Technology, Boundary Layer and Turbulence Group

Brian Farrell, Harvard University, 23-28 January 1994 and 1 August to 1 September 1994, Boundary Layer and Turbulence Group

Graham Feingold, CIRES, University of Colorado, 16-18 August 1994, Boundary Layer and Turbulence Group

Rossella Ferretti, University of L'Aquila, Italy, 24 August to 1 September 1994, Mesoscale Prediction Group

Theodore Funk, National Weather Service, Kentucky, NSSL, Mesoscale Research and Applications Division--Boulder

Tzvi Gal-Chen, Center of Analysis and Prediction of Storms, University of Oklahoma, Mesoscale Analysis Group

Kun Gao, Hangzhou University, China, 26 February 1992 to 30 April 1994, Mesoscale Prediction Group

Joanne George, Unaffiliated, 1 March to 1 April 1994, Physical Meteorology Group

Evelyn Donell Grell, NOAA, 24 August to 1 September 1994, Mesoscale Prediction Group

Georg Grell, NOAA, 24 August to 1 September 1994, Mesoscale Prediction Group

Robert Grossman, University of Colorado, 16 July 1993 to 16 July 1995, Mesoscale Analysis Group

Vanda Grubisic, Yale University, 7 September to 7 November 1993, Cloud Systems Group

Yong-Run Guo, Shanghai Meteorological Center, 19 March 1991 to 31 January 1994, Mesoscale Prediction Group

John Gyakum, McGill University, 7-14 August 1994, Mesoscale Prediction Group

John Hallett, Desert Research Institute, Physical Meteorology Group

James Heimbach, University of North Carolina, 6-17 June 1994, Cloud Scale Modeling Group

Chris Herbster, Florida State University, 24 August to 1 September 1994, Mesoscale Prediction Group

Alan Hills, 30 March 1992 to 28 February 1995, MMM Director's Office

Yuan Ho, Center of Analysis and Prediction of Storms, University of Oklahoma, 23 July to 5 September 1994, Cloud Scale Modeling Group

Albertus Holtslag, Royal Netherlands Meteorological Institute, 16-18 August 1994, Boundary Layer and Turbulence Group

Andrew Hsu, University of Colorado, 1 June to 2 September 1994, Cloud Scale Modeling Group

Hsiao-Ming Hsu, Woods Hole Oceanographic Institute, Mass., 19 January 1994 to 19 January 1997, joint appointment with RAP and Cloud Scale Modeling Group

Zailiang Hu, University of Arizona, 6-17 June 1994, Cloud Scale Modeling Group

Wei Huang, Peking University, China, 1 August 1994 to 31 July 1995, Mesoscale Prediction Group

Rick Igau, Texas A&M University, 23 June to 24 August 1994, Mesoscale Analysis Group

Petros Ioannou, Harvard University, 1 August to 1 September 1994, Mesoscale Dynamics Group

Cliff Jacobs, National Science Foundation, 4-5 May 1994, MMM Director's Office

Hermann Jakobs, University of Cologne, Germany, 24 August to 1 September 1994, Mesoscale Prediction Group

Gregory Jenkins, Pennsylvania State University, 24 August to 1 September 1994, Mesoscale Prediction Group

Mary Ann Jenkins, York University, Canada, 6-25 June 1994 and 14-28 August 1994, Cloud Scale Modeling Group

Alain Joly, Centre National de Recherche Meteorologique, France, Mesoscale

Dynamics Group

Cyrus Jones, University of Arizona, 6-17 June 1994, Cloud Scale Modeling Group

Sarah Jones, University of Munich, Germany, 8-11 November 1993, Mesoscale Prediction Group

Josh Karotky, National Weather Service, 24 August to 1 September 1994, Mesoscale Prediction Group

John Keller, Massachusetts Institute of Technology, 16-18 August 1994, Boundary Layer and Turbulence Group

Robert Kelly, University of Wyoming, 13-14 January 1994, Boundary Layer and Turbulence Group

Daniel Keyser, State University of New York, Albany, 9-15 January 1994 and 15-21 May 1994, Mesoscale Dynamics Group

Christoph Kiemle, Deutsche Luft und Raumfahrt, Germany, 30 August to 19 September 1994, Boundary Layer and Turbulence Group

Yoshifumi Kimura, CIRES, University of Colorado, 2 July to 30 September 1994, Boundary Layer and Turbulence Group

Brian Klimowski, University of Wyoming, 2-8 December 1993, 6-17 June 1994, joint appointment with RAP, Cloud Scale Modeling Group

Ernst Klinker, European Centre for Medium-Range Weather Forecasts, England, Cloud Systems Group

David Knight, State University of New York, Albany, 24 August to 1 September 1994, Mesoscale Prediction Group

Ian Knight, CSIRO, Australia, 14-28 August 1994, Cloud Scale Modeling Group

Yefim Kogan, University of Oklahoma, 16-18 August 1994, Boundary Layer and Turbulence Group

Fred Kopp, South Dakota School of Mines and Technology, 16-18 August 1994, Boundary Layer and Turbulence Group

David Kristovich, Illinois State Water Survey, Mesoscale Analysis Group

Steve Krueger, University of Utah, 20-25 June 1994 and 16-18 August 1994, Cloud Scale Modeling Group and Boundary Layer and Turbulence Group

George Lai, NASA, 24 August to 1 September 1994, Mesoscale Prediction Group

Neil Laird, Illinois State Water Survey, Mesoscale Analysis Group

Winnie Lambert, Pennsylvania State University, 1 August 1993 to 2 September 1994, Mesoscale Prediction Group and Boundary Layer and Turbulence Group

John Latham, University of Manchester, England, 8 March 1993 to 31 December 1994, Physical Meteorology Group

Alexis Lau, Hong Kong Institute of Science and Technology, 1 May 1994 to 1 October 1996, joint appointment with RAP and Mesoscale Prediction Group

William Lau, NASA, 2-3 November 1993, Cloud Systems Group

Richard Laursen, Boston University, Physical Meteorology Group

Paul Lawson, SPEC, Inc., Mesoscale Analysis Group

Francois-Xavier Le Dimet, Laboratoire de Modelisation et Cacul, France, 24-28 August 1994, Mesoscale Prediction Group

Mark Leidner, Pennsylvania State University, 24 August to 1 September 1994, Mesoscale Prediction Group

Verne Leverson, Bureau of Reclamation, Denver, 24 August to 1 September 1994, Mesoscale Prediction Group

Stephen Lewellen, West Virginia University, 16-18 August 1994, Boundary Layer and Turbulence Group

Shang-Wu Li, Central Weather Bureau, Taiwan, 24 August to 1 September 1994, Mesoscale Prediction Group

Ching-Long Lin, Stanford University, 1 March 1994 to 1 March 1995, Boundary Layer and Turbulence Group

Hong Lin, Stockholm University, 6-14 September 1994, Physical Meteorology Group

Pay-Liam Lin, National Central University, Taiwan, 24 August to 1 September 1994, Mesoscale Prediction Group

Kuo-Nan Liou, University of Utah, Physical Meteorology Group

Yuei-An Liou, University of Michigan, 24 August to 1 September 1994, Mesoscale Prediction Group

Changhai Liu, Texas A&M University, 1 May 1994 to 30 April 1996, Cloud Systems Group

Yubao Liu, Chinese Academy of Meteorological Sciences, 24 May 1993 to 23 May 1995, Mesoscale Prediction Group

Ian MacPherson, Laboratoire de Recherches en Vol, Canada, 13-14 January 1994, Boundary Layer and Turbulence Group

Malcolm MacVean, Royal Meteorological Office, United Kingdom, 16-18 August 1994, Boundary Layer and Turbulence Group

Roop Mahajan, University of Colorado, Cloud Systems Group

Larry Mahrt, Affiliate Scientist, Oregon State University, 13-14 January 1994, Boundary Layer and Turbulence Group

Andrew Majda, Princeton University, 15-22 May 1994, joint appointment with: HAO and Boundary Layer and Turbulence Group

Jakob Mann, Riso National Laboratory, Denmark, 14 May to 27 September 1994, Boundary Layer and Turbulence Group

Len Margolin, Los Alamos National Laboratory, 20-29 October 1993, 14-18 March 1994, Cloud Systems Group

Hal Marshall, University of Michigan, 24 August to 1 September 1994, Mesoscale Prediction Group

Thomas Marshall, University of Mississippi, Physical Meteorology Group

John Marwitz, Colorado State University, Physical Meteorology Group

Paul Mason, Royal Meteorological Office, United Kingdom, 16-18 August 1994, Boundary Layer and Turbulence Group

Clifford Mass, University of Washington, 24 August to 1 September 1994, Mesoscale Prediction Group

Graeme Mather, Cloudquest, South Africa, Physical Meteorology Group

Sergey Matrosov, CIRES, University of Colorado, Physical Meteorology Group

David Matthews, Bureau of Reclamation, 1 October 1993 to 1 October 1994, Cloud Scale Modeling Group

Shane Mayor, St. Louis University, 9 May to 9 December 1994, Boundary Layer and Turbulence Group

James McCaa, University of Washington, 24 August to 15 September 1994, Mesoscale Prediction Group

Eugene McCaul, NASA, 16-23 October 1993, 11-15 July 1994, Mesoscale Dynamics Group

Margie McDermott, University of Wyoming, 13-14 January 1994, Boundary Layer and Turbulence Group

Gregory McFarquhar, Scripps Institute of Oceanography, 7-9 July 1994, Physical Meteorology Group

John McGinley, NOAA, Mesoscale Dynamics Group

John McHenry, MCNC Environmental Programs, 24 August to 1 September 1994, Mesoscale Prediction Group

Gregory Melvin, University of Colorado, 1 July 1994 to 30 June 1995, Physical Meteorology Group

Philip Merilees, Atmospheric Environment Service, Canada, 12-15 July 1994, MMM Director's Office

Bettina Messmer, Laboratory for Atmospheric Physics, Switzerland, 2-3 March 1994, Mesoscale Analysis Group

Dmitrii Mironov, ICSC World Laboratory, Italy, 25 October to 7 December

1993, Boundary Layer and Turbulence Group

Steven Mullen, University of Arizona, 27-29 October 1993, MMM Director's Office

Balu Nadiga, Los Alamos Laboratory, 4-18 February 1994 and 7 April 1994, Cloud Systems Group

Ravi Nanjundiah, Argonne National Laboratory, 24 August to 1 September 1994, Mesoscale Prediction Group

Paul Neiman, NOAA, Cloud Scale Modeling Group

Alan Nelson, NASA, 13-14 January 1994, Boundary Layer and Turbulence Group

Jon Nelson, University of Colorado, 11 May 1994 to 11 May 1995, Physical Meteorology Group

Harry Ochs, Illinois State Water Survey, 22-23 October 1993, Cloud Systems Group

Harold Orville, South Dakota School of Mines and Technology, 16-18 August 1994, Boundary Layer and Turbulence Group

David Packham, Bureau of Meteorology, Australia, Cloud Scale Modeling Group

Jacques Pasquier, University of Manchester, England, 16-18 August 1994, Boundary Layer and Turbulence Group

Edward Patton, University of California, Davis, 15 September 1993 to 15 September 1994, Boundary Layer and Turbulence Group

Judy Pechmann, University of Utah, 24 August to 1 September 1994, Mesoscale Prediction Group

Walter Petersen, Colorado State University, NSSL

James Pinto, University of Colorado, 24 August to 1 September 1994, Mesoscale Prediction Group

Manuel Pondeca, Florida State University, 23 August 1994 to 22 August 1995, Mesoscale Dynamics Group

Hoi-To Poon, Hong Kong Institute of Science and Technology, 24 August to 1 September 1994, Mesoscale Prediction Group

Annick Pouquet, Centre de la Recherche Scientifique, France, 3-17 August 1994, Boundary Layer and Turbulence Group

Alexander Praskovsky, Central Aerohydrodynamic Institute, Russia, 1 October 1993 to 12 April 1994, 1 July to 31 October 1994, joint appointment with ATD, Cloud Systems Group, Boundary Layer and Turbulence Group, and GTP

Joe Prusa, Iowa State University, 2 July to 16 August 1994, joint appointment with ACD and Cloud Systems Group

Janusz Pudykiewicz, Atmospheric Environment Service, Canada, 9-15 May 1994, Cloud Systems Group

Gordon Pusch, Argonne National Laboratory, 24 August to 1 September 1994, Mesoscale Prediction Group

David Randall, Colorado State University, 4-5 November 1993 and 16-18 August 1994, Boundary Layer and Turbulence Group

Robert Rauber, University of Illinois, Urbana, 22-23 October 1993, Mesoscale Analysis Group and Cloud Systems Group

Fred Ralph, NOAA, Cloud Systems Modeling Group

Peter Ray, Florida State University, 12-13 May 1994, joint appointment with ATD and MMM Director's Office

Richard Reed, Affiliate Scientist, University of Washington, 7-30 October 1993, 24 January to 5 February 1994, 31 May to 9 June 1994, 22 August to 2 September 1994, Mesoscale Prediction Group

Jon Reisner, Los Alamos National Laboratory, Cloud Systems Group

Dennis Rodgers, NOAA, Mesoscale Dynamics Group

David Rogers, Colorado State University, Physical Meteorology Group

Steven Rutledge, Colorado State University, National Severe Storms Laboratory

Hans Georg Schreiber, Deutsche Luft und Raumfahrt, Germany, 30 August to 19 September 1994, Boundary Layer and Turbulence Group

Kelly Schrieber, University of Wisconsin, 16-18 August 1994, Boundary Layer and Turbulence Group

Wayne Schubert, Colorado State University, 16-18 August 1994, Boundary Layer and Turbulence Group

Donald Schleede, State University of New York, Brockport, 24 August to 1 September 1994, Mesoscale Prediction Group

Ralph Schwartz, University of Washington, 24 August to 1 September 1994, Mesoscale Prediction Group

Nelson Seaman, Pennsylvania State University, 24 August to 1 September 1994, Mesoscale Prediction Group

Thomas Seliga, University of Washington, 9-14 December 1993, joint appointment with RAP and Cloud Systems Group

Piers Sellers, NASA, 13-14 January 1994, Boundary Layer and Turbulence Group

Yolande Serra, Scripps Institute of Oceanography, 4-20 May 1994, NSSL, Mesoscale Research and Application Division--Boulder

Qingqin Shao, University of Arizona, 16-18 August 1994, Boundary Layer and Turbulence Group

Alan Shapiro, Center of Analysis and Prediction of Storms, University of Oklahoma, Mesoscale Analysis Group

Melvyn Shapiro, NOAA, Mesoscale Prediction Group

Yang-Fang Sheng, National Central University, Taiwan, 24 August to 1 September 1994, Mesoscale Prediction Group

Lei Shi, SeaSpace Corporation, San Diego, 24 August to 1 September 1994, Mesoscale Prediction Group

Steven Siems, Monash University, Australia, 21-24 August Boundary Layer and Turbulence Group

Pier Sieresma, Royal Netherlands Meteorological Institute, 16-18 August 1994, Boundary Layer and Turbulence Group

Christopher Smith, Massachusetts Institute of Technology, 16-18 August 1994, Boundary Layer and Turbulence Group

Zbigniew Sorbjan, University of Oklahoma, 1-7 December 1993 and 6-17 June 1994, Cloud Systems Group and Cloud Scale Modeling Group

Peter Sousounis, University of Michigan, 24 August to 1 September 1994, Mesoscale Prediction Group

David Stauffer, Pennsylvania State University, 24 August to 1 September 1994, Mesoscale Prediction Group

David Stensrud, NSSL, Norman, Okla., 27-29 October 1993, 5-8 July 1994, 24 August to 1 September 1994, Mesoscale Prediction Group and MMM Director's Office

Bjorn Stevens, Colorado State University, 16-18 August 1994, Boundary Layer and Turbulence Group

Richard Stodt, Bureau of Reclamation, Denver, 24 August to 1 September 1994, Mesoscale Prediction Group

Mark Stoelinga, Pennsylvania State University, 1 August 1993 to 31 May 1995, Mesoscale Prediction Group

Roland Stull, University of Wisconsin, 16-18 August 1994, Boundary Layer and Turbulence Group

Jielun Sun, Oregon State University, 13-14 January 1994, Boundary Layer and Turbulence Group

Juanzhen Sun, University of Oklahoma, 3 January 1989 to 26 May 1994, Cloud Systems Group

Ian Sykes, Aeronautical Research Associates, Princeton, N.J., 16-18 August 1994, Boundary Layer and Turbulence Group

Marcin Szumowski, University of Illinois, 22-23 October 1993, 28 May to 1 August 1994, Cloud Scale Modeling Group

Wei-Kuo Tao, NASA, 20-23 October 1993, Mesoscale Prediction Group

Peter Taylor, York University, Canada, Boundary Layer and Turbulence Group

Jutta Thielen, University of Manchester, England, 6-17 June 1994, Cloud Scale Modeling Group

Jeffrey Tilley, University of Colorado, 24 August to 1 September 1994, Mesoscale Prediction Group

Gregory Tropoli, University of Wisconsin at Madison, Cloud Systems Group

Mark Tschudi, University of Colorado, 24 August to 1 September 1994, Mesoscale Prediction Group

Donna Tucker, University of Kansas, 8 June to 15 July 1994, and 24 August to 1 September 1994, Mesoscale Prediction Group

Aad van Ulden, Royal Netherlands Meteorological Institute, 16-18 August 1994, Boundary Layer and Turbulence Group

Paul Vaillancourt, McGill University, Canada, 6-20 June 1994, Cloud Systems Group

Francisco Valero, Scripps Institute of Oceanography, Physical Meteorology Group

Gabor Vali, University of Wyoming, 6-17 June 1994, Cloud Scale Modeling Group

Mike Vander Varste, South Dakota School of Mines and Technology, 16-18 August 1994, Boundary Layer and Turbulence Group

Hans Verlinde, Pennsylvania State University, 13 November to 3 December 1993, Cloud Systems Group

Ge Verver, Royal Netherlands Meteorological Institute, 4-18 December 1993, Boundary Layer and Turbulence Group

Mickey Wai, Royal Observatory, Hong Kong, 24 August to 1 September 1994, Mesoscale Prediction Group

Anyu Wang, Zhougshan University, China, 14 September 1994 to 14 March 1995, Mesoscale Prediction Group

Shouping Wang, NASA, 16-18 August 1994, Boundary Layer and Turbulence Group

Ting-An Wang, North Carolina State University, 24 August to 1 September 1994, Mesoscale Prediction Group

Wei Wang, Pennsylvania State University, 30 October to 6 November 1993, Mesoscale Prediction Group

Yansen Wang, NASA, 24 August to 1 September 1994, Mesoscale Prediction Group

Thomas Warner, Pennsylvania State University, 1 June 1993 to 1 August 1994, joint appointment with RAP and Mesoscale Prediction Group

Jeffrey Weil, CIRES, University of Colorado, 1 April 1990 to 30 September 1994, Physical Meteorology Group

Joseph Werne, University of Chicago, 1 September 1994 to 31 August 1995, Boundary Layer and Turbulence Group

Melanie Wetzel, Desert Research Institute, 24 August to 1 September 1994, Mesoscale Prediction Group

Jeffrey Whitaker, CIRES, University of Colorado, 1 August 1993 to 31 December 1994, Mesoscale Dynamics Group

Seth White, University of Colorado, 6 October 1993 to 5 October 1994, Boundary Layer and Turbulence Group

Louis Wicker, Texas A&M University, 7-21 August 1994, Mesoscale Dynamics Group

James Wilczak, NOAA, Cloud Systems Group

Robert Wilhelmson, National Center for Supercomputing Applications, University of Illinois, Mesoscale Dynamics Group

James Wilson, University of Denver, Physical Meteorology Group

Darrell Winner, University of California Technology, 24 August to 1 September 1994, Mesoscale Prediction Group

Wolfram Wobrock, Universite Blaise Pascal, France, 6-17 June 1994, Cloud Scale Modeling Group

Xiaoqing Wu, University of California at Los Angeles, 1 October 1993 to 30 September 1995, Cloud Systems Group

Matthew Wyant, University of Washington, 16-18 August 1994, Boundary Layer and Turbulence Group

John Wyngaard, Pennsylvania State University, Boundary Layer and Turbulence Group

Aijun Xiu, MCNC Environmental Programs, North Carolina, 24 August to 1 September 1994, Mesoscale Prediction Group

Qin Xu, University of Oklahoma, 2-15 October 1993, Mesoscale Prediction Group

Xianyong Xu, University of Wyoming, 6-17 June 1994, Cloud Scale Modeling Group

Ming Xue, Center for Analysis and Prediction of Storms, Norman, Okla., Mesoscale Dynamics Group

Jun-Iche Yano, Monash University, Australia, 18 March to 30 June 1994, joint appointment with CGD and Cloud Systems Group

Robert Zamora, NOAA, 24 August to 1 September 1994, Mesoscale Analysis Group

Isztar Zawadski, McGill University, Canada, Mesoscale Analysis Group

Da-Lin Zhang, McGill University, 24 August to 1 September 1994, Mesoscale Prediction Group

Wenjie Zhao, Princeton University, 24 August to 1 September 1994, Mesoscale Prediction Group

Li Zhe, University of Colorado, 24 August to 1 September 1994, Mesoscale Prediction Group

Yong Zheng, University of Oklahoma, 16 February to 9 March 1994, Mesoscale Prediction Group

Ming Yu Zhou, National Research Center for Marine Environmental Forecasts, China, 7 May to 3 October 1994, Mesoscale Analysis Group and Boundary Layer and Turbulence Group

Edward Zipser, Texas A&M University, 21 June to 3 September 1994, Mesoscale Analysis Group http://www.ncar.ucar.edu/archives/asr/ASR94/MMM/refpub.html Go

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MMM Refereed Publications, FY 94

Non-refereed Publications

BARTH, M.C., 1994: Numerical modeling of sulfur and nitrogen chemistry in a narrow cold-frontal rainband: The mpact of meteorological and chemical parameters. *Journal of Applied Meteorology* **33**,855-868.

BROCK, C.A., H.H. JONSSON, J.C. WILSON, J.E. DYE, D. BAUMGARDNER, S. BORRMANN, M.C. PITTS, M. OSBORN, R.J. DeCOURSEY, and D.C. WOODS, 1993: Relationships between optical extinction, backscatter and aerosol surface and volume in the stratopshere following the eruption of Mt. Pinatubo. *Geophysical Research Letters* **20**, 2555-2558.

BRUINTJES, R.T., T.L. CLARK, and W.D. HALL, 1994: Interactions between topographic airflow and cloud/precipitation development during the passage of a winter storm in Arizona. *Journal of the Atmospheric Sciences* **51**, 48-67.

BRUINTJES, R.T., and R.R. CZYS, 1994: A review of hygroscopic seeding experiments to enhance rainfall. *Journal of Weather Modification* **26**, 41-52.

CHEN, S.-J., and Y.-H. KUO, 1994: Cyclones and northern hemispheric temperature. *Theoretical and Applied Climatology* **49**, 85-89.

CLARK, T.L., W.D. HALL, and R. BANTA, 1994: Two- and three-dimensional simulations of the 9 January 1989 severe Boulder windstorm: Comparison with observations. *Journal of the Atmospheric Sciences* **51**, 2317-2343

CROOK, N.A., 1994: Numerical simulations initialized with radar-derived winds. Part I: Simulated data experiments. *Monthly Weather Review* **122**, 1189-1203.

CROOK, N.A., and J.D. TUTTLE, 1994: Numerical simulations initialized with radar-derived winds. Part II: Forecasts of three gust-front cases. *Monthly Weather Review* **122**, 1204-1217.

DAVIS, C. A., and M. L. WEISMAN, 1994: Balanced dynamics of mesoscale vortices produced in simulated convective systems. *Journal of the Atmospheric Sciences* **51**, 2005-2030.

GENT, P.R., J.C. McWILLIAMS, and C. SNYDER, 1994: Scaling analysis of curved fronts: Validity of the balance equations and semigeostrophy. *Journal of the Atmospheric Sciences* **51**, 160-163.

GOTOH, T., R.S. ROGALLO, J.R. HERRING, and R.H. KRAICHNAN, 1993: Lagrangian velocity correlations in homogeneous isotropic turbulence. *Physics of Fluids* **A5**, 2846-2864.

HALLETT, J., and C.A. KNIGHT, 1994: On the symmetry of snow dendrites. *Atmospheric Research* **32**, 1-11.

HEIMBACH, J.A., and W.D. HALL, 1994: Applications of the Clark Model to winter storms over the Wasatch Plateau. *Journal of Weather Modification* **26**, 1-11.

HERRING, J.R., and R.M. KERR, 1993: Development of enstrophy and spectra in numerical turbulence. *Physics of Fluids* **A5**, 2792-2798.

HERRING, J.R., R.M. KERR, and R. ROTUNNO, 1994: Potential vorticity in unstratified turbulence. *Journal of the Atmospheric Sciences* **51**, 35-47.

HORST, T.W., and J.C. WEIL, 1994: How far is far enough?: The fetch requirements for micrometeorological measurement of surface fluxes. *Journal of Oceanic and Atmospheric Technology* **11**, 1018-1025.

JORGENSEN, D.P., and B.F. SMULL, 1993: Mesovortex circulations seen by airborne Doppler radar within a bow-echo mesoscale convective system. *Bulletin of the American Meteorological Society* **74**, 2146-2157.

KLEMP, J.B., R. ROTUNNO, and W.C. SKAMAROCK, 1994: On the dynamics of gravity currents in a channel. *Journal of Fluid Mechanics* **269**, 169-198.

LeMONE, M.A., and M.W. MONCRIEFF, 1994: Momentum and mass transport by convective bands: Comparisons of highly idealized dynamical models to observations. *Journal of the Atmospheric Sciences* **51**, 281-305.

LeMONE, M.A., and M.W. MONCRIEFF, 1993: Momentum transport by convective bands: Comparisons of highly idealized dynamical models to observations. Chapter 6, in *The Representation of Cumulus Convection in Numerical Models of the Atmosphere,* Meteorological Monographs 24, No. **46** (K.A. Emanuel and D.J. Raymond, Eds.), American Meteorological Society, 246 pp.

LENSCHOW, D.H., J. MANN, and L. KRISTENSEN, 1994: How long is long enough when measuring fluxes and other turbulence statistics? *Journal of Atmospheric and Oceanic Technology* **11**, 661-673.

MANN, J., and D.H. LENSCHOW, 1994: Errors in airborne flux measurement. *Journal Geophysical Research* **99**, No. D7, 14519-14526.

MOENG, C.-H., and P.P. SULLIVAN, 1994: A comparison of shear- and buoyancy-driven planetary boundary layer flows. *Journal of the Atmospheric Sciences* **51**, 999-1022.

MURAKAMI, M., T.L. CLARK, and W.D. HALL, 1994: Numerical simulations of convective snow clouds over the Sea of Japan; Two-dimensional simulations of mixed layer development and convective snow cloud formation. *Journal of the Meteorological Society of Japan* **72**, 43-62.

PALUCH, I.R., D.H. LENSCHOW, S. SIEMS, S. McKEEN, G.L. KOK, and R.D. SCHILLAWSKI, 1994: Evolution of subtropical marine boundary layer: Comparison of soundings over the eastern Pacific from FIRE and HaRP. *Journal of the Atmospheric Sciences* **51**, 1465-1479.

PARUNGO, F., J. ROSINSKI, M.L.C. WU, C.T. NAGAMOTO, Z. MINYU, and Z. Ni, 1993: Variation of sulfate aerosol concentrations over the western Pacific and their effect on clouds, radiation and precipitation. *Acta Oceanologica Sinica* **12**, 521-534.

PRUSA, J., P. SMOLARKIEWICZ, and R. GARCIA, 1993: Application of time variable coordinate transformation and semi-Lagrangian methods to the study of deep gravity waves. *Bulletin of the American Physical Society* **38**, 2224.

REISNER, J.M., and P.K. SMOLARKIEWICZ, 1994: Thermally forced low Froude number flow past three-dimensional obstacles. *Journal of the Atmospheric Sciences* **51**, 117-133.

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Cloud System Studies

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Cloud, Aerosol, and Precipitation Physics and Chemistry

Studies of Ice Formation

Several related projects addressed unexplained aspects of ice formation in clouds and studied fundamental physical processes related to ice formation. The 1994 Winter Icing and Storms Project (WISP94) focused on field observations related to ice formation in wintertime clouds, especially in wave and upslope clouds, to investigate the roles of heterogeneous ice nuclei in those clouds. Studies in high-altitude wave clouds investigated the role of homogeneous nucleation in ice formation, and studies of cirrus clouds investigated the dependence of size distributions and optical properties of ice crystals on temperature. Some instrument development to support ice nucleation studies was started, and new theoretical and laboratory investigations also focused on ice formation.

The Winter Icing and Storms Project (WISP)

The primary objectives of the 1994 field observing campaign in WISP were to document and understand ice formation in winter clouds of the WISP study area in northcentral Colorado. Two cloud types, laminar wave clouds and upslope clouds, were the focus for these studies because of the relative simplicity of airflow in those cases and the expectation that this would lead to relatively simple patterns in ice formation. MMM scientists Rasmussen, Cooper, Bruintjes, C. Davis, Janice Coen, and Szoke participated with other NCAR scientists and with investigators from the University of Wyoming (John Marwitz, Gabor Vali, Robert Kelly), Colorado State University (Paul DeMott, David Rogers, V. Chandrasekar), the University of Nevada, Desert Research Institute (John Hallett), the NOAA/Forecast Systems Laboratory (FSL) (John) Brown), the NOAA Environmental Technology Laboratory (Robert Kropfli, Brooks Martner, Roger Reinking), and other groups in the conduct of this study.

Wave cloud observations documented that there is considerable variability in ice concentrations beyond that controlled by supercooling, and much of that variability is associated with variability in aerosol content (and hence with altitude). Upslope clouds were found to have ice concentrations higher than expected from measurements of ice nuclei, and those concentrations persisted long after initial ice concentrations should have sedimented from the clouds. Unexplained ice formation associated with evaporation, especially in wave clouds, was also observed. The extensive data set collected in this project will provide the basis for analyses to be undertaken in the next several years.

As part of efforts to understand ice formation, aerosol samples were collected in bags from inflow regions to wave clouds and other source regions for ice formation, and these samples were processed in the Colorado State University (CSU) cloud chamber by Paul DeMott and David Rogers (both of CSU). Comparisons between these results and the concentrations observed in the clouds will help determine nucleation modes active in the clouds, and will determine if aerosol samples can provide good predictions of ice concentrations that form in the clouds. In addition, filter samples were collected and are being processed in a variety of ways to learn if those measurements can explain or correlate with the ice concentrations that formed in the clouds.

In addition, a major modeling component using the MM5 was incorporated into the experiment with the dual objectives of experimental planning and model verification. This aspect of the experiment is described elsewhere in this report.

Ice-Cloud Microphysical and Radiative Properties: Results from the Central Equatorial Pacific Experiment (CEPEX)

Heymsfield and Gregory McFarquhar (Center for Clouds, Chemistry, and Climate (C4)/Scripps Institute of Oceanography) collaborated to analyze measurements acquired in tropical cirrus anvils during CEPEX and in the vicinity of Kwajalein, Marshall Islands. The data spanned the temperature range zero degrees Centigrade to about -85 degrees Centigrade. The focus of the study was to explore the hypothesis that colder clouds have smaller and hence more reflective ice crystals. They found that indeed a systematic decrease in mean particle size occurred with decreasing temperature, and bulk microphysical properties (particle cross-sectional area, ice water content) also decreased. Together with Francisco Valero (Scripps Institute of Oceanography) and Kuo-Nan Liou (University of Utah), they are now relating these cloud microphysical properties to cloud albedo.

Wave and Cirrus Clouds

Heymsfield and Larry Miloshevich examined the conditions required for ice formation at low temperature. Their analyses of measured ice crystal concentrations in wave clouds showed that homogeneous ice nucleation produces a rapid transition from solution droplets to ice crystals throughout the temperature range -35 to -56 degrees Centigrade. Significant concentrations of ice crystals only appear near water saturation at -39 degrees Centigrade, but can appear about 73 percent relative humidity with respect to water at -56 degrees Centigrade. A similar analysis was performed using cirrus observations made during the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE) II project. The relative humidities measured in clear air, although well above ice saturation, place a lower bound on the relative humidity required for cirrus formation at about 10 percent below the limit found for wave clouds. The FIRE II measurements also showed the vertical structure of cirrus to consist of three microphysically distinct regions: a highly ice-supersaturated ice production region near cloud top, an ice-supersaturated ice crystal growth region, and a sublimation region near cloud base formed by fallout of ice into ice-subsaturated air.

Fundamental Physics of Ice Formation

Charles Knight completed most major topics in his ongoing research on nonequilibrium antifreeze. This work, conducted in collaboration with Arthur DeVries (University of Illinois), Richard Laursen (Boston University), John Duman (Notre Dame), and others, demonstrated that antifreeze found in fish living in cold seas operates not by depressing the equilibrium freezing point, as in conventional antifreeze solutions, but rather by inhibiting growth of any ice that forms. This inhibition results from the incorporation of long-chain molecules of the antifreeze into the ice lattice in ways that suppress further growth. An aspect of this work completed during 1994 was the demonstration that mirror-image winter flounder antifreeze, synthesized by Laursen, has a mirror-image pattern of adsorption on ice as required by the current theory.

Knight continued work with John Hallett (University of Nevada, Desert Research Institute) on a new theory of snow crystal growth, which seeks to explain the formation of snow dendrites by attributing their formation to nucleation rates at the ice surface. In addition, Jon Nelson (visitor, University of Colorado) started an experimental study of ice crystal growth from the vapor below water saturation, in Knight's laboratory, to answer some theoretical questions relevant to the formation of ice in cirrus clouds.

Mechanisms of Precipitation Formation

First Echo Studies and Precipitation Formation in Small Cumulus

Knight and Miller continued their studies interpreting the dual-wavelength radar data from CaPE in 1991. Ambiguities remain in separating the Bragg from Rayleigh scattering components, since it appears that Bragg scattering is a significant component of the reflectivity at 3-cm wavelength and that the Bragg signal does not conform to the idealized model sometimes used to predict its wavelength dependence. The Small Cumulus Microphysics Study (SCMS) proposed for Florida in July-August 1995 will be able to address these ambiguities. It is difficult to reach firm conclusions concerning the onset of coalescence growth in the warm, Florida cumulus clouds from the CaPE data alone because of insufficient trustworthy, coordinated, microphysics measurements from aircraft, but the analyses of CaPE data are helping determine needs for SCMS.

Influences of Large Cloud Condensation Nuclei (CCN), and Hygroscopic Seeding Studies

To investigate recent reports of successful cloud seeding using hygroscopic material, some calculations and field investigations were undertaken to help evaluate the potential for such seeding and to consider the effects of large CCN on the initiation of the warm-rain process. Past efforts to seed clouds have used low concentrations of particles having diameters of 10 microns or more, in an effort to provide embryos for the growth of rain via coalescence. Some recent reports from South Africa have suggested that significant acceleration of warm-rain formation may result from the injection of high concentrations of hygroscopic particles of 0.5-1.0 micron diameter, which compete with natural CCN for water vapor at cloud base and hence may produce a broader initial droplet spectrum more conducive to coalescence. Cooper and Bruintjes, in collaboration with Graeme Mather (Cloudquest, South Africa), investigated this conjecture using calculations of the initial evolution of the droplet spectrum and observations of the droplet size distributions in seeded clouds. The calculations and observations both support the hypothesized broadening of the initial droplet spectrum and associated initial acceleration of coalescence, although further studies of the seeding technique are needed to consider effects at later stages.

Studies of Stratospheric Aerosols and Polar Stratospheric Clouds (PSCs)

James Dye, Darrel Baumgardner (ATD), Bruce Gandrud (ATD), Keith Barr, and Katja Drdla (ASP visitor, UCLA) participated in the Airborne Southern Hemisphere Ozone Experiment/Measurements for Assessing the Effects of Stratospheric Aircraft (ASHOE/MAESA). ASHOE/MAESA was designed to examine the causes of ozone loss in the southern hemisphere and to investigate polar, mid-latitude, and tropical processes responsible for the ozone loss and how stratospheric aircraft might effect these processes. The project was conducted from March to November 1994 with four deployments of the NASA ER-2 from Christchurch, New Zealand.

Measurements of stratospheric sulfate aerosols were obtained from the instrument during the ER-2 deployments and additionally during the mid-July to mid-August deployment, PSCs were encountered on two of the flights. Preliminary analysis of the measurements obtained from the Multi-angle Aerosol Scattering Probe (MASP) show that the formation processes for these PSCs were similar to those found in the Arctic on flights of the ER-2 from Stavanger, Norway during the Airborne Arctic Stratospheric Experiment (AASE). As observed in AASE, the onset of PSCs occurred at 192 to 193 K, a couple of degrees colder than the 195 K temperature for which formation of nitric acid trihydrate (NAT) particles is expected. This is an important verification of our understanding of PSC formation. Contrary to the present findings, measurements obtained late in the life cycle of the Antarctic vortex during the Airborne Antarctic Ozone Experiment (AAOE) had shown that PSC formation started near 195 K where saturation of nitric acid with respect to nitric acid trihydrate occurs. This difference probably can be attributed to all of the sulfate aerosols being frozen for the AAOE measurements and therefore presenting little barrier for the nucleation of NAT particles. Analysis will continue on these interesting observations.

Measurements inside the polar vortex also showed large reductions in aerosol concentration, surface area, and volume compared to outside the vortex. This was particularly true on flights in which the ER-2 was able to fly deeper into the vortex and more chemical processing had occurred. Additional work will be needed to see if this reduction is only the result of subsidence of the sulfate layer within the vortex or also by the removal of sulfate aerosol through sedimentation of PSC particles.

Drdla, working with her colleagues at UCLA and NCAR, modeled the microphysical processes in PSC formation and compared the results of the model with observations made in Arctic PSCs during AASE. When the classical approach of assuming PSCs are nitric acid tridydrate particles grown via the condensation of nitric acid and water onto frozen sulfate particles is modeled, the model predicts the formation of the PSC at much warmer temperatures than actually occurs. The work strongly suggests that for the 24 January 1989 PSC event, the observations are best explained by the uptake of nitric acid and water onto liquid sulfuric acid solution droplets to form ternary solution droplets with nitric acid, sulfuric acid, and water composition. The results also suggest that some polar stratospheric clouds may be composed of liquid particles while other clouds may be solid.

Effects of Clouds on Tropospheric Chemistry

In an effort to understand the effects of clouds on clear-air chemistry, Mary Barth (joint appointment with ACD) developed a gas and aqueous chemistry module to use with either a cloud model or a regional chemistry transport model. This chemistry module can be used as a tool to test several assumptions used in the regional model. For example, it can be used to examine how the chemistry differs when a constant liquid water content is assumed compared to when the liquid water content is allowed to vary. During the next year, the chemistry module will be attached to a cloud model and applied to a scenario that will allow model results to be compared with observations.

Thunderstorm Electrification

Particle Charge Measurements

Thomas Marshall (University of Mississippi), Daniel Breed, Dye, and Joanne George developed semi-automated techniques for reducing and analyzing particle charge/2D image data collected by the NCAR sailplane during CaPE. About one-half million particles have been processed, and as Weinheimer et al., 1991, found in a New Mexican storm, there is wide variability in the ratio of charged particles to uncharged particles. Preliminary analysis revealed an interesting variation from predominantly positive to negative charges across the sailplane's spiral at essentially the same in-cloud temperature.

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Boundary Layers and Turbulence

Boundary Layer Modeling and Parameterization

Keith Ayotte (visitor, Atmospheric Environment Service (AES), Canada) and Peter Sullivan collaborated with Chin-Hoh Moeng, McWilliams, Joseph Tribbia, William Large, Scott Doney (all four of CGD), John Wyngaard (Pennsylvania State University), Anders Andren (Upsalla University, Sweden), Albertus Holtslag (Royal Netherlands Meteorological Institute (KNMI), the Netherlands) on an evaluation and comparison of turbulence closure schemes used in large-scale (climate) models. The examination compared large-eddy simulations (LESs) of planetary boundary layers (PBLs) with stabilities ranging from neutral to strongly convective. To date, the study involves ten PBL cases with seven closure types. A number of performance measures have been defined to facilitate the quantitative comparison and evaluation against the LES model output.

Ayotte extended his previous work on higher order turbulence closure in flow over hills to a fully three-dimensional model of turbulent flow over topography. The work involves the development and extensive use of automated source code generation (ACG) for production of the model source code. The ACG methods involve symbolic manipulation and a number of parsing techniques to produce compilable model source code. Work is also underway on assimilating mean and turbulence data into the model using an adjoint model based on optimal control theory. The method makes use of a tangent linear model which is also produced using ACG. The resultant model produces three-dimensional mean flow and Reynold stress solutions of topographically forced flows on scales of a few tens of meters to a few kilometers. An example of the mean flow field about an isolated circular hill is shown in the accompanying figure. The figures show streamlines deflected over and around the crest of the hill in response to pressure and Reynolds stress perturbations caused by the hill.

Theoretical Studies of the Convective Mixed Layer

K. Davis, working with Lenschow, completed a theoretical study of the limits of the mixed-layer assumptions describing a quasi-steady, convectively-mixed boundary layer. These assumptions are commonly invoked in models of the convective boundary layer. The derived limits on the assumption can be used to guide observational investigations of boundary-layer structure. Profiles of biogenic hydrocarbons, obtained by ACD personnel and used by Davis to estimate isoprene and terpene emissions from a Georgia forest, show fairly frequent violations of the mixed-layer assumptions with respect to these species in early to late afternoon hours.

K. Davis, assisting Peter Bakwin (NOAA) demonstrated the theoretical feasibility of long-term, large-area monitoring of carbon dioxide fluxes using eddy-correlation measurements on very tall towers. A 400 m tower will be instrumented for monitoring the carbon dioxide fluxes over a mixed forest in northern Wisconsin for at least one year.

Air-Surface Interactions

During this past summer, Lenschow, Steven Oncley (ATD), Jakob Mann (visitor, Riso National Laboratory, Denmark), K. Davis, and Qing Wang (ASP visitor, Pennsylvania State University) participated in the BOREAS over the boreal forest of central Canada. They measured the variation of temperature, humidity, carbon dioxide and ozone fluxes across the boreal forest from the prairies on the South to the sub-Arctic tundra on the North throughout the summer using the NCAR Electra aircraft. These data will be combined with other aircraft and tower measurements to estimate variations in air-surface exchange over the different ecosystems making up this region for use in developing parameterizations for and validating global and regional scale numerical models.

A Mechanism for Stratocumulus Breakup

Mechanisms that lead to the breakup of PBL stratocumulus are important in the climate context because they result in a dramatic decrease in cloud cover. Moeng, Lenschow, and David Randall (CSU) investigated the roles of radiative and evaporative cooling feedback in determining stratocumulus breakup. They showed that under most conditions, the feedback between cloud-top radiative cooling and entrainment is negative, while between cloud-top evaporative cooling and entrainment it is positive. To study the competing role between these two feedback mechanisms, they generated three stratocumulus-topped PBLs using LES. They found that only when the evaporative feedback dominates the radiative feedback, can the cloud break up quickly.

Marine Stratiform Cloud

Wang and Lenschow studied the development of cumulus clouds underneath marine stratocumulus using data from the Atlantic Stratocumulus Transition Experiment (ASTEX). The cumulus provide a conduit for relatively moist air from near the surface to replenish the stratocumulus which tend to dry out due to entrainment. They also found indications of stronger entrainment at the tops of the cumulus which penetrate through the stratocumulus.

Radar Reflectivity and Cloud Liquid Water in Nonprecipitating Clouds

Ilga Paluch, Knight, and Miller found that cloud droplet size spectra measured in nonprecipitating cumulus in Florida show a remarkably good correlation between calculated radar reflectivity factor (dBZ = 10logZ) and cloud liquid water content (LWC). This correlation was not expected and requires explanation. The calculated points were expected to be scattered within an area bounded by values representing the extreme cases of perfectly homogeneous and perfectly inhomogeneous mixing, but the Florida data points fall along a well-defined straight line with a slope of 0.85 on a log(LWC) - logZ plot. The observed slope can be explained by assuming that mixing is homogeneous over short distances, but highly nonuniform over distances of the order of 100 m, i.e., the present aircraft sampling distance. If this interpretation is correct, current views of cloud microstructure will need to be revised.

Baroclinic Boundary Layers Over Land

LeMone, Moeng, and Lenschow worked with Mingyu Zhou (National Research Center for Marine Environmental Forecasts, China), Grossman, and Zamora on an observational study of the mean and turbulence structure of the baroclinic boundary layer on five fair-weather days in the Stormscale Operational and Research Meteorology (STORM) Fronts Experiment Systems Test (STORM-FEST) experiment. Of particular interest are the wind profile and its origins, and the comparison, evaluation, and integration of data from diverse sources, including the NCAR King Air aircraft, five NOAA/WPL 915-MHz wind profilers, radiosondes, Portable Automated Mesonet (PAM) II, and Atmospheric Surface Turbulence Exchange Research (ASTER). The profiles that result should be useful in testing boundary-layer parameterization schemes. Moeng will do large-eddy simulations of one or more of these days to see if the observed wind profiles can be reproduced.

Central Equatorial Pacific Experiment (CEPEX)

Grossman and Kuettner analyzed evaporation measurements made at 33 m by a NOAA P-3 aircraft over the central equatorial Pacific, as part of CEPEX. The central issue is the variation of evaporation with sea surface temperature, since this relationship may be an important feedback process in the regulation of sea surface temperature in the CEPEX region and the western Pacific warm pool to the west.

Boundary Layer Array Facility

LeMone, Blumen, Grossman, and John Pflaum (NOAA) continued to develop plans for a boundary-layer facility, now known as the Cooperative Atmosphere-Surface Exchange Site (CASES). The objective is to have a combination of prepared instrument sites (including easily accessible phone and electrical hookups) and routinely-collected data. In addition, a boundary-layer data archive might be established. Such an array would facilitate both small science and educational efforts, as well as support future meteorological, hydrological, and interdisciplinary field experiments in conjunction with the U.S. Weather Research Program (USWRP), GEWEX, NASA, and DOE/ARM. With this in mind, they have selected a 50 times 100 km site for the array that coincides with the Walnut River Basin to the east of Wichita, Kansas, and included hydrologists and atmospheric chemists in a planning meeting in January, which resulted in a prospectus document. Blumen attended a second meeting at the University of Nebraska to discuss CASES with the ecological community.

Evaluation of Surface Parameterization

Jimy Dudhia collaborated with Oncley on validating the MM5 surface flux parameterization against direct measurements from fast-response sensors on towers and in low-flying aircraft. The four simulated STORM-FEST 1992 cases in northeast Kansas revealed that, while MM5's algorithms are accurate, using MM5's climatological soil moisture availability can lead to large errors in latent and sensible heat flux owing to large natural fluctuations in surface wetness in periods of a few days. This result has led to research on better initialization techniques for MM5's soil moisture.

Langmuir Turbulence in the Ocean PBL

In oceans and large lakes strong streamwise vortices are frequently observed just below the water surface. These organized motions are termed Langmuir circulations and there is continuing debate as to the importance of these motions in the oceanic PBL. McWilliams and Sullivan have been studying Langmuir circulations as described by the Craik-Leibovich (CL) theory using LES. The CL theory accounts for surface gravity waves, and it appears that the latter plays an important role in the formation of coherent structures, i.e., Langmuir circulations in the oceanic boundary layer. A turbulent Langmuir number based on the ratio of the surface friction velocity and Stokes drift of the surface gravity waves is the controlling parameter, which determines whether streamwise or hairpin vortical structures are dominant in a shear driven oceanic PBL.

Analysis of LES Flow Fields

Ching-Long Lin (visitor, Stanford University), McWilliams, Moeng, and Sullivan investigated coherent structures in shear-dominated planetary boundary layer (SPBL) flows generated LES to gain physical insight into the dynamic processes of turbulence production and provide the foundation for future structural modeling.

Coherent fluxes and vortical structures affect one another and play significant roles in the dynamics of SPBL. "Streaky" flux structures and quasi-streamwise vortical structures dominate the surface layer, while hill-like flux structures and horseshoe vortical structures dominate the outer layer. Streaky fluxes can collide, merge, induce quasi-streamwise vortical structures, or form flux hills. These hill-like fluxes likely induce high-altitude horseshoe vortical structures. Growing vortical structures can also modify the flux structures. Statistical quantities such as how much flux is associated with the coherent process and how often vortical structures appear in a finite area are being studied.

Intercomparison of Computer Generated Stratocumulus Topped PBLs

A major focus of the GEWEX GCSS program is to use Cloud Resolving Models (CRMs) or LESs to generate a data base for the development and testing of boundary-layer-cloud parameterization schemes for use in GCMs. To examine the accuracy of LES or CRM in representing PBL stratocumulus, Moeng and William Cotton (CSU) organized an international workshop on Boundary Layer Clouds, which took place at NCAR during 16-18 August 1994. During that workshop, the participants compared turbulent statistics from computer generated stratocumulus-topped PBLs. The models included ten 3D LES codes, three 2D CRMs, and seven one-dimensional (1D) ensemble closure schemes (the latter were developed for GCM use).

Lagrangian Particle Modeling

In collaboration with Moeng and Sullivan, Jeffrey Weil (visitor, University of Colorado) used Lagrangian "particle" models to compute the mean and root-mean-square (rms) fluctuating concentration fields due to a passive scalar source in the convective boundary layer. This is a statistical approach in which the mean and rms concentrations are found by tracking a large number of single particles and particle pairs, respectively. The unique aspect of the calculations is the use of time-dependent velocity fields from LESs to do the particle tracking. The approach uses the resolved LES fields to compute the particle displacements due to the large eddies and a stochastic model to treat the motion due to the unresolved subgrid-scale eddies. The calculations are being carried out with LES fields for weakly-, moderately-, and strongly-convective boundary layers.

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NCAR Geophysical Turbulence Program in MMM

The NCAR Geophysical Turbulence Program (GTP) within MMM is comprised of Herring, Robert Kerr, Lenschow, and Moeng. In addition, visitors Joseph Werne (ASP visitor, University of Chicago) and Yoshifumi Kimura (visitor, University of Colorado) are active participants.

Research in geophysical turbulence in MMM in the past year concentrated on questions of fundamental importance to homogeneous turbulence, vortex dynamics, and convection. Utilizing large, direct simulations, some of the questions being addressed are the influence of walls on convection and vortices, the roles of stratification and rotation, in affecting diffusion, and the role of vortices in homogeneous turbulence.

Direct Numerical Simulations (DNS) of Thermal Convection

In convection, the now classic laboratory experiments of Libchaber and colleagues (Chicago, 1987) which demonstrate non-classical scaling properties for convective turbulence are useful. Important questions regard the generality of this non-classical scaling as well as how the detailed physics responsible impacts atmospheric convection. Simulations conducted by Herring, Kerr, McWilliams, Werne, Axel Brandenburg (ASP visitor, HAO), and Keith Julien (ASP/HAO visitor), in collaboration with Sonya Legg (CGD), have demonstrated that the non-classical scaling behavior is a general feature of many different turbulent convecting systems which share apparently nothing more than coherent fluid structures bounded by rigid upper and lower surfaces. Calculations spanning both 2D and 3D for a wide array of aspect-ratios, side-wall boundaries (periodic or impenetrable), and rates of external rotation were examined, and all reproduce the non-classical scaling. In all cases, the thermal boundary layer is strongly sheared, consistent with a recent theory for the non-classical scaling. To illustrate the phenomena two figures from one of the large 288 x 288 x 96 convection calculations are shown in the accompanying image.

Rotation profoundly affects the organization and dynamics of turbulent convective motion. Strong vortical interactions between buoyant plume/vortices produce efficient mixing in horizontal planes (normal to the rotation direction). In fact, the mixing process is so efficient that bulk thermal gradients result at mid-layer, unlike the non-rotating solutions. Nevertheless, as is noted above, the scaling of heat transport with temperature-drop across the convective domain remains unaltered. Temperature and vorticity fields, viewed from above, are shown in the two figures for a strongly rotating solution computed with 384 x 384 x 193 spectral modes.

A program to determine to what degree the penetrative convection in the atmosphere exhibits non-classical behavior is underway within the MMM and CGD components of the GTP. Fully spectral, direct numerical simulations of penetrative surface-layer dynamics will be conducted using the CRAY T3D and the CRAY YMP. The goals are to understand and develop appropriate parameterization schemes for the basic physical processes involved in both the surface-, layer-, and penetration-dynamics of convective turbulence with coherent structures.

Vortex Dynamics

In vortex dynamics, the role of vortices in homogeneous turbulence and stratification are being investigated. There is interest in how the structures (i.e., sheets, shear patches, tubes, and, for inviscid flows, singularities) modify the traditional expectations based on statistical theories. Several university groups studying vortex were provided large data sets. In this connection, the GTP recently held a mini-workshop designed to discuss both the scientific issues involved and how best to access and interpret the large numerical data sets used in this research. Discussions were held with RAP and Clark on how these issues might be related to dynamics involved in aircraft safety and forest fires.

New Dynamical Method for LES

With Andrzej Domaradzki (University of Southern California) and Gillis Barbier (L'Ecole Polytechnique, France) large direct numerical data sets were investigated from the point of view of understanding the subgrid terms modeled in large-eddy simulation. The approach was taken that the subgrid scale terms could be modeled by interactions between the large-scale flow and a modeled subgrid vorticity based on dynamic vorticity production rates. This places the model in the class of dynamic backscatter models currently in vogue. The model shows several improvements over the prevalent Smagorinsky model which does not have backscatter, while demonstrating why the Smagorinsky model has proven so powerful over the years. It has the advantage over existing backscatter models of not requiring the addition of a Smagorinsky-type term to assure stability.

Stably Stratified Turbulence

In the study of stably stratified turbulence, Kimura and Herring showed that the familiar picture of strongly stratified turbulence being comprised of patches of vertical vorticity is incomplete without regions of intense horizontal vorticity, which accounts for most of the dissipation. This study leads one to question the idea that stably stratified turbulence can resemble 2D turbulence. The two accompanying figures show the typical enstrophy (mean squared vorticty) field for unstratified, isotropic turbulence and stratified turbulence. Note that for isotropic turbulence, the vorticity is in randomly oriented tubes, while for stratified turbulence, it is in flattened horizontally-oriented patches.

Potential Vorticity and Turbulence

Herring, Kerr, and Rotunno examined the cascade of potential vorticity in decaying isotropic turbulence. The study showed that molecular effects were surprisingly effective in creating, in certain circumstances, potential vorticity. Molecular effects are not confined to small scales, but are spread fairly uniformly over all scales of motion, and in together with comparing and diffusion of which leads one to question of use of potential vorticity as a marker in geophysical flows.

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Numerical Techniques

Moist Thermodynamics in a Semi-Lagrangian/Eulerian Analystic Model

Grabowski and Smolarkiewicz incorporated moist bulk (Kessler-type) warm-rain microphysical parameterizations into the semi-Lagrangian/Eulerian anelastic model using terrain-following coordinate transformation. The central issue concerned was a semi-Lagrangian integration of the rain evolution equation that encounters numerical difficulties (due to departures of precipitation trajectories from those of fluid parcels) absent in Eulerian models. Comparisons between the semi-Lagrangian/Eulerian cloud model of Smolarkiewicz and traditional hybrid Eulerian cloud model using simulations of a moist thermal rising from rest and a moist airflow over an isolated topography show excellent performance of the new model in terms of both cost and accuracy. Similar performance of the semi-Lagrangian and forward-in-time Eulerian counterparts of the model were found.

Variational Solver for Elliptic Problems in Atmospheric Flows

The numerical integrations of linear elliptic equations can lead to serious difficulties when solving complex boundary value problems. Smolarkiewicz and Margolin sought to overcome such difficulties by developing a fairly simple, yet powerful, generalized conjugate residual (Krylov-type) solver capable of inverting the linear elliptic operators resulting from the discretization of complex dynamic problems typical of atmospheric applications. The utility of the method was documented in two distinct classes of codes: (1) anelastic nonhydrostatic semi-Lagrangian and Eulerian models using a time-dependent terrain-following coordinate transformation, for modeling small scale atmospheric dynamics; and (2) semi-Lagrangian and Eulerian variants of semi-implicit shallow-water models on the sphere, for implicit modeling of high-speed propagating modes in elastic systems on global scales. They are currently developing generalized stopping criteria for recognizing convergence which can further improve the efficiency of the solvers.

High Performance Computing for Atmospheric Flows

William Anderson and Smolarkiewicz ported two distinct codes addressing fundamental problems common to the majority of atmospheric fluid models from the Cray Y-MP to the Connection Machine 5 (CM-5). The generalized conjugate residual solver integrates the linear, non-symmetric, definite elliptic problems typical of atmospheric applications; the Multidimensional Positive Definite Advection Transport Algorithm (MPDATA) solver (embedded in an idealized GCM framework) provides second-order-accurate nonoscillatory approximations to a fully multidimensional transport problem cast in arbitrary curvilinear coordinates. Porting these two programs to the distributed memory, massively parallel architecture provided a number of insights. For example, numerically isotropic operations (such as, computing the divergence of fluxes) that imply equal amounts of communication along all grid directions may need to have the data distributed across the processors anisotropically for the best performance. For the 32 processor CM-5 at NCAR, the speeds achieved were equivalent to those attainable on 1 to 2 Y-MP processors. This exercise will extrapolate to other forthcoming distributed-memory parallel machines (e.g., Cray T3D).

Non-Darcian Flow in Porous Media: Application to Heat Sinks

Smolarkiewicz, Varaprasad Calmidi (visitor, University of Colorado), and Roop Mahajan (University of Colorado) established a collaborative effort combining the numerical and experimental analysis of flows in porous media. Certain types of rigid porous media dissipate large amounts of heat by forced convection. The phenomenon that describes this large heat dissipation is termed thermal dispersion. Detailed study of this phenomenon is done both experimentally and numerically. Numerical studies are particularly attractive due to the simplicity of their execution compared to equivalent laboratory measurements. Preliminary results show that the numerical simulations are within five percent of the experimental values. Insofar as the engineering interests are concerned, this study is to help in the development of high performance heat sinks for electronic cooling. From the meteorological viewpoint, this effort validates a new semi-Lagrangian/Eulerian nonhydrostatic fluid model in a controlled laboratory environment, and it explores suitability of the porous media approach for atmospheric applications.

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RESEARCH APPLICATIONS PROGRAM AT NCAR

The major accomplishment for RAP this year was the conduct of two major field programs, LANTEX and WISP94 .

I. Introduction

The Research Applications Program (RAP) conducted a wide variety of activities during 1994 including a major winter storms field program (WISP94), a major field and modelling study of terrain-induced windshear and turbulence at the site of the new Hong Kong Airport (LANTEX), and the development of a new prototype weather display system. These activities reflect the emphasis of RAP on focussed research and its application. Primary sponsors of RAP activities during this year were the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA) and the Hong Kong government. In the following, we present brief summaries of RAP activities during 1994 .

II. Significant Accomplishments

- The Winter Icing and Storms Project 1994 (WISP94) was conducted, with thirty-seven weather events studied.

- Radiative transfer models were developed to retrieve vertically integrated water vapor, liquid and ice from 3-channel radiometer data.

- The WISP94 Real-time Icing Prediction and Evaluation Program (WRIPEP) was conducted during WISP94. This project statistically evaluated turbulence algorithms as applied to the Eta, MAPS and MM5 models.

- A snowfall nowcasting experiment (SNOW94) was jointly conducted with United Airlines in support of their ground de-icing fluid testing activities.

- A small-scale numerical model was combined with Lincoln Laboratory's terminal winds analysis system to forecast gust fronts.
- The Hong Kong LANTEX field program was conducted, with about twenty-five cases of significant terrain-induced turbulence studied.
- A real-time system (Three-Dimensional Terminal Viewer) that depicts the weather and terrain in three dimensions from various points of view was developed.
- A real-time weather display system called Aviation Weather Products Generator (AWPG) was developed.

III. Icing and Winter Storms

A. WISP94

The Winter Icing and Storms Project (WISP) is a cooperative research effort designed to study the structure and evolution of winter storms. Its fourth field effort, WISP94, took place between 25 January and 25 March 1994 in northeastern Colorado.

The primary goals of WISP are: 1) to improve our understanding of processes involved in the production and depletion of supercooled liquid water (SLW) in winter storms and 2) to improve forecasts of aircraft icing. Previous field programs have clarified processes which contribute to liquid production but have shed little light on ice initiation -- nucleation and early growth. Understanding these processes is vital to completing our knowledge of supercooled liquid production and depletion in the atmosphere. WISPIT (WISP Instrument Test) was conducted in winter 1992-93 to test both concepts and models for ice nucleation and to test instrumentation for the measurement of small ice particles. Based on the success of that limited field program, WISP94 was planned to focus on ice initiation studies.

The initiation of ice crystals both in wave clouds over the Rocky Mountains and in upslope storms in eastern Colorado received highest priority during WISP94. Secondary priority was given to the studies of cold surges, the formation of large supercooled droplets and precipitation evolution.

The scientific goals of the ice initiation portion of WISP94 were:

- To document ice crystal concentrations in wintertime storms as a function of location, altitude and temperature and to determine their dependence on possible controlling factors such as cloud type and air parcel trajectory,
- To investigate the extent to which ice concentrations are predictable from or correlated with the number of ice nuclei and to learn if natural ice crystal concentrations can be duplicated by processing air samples in a large cloud chamber,
- To investigate the possible roles of supersaturation, evaporation, electrification, large drops and pollution in ice formation,
- To study ice formation in wave clouds and to use relevant observations for inferring ice production mechanisms in cloud types found in the Colorado Front Range area, and
- To search for correlations between ice crystal concentrations and factors that may influence large droplet concentrations, riming, aerosol particle concentrations, etc.

Extensive in situ and mobile observational facilities were available for WISP94. Most of the data were displayed in real time at the Foothills Laboratory RAP Operations Center Facility. NCAR's CP-3 5-cm Doppler radar was used for storm surveillance and for tracking and directing the research aircraft. The CSU-CHILL 10-cm radar obtained multiparameter measurements and NOAA's K-band (.86 cm) radar was used to observe the fine-scale cloud structure. NOAA operated two dual-channel, fixed beam and one steerable beam microwave radiometers, as well as a lidar ceilometer. CLASS balloons were launched at 3-hr intervals during storms from five fixed and two mobile sites. More than 100 volunteers, including a large number of High School students, were organized into a snow observer network. A mobile crystal observation van was used to obtain detailed surface measurements of snow for comparison with the radar measurements and to obtain air samples for processing in the Colorado State University Atmospheric Science Department's cloud chamber.

The NCAR Electra was the primary airborne ice nucleus and aerosol sampling platform. The University of Wyoming King Air provided cloud physics and aircraft performance measurements. During the latter half of the project, the University of Massachussetts' W-band (3 mm) radar was installed on-board the King Air for detailed observations of cloud structure.

The MM5 model, with a cloud microphysics package developed as part of previous WISP research efforts, was run twice daily. Nested grids of 60, 20 and 6.7 km horizontal resolution were available. These runs were used in operations planning as well as in an assessment of overall model performance and the microphysical parameterization.

During WISP94 thirty-seven weather events were studied. Of these, fifteen events were wave clouds, twelve events were upslope clouds, and the remainder consisted of cold surges, snowbands, lee cyclones and other winter weather events of interest to the project. A comprehensive set of ice nucleus filters and bulk aerosol samples were collected in the air and at the surface and are being processed for comparison with ice crystal measurements to determine factors controlling ice formation. Large supercooled droplets were found in stratiform upslope clouds on at least eight flights, and flight patterns were flown to determine their association with shear layers near cloud top as well as other turbulence-generating mechanisms. The real-time MM5 runs helped forecasters determine the arrival time of cold surges in order that the research aircraft, radars, CLASS soundings and mobile microphysics van could be deployed to document their passage. The CSU CHILL and NOAA-K radars collected excellent data sets which, when combined with the airborne and surface hydrometeor measurements, will help interpret polarization measurements in terms of ice crystal type.

WISP94 was a multiagency program, which included scientists from the following organizations:

- NCAR Research Applications Program and Mesoscale and Microscale Meteorology Division,
- Atmospheric Technology Division and Atmospheric Chemistry Division
- NOAA Environmental Technology Laboratory
- NOAA Forecast Systems Laboratory
- Colorado State University
- University of Wyoming
- University of Wisconsin at Madison
- University of Manchester, England
- University of Illinois, Champaign-Urbana
- Yale University
- ATEK Inc.

Roy Rasmussen is the WISP scientific coordinator and the chairman of the WISP Scientific Steering Committee and Marcia Politovich is the WISP field operations coordinator. A data catalog is available from the Research Applications Program.

B. Estimation of Ice, Liquid and Vapor by Remote Sensor Measurements Made During WISP94

1. Forward-Based Radiative Transfer Model for Winter Clouds

A parametric radiative transfer model, developed by Li Li and J. Vivekanandan, focusses on the detection and quantification of supercooled water, vapor, and ice in winter clouds. The model can be easily adapted to both ground-based and spaceborne radiometry applications. A typical mean vertical structure of the atmosphere is assumed. The water vapor density profile is approximated by an exponential function defined by integrated water vapor amount and scale height. A linear temperature profile is described by an effective lapse rate and an effective near-surface temperature. A layer of homogeneous liquid cloud profile is specified by its cloud base height, cloud thickness, and liquid cloud water content. A layer of ice cloud above the liquid cloud is defined in a similar way except that the scatterers' mean size and bulk density are also specified. A pressure profile can be derived from the surface pressure and the vertical temperature profile. To avoid unreasonable atmospheric structures, the following constraints are imposed:

- Relative humidity must be less than 100%;
- Liquid cloud temperatures must be between -20 degrees C and 5 degrees C;
- Ice cloud temperatures must be below 0 degrees C;
- Since appreciable quantities of snow or other ice particles in a supercooled cloud quickly deplete supercooled cloud droplets, an ice cloud is kept above the liquid cloud; consequently, co-existence of supercooled liquid water and ice particles is not allowed.

It should be noted that meteorological parameters defined above form a complete set of input to our physical model. No other intermediate optical parameters are used; therefore, an intermediate retrieval algorithm is unnecessary.

NOAA ground-based dual-channel radiometers measure downwelling radiation in the zenith direction at 20.6 and 31.65 GHz. In addition, one of the radiometers has a 90 GHz channel. The radiative transfer processes are determined basically by molecular oxygen, water vapor, liquid water and ice. The 20.6 GHz channel, which is offset from a weak water vapor resonant line at 22.235 GHz, senses mainly the integrated vapor and is less sensitive to the pressure and water vapor profiles. The 31.65 GHz channel is primarily sensitive to liquid water, and the 90 GHz channel is sensitive to the absence of ice in the scattering regime. Both emission and scattering should be considered at 31.65 GHz and 90 GHz channels. In this work, we use Liebe's millimeter-wave propagation model (MPM) to calculate the gaseous absorption at all three channels. The Rayleigh approximation is applied to compute the absorption of cloud liquid droplets. The Mie theory is used to obtain extinction and scattering properties of ice particles. The ice particle size distribution is specified by a modified Gamma size distribution. The invariant imbedding method of vector radiative transfer theory is used to simulate absorption, emission, and scattering processes. This model will be used to generate training vectors for the neural network-based retrieval model discussed in the next section.

2. Neural Network-Based Radiative Transfer Models for Winter Clouds

Li and Vivekanandan have designed a neural network-based retrieval procedure for water vapor and cloud liquid using 20.6 and 31.65 GHz channels. Based on a long-time winter seasonal average, we assume that the liquid water equivalent for the vapor distribution is between 0.4 and 0.96 cm and the total liquid water in the column is between 0 and 0.8. The other variables are fixed at a surface pressure = 83 kPa, vapor scale height = 2 km, cloud thickness = 1 km, cloud base height = 1.5 km, near surface temperature = -2 degrees C and effective lapse rate = 6 degrees per km. Since the NOAA radiometers are well calibrated at the 20.6 and 31.65 GHZ channels, we ingest NOAA's retrieved results into our physical models. By comparing the simulated brightness temperatures with radiometer measurements, the bias in the physical model is estimated. Then the dual input and dual output neural network is trained by a set of bias-free simulated data. A dry adiabatic atmospheric sounding and the corresponding three-channel brightness temperatures are used to calibrate the 90 GHz channel in the absence of any ice clouds.

The actual brightness temperature measurements of the two and three-channel radiometers are used to retrieve vapor, liquid and ice quantities. Results of two and three-channel neural network models are compared with the radiosonde observations of vapor and to NOAA's retrieval of vapor and liquid. In the case of a two-channel technique, downwelling brightness temperatures were measured by a NOAA radiometer located at Platteville, Colorado, on 15 March 1991. Results show excellent agreement between neural network-based inverted quantities and NOAA's retrieval techniques. Any deviation between remotely sensed vapor amounts and radiosonde observed values is primarily due to the spatial variation of vapor.

Three-channel radiometer measurements collected by the Erie radiometer were also processed. Comparison between the three-channel radiometric retrieval of water vapor and liquid water with NOAA's model results showed good agreement. Water vapor values retrieved by NOAA and from the neural networks have been compared against independent radiosonde measurements. Assuming the radiosonde data is accurate, the three-channel model-produced results are about the same as, or better than, those of NOAA's dual-channel model. The additional 90 GHz channel enabled the retrievals of mean ice particle size. It is worth mentioning that the forward model can match accurately the measured brightness temperature when it is initialized with the retrieved microphysical quantities of the three-channel model. In other words, the retrieved quantities are indeed a model solution. Therefore it is feasible to retrieve ice information using ground-based three-channel radiometers. Thus, a well-trained neural network is capable of retrieving water vapor, cloud liquid, and cloud ice. The performance of these techniques can be verified by comparing with radar and aircraft estimated values of the same.

C. WISP Real-Time Icing Prediction and Evaluation Program (WRIPEP)

As part of the WISP94 field program, a comprehensive evaluation program was conducted to evaluate a set of diagnostic icing and turbulence algorithms as applied to different numerical models. The program, WISP94 Real-time Icing Prediction and Evaluation Program (WRIPEP), ran concurrently with the WISP94 project from 25 January to 25 March 1994. WRIPEP consisted of a real-time display for visualizing the icing and turbulence forecasts, and a statistical package to evaluate the forecast quality of a number of model-algorithm couplings. Roelof Bruintjes, Gregory Thompson and Frank Hage designed and developed WRIPEP while Barbara Brown and Randy Bullock developed the statistical analysis package.

The overall purpose of WRIPEP is to evaluate (in real time and post-analysis) the present icing and turbulence algorithms, as applied to the most up-to-date numerical forecast models, and to conduct a near real-time verification exercise using pilot reports and in situ measurements from the research aircraft.

The WRIPEP display is quite flexible and has many features. An example shown in Figure 1 , consists of four X-windows and a Graphical User Interface (GUI) for responding to users' requests. Three of the windows are used to show model-generated forecasts while the fourth (lower-right) is used to show symbolic products such as pilot reports (PIREPs), AIRMETs, and SIGMETs. The display is designed for icing and turbulence forecasts, but it could be easily modified to include ceiling and visibility or other aviation products.

The primary numerical forecast models used to calculate icing and turbulence potential were the Eta and MAPS systems run at the National Meteorological Center (NMC). The Eta model is a recent NMC development; one of its fundamental aspects is the incorporation of step topography and the vertical eta coordinate. The Mesoscale Analysis and Prediction System (MAPS) was developed at NOAA's Forecast Systems Laboratory (FSL) and now runs operationally at NMC as the Rapid Update Cycle (RUC). In addition, the fifth-generation Penn State/ NCAR mesoscale model (MM5) was run at NCAR in real time during the field program and has been utilized in this study as well.

Three diagnostic icing and two turbulence algorithms were applied to output from each model configuration. These icing algorithms, in various stages of development and testing by several organizations cooperating in WRIPEP, use temperature and relative humidity thresholds to diagnose cloudy environments conducive to icing. The 40 km version of the Eta model and all resolutions of the MM5 model contained water and ice parameterizations that explicitly predicted cloud liquid water and ice fields. These, too, were used in predicting locations of aircraft icing and were verified statistically.

The statistical analyses do not indicate that one algorithm is superior to the others; however, the algorithm developed by RAP does provide operational forecasters the opportunity to assess its skill and also refine the automated diagnostic output with additional data sources such as satellite data and surface observations.

An overview of WRIPEP and results from the performance of the algorithms together with the statistical analyses are summarized in a series of three conference papers to be presented at the 1995 American Meteorological Society (AMS) Annual Meeting in Dallas.

D. 11 March 1993 Cold Surge

Christopher Davis has studied a mesoscale cold surge observed during the WISPIT field experiment. This was a transient feature marked primarily by a sudden increase in windspeed and brief heavy snow over northeastern Colorado during 11-12 March 1993. Abrupt changes in surface pressure and temperature indicative of a gravity current were not noted. Gradual temperature falls and pressure rises were observed behind the velocity surge; however, there was no cyclonic wind-shift nor did the feature last for more than a few hours, suggesting that it was not a classical front. Data indicates that the surge originated near the peak of the Cheyenne ridge, a 400 m, east-west elongated hill near the border between Colorado and Wyoming. Simulations using an idealized, two-dimensional isentropic model show that the transient surge results from impulsively started flow over heated terrain. Heating creates convergence that is in-phase with the velocity surge at the leading edge of the topographic wave. The result is a coherent disturbance in velocity which moves downstream at nearly the mean-flow speed.

Simulations with the PSU/NCAR nonhydrostatic model (MM5) using a horizontal resolution of 6.7 km captured the evolution of the observed surge. These simulations identify the surge as a topographic wave that is modified by heating, but they also indicate an important role played by latent heating in the updraft at the leading edge of the surge. Because the latent heating occurs mainly downstream from the Cheyenne Ridge, the formation of the topographic wave is unaltered by it; however, the updraft at the leading edge of the surge greatly intensified, leading to a narrow, propagating band of heavy snow.

E. Case Study of a WISP91 Freezing Drizzle, Snowfall and Aircraft Icing Event

Ben Bernstein and Politovich analyzed a WISP91 freezing drizzle case in which mesoscale weather features played an important role in the development of a hazardous icing situation. During 16-17 March 1991, a weak low pressure system moved across south-central Colorado and brought a complicated weather scenario to the Denver area. In advance of the system, strongly stratified, moist, sub-freezing air was drawn into eastern Colorado. South-southeasterly winds forced this air to rise along the southern slope of the Palmer Lake Divide (PLD), a 2500 m high ridge which extends eastward from the Rocky Mountains, just north of Colorado Springs. The additional lift caused by upslope conditions formed an extensive area of moderate freezing drizzle on the south side of the PLD. These conditons persisted for several hours during the early morning of 16 March (approximately 3:00 a.m. to 7:00 a.m. LT) from Colorado Springs to Limon, Colorado. The freezing drizzle turned to snow after 1500 UTC, 16 March (8:00 a.m. LT).

At that time, the center of the low pressure system was approaching Colorado from the southwest. Satellite imagery showed that an area of cold cloud tops, indicating a deep cloud layer, was associated with the area of snowfall. A series of soundings was launched from a network of seven CLASS (Cross-Chained LORAN Atmospheric Sounding System) sites across northeastern Colorado as the system approached. These soundings revealed the existence of a deep, dry layer above the strongly stratified, subfreezing layer of air near the surface. This dry layer appears to have been caused by a long period of downward motion, as westerly winds descended the eastern slopes of the Rocky Mountains in advance of the center of the low. Snow falling from the upper-level cloud sublimated in this dry layer; after several hours the layer had sufficiently moistened so that crystals survived the fall to the ground. Thus, the dry layer served to delay the initial northward advance of snowfall at the surface behind the leading edge of the cold air, as was evidenced by a lag in the northward progression of reflectivity recorded by WISP research radars. As the low pressure center moved across the WISP domain, winds aloft switched from southerly to easterly. The area of snow moved toward the foothills from the eastern end of the network (near the Kansas-Colorado border). Again, the elevated dry layer delayed the progression of snowfall reaching the ground and kept it from falling into a low-level shallow supercooled liquid cloud in the western part of the network. By 0300 UTC, 17 March, an eastward-moving low pressure system had passed Denver. This caused the westward progression of deep cloud and snowfall to cease, leaving the shallow supercooled cloud layer intact. The University of Wyoming King Air research aircraft performed a sounding near Greeley at 0305, 17 March, and found large supercooled liquid water droplets near the top of the cloud. Large droplets are particularly hazardous to aircraft, because they may rapidly create rough accretions of ice on the airframe and significantly hamper aircraft performance. Data from a nearby microwave radiometer and wind profiler indicate that the supercooled liquid water dissipated just after the aircraft flight and that shear conditions necessary for the formation of large droplets (as described by Pobanz et al. 1994) had only formed about an hour before the flight. The shallow liquid cloud was limited in extent, with clear skies to the west and snowfall to the east of Greeley. This case shows the transient nature of some icing events and the interplay between upper and lower-level cloud features in producing freezing drizzle.

F. Determination of Supercooled Liquid Layers Using Combined Remote Sensors

Measurements from ground-based remote sensors, including dual-channel microwave radiometers, ceilometers, radio-acoustic sounding systems (RASS), and a K-band (.86 mm wavelength) radar were combined to produce vertically-resolved water vapor and liquid water profiles through the atmosphere. This work was conducted by Politovich in collaboration with the NOAA ETL.

At present, there is no single instrument that can reliably, accurately and remotely determine the distribution of cloud liquid water in the atmosphere. This information would be useful for several applications, the most notable being aircraft icing, numerical model initialization, and weather modification. In order to estimate altitudes at which supercooled liquid resides in the atmosphere, the following information is needed:

- integrated liquid water - to establish the amount of liquid
- temperature sounding - to determine whether and where liquid is supercooled
- liquid cloud base altitude - to determine the lower limit of cloud liquid
- liquid cloud top altitude - to determine the upper limit of cloud liquid

The most difficult measurement to obtain is the liquid cloud top height. One method tested uses a simple adiabatic parcel lifting model initiated at a height determined from a ceilometer, temperature and pressure from RASS or rawinsonde, along with total integrated liquid water (ILW) from a ground-based dual-channel microwave radiometer to obtain an estimate of the liquid cloud top. This tends to underestimate the true liquid cloud top; for two cases examined in detail, 61% of icing pilot reports in the area were from above this cloud top estimate. Vertical cloud boundaries from a K-band radar were also used in the study; these often indicated thicker clouds than were observed from the research aircraft, possibly due to the ambiguity of the ice/liquid phase distinction. In addition to defining vertical limits for cloud liquid, initial attempts at estimating the liquid water profile were tested. The simplest assumption is that liquid water is distributed uniformly through the vertical extent of the cloud. Comparisons with actual soundings through clouds show this to be a a poor assumption, but it serves as a useful first guess.

The simple adiabatic model described above provides another estimate of the liquid water profile. As air parcels rise and vapor condenses, liquid increases with height in a prescribed manner assuming no depletion by entrainment or ice processes. The actual amount of liquid condensed depends upon the temperature and, to a secondary extent, on the pressure at cloud base; but the shape of the profile is similar for most temperatures. Layers of air may also be lifted to cool and form clouds; the resulting liquid profiles depend on the initial temperature and moisture profiles of the lifted air. This information is generally not available in real time, however. In addition, along with the lifting process, entrainment or interaction with the ice phase (e.g., preferred deposition or riming) may alter the liquid profile from an adiabatic one.

If data are available to characterize the profile of SLW at a location of interest, these data may be used to construct a profile which may be used as a "climatological" mean. Such a profile was derived from thirty-six vertical soundings through cloud obtained during WISP. After retrieving cloud base and top altitudes and measuring the ILW, a climatological profile may be applied to provide an estimate of liquid water as a function of height.

These methods for estimating the liquid profile are shown in the figure as direct comparisons between estimated profiles and measurements obtained from research aircraft. The adiabatic and climatological profiles are in general agreement with the aircraft measurements and are definitely more realistic than the uniform profile. Several sources of error influence the comparisons. There is some degree of error inherent in the liquid water measurements from the aircraft-borne instruments and the radiometer. Additional differences may be contributed by horizontal variations of liquid and the fact that the aircraft sounding locations were 20-32 km away from the radiometer site.

The clouds used in this study were probably "best-case" candidates for these tests, that is, they were totally supercooled and had little to no precipitation. Our studies show that these methods hold some promise for estimating liquid water by remote sensing and provide a basis for additional studies in this area.

Two papers were recently completed describing details of this study and a companion study which included water vapor profiling: "Moisture Profiling of the Cloudy Winter Atmosphere Using Combined Remote Sensors" by Stankov et al. (1994) and "Determination of Liquid Water Altitudes Using Combined Remote Sensors" by Politovich et al. (1994).

G. Real-time MM5 Runs During WISP94 and Evaluation

Kevin Manning, David Gill and Davis carried out a real-time forecasting exercise using the nonhydrostatic, PSU/NCAR model (MM5) in support of WISP94 field operations. The central aims of the exercise were (1) to guide WISP94 field operations, with special attention to the forecast range from 6 to 24 hours and at higher resolution than available from NMC's operational models; (2) to test the new Reisner (Option 4) mixed-phase microphysics for a large sample of simulations of winter weather; (3) to investigate the added value of increasing horizontal resolution to 6.7 km in order to better represent terrain effects and frontal structures. A total of 120 forecasts were made during a 60 day period from 25 January to 25 March 1994. Forecasts were run twice daily, each for 24 hours. Preliminary results from model verification studies indicate that the excessive cloudiness in the upper troposphere was not removed by mixed-phase microphysics, suggesting that more sophisticated microphysics is needed or other factors such as the accuracy of the advection of moisture variables should be considered.

H. Intercomparisons Between Observations and Model Microphysics

Jon Reisner, Roelof Bruintjes and Rasmussen continued to further upgrade the microphysical parameterizations implemented in the NCAR/Penn State MM5 model. In the previous version of the microphysical parameterization only the mixing ratios for the different water species in the model were predicted and the number concentration of the ice species were prescribed. This was changed in the upgraded version of the parameterization to include predictions for the number concentrations of ice, snow and graupel. Observations from WISP cases showed cloud liquid water being depleted too rapidly when a fixed number concentration was prescribed, leading us to implement equations to explicitly predict number concentration of ice species.

In order to test the performance of the parameterization and examine the explicit prediction of supercooled liquid water (SLW), numerical simulations were conducted for three different WISP cases representing different types of storms. These were 1) an anticyclonic storm (13-15 February 1990); 2) a shallow cyclonic storm (13-14 March 1990); and a deep cyclonic storm (5-7 March 1990). The simulations were conducted using four different domains with different horizontal resolutions of 60 km, 20 km, 6.7 km, and 2.2 km. The 20 km domain was run concurrently with the 60 km domain, whereas the 6.7 and 2.2 km domains were run in a one-way nest mode. Initial and boundary data for the 60 km domain were supplied from the NMC's archived forecast model fields. The results from the simulations were compared to data obtained from the WISP 1990 field program.

Comparisons between the model results and the observations revealed that riming and depositional growth of snow and/or graupel were the dominant microphysical processes responsible for the depletion of SLW especially when the number concentrations of the ice species were fixed. When the number concentrations of the ice species were explicitly predicted, riming and depositional growth were limited and the simulated microphysical fields showed better agreement with the observations.

Reisner, Bruintjes and Rasmussen are currently preparing a paper describing the results from these experiments.

I. Comparison of SSM/I and Model Estimates of Integrated Cloud Water

Bruintjes and Thompson in collaboration with Tom Lee from the Naval Research Laboratories in Monterey, California are comparing satellite measurements of integrated water vapor (IWV) and integrated liquid (ILW) water with model based values of these quantities.

Ideally, accurate forecasts of aircraft icing should be determined by forecasts of supercooled liquid water and the size and concentration of cloud droplets. However, numerical models operationally in use at the NMC have only begun to incorporate explicitly prognosed cloud liquid water. In these early versions, there are a few inherent problems with model-generated cloud liquid water. First, since there are no measurements of this parameter, models cannot begin with an initial analysis field of cloud liquid water. Second, most analyses smooth out the relative humidity horizontally and vertically since they are produced on horizontal scales of approximately 60 km and vertical scales of 500 m or more; some finer scale variations exist. This tends to de-emphasize important regions of high humidity. Last, combining these two factors results in a "spin-up" problem. Since cloud water is not an analyzed field, a model must produce its own cloud water by increasing the already too low (analyzed) relative humidity to saturation, then converting humidity to cloud liquid water using parameterizations which themselves have limitations.

Validation data for an icing forecast are sparse at best, coming mostly from ground-based upward-looking microwave radiometers which give accurate point or small-area measurements and from experimental aircraft observations. Aircraft pilot reports give qualitative information about icing but cannot be used to quantify cloud liquid water. However, over oceans, the Special Sensor Microwave Imager (SSM/I) aboard the Defense Meteorological Satellite Program (DMSP) spacecraft gives good estimates of integrated liquid water and excellent estimates of integrated water vapor at a spacing of 25 km. Thus, there exists an opportunity to assess model performance in terms of integrated cloud liquid water and integrated water vapor over large oceanic regions.

Comparisons over the eastern Pacific Ocean between the SSM/I data and numerical model output data collected during WISP94 were conducted to evaluate the model performance. A comparison with the SSM/I data was conducted using explicitly predicted cloud liquid water from: 1) NMC's soon-to-be operational mesoscale Eta model and 2) the fifth-generation PSU/NCAR mesoscale model (MM5). Both models include parameterizations to explicitly predict water and ice species. Two parameters, integrated liquid water and integrated water vapor, were compared with the SSM/I measurements. While integrated liquid water is the more critical parameter, integrated water vapor is more accurately obtained from both the models and the SSM/I and also can provide useful comparisons. A total of ten case days were investigated.

The comparisons indicated that numerical model cloud liquid water parameterizations appear to perform best in strong, dynamically forced, synoptic-scale situations. Weakly-forced, mesoscale features provide the biggest challenge to liquid water parameterizations, showing substantial differences between model and satellite fields of ILW and IWV.

The poor correspondence between SSM/I data and model-predicted ILW emphasized the need for improving model initializations of moisture fields. From the case studies, it appears likely that significant improvements to numerical model forecasts can be gained by incorporating satellite data. This is obviously true for 24-hr and longer forecasts but may also be true for short-term forecasting.

A paper describing the preliminary results from the comparisons was submitted for presentation at the 1995 American Meteorological Society Annual Meeting in Dallas.

IV. Snowfall Nowcasting (SNOW) 1994 Project

The overall goal of this FAA-funded effort is to provide accurate real-time and 0-30 minute nowcasts of the snowfall rate in the airport area for ground de-icing purposes. In order to do this, real-time snowgauge and radar data are combined into a user friendly product. Key activities this year included deployment of a snowgauge network by Jeff Cole and Rasmussen to test various snowgauges and wind shielding devices, evaluation of the snowgauge performance by Charles Wade, development of an initial Z-S algorithm by Wayne Adams, development of a user-friendly display by Hage and evaluation of two snow echo extrapolation techniques by Gregory Stossmeister. Rasmussen is the overall project manager for this project.

A. Snowgauge Evaluation

As part of Project SNOW, Cole and Rasmussen deployed a snowgauge network in order to evaluate the performance of various commercially-available snowgauges and wind shielding devices used to measure the liquid-equivalent water content of winter-time solid precipitation (snow, sleet, snow pellets). (A snowgauge is essentially equivalent to a raingauge, but has an ethylene glycol solution in the catchment container to dissolve the solid precipitation and prevent freezing of the liquid contents. A layer of oil retards evaporation from the solution.) The gauges were evaluated in terms of their ability to provide accurate, reliable, real-time measurements of snowfall liquid-equivalent accumulation with a resolution of 0.25 mm. The data collected from the snowgauges was used to monitor snowfall rates and water content for commercial aircraft deicing operations and to aid in the development of radar-reflectivity algorithms used to monitor and predict snowfall rates at the ground.

Seven combinations of snowgauges and shields were evaluated at three sites. At the National Weather Service site at Stapleton, an 8-inch Belfort weighing snowgauge with a Canadian Nipher shield was co-located next to the NWS Belfort gauge with an Alter shield. Hourly observations of snowfall liquid-equivalent accumulation from the NWS gauge were provided by the NWS. A second site at Stapleton was located adjacent to the United Airlines maintenance hanger on Quebec St. At this site a 12-inch Electronic Techniques, Inc. (ETI) weighing snowgauge was located inside a Wyoming shield, and two 8-inch Belfort gauges (one with a Nipher shield and one with no shield) were located nearby. Data from these two sites were recorded using a Campbell Scientific Data Logger. An automated weather station provided real-time observations of ambient meteorological conditions.

The third site was located at the NWS Automated Surface Observing System (ASOS) site at Denver International Airport. Gauges at this site consisted of an 8-inch ETI gauge with Nipher shield, an ASOS heated tipping bucket gauge and an ASOS Light-Emitting Diode Weather Indicator (LEDWI) sensor.

Ten rain and snowfall events between January and April 1994 provided an opportunity to evaluate the various gauges and shields under a variety of weather conditions. Wade analyzed these data and found that the gauges are capable of accurate, high-resolution precipitation measurements, provided that shielding is used to reduce the effects of wind. The unshielded gauge at Stapleton typically undermeasured precipitation amounts by 50%. The most significant problem encountered was due to snow sticking to the inside surfaces of the gauge orifice and not being recorded in real time. This effect was variable but sometimes amounted to an under estimation of precipitation by up to 30%. The LEDWI sensor provided useful information on when precipitation was falling and on its relative intensity, but the quantitative rates appeared to be too high. The heated tipping bucket on the ASOS consistently underestimated precipitation amounts by a factor of two or more and does not appear to be a useful or reliable measurement.

During the winter of 1994/1995 the gauges will again be deployed in the field in an effort to improve the measurements. An effort will be made to reduce or eliminate the problem with snow and ice which accumulates on the inside surfaces of the gauge or shield.

B. Development of Real-Time Z-S Algorithm

Adams has continued development of real-time Z-S models. He found that advection effects have a much more significant impact on the Z-S relationship than on radar-rainfall relationships. Three Z-S models -- the familiar power-law model and two neural-network-based approaches -- all perform very poorly in high-wind-speed events unless great care is taken to temporally and spatially shift radar and snowgauge measurements to maximize the correlation between them. One component of this shift is the fall-speed time delay. In this case, snow, with its much narrower spread of fall velocities, is easier to analyze than rain.

Variations in the relationship between snowfall rate and reflectivity factor poses special problems for a real-time Z-S relationship. Ideally, the relationship will be based on recent data; however, a good regression fit requires a minimum number of Z-S pairs, as well as minimum variations in the values of both Z and S. So a trade off must be made between plasticity and stability, and some limits must be placed on the values of the regression coefficients so that noisy Z-S data do not bias the model to predict unrealistic snowfall rates.

One possible solution to this dilemma is to project snowfall accumulation (for, say, 30 minutes) based on the integral of the reflectivity factor (that is, integrate both "sides" of the Z-S relationship). A regression model based on these data should be less vulnerable to Z-S scatter; preliminary results support this hypothesis. In reality, accumulation projections are what is actually needed to support terminal-area ground de-icing anyway. The procedure of obtaining S from snowfall amounts (a numerical derivative of noisy data) and then re-integrating S to obtain snowfall amounts is rather circuitous and is responsible for at least some of the inaccuracies of Z-S-based snowfall projections.

C. Snow Echo Tracking Methods

Stossmeister evaluated two algorithms developed at NCAR to extrapolate radar reflectivity patterns. The first algorithm is called TITAN which stands for Thunderstorm Identification, Tracking, Analysis, and Nowcasting. This algorithm is an object-oriented approach to the problem. It is dependent on identification of thunderstorm "cells" in a radar volume which it can trace backward in time and extrapolate forward into the future. The second algorithm developed for winter applications is called REP which stands for Radar Echo Prediction. The REP algorithm was designed for large amorphous areas of reflectivity which contain regions moving in different directions at different speeds. Snowbands with differential motion are often observed in the Front Range area. Such storms are often poorly handled by TITAN. The REP algorithm operates on the principle of pattern matching. The original gridded data representation of the storm is divided into a number of cells which are spatially logged over previous observation of the storm to find the best match with the previous data plane. The motion of the subgrids is then extrapolated into the future to "predict" the reflectivity field.

The two tracking methods are being tested using data obtained from fifteen snowfall events observed near Denver. The goal of the evaluation is to determine the strengths and weaknesses of each algorithm and to decide which algorithm provides the best extrapolation of radar echo during winter storm conditions.

Average probability of detection and false alarm rate scores computed for one winter season suggest that the TITAN algorithm in its present configuration has skill over persistence in the 10-30 minute time period for reflectivities greater than 25 dBZ. TITAN outperformed persistence in the lower reflectivity ranges only in the 10-20 min time frame. This result may be misleading however, due to a significant number of cases where echo covered most of the verification area. As of this writing, the evaluation of the REP algorithm was not sufficiently complete to report skill statistics. A more detailed examination of the evaluation results is ongoing in order to determine the performance characteristics of both TITAN and REP in comparison with persistence in different weather situations. A more detailed analysis of the skill scores on a radar volume-by-volume basis will be performed in an attempt to define each algorithm's performance characteristics as a function of radar echo characteristics. Radar data from other winter seasons may also be used to produce a more varied set of input data since weather characteristics vary greatly from year to year. Testing of the algorithms for real-time operations with NEXRAD radar data will begin this winter.

D. Meteorological Conditions Associated with Ground De-Icing Accidents

Rasmussen, Cole, and Kevin Knight have analyzed the meteorological conditions associated with commercial large jet-aircraft accidents in which ice accumulation on the wing prior to takeoff was a primary factor in the accident. Of the ten large jet-aircraft accidents in which wing surface ice contaminants were considered a contributing factor, seven had weighing snowgauge data available. Of these, five were snow events and two were freezing drizzle events. The common factors in the five snow cases were light precipitation rates (0.08-0.1 inches/hr), temperatures of 25 to 31 degrees F, and windspeed 8 to 13 knots. This particular combination of meteorological conditions may be very conducive to the buildup of hazardous ice accumulations on critical aircraft surfaces. The nearly identical liquid equivalent precipitation rate suggests that accidents may be avoided if snowstorm periods with precipitation rates equal to or greater than this value are avoided. This would require a real-time estimate of liquid equivalent snowfall rate to be available to ground operations coordinators and airline station control centers.

In contrast to snowfall rate, no common visibility value was apparent. For instance, visibility was found to range from 0.25 to 2 miles.

Figure 1 presents a plot of visibility versus precipitation rate as well as regression lines from previous studies of snowfall rate and visibility, including recent results from an ASOS visibility sensor comparison with an ETI weighing gauge with a Nipher windshield that we conducted during the winter of 1993-1994 at the Denver ASOS site. Also indicated on the right hand side is the NWS snowfall categories for snowfall rate based on visibility. The results show that visibility has a nearly order of magnitude variation at the critical snowfall rate of 0.1 inch per hr, and that this variation spans the NWS visibility-defined snowfall rate categories of S-, S, and S+. Thus, the use of visibility to determine snowfall rate, especially rates near the critical value of 0.1 inch per hr, is not recommended. Part of the reason for the wide scatter in visibility for a given snowfall rate is the observed order of magnitude variation in snowflake density for a given snowflake size. Since visibility reduction due to a snowflake is proportional to the cross-sectional area of the snowflake and not the density of the snowflake, wide variations in precipitation rates are possible for a given snowflake size due to variations in snowflake density. This can often be very misleading to pilots and ground operations, who often rely on visual estimates of snowfall rate in the absence of other data. In particular, the high visibility during the La Guardia accident was also noted by the first officer of the aircraft. He described the snowfall as "not heavy, no large flakes". Since he did not have access to any real-time liquid equivalent precipitation rate, the only way he could make a judgement that the snowfall rate was not heavy was by visibility; and he even notes that there were no large flakes. This visual estimate of snowfall rate gave him a false sense of security that the conditions were not that bad, when in fact the conditions were actually similar to those in previous ground de-icing accidents. The La Guardia weather observer characterized the snow as wet, which is consistent with the snowflakes having a high density, leading to the high precipitation rates observed. Thus, the use of visibility to estimate snowfall rate for ground de-icing purposes should be avoided. A paper describing these results in more detail will be presented at the Aviation Weather Conference in Dallas, Texas in January.

V. Convective Weather Detection

Hail avoidance is of major concern to the aviation community. Damage to airfoils can significantly degrade aircraft performance by reducing lift. In-flight encounters can shatter windshields and are the primary cause of in-flight engine shutdowns. The accurate detection of hail would have obvious benefits. Although hail detection has been the subject of numerous studies, an independendent testing of suggested techniques has not been done. Consequently, RAP conducted field programs during the summers of 1992 and 1993 to collect the necessary in situ hail measurements and radar observations. Research activities during 1993 were concerned primarily with the evaluation of algorithms that identify hail storms based on radar reflectivity measurements alone. Future work will determine the added improvement, if any, that multiparameter radar measurements provide for hail detection. Also, a preliminary investigation was conducted in which the radar signatures for hail were verified by in situ particle measurements made by research aircraft.

A. Verification of Reflectivity-based Hail Algorithms

Cathy Kessinger has completed an evaluation of three radar reflectivity-based hail algorithms that included the Next Generation Radar (NEXRAD) hail algorithm, currently used with the NWS WSR-88D radars, and two algorithms from the National Severe Storms Laboratory (NSSL) that are planned replacements for the NEXRAD hail algorithm: the Probability of Hail (POH) and the Probability of Severe Hail (POSH). During the 1992 and 1993 field projects, surface hail reports were collected by hail intercept crews, a volunteer observing network, the Mountain States Weather Services, and the NWS. These reports formed the verification database for the evaluation effort. The hail reports were edited to correct time or space errors.

The hail algorithms were run in real time using data from the Mile High Radar (MHR) located 15 km northeast of Denver Stapleton Airport. A co-location program was used to match the verification data (hail and rain reports) with hail storm designations made by the algorithms. The matching was accomplished by defining storms as either 30 or 40 dBZ envelopes and by defining influence areas with radii of 5, 10 and 15 km about a reporting site. Contingency tables were created for computation of the Critical Success Index (CSI), the Probability of Detection (POD), the False Alarm Ratio (FAR), the Miss Rate (MR), and the Heidke Skill Score. To evaluate algorithm performance at increasing hail sizes, these quantities were computed for all hail reports, and for hail greater than or equal to 6 mm, greater than or equal to 13 mm, and greater than or equal to 19 mm. Similar to an evaluation done by NSSL, this study found that the NEXRAD "hail" algorithm performed with the least skill (a CSI of 0.47 for any size hail and a storm definition of 30 dBZ). Inclusion of the NEXRAD "probable hail" category with the "hail" designations improved skill levels considerably (a CSI of 0.72).

Because the algorithm detections by POH and POSH are expressed as percentages, a search for a "hail"/"no hail" threshold was conducted. Although designed to detect severe (large) hail the best performances with the NSSL algorithm for hail in Colorado were found for hail of any size. The best performance for the POH parameter was a CSI of 0.90 at an algorithm designated hail probability of 10%. This result was achieved for verification areas with 10 and 15 km radii and for the 40 dBZ storm outline. The best performance for the POSH parameter was 0.86 for verification areas with 15 km radius and the 40 dBZ outline. As hail size increased the performance of all algorithms decreased.

B. A Case Study of a Northeastern Colorado Hail Storm

As a starting point for the multiparameter hail detection work, Edward Brandes, Vivekanandan, John Tuttle and Kessinger began a study that compared radar measurements from the CP-2 radar to in situ particle observations made on 24 June 1992 by the T-28 aircraft operated by the South Dakota School of Mines and Technology. Excellent agreement was found between multiparameter radar signatures of hail, raindrops, and mixed-phase precipitation and in situ observations. Radar reflectivity estimates determined by direct (radar) measurement and estimates computed from observed particle distributions generally agreed within 5 dB. Maximum values of differential reflectivity (ZDR) and the fractional contribution of liquid water to total reflectivity differed by less than 0.8 dB and a factor of two, respectively.

The storm had a positive ZDR column that extended more than 2 km above the melting level. Similar columns have been thought to play an important role in hail formation. The column of the 24 June storm was nearly coincident with the storm updraft and contained mixed-phase precipitation. The aircraft data revealed that the ZDR measurement was dominated by a small number of very large raindrops (some exceeding 5 mm in diameter). Trajectories computed with a precipitation growth model suggest that the drops originated primarily with partially or totally melted particles from a quasi-stationary feeder band within the inflow air to the storm and from the storm's reflectivity core. Particle observations and radar measurements at approximately the -2 degrees C level in the column revealed that the fractional contribution of drops to radar reflectivity was roughly 0.5 to 0.8. However, the concentration of supercooled water represented by the drops (a maximum of 0.7 g per cubic meter and an average of 0.2 g per cubic meter) was about half that associated with cloud water. Hence, the relative importance of the large drops and consequently the ZDR column to hail production may be minor.

VI. Convective Weather Forecasting

The goal of this effort sponsored by the FAA is to develop automated techniques for place specific 0-2 hr forecasts of convective weather phenomena that are a hazard or efficiency concern to the aviation weather community. This includes the use of numerical modelling and rule-based methods to forecast initiation, growth, movement and dissipation of thunderstorms. Radar-based techniques for automatically detecting and extrapolating convergence lines, convective storms and cumulus clouds are essential for the thunderstorm forecasting effort.

A. Auto Nowcast Algorithm Evaluation

NCAR has developed a rule-based automated thunderstorm forecast algorithm . Sandra Henry is currently utilizing the automated thunderstorm forecast algorithm to evaluate the accuracy of 30-minute thunderstorm forecasts. The algorithm also provides a scientific tool that allows continued development and fine-tuning of the forecast rules. Results from the algorithm show that the automated forecast rules currently implemented into the algorithm are capable of producing very good forecasts of thunderstorm initiation. However, the quality of the forecast is very dependent on the accuracy of automatically detecting and extrapolating boundary-layer convergence lines. The automatic boundary detections are generated by an algorithm called MIGFA .

Forecasts of thunderstorm extrapolation and dissipation are based largely on the performance of TITAN (an algorithm that automatically detects and extrapolates storms). One of the primary weaknesses identified with the algorithm thus far is the need to identify cumulus clouds and their various stages of development. The algorithm's inability to distinguish between radar echoes associated with cumulus clouds and those associated with other clouds (e.g. mid-level stratiform clouds) can lead to significant over forecasting of thunderstorms.

B. Evaluating MIGFA

Integral to the automated thunderstorm forecast algorithm being developed at RAP is the radar detection and forecast position of surface convergence boundaries. MIT/Lincoln Laboratories has developed a Machine Intelligent Gust Front Detection Algorithm (MIGFA) that has been found to perform reasonably well in the detection of convergence lines and reflectivity thin lines using TDWR data. A version of this algorithm was brought to RAP and modified to run off the Mile High Radar (MHR) data. Rita Roberts has evaluated the performance of MIGFA on a limited number of MHR cases which resulted in an average POD of 66% and FAR of 6%. Problems in performance were related to 1) difficulty in boundary detection in regions of high clutter and weak convergent flow, 2) the use of only one elevation scan for identification of boundary locations, 3) the inability to consistently detect stationary, radially-aligned boundaries or spatially diffuse reflectivity thin lines, and 4) false detections due to range ambiguous data from MHR.

To enhance the detection of thin lines on radar reflectivity images, a continuous, 2-D wavelet transform technique was tested by Jason Helland and Carl Hagelberg and incorporated into the MIGFA code. The spectrum of the wavelet consists of two localized Gaussian-shaped peaks which enables the wavelet transform to act as a very selective filter. Use of the wavelet transform then lends itself to both the reduction of noise (specifically ground clutter and data outliers) and multiscale analysis of images to improve detection of a wider range of thin line features. Tests of the wavelet transform technique involved a two-step process: 1) projecting the reflectivity image onto a directionally selective wavelet basis, and 2) combining the multiscale-multiorientation information into an enhanced interest image. The intensity of pixels on this image is proportional to the potential that the pixel lies on a thin line feature. Preliminary tests of this technique using MIGFA indicate that the multiscale analysis improves the range of detection capability; however, thorough testing is warranted.

Additional efforts are underway to ingest NEXRAD data into MIGFA, as the first step toward getting the autonowcaster algorithm to run off of any NEXRAD dataset.

C. Numerical Modelling with ITWS

Research continues on methods to forecast winds in the terminal environment. In collaboration with Lincoln Labs/MIT, Andrew Crook has examined the ability of a small-scale numerical model to forecast the motion of gust fronts from Lincoln's Terminal Winds analysis system. The analysis system produces winds at 2 km resolution every 5 minutes, using data from TDWR and WSR-88D radars and LLWAS. A thermodynamic retrieval uses wind data over several time levels. Once the buoyancy field has been retrieved, the model can be integrated forward to produce a forecast. Figure 1 , shows a 40 min forecast of a gust front that moved over Memphis airport on 9 June 1994. A verification analysis showed that the numerical forecast improved over persistence by approximately 30% after 40 minutes.

Research has also been performed on other methods to improve these forecasts. Jenny Sun has examined the ability of the adjoint method to retrieve the buoyancy field. Tests on various datasets have shown that the adjoint method can retrieve the buoyancy field with greater accuracy than the traditional retrieval technique, because of the way it handles noise in the data. Tuttle has also examined the performance of the TREC algorithm (Tracking Reflectivity Echoes by Correlation) in retrieving the horizontal windfield from WSR-88D data. The TREC algorithm could substantially improve the winds produced by the Terminal Winds Analysis System.

D. Thunderstorm Forecasting Research

1. Cloud detection:

Cindy Mueller conducted research into comparisons between early cumulus cloud detection by satellite and radar. Monitoring cumulus cloud location and development is critical to the very short period forecasting of thunderstorm initiation. Earlier studies by Knight and Miller (1993) have shown that 10 cm wavelength radar can detect cumulus clouds even in the earliest stages as a result of Bragg scattering in the -10 to 10 effective dBZ range. Figure 2 shows close agreement between cumulus clouds detected by radar and satellite. Because of limitations by each technique under certain conditions it is advantageous to utilize both methods to monitor cumulus cloud development.

2. Horizontal convective rolls:

A comprehensive study of horizontal convective rolls using CaPE data from the summer of 1991 is being conducted by Tammy Weckwerth (ASP/RAP). She has found that rolls exist within a variety of environmental conditions including surprisingly low boundary-layer windshears (~2 X 10-3 per sec). There is a range of wind speed/surface heat flux values in which the most linear rolls exist. An examination of storm initiation by rolls has shown that the rolls often trigger thunderstorms in Florida. Reasons for storm initiation at specific locations along the rolls proved to be indeterminable with the available data.

This study also includes an examination of the causes of the along-roll features, called "pearls on a string" by Kuettner (1971). These along-roll features are not only seen in the satellite imagery as periodic cumulus clouds but also within the boundary layer as periodic kinematic features derived from dual-Doppler analysis. Figure 3 shows the northwest-southeast rolls, as delineated by the convergence field and time changes in the vertical vorticity field.

3. Convergence line initiation of thunderstorms:

James Wilson and Dan Megenhardt have initiated a study to examine the frequency of storm initiation and storm lifetime with respect to the windshear vector relative to convergence line orientation and motion. Numerical studies by Rotunno et al. (1988) showed storm initiation was favored when there was a balanced horizontal vorticity condition along the boundary which produced erect updrafts. This condition can be achieved when the environmental winds oppose the boundary motion at low levels and are nearly equal to the boundary motion at cloud level (Wilson and Mueller, 1993). The data from CaPE is being used for this study.

VII. Turbulence

During the past few decades, a great deal of pure and applied research has been performed to better understand atmospheric turbulence. These wide ranging efforts dealt with turbulence phenomenology, in-situ and remote detection, numerical modelling, operational forecasting and the response of aircraft in turbulence. The direct application of the resultant knowledge to operational meteorology and aviation has been somewhat limited. This is primarily the result of an all too common problem: inadequate real-time measurements. The only direct measurement of turbulence intensity currently available is from pilot reports (PIREPs). The lack of adequate atmospheric measurements also limits the ability of aviation meteorologists and numerical weather models to generate accurate forecasts of turbulence.

Turbulence has a significant impact on flight efficiency in the tactical and strategic use of airspace. This impact is directly related to the aircrew's desire to avoid impending turbulence encounters and the lack of definitive planning information to know where to expect these encounters. Results include the introduction of delays as crews execute reroutes and altitude changes to avoid encounters, accompanying increases in fuel consumption, and additional workload for pilots and controllers as they coordinate these changes.

Automated reporting of meteorological data from commercial aircraft is an extremely valuable source of information for the operational aviation and meteorological communities. Currently, the Aircraft Communications Addressing and Reporting System (ACARS) provides access to wind and temperature measurements from commercial aircraft. Advances in data-link technologies, combined with the future implementation of the Automatic Dependent Surveillance (ADS) system will provide ever wider access to this data. Augmenting the qualitative, intermittent and subjective AIREPs with quantitative, automated and aircraft-independent turbulence measurements is a high priority within both the air traffic and meteorological communities.

Recognizing the need to ensure the standardization, applicability, and accuracy of aircraft-reported meteorological data, the Air Navigation Commission of the ICAO has created the Automatic Air Reporting Study Group (ATAR SG) to provide advice in this area. Early on, an ad-hoc group of meteorological experts, the predecessor to the ATAR SG, recognized that efforts were needed to determine a method for generating a real-time turbulence algorithm suitable for automated air-reports. Larry Cornman responded to this requirement by developing a fully automated, computationally efficient algorithm designed to be installed on commercial aircraft. In order to maximize the cost effectiveness of generating these automated air reports, the algorithms have been designed to use currently available on-board data and computational resources.

Operational demonstrations of the NCAR turbulence algorithm on commercial aircraft will occur over the next several years in conjunction with the NOAA/FAA/NCAR Commercial Aircraft Sensing of Humidity (CASH) program. Researchers from Transport Canada are also participating in validation efforts involving the NCAR in-situ turbulence algorithm. Discussions with the ICAO are underway regarding adoption of the NCAR algorithm as an international standard for the automated reporting of turbulence from commercial transport aircraft.

VIII.

Feasibility Studies for an Operational Windshear Warning System at the New Hong Kong International Airport

A new airport is currently under construction in Hong Kong to replace the aging and saturated Kai Tak International Airport. The new airport is situated on a small island called Chep Lap Kok (CLK) just a few kilometers west of the much larger and relatively mountainous Lantau Island. Since the prevailing boundary-layer flow in the Hong Kong region is generally from the east, the new airport lies in the lee of Lantau Island. This situation creates the possibility that, under certain circumstances, terrain-induced windshear and turbulence (TIWT) produced by the flow over Lantau Island may be strong enough to impact aircraft operations at CLK. Indeed, previous studies have shown that significant TIWT does occur in this area. Therefore, the Research Applications Program in collaboration with the Royal Observatory of Hong Kong has begun to assess the feasibility of an operational system to detect and warn of the presence of significant TIWT. A scientific examination of the nature of the flow over Lantau Island has been emphasized during the early phases of this program, including climatological, numerical and field studies.

A review and reexamination of previous studies by Peter Neilley, Teddie Keller and Brant Foote has revealed that significant turbulence at the new airport site can be expected to occur during any of the basic climatological weather regimes common to Hong Kong. Further, these studies suggested that boundary-layer windspeeds in excess of about 10 meter per sec may be sufficient to generate significant TIWT in the lee of Lantau. The degree of turbulence was found to decrease with height and distance from the Islands.

In order to obtain a better understanding of the nature of the flow over Lantau Island, a series of fine-scale numerical modelling experiments has been conducted by Keller and Terry Clark. Since the parameter space that governs the flow over the island is large (there essentially is an infinite combination of wind and stability profiles possible), two separate approaches to the design of the model experiments have been taken in order to simplify this study. The first approach was to build upon the current knowledge of flow over terrain and the behavior of terrain-induced gravity waves by initializing the model with relevant idealized profiles of wind and stability that have been studied previously. The changes in the perturbation response of the flow over Lantau Island to prescribed changes in the ambient profile parameters that are known to affect that response (e.g. Froude number, critical-level height, etc.) are then observed. The second approach was to initialize the model with observed profiles during times known to be associated (or not associated) with turbulence at CLK.

The results from the idealized profile simulations have shown considerable sensitivity of the response to some of the details of the idealized profiles. For example, runs in which a low-level easterly flow of 15 m/s reversing to a westerly flow aloft (through a tanh profile) with a constant static stability of 0.01 per sec showed that the height of the critical level played an important role in determining the magnitude of the perturbed response with maximal response found for critical levels near 2.5 km. Similar sensitivity to the ambient windspeed was also found with the largest perturbations found for flows (using the same static stability) around 10 meter per sec. Lesser sensitivity was found for changes in the wind direction and the degree of shear near the critical level. One set of experiments in which an orthogonal component of wind was added to the basic flow revealed that the nature of the downstream response strongly depended on the details of this orthogonal flow profile. In these cases, the definition of a critical level is called into question and the dynamics of gravity wave behavior in such three-dimensional shear flows is largely unexplored. These results also suggest that accurate predictions of the terrain-induced turbulence may require frequent and precise information on the structure of the boundary layer flow.

The numerical modelling studies using actual sounding data performed to date have concentrated on a few summer situations in which significant turbulence was known to have occurred. During these cases, no critical-level was present in the ambient flow and the low-level static stability was generally quite small. Initial modelling efforts on these cases suggest that very high horizontal resolution is needed to capture the turbulence flow response. This suggests that a small-scale dynamical mechanism such as mechanical vortex shedding in the surface layer of the terrain may be responsible for the observed turbulence in these cases.

The Hong Kong Program has also embarked on an extensive field program called LANTEX centered on the observations taken with NCAR's instrumented King Air aircraft. The King Air has been routinely sampling the turbulence environment in the vicinity of CLK since April 1994. The field study program also deployed a Doppler lidar at CLK, an ATD integrated sounding system based at an upstream site, and a large array of automated surface weather observing stations scattered throughout the Hong Kong Territories. As of August 1994, fourteen significant turbulence cases have been observed including several cases qualitatively described as being "severe enough to cause a 747 to go around." In these severe cases, vertical velocity variations of about 5 meter per sec were observed all along the proposed landing and takeoff corridors. Preliminary analysis of the field program cases to date, suggest that mean boundary layer windspeed is a skillful predictor of the turbulence intensity produced by Lantau Island. This suggests that for these summertime cases with low stability and no significant wind shear or critical levels that mechanical mixing induced by the details of the terrain may be the principle mechanism responsible for the generation of the turbulence. Verification of the high amplitude gravity wave breaking mechanism explored with the numerical modelling studies awaits upcoming flights in the fall and winter when conditions more conducive to gravity wave amplification are common.

An important aspect of the work to assess the feasibility of an operational windshear warning system will be the construction of a functional prototype. Preliminary work has been carried out by Gerry Wiener and Zhonqi Jing to define a general system architecture to support TIWT detection and forecast algorithms. It is envisioned that the OWWS algorithms will be based upon fuzzy-logic methodology. This technique combines the qualitative knowledge of an expert system with the quantitative methods of a numerical algorithm. It incorporates all available information and builds upon consensus of this information (wind profiler data, anemometer data, MM5 model output, and Clark model lookup tables, etc.). Each input data source will be pre-processed to a usable stage (e.g., wind and/or turbulence measurements from the profiler) and then passed along with quality control information to the fuzzy-logic algorithm. Using this framework, the algorithms will be robust and accurate producing the best possible detection probabilities and lowest false alarm rates, given the available data. Furthermore, this type of algorithmic system will be flexible in terms of including new data sources, if they become available.

One important data source to the OWWS algorithms will be the wind profilers. Wind profilers have been shown to produce reliable and accurate wind measurements in steady-wind and minimal-clutter environments. However, in strongly varying winds, clutter and/or rain data from these devices can become erroneous. In order to use profilers for automated TIWT detection, these problems must be overcome. Cornman and Cory Morse have been working together in developing better algorithms to provide the required operational utility including thorough analysis of the theoretical wind measurement capabilities of boundary layer profilers. From a mathematical and numerical analysis, the specific parameters of a linear windfield that can be reliably estimated have been determined. Algorithms that build upon this information have been developed and, in this preliminary stage, show great potential in the ability to produce high temporal resolution (1-2 min), wind vector and turbulence estimates. Further research is needed to solve the contamination effects of clutter, variable signal-to-noise ratios, velocity folding and falling precipitation.

IX. Terminal Area Surveillance System

The Terminal Area Surveillance System (TASS) program within the Federal Aviation Administration is developing a radar system that will perform both aircraft surveillance and weather hazard detection functions. This system is early in the research and development process and will probably utilize electronically steered beam technology. The electronic beam steering should provide greater flexibility in dynamically allocating radar resources between aircraft surveillance and weather observations than has been possible in previous systems with mechanically scanned antennas. RAP is providing expertise in determining scan strategies appropriate for the detection of hazardous weather phenomena, developing automated methods for detection of the phenomena and creating three-dimensional graphical displays for their depiction.

A. Scan Strategy

In order for the TASS system to perform its meteorological functions, Brandes and Vivekanandan have proposed that a full hemispherical surveillance scan be obtained at regular intervals. By necessity, this scan (and others developed for monitoring weather hazards) is interlaced among aircraft surveillance scans. The surveillance scan will consist primarily of low resolution radar reflectivity information that will be used to identify regions with possible weather hazards. Special high resolution scans that sample only in regions of potential hazard will then be implemented. The special scans may be made of detailed reflectivity information and radial velocity measurements. This information will be processed by other algorithms to quantify the hazard and to monitor trends in intensity. Strategies have been produced for a wide variety of phenomena.

Several radar designs with widely different sampling characteristics have been proposed for use in the TASS system. To aid in the design and evaluation of potential radar configurations, as well as evaluation of the proposed scan strategies, Vivekanandan and Charlie Le are developing a TASS radar simulator. This simulator will use observed or modelled data of weather phenomena as input and produce data representative of the radar design and scan strategy as output. Through the use of the simulator, the system designs and scan strategies will be tested and optimized without the need to build a series of costly hardware prototypes.

B. Microburst Algorithm

Dave Albo has developed a new microburst detection algorithm for use in demonstrating the weather detection capabilities of the TASS radar. This algorithm uses fuzzy logic techniques to combine a variety of information to determine the existence of microburst events. The information used consists of an estimation of windshear, an estimate for the presence of precipitation and its effect on the likelihood of microbursts, and an estimate of the effect of clutter contamination on microburst detection. These estimates are combined and used to build areas most likely to be microbusts, which are matched against expected microburst size and shape criteria, with final microburst shapes drawn around the appropriate regions. The algorithm performs comparably to the existing TDWR microburst detection algorithm on the datasets evaluated, and performance is maintained through the lower data resolutions that are anticipated for TASS scanning.

C. Three-Dimensional Display

Bill Myers has led the effort to enhance the 3DTV, the Three-Dimensional Terminal Viewer , which provides the user with a perspective view of real-time aviation weather hazards in the terminal area from a variety of viewpoints, e.g., from the cockpit of any aircraft or the airport control tower. Enhancements included a high resolution airport model, a configurable air traffic simulation system and further developments of prototype 3-D aviation weather hazard glyphs (icons) all integrated into a standard simulation environment. The inclusion of the high resolution airport model along with positional data from all ground vehicles could provide a means for airport operation under poor visibility conditions. The air traffic simulation is the first step in development of an air traffic study or training system to examine the effects of different terminal area air traffic management strategies in the presence of aviation weather hazards. In contrast to simply making the glyphs cognitive extensions of the the 2-D graphical icons currently in use in the aviation weather system today, as was done in the previous version of 3DTV, the development of new glyphs to represent aviation hazards examines the use of suggesting atmospheric dynamics in the presentation of a hazard region to more intuitively communicate the nature of the hazard.

The representation of data and extracted features as an aviation weather hazard "virtual world" in which one is "immersed" was also explored. In a collaborative effort with NCAR's Scientific Computing Division (SCD), the software was ported to an immersive environment called the CAVE developed by NCSA. This environment is characterized by projecting the application onto three walls and floor of a room in stereo. When the users, wearing shutter glasses, view this scene, they have the impression of being immersed in a 3-D environment complete with depth perception. Navigation paradigms for exploring this world and previewing flight paths were also explored. This immersive system was presented by Myers at the ACM/IEEE SIGGRAPH conference.

X. Aviation Weather Products Generator (AWPG) Prototype Development

Scientific activities at NCAR/RAP include research on thunderstorm hazards (hail, turbulence, windshear, and heavy rain), thunderstorm prediction and lifecycle evolution, in-flight icing, ground de-icing, snowfall, clear air turbulence, terrain induced windshear and turbulence, and ceiling and visibility. The end result of these research activities will be a new aviation weather products, display and system concepts. A critical step in the development of new products is to ensure that the final product and display concepts meet the user needs without impacting work load.

A number of system prototypes are being developed by Diedre Garvey, Tom Wilshire, Steve Delp, Nancy Rehak, Mike Dixon and Paul Burry that will allow users to view high resolution weather products tailored for their particular need. New high resolution weather sensing systems (radars, wind profilers, aircraft measured data, etc.) allow for the development and distribution of four-dimensional (three space dimensions plus time) datasets. The new data are processed into high resolution, 4-dimensional grids of aviation impact (icing, turbulence, ceiling, etc) and state of the atmosphere (wind, temperature, pressure) variables. NCAR/RAP is developing display capabilities that utilize the four-dimensional data and present the information to users in a tailored format. A system titled the "Aviation Weather Products Generator (AWPG)" has been developed that allows aviation users to graphically view weather at specific altitudes and along user selectable routes of flight.

During the past year, RAP has been extensively involved in working with the FAA user working groups to define the user needs and requirements for advanced aviation weather products. Input from flight service specialists and enroute traffic managers was used to design and tailor AWPG weather products particular to these functions.

An AWPG software system was developed and documented. System products include a high resolution 2-dimensional national radar mosaic, national lightning mosaic, flight advisories, and flight category (IFR, VFR, etc.). Four dimensional products (three-space dimensions plus a forecast capability) include icing potential, turbulence potential, winds, temperature, and freezing level. The four-dimensional products are derived from the state variables from both the NOAA-developed Eta and RUC models. The algorithms required for deriving the aviation impact variables (icing, turbulence, wind, temperature and freezing level) were the results of scientific research being conducted at NCAR and NOAA/FSL.

Initial product and display concepts developed for the prototype AWPG system were transferred to industry during the year. Cooperative Research and Development Agreements (CRDAs) were developed between the FAA and industry and NCAR/RAP served as the FAA's agent. The CRDAs were established to accelerate the development process with the hope that the NCAR-developed technology will make it to the commercial market quickly. CRDA participants during 1994 included Kavouras, WSI, GTE, Lockheed and Harris Corporation.

Scientific research and the development of advanced product prototype systems coupled with industry CRDA's makes a powerful technology transfer capability within RAP.

XI. Aviation Weather Development Laboratory (AWDL)

Located within the National Center for Atmospheric Research's Research Application Program (NCAR/RAP) is the Aviation Weather Development Laboratory (AWDL) . The AWDL was created as a long term research, development and demonstration laboratory to support the development and evaluation of advanced aviation weather products and other technology transfer activities. The AWDL facility is shared amongst RAP's research programs and sponsors include the FAA, the NSF, the Government of Hong Kong and NASA.

The components that make up the AWDL include science, engineering, user interface, validation, and demonstration. The AWDL concept allows for experimental weather products to be field tested at user sites such as FAA facilities (Air Traffic Control Tower, Terminal Radar Approach Control, Automated Flight Service Station), NWS facilities (Weather Forecast Office, National Aviation Weather Advisory Unit) and industry facilities (Airline Meteorology Office, Dispatch).

The AWDL rapid prototyping capability allows users to gain experience with new systems, test them in a real working environment and provide input for future development and refinement. End system users are involved with product development from concept definition through implementation. End users include pilots, controllers, traffic managers, supervisors, and airline and airport operators.

XII. NASA Airborne Windshear Detection

During the summers of 1991 and 1992, the NASA/Langley 737 flew microburst penetration missions in Denver, Colorado and Orlando, Florida, both sites for TDWR testbed radar operations. Part of this work centered around developing better wind shear detection methods for ground-based TDWR systems.

F-factor has become an industry standard when working with airborne systems and discussing aircraft performance. Both divergent shear and downdrafts contribute to F-factor, and each contributes depending upon how fast an event is traversed. The current TDWR algorithms do not use a performance-based metric for determining windshear related hazards; rather they use head-wind loss as the hazard criteria. While a significant and largely successful effort has been made towards stable headwind loss estimates, until recently little effort had been targeted at performance-based windshear hazard estimates from ground-based radar. NCAR, along with MIT/Lincoln Laboratory, has recently addressed this need.

Based on simulation studies by Albo and Kent Goodrich, efforts have been focussed exclusively on two-dimensional least-squares methods for estimating shear with single-Doppler radar data. While this work does not constitute a performance-based windshear detection algorithm, it is the basis for one.

By far the most difficult problem in algorithm development is "truthing". The NASA deployments offer an unprecedented opportunity to compare radar measurements of hazardous shear to what actually existed. There are many pitfalls and problems when comparing results of two such disparate systems as Doppler radar and in situ aircraft measurements: sampling volumes and sampling intervals are vastly different. Common sampling volumes and simultaneous sampling times are the exception rather than the norm. But with sufficient care, meaningful results can be extracted and such is the case here.

Kim Elmore (the primary investigator) found that 2-D F-factor estimates compare well with the NASA in situ F-factors -- correlation coefficient of 0.69 and slope of 0.74, all significant at the 99% confidence limit. One interesting result is that while the vertical wind may make up as much as 50% (about 20% on average) of the total F-factor, improving the vertical wind estimate does not significantly improve the overall statistics. Most poor statistical comparisons can be attributed to four effects: phase-type misalignments, excessive distance from the radar, disparate spatial resolution and/or excessive aircraft path and radar beam separation. In fact, results from this work indicate the radar derived F and in situ F compare better than the raw ensemble statistics at first indicate.

XIII. Staff, Visitors and Collaborators

Dates refer to visitor's stay at NCAR during FY94. No dates are given for collaborators who did not visit NCAR.

Gunnar Aaro; Luftartsverket, Ost-Norge - Oslo ATCC; Applied Science and Engineering Groups

Joan Bauerlein; Luftartsverket, Ost-Norge - Oslo ATCC; Applied Science and Engineering Groups

Stan Benjamin; National Oceanic and Atmospheric Administration; Applied Science Group

E.A. Betterton; University of Arizona; Applied Science Group

Howie Bluestein; University of Oklahoma; Applied Science Group

V.N. Bringi; Colorado State University; Applied Science Group

John Brown; National Oceanic and Atmospheric Administration; Applied Science Group

Mary Cairns; National Oceanic and Atmospheric Administration; Applied Science Group

John Cardwell; University of Manchester Institute for Science and Technology; Manchester, England; Applied Science Group

C.H. Chan; University of Washington; Applied Science Group

Kin Sang Chim; Hong Kong University of Science and Technology; Applied Science and Engineering Groups

Jay-Chung Chen; Hong Kong University of Science and Technology; Applied Science and Engineering Groups

Don Chisholm; Phillips Lab/GPAP; Applied Science Group

Young-Il Choe; Korea Civil Aviation Bureau; Applied Science and Engineering Groups

Zou Chunshen; China Meteorological Administration; Applied Science and Engineering Groups

Chris Clarke; Colorado State University; Applied Science Group

Rodney Cole; MIT Lincoln Laboratories; Applied Science Group

Harry Colella; Martin Marietta; Applied Science and Engineering Groups

W.R. Cotton; Colorado State University; Applied Science Group

R.R. Czys; Illinois State Water Survey; Applied Science Group

Richard Delanoy; MIT Lincoln Laboratory; Applied Science Group

Paul DeMott; Colorado State University; Applied Science Group

Geoff DiMego; National Oceanic and Atmospheric Administration; Applied Science Group

Jim Evans; MIT Lincoln Laboratory; Applied Science Group

Warren Fellner; Federal Aviation Administration; Applied Science and Engineering Groups

Henry Fields; NAWAU; Applied Science Group

Cecilia Girz; National Oceanic and Atmospheric Administration; Applied Science Group

Paul Gluhosky; Yale University; Applied Science Group

Georg Grell; National Oceanic and Atmospheric Administration; Applied Science Group

Zhang Guocai; China Meteorological Administration - Beijing; Applied Science and Engineering Groups

M. Hagen; Inst. f. Physik d. Atmosphare; Applied Science Group

Art Hansen; Federal Aviation Administration; Applied Science and Engineering Groups

He Hao; Civil Aviation Administration of China; Applied Science and Engineering Groups

Hui He; Yale University; Applied Science Group

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Yan Hong; China Meteorological Administration - Beijing; Applied Science and Engineering Groups

C. Hreberach; University of Oklahoma; Applied Science Group

Li Huibin; Civil Aviation Administration of China; Applied Science and Engineering Groups

George Hunger; Seagull Technology; Applied Science and Engineering Groups

J.N. Hwang; University of Washington; Applied Science Group

Seiji Itoh; Matsushita Communications Industrial Co., Ltd - Yokoham, Japan; Applied Science Group

Max Ivey; Hong Kong University of Science and Technology; nology; Applied Science and Engineering Groups

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Xue Jishan; China Meteorological Administration - Beijing; Applied Science and Engineering Groups

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Sheldon Katz; Martin Marietta; Applied Science and Engineering Groups

John Keller; MIT Lincoln Laboratory; Applied Science Group

Gene Kingsbury; Federal Aviation Administration; Applied Science and Engineering Groups

Kenneth Klasinski; Federal Aviation Administration; Applied Science Group

Steven E. Koch; North Carolina State University; Applied Science Group

S.C. Kot; Hong Kong University of Science and Technology; Applied Science and Engineering Groups

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T.W Krauss.; National Hydrology Research Centre; Applied Science and Engineering Groups

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C.Y. Lam; Royal Observatory, Hong Kong; Applied Science and Engineering Groups

Sharon Lau; Royal Obseratory, Hong Kong; Applied Science and Engineering Groups

Chang-Soo Lee; Korea Airports Authority; Applied Science and Engineering Groups

Jean T. Lee; University of Oklahoma/CAPS; Applied Science Group

Ophelia Lee; Hong Kong University of Science and Technology; Applied Science and Engineering Groups

Thomas Lee; Naval Research Laboratories; 8 August-12 August; Applied Science Group

Kenneth Leonard; Federal Aviation Administration; Applied Science and Engineering Groups

Jennifer Mahoney; National Oceanic and Atmospheric Administration; Applied Science Group

Adrian Marroquin; National Oceanic and Atmospheric Administration; Applied Science Group

Stephen Martin; Sandia National Laboratories; Applied Science Group

Brooks Martner; National Oceanic and Atmospheric Administration; Applied Science Group

John Marwitz; University of Wyoming; Applied Science Group

G.K. Mather; Cloudquest - Nelspruit, South Africa; Applied Science Group

Warren McEvoy; Federal Aviation Administration; Applied Science and Engineering Groups

John McGinley; National Oceanic and Atmospheric Administration; Applied Science Group

Peter Meischner; Institute fur Physik d'Atmosphare; Applied Science Group

P.W. Mielke, Jr.; Colorado State University; Applied Science Group

Joe Miller; Seagull Technology; Applied Science and Engineering Groups

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Stu Muench; Phillips Lab/GPAP; Applied Science Group

Everett Nickerson; National Oceanic and Atmospheric Administration; Applied Science Group

Don Norquist; Phillips Lab/GPAP; Applied Science Group

Anders Nystrom; Swedish Institute of Space Physics; Applied Science Group

Harold Ochs; Illinois State Water Survey; Applied Science Group

B.M. Pobanz; Lawrence Livermore Laboratory; Applied Science Group

Eugene Poolman; South African Weather Bureau; Applied Science Group

Hoi-To Poon; Hong King Royal Observatory; 28 August-8 September; Applied Science Group

Kim Yong Pyo; Korean Civil Aviation Bureau; Applied Science and Engineering Groups

Jim Ramer; National Oceanic and Atmospheric Administration; Applied Science Group

Peter Ray; Florida State University; Applied Science Group

Robert Rauber; University of Illinois; Applied Science Group

Al Rodi; University of Wyoming; Applied Science Group

Paul Ruscher; Florida State University; Applied Science Group

R.W. Russell; University of California, Irvine; Applied Science Group

Tom Schlatter; National Oceanic and Atmospheric Administration; Applied Science Group

Nelson Seaman; Pennsylvania State University; Applied Science Group

Mimi Shen; Seagull Technology; Applied Science and Engineering Groups

Danny Sims; Raytheon Service Company; Applied Science Group

Sung Ki Soo; Korean Civil Aviation Bureau; Applied Science and Engineering Groups

John Sorensen; Seagull Technology; Applied Science and Engineering Groups

Boba B. Stankov; National Oceanic and Atmospheric Administration; Applied Science Group

Anders Stjernman; Swedish Institute of Space Physics; Applied Science Group

Yoon Tae Suk; Korean Civil Aviation Bureau; Applied Science and Engineering Groups

Ki-Soo Sung; Korea Aviation Bureau; Applied Science and Engineering Groups

Mark Tepper; Hong Kong University of Science and Technology; Applied Science and Engineering Groups

Merhala Thurai; 14 August-18 August; Rutherford Appleton Laboratory, Chilton, U.K.; Applied Science Group

L. Tsang; University of Washington; Applied Science Group

Francis Kwan-Leung Tse; Hong Kong University of Science and Technology; Applied Science and Engineering Groups

Joseph Turk; Colorado State University; Applied Science Group

Koji Ukena; Matushita Communications Industrial Co., Ltd. - Yokoham, Japan; Applied Science and Engineering Groups

Kenneth Van Sickle; National Science Foundation; Applied Science and Engineering Groups

J. Verlinde; Pennsylvania State University; Applied Science Group

R.M. Wakimoto; University of California, Los Angeles; Applied Science Group

Chi Wenjiang; China Meteorological Administration - Beijing; Applied Science and Engineering Groups

Wesley Wilson; MIT Lincoln Laboratory; Applied Science Group

Marilyn Wolfson; MIT Lincoln Laboratory; Applied Science and Engineering Groups

Vince Wong; University of Oklahoma; Applied Science Group

Wang Xiaomin; China Meteorological Administration; Applied Science Group

Quan Xungang; China Meteorological Administration; Applied Science Group

Tae-Seok Yoon; Korea Civil Aviation Bureau; Applied Science and Engineering Groups

Choo Young; Korea Civil Aviation Bureau; Applied Science and Engineering Groups

Xu Yu Dun; Civil Aviation Administration of China; Applied Science and Engineering Groups

Kim Jong Yui; Korea Aviation Bureau; Applied Science and Engineering Groups

He Cheng Zi; Civil Aviation Administration of China; Applied Science and Engineering Groups

Jing-Meng Zou; China Meteorological Administration; Applied Science and Engineering Groups

Peter Zwack; Ecole Nationale de la Meteorologie; Applied Science Group

XIV. Publications

Refereed Publications

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Wesley, D.A., R. Rasmussen and B. Bernstein: Effects of the Longmont Anticyclone on mesoscale processes. *Preprints, 6th Conf. on Mesoscale Processes,* Portland, 18-22 July. Amer. Meteor. Soc., Boston, 515-518.

The **Scientific Computing Division (SCD)** provides supercomputing resources and services to support research in the atmospheric, oceanic, and related sciences. Much of the research in these disciplines requires large computer models and generates large amounts of data.

SCD's mission is to:

- *provide supercomputing resources needed for the development and execution of large, long-running numerical simulations and the archiving, manipulation, and analysis of large datasets;*
- *network and data communications capabilities required for an international user community to access NCAR computational and data resources; and*
- *a computing environment that emphasizes reliability, high performance, and user productivity.*

1994 Annual Scientific Report

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Important Contributions by Section

Efforts in Support of High Performance Computing

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Significant Accomplishments . . . .

NCAR and UCAR, with help from the National Science Foundation and the High Performance Computing and Communications (HPCC) program, established the Climate Simula tion Laboratory (CSL) at the NCAR Mesa Laboratory. The mission of the CSL is to provide sufficient supercomputer resources to the U.S. Global Change Research Program to help answer the fundamental questions of which natural processes are most important to understanding and predicting climate and how best to characterize those processes. During FY94 SCD installed six major computing systems in the CSL with an aggregate computational capability of about 2 gigaflops.

During the past year, SCD has been engaged in two major collaborations with industry. In the first , SCD has worked with Cray Computer Corporation (CCC) to demonstrate and enhance the operability of a CRAY 3 supercomputer. Second, as a part of the NSF/GEO HPCC program, near the end of FY93 SCD purchased and installed an entry-level scalable parallel processing system from IBM (an 8-processor SP-1). The associated collaboration helped IBM uncover and correct a number of hardware and software problems and gave SCD valuable experience with a new massively parallel (MPP) architecture.

Major reanalysis projects have begun in response to the need for better analyses of the winds and temperature of the global atmosphere. Reanalyses will allow us to say more about global weather interconnections and enable us to analyze global climate change and variability. Production started at the National Meteorological Center (NMC) and at the European Centre for Medium-range Weather Forecasts (ECMWF) in mid-1994. The goal of the NMC/NCAR reanalysis project is to make new analyses of the atmosphere for each 6 hours, for many years, starting at least in 1957, and perhaps in 1950.

SCD held its Tenth User Conference 3-5 August 1994, focusing on programming languages for parallel processing and information technology. In addition to 75 people attending the conference onsite, the conference was broadcast to two universities via multicast over the Internet. In conjunction with the conference, SCD offered a new, two-day Fortran 90 class on 1-2 August and a half-day Hypertext Markup Language (HTML) Class on 3 August. Both of these classes were extremely popular with the NCAR and university communities.

By the end of FY94, SCD had inc reased computing capacity available to the general user community by approximately 25%, primarily through the availability of the CRAY EL Cluster. Most of this additional capacity is a by-product of the CSL. This additional computing capacity makes it feasible to increase the amount of time on on the CRAY Y-MP8/864 (shavano) that is dedicated to long-running, multitasked simulations.

The NCAR/UCAR Network Coordina tion and Advisory Board (NCAB) was formed in the Spring of 1993. The NCAB reports to the Director of SCD and is chartered to assist SCD with network planning and management. The scope of the committee encompasses the performance and function of the network cabling plant and all associated network hardware. In particular, the NCAB assists SCD in:

1. setting priorities;
2. defining standard services, contract services, and special services;
3. developing operational policies and procedures to encourage compliance;

4. contributing to and reviewing long-term plans; and,
5. formulating recommendations to the NCAR/UCAR management as to how network costs should be apportioned.

The NCAB has become a valuable part of the process to plan, install, and support state-of-the-art networking at UCAR/NCAR.

Recognizing the potential of multimedia technology for a variety of information exchange activities, SCD established the first NCAR World Wide Web (WWW) server in August 1993. (Other divisions have since established their own division-specific servers, and SCD is assisting UCAR in creating a Web site for UCAR related activities.)

SCD staff and members of NCAR's Research Applications Program (RAP) participated in a cooperative project to demonstrate state-of-the-art visualization. The project involved conversion of RAP's 3-D terminal viewer (3DTV) software to equipment used in a three-dimensional exhibit termed the **C**a ve **A**utomatic **V**irtual **E**nvironment (CAVE) at SIGGRAPH 94. This project was a foray into "cutting edge" virtual reality, and it provided a unique opportunity to push visualization software and hardware to their fullest. It was also the most popular CAVE exhibit at SIGGRAPH 94. A video animation sequence gives you a feel for the CAVE exhibit.

US West approved funding for a high-speed networking trial in the Boulder, Colorado, metropolitan area called (Boulder ATM Area Network). This trial is intended to prove a new distributed "access node" architecture employing an Asynchronous Transfer Mode (ATM) switching fabric running over OC3c fiber optic links at 155 Mbps. This architecture is designed to support voice, data, video, and multimedia communications with a wide range of bandwidths.

SCD is involved in the installation and administration of the CO-OP 3D project, a distribu ted computing research project funded by the Advanced Research Projects Agency (ARPA). This project uses the Advanced Communications Technology Satellite (ACTS) to set up high-speed data communication links between NCAR, the Ohio Supercomputer Center (OSC), and the Great Lakes Environmental Research Lab (GLERL). An atmospheric forecast model and a Lake Erie forecast model will be coupled and distributed between NCAR and OSC using the ACTS data links. The project includes simultaneous, concurrent, real-time control of the model and visualization of the results at the sites.

SCD began a major voice and data communications facilities upgrade between the Foothills Lab (FL), UCAR North (UN), and UNAVCO (UV) buildings. The project includes trenching from FL to UN and UV on private right-of-ways, installing private conduit and wiring including fiber optics and unshielded twisted pair (UTP), providing remote voice trunks over UTP between UN and UV, private T1 services over fiber, ethernet over fiber (10 million bits per second, Mbps), and fiber distributed data interface (FDDI) over fiber (100 Mbps). This project will greatly enhance the communications capabilities at UN and UV. The full T1 available to voice will double the available bandwidth. The fiber provides a growth path to faster wide area network (WAN) and local area network (LAN) technologies such as ATM (>155 Mbps) as they are required.

SCD began using a new technique called "multicasting," which is proving useful for distan ce learning, local group and individual interaction, and video conferences. Multicasting provides live audio, video, and white board tools via the Internet Engineering Task Force (IETF) Internet Multicast Backbone (the Mbone). SCD used multicasting in classes and conferences.

Staff, Visitors, and Collaborators

Staff

Administration

Bill Buzbee (director)
Pete Peterson (deputy director)
Bernie O'Lear (associate director)
Julia Chapin
Jonna Colacci
Sylvia Darmour
Karen Friedman
Jana Jones
Janice Kline
JoAn Knudson
Rosemary Mitchell

Computational Support

Richard Sato (manager)
Jeanne Adams
John Adams
Dan Anderson
Olivia Bortfeld (1/2)
Joe Choy
John Dennis
Steve Hammond
Rich Loft
Paul Swarztrauber

Computer Operations and Facilities

Gary Jensen (manager)
Robert Niffenegger (manager)
Donna Barday-Rowland
Gregory Berman
Melissa Breedlove
Glenn Brown
Nancy Brown
Gaynez (Bo) Connell
Marlene Furmanek
Julie Harris

Roxanne Hays
Ed Heitschel
Sue Jensen
Dick Lindenmoyer
Stan McLaughlin
Sue McLaughlin
Andy Robertson
Jim Robinson
Susan Schemel
Larry Scott
Steve Tannen
Wes Wildcat

Data Support

Roy Jenne (manager)
Dennis Joseph
Roy Barnes
Olivia Bortfeld (1/2)
Joey Comeaux
Bob Dattore
Chi-Fan Shih
Wilbur Spangler
Ilana Stern
Gregg Walters
Steve Worley

Distributed Services and Scientific Visualization

Phylecia Brandley (manager)
Ethan Alpert
Ed Arnold
Brian Bevirt
Jeff Boote
Dave Brown
Fred Clare
John Clyne
Linda Fraser
Mary Haley
Dave Kennison
Bob Lackman
Jacque Marshall
Greg McArthur
Don Middleton-Link
Herb Poppe
Craig Ruff
Tim Scheitlin
Mark Uris
Greg Woods

High Performance Systems

John Sloan (manager)
Barb Bateman

Mary Ann Ciuffini
Dennis Colarelli
Kathy Fryberger
George Fuentes
Gene Harano
John Merrill
Gene Schumacher
Erich Thanhardt

High Performance Networks

Bernie O'Lear (manager)
Charles Albrecht
Steve Chapel
Rachelle Daily
Rich Gallup
Del Harris
Scott Hays
Belinda Housewright
Paul Hyder
Basil Irwin
Marla Meehl
Don Morris
Long Moua
Dan Norman
Jim VanDyke

User Services

Ginger Caldwell (manager)
Aaron Andersen
Mary Buck
Lee Carter
Susan Cross
Nancy Dawson
Christine Guzy
Sally Haerer
Ken Hansen
Jeff Kuehn
Lynda Lester
Peter Morreale
Tom Parker
Jim Petruzzelli
Juli Rew
Susan Smith
Dick Valent
Janie Young

Visitors and Collaborators

Dates refer to the visitor's stay at NCAR during FY 94. No dates are given for collaborators who did not visit NCAR.

Robert Bell; CSIRO Supercomputing Facility, Carlton, Australia; September 1994; supercomputer operations, Operations and Facilities Section

Michael Boettinger; German Climate Research Center, Hamburg, Germany; August 1994; NCAR Graphics, Distributed Services and Scientific Visualization Section

Reinhard Budich; Max-Planck-Institute for Meteorology, Hamburg, Germany; August 1994; NCAR Graphics, Distributed Services and Scientific Visualization Section

Garrett Campbell; Colorado State University; satellite data project, Data Support Section

John Drake; Oak Ridge National Laboratory; CHAMMP project, Computatonal Support Section

Joe Elms; NOAA-NCDC; COADS project, Data Support Section

Ian Foster; Argonne National Laboratory; CHAMMP project, Computational Support Section

Rex Gibson; ECMWF, Reading, United Kingdom; Data Support Section

Phil Jones; Los Alamos National Laboratory; February 1994; CHAMMP project, Computational Support Section

David Kahanner; US Office of Naval Research Asia and National Institute of Standards and Technology; May 1994; Computational Support Section

Eugenia Kalnay; NOAA- NMC; reanalysis project, Data Support Section

Ernest Kung; University of Missouri; data for reanalysis, Data Support Section

Bob Malone; Los Alamos National Laboratory; February 1994; CHAMMP project, Computational Support Section

Cliff Mass; University of Washington; update Northern Hemisphere analyses on CD-ROM, Data Support Section

John Michalakas; Argonne National Laboratory; CHAMMP project, Computational Support Section

Ravi Nanjundi; Argonne National Laboratory; CHAMMP project, Computational Support Section

Bram Oort; GFDL; global upper air data and data for reanalysis

Cheri Pancake; Oregon State University; March 1994; parallel computing

Bill Rossow; GISS, Goddard Institute; August 1994; Data Support Section

David Semeraro; Oak Ridge National Laboratory; CHAMMP project, Computational Support Section

Scott Woodruff; NOAA, Environmental Research Laboratory; COADS ship data project, Data Support Section

Pat Worley; Oak Ridge National Laboratory; CHAMMP project 1992; High Performance Systems and http://www.ncar.ucar.edu/archives/asr/ASR94/SCD/scdpubs.html Go

Publications

Refereed Publications

Adams, J., 1993: MUDPACK-2: Multigrid Software for Elliptic Partial Differential Equations on Uniform Grids with any Resolution, *Applied Mathematics and Computation* 53, 235-249.

Bailey, D. H., and P. N. Swarztrauber, 1994: A fast method for the numerical evaluation of continuous Fourier and Laplace transforms, *SIAM Journal on Scientific Computing* 15, 1105.

Buzbee, B., 1993: Workstation Clusters Rise and Shine, *Science* 261, 235-249.

Elms, J.D., S.D. Woodruff, S.J. Worley, and C.S. Hanson, 1993: Digitizing Historical Records for the Comprehensive Ocean-Atmosphere Data Set COADS, *Earth Systems Monitor* 4, No. 2, 4-10.

Sloan, J.L., O'Lear, B.T., Kitts, D.L., and Irwin, B.L., 1993: MaSSIVE(tm): The Mass Storage System IV Enterprise. *Proceedings IEEE* 81, No. 4, 621-630.

Swarztrauber, P. N., 1993: The vector harmonic transform method for solving partial differential equations in spherical geometry, *Monthly Weather Review* 121 3415-3437.

Woodruff, S.D., S. J. Lubker, K. Wolter, S.J. Worley, and J.D. Elms, 1993: Comprehensive Ocean-Atmosphere Data Set (COADS) Release 1a: 1980-1992, *Earth Systems Monitor* No. 1, 1, 4-8.

Other Publications

Brady, C., Colarelli, D., Newman, H., and Schumacher, G., 1994: New Strategies for File Allocation on Multi-Device File Systems. In *Proceedings of the 33rd Cray User Group Meeting*, San Diego, Calif., 446-452.

Ciuffini, M. A., 1994: Planning and Conducting a UNICOS Operating System Upgrade. In *Proceedings of the 33rd Cray User Group Meeting*, San Diego, Calif, 224-230.

Guzy, C., 1994: Electronic Publishing, from High-Quality Publications to Online Documentation. In *Proceedings of the 33rd Cray User Group Meeting*, San Diego, Calif., 380-382.

Kuehn, J., 1994: Applications of Multimedia Technology For User Technical Support. In *Proceedings of the 33rd Cray User Group Meeting*, San Diego, Calif., 360-364.

Loft, R.L., and Sato, R.K., 1993: Implementation of the NCAR CCM2 on the Connection Machine. In *Proceedings of the Fifth ECMWF Workshop on the Use of Parallel Processors in Meteorology*, Reading, England, European Center for Medium Range Weather Forecasting, 371-388.

Morreale, P., 1994: Tools For Accessing Cray Datasets On Non-Cray Platforms. In *Proceedings of the 33rd Cray User Group Meeting*, San Diego, Calif., 300-303.

Parker, T., 1994: Confessions of a Consultant (A compendium of miscellaneous tools/scripts/hints/tips/techniques). In *Proceedings of the 33rd Cray User Group Meeting*, San Diego, Calif., 499-502.

Rew, J., 1994: Online Documentation: New Issues Require New Processes. In *Proceedings of the 33rd Cray User Group Meeting*, San Diego, Calif., 372-375.

Shea, D.J., S.J. Worley, I.R. Stern, and T.J. Hoar, 1994: *An Introduction to Atmospheric and Oceanographic Data*. Technical Note NCAR/TN-404+1A, NCAR, Boulder, Colo.

Sloan, J. L., 1994: Flying with Instruments: Characterizing the NCAR MSS-III Workload. In *Proceedings of the 13th Mass Storage Systems Symposium*, Annecy, France, IEEE.

Sloan, J. L., 1994: Workload Metrics for the NCAR Mass Storage System. In *Proceedings of the 33rd Cray User Group Meeting*, San Diego, Calif., 387-391.

Educational Activities

NCAR's educational activities include programs for groups from kindergarten through postdoctoral levels. Scientific visitor programs, graduate research assistantships, postdoctoral appointments, colloquia, seminars and workshops support university programs to educate the next generations of scientists, engineers, and scholars in general. The Advanced Study Program (ASP) and the Summer Employment Program (SEP) provide students and graduates the opportunity to explore their educational and scientific interests in the laboratory setting.

NCAR also places a high priority on K-12 educational outreach, as well as on other educational programs that increase public awareness and understanding of atmospheric science issues. Because climate, pollution, and the environment are part of the everyday awareness of young people, the atmospheric sciences offer an unusual opportunity to teach science in attractive, relevant ways. NCAR's Exhibits and Education and Tour programs and Project LEARN (Laboratory Experience in Atmospheric Research at NCAR) help teachers exploit this opportunity as well as reach out to students and the general public. In addition, individual staff throughout NCAR serve as graduate advisors or adjunct faculty at universities, make presentations to classes and public groups, write textbooks or textbook chapters, judge science fairs, or tutor elementary through secondary school students in math and science.

Significant Accomplishments

- In FY 94 the Advanced Studies Program (ASP) hosted eight NCAR Graduate Fellows (NGFs) and 36 Postdoctoral Fellows. Two new NGFs began appointments, two continued, and four completed their terms. However, in response to budget pressures, no new NGF appointments were made during the last half of the fiscal year and no new appointments are contemplated for the coming year. Fifteen new postdocs began their appointments; 12 continued, and 15 completed their terms.
- The 1994 UCAR Summer Employment Program (SEP) for minority and women undergraduates enrolled 11 students. Eight of the students worked in NCAR with at least one student placed in each division. The other three students were placed in UCAR programs.
- NCAR hosted its third and final teacher enhancement institute under Project LEARN (Laboratory Experience in Atmospheric Research at NCAR). During the life of the project more than 65 NCAR or UCAR scientists and staff worked with 40 teachers from California, Colorado, North Carolina, and Texas to increase teacher understanding of atmospheric and related sciences. These teachers have in turn trained more than 800 teachers who have reached 75,000 students since 1992. During the 1994 summer institute, 25 scientists created lab day experiences for teachers to provide them opportunities for direct experience of scientific investigation.
- A proposal for "Project LEARN II: Atmospheric Science Explorers" was submitted to the NSF Teacher Enhancement Program. This three and one half year project would provide training to teachers in rural districts in Colorado.
- "Thunderstorm Detectives", a traveling exhibit that highlights NCAR's microburst research and technology transfer began a two-year national tour of science museums and airports in 16 U.S. cities. This represents NCAR/UCAR's first major science exhibition, which six million people are expected to see.
- After being selected to participate in the Science Exhibits Starter Sets Program sponsored by the Exploratorium; in San Francisco and NSF, NCAR raised matching funds from local foundations and corporations to bring seven interactive, hands-on exhibits to the Mesa Laboratory.

Selected Educational Activities in Fiscal Year 1994

Activity	Number	Number of Institutions Involved
Postdoctoral fellows	88	54
NCAR graduate fellows	8	7
Graduate research assistants	76	35
Undergraduate research assistants	96	14
Cooperative theses completed	6	5
Summer Program for minority undergraduates	8	7
NCAR teaching appointments at universities	34	9
NCAR advisors on graduate research	97	35
Workshops sponsored by NCAR	53	
Seminars and lectures sponsored by NCAR		
Scientific	618	
Nontechnical	155	
TOTAL	773	
K-12 teacher visitors for inservice training	148	
Members of the public touring NCAR*	2,383	
Students (all ages) touring NCAR*	3,799	

These are numbers of people who took guided tours. Visitors who took self-guided tours were not counted.

Advanced Study Program

The Advanced Study Program (ASP) was created early in the history of NCAR to provide a mechanism for looking to the future of the atmospheric sciences. This function is exercised today in two ways. ASP arranges for a number of scientists near the beginning of their careers to work for a time at NCAR, both to gain familiarity with work on major atmospheric science problems and to learn how to make best use of NCAR's capabilities. The program also provides for the examination of research areas that are particularly timely or that, despite having long-term importance, are relatively under emphasized at NCAR or in the community. The first of these activities--bringing new scientists to NCAR--is organized within the Visitor Program. The second--supporting selected areas of research--consists of convening workshops on forward-looking issues, selecting visitors from a wide spectrum of interests to work with NCAR staff, and supporting more-experienced visitors in areas of possible future importance to the atmospheric sciences.

ASP has several roles in the educational process for individuals in the atmospheric sciences broadly defined. The core programs are the postdoctoral appointments for young scientists within four years after the completion of a Ph.D. or equivalent; NCAR Graduate Fellowships which allow young scientists to complete a doctoral thesis while in residence at NCAR; and the summer colloquium, designed to focus attention on a current topic research of special interest. Opportunities to serve as fellows are advertised broadly and appointments are made competitively. While at NCAR, fellows generally choose to work directly with colleagues in one of the science or facility divisions. The detailed reports of the fellows' work will be found in the individual divisional reports.

ASP also serves as host for a few senior visitors. During FY-94 Professor Laney Mills from the University of Charleston spent a sabbatical leave with ASP developing material for introducing research and teaching in the atmospheric sciences into the physics program at his university. Professor Ed Lorenz made a shorter visit during the summer in order to work with a number of scientists on the NCAR staff. During the year ASP was also asked to host the NCAR interdivisional program on geophysical turbulence. This program, which traces its history back to the earliest days of NCAR, involves scientists from several divisions, visitors from other institutions, and workshops. Its administration had been passed yearly among the various divisions involved, but it was decided that having ASP, with its experience in care of visitors and arranging workshops, as permanent host would improve the effectiveness of the program.

Summer Colloquium

ASP and the High Altitude Observatory (HAO), with partial support from NASA, hosted a summer colloquium on "Current Trends in Solar and Astrophysical Magnetohydrodynamics" in August 1994. Thomas Bogdan (HAO) coordinated the sessions, which featured 30 lecturers from 24 institutions. The 98 participants represented 56 institutions from 13 foreign countries and the United States.

The colloquium addressed five topics: coronal magnetic fields and magnetic non-equilibrium, photospheric magnetic fields and magnetic intermittency, interaction of flows with magnetic fields and dynamo action, magnetic fields and transport of angular momentum in stars, and magnetic fields, solar variability, and climate change.

Global Change Instruction Program

Through the Global Change Instruction Program (GCIP) of ASP, NCAR staff have collaborated with a number of universities to produce a series of curriculum modules for undergraduate students. Titled Understanding Global Change: Earth Science and Human Impacts, the series includes both introductions to scientific principles and substantive discussions of specific global change issues. During FY 94, two modules were completed and distributed: *Biological Consequences of Global Climate Change,* by Christine Ennis (National Oceanic and Atmospheric Administration) and Nancy Marcus (Florida State University); and *Climatic Variation in Earth History,* by Eric Barron (Pennsylvania State University). Over 2000 copies of various titles in the series were distributed during the year. The series of eight modules will be issued by a commercial publisher in the near future; a contract is being finalized as of this writing.

The NSF Division of Education and Human Resources has funded the creation of six more modules and supplemental materials over the next two years. Scientific director for this second phase of the GCIP will be Tom Wigley (CGD and Walter Orr Roberts Institute).

Summer Employment Program

SEP's primary goal is to encourage minorities to consider careers in atmospheric and related sciences. Specifically, its goal is to introduce students to the research at NCAR and to encourage participants to return to NCAR later in their academic and professional careers. This goal takes into consideration that the composition of the nation's workforce is rapidly changing, and if accomplished, would further diversify NCAR's workforce.

SEP students met with Dr. Neal Lane, National Science Foundation Director when he visited NCAR during the summer. As a result of the meeting, Kandis Boyd (Iowa State University) was invited to participate in the NSF Diversity Conference in Washington, DC in September. The students also met with faculty, staff, and graduate students in the Atmospheric Sciences Department at Colorado State University. Both experiences served to enlighten the students about graduate school opportunities and the importance of integrating scientific research and education.

Information Support Services

ISS is responsible for NCAR's K-12 education and public outreach activities. These activities and programs are carried out through the Information and Education Outreach Program, the Media Relations Office and Project LEARN.

Information and Education Outreach Program

Education and Tour Program. Since 1986, the Education and Tour Program has coordinated a program providing information and interaction between NCAR staff and the visiting public. Annually, about 4,000 students and their teachers come to NCAR to attend presentations on the Center and its research activities. Some of the presentations are inservices specifically for teachers to give them background about NCAR. Following renovation of the Mesa Lab, for the first time the program now has a classroom, outfitted with seating for 30, running water for demonstrations, computer with expanded monitor, and individual student supplies ranging from rulers to magnifying glasses. The classroom is also equipped with displays, including a 6 1/2-ft-long section of a NASA Aerobee rocket flown by NCAR scientists 26 years ago and a weather instrument shelter which will be installed outside the classroom on the mesa. Teacher workshops and student presentations can now include a wide variety of hands-on demonstrations.

Adjacent to the classroom is the Educational Resource Center which houses a collection of NCAR-related and science education resources. Teachers, parents interested in their children's education, and visitors seeking technical information have access to the center's wide variety of resource materials including audiovisuals; science books and journals; and information about other organizations' resources. The center provides access to Internet resources on Gopher and Mosaic, including Blue Skies and the Weather Underground and CD-ROM educational resources.

Networking with organizations similar to NCAR has always been another primary activity of the program, both to communicate NCAR's presence in the expanding national arena of K-12 science education and to acquire information about other organizations to share at NCAR and beyond. This year, NCAR's presence at three meetings was especially useful in accomplishing this aim: NCAR staff networked with Department of Energy (DOE) labs and facilities at DOE's annual Science Educators' meeting; collaborated with professional society and government science organizations to help form a new national Coalition of Earth Science Education; and, along with teachers from the 50 states and other federally related organizations, participated in the first U.S. Global Change Education conference. Throughout the year, several labs and agencies sent staff or their own teacher groups to visit NCAR. One of the more mutually useful visits was from Sandia National Laboratories, Livermore, CA, which sent two of its education staff on a two-day site visit to see NCAR's education facilities and meet with local area connections.

Exhibits Program. The "Thunderstorm Detectives" exhibit debuted at the American Museum of Science and Energy in Oak Ridge, TN in November 1993. Since then, its two copies have traveled to the Carnegie Science Center (Pittsburgh, PA), Science Spectrum (Lubbock, TX) where educators worked with the National Weather Bureau to host a week-long series of workshops, Douglas International Airport (Charlotte, NC), and the Fort Worth Museum (Ft. Worth, TX). Future sites through 1995 include: Ann Arbor Hands-On Museum (Ann Arbor, MI), Catawba Science Center (Hickory, NC), Evansville Museum of Arts and Sciences (Evansville, IN), Lied Discovery Museum (Las Vegas, NV), Museum of Science and Industry (Chicago, IL), Rochester Museum (Rochester, NY), Kansas City International Airport (Kansas City, MO), Nashville International Airport (Nashville, TN), and the Louisville International Airport (Louisville, KY). The Association of Science and Technology Centers (ASTC) which handles logistical arrangements for the traveling exhibit reports that it has been very well-received by museum staff and visitors alike. More than 12,000 posters printed for the exhibit (with hands-on activities for middle school students) have been distributed to host sites, television stations, and teachers through the National Science Teachers Association.

After being selected last year to participate in the Science Exhibits Starter Sets Program sponsored by the Exploratorium in San Francisco and NSF, NCAR raised matching funds from three major Colorado philanthropic organizations: the Boettcher Foundation, the Gates Foundation, and the Adolph Coors Foundation. Also contributing from the Boulder community were Syntex Chemicals, Bank One Boulder, Synergen, Valleylab, and Public Service Company of Colorado. The exhibit collection includes:

- Tornado, a ten-foot tall vortex created with ultrasonic mist that visitors can interact with and touch
- Chaotic Pendulum, a device that demonstrates principles of chaos when spun by visitors who try to predict its behavior
- Turbulent Orb, a 30-inch diameter glass sphere that when spun or stopped, displays effects of global circulation patterns
- Fog Chamber, an instrument allowing visitors to explore the dynamics of changes in air pressure and dew point, sometimes creating fog in the process
- Blue Sky, an experiment that shows why the sky is blue during the day and why sunrises and sunsets are different colors in the red spectrum of light
- Quiet Lightning, a seven-foot tall plasma tube that can create electrical discharges resembling lightning
- Light Island, an experimental bench with lenses, prisms, diffraction devices, filters, and mirrors that enables visitors to explore properties of visible light, the solar spectrum and other phenomena.

The new exhibits are greatly enhancing NCAR's capability as a regional educational resource and its infrastructure for developing national programs in informal science education. Since their installation, visits from students and teachers as well as the general public have increased dramatically; this increased demand is expected to continue in future. A brief history of UCAR and NCAR exhibit was also developed and opened to the public in mid-September.

Audiovisual Services A major project during 1994 was the development of a digital media catalog of NCAR photos, films and videos. This collection includes images on climate change and pollution; clouds; computers and computer modeling; research instruments and equipment; the NCAR--building, people and the site; satellite images; solar images; weather and phenomena. The entire slide loan collection was transferred onto photo CDs to expand the usefulness of the images both in electronic publishing and for scientific and educational presentation. To improve access to and utility of NCAR's footage on weather phenomena, 45 minutes of weather films were transferred onto one master video tape. This new video and the numerous other resources in the collection are available to educators, researchers, librarians, science teachers, publishers, film and video producers, and the print media both in this country and abroad at reasonable cost. During 1994 countless books, photo CDs, magazines, video, and broadcast products were produced using images from NCAR's collection. The audience reached numbers in the millions through print and electronic media such as *Newsweek*, *Encyclopedia Britannica*, *New York Times*, *Discover*, *National Geographic*, *Weatherwise*, and ABC, NBC, CBS, CNN and their affiliates.

LASERS. The Learning about Science Easily and Readily Series (LASERS), begun in 1990, is a program to inform nonscientists within UCAR and throughout the local community on topics in atmospheric science. Several one-hour talks are presented each year, typically by NCAR scientists. Four- to eight-page handouts serve as background material for each talk and as stand-alone updates on the topic at hand. Each handout is written and designed by the Outreach Program in close collaboration with the presenting scientist.

Three LASERS talks were developed for November/December 1993. Each of these talks was presented twice, once at each of the major NCAR laboratories (Mesa and Foothills).

--Learning about Global Warming from the Media (Kris Wilson, University of Colorado Department of Geography) examined how college students and journalists find out about global warming and the greenhouse effect and where they obtain that knowledge.

--Constant as the Sun? A Look at Solar Variability (Peter Fox, NCAR High Altitude Observatory) explored how computer models and earth- and satellite-based instruments reveal much about how the sun varies across time, both in its well-known 22-year magnetic cycle and in other ways.

--Children of the Tropics: El Niño and La Niña (Kevin Trenberth, NCAR Climate and Global Dynamics Division) explained the mechanics of this cyclic warming and cooling of the tropical Pacific and outlined the impact on North American climate.

All 16 LASERS handouts produced to date by the Outreach Program continue to be available free of charge to members of the public who call or visit NCAR requesting information on a topic covered by LASERS.

Media Relations

The overall goal of Media Relations at UCAR is to educate and inform a variety of audiences including members of Congress, NSF, and the lay public, about NCAR research and other UCAR activities. The principal conduits for this message are newspapers and magazine articles and radio and television programs, all based on interviews with scientific specialists arranged by the Media Relations Office. During the past year, Media Relations has become more directly involved in educational activities by arranging interviews for a variety of media whose goal is to motivate students of all ages who may choose science as a career.

Twice during 1994, UCAR Media Relations worked with a nationally syndicated live action children's program, "News for Kids," which has won the endorsement of the National Education Association. The half-hour magazine-style program is designed to inform, educate and entertain young people with current events, science projects and kids talking to kids about issues that are important to them. The program includes segments on current events and issues, educational at-home science projects and a toll-free phone number that kids can use to interact with the program.

The program, which airs on more than 126 television stations across the country is headquartered at the Denver bureau of NBC and features two local 12-year-old reporters. They visited NCAR's Aviation Weather Development Laboratory and interviewed Kim Elmore about wind shear hazards at airports. Elmore demonstrated the virtual reality software programs developed by NCAR's Research Applications Program. The young reporters made another visit to

NCAR's Mesa Laboratory to film the new Exploratorium exhibits.

Media Relations also worked with Pioneer Productions from London, England, which is producing a series of half-hour programs termed the Wonders of Weather, which will air on the Learning Channel in 1995. Senior scientist Charles Knight of MMM was filmed in his laboratory cold room to demonstrate how snowflakes and raindrops form.

Project LEARN

Project LEARN (Laboratory Experience in Atmospheric Research at NCAR) is an experiential program for middle- and junior-high school science teachers. The program brought teams of teachers from eight school districts in California, Colorado, North Carolina, and Texas to the Project LEARN summer institute at NCAR for three consecutive years beginning in FY 92 for in-depth training and support. The teachers then returned to their school districts to serve as science resource people who can develop curriculum appropriate to their own sites and who can train other teachers through district inservices. 1994 was the third year of the program, which is directed by Carol McLaren, Joyce Gellhorn, and CGD scientist, Pat Kennedy.

In addition to presenting scientific concepts and research findings to teachers during the 1994 summer institute, 25 NCAR scientists created lab experiences for the teachers. Some teachers flew on the Lockheed Electra gathering atmospheric data, and others launched weather balloons, cut up hailstones, made computer visualizations, crunched climate data on the Cray computer, and visited the CHILL RADAR site. Teachers also attended pedagogic and leadership training sessions led by educational experts and received hands-on training in the use of Internet as a communication and resource tool for the classroom. They worked in teams to plan inservice training in their districts and shared strategies for adapting curriculum to incorporate atmospheric sciences.

Teachers worked in teams to edit five atmospheric science curriculum modules that can be incorporated into existing life science, general science and physical science curriculum at the middle school level. Each module, drafted during the 1993 institute, focuses on one theme and an area of NCAR research: Greenhouse Gases, Ozone, Biosphere-Atmosphere Interactions, Atmospheric Dynamics, and the Water Cycle. Teachers tested the modules in the classroom and shared them with colleagues at inservices. The modules are currently being edited and are expected to be in final form by spring 1995. Teachers earned 2 units of graduate credit from the University of Colorado for participation in the institute.

During the academic year teachers worked to disseminate what they gained from Project LEARN. Each district team of teachers presented one or more inservices to their colleagues, with attendance ranging from 6 to more than 100 teachers at each inservice. With the average middle level teacher reaching more than 120 students each day, the program can significantly impact science curriculum in those districts. To date, the project has reached nearly 800 teachers and 75,000 students. Some teachers also made presentations at the National Science Teachers Association convention in Denver, taught a course for pre-service teachers at the University of Houston, Clear Lake, and worked with representatives of the National Weather Service and local television weather casters. The Texas teams also presented at their state middle school science conference. According to project evaluator Ron Anderson (University of Colorado), "Project LEARN has been successful in helping teachers change their science curricula and use new teaching approaches. More atmospheric science content is being incorporated into the curricula, new laboratory activities are in use, laboratory work is more frequent, and there is a new sense of excitement about science on the part of both teachers and students."

Staff, Visitors, and Collaborators

Staff

Advanced Study Program Staff

John Firor (director)

Barbara McDonald

Judith Miller (80%)

Information Support Services Staff

Karon Kelly (manager)

Information and Education Outreach Program

Anatta (75%)

Marie Boyko (manager, until 21 January)

Millicent Butterworth

Louise Carroll

Steven Davis (75%)

Robert Henson (75%)

Irene Munoz

Juanita Razo

Lucy Warner (87.5%)

Media Relations

Anatta (25%)

Joan Frisch (manager)

Project LEARN

Joyce Gellhorn (principal investigator, 65%)

Patrick Kennedy (principal investigator, 20%)

Carol McLaren (principal investigator, 65%)

Caroline Hanson

Summer Employment Program Staff

Edna Comedy (associate vice-president, Human Resources)

Anna Reyna-Arcos

Visitors

ASP Graduate Fellows

Lynne Bennett; University of Colorado; potential for interstate water transfers under climatic uncertainty; Kathleen

Miller, ESIG

Yung-ping Chou; Columbia University; magnetohydrodynamic equilibrium of the solar atmosphere; Boon Chye Low, HAO

Katja Drdla; University of California, Los Angeles; Comparison of model predictions and measurements of solar stratospheric clouds; James Dye, MMM

Cindy Nevison; Stanford University; modeling of trace gas fluxes--N2O; William Holland, ACD

Irina Petropavlovskykh; Central Aerological Observatory, Russia; atmospheric photochemical effects of solar radiation; Sasha Madronich, ACD

Jordan Powers; University of Washington; mesoscale gravity waves; Ying-Hwa Kuo, MMM

Anji Seth; University of Michigan; land-surface heterogeneities in atmosphere-biosphere interactions; Filippo Giorgi, CGD

Tammy Weckwerth; University of California, Los Angeles; convection initiation associated with horizontal convective rolls; James Wilson, RAP

ASP Postdoctoral Fellows

Steve Arendt; University of Chicago; study of vorticity and stratified fluids

Brad Baker; University of Washington; cloud microphysics and turbulence

Jian-Wen Bao; Pennsylvania State University; four-dimensional data assimilation using the adjoint method

Axel Brandenburg; Nordic Institute for Theoretical Physics, Copenhagen, Denmark; explaining the solar dynamo and differential rotation

Antonietta Capotondi; Massachusetts Institute of Technology; assimilation of altimeter data into ocean circulation models

Manfred Cuntz; University of Heidelberg, Federal Republic of Germany; stellar atmospheres

Kenneth Davis; University of Colorado at Boulder; trace gas fluxes and transport in the boundary layer

Oliver Espagnet; Pic du Midi Observatory, France; interactions between granulation and solar oscillations

Frederic Fabry; McGill University, Canada; radar meteorology and lidar research

Carl Hagelberg; Oregon State University; modeling and analysis of microfronts with the intention of data assimilation

Christopher Holloway; University of Colorado; wave propagation, scattering from rough surfaces, and antenna analysis and design

Theresa Huang; University of Michigan; numerical modeling of the middle atmosphere; dynamic, radiative, and chemical interactions and feedback

Gregory Jenkins; University of Michigan; investigation of the Archean climate

Brian Johnson; University of Michigan; remote sensing, radiative transfer and Fourier transform spectroscopic studies of stratospheric trace gases and aerosols in ozone chemistry

David Kingsmill; University of California, Los Angeles; the convection initiation problem

Rodney Kinney; University of Texas at Austin; magnetohydrodynamical turbulence and solar atmosphere

Joanie Kleypas; James Cook University of North Queensland, Townsville, Australia; response of coral reef ecosystems to global climate change

Jean-Francois Lamarque; Catholic University of Louvain, Belgium; coupling the MM4 model with a chemistry package describing ozone chemistry

Kathleen Lantz; University of Colorado at Boulder; development of a trajectory-chemistry model

Luning Li; Indiana University, statistical analysis, turbulence and global circulation

Melanie Mason; University of Colorado at Boulder; study of aluminum industry contributions to greenhouse gases and global climate change

Kenneth Minschwaner; Harvard University; radiative processes: influence on climate and stratospheric photochemistry

Suzanne Paulson; California Institute of Technology; field measurements, laboratory atmospheric chemistry, and atmospheric modeling

Jordan Powers; University of Washington; mesoscale gravity waves

Mark Rast; University of Colorado at Boulder; compressible turbulence in an ionizing fluid

Sergei Rodionov; State Oceanographic Institution, Moscow, Russia; changes in levels of large lakes

Fabrizio Sassi; University of Bologna, Italy; transport and chemistry in the middle atmosphere

David Smith; University of Chicago; climatic consequences of river basin development

Mark Smith; University of Arizona; optical techniques applied to atmospheric chemistry and global change

Steven Smith; University of California, Los Angeles; plasma physics

Robert Tomas; University of Colorado at Boulder; large-scale atmospheric disturbances with time scales from a week to a month

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Advanced Studies Program (ASP)

The Advanced Study Program (ASP) was created early in the history of NCAR to provide a mechanism for looking to the future of the atmospheric sciences. This function is exercised today in two ways. ASP arranges for a number of scientists near the beginning of their careers to work for a time at NCAR, both to gain familiarity with work on major atmospheric science problems and to learn how to make best use of NCAR's capabilities. The program also provides for the examination of research areas that are particularly timely or that, despite having long-term importance, are relatively under emphasized at NCAR or in the community. The first of these activities--bringing new scientists to NCAR--is organized within the Visitor Program. The second--supporting selected areas of research--consists of convening workshops on forward-looking issues, selecting visitors from a wide spectrum of interests to work with NCAR staff, and supporting more-experienced visitors in areas of possible future importance to the atmospheric sciences.

ASP has several roles in the educational process for individuals in the atmospheric sciences broadly defined. The core programs are the postdoctoral appointments for young scientists within four years after the completion of a Ph.D. or equivalent; NCAR Graduate Fellowships which allow young scientists to complete a doctoral thesis while in residence at NCAR; and the summer colloquium, designed to focus attention on a current topic research of special interest. Opportunities to serve as fellows are advertised broadly and appointments are made competitively. While at NCAR, fellows generally choose to work directly with colleagues in one of the science or facility divisions. The detailed reports of the fellows' work will be found in the individual divisional reports.

ASP also serves as host for a few senior visitors. During FY-94 Professor Laney Mills from the University of Charleston spent a sabbatical leave with ASP developing material for introducing research and teaching in the atmospheric sciences into the physics program at his university. Professor Ed Lorenz made a shorter visit during the summer in order to work with a number of scientists on the NCAR staff. During the year ASP was also asked to host the NCAR interdivisional program on geophysical turbulence. This program, which traces its history back to the earliest days of NCAR, involves scientists from several divisions, visitors from other institutions, and workshops. Its administration had been passed yearly among the various divisions involved, but it was decided that having ASP, with its experience in care of visitors and arranging workshops, as permanent host would improve the effectiveness of the program.

Summer Colloquium

ASP and the High Altitude Observatory (HAO), with partial support from NASA, hosted a summer colloquium on "Current Trends in Solar and Astrophysical Magnetohydrodynamics" in August 1994. Thomas Bogdan (HAO) coordinated the sessions, which featured 30 lecturers from 24 institutions. The 98 participants represented 56 institutions from 13 foreign countries and the United States.

The colloquium addressed five topics: coronal magnetic fields and magnetic non-equilibrium, photospheric magnetic fields and magnetic intermittency, interaction of flows with magnetic fields and dynamo action, magnetic fields and transport of angular momentum in stars, and magnetic fields, solar variability, and climate change.

Global Change Instruction Program

Through the Global Change Instruction Program (GCIP) of ASP, NCAR staff have collaborated with a number of universities to produce a series of curriculum modules for undergraduate students. Titled Understanding Global Change: Earth Science and Human Impacts, the series includes both introductions to scientific principles and substantive discussions of specific global change issues. During FY 94, two modules were completed and distributed: *Biological Consequences of Global Climate Change*, by Christine Ennis (National Oceanic and Atmospheric Administration) and Nancy Marcus

(Florida State University); and *Climatic Variation in Earth History*, by Eric Barron (Pennsylvania State University). Over 2000 copies of various titles in the series were distributed during the year. The series of eight modules will be issued by a commercial publisher in the near future; a contract is being finalized as of this writing.

The NSF Division of Education and Human Resources has funded the creation of six more modules and supplemental materials over the next two years. Scientific director for this second phase of the GCIP will be Tom Wigley (CGD and Walter Orr Roberts Institute).

Staff, Visitors and Collaborators

Staff

Advanced Study Program Staff

John Firor (director)

Barbara McDonald

Judith Miller (80%)

Information Support Services Staff

Karon Kelly (manager)

Information and Education Outreach Program

Anatta (75%)

Marie Boyko (manager, until 21 January)

Millicent Butterworth

Louise Carroll

Steven Davis (75%)

Robert Henson (75%)

Irene Munoz

Juanita Razo

Lucy Warner (87.5%)

Media Relations

Anatta (25%)

Joan Frisch (manager)

Project LEARN

Joyce Gellhorn (principal investigator, 65%)

Patrick Kennedy (principal investigator, 20%)

Carol McLaren (principal investigator, 65%)

Caroline Hanson

Summer Employment Program Staff

Edna Comedy (associate vice-president, Human Resources)

Anna Reyna-Arcos

Visitors

ASP Graduate Fellows

Lynne Bennett; University of Colorado; potential for interstate water transfers under climatic uncertainty; Kathleen Miller, ESIG

ng Chou; Columbia University; magnetohydrodynamic equilibrium of the solar atmosphere; Boon Chye Low, HAO

Katja Drdla; University of California, Los Angeles; Comparison of model predictions and measurements of solar stratospheric clouds; James Dye, MMM

Cindy Nevison; Stanford University; modeling of trace gas fluxes--N2O; William Holland, ACD

Irina Petropavlovskykh; Central Aerological Observatory, Russia; atmospheric photochemical effects of solar radiation; Sasha Madronich, ACD

Jordan Powers; University of Washington; mesoscale gravity waves; Ying-Hwa Kuo, MMM

Anji Seth; University of Michigan; land-surface heterogeneities in atmosphere-biosphere interactions; Filippo Giorgi, CGD

Tammy Weckwerth; University of California, Los Angeles; convection initiation associated with horizontal convective rolls; James Wilson, RAP

ASP Postdoctoral Fellows

Steve Arendt; University of Chicago; study of vorticity and stratified fluids

Brad Baker; University of Washington; cloud microphysics and turbulence

Jian-Wen Bao; Pennsylvania State University; four-dimensional data assimilation using the adjoint method

Axel Brandenburg; Nordic Institute for Theoretical Physics, Copenhagen, Denmark; explaining the solar dynamo and differential rotation

Antonietta Capotondi; Massachusetts Institute of Technology; assimilation of altimeter data into ocean circulation models

Manfred Cuntz; University of Heidelberg, Federal Republic of Germany; stellar atmospheres

Kenneth Davis; University of Colorado at Boulder; trace gas fluxes and transport in the boundary layer

Oliver Espagnet; Pic du Midi Observatory, France; interactions between granulation and solar oscillations

Frederic Fabry; McGill University, Canada; radar meteorology and lidar research

Carl Hagelberg; Oregon State University; modeling and analysis of microfronts with the intention of data assimilation

Christopher Holloway; University of Colorado; wave propagation, scattering from rough surfaces, and antenna analysis and design

Theresa Huang; University of Michigan; numerical modeling of the middle atmosphere; dynamic, radiative, and chemical interactions and feedback

Gregory Jenkins; University of Michigan; investigation of the Archean climate

Brian Johnson; University of Michigan; remote sensing, radiative transfer and Fourier transform spectroscopic studies of stratospheric trace gases and aerosols in ozone chemistry

David Kingsmill; University of California, Los Angeles; the convection initiation problem

Rodney Kinney; University of Texas at Austin; magnetohydrodynamical turbulence and solar atmosphere

Joanie Kleypas; James Cook University of North Queensland, Townsville, Australia; response of coral reef ecosystems to global climate change

Jean-Francois Lamarque; Catholic University of Louvain, Belgium; coupling the MM4 model with a chemistry package describing ozone chemistry

Kathleen Lantz; University of Colorado at Boulder; development of a trajectory-chemistry model

Luning Li; Indiana University, statistical analysis, turbulence and global circulation

Melanie Mason; University of Colorado at Boulder; study of aluminum industry contributions to greenhouse gases and global climate change

Kenneth Minschwaner; Harvard University; radiative processes: influence on climate and stratospheric photochemistry

Suzanne Paulson; California Institute of Technology; field measurements, laboratory atmospheric chemistry, and atmospheric modeling

Jordan Powers; University of Washington; mesoscale gravity waves

Mark Rast; University of Colorado at Boulder; compressible turbulence in an ionizing fluid

Sergei Rodionov; State Oceanographic Institution, Moscow, Russia; changes in levels of large lakes

Fabrizio Sassi; University of Bologna, Italy; transport and chemistry in the middle atmosphere

David Smith; University of Chicago; climatic consequences of river basin development

Mark Smith; University of Arizona; optical techniques applied to atmospheric chemistry and global change

Steven Smith; University of California, Los Angeles; plasma physics

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Community Service Activities at NCAR

Community service plays an important role in the lives of NCAR scientists. This year, we have compiled a list of selected activities that represent this aspect of a scientist's career at NCAR. We have included:

- Editorships
- Scientific Committee and Advisory Panel appointments
- Honors and Awards bestowed by other institutions.

While this is not an exhaustive list, it does represent the breadth of service to the research and educational communities with which we interact.

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