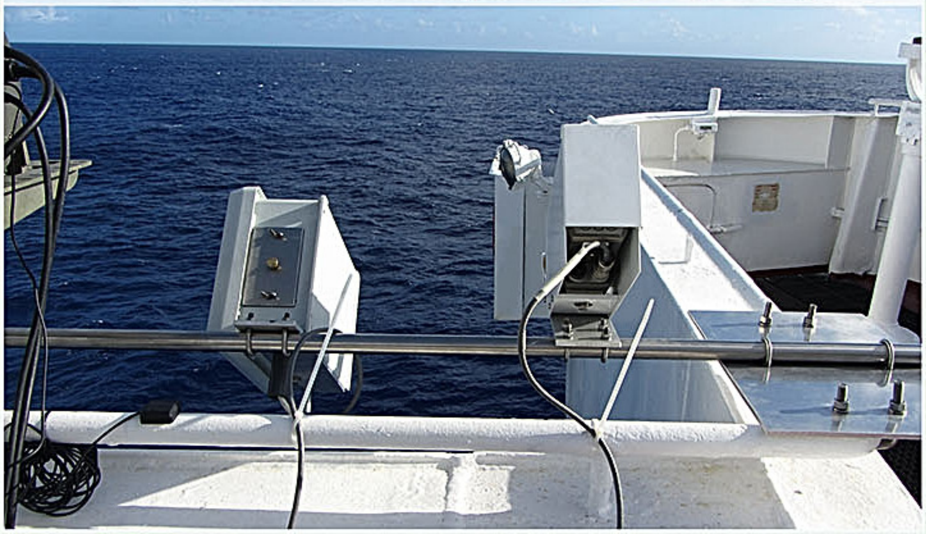
ASR Atmospheric System Research Science Team Meeting

Potomac, Maryland • March 18 – March 21, 2013

Marine ARM GPCI Investigation of Clouds (MAGIC)



Two-Column Aerosol Project (TCAP)

U.S. DEPARTMENT OF ENERGY

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Contents

1.0 Executive Summary

Introduction

This document contains the summaries of papers presented in poster format at the 2013 Atmospheric System Research (ASR) Science Team Meeting held in Potomac, Maryland. Nearly 250 posters were presented during the Science Team Meeting. Posters were sorted into the following subject areas: aerosol-cloud-radiation interactions, aerosol properties, atmospheric state and surface, cloud properties, dynamics/vertical motion, field campaigns, infrastructure and outreach, instruments, modeling, precipitation, and radiation. To put these posters in context, the status of ASR at the time of the meeting is provided here.

Background

The U.S. Department of Energy's (DOE) Atmospheric System Research (ASR) is an observation-based research program created in October 2009 to advance process-level understanding of the key interactions among aerosols, clouds, precipitation, radiation, dynamics, and thermodynamics using data from the Atmospheric Radiation Measurement (ARM) Climate Research Facility. The ARM Facility is a DOE scientific user facility for the study of global climate change by the national and international research community. Planned enhancements to the ARM Facility, funded through the American Recovery and Reinvestment Act of 2009, were implemented in 2010 and 2011 and resulted in 143 new instruments and increased research capabilities for the ARM user community, including ASR scientists.

A tight coupling of the ARM Climate Research Facility and ASR will allow the atmospheric system to be better observed and understood in a comprehensive, end-to-end fashion. ASR is designed to recognize the atmospheric system as an aerosol-cloud-precipitation continuum operating within a microphysical and macrophysical environment characterized by radiation, dynamics (including meteorology), and thermodynamics. That continuum stretches seamlessly across scales from gases and primary particles emitted to the atmosphere, through evolving aerosol populations, to the clouds that form on aerosol particles, and the cloud systems that produce precipitation to complete the hydrologic cycle. ASR's defining objective is a detailed, process-level understanding of this system that leads to improved simulations by climate models.

References

Atmospheric System Research (ASR) Science and Program Plan. 2010. U.S. Department of Energy. http://science.energy.gov/~/media/ber/pdf/Atmospheric_system_research_science_plan.pdf.

2.0 Aerosol-Cloud-Radiation Interactions

Aerosol-induced changes in cloud field properties and precipitation of tropical convective clouds

Seoung-Soo Lee, NOAA Earth System Research Laboratory
Graham Feingold, NOAA Earth System Research Laboratory

Aerosol effects on condensed water and precipitation in a tropical cloud system driven by deep convective clouds are investigated for two-dimensional simulations of two-day duration. Although an assumed ten-fold increase in aerosol concentration results in a similar temporal evolution of mean precipitation and a small (9%) difference in cumulative precipitation between the high- and low-aerosol cases, the characteristics of the convection are much more sensitive to aerosol. The convective mass flux and temporal evolution and frequency distribution of the condensed water path WP (sum of liquid and ice water paths) differ significantly between unperturbed and aerosol-perturbed simulations. There are concomitant differences in the relative importance of individual microphysical processes and the frequency distribution of the precipitation rate (P). With increasing aerosol, (1) the convective mass flux increases, leading to increases in condensation, cloud liquid, and accretion of cloud liquid by precipitation; (2) autoconversion of cloud water to rain water decreases; (3) the WP spatial distribution becomes more homogeneous; and (4) there is an increase in the frequencies of high and low WP and P and a decrease in these frequencies at the mid-range of WP and P. Thus, while aerosol perturbations have a negligible influence on total precipitation amount, for the case considered, they do have substantial influence on the spatiotemporal distribution of convection and precipitation.

Arctic winter longwave aerosol indirect effect with a new parameterization of frost flower salt particle emissions

Li Xu, University of Michigan, Ann Arbor
Lynn Russell, Scripps Institution of Oceanography
Richard Somerville, Scripps Institution of Oceanography

Frost flowers are clusters of highly saline ice crystals growing on newly formed sea ice or frozen lakes. Based on observations of particles derived from frost flowers in the Arctic, we formulate an observation-based parameterization of a seawater-derived aerosol source function from frost flowers. The particle flux from frost flowers in winter is of the order of 10^6 m-2 s-1 at the wind speed of 10 m s-1, but the source flux is highly sensitive to the wind speed. We have implemented this parameterization in the regional model of WRF-Chem. The WRF-Chem was configured using two-way nested domains with grid spaces of 30 kilometers and 6 kilometers. The period of 31 January 2009 00:00 UTC through 3 February 2009 21:00 UTC was chosen for the simulation. This period maximized the amount of sodium and chloride measured in Barrow, Alaska. The preliminary results suggest that the addition of salt particle sources from frost flowers increases both sodium chloride and cloud droplet number concentration as well as cloud liquid water path, thereby resulting in the enhancement of cloud longwave forcing in Arctic winter.

Assessment of the precipitation susceptibility of stratocumulus clouds

Graham Feingold, NOAA Earth System Research Laboratory
Allison McComiskey, National Oceanic and Atmospheric Administration

Precipitation susceptibility So has been proposed as a means of quantifying the potential influence of changes in precipitation resulting from changes in drop (or aerosol) concentration. Various methods of assessing its magnitude in warm clouds have yielded sometimes conflicting trends in So with increasing liquid water path. For example, cloud parcel models, large-eddy simulations (LES), and some satellite analyses show a characteristic increase in So from very low values at low liquid water path (LWP) to some maximum at an intermediate LWP, followed by a steady decrease thereafter. On the other hand, heuristic models and aircraft observations show So decreasing monotonically with increasing LWP. The argument is that as LWP increases, the balance between (drop concentration-dependent) autoconversion and (drop concentration-independent) accretion shifts steadily in favor of accretion, and therefore So decreases monotonically.

In this presentation we will attempt to resolve the discrepancies between these results using a number of modeling techniques ranging from box models of stochastic collision-coalescence to ensembles of parcel models run along trajectories derived from LES. We will show that although the shift in balance from autoconversion to accretion does indeed decrease So, the time available for collision-coalescence is a key controlling parameter that can explain the non-monotonic trend in So.

Boundary-layer mixing state and vertical distribution of aerosol at high-latitude locations

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Matthew Shupe, University of Colorado

Of the uncertainties surrounding our understanding of global climate, one of the largest involves the relationships between aerosols and clouds and the resulting impacts on atmospheric radiation and precipitation. In order to overcome limitations resulting from a lack of aerosol profile measurements, traditional studies of these relationships have used surface aerosol measurements as a proxy for aerosol at cloud height. In many locations, clouds occur in well-mixed boundary layers, allowing for such assumptions. At high latitudes, however, the atmosphere is often very stable, and aerosol particles are often advected from remote source regions. The stable atmosphere only features limited vertical mixing, meaning that aerosol properties at the surface and cloud height may be very different from one another. Therefore, the conclusions from previous attempts at quantifying aerosol-cloud interactions for Arctic clouds using surface-based aerosol measurements are challenging to interpret. In the current work, we use measurements from various high-latitude locations to demonstrate the relationship between surface and elevated aerosol properties under different boundary-layer mixing states. Mixing state is derived from a combination of temperature profiling devices (e.g., radiosondes) and remote sensors (e.g., millimeter-wavelength cloud radar), while aerosol measurements come from both surface- and aircraft-based sensors. Measurements will come from several campaigns, including the Indirect and Semi-Direct Aerosol Campaign (ISDAC), the Mixed-Phase Arctic Clouds Experiment (M-PACE), and the Arctic Summer Cloud Ocean Study (ASCOS). We will demonstrate under what conditions surface aerosol properties can and cannot be used to evaluate aerosol-cloud interactions for low-level Arctic clouds.

Diurnal variation of aerosol effects on cloud and radiative forcing over the DOE ARM SGP site

Hongru Yan, University of Maryland
Zhanqing Li, University of Maryland

Aerosols can modify cloud particle size, fraction and height, all of which change cloud radiative forcing. For convective clouds, these changes in the shortwave and longwave may be very large in magnitude and opposite in sign, leading to an uncertain net effect that depends highly on the diurnal variation of deep convective clouds and their interaction with aerosols. In this study, we will use high temporal resolution data from ground-based instruments, a geostationary satellite, and a reanalysis data set to study diurnal variations of various aerosol effects, especially the aerosol invigoration effect (AIV) and its radiative forcing at the Southern Great Plains site. We present preliminary results showing a consistent AIV present at the site. We show that the fraction of the core of a DCC first increases with cloud nuclei (CN) concentration when CN is less than 2000 cm-3, and then decreases. However, the cloud fraction increases with increasing CN concentration when the CN concentration is greater than 5000 cm-3. The areal coverage of the cloud anvil monotonously increases with CN concentration. Whatever the vertical velocity, the cloud-top height increases with CN concentration. We will also estimate aerosol-induced changes in cloud radiative forcing obtained from combining radiative fluxes retrieved from both GOES observations and model calculations for DCCs present at different levels of CN concentration.

Heavy air pollution suppresses summer thunderstorms in central China

Xin Yang, University of Cambridge
Zhanqing Li, University of Maryland
Tianyi Fan, University of Colorado

Fifty years (1951–2005) of rainfall, thunderstorms, temperatures, winds, and visibility data have been analyzed at the heavy polluted Xian Valley, near Mount Hua in central China, for assessing the impact of the increasing air pollution on convective precipitation. Humidity-corrected visibility is used as a proxy for aerosol optical depth (AOD), which is often so heavy that it stabilizes the lowest troposphere. The stabilization resulted in less vertical exchanges of air, which caused reduction in the lowland (Xian) surface winds and increase in the highland (Mount. Hua) wind speeds. The decreased instability caused a decrease in the frequency of the thunderstorm normalized by rainfall amount in the lowland due to the thick aerosol layer above, but not at the highland, above which the aerosol layer was much thinner. The indicated decreasing trend of highland precipitation was associated with a weak decreasing trend in thunderstorm frequency. Light and moderate (<25 mm day-1) rainy days contributed to this decrease. These patterns of rainfall changes at the highland are consistent with the microphysical suppressive effects of aerosols. Despite the dramatic relative decrease in the already originally scarce thunderstorm activity in the Xian Valley, rainfall amount there appears to have little diurnal cycle, and respectively shows little trend with the increasing aerosol amounts. Only small fraction of the rainfall in Xian is generated by local instability. The finding may be extended to other areas where local surface heating dominates rainfall amount.

Investigation of multi-decadal trends in aerosol direct radiative effect from anthropogenic emission changes over North America and North Hemisphere by using a multiscale two-way coupled WRF-CMAQ mode

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Jia Xing, U.S. Environmental Protection Agency
David Wong, U.S. Environmental Protection Agency
Jonathan Pleim, U.S. Environmental Protection Agency
Rohit Mathur, U.S. Environmental Protection Agency
Chuen-Meei Gan, EPA NERL Atmospheric Modeling and Analysis Division
ST Rao, U.S. Environmental Protection Agency
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Anthropogenic aerosols play a dominant role in “global dimming or brightening”. However, aerosol radiative effects are still recognized as some of the largest sources of uncertainty among the forcers of climate change. This study will systematically investigate changes in anthropogenic emissions of short-lived aerosol precursors over the past two decades (1990–2010) in the Northern Hemisphere (especially in the United States), their impacts on aerosol loading, and subsequent impacts on regional radiation budgets. The hypothesis that changes in surface solar radiation over time are caused by the changing patterns of anthropogenic emissions of aerosols and aerosol precursors will be tested in this study. A new two-way coupled meteorology and atmospheric chemistry model composed of the Weather Research and Forecast (WRF) model and the Community Multiscale Air Quality (CMAQ) model has been developed by the U.S. Environmental Protection Agency. This two-way model is being run for 20 years (1990–2010) on both a 12-km resolution grid that covers most of North America and a 108-km resolution domain for the Northern Hemisphere. A newly developed 20-year U.S. emission inventory is used in order to accurately reflect the emission trends resulting from progressively more stringent air quality regulations as well as population trends, economic conditions, and technology changes in motor vehicles and electric power generation. Global data sets are used for the emissions outside the U.S. The direct effects of aerosols on shortwave radiation are considered in this WRF/CMAQ model. New algorithms on the calculation of aerosol optical properties and radiation have been developed for considering of both computational efficiency and more realistic aerosol states. Preliminary model simulations for 1990 and 2006 are being evaluated both for their performance in comparison to observed concentrations and simulation of observed trends (details about observations are reported in the poster by Gan et al.) in concentrations and surface radiation. Aerosol mixing state is a key factor for the calculations of aerosol optical properties. A more realistic core-shell model will be tested to demonstrate the uncertainties on the treatment of aerosols in this study. Different nudging strategies on atmosphere and soil will be compared in sensitivity studies in order to get a balance between strong signal of aerosol effects and good model performance.

Long-term study of aerosol invigoration effect over DOE ARM SGP

Hongru Yan, University of Maryland
Zhanqing Li, University of Maryland

Aerosols can invigorate convective clouds by increasing cloud-top height, thickness, and cloud fraction, which alter the radiative balance of the Earth-atmospheric system. Herein, we use long-term continuous ground-based observation, reanalysis data set, and geostationary (GOES) satellite retrievals to study the aerosol invigoration effect (AIV) and its radiative forcing at the ARM Southern Great Plains site. Due to the competing shortwave and longwave radiative effects and diurnal variation of clouds, it is unknown if the daily mean cloud radiative forcing mediated by the AIV is positive or negative for which continuous GOES satellite and surface observations.

Analyses of both ground and satellite measurements reveal consistently the AIV. We found that the fraction of the core of deep convective clouds (DCC) firstly increases with CN concentration when CN is less than 2000 cm-3 and then decreases. However, when CN concentration is larger than 5000 cm-3, cloud fraction begins to increase with CN concentration increases. The fraction of cloud anvil monotonously increases with CN concentration. Whatever the vertical velocity is, the cloud-top height always increases with CN concentration increases, while for the relationship between anvil cloud fraction and CN concentration, the anvil cloud fraction only increases with CN concentration under updraft condition.

We are combining radiative flux retrieved from both GOES observation and model calculations to determine cloud radiative forcing for DCCs under different levels of CN concentration due to changes in cloud-top height of the DCC and expansion of optically thin anvil clouds. Some preliminary results will be presented.

Long-term trends in radiation brightening in the United States during 1995–2010

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Jonathan Pleim, U.S. Environmental Protection Agency
Rohit Mathur, U.S. Environmental Protection Agency
Chuck Long, Pacific Northwest National Laboratory
Chao Wei, U.S. Nuclear Regulatory Commission
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Long-term surface observations (1995–2010) of shortwave radiation, aerosol optical depth (AOD) and aerosol concentration from several networks (SURFRAD, CASTNET, IMPROVE, and ARM) in the U.S. are analyzed to infer the association between trends in tropospheric aerosol burden and radiation across the country. Seven regions with varying climatology are selected in this assessment to better understand the spatial and temporal distributions of aerosols and clouds in conjunction with their direct, semi-direct, and indirect effects on radiation. A well-constructed emission data set from Xing et al. (2012) is used to verify the hypothesis that the reductions in anthropogenic aerosol burden resulting from substantial reductions in emissions of sulfur dioxide and nitrogen oxides over the past 15 years across the U.S. has caused an increase in shortwave (SW) radiation near surface. The trend analysis indicates a SW radiation "brightening," particularly in the eastern U.S. However, this phenomenon is less pronounced in the western U.S., since many of the Clean Air Act (CAA) control measures were aimed at coal-fired power plants that are more prevalent in the eastern U.S. Moreover, these locations could be influenced by local terrain influences as well as episodic long-range pollution transport, which may contribute to the lack of a clear association between trends in aerosol burden and surface radiation at these locations. The existence of a strong association between trends in surface solar radiation and aerosol burden provide a unique test for current generation of climate-chemistry models. Multi-decadal model calculations with the coupled Weather Research and Forecasting Community Multiscale Air Quality Model (WRF-CMAQ) model (Wong et al. 2012) are being set up for the 1990–2010 period to test the ability of the model to simulate not only the changes in aerosol burden over the U.S. arising from the implementation of the CAA, but also the associated radiation brightening as indicated in the present analysis. The results of the analysis will be presented together with the emission trends in the poster. Early results from the modeling studies and their comparison with the trends inferred from the observations will be reported in a companion poster by Wei et al.

Mechanisms for indirect effects from aerosol pollution on glaciated clouds

Vaughan Phillips, University of Leeds

Our "aerosol-cloud model" with hybrid bin/2-moment bulk microphysics that treats ice morphology and the dependency of shape parameters on cloud particle size was developed during this Atmospheric System Research project. A very recent upgrade, published in 2013, to our ice-nucleation scheme has been included in the model.

Earlier in the project, the model was validated for mesoscale simulations of deep convective systems in two field campaigns, Cloud Land Surface Interaction Campaign (CLASIC) and Tropical Warm Pool-International Cloud Experiment (TWP-ICE). The validation included cloud particle number concentrations, after initialising it with aerosol conditions of loading.

Results from sensitivity tests are shown in the presentation, revealing the separate contributions to the aerosol indirect effect via cold clouds, due to their changes in lifetime and in radiative/microphysics properties. The cold-cloud indirect effect is much smaller than the warm-cloud indirect effect.

The impact on cold clouds from soluble aerosols in pollution boosting homogeneous freezing aloft and altering cirriform clouds' extent is documented for the simulations.

Microphysical, macrophysical, and radiative impacts of aerosol on different cloud systems

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The Weather Research and Forecasting (WRF) model was previously adapted to include the aerosol indirect effect via a two-moment bulk microphysics scheme and the aerosol direct effect via a modified Goddard radiation scheme. Three cases from the March 2000 Cloud Intensive Observational Period campaign and three cases from 2009 Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO) field campaign at the ARM Climate Research Facility's Southern Great Plains site were examined, including a developing low-pressure system, a cold frontal passage, a series of non-precipitating or weakly precipitating stratus and cumulus, etc. The observed profile of the aerosol concentration from the in situ measurements was used for the control run, and the perturbations are made on the aerosol profile in the sensitivity studies. To investigate the effect of aerosol radiative effect, each profile was run with and once without the modified Goddard scheme for each case. For warm and stratiform precipitation events, generally a reduction of precipitation was found with more aerosols introduced. For mixed-phase and convective precipitation events, generally a nonlinear trend was found where the moderate profiles had the highest rain rates. Including or removing the direct effect proved to have a statistically significant effect of cloud fraction. In all the cases, the liquid water path

(LWP) roughly increased with the elevation of aerosol concentrations, corresponding to a decrease in surface shortwave radiation. The outgoing longwave radiation was mainly regulated by the cloud fraction, but had a lower magnitude of change than the shortwave radiation. Therefore, the changes of shortwave radiation induced by aerosols dominated the temperature variation. Results from this study suggest that aerosols play a critical role in macro- and micro-properties of different clouds and the precipitation efficiency. Meanwhile, the direct effect of aerosol has to be taken into account if we aim at an accurate assessment of the aerosol-cloud-radiation interaction in the different cloud systems.

Modeling aerosols and their interactions with shallow cumuli

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The Cumulus Humilis Aerosol Processing Study (CHAPS), which was conducted during June 2007 near Oklahoma City, Oklahoma, provides a useful data set for evaluating the ability of models to accurately simulate cloud-aerosol interactions in shallow cumuli. In this study, the Weather Research and Forecasting model coupled with chemistry (WRF-Chem), was used to simulate aerosols, clouds, and their interactions during CHAPS with 2-km horizontal grid spacing. The model reproduces the observed trends of higher nitrate volume fractions in cloud droplet residuals compared to interstitial non-activated aerosols. Comparing simulations with cloud chemistry turned on and off, we show that nitric acid vapor uptake by cloud droplets explains the higher nitrate content of cloud droplet residuals. The model also reasonably represents the observations of the first aerosol indirect effect where pollutants in the vicinity of Oklahoma City increase cloud droplet number concentration and decrease the droplet effective radius. In addition, as documented using an offline optical code, simulated aerosol optical properties depend on several compensating effects including aerosol water content, size-resolved chemical composition, and refractive index of various particle chemical species. The simulations clearly show an increase in simulated absorption and a decrease in single-scattering albedo (SSA) within the Oklahoma City plume. This study highlights the ability of regional-scale models to represent some of the important aspects of cloud-aerosol interactions associated with fields of short-lived shallow cumuli.

Modeling radiative impact of aerosols over south Asia constrained by observations of vertical distribution

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It has been suggested that high aerosol loadings in south Asia may impact the regional energy balance and hydrological cycle significantly. However, most of the aerosol and climate simulations in this region are global climate model (GCM) studies, which generally under-predict compared with satellite-observed aerosol optical depth (AOD). Also there is a lack of quantification of aerosol vertical distributions in those large-scale models. In the present study, we will address two questions: (1) does the under-prediction in AOD exist uniformly in height, and (2) how do the discrepancies between the simulated and observed AOD affect the radiative balance and heating in the atmosphere? We will present 12-km Weather Research and Forecasting coupled with chemistry (WRF-Chem) simulations and evaluations of aerosol and cloud properties from data gathered during the Ganges Valley Aerosol Experiment (GVAX). While the regional model simulates the spatial distribution and seasonal cycle of AOD similar to observations, the modeled zonal mean (0–25°N, 60–95°E) AOD is nearly a factor of two lower than the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data. Comparisons with the micropulse lidar (MPL) measurements at the mountain-top site (Nainital: 29°N, 79°E, 1900 m) and a valley site (Kanpur: 26°N, 80°E, 120 m) indicate that aerosol extinction is significantly under-predicted from the surface to 2 km and over-predicted at higher altitudes. This bias in aerosol extinction profile can lead to an increase in the planetary boundary-layer (PBL) radiative heating, more than what is due to a larger column AOD increase. Sensitivity studies are conducted to examine the impact on the radiative balance and cloud properties, by increasing aerosol extinction uniformly in height (Experiment I) and below 2 km only (Experiment II) by a factor of two at each time step, with the same single-scattering albedo. The calculated monthly mean AOD in Experiment II agrees the best with the MODIS AOD and the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) aerosol extinction profiles, compared to the control run and the Experiment I. Radiative forcing of aerosols increases from -4.1 W m-2 in the control run to -6 W m-2 in Experiment II at the top of atmosphere and from -9.7 W m-2 to -14.3 W m-2 at the surface. Uniformly increasing aerosol extinction (Experiment I) enhances the aerosol perturbation on equivalent potential temperature profile as in the control run. But increasing aerosol extinction below 2 km only (Experiment II) leads to different responses in lapse rate. The impact on predicted cloud cover depends on the combination of the feedback in lapse rate and turbulence intensity.

Model simulations of aerosol, cloud, and precipitation effects in comparison with ARM data

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The objectives of our proposal are to evaluate the capabilities of the Community Atmosphere Model version 5 (CAM5) model to capture cloud-aerosol-precipitation interactions, to identify weaknesses, and to ascertain possible improvements. This study will be carried out through a combination of cloud system-resolving model (CSRM) studies, studies with CAM5 and the CAM5 single-column model (SCM), and comparison of both with ARM measurements. We will carry out simulations and compare the CSRM with the CAM5 SCM model to test the response of CAM5 SCM low-level clouds to increases in aerosols. We would also systematically degrade our CSRM simulation to the physics represented in CAM5 in order to understand the causes of differences.

The first step in our proposal is to examine the data from the ARM Southern Great Plains (SGP) site to pick time periods that can be informative for determining the proper representation of aerosol/cloud interactions in global models. We focus on data from the SGP site, since this site has a wide variety of cloud types as well as the most up-to-date and complete data systems. Our intension is to separate low liquid water path (LWP) clouds from high LWP clouds, in order to focus on specific aerosol-precipitation response regimes (Li et al. 2011). We pick time periods within this regime with low and high aerosol concentrations to test the CSRM. We examine whether these periods have similar large-scale forcing data. In this poster we report our progress in examining the ARM data for representative time periods that can be used in our study.

Observational constraints of aerosol-cloud-drizzle interactions for warm clouds using AMF measurements in Europe

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To advance our understanding of why climate models produce a large aerosol indirect effect, one of the key actions, identified by the Atmospheric System Research (ASR) Cloud-Aerosol-Precipitation Interactions (CAPI) working group, is to enhance observational constraints by assessing statistical dependency of drizzle on aerosol and cloud properties from climatologically contrasting sites. To provide such constraints, we focus on warm boundary-layer clouds and analyse observations from the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Mobile Facility deployments in Germany in 2007 and in the Azores during 2009–2010. Using measurements from cloud radar, lidar, microwave radiometer, and aerosol observing systems, we will show how the drizzle rate at cloud base varies with cloud liquid water path and ambient aerosol. We will also demonstrate how the probability of precipitation and the precipitation susceptibility respond to ambient aerosol loading and whether these responses agree with those suggested by state-of-the-art models and satellite observations.

Quantifying the dust impacts on the ice generation in supercooled stratiform clouds

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Dust particles are known as one main source of ice nuclei (IN). However, there are large uncertainties in the effectiveness of dust particles as IN. In this study, we combine ground-based and satellite active remote sensing to evaluate dust impacts on ice generation in supercooled stratiform clouds. Multi-year ground-based observations at Barrow, Alaska, show that springtime arctic stratiform mixed-phase clouds are often influenced by long-range transport of Asian dust. When cloud-top temperature is colder than -15°C, this seasonal dust influence results in significantly lower liquid mass partitions than the other seasons in the mixed-phase clouds. Four years of collocated Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and CloudSat measurements are used to find mid-level stratiform clouds embedded in dust layers. Results showed that ~98% dusty mid-level stratiform clouds are in mixed-phase at cloud-top temperature around -15°C, while the non-dusty similar clouds in the same geographical region only reach this magnitude of mixed-phase occurrence until ~-30°C. To quantitatively evaluate the impacts of dust particles on the ice generation, we explored the relationship of ice number concentration and layer maximum radar reflectivity with in situ measurements, 1D ice particle growth models, and 3D cloud-resolving model simulations. Results indicated that ice crystal number concentration in mixed-phase stratiform clouds can be estimated from CloudSat and CALIPSO measurements within uncertainties of about a factor of two statistically. By comparing estimated ice concentrations in the dusty and non-dusty stratiform clouds, it was found that dust can enhance ice number concentrations in stratiform mixed-phase clouds at a given temperature by a factor of 2 to 5, and the dust ice enhancement is strongly a function of dust concentration and mineralogical composition. The fraction of dust activated as IN is also estimated from CloudSat and CALIPSO measurements and compared with laboratory and modeling results. Although there are inherent uncertainties in the remote sensing approaches, it provides a much-needed global view on dust impacts on the ice generation.

Relationship between oxidation level and optical properties of laboratory secondary organic aerosols

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Paul Davidovits, Boston College

Recent studies indicate that light-absorbing brown carbon (BrC), including secondary organic aerosol (SOA), contributes significantly to global radiative forcing. Here, the correlation between the level of oxidation and optical properties of secondary organic aerosols (SOA) is quantitatively examined. SOA was generated in the absence of NOx by the OH oxidation of four gas-phase precursors chosen to represent surrogates as indicated: alpha-pinene (biogenic SOA), tetrahydrocyclopentadiene (JP-10) (anthropogenic aliphatic SOA), naphthalene (anthropogenic aromatic SOA), and guaiacol (biomass burning SOA). The SOA was produced by OH exposures ranging from 8E10 to 2E12 molec/cm3*s, approximately equivalent to 0.6 to 15 days of atmospheric exposure. Optical properties were measured in real time for suspended aerosols using cavity ring-down photoacoustic spectrometry (CRD-PAS) at 405 nm and on filter-collected particles over wavelengths ranging from 300 to 600 nm using ultraviolet-visible (UV-VIS) spectrometry. Taken together, these measurements yielded the real and imaginary parts of the refractive indices as well as the associated mass-specific absorption cross-sections as a function of wavelength. The absorption cross-sections obtained with CRD-PAS and UV-VIS techniques agree to within ~20%. Aerosol mass spectra were measured with a time-of-flight aerosol mass spectrometer. The mass spectra yielded oxygen-to-carbon (O/C) ratios ranging from 0.38 to 1.25 and hydrogen-to-carbon (H/C) ratios ranging from 0.89 to 1.38.

The SOA mass spectra together with the O/C and H/C ratios provide information about possible reaction mechanisms that influence SOA oxidative aging. Within the range of experiments, the real component of the SOA refractive index ranged from about m = 1.45 to 1.66, decreasing slightly with increasing O/C ratio for each SOA type. The imaginary part of the refractive index and associated absorption cross-section increases with O/C ratio and is strongly wavelength-dependent. At 405 nm, the imaginary component of the refractive index ranged from k ~1E-4 to 3.6E-3. The corresponding absorption cross-sections ranged from ~0.001 to 0.088 m2/g. By comparing our measurements with previous studies conducted in the presence of NOx, the effect of NOx on the optical properties of alpha-pinene and naphthalene SOA was quantitatively determined. Our measurements suggest that oxidative aging of SOA may provide a significant global source of atmospheric radiation.

Role of wind shear at different levels in aerosol effects on deep convective clouds

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Aerosols could invigorate or suppress convection by serving as cloud condensation nuclei (CCN). Our previous studies indicated that vertical wind shear plays a key role in determining whether aerosols enhance or suppress convective intensity. That is, aerosols generally enhance convection under weak wind shear conditions for warm-based deep convective clouds; increasing wind shear dampens the aerosol invigoration effect and even leads to a suppression effect. However, the vertical wind shear at the different levels should have a very different impact on cloud dynamics, which could lead to significantly different aerosol effects on convection. In this study, we conduct the sensitivity study by changing the wind shear intensity at the lower level (0–5 km), the middle level (5–10 km), and the upper level (above 10 km) using the Weather Research and Forecasting (WRF) model with spectral-bin microphysics (SBM) to look into how aerosol impact on deep convective clouds changes with the different levels of wind shear and which level of wind shear plays a more significant role in terms of aerosol effects on cloud dynamics, macrophysical and microphysical properties, and radiative forcing. We find that CCN effects are the most significant under larger low-level or middle-level wind shear conditions. When wind shear is very high in the upper levels, CCN effects are much reduced.

Sorting out impact of aerosols on cloud, radiation, precipitation, circulation, and storms from observations and modeling

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While many individual mechanisms have been proposed concerning the impacts of aerosols on various cloud variables, precipitation, atmospheric circulation, and thunderstorms through their radiative, microphysical, and thermodynamic effects, the greatest challenge is untangling them from observational data. Taking advantage of both long-term routine and campaign measurements made at the Southern Great Plains (SGP) Central Facility and a short-term field experiment undertaken in China, as well as satellite data, we are tackling the problem from many perspectives using a variety of tools including targeted modeling exercises. We will highlight results from the following recently published and ongoing studies:

- Using long-term ground and geostationary satellite-based measurements made at the SGP Central Facility, the effects of aerosols on cloud fraction, cloud thickness, cloud anvil expanse, and associated radiative forcings are explored.
- Using a plethora of global A-Train polar-orbiting satellite data, radiative effects of aerosol invigoration on deep clouds are investigated.
- Using over 50 years' worth of meteorological data taken in China, clues concerning the separation of aerosol effects from those of greenhouse gases, urbanization, and general meteorology are gleaned.
- Using data from the ARM Mobile Facility (AMF) China deployment, various aerosol effects on clouds and precipitation are modeled.
- Using data from the Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO) field campaign, the first aerosol indirect effect and its influential factors are established.

Combining the merits of observational data and modeling appears to be a promising approach toward shedding light on the overarching problem encapsulated by the title of this presentation.

http://www.atmos.umd.edu/~zli

A study of the semi-direct and indirect aerosol effects on the Arctic region during the ISDAC campaign using WRF-CHEM

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The Arctic region plays a very important role in our weather and climate system. However, numerical modeling of the weather and climate system in this region is a highly complex scientific problem and not well understood. In this study, the understanding of aerosol effects on clouds and the surface energy budget in the Arctic region has been improved by integrating observational analyses from the ISDAC field campaign (April 2008) and numerical simulations from the WRF-CHEM mesoscale meteorological model. Two case studies are examined: April 7–10, 2008 (clean case) and April 18–21, 2008 (polluted case).

Suggestion of observation-based framework designed for the study of aerosol-cloud-precipitation interactions

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The scale of aerosol-cloud microphysics ranges from submicron to at most millimeter scale of drizzle drop, whose interactions seem to be resolvable with in situ measurements only, or possibly ground-based remote sensing measurements such as those gathered by the ARM Climate Research Facility. The basic assumption for the observation-based aerosol-cloud interactions (ACI) study is that the horizontal variability of clouds and aerosols is trivial with the assumption of homogeneous stratiform clouds and flat surfaces so that it could provide researchers with better opportunities for the study of aerosol effects only. Even aerosol-cloud interactions are strongly modulated and controlled by environmental conditions like stability, updraft velocity, and humidity, which can be in part classified by adiabaticity (Kim et al. 2008, 2012). Extending the subject to precipitation, Lee and Feingold (2010) and Lee et al. (2012) recently emphasized and demonstrated the possible aerosol influence on cloud system organization and distributions of cumulus precipitation as well as aerosol modification of cloud microphysical properties. Cloud-aerosol-precipitation interactions (CAPI) have so complicated feedback mechanisms that it is difficult to differentiate aerosol impacts accompanying instability-driven forcing from response results such as changes in circulation and precipitation, etc., based on the general framework of ground-based remote sensings.

Probably, if mean horizontal wind is predominant, it will be possible to separate CAPI response field from aerosol forcing domain. Ground-based remote sensings would be arranged with help of an available ARM Mobile Facility, considering suitable properties for each forcing and response domain, respectively. Temporal resolution and spatial distance of selected instruments should be identified in advance by carefully designed simulations with varying environmental conditions—mean advection wind, updraft velocity, cloud-top height, temperature profile, etc. The response area (or distance) can be determined by comparing advection and updraft time scales. Certainly, synthesizing ground and satellite remote sensings and simulations for the forcing and response domains will be ideal in monitoring changes in dynamic fields and eventually for the fundamental understanding of CAPI.

Tornadoes do not have a weekly anthropogenic cycle and by their nature supercells have minimal susceptibility to aerosol influences

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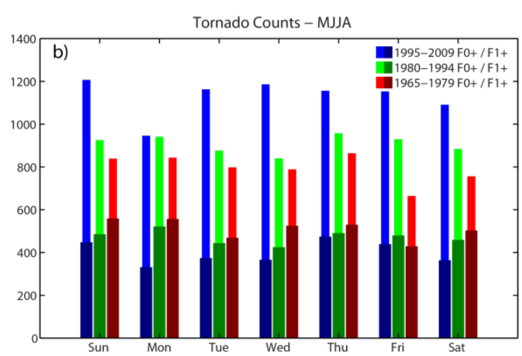

A recent paper (Rosenfeld and Bell 2011: "Why do tornadoes and hailstorms rest on weekends," *Journal of Geophysical Research*) has purported to show that high concentrations of aerosol modulate the frequency of tornadoes yielding an anthropogenic weekly cycle in tornado occurrence. The physical explanation proposed by Rosenfeld and Bell for how increased aerosol concentrations would cause increased frequency and severity of tornadoes and hail in supercells is inconsistent with actual supercell storm structures and their environments. Supercell updrafts, especially the main updraft which often has a characteristic bounded weak echo region, already have limited growth of drops below the 0°C level, muting any of the purported aerosol influences. Rosenfeld and Bell propose that aerosol-enhanced clouds have fewer and larger raindrops, which would lessen the potential for evaporative cooling and thus yield weaker (warmer) outflow from the storm. However, the distribution of precipitation particles and formation pathways varies markedly from sector to sector within supercell storms, making the aerosol linkage to outflow temperature near the tornado indirect at best. Meteorological parameters such as boundary-layer relative humidity and lifted condensation level (LCL) height have proven to be skillful at discriminating tornadic supercells from non-tornadic supercells without taking into account the aerosol content or the size distribution of hydrometeors.

Further, investigation of spring and summer tornadoes within the U.S. east of 100°W longitude indicates that there is no robust weekly cycle or mid-week maximum in tornado occurrence or tornado days. We examine 19,825 tornado cases over the months May–August for the years 1965–2009. We distinguish between all tornadoes of intensity F0 and greater (F0+) and F1 and greater (F1+). This distinction is made since F1+ tornadoes are more consistently reported than F0s. There are many more F0s than F1s—typically 30–70% depending on the period examined—since frequency of tornadoes falls off as the intensity increases. The days of the week for which the maximum and minimum in tornado counts occur varies depending on the specific period of time examined and whether F0 tornadoes are included or not (see figure).

What can be learned from ARM shortwave hyperspectral observations?

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Alexander Marshak, NASA Goddard Space Flight Center
Yuri Knyazikhin, Boston University
J.-Y. Christine Chiu, University of Reading
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The transition zone between cloudy and clear air is a region of strong aerosol-cloud interactions where aerosol particles humidify and swell while cloud drops evaporate and shrink, and vice versa. In an effort to improve our understanding of the transition zone, we study the radiative signature of transmitted shortwave radiation using radiative transfer models and observations of the recently renovated shortwave spectrometer (SWS) and the recently deployed shortwave array spectrometer-zenith (SASZE). This work serves as a step in closing the surface shortwave radiation gap that exists between models and observations at the surface under fully 3D cloud scenes. The transition zone also plays a vital role in climate questions surrounding aerosol-cloud interactions, or “aerosol indirect effects”. It was discovered that the spectra in the transition zone could be represented by a linear combination of the spectra taken in the contiguous cloudy and cloudless regions. The linear relationship results in a spectrally invariant slope and intercept. The slope, fit over a range of visible wavelengths, is mostly dependent on the cloud optical thickness, and the intercept, fit over wavelengths in the near-infrared, is dependent on both the optical thickness and the particle size. Due to normalization to the cloud-free spectra, both the slope and the intercept only weakly depend on the surrounding aerosols and surface properties. We explore the use of this relationship as a means for understanding the spectral response to the transition zone and changes in the particle size there. An algorithm is proposed, and the limitations of the algorithm are presented.

What is column-integrated aerosol remote sending telling us about cloud condensation nuclei?

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Since aerosol measurements from space were first made, there has been a desire to use them as proxy estimates of the concentration of cloud condensation nuclei (CCN) in the boundary layer. A number of studies have shown that concentration of aerosol particles in the accumulation mode is a good proxy for CCN concentration (N_CCN). However, spaceborne aerosol measurements typically use the column-integrated optical depth aerosol optical depth (AOD) as a proxy for CCN. There are several reasons why N_CCN is not uniquely predicted from AOD: (a) hygroscopic growth may vary from location to location and with cloud conditions, (b) the dry aerosol size can vary in time and space, (c) the depth of the layer in which most of the scattering takes place can vary. In this study, we use a variety of different observational and modeling results to assess these potentially complicating factors in the estimation of CCN concentration from space.

The following three areas are explore various aspects of the problem:

- We use a large number of rawinsonde launches and collocated cloud property information from the Clouds, Aerosol and Precipitation in the Marine Boundary Layer (CAP-MBL) ARM Mobile Facility (AMF) deployment on Graciosa Island in the Azores to quantify the hygroscopic growth contribution to AOD and explore its variability and relationship with cloud cover and other factors.
- We use data from the VOCALS Regional Experiment to assess the geographical variability in the factors controlling AOD from a polluted region to a clean region. We show how small increases in aerosol particle size and the depth of the boundary layer both have a major impact on the offshore gradient in AOD. This is such that these variations almost cancel out the impact on AOD of an almost threefold decrease in accumulation mode and CCN concentration moving offshore.
- We use WRF-Chem simulations over the southeastern Pacific (VOCALS region) to explore the correlation between aerosol properties in clear regions and cloud microphysical properties in adjacent cloudy regions to explore the impact of spatial separation of aerosol and cloud properties on the correlations between these variables.

3.0 Aerosol Properties

Acid-base chemical reaction model for nucleation rates in the polluted atmospheric boundary layer

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David Hanson, Augsburg College
Peter McMurry, University of Minnesota

This poster summarizes our recent discoveries regarding the chemical and physical processes that determine boundary-layer nucleation rates. The new model for nucleation rates that we developed is based on measurements of neutral molecular clusters with the cluster chemical ionization mass spectrometer (Cluster CIMS) and measurements of number distributions down to 1 nm with a scanning mobility particle spectrometer that utilizes our new diethylene glycol condensation particle counter (the DEG SMPS). Together, these instruments allow measurements of the entire number distribution down to one molecule. In addition, the ambient pressure proton transfer mass spectrometer (AmPMS) provided critically important measurements of basic gases including ammonia and amines. The model is based on measurements carried out using these instrument systems in Atlanta (2009) and in laboratory chamber studies (2010).

The model is the simplest model we could find that is consistent with our observations. It shows that a sequence of acid-base chemical reactions leads to the formation of stable clusters. This model leads to a simple analytic expression for nucleation rates that is in reasonable agreement with atmospheric observations.

Adsorption of organic molecules may explain growth of newly nucleated clusters and new particle formation

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New particle formation (NPF) in the atmosphere influences the concentrations of atmospheric aerosols and therefore their impact on climate. New particle formation is a two-stage process consisting of homogeneous nucleation of thermodynamically stable clusters followed by growth of these clusters to a detectable size (> 3 nm). Due to the large coagulation rate of clusters smaller than 3 nm with the pre-existing aerosol population, these clusters must grow quickly in order to survive and form new particles. While some previous modeling and field studies have indicated that condensation of low-volatility organic vapor may play an important role in the initial growth of the clusters, due to the small size of the clusters and the relatively high vapor pressure and partial molar volume of even highly oxidized organic compounds, the strong Kelvin effect may prevent typical ambient organics from condensing on these clusters. However, earlier studies did not consider that adsorption of organic molecules on the cluster surface, due to the intermolecular forces between the organic molecule and cluster, may occur and substantially alter the growth process under sub-saturated conditions. Using the Brunauer-Emmett-Teller

(BET) isotherm, we show that the adsorption of organic molecules onto the surface of clusters may significantly reduce the saturation ratio (by up to a factor of 100) required for condensation of organics to occur and therefore may provide a physico-chemical explanation for the enhanced initial growth by condensation of organics despite the strong Kelvin effect. The effect of adsorption on initial cluster growth rate and new particle formation will be discussed.

Aerosol flux measurement in CARES and TCAP

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Aerosol particle fluxes in the boundary layer have been calculated from aircraft measurements by the ARM Aerial Facility (AAF) G-1 research aircraft for two field campaigns, the Carbonaceous Aerosols and Radiative Effects Study (CARES) and the Two-Column Aerosol Project (TCAP), when the aircraft was over land. The aerosol particle fluxes were calculated from the vertical velocities as measured by the G-1 gust probe, and the total aerosol particle concentrations were measured by the AAF ultra-high sensitivity aerosol spectrometer (UHSAS). Both measurements were determined at 10-Hz-meter resolution, which corresponds to a 10-meter spatial resolution; previous aircraft measurements at lower time resolution were not able to resolve the updrafts and downdrafts in the boundary layer, which is necessary for the aerosol flux calculation.

The calculated aerosol particle fluxes for CARES as measured in Sacramento, California, and likewise for TCAP in Cape Cod, Massachusetts, will be compared with respect to different forestations at these two different sites.

Aerosol Life Cycle working group value-added and evaluation products: recently produced and currently in progress

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Aerosol particles affect climate and climate change by scattering and absorbing solar radiation. The objective of the Aerosol Life Cycle working group is to improve understanding of the roles of aerosols in the climate system and specifically to decrease uncertainty in radiative forcing by aerosols, whether through direct interaction with solar radiation or indirectly through aerosol-cloud processes.

The ARM Infrastructure supports these objectives through processing of measurements collected at ARM facilities. Such processing has several aims including improved instrument operation (data screens, outlier rejection), improved interpretation of measurement data (quality control, for example), and retrieval of properties not directly available from the instrument measurements themselves such as aerosol optical depth (AOD) and intensive aerosol properties from both in situ and remote sensing measurements.

Here we present results highlighting recently generated value-added products (VAPs) with emphasis on products related to aerosol optical properties. Aerosol products have been delivered or are in progress at every existing ARM facility, permanent fixed sites as well as at each location that an ARM Mobile Facility (AMF) has operated.

Aging of biomass burning aerosols

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During the Fire Lab at Missoula Experiment 4 (FLAME 4) campaign in fall 2012 we systematically explored conditions associated with the aging of biomass burning smoke. Smoke samples from several different fuel burns were injected into two identical smog chambers with substantial dilution to roughly ambient aerosol concentrations. One chamber was held as a control, while the other was subject to an aging-related perturbation. Often the control was chemistry-free, while the perturbation was exposure to an oxidant (OH, ozone, etc). In some cases the control versus perturbation was low versus high NO_x with oxidation in each case, or darkness versus UV illumination. Broadly, introduction of ozone reliably showed a significant capacity for generation of additional aerosol, while introduction of OH radicals reliably oxidized the aerosol with variable effects on the total aerosol mass.

Application of the stochastic particle-resolved model PartMC to chamber experiments

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The stochastic particle-resolved aerosol model Particle-resolved Monte Carlo code for atmospheric aerosol simulation (PartMC) is a recently developed aerosol model that explicitly resolves and tracks the size and composition of individual particles as they undergo transformations by coagulation and condensation in the atmosphere. This approach spreads the initial aerosol size distribution over a finite number of Monte Carlo particles and allows them to evolve using the appropriate probabilities for coagulation and other processes.

For this study we adapted PartMC to represent the aerosol evolution in an aerosol chamber, with the intention to use the model as a tool to interpret and guide chamber experiments in the future. For this purpose we added chamber-specific processes such as wall loss due to particle diffusion and sedimentation and dilution effects due to sampling using the approach by Naumann (2003). We also implemented a treatment of fractal particles based on Naumann (2003) to account for the morphology of agglomerates and its impact on particle dynamics.

Here we show our model validation using experimental data from an aerosol chamber at the Department of Civil and Environmental Engineering at the University of Illinois. We obtained several size distribution data sets from coagulation experiments with ammonium sulfate particles. Moreover, scanning electron microscope (SEM) images of the filters provided evidence that coagulation significantly altered the particle structure from primary spherical particles to fractal-like agglomerates. We developed a fitting optimization approach to determine the best-estimate values for the wall loss parameters based on minimizing the L2-norm of the model errors of number and mass distributions. Obtaining the best fit required taking into account the non-spherical structure of the particles.

Black carbon from biomass burning

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Approximately 50% of black carbon (BC) aerosols come from wildfires and are estimated to contribute up to ~0.6 W/m2 warming of the atmosphere globally. Organic carbon (OC) from fires condenses and/or mixes with BC resulting in an overall lower forcing of 0.03±0.12 Wm-2 from biomass burning. However, this reduction depends strongly on the composition of the carbonaceous aerosols and on the mixing state of OC and BC. Detailed model treatments and laboratory measurements indicate that a BC core coated with a non-absorbing OC layer enhances absorption with a positive climate forcing.

However, the real-time identification of the coating on this internally mixed BC in the field has only recently become detectable with the analysis of lag times between the scattering and incandescence signals in measurements from the single-particle soot photometer (SP2). Direct online measurements of BC are made with the SP2, which measures the mass of the particles by incandescence on an individual particle basis, from nearby and aged wildfires in addition to those produced in the laboratory. We investigate BC in concentrated wildfire plumes from the two largest wildfires in New Mexico's history with different ages and compare them to BC from indoor generation from single-source fuels (e.g., ponderosa pine) sampled during the Fire Lab At Missoula Experiments IV (FLAME-IV) at the US Forest Service Rocky Mountain Research Station's Fire Science Laboratory in Missoula, Montana in November 2012. Plumes from the Las Conchas (LC) Fire, a wildfire that occurred in July–August of 2011 and burned ~157K acres, were sampled in the near-field after only a few hours of aging. Older plumes from the Whitewater Baldy (WB) Fire (May–June 2012) that burned ~300K acres were sampled from further afield with an aging period of 7–9 hours. FLAME-IV includes real-time sampling from direct emissions, well-mixed samples, and aging studies.

Characterization of individual ice nuclei collected during CARES and a new view on immersion freezing kinetics

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Rachel OBrian, Lawrence Berkeley National Laboratory
Ryan Moffet, University of the Pacific
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We investigate particles collected during the Carbonaceous Aerosols and Radiative Effects Study CARES) campaign for their ability for cold cloud formation. A combination of micro-spectroscopic and optical single-particle analytic methods is applied to relate individual particle physical and chemical properties with observed water uptake and ice nucleation. The most efficient ice nuclei (IN) from a particle population are identified and characterized. Single-particle characterization is provided by computer-controlled scanning electron microscopy with energy dispersive analysis of X-rays and scanning transmission X-ray microscopy with near-edge X-ray absorption fine structure spectroscopy. A vapor controlled cooling-stage coupled to a microscope system is applied to determine the onsets of water uptake, immersion freezing, and deposition ice nucleation as a function of temperature (T) as low as 200°K and relative humidity (RH) up to water saturation. These measurements reveal that the majority of particles collected during CARES are coated by organic material. The identified IN, active above the homogeneous ice nucleation threshold, are also coated by organics and are thus similar to the majority of the particles that do not nucleate ice. This suggests that highly abundant and chemically complex organic aerosol, typical of an urban environment, can initiate ice formation.

In another set of experiments we study immersion freezing of micrometer-sized water and aqueous solution droplets containing various IN such as humic acid compounds and biological and mineral dust particles. These compounds show significantly enhanced freezing T compared to homogeneous ice nucleation. The immersion freezing T follows solution water activity (aw) similar to the aw-based homogeneous ice nucleation description. That is, it follows the ice melting curve shifted by a constant value in aw. We find that along the experimentally determined freezing curve (as a function of aw and T) the nucleation rate coefficient, Jhet, in units per surface area and time is constant. Particle aw in equilibrium equals ambient RH, allowing straightforward implementation into cloud models. Changes in IN surface areas result in a corresponding change in freezing T and Jhet as expected from classical nucleation theory. The findings allow for a new and computationally low-demand description of immersion freezing by knowledge of RH and IN surface area only, independent of the type of solute and applicable to a variety of atmospheric conditions.

Continuous ground-based observation of aerosol optical properties in Tsukuba, Japan (trend and climatology)

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In order to investigate optical properties of aerosol, scattering coefficients and absorption coefficients have been continuously measured since January 2002 using an integrating nephelometer (TSI model 3563) and an absorption photometer (Radiance Research PSAP, PSAP3) during dry conditions at Tsukuba, Japan. Using these data, the recent 10 years trend of aerosol properties and climatology was investigated.

The results show that the aerosol characteristics have seasonal variation and the tendency to decrease or increase. These tendencies were significant in the confidence level 95%. The extinction, scattering, and absorption coefficients (1/m) had trends to decrease in the period from 2002 to 2012: -6.05x10-6, -4.94x10-6(1/year) at wavelength of 550nm and -1.11x10-6(1/year) at wavelength 526nm, respectively. The single-scattering albedo (SSA) has the trends to increase in the same period: 4.27x10-3(1/year) at wavelength of 550nm. Asymmetry factors have the trends to decrease in the same period: -2.22 x10-3(1/year) at wavelength 550nm. The extinction Ångström exponent has the tendency to increase, and the effective radius has the tendency to decrease. These tendencies are consistent with the tendency of asymmetry factor. The values of absorption Ångström exponent were about 1.0 and have seasonal variation. The absorption Ångström exponent had the trend to increase in the period from 2006 to 2012: 1.15x10-2(1/year). The change of absorption Ångström exponent suggests the change in the composition of light-absorbing aerosol. These tendencies are consistent with the results of radiometer data analysis.

Using data in the period from 2006 to 2012, the frequency distributions of aerosol properties were investigated. In this period, a 3-wavelength PSAP 3 was used. The most frequent values of extinction and absorption coefficients are 35x10-6(1/m) at wavelength of 550nm and 5x10-6(1/m) at wavelength of 526nm, respectively. The most frequent value of SSA was 0.855 at wavelength of 550nm. The characteristic of frequent distribution in every season was characterized by the dominant air mass in every season.

Continuous light absorption photometer (CLAP) performance

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The continuous light absorption photometer (CLAP) photometer is a multifilter absorption photometer developed at NOAA's Earth System Research Laboratory. The instrument measures the aerosol absorption coefficient at three visible wavelengths: 470, 528, and 660 nm. The instrument has eight sample spots and two reference spots per filter and is heated to 38°C. To date 25 CLAP instruments have been deployed and are in operation as part of the NOAA cooperative instrument network. The ARM Facility has three of these instruments in operation as part of the Southern Great Plains (SGP), ARM Mobile Facility (AMF) and North Slope of Alaska (NSA) aerosol observing systems (AOS). Results showing data precision, comparison with the particle soot absorption photometer (PSAP) at multiple sites, and preliminary results from a laboratory comparison between the several CLAPs, PSAPs, Thermoscientific multiangle absorption photometer (MAAP), Aerodyne cavity attenuated phase shift (CAPS) monitor and TSI nephelometer will be shown. A comparison of the Bond et al. PSAP correction scheme will be compared to a new two-stream radiative transfer model for transmission through a filter media will also be presented.

Effects of coatings on laser-induced incandescence measurements of black carbon

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Refractory black carbon particles are believed to have a large influence on climate through direct radiative forcing and by reduction of surface albedo of snow and ice in the cryosphere. The optical properties of atmospheric particles containing black carbon are uncertain, and the specific sources of these particles found in polar regions are also not well known. Laser-induced incandescence (LII) has been employed to measure atmospheric black carbon, but the interpretation of LII data is often complicated by the presence of coatings on these particles. Refractory black carbon particles found in the atmosphere are often coated with unburned fuel, sulfuric acid, water, ash, and other combustion by-products and atmospheric constituents. Coatings can alter the optical and physical properties of the particles and therefore change the response of optical diagnostics. A fuller understanding of how coatings affect LII is needed before the technique can be applied reliably to a wide range of particles. We have investigated the effects of coatings on combustion-generated black carbon particles using time-resolved LII measurements. Particles were generated in a coflow diffusion flame, extracted, cooled, and coated with oleic acid. The diffusion flame produces highly dendritic soot aggregates with similar properties to those produced in diesel engines. A thermodenuder was used to remove the coating. A scanning mobility particle sizer (SMPS) was used to monitor aggregate sizes, a centrifugal particle mass analyzer (CPMA) was used to measure coating mass fractions, and transmission electron microscopy (TEM) was used to characterize particle morphologies. The results demonstrate striking differences in LII temporal evolution and dependence on laser fluence between coated and uncoated particles. The LII signal appears to be sensitive to coating-induced particle morphology and optical changes. These results can be understood in the context of energy and mass balance during laser heating and conductive and evaporative cooling and are consistent with predictions based on an LII model that includes a heavy organic coating.

Evaluation of secondary organic aerosol (SOA) sources, growth, and sinks

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The scientific understanding of processes involved in the formation, chemical ageing, and removal of secondary organic aerosol (SOA) is still very limited. Here we summarize the results of three regional and explicit-chemistry modeling studies of (1) SOA formation and regional growth over a pine forest in Colorado, (2) contribution of glyoxal to SOA formation in California (Carbonaceous Aerosols and Radiative Effects Study [CARES], California Nexus [CalNex]), (3) the effect of dry deposition of gases on SOA formation (Megacity Initiative: Local and Global Research Observations [MILAGRO], Mexico City).

(1) The SOA formation and regional growth from biogenic precursors is of particular interest given their abundance in the atmosphere and has been investigated in 2011 in a pine forest using the Weather Research and Forecasting Chemistry (WRF-Chem) model and Generator of Explicit Chemistry and Kinetics of Organics in the Atmosphere (GECKO-A). We have quantified the relative contribution of different biogenic precursors to SOA, and investigated the relative contribution of OH, O_3 and NO_3 chemistry to SOA mass and in situ SOA formation. We show that the optically active regional SOA is substantial due to the large area covered by forests as the SOA formation continues for several days in the background forest air. We investigate whether the simplified SOA parameterizations used in 3D models can capture this growth.

(2) The dominant fraction of SOA is thought to be formed via gas-phase oxidation of precursors, but recent laboratory and field studies suggest that aqueous and heterogeneous chemistry within the particle (e.g., from glyoxal) play an important role. In our study we investigate the regional

contribution and variability of glyoxal to SOA formation using WRF-Chem that has been extended to include an updated description of the formation of glyoxal and its SOA. We find that Los Angeles is a hotspot for SOA from glyoxal and that a photochemically controlled pathway dominates. The improved model identifies a hot spot of glyoxal SOA in the southeastern US, and provides a useful tool for selection of locations for future studies.

(3) The dry deposition removal of organic compounds and its impact on SOA mass is currently poorly understood and represented in chemistry-climate models. The main reason for this omission is that current models use simplified SOA mechanisms, therefore losing information on other important properties of individual molecules that are needed to calculate dry deposition. Here, we apply GECKO-A to estimate the influence of dry deposition of gases on SOA concentrations downwind of Mexico City. We show that dry deposition of oxidized gases is not an efficient sink for SOA, as it removes <5% of SOA within the city's boundary layer and ~15% downwind.

Evaluation of simulated aerosols and clouds in CAM5 with different representation of aerosol microphysics

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A sectional aerosol package (Sect) that precisely links precursor gases to aerosol formation and size distribution for Community Atmosphere Model (CAM) 5 has been developed at Lawrence Livermore National Laboratory. This aerosol module integrates the Model of Ozone and Related Tracers (MOZART) gas chemistry with Model of Aerosol Dynamics, Reaction, Ionization, and Dissolution (MADRID) aerosol microphysics and an online biogenic emission system, Model of Emissions of Gases and Aerosols from Nature (MEGAN). Formation of secondary organic aerosols (SOAs) is simulated from 4 anthropogenic and 14 biogenic organic aerosol precursors. One unique aspect of CAM5/Sect is its capability to account for the impacts of interactive chemistry and size-resolved aerosol properties on atmospheric aerosol burdens. In addition to SOAs, other aerosol types simulated include sodium, sulfate, ammonium, nitrate, chloride, dust, primary black carbon, and organic carbon. The prognostic size-resolved aerosol components are subsequently coupled to photolysis, heterogeneous, and aqueous phase chemical reactions as well as cloud nucleation process. The number of constituents carried in CAM5/Sect is 335, as compared to 25 for the default version of CAM5 with the modal aerosol package (CAM5/MAM).

We started with two-degree horizontal resolution and eight size bins (0.02–10 micron in diameter) and are testing the model capability at high resolution for future use during field campaigns. Simulations of CAM5/Sect and initial comparisons of aerosol concentrations and cloud properties to ARM data will be presented. Evaluation of CAM5 applications with different representation of aerosol microphysics will also be addressed.

First in situ estimates of the contribution of nitrated aromatics to wood-burning brown carbon light absorption

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We show for the first time quantitative in situ measurements of five nitrated aromatic (NA) compounds in ambient air (nitrophenol $C_6H_5NO_3$, methylnitrophenol $C_7H_7NO_3$, nitrocatechol $C_6H_5NO_4$, methylnitrocatechol $C_7H_7NO_4$, and dinitrophenol $C_6H_4N_2O_5$) measured with a micro-orifice volatilization impactor (MOVI) high-resolution chemical ionization mass spectrometer in Detling, UK, during winter time. NA absorb radiation in the near-ultraviolet (UV) range of the electromagnetic spectrum and thus are among the high number of poorly constrained compounds of light-absorbing organic matter ("brown carbon"), affecting climate and air quality. Total concentrations varied between less than 1 and 98 ng m 3, with a mean value of 20 ng m-3. We conclude that NA measured in Detling have a significant contribution from biomass burning with an estimated emission factor of 0.2 ng (ppb CO)-1. Particle light absorption measurements by a 7-wavelength aethalometer in the near-UV (370 nm) and literature values of molecular absorption cross-sections are used to estimate the contribution of NA to wood-burning brown carbon UV light absorption. We show that these five NA are potentially important contributors to absorption at 370 nm measured by an aethalometer and account for 6±3% of UV light absorption by brown carbon. They can thus affect atmospheric radiative transfer and photochemistry and with that climate and air quality.

From sea to forest: measurements of atmospheric nanoparticle composition at two remote northern European locations

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This poster summarizes measurements of the composition of 10–30 nm diameter atmospheric nanoparticles from two remote locations in northern Europe during spring 2011. The measurements were performed using the Thermal Desorption Chemical Ionization Mass Spectrometer (TDCIMS) [1], which was recently upgraded to a high-resolution, time-of-flight mass spectrometer, at Hyytiälä Forestry Station, Finland, (April 8–28) and Mace Head Research Facility, Ireland, (May 13–31)[2]. Since new particle formation at Hyytiälä normally originates with clean arctic and marine air masses[3], comparisons of the two sites may provide some insights into the formation and evolution of aerosols in the Boreal Region.

At the coastal site, several apparent open ocean nucleation events[4] were observed. The TDCIMS-derived particle composition measurements and concurrent observations from a hygroscopicity tandem differential mobility analyzer (HTDMA) suggest that nascent particles during these events contain both significant organic and inorganic (chloride and sulfate) components. We hypothesize that these marine aerosol result from the growth of small sea salt-sulfate seeds by condensation of organic vapors. The atmospheric nanoparticles observed at Hyytiälä contained nitrate, sulfate, and highly oxygenated organic acids. Nitrate ions, which we hypothesize are derived from particulate organic nitrates that dissociate during analysis, were observed in all particles as small as 15 nm in diameter and displayed a diurnal concentration profile that peaked during the morning hours.

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Green leaf volatile (GLV) emissions from the central Amazon

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The Amazon Basin is a critical component governing Earth's climate through large continuous surface fluxes of energy, water, and carbon. In the last decade, the Amazon has suffered two short-lived but severe droughts resulting in extensive tree mortality. Although global climate models predict that Amazonian droughts may intensify in both frequency and duration in the future, several key land-atmosphere processes remain highly uncertain. Laboratory studies have revealed that green leaf volatiles (GLVs) represent a large group of fatty-acid oxidation products known to be released into the atmosphere by plants at high rates in direct response to drought stress and associated environmental conditions including high light and temperature. Chamber studies suggest that once emitted into the atmosphere, GLV oxidation can produce secondary organic aerosol serving as effective cloud condensation nuclei, a process that may play a significant but unknown role in water recycling in the Amazon Basin. It was traditionally considered a minor component of biogenic volatile organic compound (BVOC) emissions from terrestrial ecosystems, but here we report the first in situ observations of highly vertically resolved atmospheric GLV concentrations within and above a primary rainforest during the 2010 drought in the central Amazon.

Ice-nucleating properties of uncoated and coated mineral dust particles

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Mineral dust particles contribute to a major component of global aerosol fraction, and substantial evidence indicates that dust particles are most effective ice nuclei (IN). However, the ice-nucleating ability of mineral dust particles could be altered if they are coated with soluble materials such as sulfates. We report ice nucleation laboratory experiments showing that IN properties of coated dust particles depend upon the mineralogy of the dust particles.

The ice nucleation ability of uncoated and coated dust particles was investigated at three temperatures: -25°C, -30°C, and -35°C. Particles were size-selected and coated with sulfuric acid, and coating thickness was estimated by measuring the hygroscopicity properties of dust-coated particles. Only coated Arizona test dust particles showed suppression of IN ability; the ice-nucleating ability of other particles such as illite, kaolinite, montomorillonite, and quartz was not altered. This suggests mineralogical compositions dictate the chemical reactions with sulfuric acid that affect the ice-nucleating abilities. Results and conclusions with atmospheric implications will be presented.

Importance of mixing state for modeling aerosol impacts

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Individual aerosol particles are a complex mixture of a wide variety of species, such as soluble inorganic salts and acids, insoluble crustal materials, trace metals, and carbonaceous materials, requiring a high-dimensional representation in models. The capabilities of traditional models to treat this high dimensionality are currently very limited, and this introduces serious shortcomings in our understanding of chemical reactivity, cloud condensation nuclei activity, radiative properties, and health impacts of aerosol particles. In contrast, the stochastic particle-resolved model PartMC-MOSAIC (Particle-resolved Monte Carlo code for atmospheric aerosol simulation and Model for Simulating Aerosol Interactions and Chemistry) explicitly resolves the composition of individual particles in a given population of different types of aerosol particles. This approach tracks the evolution of the aerosol mixing state owing to emission, dilution, condensation, and coagulation. This model framework fills several crucial gaps in the way atmospheric aerosol particles are modeled: (1) It improves the theoretical understanding of aerosol mixing state representations, (2) it serves as a benchmark regarding mixing state for more approximate models, (3) it provides a way to estimate parameters needed by larger-scale models. Here we will show evaluations of the importance of mixing state on different climate-relevant aerosol properties based on particle-resolved model simulations. We will discuss the role of aerosol aging in this context.

The influence of functional groups on organic aerosol hygroscopicity

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Organic aerosols in the atmosphere are composed of a wide variety of species, reflecting the multitude of sources and growth processes of these particles. Especially challenging is predicting how these particles may act as cloud condensation nuclei (CCN). Köhler theory relates the particle's dry diameter to its critical supersaturation. A hygroscopicity parameter, kappa, parameterizes this relationship in terms of the particle's chemical composition. Previous studies have characterized kappa values for a range of organic model compounds. Here we extend these studies by designing new model systems that allow systematic investigation of the influence of the number and location of particular functional groups on the organic aerosols' kappa value. Organic compounds were synthesized via gas-phase and liquid-phase reactions. Gas-phase products were collected on filters and extracted using ethyl acetate. Filter extracts and liquid-phase products were then fractionated by reversed-phase high-performance liquid chromatography using gradient elution with acetonitrile and water. The eluate was atomized, the solvent was removed by evaporation, and the residual aerosol particles were analyzed as a function of retention time using high-resolution scanning flow CCN analysis. Individual organic compounds eluting from the synthesized mixture were identified using thermal desorption particle beam mass spectrometry. These experiments yielded changes in kappa that can be attributed to the addition of one or more hydroxyl, nitrate, carboxyl, aldehyde, hydroperoxide, and methylene functional groups while otherwise maintaining the structure of the organic molecule. Our results show that the addition of hydroxyl and carboxyl groups can significantly increase a particle's kappa value, while the addition of hydroperoxide, nitrate, and methylene groups does not. We anticipate that our results contribute to a mechanistic understanding of chemical aging and will help to guide input and parameterization choices in models that rely on simplified treatments such as the atomic oxygen-to-carbon ratio to predict the evolution of organic aerosol hygroscopicity.

In situ derived aerosol optical properties during the TCAP Phase-I campaign

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Evgueni Kassianov, Pacific Northwest National Laboratory
Celine Kluzek, Pacific Northwest National Laboratory
Mikhail Pekour, Pacific Northwest National Laboratory
Arthur Sedlacek, Brookhaven National Laboratory
John Shilling, Pacific Northwest National Laboratory
Yohei Shinozuka, NASA
Jason Tomlinson, Pacific Northwest National Laboratory
Jacqueline Wilson, Pacific Northwest National Laboratory
Alla Zelenyuk-Imre, Pacific Northwest National Laboratory

The uncertainties in atmospheric radiative forcing are in part a result of limited knowledge of aerosol optical properties. In this presentation, we discuss in situ measurements of aerosol optical properties obtained during Phase I of the Two-Column Aerosol Project (TCAP) and explore their links with aerosol chemical and physical properties. The TCAP field campaign is designed to provide observations of the size distribution, chemical composition, and optical properties of aerosols within and between two atmospheric columns off the eastern seaboard of the United States. These columns are separated by 200–300 km and were sampled in July 2012 during a summer intensive operation period (IOP) using the U.S. Department of Energy's Gulfstream-1 (G-1) and NASA's B200 aircraft and the surface-based DOE Atmospheric Radiation Measurement (ARM) Climate Research Facility's Mobile Facility (AMF) located at Cape Cod. Initial analysis indicates that the type and/or composition of aerosols at lower altitudes (below 3 km) and higher altitudes (3–4 km) were different, yielding different aerosol optical properties. For example, aerosols observed at higher elevations are more hygroscopic with lower single-scattering albedo than aerosols observed at lower altitudes. Initial results will be presented at the ASR Science Team Meeting.

Investigating sources of secondary organic aerosols and linking laboratory and field studies with a rapid-flow reactor

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Recent field studies reveal large formation of secondary organic aerosol (SOA) under urban polluted ambient conditions, and there are indications of strong synergy between anthropogenic pollution and biogenic volatile organic compounds (VOCs) in increasing SOA formation. Analysis of previous field studies depend on assumptions about vertical mixing, regional dispersion, and photochemical age in order to relate the evolution of SOA versus its precursors and oxidants, which limits the scientific insights achievable under many conditions. To directly study SOA formation in ambient air in real-time, our group has demonstrated a Potential Aerosol Mass (PAM) photo-oxidation flow reactor in conjunction with an Aerodyne aerosol mass spectrometer (AMS), a scanning mobility particle sizer (SMPS), and a proton-transfer-reaction mass spectrometer (PTRMS). We have used this system to characterize SOA formation in (a) urban air during CalNex-LA-2010 in the Los Angeles area of California, (b) forest air at the US Forest Service (USFS) Manitou Forest in Colorado during BEACHON-RoMBAS-2011, and (c) biomass smoke in at the USFS Fire Science Lab in Missoula, Montana, during FLAME-3. The PAM reactor uses mercury lamps to create OH concentrations up to 10,000 times ambient levels. High oxidant concentrations accelerate the processing of volatile organic compounds and inorganic gases and their growth into the aerosol phase. PAM photochemical processing can represent up to approximately 20 days of equivalent atmospheric aging in the span of 4 minutes of residence time in the reactor, and PAM-processed aerosols have shown aging signatures and sulfate and SOA yields similar to ambient and large chamber studies. In some campaigns we used a gas-phase denuder to study heterogeneous OH processing of the pre-existing aerosol or injected O_3 or N_2O_5 in PAM without lights to investigate SOA formation from O_3 or NO_3 oxidation. In all cases PAM OH photoxidation enhances SOA at intermediate exposure but results in net loss of OA at very long exposures. SOA formation greatly exceeds that calculated from the measured precursors in urban and forest air. PAM oxidation also results in a similar slope in the Van Krevelen diagram than ambient oxidation. A model of the radical and oxidation chemistry has been developed to characterize the reactor under different conditions and understand its sensitivities. Lab experiments are used to determine SOA yields for key precursors of the above campaigns and also to study SOA formation under conditions simulating the 2010 Gulf of Mexico oil spill.

https://sites.google.com/site/pamwiki/

Kinetics of CCN activation and droplet growth observed in recent field campaigns

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Atmospheric aerosols can indirectly influence global climate budget by changing the microphysical structure, lifetime, and coverage of clouds. While it is generally agreed that aerosol indirect effects act to cool the Earth-atmosphere system by increasing cloud reflectivity and coverage, the magnitudes of the indirect effects are poorly understood. The formation of cloud droplets from aerosol particles is kinetically controlled by the availability of water vapor, equilibrium water vapor pressure above the growing droplet surface, and both the gas phase and aerosol phase mass transfer resistances. It has been hypothesized that the formation of surface organic films or the delay in dissolution of solute could significantly delay the growth of cloud droplets. Such delay could lead to a higher maximum supersaturation within a rising cloud parcel, and therefore a higher droplet number concentration and smaller droplet size at constant liquid water content. When only a subset of the droplets experiences significant growth delay, the overall droplet size spectrum will be broadened, which facilitates the formation of precipitation.

During three recent field campaigns (CalNex-LA, CARES, and the Aerosol Intensive Observation Period at Brookhaven National Laboratory), the CCN activity and droplet growth of size-selected particles ranging from 25 to 320 nm were characterized by a cloud condensation nuclei (CCN) counter under supersaturations from 0.1% to 0.8%. The three campaigns allow us to examine the droplet growth for many representative organic aerosol types, including biogenic secondary organic aerosol (SOA), anthropogenic SOA, and organic aerosols from biomass burning. The droplet growth of size-selected ambient particles inside the CCN counter was found to be influenced by a number of parameters, including particle critical supersaturation, heterogeneity in particle composition, and particle concentration. For example, reduced droplet growth due to water vapor depletion was observed when particle concentration was higher than 200 cm^-3. The influences of the different parameters on droplet growth were modeled and compared with measurements. The potential impact of surface organic film on droplet growth was isolated by comparing the droplet growth of size-selected ambient particles to that of ammonium sulfate particles with the same critical supersaturation, and the results are discussed.

Modeling black carbon aging with PartMC-1D

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The chemical reactivity, cloud condensation nuclei activity, radiative properties, and health impacts of black-carbon-containing particles depend crucially on the aerosol mixing state. The recently developed stochastic particle-resolving aerosol box model PartMC-MOSAIC has allowed unique insight into the evolution of aerosol mixing state as it tracks per-particle evolution for an aerosol population undergoing coagulation, condensation, dilution, and emission in a Lagrangian air parcel.

We developed this model further by coupling it with the single-column version of the Weather Research and Forecast (WRF) model. The resulting spatially resolved model PartMC-1D predicts the per-particle size and composition as well as transport processes driven by local meteorology to provide detail about the spatial distribution of particles and further insight into the evolution of the aerosol mixing state.

Here we present spatially and particle-resolved simulation results of black carbon aging in a polluted boundary layer. While the bulk concentration of black carbon was well-mixed in the boundary layer during the day, there was a strong dependence of black carbon mixing state on height with fresh black carbon particles existing in only the lowest layers. Maximum surface concentrations were found in the early morning hours due to an increase in gasoline vehicle emissions at a time of low atmospheric mixing. Based on these results we quantify the implications for cloud condensation nucleation activity and optical properties of black-carbon-containing particles.

Modeling regional-scale variability of organic aerosols in the atmosphere

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In the first part of this poster, simulations of carbonaceous and inorganic aerosols made by the Weather Research and Forecasting Chemistry (WRF-Chem) model with the MOSAIC aerosol model and a volatility basis set approach of representing secondary organic aerosol (SOA) are evaluated using measurements collected during the Carbonaceous Aerosols and Radiative Effects (CARES) field campaign in California during June 2010. When using the 2008 emission inventory for California, predictions of organic matter agree reasonably well with aerosol mass spectrometer (AMS) measurements in the Sacramento and San Joaquin Valleys. However, estimates of primary organic aerosol (POA) derived from the AMS data suggest simulated primary organic aerosol (POA) was too high and simulated SOA was too low. Simulated black carbon (BC) was also too high compared to surface and aircraft measurements. It is likely that simulated biogenic source of SOA was too low, since simulated isoprene was low by a factor of two. Shilling et al. found enhanced SOA formation when the Sacramento plume interacted with biogenic species, and possible mechanisms for this are being investigated with the model.

For the second part of this poster, we investigate the important issues of particle-phase changes in volatility and gas-phase fragmentation versus functionalization reactions affecting the formation and evolution of SOA. We show that under any realistic assumptions of mass accommodation coefficient, our analysis of measured evaporation rates of SOA imply significantly lower “effective volatility” than those derived from SOA growth in smog chamber, pointing towards the role of particle phase changes after SOA formation. Thus, models may need to use different parameters to describe SOA volatility during and after formation. Using both a box model and the 3D chemical transport model, we investigate the implications of low “effective volatility” of SOA and gas-phase fragmentation reactions. All our box model configurations using multi-generational gas-phase chemistry predict one-two orders of magnitude higher SOA loadings compared to the models that neglect this chemistry.

Previous models with multi-generational chemistry limited to functionalization reactions are known to eventually produce too much SOA, and including fragmentation reactions significantly reduces SOA production. The 3D model demonstrates complex variations in spatial and temporal distribution of SOA with varying degrees of fragmentation. In addition, the treatment of SOA as semi-volatile or non-volatile also causes variations in predicted SOA loadings in the atmosphere.

New particle formation and growth from the reaction of methanesulfonic acid with amines and the ozonolysis of terpenes

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Airborne particles are known to negatively impact health and visibility. They also substantially influence climate via scattering incoming solar radiation and cloud formation/processes. Secondary organic aerosol (SOA) constitutes a large fraction of the global airborne particles budget. They are formed from the reaction of gaseous precursors to form low- and semi-volatility products that either nucleate to form new particles or condense on existing seed particles, causing them to grow. Although in the atmosphere, nucleation has been associated primarily with gas phase H_2SO_4, there is increasing evidence that organic compounds may play a significant role. In addition, biogenic species such as terpenes are known to play an important role in determining the mass loading of particulate matter.

We present here experiments of new particle formation and growth from two different systems including (1) the reaction between methanesulfonic acid, amines and water and (2) the ozonolysis of terpenes. Experiments were performed using two unique flow reactors with reaction times that cover the range from seconds to hours. For each system, size distribution and chemical composition of the SOA were measured, as well as the gas-phase concentrations of the precursors. The identity/nature of the species and the mechanisms involved in the first nucleation steps and/or the growth of the SOA will be presented.

On the role of particle mixing state in heterogeneous and multiphase reaction kinetics

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The rate at which trace gases are accommodated at the gas-particle interface is a complex function of single-particle chemical composition, morphology, and physical phase state. To date, the vast majority of atmospheric observations and models designed to interpret these measurements focus on the ensemble average of aerosol particle mass, assuming that each individual particle has the same chemical identity as the average state (internally mixed) as opposed to treating individual particles as having unique chemical composition (externally mixed). Here, we assess the impact of particle mixing state on heterogeneous and multiphase reaction kinetics using the reactive uptake of N2O5 and HOCl on sea-spray aerosol as a model system. Simultaneous observations of single-particle chemical composition made using single-particle aerosol mass spectrometry and scanning transmission X-ray microscopy, combined with in situ measurements of N_2O_5 and HOCl reactive uptake, are used to constrain model parameterizations under both internal and external mixing assumptions. We describe results obtained from ambient studies conducted at the Scripps Institution of Oceanography (SIO) Pier in La Jolla, California, and laboratory studies conducted using a newly developed air-sea interaction facility at the SIO hydraulics laboratory. These studies permit assessment of the dependence of the reactive uptake for N_2O_5 and HOCl on the presence of organic films and the mixing state of organic compounds within nascent sea-spray aerosol.

Organic aerosol value-added product: method development and year-long results from SGP

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Organic aerosol (OA) makes up a large portion of aerosols in the atmosphere. A better understanding of the chemical composition of OA is needed to quantify the effects that aerosols have on radiation and clouds. OA is composed of thousands of species, making its chemical and physical properties difficult to characterize. However, recent studies indicate that the application of multivariate factor analysis on ambient OA data acquired with aerosol mass spectrometers (AMS) can lead to the identification of distinct OA factors representative of different sources and evolution processes. The OA factors thus determined can be particularly useful for closure studies on aerosol optical and cloud condensation properties. Three aerosol chemical speciation monitors (ACSM) were recently added to two long-term measurement sites (Tropical Western Pacific and Southern Great Plains) and a mobile facility supported by the ARM Climate Research Facility. The ACSM is a smaller version of an AMS designed to provide long-term, continuous measurements of aerosols with low maintenance. In this presentation, we will report the development of methods that take measurements of total OA and mass spectral information from the ACSM and derive OA factors using Positive Matrix Factorization (PMF). We will describe how the OA factors are derived, the quality assurance (QA) procedures, and comparisons of side-by-side measurements from AMS and ACSM instruments deployed during the Aerosol Life Cycle Intensive Operational Period at Brookhaven National Laboratory. The code generated in this analysis will be run within the ARM Data Management Facility, and the new data product, called Organic Aerosol Composition (OACOMP), will be added to the ARM Data Archive. The results from over a year-long period of ACSM measurements from the SGP site will be presented, along with an analysis that explains the seasonal and multi-day variations in inorganic and organic aerosol components.

Overview of ClearfLo: study of aerosol sources and processing at a rural site southeast of London

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Clean Air for London (ClearfLo) is a large, multidisciplinary study of the London urban atmosphere aimed at understanding the relationships between surface meteorology, gas-phase composition, and particulate matter from multiple sites: at a city street site (urban London), a city background site (away from local traffic sources) and at a rural location (outflow from the London urban area). We deployed a suite of instruments at the rural site approximately 50 km southeast of London in Detling, UK, during January–February 2012. Measurements included aerosol chemical, optical and microphysical properties, gas-phase tracers, secondary organic aerosol (SOA) precursors, and radiative and meteorological conditions. During the six-week campaign, we sampled air masses from several distinct sources. Winds from the southwest passed over a large road 200 m from the site and brought air masses characterized by highly variable CO, indicating local sources, high black carbon concentrations, and hydrocarbon-like aerosol chemical composition. When the wind was from the east and northeast, we sampled outflow from the European continent. The gas-phase composition indicated an aged air mass, and particle composition was predominately oxygenated organics, nitrate, and sulfate. Outflow from London was sampled during periods when the wind was from the northwest. In addition to regional air quality, the wintertime study provided information on gas and particle emissions from local home-heating solid fuels. We will present case studies of different particle sources, including a comparison of chemistry and optical properties, as well as comparisons with urban London particulate measurements.

PASS3 measurements from two DOE ARM aerosol observing systems (AOS): SGP and the recent MAOS deployments for PACE and TCAP

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Aerosol absorption and scattering are reported from the three-wavelength photoacoustic soot spectrometers (PASS3, Droplet Measurement Technologies) located in two DOE ARM aerosol observing systems (AOS) from within the last year. Stationary measurements have been made at the Southern Great Plains (SGP) Central Facility in Ponca City, Oklahoma, since January 2013 at 405 nm, 532 nm, and 781 nm with an upgraded instrument. Improved lasers with increased laser powers and an external acoustic filter have been deployed to increase instrumental signal-to-noise ratios over those previously made from 2009 to 2012. Results from the PASS3 within the two recent MAOS deployments will also be shown. The Pajarito Aerosol Coupling to Ecosystems (PACE) campaign occurred in the winter of 2012 at Los Alamos National Laboratory in New Mexico, and the Two-Column Aerosol Project has been a two-phase project occurring during two different seasons in Cape Cod, Massachusetts, during summer 2012 and winter 2013. Absorption and scattering measurements are compared with collocated measurements made with the particle soot absorption photometer (PSAP, Radiance Research) at 467 nm, 530 nm, and 660 nm, and a cavity attenuated phase shift spectrometer (CAPS, Aerodyne, Inc.) that measures particulate extinction (absorption + scattering) at 450 nm.

Phase, viscosity, morphology, and room temperature evaporation rates of SOA particles at low and high relative humidities, and their interaction with hydrophobic organics

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Formation, properties, transformations, and temporal evolution of secondary organic aerosol (SOA) particles strongly depend on particle phase. Semi-volatile molecules that comprise SOA particles were assumed to form a low-viscosity solution that maintains equilibrium with the evolving gas phase by rapid evaporation condensation. However, recent studies by our and other groups indicate that SOA particles are in a semi-solid, highly viscous phase, and their evaporation rates are orders of magnitude slower than predicted.

Given that atmospheric relative humidity (RH) can change particle phase, it is important to investigate the effect of RH on the phase and evaporation kinetics of SOA particles. To this end, SOA particles were generated at low and high (~90%) RH, and their evaporation kinetics and phase were characterized as a function of RH.

In the ambient atmosphere, SOA particles form in the presence of a mixture of different organic compounds, which are present at or below their equilibrium vapor pressure and thus have been ignored.

However, our data show that these compounds can adsorb to the surface of particles during SOA formation, becoming trapped in the highly viscous SOA, and affect particle properties.

We examine the interaction between SOA particles and different hydrophobic organics representing typical anthropogenic emissions by making SOA in the presence of the vapors of these hydrophobic organics and characterizing their properties. We find that the interaction between SOA and hydrophobic organics leads to a symbiotic relation, in which trapped hydrophobic organics are protected from evaporation and the oxidizing atmosphere, and the presence of hydrophobic organics virtually stops SOA evaporation.

We also demonstrate that it is possible to directly measure the diffusion rates of these molecules in SOA and use them to calculate the SOA viscosity of 10^8 Pa s. Such a high viscosity is characteristic of tars and is consistent with published measurements of SOA particle bounce, evaporation kinetics, and the stability of two reverse-layered morphologies.

Measurements on aged SOA particles doped with pyrene yield an estimated diffusivity ~3 times smaller, indicating that hardening occurs with time, which is consistent with the increase in SOA oligomer content, decrease in water uptake, and decrease in evaporation rate previously observed with aging.

Probing rBC-containing particle morphology with a single-particle soot photometer (SP2)

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Knowledge of the structure and mixing state of black-carbon-containing particles is important for calculating their radiative forcing and provides insight into their sources and life cycles. Recent analysis of the single-particle signals from a single-particle soot photometer (SP2) instrument for black-carbon-containing particles has identified a significant fraction where the black carbon component may reside on or near the surface of the particle as opposed to in a core-shell configuration. Traditionally, core-shell configurations are assumed in which the black carbon core is surrounded by a shell of non-refractory material. During the DOE-sponsored Aerosol Life Cycle field campaign held in summer 2011 at Brookhaven National Laboratory on Long Island, New York, episodes were encountered in which a high fraction of particles containing black carbon had such configurations. These episodes corresponded to air masses that contained biomass burning plumes (Sedlacek et al. 2012). Subsequent analysis found similar episodes in additional field campaigns in Colorado and California in which high fractions of black-carbon-containing particles exhibited a similar configuration. These episodes also corresponded to biomass burning plumes. In an effort to evaluate this interpretation and explore formation mechanisms for these types of particle morphologies, a series of laboratory-based experiments examining the coagulation of Regal black (surrogate for collapsed soot) with model non-refractory coatings dioctyl sebacate (surrogate for organic aerosols with liquid-like character) and deliquesced ammonium sulfate (solid) were carried out. The results of these experiments and their potential implications on black carbon radiative forcing will be discussed. In addition to the laboratory study, preliminary analysis from the summer portion of the Two-Column Aerosol Project (TCAP) field campaign will also be presented.

Sedlacek III, Arthur, ER Lewis, LI Kleinman, J Xu, and Q Zhang. 2012. "Determination of and Evidence for Non-core-shell structure of particles containing black carbon using the single-particle soot photometer (SP2)." *Geophysical Research Letters* 39: L06802, doi:10.1029/2012GL050905.

Progress on the analysis of aerosol optical properties from CARES

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During June 2010, three multi-wavelength cavity ring-down extinction instruments were used at the T0 (Sacramento, California) and T1 (Cool, California) ground sites for the Carbonaceous Aerosols and Radiative Effects Study (CARES) field campaign to obtain aerosol optical properties and how they varied with size, relative humidity, and thermo-denuding. Light absorption coefficients were also measured at T0 using a photo-acoustic instrument operating at two wavelengths both before and after thermo-denuding. Some analysis of the rich data set has been completed and published, some is nearing completion, and some is planned for the near future. The analysis of the thermo-denuded aerosol extinction and absorption showed very little difference in the absorption when an optically significant amount of clear organic matter was removed from the particles (as judged by the change in extinction). This observation stands in contrast to the theoretical expectations that a clear coating on black carbon particles tends to increase the absorption coefficient via light focusing through lensing. Subsequent electron microscopy measurements suggest that a substantial fraction of the BC-containing particles sampled during CARES did not have a core-shell morphology (which leads to the largest enhancement factors), consistent with the optical measurements. In a separate line of investigation, the dependence of extinction or scattering on relative humidity, characterized by an optical hygroscopic aerosol growth factor, γ {where $b^{ext}(\%RH) = b^{ext}(dry) * (100\% - \%RH)^{-\gamma}$} was found to depend strongly on particle size and composition, with some periods of higher than expected particle growth for mainly organic aerosols. The role of super-micron particles ($D^p >$ 1.0 μm) in the observed optical growth is still being investigated and appears to have been important, but it still seems likely that some of the organic aerosols observed during CARES had greater than expected hygroscopicity. Planned future analyses also include the use of three-wavelength extinction coefficient data at both ground sites to produce a separation of fine and coarse mode scattering and an estimate of the effective radius for the observed particle distributions, potentially allowing a complete retrieval of size and hygroscopic growth, using only the optical data for future field campaigns and longer-term unattended monitoring applications.

Properties of aerosol in the North Atlantic free troposphere at the Pico Mountain Observatory, Azores

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Robert Owen, Michigan Technological Research Institute
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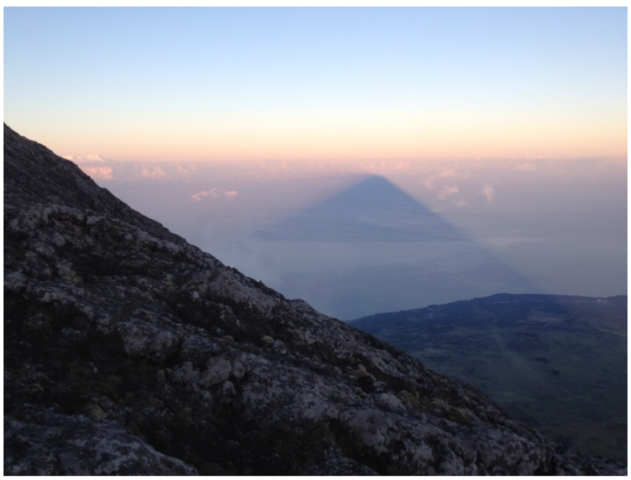
Jacques Hueber, University of Colorado



The Pico Mountain Observatory is located at an altitude of 2225 meters above sea level in the summit caldera of the Pico volcano in the Azores, Portugal (38.47°N, 28.40°W). The scientific value of the station stems from the fact that this is the only permanent free-tropospheric monitoring station in the central North Atlantic, with negligible influence from local sources and that frequently samples air from the North American continent. Thus, it is an ideal site for studying long-range transported pollution. The station started operating in 2001 with a focus on gaseous species (e.g., ozone, carbon monoxide, nitrogen oxides, and non-methane hydrocarbons) and aerosol particles that absorb light (black carbon [BC] and aerosol dust). The absorbing aerosol mass concentrations, in units of equivalent black carbon mass concentrations, have been monitored using a seven-wavelength aethalometer (Magee scientific model AE31). Ancillary measurements at the station include meteorological parameters such as temperature, relative humidity, pressure, wind direction, and speed. Due to the harsh environmental conditions at the site, most measurements have been performed during the summer seasons. In the summer of 2012, new aerosol instrumentation and samplers were installed at the station. The new equipment includes a three-wavelength nephelometer (Ecotech model Aurora 3000) that measure aerosol scattering and backscattering fraction, a set of four high-volume samplers for the collection and chemical analysis of aerosol, a sequential sampler to collect aerosols on membranes and grids, and an optical particle counter. Membranes and grids are analysed offline with scanning and transmission electron microscopy to study morphological properties and elemental composition of the aged aerosols.

In this poster we will discuss some of the analysis of the decadal BC mass concentration data, as well as some analysis of the new aerosol data with a focus on aerosol optical properties and morphology. Analysis of these properties is important for a better understanding of aerosol's life cycle and ageing during their transport over the Atlantic, with implications on aerosol radiative properties and climate science.

http://instaar.colorado.edu/pico/

Real-time size-distributed measurement of aerosol mass concentration

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This report covers research conducted under DOE sponsorship pertaining to atmospheric aerosols that play an important role in climate change. The creation, presence, and decay of particles in the atmosphere determine cloud formation as well as penetration of solar radiation through the atmosphere. Accurate data of atmospheric aerosols are needed to predict global warming and climate change.

This project has been concerned with the development of instrumentation for airplane-based aerosol measurements. As a starting point, we have used our state-of-the-art aerosol sampling instrument known as the micro-orifice uniform deposition impactor (MOUDI). This instrument consists of multiple stages, and at each stage, aerosols of a certain size class are deposited on an impaction plate. Aerosol size ranges from 10 nanometers (very fine) to 10 microns (very coarse). When used aboard an aerial vehicle, the MOUDI allows determination of accumulated aerosol masses in each size class for the entire flight trajectory, because the aerosol mass is determined through laboratory analysis on the ground. Detailed information such as differences between the aerosol size distribution near and far from a cloud and the effect of altitude on the aerosol size distribution is not available. Hence, the objective of the present research has been to investigate the feasibility of sensor technologies that would enable real-time mass measurements at each stage of a MOUDI-type instrument.

The desired sensor technology has now been proven in our Phase I laboratory work. Impedance-based quartz crystal microbalance (IQCM) is shown to be compatible with the individual aerosol collection stages of the MOUDI and would meet the real-time measurement need of the atmospheric research program. The gold disc in the accompanying image is an IQCM sensor mounted to a MOUDI stage, with white dots representing the deposited aerosols. Impedance versus frequency curve of the sensor has two characteristic frequencies (fs and fp), which vary linearly with the mass of the deposited aerosols. The IQCM sensors provide stable output with nanogram resolution.

In the next phase of this project, this technology will be used to develop and deliver flight-worthy aerosol measuring instruments, where aerosol mass would be monitored in real-time for each size class. Further, accessories will be provided to measure the moisture uptake and the deliquescence and efflorescence relative humidity values of the collected samples during the flight.

Relationship between the cloud condensation nuclei concentration and aerosol optical properties and their impact factors

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Cloud condensation nuclei (CCN) concentration is one of the most important properties for understanding the effects of aerosols on climate forcing. However, global measurements of CCN concentrations are scanty. To assess the remote sensing of CCN concentration, this study investigates the relationship between the aerosol optical properties and CCN concentration, as well as the effects of meteorological factors (e.g., relative humidity, wind, hygroscopicity, etc.) on their relationship, based on the observations at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains

(SGP) site and observations from ARM Mobile Facility (AMF) deployments— the Graciosa Island (GRW) site in the Azores, the Black Forest region (FKB) site in Germany, the Ganges Valley region (PGH) site in India, and the Niamey (NIM) site in Niger.

The relationship between CCN concentration at 0.4% supersaturation and aerosol optical depth (AOD) at 500 nm is fitted by a power law equation, which showed both good correlation with R2=0.88 at the SGP site and poor correlation with R2=0.19 at the GRW site. Use of the AOD and Angstrom exponent (α) can improve their relationship at both sites, with R2 increasing to 0.95 and 0.56 at the two sites, respectively. Since the aerosol scattering/absorption coefficients were measured at the same altitude as the CCN measurements, the relationship between the aerosol scattering/absorption coefficients and CCN concentration is better than that between the AOD and CCN concentration. The ambient relative humidity (RH) plays an important role in the relationship. Aerosol optical loading (e.g., AOD) measured at lower RH or dry condition is a better proxy of CCN than under high RH or wet conditions. The hygroscopic growth factor affects the relationship between CCN and AOD, which may be accounted for by virtue of the swelling factor. For the relatively strong absorbency aerosol with single-scattering albedo (SSA) <0.8, the relationship between the combination of aerosol extinction coefficients and α and CCN concentration is better than that between the aerosol extinction coefficient alone and CCN concentration. However, for relatively strong scattering aerosol with SSA>0.9, the result is the reverse. This indicates that the aerosol compositions also significantly influence the ability of remote sensing CCN concentration and must be considered in order to improve this relationship.

Sparse particle models for data analysis and assimilation

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Yangang Liu, Brookhaven National Laboratory
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This poster illustrates several members from a class of sparse particle models, with specialization to sparse aerosol models (SAMs), derived from linear programming (LP). The same approach also applies to cloud particle populations, and this application is under exploration. Examples of SAMs are presented with applications to data analysis and assimilation including the calculation of rigorous, nested, upper and lower bounds on aerosol physical and optical properties. The quadrature method of moments (QMOM), which provides a highly accurate approach to aerosol simulation while preserving computational efficiency, falls into this sparse aerosol models class. Here it is shown how other SAMs can be constructed, which are not based on moments of the particle size distribution. Examples of data assimilation will be presented based on simulated light extinction coefficient measurements (wavelengths from 0.3 to 1.1 micron) for one of the Hoppel aerosol test distributions (Hoppel et al., 1990, *Journal of Geophysical Research*: 3659). The examples include: (1) bounding the extinction coefficient using moments of the test distribution as LP constraints and (2) the inverse problem of bounding lower-order moments using the simulated extinction coefficient measurements as LP constraints. Next we partition the test aerosol size distribution into various numbers of sections and use the known particle number concentrations in each section as LP constraints to bound extinction coefficient and lower-order moments. The extent to which the bounds are refined through a doubling and then quadrupling the number of sections provides a quantitative measure of information achievable through subgrid resolution. Potential applications of sparse particle models to Kalman filtering are also discussed.

Spectro-microscopic characterization of liquid-liquid phase separation in aerosols

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Allan Bertram, University of British Columbia
Ryan Moffet, University of the Pacific
Mary Gilles, Lawrence Berkeley National Laboratory

The liquid-liquid phase separations of laboratory-generated aerosol particles were investigated using (1) scanning transmission X-ray microscopy/near-edge X-ray absorption fine structure spectroscopy (STXM/NEXAFS) coupled to a relative humidity (RH) controlled in situ cell and (2) environmental scanning electron microscopy (ESEM). In previous work, samples have been prepared by extraction from filter material and subsequent generation of larger particles. The techniques used here, however, are well-suited for analyzing the phase separations of ambient particles with no prior processing. The aerosol particles were comprised of 1:1 and 3:1 HMMA: ammonium sulfate. HMMA is a nine-carbon, aromatic compound that is used as a proxy for water-soluble organic compounds found in atmospheric aerosols. Preliminary results show that liquid-liquid phase separations occur at RHs between the deliquescence and efflorescence points, and that the organic phase surrounds the inorganic phase. The STXM/NEXAFS technique provides insight into the chemical bonding environment in the two phases both before and after separation for atmospherically relevant particles of 1–3 µm diameter.

Statistical mechanics of multilayer sorption: surface tension

Anthony Wexler, University of California
Cari Dutcher, University of California
Simon Clegg, University of California

Mathematical models of surface tension as a function of solute concentration are needed for predicting the behavior of surface processes relevant to the environment, biology, and industry. Current aqueous surface tension-concentration models capture either solutions of electrolytes or those of organics, but a single set of equations has not yet been found that represents both in one unified framework. In prior work we developed an accurate model of the activity-concentration relationship over the full range of compositions by extending the Brunauer-Emmett-Teller (BET) and Gugenheim, Anderson, and De Boer (GAB) isotherms models to multiple-sorbed monolayers. Here we employ similar statistical mechanical tools to develop a simple equation for the surface tension-composition relationship that differs remarkably from prior formulations in that it (1) works equally well for organic and electrolyte solutes and their mixtures, (2) does not contain any factors representing the relative amounts of solute in the bulk or at the surface—this is captured by surface-bulk equilibria in the model, and (3) is accurate over the entire RH range.

http://www.aim.env.uea.ac.uk/aim/aim.php

TCAP 1 particle-into-liquid-sampler aircraft data

Thomas Watson, Brookhaven National Laboratory

The Particle-into-Liquid Sampler (PILS)-Ion Chromatography (IC) instrument is an aqueous solution-based technique for determining bulk chemical composition of ambient aerosol particles. The size ranges measured range from approximately 70 nm to 2.5µm in diameter. The chemical species measured are:

- Li^{+}, Na^{+}, NH^{-4+}, Mg^{2+}, K^{+}, Ca^{2+}
- Cl^{-}, Br^{-}, NO_3^{-}, $H_2PO_4^{3-}$, SO_4^{2-}, $C_2O_4^{2-}$

The data from the PILS are essential to calibrate the aerosol chemical speciation monitor (ACSM) in the Mobile Aerosol Observing System Aerosol module (MAOS-A) and the aerosol mass spectrometer (AMS) on the G-1.

PILS data were collected on 10 flights of the DOE G-1 during the Two-Column Aerosol Project (TCAP) from July 9 through July 25, 2012. The total mass data from the PILS have been correlated with the data from the three-color nephelometer and delay times for the PILS determined. The delays were consistent between all 10 flights and were 324 seconds with a standard deviation of the mean of 1 second. A time series of ions, the mass distribution of ions, and the correlation of ion pairs will be presented for selected flights, and comparisons with other instruments making aerosol mass measurements will be made. A comparison with the aircraft data and the PILS measurements made at the MAOS ground site will also be presented, as will correlation of ions measured at the ground site with wind direction.

Ten years of aerosol chemical and optical properties at SGP and NSA: building regional aerosol models for radiative transfer

Allison McComiskey, National Oceanic and Atmospheric Administration
John Ogren, NOAA Earth System Research Laboratory
Ellsworth Dutton, NOAA OAR Earth System Research Laboratory
Patricia Quinn, NOAA Precision Measurement Equipment Laboratory
Joyce Harris, NOAA Climate Monitoring and Diagnostics Laboratory
Anne Jefferson, NOAA Grants Management Division

Primary grounds for uncertainty in constraining aerosol radiative forcing are (1) the ability to characterize the spatial and temporal distribution of different aerosol types across the globe and (2) understanding the relationship between aerosol chemical, physical, and optical properties. Long-term observations of global aerosol from space show that, while aerosol is highly variable through space and time, seasonal and regional average aerosol amounts are remarkably consistent. However, space-based measurements are not well-suited to determining aerosol type or intensive optical properties required for calculating radiative forcing. Climate models determine aerosol optical properties from estimated distributions of chemical and physical properties, hence, characterizing the relationship between these and optical properties is critical for model evaluation. Well-distributed, continuous, ground-based monitoring at regionally representative sites can provide constraints on the global distribution of relevant aerosol properties. We use decade-long data sets from the Southern Great Plains (SGP) and North Slope of Alaska (NSA) sites to characterize the temporal variability of aerosol optical properties and radiative forcing and to examine the relationship of this variability to their chemical composition. The results are used to evaluate standard aerosol models that are required to convert aerosol mass and number by chemical species to optical properties for assessing the radiative impact of aerosol on current and future climate.

Thermodynamic modeling of atmospheric aerosols: predicting water content and solute activities

Cari Dutcher, University of California
Xinlei Ge, University of California
Anthony Wexler, University of California
Simon Clegg, University of California

Accurate models of water and solute activities in atmospheric aerosols are central to predicting aerosol size, optical properties, and cloud formation. A powerful method has been recently developed (Dutcher et al. *Journal of Physical Chemistry C* 2011, 2012) for capturing the thermodynamic properties of multicomponent aerosols at low and intermediate levels of RH (< 90% RH) by applying the principles of multilayer adsorption to ion hydration in solutions. In that work, statistical mechanics was used to model adsorption of a solvent on to n energetically distinct layers in the hydration shell surrounding the solute molecule in aqueous mixtures. Here, we extend the model to the 100% RH limit and reduce the number of adjustable model parameters, allowing for a unified thermodynamic treatment for a wider range of atmospheric systems. The long-range interactions due to electrostatic screenings of ions in solution are included through a mole fraction based Pitzer-Debye-Hückel (PDH) term. Equations for the Gibbs free energy, solvent and solute activity, and solute concentration are derived, yielding remarkable agreement of the solute concentration and osmotic coefficients for solutions over the entire 0 to 100% RH range. The number of adjustable model parameters is reduced by relating the values of the energy of adsorption to each hydration layer to known short-range Coulombic electrostatic relationships. The effect of the PDH long-range and Coulombic short-range electrostatics on the mixing relationship is explored and new insights into the molecular relationships within atmospheric aerosols is discussed. Fields beyond atmospheric aerosol science, including geological and ocean solution thermodynamics, may benefit from the models developed in this work.

http://www.aim.env.uea.ac.uk/aim/aim.php

What do correlations tell us about anthropogenic-biogenic interactions in the Sacramento plume during CARES?

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Chongai Kuang, Brookhaven National Laboratory
Arthur Sedlacek, Brookhaven National Laboratory
Gunnar Senum, Brookhaven National Laboratory
Stephen Springston, Brookhaven National Laboratory
Jian Wang, Brookhaven National Laboratory
Qi Zhang, University of California, Davis
John Shilling, Pacific Northwest National Laboratory
Rahul Zaveri, Pacific Northwest National Laboratory

During the Carbonaceous Aerosols and Radiative Effects Study (CARES) field campaign the G-1 aircraft was used to sample aerosol and gas-phase compounds upwind, over, and downwind of Sacramento. We present data from 13 flights in which the wind direction was from the southwest. Our data set is further restricted to be from the boundary layer on transects perpendicular to the wind direction. There were a total of 66 transects. Our objective is to empirically determine the fraction of organic aerosol (OA) that can be attributed to anthropogenic and biogenic sources. Of particular interest is the question of whether the simultaneous presence of anthropogenic and biogenic precursors leads to enhanced concentrations of OA as has been found by Setyan et al. (2012) and Shilling et al. (2013).

CO and MVK+MACR were used as tracers of anthropogenic and biogenic emissions. MVK+MACR has a short atmospheric lifetime, so that its presence only explicitly addresses biogenic inputs to an air mass over a few-hour time span. It is, however possible, that elevated concentrations of MVK+MACR are indicative of meteorological conditions such as temperature, sunlight, ventilation, and wind direction that are favorable for the occurrence and accumulation of biogenic volatile organic compounds (VOCs).

Three sets of calculations were performed. First is a correlation/regression analysis testing the relation between OA and various combinations of CO and MVK+MACR, treating each of the 66 transects as a separate data set. The average R^2 for OA vs. CO is 0.63. In the bi-linear regression [OA]s = b1[CO]s +b2[MVK+MACR]s, where "s" indicates a standardized variable, R^2 = 0.69 and the average ratio b1/b2 shows that CO has approximately 10 times the weight of MVK+MACR in explaining OA. Adding an A-B interaction term, b3[CO]s[MVK+MACR]s to the bi-linear regression yields R^2= 0.72, b1/b2 still >10, and on average a negative sign for b3. Second, perturbations (Deltas) were defined for each transect as the 90th percentile of concentration minus the 10th percentile. Correlations were done amongst transects, thereby bringing in flight to flight concentration variations. In regressions with a single independent variable Delta CO, MVK+MACR or ozone could explain, respectively, 69%, 14%, or 85% of the variance of Delta OA. Third, the transect Deltas were split into nine subsets. The subset having high Delta CO and high DeltaMVK+MACR had a greater DeltaOA than would be predicted based on trend lines from the other data sets. Our third calculation differs only in detail from those published.

4.0 Atmospheric State & Surface

Atmospheric carbon and land-atmosphere interactions research

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Ian Williams, Lawrence Berkeley National Laboratory
Daniel Feldman, Lawrence Berkeley National Laboratory
Sebastien Biraud, Lawrence Berkeley National Laboratory
William Riley, Lawrence Berkeley National Laboratory
Marc Fischer, Lawrence Berkeley National Laboratory
Dave Billesbach, University of Nebraska, Lincoln
William Collins, Lawrence Berkeley National Laboratory

Carbon and water cycles are tightly coupled in terrestrial ecosystems, giving rise to ecosystem-atmosphere feedbacks that affect surface energy forcing, clouds, and atmospheric CO_2 concentrations. Understanding ecosystem influences on atmospheric conditions and CO_2 concentrations, and accurately representing the effects of CO_2 concentrations on radiative forcing, are critical to predicting climate change due to anthropogenic CO_2 emissions and land use change. The main goal of the ASR research on atmospheric carbon at Lawrence Berkeley National Laboratory is to better understand ecosystem-climate interactions, and especially those mediated by carbon, water, and energy exchanges. This work bridges spatial scales from the plot to the region, using a combination of measurements and models. We apply observations, models, multiple tracers, and DOE facilities (primarily the ARM Climate Research Facility at the Southern Great Plains [SGP]) to:

- Quantify regional CO_2 sources, sinks, and concentrations in SGP. We are producing a coordinated suite of carbon cycle measurements to support scaling and integration exercises in the SGP, sensor validation, and improvements to land-surface models. In addition, this project is closely coordinated with the ARM Airborne Carbon Experiment that is making weekly airborne observations of CO_2 and other trace gases. We are also investing in new high risk, high payoff capabilities like (1) the "aircore" for whole column greenhouse gas sampling and (2) carbonyl sulfide as a tracer for gross primary productivity (supported jointly by the ASR and Terrestrial Ecosystem Science programs).

- Improve model characterization of ecosystem-atmosphere interactions, including the influences of clouds and drought on carbon cycling and feedbacks to atmosphere. To produce better land-surface forcing, we have developed a modeling framework to ingest Mesonet climate forcing, U.S. Department of Agriculture crop and vegetation cover at 30 m, and 1-m U.S. Geological Survey soil characterization data into CLM4.5 (the land model integrated in the DOE National Center for Climate Research [NCAR] Community Earth System Model). To investigate the effects of clouds and aerosols, we performed cross-spectral analyses of surface CO_2 fluxes, latent heat fluxes, and diffuse-direct radiation fraction at daily-seasonal timescales.

- Improve prediction of CO_2 effects on radiation and temperature, based on measurement-model comparisons of long-term spectral and infrared radiation trends at SGP.

Clouds, aerosols, and water and carbon cycles over the Southern Great Plains

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Margaret Torn, Lawrence Berkeley National Laboratory
William Riley, Lawrence Berkeley National Laboratory

Clouds and aerosols can have significant impacts on carbon cycle dynamics by modifying both the quality and amount of solar radiation for photosynthesis. Changes in field-scale surface carbon dioxide fluxes were previously demonstrated in response to changes in diffuse light fraction associated with cloud cover and aerosol loading, yet the dynamics of these responses remain unexplored and are critical for predictive understanding of land climate. In particular, stomatal conductance has a dual role in controlling water and CO_2 fluxes and can support feedbacks involving aerosols and clouds. We performed cross-spectral analyses of surface CO_2 fluxes, latent heat fluxes, and the diffuse-direct fraction to identify potential coupling between solar radiation regimes and vegetation fluxes at time scales from daily to seasonal, using eddy covariance and collocated broadband solar radiometer data from the ARM Southern Great Plains Central Facility. We found moderate coherence (squared coherence of 0.5–0.7, statistically significant at the 95% confidence level) between diffuse fraction and both surface CO_2 and latent heat fluxes at synoptic time scales of 2–4 days, with weaker evaporation and stronger respiratory CO_2 fluxes (or weaker uptake) coinciding with enhanced diffuse fraction, during the growing season for winter wheat. These results suggest daily weather variability as the primary pathway for solar radiation to couple crop and climate systems and a potential role of vegetation in explaining the climatic drift seen in general circulation models. Simulations with a coupled Community Earth System Model (CESM) will be presented to elucidate the significance of land-atmosphere feedbacks in supporting the observed coherence between diffuse fraction and surface fluxes and its impact on longer-term carbon and water budgets.

Comparison of atmospheric boundary-layer structures over land and ocean as observed by ARM ground-based and space-based lidar measurements

Tao Luo, University of Wyoming
Zhien Wang, University of Wyoming
Damao Zhang, University of Wyoming

Boundary-layer processes are important in climate, weather, and air quality. A better understanding of the structure and behavior of the atmospheric boundary layer is required for understanding and modeling of the chemistry and dynamics of the atmosphere on all scales. With ARM Climate Research Facility micropulse lidar (MPL) and radiosonde measurements, we developed and evaluated a lidar-based method to determine the height of the boundary layer and mixing layer. In this paper, the diurnal and season cycles of atmospheric boundary-layer depth and vertical structure over land and ocean are compared based on measurements at the Tropical Western Pacific (TWP) C2 site and the Southern Great Plains (SGP) site. The new method is also applied to satellite lidar measurements to derive an atmospheric boundary-layer structure database. Results will illustrate that combined ground and satellite measurements offer a more complete view of the temporal and spatial variations of the atmospheric boundary layer.

Evidence for a Manus persistent near-surface night inversion

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Donna Holdridge, Argonne National Laboratory
Paul Ciesielski, Colorado State University Department of Atmospheric Science

During the ARM Madden-Julian Oscillation (AMIE) Manus campaign period, some near-surface temperature and moisture "oddities" were brought to light and investigated. The results are documented in an ARM Technical Report by Long and Holdridge (2012). While some minor improvements in sonde launch procedures were recommended and implemented, and other factors which have some minor effect on the surface temperature and humidity values were found, the sonde profiles themselves are shown to be within the uncertainty of the instruments used. It turns out the perceived "oddities" are the result of using unforced air ventilated surface data at Manus, in combination with the brief "GTS" sonde messages along with some of the methodology used for monitoring and evaluating sonde data during the campaign. With this intense scrutiny of the Manus sondes and the availability of 8/day sonde profiles, the investigation did turn up strong evidence that a near-surface layer at the ARM Manus site persistently developed temperature inversions during the night time.

We will present an analysis of the AMIE-Manus low-level sonde and surface meteorological data showing that the inversions form most nights, with a contributing factor being the prevalent calm conditions with wind speeds only rarely greater than 4 m/s. Comparison with equivalent analyses from AMIE-Gan exhibit infrequent night inversions that only occur with surface wind speeds less than 4 m/s. The inversions have an average pressure depth of about 7 mb, but also in the nightly increase of relative humidity to an average near 90%.

Reference: Long, CN and DJ Holdridge. 2012. Investigations of Possible Low-Level Temperature and Moisture Anomalies During the AMIE Field Campaign on Manus Island. U.S. Department of Energy. DOE/SC-ARM/TR-119, http://www.arm.gov/publications/tech_reports/doe-sc-arm-tr-119.pdf.

http://campaign.arm.gov/amie/

Integrating the microwave radiometer profiler into a Merged Sounding data product

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Michael Jensen, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory
Mark Miller, Rutgers University

A new radiosonde-related data product is now under development to provide near-continuous thermodynamic profile data that are suited for application in observation and model comparisons. Formulated as a modification to the Merged Sounding value-added product (VAP), this new data product incorporates output from the microwave radiometer profiler (MWRP) in place of European Centre for Medium-Range Weather Forecasts (ECMWF) model output to generate thermodynamic profiles at 1-minute intervals between radiosonde launches. This poster summarizes the scientific basis for development, and analyses of thermodynamic profiles produced using preliminary product output are presented in comparison to results derived from currently available radiosonde-related VAPs and results derived from large-scale model output.

Investigating variability in the Australian monsoon and rainfall with cluster analysis

Stuart Evans, University of Washington
Roger Marchand, University of Washington
Thomas Ackerman, University of Washington

Northern Australia experiences a strong seasonal cycle: wet monsoon flow during austral summer and dry continental flow during winter. During the monsoon season the weather can be divided into active and break periods. The timing of the onset and the retreat of the monsoon as well as the intensity of the monsoon are known to have strong relationships with the El Nino-Southern Oscillation (ENSO). Well within the tropics, northern Australia also feels the effects of the Madden-Julian Oscillation (MJO), which has been shown to affect rainfall. Over the past several decades Darwin, Australia has experienced an increase in rainfall, though with large interannual variability. Here, we use an atmospheric classification for the Darwin region to investigate the sources of the trends and variability in the monsoon and precipitation.

We have previously developed an atmospheric classification technique that applies a clustering algorithm to reanalysis data to define a set of atmospheric states. We performed a classification for a region surrounding Darwin, Australia, that defines eight atmospheric states. We use this set of states, especially two that correspond to the active and break periods of the monsoon, to classify the state of the atmosphere at Darwin for the 32-year period of the ERA-Interim project.

We use the time series of state to precisely identify the onset (first occurrence of one of the monsoon states) and retreat (last occurrence) of the monsoon each season, to identify when the monsoon switches between active and break periods within each season, and to define additional metrics such as monsoon duration and strength. On interannual timescales, our metrics capture the known relationships between the Australian monsoon and ENSO and demonstrate that the monsoon has become more active over the past 32 years. On intraseasonal timescales, we show that the timing of the transitions between active and break periods are influenced by the passage of the MJO. We also use the atmospheric classification to explain trends and variability in rainfall at Darwin. We find that while year-to-year variability in rainfall is best explained by changes in the precipitation associated with each atmospheric state, the long-term trend toward more rain at Darwin is due to the increasingly active monsoon season.

Multi-satellite observations of NOx emissions increase in Indian thermal power sector from 1996 to 2010

Zifeng Lu, Argonne National Laboratory
David Streets, Argonne National Laboratory

Nitrogen dioxide (NO_2) and nitric oxide (NO), together known as nitrogen oxides (NO_x), have broader effects on human health, atmospheric composition, acid deposition, air/water quality, visibility, radiative forcing, etc. As the second largest NOx emitting country in Asia, India is of increasing concern. Thermal power plants are the most important point sources in India, and their NO_x emissions (E) have been reported to increase at a remarkable rate since the mid-1990s due to the rapid economic development, the growing electricity demand, and the absence (or weak enforcement) of regulations. In this study, we present the NO_x emissions from Indian public thermal power plants for the period 1996−2010 using a unit-based methodology and compare the emission estimates with the satellite observations of NO_2

tropospheric vertical column densities (TVCDs) from four spaceborne instruments: GOME, SCIAMACHY, OMI, and GOME-2. Results show that NOx emissions from Indian power plants increased by at least 70% during 1996−2010. Coal-fired power plants, NO_x emissions from which are not regulated in India, contribute ~96% to the total power sector emissions, followed by gas-fired (~4%) and oil-fired (<1%) plants. A number of isolated NO_2 hot spots are observed over the power plant areas, and they match the locations of thermal power plants reasonably well. Good agreement between NO_2 TVCDs and NO_x emissions is found, especially for areas dominated by power plant emissions. Average NO_2 TVCDs over power plant areas were continuously increasing during the study period, and power plants are estimated to contribute more than 90% to the increment. We find that the ratio of $\Delta E/E$ to $\Delta TVCD/TVCD$ changed from greater than one to less than one around 2005−2008, implying that a transition of the overall NO_x chemistry occurred over the power plant areas, which may cause significant impact on the atmospheric environment. The results of this work provide us a better understanding of the large NOx releases from the Indian power sector for recent years, and further contribute to our ongoing attempts to assess the usefulness of satellite retrievals for quantifying large point source (LPS) emissions.

5.0 Cloud Properties

3D cloud reconstructions from scanning radar simulations for shortwave radiation closure

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Robin Hogan, University of Reading
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Accurate representation of clouds and their radiative impact in climate models has been a great challenge in climate change prediction. To improve cloud formulations, we not only need to advance our understanding of cloud life cycle and aerosol-cloud-precipitation interactions but also need to make detailed routine cloud observations. In the past, clouds have been observed from a “soda-straw” view; as a result, their evolution and three-dimensional (3D) structures must be derived based on certain assumptions, making it difficult to tackle cloud problems in a fully 3D situation. The new Atmospheric Radiation Measurement (ARM) Climate Research Facility scanning radars provide a unique opportunity to make robust 3D cloud observations. Here we explore this new capability and investigate how scanning strategy affects 3D cloud reconstructions and shortwave surface radiation closure. We will evaluate six prototype scanning strategies used in ARM operations and demonstrate their performance for shallow cumulus clouds generated with contrasting ambient aerosol amounts. We will also highlight how sampling and reconstruction of clouds are affected by inconvenient reality, such as limited radar sensitivity and the presence of drizzle. Providing insight for decision-making of radar scanning strategy, this work looks to find the optimum scanning strategy from both a radiative and microphysical viewpoint.

Analysis of a parallel stratiform mesoscale convective system during the Midlatitude Continental Convective Clouds Experiment

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Michael Poellot, University of North Dakota
Zhaoxia Pu, University of Utah
David Delene, University of North Dakota
Mark Askelson, University of North Dakota

The parallel stratiform (PS) mode of mesoscale convective systems (MCSs) has received little research attention compared to the trailing stratiform (TS) and leading stratiform modes. This case study examines the kinematic structure, cold-pool effects, and microphysical characteristics of a PS MCS that was sampled during the Midlatitude Continental Convective Clouds Experiment (MC3E) on May 11, 2011.

This system is analyzed using in situ data obtained with the University of North Dakota Citation II Weather Research Aircraft, data obtained using a multitude of ground-based radars, data from a dense balloon sounding network specifically set up for MC3E, and data from the Oklahoma Mesonet. Gamma distributions are fit to 10-second averaged hydrometeor spectra that were collected during level Citation flight legs. Unimodal gamma-distribution parameters (N0, μ, and λ) for the MC3E PS case are compared to TS stratiform regions sampled during the Bow Echo and Mesoscale Convective Vortex Experiment (BAMEX). Further investigation of the cold pool is also made through comparing the observations with numerical simulations from mesoscale community Weather Research and Forecasting (WRF) model.

Storm-relative line-parallel and line-perpendicular wind vectors are calculated from radar Doppler velocities. The wind field in the leading portion of the MCS is similar to the wind field from an idealized, simulated PS MCS. In the trailing portion of the MCS, an area of westerly line-perpendicular inflow may signal the presence of a rear-inflow jet, a feature not seen in the simulated PS MCS. The surface cold pool expanded to the north and south beneath the MCS 30 minutes before the MCS transitioned from a PS to a TS mode, which suggests the cold pool was a factor in the transition. A number of similarities in the unimodal gamma-distribution parameters suggest that the microphysical processes experienced by particles sampled in the TS and PS systems were similar. However, there are some differences, such as the frequency of observed bimodal spectra, which are being investigated.

Analysis of cloud retrieval uncertainty in MICROBASE

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Xiao Chen, Lawrence Livermore National Laboratory
Maureen Dunn, Brookhaven National Laboratory
Michael Jensen, Brookhaven National Laboratory

This paper presents a simple yet general approach to estimate uncertainties in ground-based retrievals of cloud properties. This approach, called as the perturbation method, quantifies the cloud retrieval uncertainties by perturbing the cloud retrieval inputs and parameters within their error ranges. The error ranges for the cloud retrieval inputs and parameters are determined by either instrument limitations or comparisons against aircraft observations. We analyzed the relative contributions to the uncertainties of retrieved cloud properties from the inputs, assumptions and parameterizations. In this study, we apply this approach to the ARM baseline retrieval value-added product, MICROBASE. Results show that different influential factors play the dominant role in contributing to the uncertainties in different cloud properties. To reduce uncertainties in cloud retrievals, efforts should be emphasized on the major contributing factors for considered cloud properties. Our results also indicate that the cloud retrieval uncertainties are sensitive to cloud types and other factors.

Arctic cloud-driven mixed layers and surface coupling state

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Amy Solomon, NOAA ESRL Physical Sciences Division
Gijs de Boer, University of Colorado/CIRES

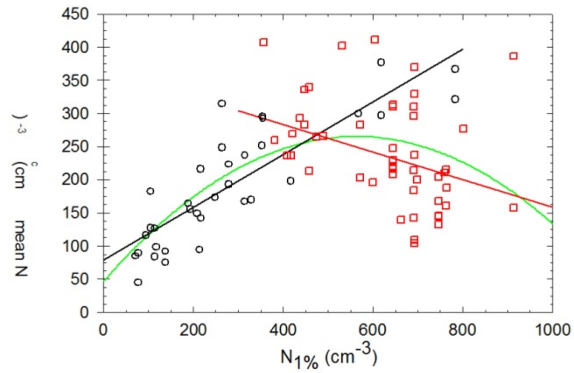
Arctic low-level clouds interact with the atmosphere and surface via many interrelated processes. The balance of cloud radiative warming and cooling effects imparts a strong control on the net surface energy budget. Cloud-driven atmospheric dynamics can impact surface turbulent heat fluxes and influence the vertical mixing of atmospheric state parameters and aerosols. Large-scale advection of heat and moisture provides the context within which these local interactions unfold. Importantly, these radiative, dynamical, and advective processes also contribute to a complex web of self-sustaining cloud processes that promote cloud maintenance over long periods of time. We examine many of these processes, with a specific focus on the dynamical linkages between clouds and the surface that influence low-level atmospheric structure and atmospheric mixing.

Comprehensive, ground-based observations from meteorological towers, remote sensors, and radiosondes are used to simultaneously characterize surface fluxes, atmospheric structure, cloud properties, and the depth of the cloud-driven mixed layer in multiple Arctic environments. Relationships among these parameters are explored to elucidate the properties of the system that determine the degree of vertical atmospheric mixing and the coupling state between cloud and surface. The influence of temperature and moisture inversions on this system is explored, as is the impact on vertical distribution of aerosol concentrations. Transitions in the coupling state are utilized to illustrate the relative roles of different processes.

Cases from the ARM North Slope of Alaska site and a station embedded in the Arctic sea-ice pack are used to contrast conditional influences related to season and surface type. It is found that over sea ice, where surface turbulent fluxes are generally weak, the coupling of cloud-level processes to the surface layer is largely due to proximity of the cloud-driven mixed layer to the surface, which appears to be primarily influenced by the larger-scale, advective environment. In contrast, when stronger surface turbulent fluxes are present, as a result of open ocean or land processes, surface-forced turbulence can also play a significant role in vertical atmospheric mixing and cloud maintenance.

CCN and vertical velocity influences on droplet concentrations and supersaturations in clean and polluted stratus clouds

James Hudson, Desert Research Institute
Stephen Noble, Desert Research Institute



CCN and cloud microphysics measurements from two California marine stratus cloud projects, the Marine Stratus Experiment (MASE) and Physics of Stratocumulus Top (POST), are compared. Cloud droplet concentrations (Nc) were positively related to CCN concentrations (NCCN) over a wide NCCN range from clean to polluted during POST (Fig. 1). But for the high NCCN range of MASE (polluted), Nc decreased with NCCN (Fig. 1). As expected in both projects Nc was positively related to vertical velocity (W), which during POST was also positively correlated with NCCN. This unforeseen W-NCCN coupling thus tended to increase the NCCN-Nc and W-Nc relationships as each reinforced the other because both NCCN and W positively influence Nc. It is shown that without the coupling between W and NCCN during POST the NCCN-Nc and W-Nc correlation coefficients (R) would have been lower as they were in MASE where W and NCCN were independent (R = -0.09). The coupling or not of W with NCCN thus seems to be responsible for the difference between the W-Nc R of POST (0.61) from that of MASE (0.46); i.e., the 0.46 R of MASE is a pure relationship whereas the 0.61 R of POST is abetted by the positive NCCN-Nc relationship in POST. Subsets of the POST data with negative W-NCCN R have lower R for NCCN-Nc and W-Nc relationships. Likewise subsets of the MASE data with positive NCCN-W relationships have positive NCCN-Nc and W-Nc relationships. The latter is virtually unchanged.

The unexpected positive relationship between W and NCCN has been theoretically predicted by Xue and Feingold (2006) because of the easier evaporation of the smaller cloud droplets of polluted clouds. This causes greater latent heat exchange, which produces TKE and buoyancy gradients that enhance mixing and entrainment (Blyth et al. 1988) that can cause further droplet evaporation and thus positive feedback to the W-NCCN positive relationship.

The supersaturation (S) of stratus clouds is important because this determines the particles that form cloud droplets in these most climatically important clouds. Conventional wisdom has held that S of stratus is < 0.3%, which means that only particles larger than 60 nm are capable of nucleating stratus cloud droplets. Results of this study confirm Hudson et al. (2010) that S in clean stratus clouds exceeds 1%, but S in polluted stratus clouds usually exceeds 0.1% and are not as low as 0.03% as indicated by Hudson et al. (2010) (see figure). The figure also demonstrates the decrease of cloud S with NCCN, which is due to competition among droplets for condensate at higher NCCN.

Characterization of cloud property retrieval uncertainty using a Markov chain Monte Carlo algorithm

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Gerald Mace, University of Utah
Steven Cooper, University of Utah

The multiple active and passive remote sensing measurements collected at the Department of Energy's ARM Climate Research Facility sites enable simultaneous retrieval of cloud and precipitation properties and air motion. Recent research (Deng and Mace 2006a, 2006b, 2008) has demonstrated success retrieving cirrus cloud properties using Gaussian least-squares-based optimal estimation (OE) techniques. These methods not only return a best estimate of the cloudy state but also an estimate of the uncertainty in the retrieval. While OE algorithms are computationally efficient and return a robust solution in linear (and sometimes moderately nonlinear) cases, their general performance is unclear for strongly non-Gaussian measurement-retrieval relationships.

Markov chain Monte Carlo methods (MCMC, Posselt 2013) can be used to produce a robust estimate of the probability distribution of a retrieved quantity for nonlinear, non-Gaussian cases (Posselt et al. 2008). In this work, we highlight the utility of MCMC methods for exploring the error characteristics and information content of ARM-based cloud property retrievals. We compare the probability distributions produced by OE and MCMC algorithms, and comment on the ability of a multi-sensor retrieval to effectively constrain vertical profiles of the cloud particle size distribution.

Deng, M, and G Mace. 2006. "Cirrus microphysical properties and air motion statistics using cloud radar Doppler moments: Part I—Algorithm description." *Journal of Applied Meteorology and Climatology* 45: 1690–1709.

Deng, M, and GG Mace. 2008a. "Cirrus cloud microphysical properties and air motions statistics using cloud radar Doppler moments Part II—Climatology." *Journal of Applied Meteorology and Climatology* 47: 3221–3236.

Deng, M, and GG Mace. 2008b. "Cirrus cloud microphysical properties and air motion statistics using cloud radar Doppler moments: Water content, particle size and sedimentation relationships." *Geophysical Research Letters* 35: L17808, doi:10.1029/2008GL035054.

Posselt, DJ, TS L'Ecuyer, and GL Stephens. 2008. 'Exploring the Error Characteristics of Thin Ice Cloud Property Retrievals Using a Markov Chain Monte Carlo Algorithm." *Journal of Geophysical Research* 113: D24206, doi:10.1029/2008JD010832.

Posselt, DJ. 2013. "Markov chain Monte Carlo Methods: Theory and Applications." In *Data Assimilation for Atmospheric, Oceanic and Hydrologic Applications, 2nd Edition*, ed. SK Park and L Xu. Springer. In press.

Characterization of the cloud life cycle during Madden-Julian Oscillation using ARM observations

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D Zermeno, University of Miami
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The present study documented the cloud and environment properties during different phases of the Madden-Julian Oscillation (MJO) using ARM observations from the Tropical Western Pacific (TWP) Manus site and Gan Island. The long-term (13 years) KAZR (Ka-band ARM zenith radar) observations from the Manus site are used to characterize the clouds based on their height location and observed precipitation into different cloud types (boundary-layer, convective precipitating versus non-precipitating, alto, and high clouds). The differences in cloud type occurrences are analyzed for different phases of the MJO. Supplemental observations from balloon soundings, microwave radiometer (MWR), and surface rainfall are used to characterize the role of humidity on the vertical cloud distribution and precipitation-water vapor relationships. The vertical structure of large-scale environment during MJO initiation phase is analyzed using six months of sounding data collected during the ARM MJO Investigation Experiment (AMIE) field campaign at Gan Island.

Characterization of the wintertime marine boundary-layer cloud properties occurring over the eastern North Pacific Ocean based upon recent shipboard observations collected during MAGIC

Maureen Dunn, Brookhaven National Laboratory
Michael Jensen, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory

This shipboard deployment of the second ARM Mobile Facility (AMF) for the Marine ARM GPCI Investigation of Clouds (MAGIC) field campaign has recently collected wintertime cloud property observations along a transect which runs from the cool waters off the California coast to the warm tropical waters of Hawaii. This transect is significant in that it runs near the GPCI intercomparison transect frequently used by cloud modelers to evaluate simulations of the transition in cloud type from stratocumulus, to cumulus, to deep convective.

The spatially varying sea-surface temperatures (SST) observations collected along this transect are reflected in the deepening of the marine boundary layer (MBL) and concomitant transitions in cloud type as the ship moves towards the west. We examine the boundary-layer depth through a detailed evaluation of the atmospheric convective indicators, convective available potential energy (CAPE) and convective inhibition (CIN). In addition, the effects of a spatially varying MBL on both the macrophysical cloud properties (cloud thickness and liquid water) and the observed microphysical properties (droplet size and concentration) are examined.

Characterizing cloud properties and synoptic variability over the Azores using self-organizing maps

David Mechem, University of Kansas
Matthew Miller, North Carolina State University
Sandra Yuter, North Carolina State University
Simon de Szoeke, Oregon State University

The ARM Mobile Facility (AMF) deployment on Graciosa Island in the Azores during 2009–2010 demonstrated that the northeast Atlantic exhibits a striking amount of variability in cloud system behavior and synoptic configuration. We apply the technique of self-organizing maps (SOMs) to characterize variability in synoptic conditions and cloud properties. SOMs are an unsupervised artificial neural network learning technique, which produce from input data a finite number of characteristic patterns: for example, the preferential synoptic configurations present in the input data. We apply the SOM technique to geopotential height and vertical motion fields from ERA-Interim reanalysis, specifically focusing on the joint variability between different meteorological variables. We use the resulting SOM products to investigate the relationship between synoptic configuration and cloud properties.

Cloud and surface properties derived from satellite data over ARM sites

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Rabindra Palikonda, Science Systems and Applications. Inc./NASA Langley Research Center
Robyn Boeke, Science Systems and Applications, Inc.
Mandana Khaiyer, Science Systems and Applications, Inc.
J Ayers, NASA Langley Research Center/Science Systems and Application
Benjamin Scarino, Science Systems and Applications, Inc.
Chris Yost, Texas A&M University

The NASA Langley Clouds and Radiation Group provides cloud and radiation properties over the ARM sites to characterize the large-scale cloud fields and top-of-atmosphere radiation over both long and short-term study areas. As the ARM surface and airborne data sets become available, it becomes possible to better characterize the uncertainties in the satellite retrievals and provide better confidence in their use for modeling initiation and validation and climatological assessment. These uncertainties are estimated by comparison of the ARM surface-based measurements with the satellite retrievals.

This study provides an updated overview of the available satellite-based products over the various domains. It also provides some new comparisons of the surface and satellite retrievals of cloud amount, optical depth, phase, particle size, height, thickness, and water path. Both the latest surface and satellite retrievals are employed as new calibrations and revised algorithms have become available. Particularly, we focus on the updated cloud property data from the Southern Great Plains (SGP) site by McFarlane and Shi (2012), which indicate that both the cloud optical depths from the multifilter rotating shadowband radiometer (MFRSR) and the microwave radiometer (MWR) liquid water path (LWP) data have been overestimated in the past by about 10%. Comparisons of both cloud and surface skin temperature data from surface and satellite data over several sites will be presented.

http://cloudsgate2.larc.nasa.gov/cgi-bin/site/showdoc?docid=4&cmd=field-experiment-homepage&exp=ARM

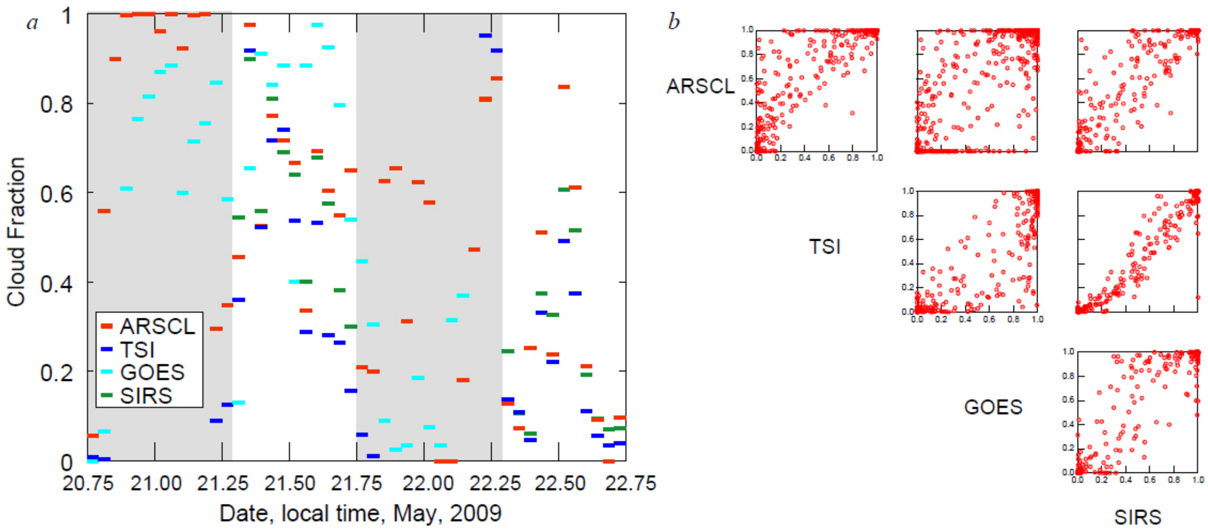
Cloud fraction: can it be defined and measured?

Stephen Schwartz, Brookhaven National Laboratory

Clouds greatly affect radiation transfer in the atmosphere and consequently climate. Globally, clouds enhance reflected shortwave (SW) flux by 47.5 ± 3 W m^{-2} and reduce outgoing longwave (LW) flux by 26.4 ± 4 W m^{-2} for a net cooling influence of 21.1 ± 5 W m^{-2} (Harrison, *Journal of Geophysical Research* 1990). The amount and properties of clouds are expected to change with increasing global temperature, but the amount and even the sign of resultant flux changes are not known, giving rise to much uncertainty in estimates of climate sensitivity and projections of climate change. Consequently it is essential that representation of clouds and their radiative influences in climate models be accurately assessed.

The conventional measure of the amount of clouds is "cloud fraction" (CF) the fraction of the atmosphere volume or column occupied by clouds. This raises the question of whether CF can be defined and how well it can be measured. If average CF is 0.5, then in round numbers, 1% error in CF corresponds to 1 W m^{-2} in SW and 0.5 W m^{-2} in LW globally. This sets the scene for how well CF must be known and provides context for differences in measurements by different techniques (Figure 1). Observationally, cloud fraction depends on resolution and threshold and on whether CF is evaluated as area average or as temporal average in a narrow-field-of-view vertical column.

This poster examines issues associated with definition and measurement of CF, compares different measures of CF at the ARM Southern Great Plains (SGP) site, and examines some of the literature. Given the importance of CF in models and the need for measurements, it might be useful to establish a Cloud Fraction Focus Group in ASR. The author invites discussion of this and suggestions for measurements or alternatives to CF, at the poster and/or by email.



a) Hourly mean CF at SGP determined by several techniques over a two-day period in May 2009. ARSCL (Clothiaux, Journal of Applied Meteorology and Climatology 2000) is time-average based on vertically pointing lidars and millimeter cloud radars; SIRS (Long, Journal of Geophysical Research 2006) is time-average based on downwelling SW irradiance within nominal 160° field of view. TSI is based on fraction of cloudy pixels within hemispheric field of view. GOES is based on average of all pixels (4-km size; satellite) within 20 km of the surface measurement site (Genkova, Proceedings of the 14th ARM Science Team Meeting 2004). Gray denotes nighttime; TSI and SIRS not available. Modified from Stevens and Schwartz (Surveys in Geophysics 2012). b) Scatterplot matrix of the several data sets for May 2009. Data provided by W Wu (Brookhaven National Laboratory 2011).

Combined analysis of observed and simulated convective and stratiform rain structures, convective dynamics, and microwave radiances on May 20th during MC3E

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Di Wu, NASA
Toshihisa Matsui, NASA Goddard Space Flight Center/University of Maryland, College Park, Earth System Science Interdisciplinary Center
Wei-Kuo Tao, NASA Goddard Space Flight Center
Andrew Ackerman, NASA Goddard Institute for Space Studies
Kirk North, McGill University
Scott Collis, Argonne National Laboratory

We integrate analysis of an ensemble of mesoscale simulations of the storm event on May 20 during the Midlatitude Continental Convective Clouds Experiment (MC3E) field campaign with ground- and satellite-based remote sensing observations. We first perform a consistent analysis of convective, stratiform, and anvil structures in simulated reflectivity fields and C-band scanning ARM precipitation radar (C-SAPR) gridded reflectivity throughout the event. We then place limited convective region wind vector observations derived from a three-point array of X-band scanning ARM precipitation radars (X-SAPR) and C-SAPR radars within the context of C-SAPR reflectivity-based structures. We compare the observations with comparably located structures within the simulations, with a focus on convective updraft and downdraft properties. We finally compare limited domain-wide snapshots of forward-simulated infrared brightness temperatures and microwave radiances with those observed using Advanced Microwave Scanning Radiometer - EOS (AMSR-E) and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments using convective and stratiform partitioning based on infrared, microwave, and C-SAPR measurements. In each simulation ensemble member, we seek coherency of deviations from observational data sets that are linked to simulated microphysics and dynamics features.

DCS cloud-precipitation properties derived from aircraft-surface-satellite observations during the MC3E IOP

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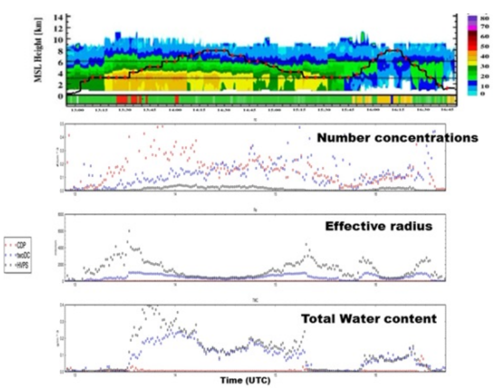
Ning Zhou, University of North Dakota
Baike Xi, University of North Dakota
Tony Grainger, University of North Dakota
Zhe Feng, Pacific Northwest National Laboratory
Patrick Minnis, NASA - Langley Research Center
Mandana Khaiyer, Science Systems and Applications, Inc.
Scott Giangrande, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory



The aircraft flight trajectory (black line and red points) with collocated NEXRAD radar reflectivity and classified three components (red-Convective core, green-stratiform region, and yellow-AC) on the May 20 case. The cloud microphysical properties measured by the UND Citation research aircraft three sensors (red-CDP, 1-49 µm; blue-2DC, 15-3,000 µm; and black-HVPS, 200-30,000 µm).

The Midlatitude Continental Convective Clouds Experiment (MC3E) was a very successful field campaign with 15 convective cases observed by the University of North Dakota (UND) aircraft and surface-satellite sensors. There are at least six deep convective systems (DCS) (April 25 and 27, May 5/10, 20, and 23–24), including the classic DCS case on May 20, which has drawn much attention for scientists to study its structure and properties from observational and modeling points of view. This research team is providing the following results for ASR/ARM community: classified DCS components (convective cores [CC], stratiform rain [SR], anvil clouds [AC]) and their corresponding vertical structures and velocities from surface radar measurements, aircraft in situ measured and GOES satellite-retrieved cloud macrophysical and microphysical properties. These results will provide ground truth for modelers to validate and improve their simulated DCS properties.

Through an integrative analysis of the data sets, we have the following preliminary results for the May 20 case. The frontal squall line system originally located southwest of the ARM Southern Great Plains (SGP) Central Facility (CF), advanced over the CF around 0:00 UTC, maturing later. The convective cores started to pass over the CF around 9:00 UTC, and heavy precipitation occurred during 10:30–11:00 UTC with a significant change in cloud properties before and after the heavy precipitation. Before precipitation, there were large graupel and ice particles with strong vertical motion in the convective cores. After that, a stratiform region developed with two distinguished layers: ice and water particles above and below the melting band, respectively. The UND Citation flew spirally up and down over the CF, mostly within 30 km of the CF during the period 13:00–17:00 UTC. Four vertical profiles above the melting band (~4 km) were measured by the UND aircraft. When the plane flew upward from 4 to 8 km, the effective radius of the ice particles decreased from 1000 μm to 300 μm as determined from the two-dimensional cloud probe (2DC) sensor with bins ranging from 15 to 3000 μm. At the 8-km level, the high-volume precipitation spectrometer (HVPS), with bins covering the range from 300 - 30,000 μm, measured effective radii that were the same as the 2DC measurements (~300 μm). But at 4 km, they were as great as 4000 μm, indicating that the HVPS detected many very large ice particles/rain drops near the melting band that were missed by the 2DC probe. The GOES-retrieved effective radius, optical depth and ice water path (IWP) over the DCS convective cores are ~80 μm, 100, and 2000 gm-2, respectively. The satellite generally retrieves ice particle sizes representative of the top portion of the cloud (~12 km for May 20).

Diagnosis of stratocumulus and deep convective clouds simulated by the NCEP/GFS using satellite and ground-based measurements

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Zhanqing Li, University of Maryland
Yu-Tai Hou, NOAA/NCEP
Howard Barker, Environment Canada

Cloud properties, cloud vertical structure, and deep convective clouds are important for meteorological studies due to their impact on both the Earth's radiation budget and adiabatic heating. The objectives of this study are to diagnose the performance of the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) model cloud simulations, to identify possible causes of the discrepancies in cloud fields, and to examine individual factors that affect the development of deep convective clouds using different types of observational data sets.

Mistreatment of such marine stratocumulus clouds in the GFS model leads to an overestimation of upward longwave flux and an underestimation of upward shortwave flux at the top-of-atmosphere. With respect to input data biases, the temperature field from the GFS is comparable to that obtained from both satellite retrievals and ground-based measurements, but the GFS relative humidity field shows a moist bias in lower atmosphere. To improve simulations of low-level clouds, two experiments are performed by using the GFS model's original atmospheric fields with a different cloud parameterization scheme. The new approach generates a large quantity of marine stratocumulus clouds over the eastern tropical oceans as well as low cloud amounts in the other regions around the world. The other experiment is use of the exponential random overlap assumption, and this method leads to an improvement for high-level clouds, a neutral impact for middle-level clouds, and deterioration for low-level clouds. Comparison of distributions and characteristics of deep convective clouds between the model simulations and satellite retrievals is made, and overall, their gross features look similar in terms of locations and spatial patterns, although a weak convection strength is seen on cloud top of deep convection in the GFS model simulations.

Empirical relationship between entrainment rate and microphysics in cumulus clouds

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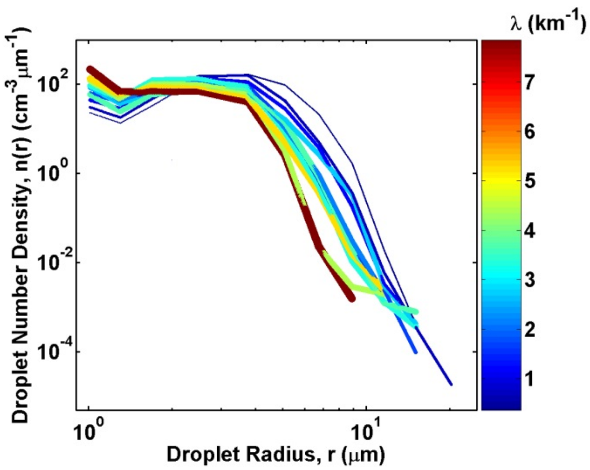
Yangang Liu, Brookhaven National Laboratory
Shengjie Niu, Nanjing University of Information Science and Technology
Andrew Vogelmann, Brookhaven National Laboratory

The relationships between fractional entrainment rate and key microphysical quantities (e.g., liquid water content, droplet number concentration, volume-mean radius, standard deviation of cloud droplet size distributions) in shallow cumuli are empirically examined using in situ aircraft observations from the RACORO field campaign over the ARM SGP site. The result shows that the microphysical quantities examined generally exhibit strong relationships with entrainment rate, and that the relationships collectively suggest the dominance of homogeneous entrainment mixing, which is unfavorable to the formation of large droplets and the initiation of warm rain in these clouds. The dominance of the homogeneous mixing mechanism is further substantiated by the dependency on entrainment rate of relationships among various microphysical variables and of cloud droplet size distributions (Figure 1). The dominance of homogeneous mixing mechanism is also quantitatively confirmed by examining the degree of homogeneous mixing in these clouds. The dominance of homogeneous mixing may be an important reason why none of these cumulus clouds were drizzling.



Cloud droplet size distributions as a function of entrainment rate (λ) in 186 growing cumulus clouds during RACORO.

Estimates of the vertical profile of entrainment rate from millimeter-wavelength radar observations

Michael Jensen, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory
Pavlos Kollias, McGill University
Chunsong Lu, Brookhaven National Laboratory
Tim Wagner, University of Wisconsin, Madison

Mixing of environmental air with buoyant plumes has important implications on cloud life cycle and subsequent impacts on the atmospheric energy and water budgets. This mixing is notoriously difficult to measure, particularly from a remote sensing point of view. Here we introduce a technique using velocity profiles from an ARM vertically pointing millimeter-wavelength cloud radar and estimates of the cloud adiabaticity in order to estimate a vertical profile of entrainment rate for shallow cumulus clouds.

Evaluation of cloud ice and snow size distributions and fallspeeds in CAM5 using observations

Trude Eidhammer, National Center for Atmospheric Research
Hugh Morrison, National Center for Atmospheric Research
Andrew Gettelman, National Center for Atmospheric Research
Aaron Bansemer, National Center for Atmospheric Research
Andrew Heymsfield, National Center for Atmospheric Research
Carl Schmitt, National Center for Atmospheric Research

The representation of ice microphysics in clouds remains a key uncertainty in climate models. Detailed in situ measurements of hydrometeor size distributions and fall speeds from several measurements have been compiled for comparison with model simulations. We focus here on two field campaigns: the 2000 ARM Spring Cloud IOP (Intensive Operational Period) in March 2000 over Oklahoma and the NASA TC4 (Tropical Composition, Cloud and Climate Coupling) mission in 2007, conducted in the tropical eastern Pacific. The moments of size distributions and weighted mean fall speeds determined from the measurements are compared with moments from modeled size distributions and fall speeds from simulations with Community Atmosphere Model (CAM) 5.1. We compare cloud ice mass and number concentrations with the measurements and to determine how well the CAM model represents the microphysical behavior in clouds. Preliminary results indicate that the measured and modeled moments are within the same order of magnitude; however, there are some differences in the trends of the moments as a function of temperature.

An examination of observationally based cloud fraction estimates over the Southern Great Plains from different platforms

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Various 1997–2011 observationally based cloud fraction estimates from different platforms over the Southern Great Plains, U.S., are investigated at multiple temporal and spatial scales. A substantial disagreement is found among different estimates. The statistical significance of the differences between different estimates is tested. The cause of the differences between different estimates is examined. Results from this study suggest that caution is needed when using cloud fraction estimates to evaluate climate models or infer climate variations and highlight the need of improving the accuracy and consistency of various cloud fraction products.

Extending 94-GHz radar retrievals of ice water content beyond the Rayleigh regime

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Ice crystal aggregates are characterized by a mass-dimension power-law having an exponent β of ~2 (β is also known as the fractal dimension). The wide range of possible β values poses a problem when retrieving cloud properties using radar, since β affects the scattering behavior of the particles at radar wavelengths.

The radar backscatter is weighted by the second moment of the particle size distribution (PSD) with respect to mass. When using a 94-GHz radar to retrieve the physical properties of frontal clouds (which have much larger ice particle sizes than cirrus clouds), ice particles with size parameter x considerably greater than 0.3 can often dominate the backscatter signal. Since Rayleigh scattering theory applies to $x < 0.3$, relationships based on Rayleigh theory that relate the Rayleigh backscatter to cloud properties are no longer valid.

To deal with this problem, we have adapted the work of Westbrook, which uses Rayleigh-Gans (RG) theory for fractal aggregates, to an ice water content-radar reflectivity (IWC-Z_e) relationship derived from Rayleigh scattering theory, thus enabling this relationship to be applied to frontal clouds using 94-GHz radar where pure Rayleigh theory is generally not applicable. The method is valid for PSD having $D_{avg} <$ 3.3 mm, where D_{avg} is the mean ice particle size. IWC retrieval uncertainties can be reduced by estimating the PSD slope parameter λ as a function of temperature and by a priori knowledge of ice particle shape. Alternatively, λ can be estimated using a snow growth model initialized by the measured radar reflectivity and temperature near cloud top.

In addition, the commonly employed radar-lidar retrievals of IWC and effective diameter may be improved for frontal cloud conditions by using this approach.

Results from a sensitivity analysis study of IWC and Z_e (effective radar reflectivity) as function of ice microphysical properties using our RG formulation are presented. We find that the ratio Z_e/IWC is highly sensitive to the mean mass-weighted particle diameter (D_m) for D_m less than 0.02 cm, beyond which it behaves more asymptotically, becoming approximately constant for $D_m > 0.06$ cm. The sensitivity of Z_e/IWC is also studied as functions of β and the mass-dimension power-law pre- factor α. Our findings suggest that Z_e/IWC is more sensitive to a change in α than for β.

Forward modeling of radar observables using a large-eddy simulation model: a new approach to optimization of cloud radar scan strategies

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The ARM Climate Research Facility has 15 state-of-the-art scanning Doppler cloud radars continuously operating to characterize the radiatively important cloud structures at the ARM observing facilities.

Currently the radars are operating in four different scan modes: vertically pointing (VPT), plan position indicator (PPI), hemispherical sky-range height indicator (HS-RHI), and cross-wind RHI (CW-RHI). Although the radar scan strategies yield valuable information regarding the cloud structures, the scan strategies have not been optimized for particular cloud types and more importantly for comparison with the cloud area/volume fraction simulated by global climate models (GCM), cloud-resolving models (CRM), or large-eddy simulations (LES).

Single-layer stratocumulus clouds were observed for a 24-hour period during the current deployment of the ARM Mobile Facility (AMF1) at Cape Cod, Massachusetts, on November 15, 2012. We have simulated this case using the Weather Research Forecasting (WRF) model in an LES mode with the innermost domain centered at the AMF and having 50-m horizontal resolution and less than 20-m vertical resolution below 1 km. The output from the model run is used to simulate the radar-observed reflectivity in all the scanning modes at the same temporal and spatial resolution as the operational cloud radars. The simulated reflectivity will include the effects of wind shear, attenuation due to gaseous absorption, and beam broadening, among other things. The cloud fraction as deduced from the radar simulation for different scan strategies will be then compared to that of WRF not only to select the best scan strategy for single-layer stratus clouds but also to improve the settings of the existing scan strategies and the scan sequence.

The four cumulus cloud modes and their progression during rainfall events: a C-band polarimetric radar perspective

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Cumulus clouds have historically been thought of as primarily consisting of two modes: shallow cumulus, with cloud-top heights (CTH) near the trade inversion layer, 1–2 km above the surface and deep cumulonimbus clouds, with CTH near the tropopause layer (~15 km). Recent recognition of a third cumulus cloud mode, the mid-level cumulus congestus cloud, has attracted significant interest to this field since identification of the congestus mode and importantly their role in the pre-conditioning of tropical deep convection is still unclear. In this study, a three-wet season data set of the Darwin C-band polarimetric radar is analysed to investigate the properties of convective cells as a function of its CTH with the motivation of identifying clear differences between the cumulus modes. The convective cells are identified using the Steiner algorithm at 2.5 km height. Then for each cell the CTH is taken as the maximum height reached by the 0-dBz radar echo above the cell, provided there is a continuous radar echo from the near ground to the CTH. We also make use of reflectivity data, drop-size distributions (DSD) parameters, and rain rate retrievals from the 2.5-km height bounded by the convective cells, as well as the vertical gradient in reflectivity (lapse rate) in the convective cells. Several interesting features in the near-ground convective cell properties and the reflectivity lapse rates associated with the shallow (CTH < 3 km), congestus (3–7 km), deep cloud (7–15 km), and overshooting tops (> 15 km) are found and will be discussed during the conference. The temporal evolution of these convective cell characteristics and the four cumulus modes around heavy rain-rate events are also investigated.

Geometry and synchronization in precipitating open cells

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Cloudy marine boundary-layer states derive their importance in the climate system from their different cloud fractions, albedos, and the associated effect on radiative forcing. Examples of cloudy marine boundary-layer states are closed cell convection, precipitating open-cell convection, and shallow cumulus convection. The conditions required for the perpetuation of a given state or for a transition between two states and the involved mechanisms are not well understood. Here, the precipitating open-cell state and its decay into a shallow-cumulus-like state under weak surface forcing are investigated, and a quantitative analysis of the geometry and synchronization of this state and of its decay is presented. It is found that the precipitating open-cell state can persist even if precipitation takes place on a grid with irregular geometry, while desynchronization of precipitation is associated with the decay of the open-cell state.

Ice concentration retrieval in mixed-phase stratiform clouds (MSCs) using radar reflectivity and 1D ice growth model

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Ice nucleation has significant impacts on the radiative property and precipitation efficiency of atmospheric clouds. However, the primary ice nucleation process is still poorly understood. Stratiform mixed-phase clouds (SMCs) provide a “simple scenario” for studying ice nucleation characteristics in clouds. Due to the weak updrafts and turbulence in SMCs, ice crystals are primarily formed in the upper part of the supercooled cloud layer, grow large in a water-saturated environment, and fall out of the mixed-phase layer. Below the liquid-dominated mixed-phase cloud layer, ice crystals continue to grow and fall until they reach the level below the ice-saturation condition. Under similar meteorological conditions in terms of cloud-top temperature (CTT) and liquid water path (LWP), ice crystal growths in SMCs are expected to be statistically identical. We confirm this with in situ data.

This simple ice generation and growth pattern offers opportunities to use radar reflectivity (Ze) measurements and other cloud properties to quantitatively infer the ice concentration. To remove the strong temperature dependency of ice growth, we developed a 1D ice growth model to calculate the ice diffusional growth along its fall trajectory in SMCs. The radar reflectivity and fall velocity profiles of ice particles calculated from the 1D ice growth model are evaluated with ARM Facility ground-based high-vertical-resolution radar measurements. Combining Ze measurements and 1D ice growth model simulations, we can retrieve the ice concentrations in MSCs at given CTT and LWP. The retrieved ice concentrations in SMCs are evaluated with in situ measurements and 3D cloud-resolving model simulations. These comparisons show that the retrieved ice concentrations are within an uncertainty of a factor of two, statistically.

Ice fog observations and new parameterization using the Weather Research and Forecasting (WRF) model

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Ice fog occurs frequently in aerosol-laden environments during the cold season at high latitudes, affecting the physical and chemical properties of the atmospheric boundary layer. It reduces visibility and is therefore a risk factor for aviation and traffic on the ground. We observed ice fog in interior Alaska at the Eielson Air Force Base and in Fairbanks and modified the Thompson microphysical scheme employed within the Weather Research and Forecasting (WRF) model.

The NCAR Video Ice Particle Sampler probe was used for continuous observations of ice crystal shape, size, and concentrations. We also used microscope slides with formvar (polyvinyl formal) to collect ice fog particles during especially heavy ice fog events during the winter 2012. Ice fog particles were generally smaller and droxtal-shaped (quasi-spherical) for sub-10-micron particles during the heaviest fog periods, while plate-shaped crystals dominated the larger sizes during lighter fog events. Fog ice water content and extinction were calculated and visibility was derived from the extinction values. The measurements further allowed conclusions on particle terminal velocities and mass-weighted fall speeds.

The Thompson microphysics scheme was modified with an improved ice nucleation parameterization, size distribution, and gravitational settling. The new ice fog parameterization accounts for significantly higher ice crystal number concentrations; the size distribution of the crystals was changed into a Gamma distribution with the shape factor of -0.5, using the observed distribution. Furthermore, the gravitational settling was adjusted to the time scale of the ice crystals to take to settle to the surface.

Improvements to near-real-time cloud detection near the terminator and impact on diurnal trends of cloud properties

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Automated cloud detection near the day/night boundary known as the terminator is uniquely difficult because of the low signal-to-noise ratio of reflected solar radiation. Threshold-based cloud detection algorithms often have difficulty setting appropriate clear-sky thresholds, and consequently, cloud amount may differ significantly than that derived from daytime and nighttime methods. The NASA Langley Clouds and Radiation Group uses a modified version of the Clouds and Earth's Radiant Energy System (CERES) cloud mask to identify clear and cloudy pixels in geostationary satellite imagery. Loops of cloud mask images derived from geostationary satellite imagery show that cloud identification near the terminator is often inconsistent with the preceding and succeeding images when the same region is processed with the daytime or nighttime methods. Cloud fraction is often overestimated near the terminator, and the magnitude is greater over land compared to water surfaces due to greater field-of-view complexity over land. Cloud physical and microphysical properties assigned to pixels mistakenly identified as cloudy contaminate studies of cloud life cycles and diurnal trends. This study presents a method, using the cloud fraction and clear and cloudy infrared brightness temperatures from previous satellite scans, to improve cloud detection accuracy near the terminator for a threshold-based cloud mask. The performance of the algorithm is evaluated using instrumentation at Atmospheric Research Measurement (ARM) Climate Research Facility sites such as the Southern Great Plains (SGP) site. The impact of false detections on hourly mean cloud properties is also investigated.

http://cloudsgate2.larc.nasa.gov/cgi-bin/site/showdoc?docid=4&cmd=field-experiment-homepage&exp=ARM

Infrared cloud imager measurements at Barrow, Alaska

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The infrared cloud imager (ICI) measures spatial and temporal cloud statistics, along with cloud optical depth up to a value of approximately 3. Because this instrument measures wide-angle, longwave infrared images, the result is a continuous day-night datastream that overcomes the difficulties of visible-wavelength imagers for nighttime and high-latitude winter clouds. The ICI is deployed as part of a field campaign at the North Slope of Alaska site in Barrow, Alaska, extending from July 2012 into August 2013. This poster will describe the instrument and show examples of data obtained in Barrow during this year-long deployment.

Insights from preliminary modeling and observational evaluation of a precipitating continental cumulus event observed during the MC3E field campaign

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A case of extensive precipitating cumulus congestus sampled during the Midlatitude Continental Convective Clouds Experiment (MC3E) field campaign is analyzed using a multi-sensor observational approach and numerical simulation. Emphasis is on the ARM Southern Great Plains (SGP) scanning ARM cloud radar (SACR) and Ka-band ARM zenith radar (KAZR) platforms to characterize the statistical behavior of the precipitating cloud system consulting the evolving distributions of radar reflectivity, Doppler velocity, and different measures of cloud geometry. Large-eddy simulation with size-resolved (bin) microphysics is employed to characterize the forcing most important in producing the salient aspects of the cloud system captured in the radar observations. In particular, we address the importance of time-varying versus steady-state large-scale forcing and the sensitivity of model-derived radar quantities to the assumed aerosol distribution used in the model.

Investigating reflectivity-liquid water content relationships in mixed-phase clouds

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Guo et al. showed a technique to partition Ka-band ARM zenith radar (KAZR) Doppler velocity spectra into reflectivity contributions from cloud (small fall velocity) and precipitation particles. This technique effectively partitions the total reflectivity between liquid and ice contributions in mixed-phase clouds. Quantifying the liquid water content (LWC) from the reflectivity (liquid contribution) remains problematic in these mixed-phase clouds because of the complex physical processes that influence the drop-size distribution (DSD). It is common to use a power law relationship, LWC = a*Zb, to derive LWCs from radar-measured reflectivities. For analytical DSDs, the coefficients a and b depend on the total number concentration of droplets and shape parameter of the DSD, which may vary widely depending on the different environmental conditions and physical processes in clouds. In particular, in mixed-phase clouds the ice particles grow at the expense of liquid droplets, impacting the liquid DSD in ways not present in liquid-only clouds. Therefore, one should anticipate larger uncertainties if only a single Z-LWC relationship is used to calculate LWC throughout the cloud. The accuracy of the retrieved LWC fields will be compromised without a corresponding understanding of the physical processes of the formation of Z-LWC relationships, even if the retrieved liquid contributed reflectivities are successfully separated from radar observations.

In our study, we combine ground-based observations and model simulations to investigate the variation of Z-LWC relationships in mixed-phase clouds. For each hour of data we define a single relationship, the a and b coefficients of which are chosen to provide the best fit to the microwave radiometer (MWR) liquid water path (LWP) over that period. We find that the radar-derived LWPs generally track the MWR LWPs well, with short periods of larger deviations occasionally. We use the DSD output from a cloud-resolving model to calculate the Z-LWC relationships at each model grid. The coefficients are found to vary depending on the microphysics and dynamics of the different stages of the cloud processes. Any improvement of our understanding of how the DSD varies with the mixed-phase cloud processes will improve LWC estimates.

Life cycle of deep convective systems in the midlatitude and tropics: from observations to simulations

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Deep convective systems (DCSs) produce heavy rainfall and large cirrus anvil cloud shields, and they play an important role in the climate system through their impact on the general circulation and cloud radiative feedback. To improve understanding of the life cycle of DCSs, a Lagrangian framework is used to investigate DCSs in the midlatitudes and the tropics. An automated cloud tracking method is used in conjunction with a multi-sensor hybrid classification to analyze the evolution of DCS structure over the central U.S. (Feng et al. 2012). Composite analysis from 4221 tracked DCSs during two warm seasons shows that for short to medium systems (lifetimes < 6 hours), the lifetime is mainly attributed to the intensity of the initial convection. Systems that last longer than 6 hours are associated with up to 50% higher midtropospheric relative humidity and up to 40% stronger middle to upper tropospheric wind shear. Such environment allows continuous growth of the stratiform rain region, thus prolonging the system lifetime. Areal coverage of thick anvil clouds is strongly correlated with the size and intensity of convection. Ambient upper tropospheric wind speed and shear also contribute to convective anvil production.

This Lagrangian framework is then applied to evaluate long-term high-resolution simulations by the Weather Research and Forecasting (WRF) model in the tropical western Pacific. In general, the simulated DCSs reproduce many satellite-observed cloud statistics, but the cloud size and convective intensity are very sensitive to the choice of different microphysics schemes. Two-moment Morrison schemes produce much larger DCSs than the WRF Single-Moment Six-Class Microphysics Scheme (WSM6) scheme due to more anvil clouds and hence agree better with observations. However, Morrison schemes overestimated precipitation by about 50%, while WSM6 overestimated by 35%. Diurnal cycles over land agree well with observations; but over the ocean, different microphysics schemes show considerable variances. As a result of the sensitivity to microphysics, differences in the simulated cloud radiative forcing at the top-of-atmosphere, surface, and atmospheric column are quantified. Results from this work suggest that while general features of the cloud life cycle of DCSs simulated by WRF agree reasonably well with observations, various cautions must be given when using these simulations for different purposes, given their wide range of results from the choice of microphysics schemes alone.

Long-term evaluation of cloud fraction simulated by seven SCMs against the ARM observations at the SGP site

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This study evaluates the performances of seven single-column models (SCMs) (European Centre for Medium-Range Weather Forecasting [ECMWF] IFS; Geophysical Fluid Dynamics Laboratory [GFDL] AM2, 3; Goddard Institute for Space Studies [GISS] model E2, and Community Atmosphere Model [CAM] 3, 4, 5) by comparing simulated cloud fraction with observations at the Atmospheric Radiation Measurement Climate Research Facility's Southern Great Plains (SGP) site from January 1999 to December 2001. Compared with the three-year averaged Active Remote Sensing of Clouds (ARSCL) cloud fraction, the ECMWF and GISS SCMs underestimate cloud fraction at all levels. The striking feature for the GFDL SCMs is the underestimation of low-level cloud fraction but overestimation of high-level cloud fraction. The three single-column CAMs (SCAMs) overestimate high-level cloud fraction but have low-level cloud fraction similar to the observation, due to the compensation between the biases in convective and non-convective cloud fractions. The frequency distribution of cloud fraction shows a large discrepancy between the observation and SCMs. In the observation, it is a distinct U-shaped distribution of cloud occurrence, heavily concentrating on near-clear (< 5%) and near-overcast (> 95%) conditions; in contrast, in the SCMs, cloud events occur much more frequently between the two extremes. The three SCAMs overestimate mid-to-low level cloud events with moderate cloud fraction ranging from 10%–55%, which can be attributed primarily to the convective cloud fraction diagnosed based on convective mass flux. Further analysis of the non-convective cloudy events reveals different relationships between cloud fraction and relative humidity in the models and observation. Results imply that the cloud schemes, especially the diagnostic cloud schemes that involve the use of threshold relative humidity, need further improvement.

Macrophysical properties of tropical cirrus clouds from the CALIPSO satellite and from ground-based micropulse and Raman lidars

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Lidar observations of cirrus cloud properties over the ARM Climate Research Facility's Darwin site are compared from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite, the ARM micropulse lidar (MPL), and the ARM Raman lidar (RL). Comparisons are made using the subset of profiles transparent to the lidar beam. RL and CALIPSO cloud fraction profiles show

excellent agreement, while the MPL detects significantly less cirrus, particularly during the daytime. For cirrus-layer geometrical thickness, better agreement is found at night, while during the day both the MPL and CALIPSO cirrus layers are thinner than the RL. We find similar diurnal cycles in MPL and CALIPSO observations which could be due to increased daytime noise—during the daytime, cirrus clouds occur less frequently (noise prevents the detection of optically thin clouds) and are geometrically thinner (the tenuous cloud top and base are harder to detect, resulting in a thinner cloud). Daytime measurements using the RL are shown to be relatively unaffected by the solar background and are therefore used to check the validity of these diurnal cycles. The RL observations also show a similar decrease in daytime cirrus at the altitudes of maximum cirrus occurrence (~15–16 km). Below 15 km the RL diurnal cycle is of smaller magnitude and is of opposite sign below 11 km (thinner cirrus at night), although not all differences are statistically significant. Through the use of hourly MPL and RL cirrus cloud thickness and by the application of daytime detection limits to all CALIPSO data we find that the decreased MPL and CALIPSO cloud thickness during the daytime is likely due to noise. Also examined is the differences in cirrus optical depth due to method used to retrieve extinction,i.e., (1) a fixed lidar ratio, (2) the retrieval of the lidar ratio using layer transmission, and (3) the RL's ability to directly measure extinction using the nitrogen channel. Overall, the results of this study highlight the vast improvement the RL provides (compared to the MPL) in ARM's ability to observe tropical cirrus clouds and consequently a ground-based data set better suited for CALIPSO comparisons. With continued operation the accumulation of a long-term RL data set of tropical cirrus, with independently retrieved extinction/backscatter and relatively higher-quality daytime measurements, will be a useful means for CALIPSO validation.

Managing uncertainty in cloud and precipitation property retrievals with multiple synergistic remote sensors

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The principal motivation for the suite of remote sensors now operating at the ARM fixed and mobile sites is to diagnose processes related to the production of clouds and precipitation in atmospheric columns. This process-related goal can be achieved through simultaneous knowledge of the vertical air motions and the cloud and precipitation microphysics in vertical columns over and in the vicinity of the ARM sites. In this paper we seek to explore the capacity for ARM measurements to simultaneously resolve the properties of clouds, precipitation and atmospheric vertical air motions. In particular, we examine the sensitivity of the science objectives to the ill posed nature of the inversion problem. We demonstrate that, under many circumstances, the background knowledge required to interpret the measurements is insufficient to the extent that little if any actual information is conveyed by the measurements regarding the microphysics extant in the atmosphere.

Minimalist model of ice microphysics in mixed-phase stratiform clouds

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The persistent presence of ice in long-lived, supercooled stratiform clouds is the result of a delicate balance between environmental conditions, ice nucleus abundance, and microphysical properties (Morrison et al. 2012, Westbrook and Illingworth 2013). The role of ice nucleation, including the origin of the ice nuclei themselves as well as the modes in which they are active, is of special interest because properties of these long-lived clouds are extremely sensitive to the amount of ice (Ovchinnikov et al. 2011). In this work we present a minimalist model that links ice microphysical properties to the ice nucleation process and to macroscale cloud properties. The model assumes steady-state conditions and low ice concentrations in the presence of supercooled liquid water. We explore model behavior in the context of clouds observed during the Indirect and Semi-Direct Aerosol Campaign (ISDAC) held during spring 2008 in the vicinity of Barrow, Alaska (McFarquhar et al. 2011). Implications for model assumptions and for ice nucleation are discussed.

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Normalization of cirrus particle size distributions from SPARTICUS, MACPEX, and TC4: comparison with results from older data sets

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The normalization of raindrop particle size distributions (Testud et al. 2001) was developed in order to compare drop-size distributions in different parts of raining systems. This formalism has been extended to ice particle size distributions (PSDs), e.g., by Delanoe et al. (2005). Here, the normalization method proposed by Delanoe et al. is applied to more recently measured data in order to see how well the results of their normalization (i.e., their fit of the normalized PSD) compare with the application of their same method to PSDs that have been corrected for the mitigation of ice shattering effects. It is found that the formulation of the normalized PSD suggested by Delanoe et al. do not provide a good fit to the normalized ice PSD obtained from the Small Particles in Cirrus (SPARTICUS), Midlatitude Airborne

Cirrus Properties Experiment (MACPEX), and Tropical Composition, Cloud and Climate Coupling (TC4) data sets. Particular attention is paid to the comparison of populations of PSD moments reconstructed from the normalized PSD stemming from the newer data sets and from the formulation suggested by Delanoe et al. The simple conclusion is that more cirrus campaigns, using modern particle size probes and shattering mitigation processing, are needed to more fully and more accurately characterize cirrus PSDs.

On the relationship between cloud optical depth and temperature: inferences from ground-based observations at ARM sites

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The dependence of cloud optical depth on cloud-top temperature has been explored using International Satellite Cloud Climatology Project (ISCCP) satellite data by Tselioudis et al. 1992 showing that cloud optical depth increases with cold temperatures and decreases with warm temperatures. There is a growing interest in using this relationship to evaluate global climate modeling results and study long-term cloud feedback on climate change (Gordon and Klein 2012). However there is a lack of systematic investigation of this relationship based on ground-based observations. To extend the approach in Del Genio and Wolf (2000) on using ARM observations, we revisit this relationship using most updated long-term high-quality-controlled data to (1) provide a more accurate quantification of this relationship and (2) explore physical mechanisms that determine the relationship.

We first select single-layer overcast cloud observations at the Southern Great Plains (SGP) and North Slope of Alaska (NSA) sites and then separate the contribution to the change of cloud optical depth with temperature due to different factors, such as cloud physical thickness, cloud water content, and cloud water and ice effective radius by using independent measurement from different instrument and retrieval algorithms. Consistent with model results and previous studies, the change of cloud water content with temperature is rather dominating the change of cloud optical depth with temperature. The results are also compared with phase 3 of the Coupled Model Intercomparison Project (CMIP3)/Cloud Feedback Model Intercomparison Project (CFMIP) global climate model results output at ARM sites. Multi-model mean is able to reproduce this relationship within the uncertainty range of observations and shows the change of cloud water content with temperature is a dominating factor, while significant spread still exists among models on detail aspects.

On using the relation between Doppler velocity and radar reflectivity to distinguish microphysical regimes in ice clouds

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For Doppler cloud radars, a power-law relation between Doppler velocity (Vd) and radar reflectivity (Z, in mm6 m-3) can be developed for each cloud and each height within that cloud. The coefficients a and b of this relation are obtained by linear regression. The power-law relation exhibits some vertical variability within a cloud. Typical values of a and b depend on relative location from cloud top, temperature, and cloud thickness. The possibility of using profiles of the thus retrieved coefficients to distinguish microphysical regimes in ice clouds is explored. The methodology is demonstrated using Doppler radar measurements from ice clouds at the Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility site in the Southern Great Plains (SGP), Oklahoma, U.S.

Probabilistic assessment of cloud fraction using Bayesian blending of two data sets: a feasibility study

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Gabriel Kooperman, Scripps Institution of Oceanography

We describe and evaluate a novel method to blend two observed cloud fraction data sets through Bayesian posterior estimation. The research reported here is a feasibility study designed to explore the method. In this proof-of-concept study, we illustrate the approach using specific observational data sets from the U. S. Department of Energy Atmospheric Radiation Measurement Climate Research Facility's Southern Great Plains (SGP) site in the central United States, but the method is quite general and is readily applicable to other data sets. The total sky imager (TSI) observations are used to determine the prior distribution. A regression model and the Active Remote Sensing of Clouds (ARSCL) value-added product radar/lidar observations are used to determine the likelihood function. The posterior estimate is a probability density function (PDF) of the cloud fraction (CF) whose mean is used as the optimal blend of the two observations. The data at hourly, daily, 5-day, monthly, and annual time scales are considered. Some physical and probabilistic properties of the cloud fractions are explored from radar/lidar, camera, and satellite observations and from simulations using the Community Atmosphere Model (CAM5). Our results imply that (1) the Beta distribution is a reasonable model for the cloud fraction for both short- and long-time means, the 5-day are skewed right, and the annual data are almost normally distributed, and (2) the Bayesian method developed successfully yields PDF of CF, rather than a deterministic CF value and is feasible to blend the TSI and ARSCL data with capability of bias correction.

Radar-radiometer retrievals of cloud number concentration and dispersion parameter in marine stratocumulus

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The retrieval of cloud microphysical properties from remote sensors is challenging. In the past, ground-based radar-radiometer measurements have been successfully used to retrieve the liquid water content profile in nondrizzling clouds but offer little constraint in retrieving other moments of the cloud particle size distribution (PSD). Here, a microphysical condensational model under steady-state supersaturation conditions is utilized to provide additional constrains to the well-established radar-radiometer retrieval techniques. The coupling of the model with the observations allows the retrieval of the three parameters of a lognormal PSD, with two of them being height-dependent. Two periods of stratocumulus from the Azores are used to evaluate the novel technique. The results appear reasonable: continental-like number concentrations are retrieved, in agreement with the drizzle-free cloud conditions. The cloud optical depth derived from the retrieved distributions compares well in magnitude and variability with the one derived independently from a narrow-field-of-view zenith radiometer. Uncertainties coming from the

measurements are propagated to the retrieved quantities to estimate their errors. In general, errors smaller than 20% should be attainable for most parameters, demonstrating the added value of the new technique.

Reconciling ground-based and space-based estimates of the frequency of occurrence and radiative effect of clouds around Darwin, Australia

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The main purpose of this work is to investigate whether estimates of the frequency of occurrence of hydrometeors and associated cloud radiative forcing as derived from ground-based and satellite active remote sensing and radiative transfer calculations can be reconciled over a well-instrumented active remote sensing site located in Darwin, Australia. It is found that the ground-based millimeter-wavelength cloud radar (MMCR)-micropulse lidar (MPL) combination at the Darwin site does not detect most of the thin cirrus clouds above 10 km height, and that the CloudSat-CALIPSO combination strongly underreports the hydrometeor frequency of occurrence below 1.5 m height. The radiative impact of these differences in cloud frequency of occurrence and the resulting cloud radiative forcing is found to be quite large, especially on the shortwave radiative fluxes. Also, although the general shape of the mean vertical profile of radiative heating rate as derived from ground and satellite radar-lidar instruments and reverberation time (RT) calculations agree pretty well, large differences (up to 0.35 Kday-1 for the shortwave and 0.8 Kday-1 for the longwave, above the melting layer) are found at some heights in the troposphere. The general conclusion of this study is that current state-of-the-art ground-based and satellite estimates of the cloud frequency of occurrence, surface downwelling fluxes, top-of-atmosphere upwelling fluxes, and mean profile of radiative heating rate cannot be fully reconciled over Darwin, although there are heights in the troposphere where good agreement is found. Caution should therefore be exercised when evaluating the representation of clouds and cloud-radiation interactions in large-scale models, and limitations of each set of instrumentation should be considered when interpreting model-observations differences.

Retrieval of cloud microphysical properties from the new shortwave array spectroradiometer

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We are developing a radiative transfer retrieval algorithm for use with the new shortwave array spectroradiometer (SAS) data. This will provide high-time-resolution retrievals of cloud thermodynamic phase and optical depth and, for single-phase clouds, liquid water droplet effective radius or ice water effective particle size. The SAS instruments operate over a wavelength range that is very sensitive to cloud properties. Here we concentrate on cloud property retrievals from the SASHE (shortwave array spectroradiometer–hemispheric) instrument, which measures the direct-beam and diffuse hemispheric irradiance spectra in 30-second intervals from about 340–1700 nm. We have analyzed a sample of spectra under overcast skies from the Southern Great Plains site, comprising mainly liquid water but for a variety of optical depths, and have elucidated retrieval confidence and uncertainties. Cloud phase is ascertained by first retrieving the effective cloud optical depth using measurements in the interval 1000–1100 nm and then examining the shape of the spectral irradiance distribution in the 1.6-micron window, which is sensitive to liquid water versus ice and mixed phase. Once a liquid water case has been identified, we then perform a least-squares fit to the irradiances at 1534 and 1593 nm, which have a strong dependence on effective droplet radius. Once this retrieval method is fully developed, it should be a promising asset for diagnosing aerosol indirect effects in cloudy atmospheres.

Scanning ARM cloud radar value-added products: the first generation

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ARM has extended its long-time vertically profiling cloud radar observation capabilities into three dimensions with the installation of the Ka-, W-, and X-band scanning ARM cloud radars (SACRs) at its facilities, creating the first such continuously operating network. Scanning strategies have been developed to provide scientifically meaningful coverage of cloud and precipitation targets. The next step required to leverage scanning cloud radar observations into meaningful cloud and precipitation research is the development of quality-controlled value-added products (VAPs).

Here we focus primarily on the first generation of SACR-based VAPs, which are currently under development. This set of products provides feature masking and correction of moments from the individual radars. We discuss the relevant algorithms and provide examples of the expected products. A primary product is the significant feature mask. A robust masking algorithm differentiates hydrometeors and other significant returns (insects, ground clutter, second trip echoes) from radar receiver noise. In general, the SACR noise floor is determined adaptively, radial-by-radial, to account for environmental fluctuations and hardware issues. However, the masking procedure does rely on a climatologically determined maximum noise value to handle cases where atmospheric returns are present throughout most or all of a radial's range gates. Nearest-in-time soundings are incorporated into the VAP to enable the estimation of water vapor attenuation and perform the associated reflectivity corrections. Sounding-derived winds are used as a first guess of horizontal winds in the unfolding of aliased mean Doppler velocities. At the Southern Great Plains site, an algorithm based on linear depolarization ratio, temperature, and ceilometer cloud-base heights is employed in the lowest few kilometers to differentiate hydrometeor and insect returns.

Examples of these products are displayed, and plans for additional SACR products are discussed. Among these are horizontal wind retrievals using the hemispherical-sky range height indicator scans and the gridding of scanning cloud radar moments.

The sensitivity of Arctic stratocumulus to moisture sources in the subcloud and cloud-top inversion layers

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Arctic mixed-phase stratocumulus (AMPS) are observed to occur approximately 45% of the time on the North Slope of Alaska, with a significant increase in occurrence during spring and fall transition seasons (Shupe 2011). Due to the presence of liquid water in these clouds, they play an important role in determining the structure of the Arctic atmospheric boundary layer and magnitudes of surface energy budget terms.

Observations indicate that the processes that maintain subtropical and Arctic stratocumulus differ due to the different environments in which they occur. For example, specific humidity inversions (specific humidity increasing with height) are frequently observed to occur coincident with temperature inversions in the Arctic. For example, a recent survey found that specific humidity inversions occurred 75–80% of the time when low-level clouds were present, and that there was a significant relationship between the existence of specific humidity inversions and AMPS that extended into the temperature inversion (Sedlar et al. 2011), highlighting the difference between AMPS and subtropical stratocumulus where the entrainment of dry air aloft prevents cloud liquid water from forming in the temperature inversion.

In this study we examine many details of springtime AMPS using results from large-eddy simulations (LES) of the DOE Atmospheric Radiation Measurement Climate Research Facility's Indirect and Semi-Direct Aerosol Campaign (ISDAC, McFarquhar et al. 2011) using the Weather Research and Forecasting model (WRF). Results from a series of studies that focus on the sensitivity to moisture sources in the subcloud layer and in the cloud-top inversion layer will be presented. The impact of these moisture sources on the dynamical-radiative-microphysical interactions that maintain the AMPS cloud will be discussed. Comparisons to a previous study of the same case with nested WRF simulations will also be presented.

http://www.atmos-chem-phys.net/11/10127/2011/acp-11-10127-2011.pdf

Synoptic regime variability at the Azores site and the corresponding variability in cloud microphysical properties

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Edward Luke, Brookhaven National Laboratory

The ARM Mobile Facility (AMF) deployment site in the Azores was located at the southern tier of the North Atlantic storm alley, thus experiencing frequent transitions between midlatitude and subtropical synoptic regimes that are related to the zonal placement of the North Atlantic storm track. Given that poleward shifts in midlatitude storm tracks constitute a substantial source of cloud and rain climate feedbacks, the Azores site serves as a promising location to examine relevant cloud properties and processes at scales ranging from synoptic to microphysical and to evaluate the ability of a suite of models to simulate the primary system behaviors.

Two different methods are used here to classify the synoptic regimes affecting the Azores site during the time of the AMF deployment. The first relies on a new climatology of midlatitude storminess that, in addition to locating the storm center, delineates the area of influence of a midlatitude storm. The second applies a clustering algorithm to cloud optical thickness-cloud-top pressure histograms over the global domain and derives the major weather states based on the morphology of the cloud field. The two methods are used to derive the major regimes of variability over the Azores site, both from the perspective of cloud property and atmospheric dynamics variability. The relationship between the two is examined in order to isolate dynamic influences on cloud property changes. Then, data from the AMF retrievals for the period of employment are composited over regime-representative time periods in order to map the relationships between microphysical and synoptic scale changes in cloud structure and properties. In addition, recently derived microphysical retrievals of drizzle particle size distributions are statistically compared with existing regime-representative large-eddy simulations of low-lying marine clouds. The results of the study will allow us to place the AMF retrievals in the context of the global-scale cloud variability and will make possible the use of these data for the study of cloud climate feedbacks and for statistical evaluation of global model and large-eddy simulations.

Thermodynamic and radiative structure of cumulus-topped tropical and subtropical marine boundary layers

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Mark Miller, Rutgers University
Bruce Albrecht, University of Miami

Marine boundary-layer fair weather cumulus clouds have a significant impact on the Earth’s radiation budget due to their high shortwave albedo. These clouds are also intimately tied to the turbulence in the boundary layer and help transport the enthalpy and moisture from the surface to the free troposphere. Due to their minuscule temporal and spatial scales compared to the global climate model (GCM) resolution, these clouds need to be parameterized in GCM simulations aimed at predicting the future climate.

We have used the data collected during the deployment of the Atmospheric Radiation Measurement (ARM) Climate Research Facility's first mobile facility (AMF1) on Graciosa Island and at the Tropical Western Pacific (TWP) Manus site when single-layered boundary-layer cumulus clouds were observed at the facilities to study their thermodynamic and radiative structure. The radiosonde data was used to study the thermodynamic structure, especially to characterize the mixed-layer and the boundary-layer inversion. We have also used the data from vertically pointing cloud radars present at the site and that from other instruments to serve as an input to a 1-dimensional radiative transfer model called the Rapid Radiative Transfer Model (RRTM). The RRTM simulations were made at a high temporal (10-second) and vertical (10-meter) resolution to accurately capture the radiative impacts of the mixed-layer inversion and the boundary-layer inversion. We anticipate the results to be useful and serve as an input for studies using single-column models to test different parameterizations.

Tropospheric humidification and cloud microphysical structure observed over the Indian Ocean during AMIE

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Angela Rowe, University of Washington
Robert Houze, University of Washington

The interaction between the tropical cloud population and the large-scale environment of the central-equatorial Indian Ocean is investigated in the context of the Madden-Julian Oscillation (MJO) during the 2011–12 ARM MJO Investigation Experiment (AMIE) field campaign. Rawinsonde measurements taken every three hours at the ARM Mobile Facility (AMF) deployment on Gan Island provide an extremely detailed view of the variability in tropospheric humidity that occurs on 2–6 day timescales, as well as the longer intraseasonal (about 30 days) timescale associated with the MJO. Combining rawinsonde data with observations from the National Center for Atmospheric Research's (NCAR) S-PolKa scanning precipitation radar shows that the heights of convective echo tops rise rapidly at about the same time that the depth of an anomalously moist layer in the mid-troposphere increases rapidly. The near simultaneous build-up of clouds and humidity occurs over a period of 3 to 6 days just prior to or at the onset of an MJO-scale convective outbreak, suggesting that pre-humidification of the troposphere over timescales of more than a week is not necessary for a deep convective phase of an MJO to form. Analysis of the upper tropospheric wind field using the rawinsonde measurements and reanalysis strongly suggest that propagation of an equatorial Kelvin wave into the central Indian Ocean region played a decisive role in cloud development by making the upper-level environment conducive to active convection, which in turn, enhanced the environmental humidity. Data from S-PolKa, combined with ARM vertically pointing Ka-band ARM zenith radar (KAZR) observations, allow for the microphysical characteristics of non-precipitating and precipitating clouds to be investigated, providing a context to describe the feedback on the surrounding environment through tropospheric moistening, heating, and radiative feedbacks.

Turbulence effect on microphysics of mixed-phase deep convective clouds

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Alexander Khain, The Hebrew University of Jerusalem

In many recent studies the effects of turbulence on collisions of cloud droplets was investigated. It was shown that turbulence in cumulus clouds increases collision rate between cloud droplets several times and decreases the height level of formation of raindrops. In the present study the potential effect of turbulence on the microstructure of mixed-phase deep convective clouds is investigated using the spectral-bin microphysical model of the Hebrew University of Jerusalem. The collision rate enhancement between ice particles as well between ice particles and water drops is investigated. It is shown that turbulence intensifies process of riming and formation of graupel.

Effects of turbulence on cloud microphysics are investigated in simulations of clouds developing under different aerosol loading. Turbulence leads to acceleration of precipitation onset. At the same time turbulence decreases amount of accumulated rain at the stage of cold precipitation.

Use of ARM Raman, HSRL and MMCR measurements to characterize cirrus cloud properties and life cycle

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Ralph Kuehn, University of Wisconsin, Madison
David Turner, National Oceanic and Atmospheric Administration

The sensitivity of the millimeter cloud radar (MMCR) to optically thin single-layer cirrus at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) site is investigated using collocated Raman lidar observations. The sensitivity is characterized in terms of cloud optical depth (OD) and infrared (IR) radiative flux using over three years of coincident Raman lidar and MMCR observations. For cases when the Raman lidar is not fully attenuated (OD < 2.0), the MMCR detects approximately 70% of the total cloud OD with the majority of missed cloud OD occurring near cloud top. If only MMCR observations are used for computing cloudy top-of-atmosphere (TOA) infrared (IR) flux, the missed cloud OD results in TOA flux biases from 0 to over 100 W/m2; however, the most frequently occurring bias is approximately 16 W/m2. This result highlights the importance of combining Raman lidar, or other sensitive cloud lidars that are able to measure cloud extinction directly, with the MMCR in order to accurately characterize the cloud radiative forcing for thin cirrus cases.

Vertical velocity retrievals in marine stratocumulus clouds

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Sandra Yuter, North Carolina State University
David Mechem, University of Kansas

The motion-stabilized NOAA W-band cloud radar was deployed as part of the VAMOS Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS-REX) field campaign, observing southeastern Pacific stratocumulus in 2008; the ARM Mobile Facility (AMF) W-band ARM cloud radar (WACR) cloud radar was deployed at Graciosa, Azores, in summer 2009–2010. We retrieve vertical air velocity from stratocumulus clouds in these locations using radar reflectivity and mean Doppler vertical velocity moments, employing the constraint that gravitational settling of hydrometeors is independent and uncorrelated to air vertical motion (Pinsky et al. 2010).

This method constructs a lookup table of mean fall speeds as a function of reflectivity and properties of the cloud, e.g., height. We find that the mean fall speed dependence on height and reflectivity is variable in time, but that the time average lookup table is robust. We test the dependence of the lookup table on fundamental properties of the cloud, e.g., distance from cloud top and cloud thickness, with the goal of explaining variations in the fall speed-reflectivity relation with these variables.

Retrieved vertical velocities are relatively robust to the choice of the lookup table. We compare this simple moment-based vertical velocity retrieval with vertical velocities from other AMF-Graciosa optimal retrievals.

6.0 Dynamics/Vertical Motion

Bringing the ARM constrained variational analysis to 3D

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The current ARM constrained variational analysis value-added product (VAP) was designed to derive atmospheric advective tendencies and vertical velocity for a single column of the atmosphere from field campaign measurements. The derived data have been used as specified dynamics to force physical parameterizations, single-column models (SCMs), cloud-resolving models (CRMs), and large-eddy simulations (LES) so that their simulations of clouds can be evaluated against observation. To take advantage of new measurements from ARM scanning cloud radars to evaluate and test these models, we extended the current constrained variational algorithm for a single column to gridded three-dimensional fields. The derived fields satisfy the internal consistency of column-integrated conservations of mass, water vapor, and energy at each spatial location. The magnitude and spatial feature of the variational adjustments to the first-guess state variables are assessed. Preliminary results are shown for the analysis of the Tropical Warm Pool-International Cloud Experiment (TWP-ICE) field campaign data. Remaining issues are discussed. The analyzed three-dimensional advective forcing and vertical velocity along with other dynamical and thermodynamical fields can be potentially used in SCM/CRM/LES to simulate three-dimensional fields of clouds, thereby significantly increasing the sampling number of observational data to evaluate and test these models.

Developing the large-scale forcing data set for AMIE-Gan

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The large-scale forcing fields (e.g., vertical velocity and horizontal advective tendencies) are required to run single-column models, cloud-resolving models, and large-eddy simulations, which are the key modeling frameworks widely used to link field data to climate model developments. In this study, we use an advanced objective analysis approach to derive the required forcing data for the ARM MJO Investigation Experiment (AMIE) on Gan Island in the Maldives in support of its cloud modeling studies. AMIE-Gan is a major ARM field campaign conducted during the period October 2011 to March 2012 in conjunction with the Dynamics of the Madden-Julian Oscillation (DYNAMO) and Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011 (CINDY2011) campaigns. The goal of AMIE-Gan is to collect necessary data for studies of the initiation, propagation, and evolution of MJO and the associated convective clouds.

The objective analysis used in this study is the constrained variational analysis method. A unique feature of this approach is to use domain-averaged surface and top-of-the-atmosphere (TOA) observations (e.g., precipitation and radiative and turbulent fluxes) as constraints to adjust atmospheric state variables by the smallest possible amount to conserve column-integrated mass, moisture, and static energy. By doing so, the final analysis data is dynamically and thermodynamically consistent. Due to the lack of a sounding array, the AMIE-Gan forcing data is derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) operational analysis, which is then constrained with the field campaign surface and TOA observations, particularly with the ground-based radar retrieved precipitations. Uncertainties in these surface observations and their impacts on the derived forcing fields are discussed. The characteristics of the large-scale forcing structures for a selected MJO event observed during the campaign are analyzed. More details about this study will be presented in the meeting.

Exploring stratocumulus cloud-top entrainment processes and parameterizations using Doppler cloud radar observations

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Observations from the ARM upward-pointing millimeter-wavelength cloud radar (MMCR) located at the Southern Great Plains (SGP) site are used to examine the vertical velocity variance and energy dissipation rate at the top of continental stratocumulus clouds. These observations are used to examine terms in the turbulence kinetic energy (TKE) budget in the entrainment zone that are related to the entrainment rate. When this budget (without wind shear) is applied to the entrainment zone, the entrainment rate is proportional to a vertical transport and pressure perturbation term minus a dissipation term and inversely proportional to the strength of the inversion. In this study we use observations from a continental stratocumulus cloud observed over the SGP for a 14-hour period. Clouds were solid during this entire period and had thicknesses of 300–400 meters and tops increasing from 800–1200 m. The turbulence forcing due to surface buoyancy fluxes and radiative cooling at cloud top is obtained from surface flux measurements and radiative transfer calculations based on the cloud characteristics derived from cloud radar and lidar observations. Vertical velocity and spectrum width observations from the MMCR at SGP are used to examine the turbulence in the top 20% (60–80 m) of the cloud, which is define as the entrainment zone. The spectrum width is used to define energy dissipation rates directly in the entrainment zone, and the vertical velocity observations are used to define vertical velocity variance for one-hour periods. These quantities are then used to examine the terms in the TKE budget in this layer. It is found for the 14 hours of observations used in this study that the variance term is strongly correlated to the dissipation rates in the entrainment zone. However, the ratio of the variance term to the dissipation rate term is 0.12 during the day and 0.06 at night. This difference indicates that the length scales involved in the turbulence and entrainment processes may depend on whether the turbulence is forced by the surface fluxes or cloud-top cooling. To further explore this possibility, the relationships among the convective velocity scales, the vertical velocity variances, and the dissipation rates are examined and compared with entrainment rates from parameterizations based on the convective velocity scale and the strength of the inversion.

Gravity waves generated by convection during TWP-ICE

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Todd Lane, University of Melbourne

Gravity waves are identified in the radiosonde observations from the Tropical Warm Pool-International Cloud Experiment (TWP-ICE) campaign and their properties deduced. For the high-frequency waves, the intrinsic period is between 20–40 minutes. The wave activity, quantified by mass-weighted variance of the vertical motion perturbations, exhibits three main features. First, the wave activity in the stratosphere has a maximum following the afternoon local convection, indicating that these waves are generated by local convection. Second, at high rain rates, there is no clear relationship between the wave activity and the rain rate, suggesting that processes other than diabatic heating by convection play roles in generating these gravity waves. Third, the wave activity was strongest in the lower part of the stratosphere below 22 km and, during the suppressed monsoon period, varies on a time scale of 3–4 days. The concentration of the wave activity in the lower stratosphere is found to be consistent with the properties of the environment in which these waves propagated (using the Scorer parameter), whereas its 3–4-day modulation is due to the variation of the convection activity in the TWP-ICE domain.

The role of tilted heating in initiation and maintenance of the MJO

Cara-Lyn Lappen, Texas A&M University
Courtney Schumacher, Texas A&M University

There is mixed evidence surrounding the role of tilted heating in perpetuating a Madden-Julian Oscillation (MJO) in the Indian and Western Pacific Oceans. When tilt is observed, it shows low-level convergence, upward motion, and a positive moisture anomaly on the east side of the MJO convective center. This fosters new convection and enables an eastward propagation of the signal. On the west side, the tilted structure shows low-level divergence, downward motion, and negative moisture anomalies. In these cases, it is believed that shallow convection ahead of the MJO's convection center (low-level tilt) preconditions the lower atmosphere with the heat and moisture needed to sustain the MJO, while stratiform heating behind the MJO signal (upper-level tilt) is helpful in maintaining the deep convection.

Implementing a technique we developed to add heating distributions to version 4 of the Community Climate System Model (CCSM4), we showed in our previous work that correctly simulating the horizontal distribution of tropical heating is critical for accurate modeling of the MJO. In this current work, we employ the same technique to look at tilted heating distributions in CCSM4, both idealized and observed. We use idealized distributions of heating that are tilted to mimic the east-west progression of shallow convective, deep convective, and stratiform clouds (observed to pass during particular MJO phases). We isolate the low-level tilt and the upper-level tilt and individually analyze the importance of each in initiating and maintaining a strong MJO signal. In addition, International Satellite Cloud Climatology Project (ISCCP) data are analyzed for tilted heating distributions and is also used to force additional CCSM4 runs.

For the idealized cases, the heating input is shifted among latitude and longitude points in a manner that is consistent with the eight phases of the MJO. CCSM4 is then run for 15 years, and the resulting MJO that is produced by all distributions is compared to that of control runs done with little or no horizontally varying heating. We perform sensitivity studies on the strength and location of heating, as well as the angle to which the tilting occurs. Preliminary results show that the addition of the low-level tilt is more important than the upper level tilt in the overall life cycle of the MJO. We also show that the most robust MJO occurs when the tilting angle between the stratiform and mid-levlevel convection is steeper than that of the tilting angle between the shallow and mid-level convection.

Seamless measurements of vertical air velocity associated with warm clouds through the integration of multiple retrieval techniques

Edward Luke, Brookhaven National Laboratory
Pavlos Kollias, McGill University

Vertical air motion retrievals in warm phase boundary-layer clouds are key to quantitatively describing cloud turbulence and for improving the retrieval of cloud and drizzle microphysical properties. This is especially true for the marine boundary-layer clouds observed by the ARM Mobile Facility during the Clouds, Aerosol, and Precipitation in the Marine Boundary Layer (CAP-MBL) campaign on Graciosa Island and in light of the deployment of a new fixed ARM site there. Several methods have been proposed to retrieve the vertical air motion. We present current efforts to produce seamless measurements of vertical air velocity within and beneath drizzling and non-drizzling warm clouds, through the integration of these retrieval techniques. Recently developed radar Doppler spectra retrievals are effective in handling light, autoconversion-driven drizzle conditions. These are combined with retrievals from a radar-moments-based approach suited to heavier accretion-dominated drizzle. Comparisons near the operational drizzle intensity boundary of these two techniques provide opportunities for mutual validation. Doppler lidar is used to characterize subcloud velocities and to provide validation at the cloud base against in-cloud retrievals.

A theory for Rayleigh damping in the free troposphere

David Romps, University of California, Berkeley

In the weak-pressure-gradient (WPG) approximation for single-column models, the Rayleigh-damping time scale is the key tunable parameter. Rayleigh damping is also used in the Matsuno-Gill model and related toy models of atmospheric circulations. This damping is usually intended as an approximation of convective momentum transport. Typical values assigned to the damping time scale range from 1 to 10 days, although no theory has previously been given to explain these values. Here, such a theory is presented. It predicts a range of time scales from 1 to 10 days, and it also gives the dependence of the time scale on convective mass fluxes (or precipitation rate), convective entrainment rate, and the shape of the wind profile. The theory also predicts that long-wavelength components of the wind profile descend more slowly than short-wavelength components. These predictions are confirmed by large-eddy simulations.

Vertical air motions and DSDs retrieved from vertically pointing KAZR, S-band, and 449-MHz radar observations during MC3E

Christopher Williams, University of Colorado, Boulder/NOAA Earth System Research Laboratory

Using DOE ARM Climate Research Facility vertically pointing radars operating at frequencies sensitive to both Rayleigh and non-Rayleigh scattering provides the opportunity to retrieve the vertical air motion and the raindrop size distribution (DSD). The retrievals need to account for five different parameters:

mean vertical air motion and vertical air motion turbulence, and three parameters that describe the intensity, mean size, and spread of the DSD. In order to retrieve the vertical air motion from two vertically pointing radars, the five retrieved parameters must be reduced to four free parameters and a constraining relationship.

The DSD can be described using a gamma function with three parameters. Previous studies have shown that these three parameters are correlated. But there is controversy in the research literature over why the three parameters are correlated. Some studies suggest that the correlation is a statistical artifact due to correlation between the raindrop spectrum moments. Other studies suggest that the correlation is not a statistical artifact and have developed constraining relationships.

Analysis of surface disdrometer observations from the Midlatitude Continental Convective Cloud Experiment (MC3E) and other field campaigns suggests a relationship between the mass-weighted mean diameter and the mass spectrum standard deviation. This relationship is not a statistical artifact due to correlations between spectrum moments and suggests a physical relationship between the two DSD parameters. There are mathematical relationships between the DSD parameters and are used to develop a new constraint to describe the gamma-shaped DSD with two parameters and a constraining relationship.

The poster presented at the ASR Science Team Meeting will have two main components. First, the poster will present how a gamma-shaped DSD can be described with two parameters and a new DSD constraining relationship. And second, the poster will present vertical air motions derived during MC3E using the Ka-band ARM zenith radar (KAZR) (35-GHz) and S-band (3-GHz) vertically pointing radar observations along with comparisons of vertical air motions derived from a 449-MHz radar.

Water vapor turbulence profiles in stationary continental convective boundary layers

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Volker Wulfmeyer, Hohenheim University
Richard Ferrare, NASA Langley Research Center
Larry Berg, Pacific Northwest National Laboratory
Rob Newsom, Pacific Northwest National Laboratory
Jan Schween, University of Cologne, Institute of Geophysics and Meteorology

The U.S. Department of Energy Atmospheric Radiation Measurement (ARM) Climate Research Facility's Raman lidar at the Southern Great Plains (SGP) site in north-central Oklahoma has collected water vapor profile data more than 90% of the time since October 2004. Three hundred cases were identified where the convective boundary layer was stationary and well-mixed for a 2-hour period, and the variance and skewness profiles were derived from the 10-second, 75-meter resolution water vapor data. These cases span the entire calendar year and demonstrate that the water vapor variance at the mixed layer top (Zi) changes seasonally and is mainly related to the gradient of the water vapor across the entrainment zone. However, the water vapor variance at Zi shows only weak correlations ($r < 0.3$) with sensible heat flux, Deardorff convective velocity scale, and turbulence kinetic energy measured at the surface. The mean water vapor skewness is asymmetric around Zi, with the mean water vapor skewness being most negative at 0.85 Zi, zero at approximately 0.95 Zi, and positive above Zi; the negative skewness below Zi is attributed to the narrow dry downdrafts penetrating into the mixed layer while the positive skewness above Zi is due to the moisture plumes that ascend above the mean mixed layer top.

The spread in the water vapor skewness is smallest between 0.95 Zi and Zi. The water vapor skewness at altitudes between 0.6 Zi and 1.2 Zi is correlated with the magnitude of the water vapor variance at Zi, with increasingly negative values of skewness observed deeper in the boundary layer as the variance at Zi increases, suggesting that in cases with larger variance at Zi there is deeper penetration of the warm, dry free tropospheric air into the boundary layer.

7.0 Field Campaigns

Airborne multi-wavelength high spectral resolution lidar observations and applications from TCAP

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NASA Langley recently developed the world's first airborne multi-wavelength high spectral resolution lidar (HSRL). This lidar employs the HSRL technique at 355 and 532 nm to make independent, unambiguous retrievals of aerosol extinction and backscatter. It also employs the standard backscatter technique at 1064 nm and is polarization-sensitive at all three wavelengths. This instrument, dubbed HSRL-2 (the second-generation HSRL developed by NASA Langley), is a prototype for the lidar on NASA's planned Aerosols-Clouds-Ecosystems mission. HSRL-2 completed its first science mission in July 2012, the Two-Column Aerosol Project (TCAP) conducted by the DOE ARM Climate Research Facility in Hyannis, Massachusetts. HSRL-2 was deployed on the NASA King Air aircraft with the NASA GISS Research Scanning Polarimeter (RSP), and flights were closely coordinated with the DOE's G-1 aircraft, which deployed a variety of in situ aerosol and trace gas instruments and the new Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR). The ARM Facility also deployed the ARM Mobile Facility (AMF) and their Mobile Aerosol Observing System (MAOS) at a ground site located on the northeastern coast of Cape Cod for the TCAP experiment.

In this poster we focus on the capabilities, data products, and applications of the new HSRL-2 instrument. Data products include aerosol extinction, backscatter, depolarization, and optical depth; aerosol type identification; mixed-layer depth; and range-resolved aerosol microphysical parameters. The aerosol microphysical parameters include aerosol effective radius, index of refraction, single scatter albedo, and concentration. These microphysical parameters retrieved from the DOE ARM data set are the world's first demonstration of range-resolved aerosol microphysical retrievals from an airborne lidar. While the lidar microphysical retrievals are not as detailed as those made in situ on the G-1 aircraft, the "curtains" of horizontally and vertically resolved microphysical information enabled characterization of the aerosol properties above and below the G-1 flight altitude on the TCAP routes, and hence characterization of the entire column. In particular, the lidar curtains of aerosol scattering and absorption will be important for TCAP radiative closure studies. More generally, applications of the HSRL-2 data set include studies of aerosol direct and indirect effects, investigations of aerosol-cloud interactions, assessment of chemical transport models, and air quality studies.

AMF2 MAGIC deployment aboard the Horizon Spirit

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Nicki Hickmon, Argonne National Laboratory

The second ARM Mobile Facility (AMF2) deployed aboard the *Horizon Spirit* in support of the Marine ARM GPCI Investigation of Clouds (MAGIC) field campaign. Unlike land-based deployments the full complement of containers and sensors could not be deployed. The small deck area behind the bridge only allowed for three of the nine containers and space for the two stabilized platforms, micropulse lidar module, balloon launch cart, and helium storage. The modular nature of the AMF2 allowed for a reconfiguration of the containers to support the science objectives and to deploy most of the sensors on the roof of the containers. However, some standard ARM sensors could not be deployed aboard a ship and new sensors and techniques had to be developed. The portable radiation package consisting of a precision infrared radiometer (PIR), precision solar pyranometer (PSP), and fast-rotating shadowband radiometer (FRSR) was deployed in place of the sky radiation (SKYRAD), ground radiation (GNDRAD), and multifilter rotating shadowband radiometer (MFRSR) systems. The AMF2's surface meteorology system was not adequate to deploy high on the mast, so a new MarineMet system and an infrared thermometer-based system were developed to measure and calculate the sea-surface temperatures for use in the bulk aerodynamic flux calculations. The marine W-band ARM cloud radar (M-WACR) needed a new stabilized platform to keep it level during ship movement. Many of the remaining sensors need real-time or post processing to remove the effects of ship movement on the data requiring the AMF2's navigation system that measures the required variables. In order to assess the performance of the sensors by the mentors of each system, a small packet of data was sent each day consisting of data quality metrics and small data plots via an Iridium satellite antenna. The full complement of data was transferred either by 3G/4G cellular network or by shipping the high-volume data via hard drives at each port of call. An overview of the MAGIC deployment and associated challenges for the AMF2's first shipboard deployment will be presented.

Comparison of cloud statistics observed by cloud and precipitation radars during the DYNAMO/AMIE experiment at Addu Atoll

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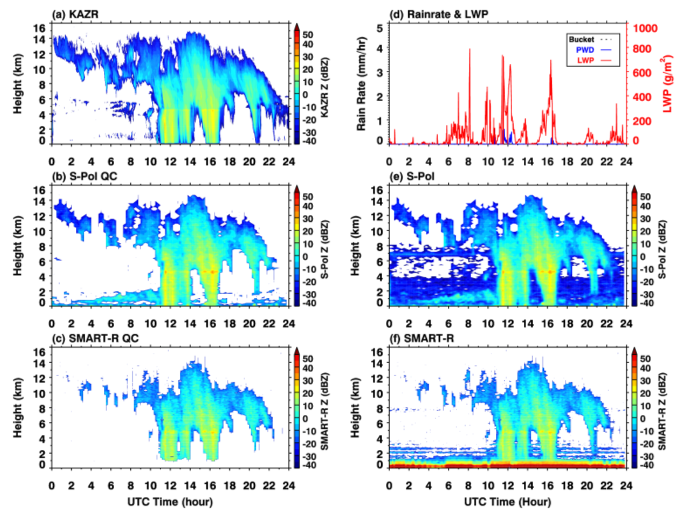
Courtney Schumacher, Texas A&M University
Scott Ellis, National Center for Atmospheric Research
Nitin Bharadwaj, Pacific Northwest National Laboratory

This study compares the measurements from the S-Band Polarization Radar (S-Pol) and Shared Mobile Atmospheric Research & Teaching Radar (SMART-R) radars to those from the more sensitive Ka-band ARM zenith radar (KAZR) during the Dynamics of the Madden-Julian Oscillation (DYNAMO)/ARM Madden-Julian Investigation Experiment (AMIE) field campaign in order to characterize the hydrometeor detection capabilities of the two scanning precipitation radars on Addu Atoll. Frequency comparisons for precipitating convective clouds and non-precipitating high clouds agree much better than non-precipitating low clouds for both scanning radars due to issues in ground clutter. On average, SMART-R underestimates convective and high cloud tops by 0.3 to 1.1 km, while S-Pol underestimates cloud tops by less than 0.4 km for these cloud types. S-Pol shows excellent dynamic range in detecting various types of clouds, and therefore its data are well-suited for characterizing the evolution of the 3D cloud structures, complementing the profiling KAZR measurements. For detecting non-precipitating low clouds and thin cirrus clouds, KAZR remains the most reliable instrument. However, KAZR is attenuated in heavy precipitation and underestimates cloud-top height due to rainfall attenuation 4.3% of the time during DYNAMO/AMIE. An empirical method to correct the KAZR cloud-top heights is described, and a merged radar data set is produced to provide improved cloud boundary estimates, microphysics, and radiative heating retrievals.



Example of collocated time-height radar reflectivity from KAZR, S-Pol, and SMART-R on 28 October 2011 at the AMF site. (a) KAZR-ARSCL reflectivity, (b) S-Pol quality-controlled reflectivity, (c) SMART-R quality-controlled reflectivity, (d) surface rain rate from weighing bucket and present weather detector rain gauges, and microwave radiometer column liquid water path, (e) S-Pol raw reflectivity, (f) SMART-R raw reflectivity.

http://campaign.arm.gov/amie/

Comparison of low-order and third-order turbulence closures in the cloud-resolving simulation of MC3E

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An intermediately prognostic higher-order turbulence closure (IPHOC) scheme is implemented in the System for Atmospheric Modeling (SAM) cloud-resolving model (CRM) version 6.10 and is compared with a low-order turbulence closure (LOC) on their abilities to simulate data from the Midlatitude Continental Convective Clouds Experiment (MC3E). The SAM is run as a 3D CRM for 45 days to cover the whole MC3E period for all simulations. The horizontal domain size used in all experiments is 256 km, while the horizontal grid size is 4 km. The vertical grid spacings are 50 m near surface and stretch to 1 km at the model top of 27 km. The results are reasonably well compared with available observations when the intermediately-prognostic higher-order turbulence closure (IPHOC) scheme was used, while the resolved kinetic energy and circulations are overestimated when the LOC scheme was used. The subgrid-scale liquid water potential temperature and total water transports play an important role in the development of the clouds, especially for the boundary-layer clouds. The influence of the subgrid-scale parameterization on cold pool for the deep convective clouds is fairly noticeable.

Data quality control for MC3E and selected case studies

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Several methods for calculating specific differential phase (Kdp) from the DOE X-band radar network at the ARM Southern Great Plains (SGP) site are investigated. Kdp is of central use for rainfall estimation and hydrometeor identification algorithms, so it is critical that a reliable Kdp algorithm be selected. As part of this comparison method, Kdp is also computed from distrometer data collected during the Midlatitude Continental Convective Clouds Experiment (MC3E). Errors and biases in the estimation of differential reflectivity are also reported. Work has also been underway to compare so-called “hand unfolding” of the X-band radial velocity data against automated methods based on three-dimensional variational (3D VAR) techniques. We will summarize these comparisons as well. Finally we will report on a selected case study from MC3E aimed at providing kinematic and hydrometeor fields for ARM model validation studies.

Field campaigns: an SGP specialty

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David Swank, ARM Climate Research Facility
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Douglas Sisterson, Argonne National Laboratory

Since its inception in 1992, the ARM Climate Research Facility’s Southern Great Plains (SGP) site has provided valuable data via an array of complex, continuously operating surface-based instruments, which are carefully attended to by Site Operations staff on a day-by-day basis. This is especially important during field campaigns. But this is only one aspect of the SGP Operations mission; the other is being directly involved in the support of field campaigns. Since 1992, the SGP has hosted more than 200 campaigns. Once SGP is notified of an approved campaign, SGP Operations works with the principal investigator (PI) to gather information to prepare for the upcoming campaign. Every department at the SGP is involved: safety, shipping and receiving, computer systems, facilities engineering, instrument maintenance, and administration support. A key tool used to gather all the information necessary from the PI is the Instrument Support Request (ISR). PIs are asked to submit this form, which provides a checklist of all aspects of logistical and safety requirements for each guest instrument and computers to be brought on site. It also identifies the required SGP support effort as well as expendables and other contracting needs. The ISR promotes a continuous dialog with the PI and field campaign participants in the early stages of planning that sets expectations so that investigators will find everything they need in place on the day they arrive. This front-end activity is critical to the success of all field campaigns. Presented are the 2012 field campaigns being conducted at the SGP, which are a good representation of the diversity of atmospheric research conducted at the SGP.

Full-column greenhouse gas profiles measured at ARM SGP

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The vertical distributions of CO_2, CH_4, and other gases provide important constraints for the determination of terrestrial and ocean sources and sinks of carbon and other biogeochemical processes in the Earth system. Remote sensing from ground-based and satellite-borne platforms requires in situ validation. We report results from a collaborative measurement campaign between the DOE Biological and Environmental Research Program (DOE-BER) and the NOAA Earth System Research Laboratory (NOAA-ESRL) to quantify the vertically resolved distribution of atmospheric carbon cycle gases (CO_2, CH_4, and CO) throughout 99% of the atmospheric column. To accomplish these measurements, a long coiled tube (or Aircore) is lofted to the stratosphere (~30 km) on a weather balloon and then collects a vertically resolved sample of air on descent. In 2012, we conducted eight successful Aircore flights from the DOE ARM Southern Great Plains (SGP) site in Oklahoma. Comparisons with collocated ARM aircraft measurements show good agreement for the lower half of the atmospheric column. In the coming year we plan to compare Aircore measurements with NASA remote sensing measurements and begin a transition from research mode to operational balloon-borne sampling that includes semi-automated recovery and on-site gas analysis at SGP. The expected outcome of this project will be an operational capability providing data that supports key DOE science objectives.

HOPE for clouds and precipitation

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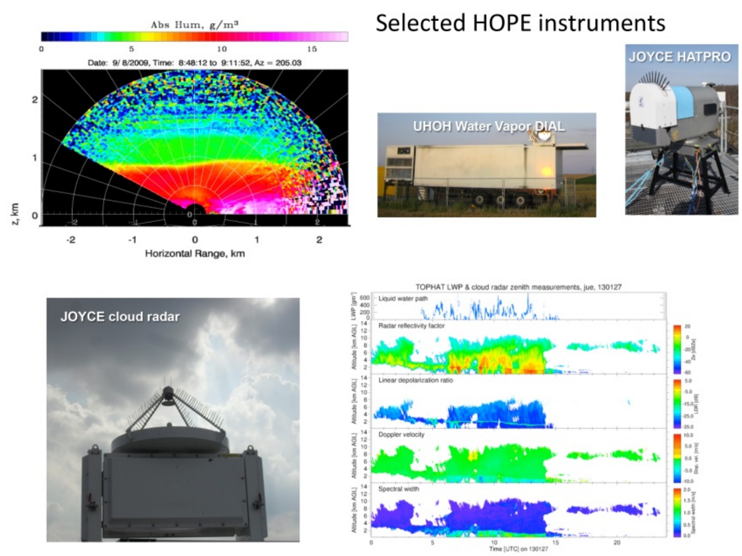
Patric Seifert, Leibniz Institute for Tropospheric Research
Clemens Simmer, University of Bonn
Volker Wulfmeyer, Hohenheim University



In order to better characterize clouds and precipitation in climate models, the German "High Definition Clouds and Precipitation for Advancing Climate Prediction" (HD[CP]2) research initiative is currently setting up a detailed and sustainable observational infrastructure. This includes the operation and harmonization of atmospheric profiling observatories delivering information of atmospheric aerosol, winds, and thermodynamic properties such as temperature, humidity, cloud, and precipitation. In April–May 2013 the HD(CP)2 Observational Prototype Experiment (HOPE) will be carried out in the direct vicinity of the Jülich Research Center with the goal to provide a critical model evaluation at the scale of the model simulations and further to deliver information on subgrid variability and microphysical properties that are subject to parameterizations even at high-resolution simulations. HOPE focuses on the onset of clouds (activation) and precipitation (auto conversion) in the convective atmospheric boundary layer. By capturing the 3D cloud distribution the measurement can support the investigation of cloud-overlap and 3D radiative effects.

- Microwave tomography of water vapor: three continuously scanning microwave radiometers will be operated simultaneously with a Raman lidar and a differential absorption lidar (DIAL) to capture the boundary-layer 3D water vapor structure within an area of roughly 5 km x 5 km during clear-sky conditions.
- Scanning cloud radar: Three cloud radars will be used to capture the spatio/temporal development of boundary-layer clouds by means of coordinated scanning procedures. Currently an integrated profiling algorithm for temperature, humidity, cloud water content (liquid water content [LWC]/ice water content [IWC]), and effective radius is being tested within a model environment. Next to combining passive and active microwave measurements from the surface, it can also include measurements from geostationary (i.e., Meteosat) as well as polar-orbiting (i.e., AMSU) satellites.
- Surface radiation balance network and radiative closure studies: a set of 100 low-cost pyranometers and several pyrgeometers will be distributed over the experiment area to observe the spatio/temporal

variability of the downwelling shortwave and longwave radiation. The observed 3D LWC fields will be applied to 3D radiative transfer models in order to reproduce the observed radiation fluxes and to recover and quantify the effect of cloud inhomogeneity on cloud radiative forcing.

http://gop.meteo.uni-koeln.de/hdcp2/doku.php

Integrated framework for retrievals in a networked radar environment and error characterization of retrievals

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The Midlatitude Continental Convective Clouds Experiment (MC3E) (Jensen et al. 2011) was a joint DOE Atmospheric Radiation Measurement (ARM) Climate Research Facility and NASA Global Precipitation Measurement (GPM) field campaign that took place from April–June 2011 in central Oklahoma centered at the ARM Southern Great Plains site. The field campaign involved a large suite of observing infrastructure currently available in the central United States, combined with an extensive sounding array, remote sensing and in situ aircraft observations, NASA GPM ground validation remote sensors, and new ARM instrumentation. The overarching goal was to provide the most complete characterization of convective cloud systems, precipitation, and the environment that has ever been obtained, providing constraints for model cumulus parameterizations and space-based rainfall retrieval algorithms over land that had never before been available. The experiment consisted of a large number of ground radars, including NASA scanning dual-polarization radar systems (NPOL) at S-band, wind profilers, and a dense network of surface disdrometers. In addition to these special MC3E instruments, there were three networked scanning X-band radar systems, four wind profilers, a C-band scanning radar, and a dual-wavelength (Ka/W) scanning cloud radar.

There is extensive literature on the retrieval algorithms for precipitation and cloud parameters from single-frequency, dual-polarization radar systems. With the cost of instruments such as radars becoming more affordable, multiple radar deployments are becoming more common in special programs, and MC3E is a textbook example of such a deployment. Networked deployments are becoming more common, popularized by the Collaborative Adaptive Sensing of the Atmosphere (CASA) program (Chandrasekar et al. 2010), resulting in networked retrievals, which were initially used for attenuation mitigation. Since then networked retrievals have expanded reach to include retrieval of drop-size distribution (DSDs) from networked X-band or Ku-band radars (Yoshikawa et al. 2012). All the above retrieval methodologies were for homogeneous, single-frequency systems; however, the multi-frequency nature of the deployment during MC3E is the motivation for the integrated formulation presented in this paper.

This paper presents a comprehensive integrated retrieval methodology to obtain microphysical retrieval such as the DSD for the complete MC3E network for the multi-frequency radar systems. The basic principles of the methodology include a Maximum Likelihood formulation of the microphysical parameter retrievals, while maximizing the posterior probabilities of the multiple retrieval systems. Numerical simulations are used to establish the integrity of the retrievals followed by demonstration with radar and in situ observations.

Light-absorbing carbonaceous aerosols at Detling in winter 2012: evidence of enhanced absorption

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Kyle Gorkowski, Los Alamos National Laboratory
Manvendra Dubey, Los Alamos National Laboratory
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Leah Williams, Aerodyne Research, Inc.
Paola Massoli, Aerodyne Research, Inc.
Ed Fortner, Aerodyne Research, Inc.
Andrew Freedman, Aerodyne Research, Inc.
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Nga Lee Ng, Georgia Institute of Technology
Claudia Mohr, University of Washington
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Joel Thornton, University of Washington

Atmospheric light-absorbing carbonaceous aerosols directly affect the Earth's radiation balance by absorbing solar radiation. A recent assessment finds the anthropogenic mean radiative forcing by black carbon (BC) to be 1.1 W m-2 (Bond et al. 2013), suggesting that BC is second only to CO_2 in warming the atmosphere. However, the magnitude of this forcing is associated with large uncertainties (0.17–2.1 W m-2) due to the complicated interaction between BC, organic carbon, and other atmospheric species and processes. For example, laboratory studies show that organic coatings on BC can enhance light absorption (Cross et al. 2009), but field observations show no enhancement in aged urban emissions (Cappa et al. 2012). Furthermore, carbonaceous aerosols from biomass burning show significant absorption at short wavelengths that was attributed to brown carbon (Lack et al. 2012). In order to elucidate these complex processes that control the variability in carbonaceous aerosols, optical and chemical properties of ambient particles were measured continuously from January 18 to February 15, 2012, at Detling, UK, during the Clean Air for London (ClearfLo) campaign. A three-laser photoacoustic spectrometer (PASS-3) was used to quantify the absorption and scattering coefficients of submicron particles. The campaign average absorption coefficients were 10.1, 8.3, and 4.4 Mm-1 at 405 nm, 532 nm, and 781 nm wavelengths, respectively. The absorption coefficients correlated to the hydrocarbon-like organic aerosol component and the biomass burning organic aerosol component that were extracted from the aerosol mass spectrometer measurements, suggesting the contribution of primary (likely vehicular exhaust) and biomass burning sources to the light-absorbing carbon particles at Detling. In addition, the BC absorption enhancement was measured by comparing the absorption of ambient particles to the absorption of particles after heating in a thermal denuder (TD). The enhancement factor ranged from 1.1 to 1.5, with higher TD temperatures resulting in greater enhancement factors. By comparing the enhancement factor from this study to other field measurements, the results suggest that the absorption properties of ambient particles may vary greatly. This study reinforces the need for more field measurements to constrain the absorption parameters used in climate models.

MAGIC: the first phase

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Minghua Zhang, Stony Brook University

The Marine ARM GPCI Investigation of Clouds (MAGIC) field campaign involves the deployment of the second ARM Mobile Facility (AMF2) on the Horizon Lines cargo ship *Spirit* making regular transects between Los Angeles and Honolulu through a region where the dominant cloud regime makes a transition from stratocumulus to trade-wind cumulus. MAGIC commenced taking measurements October 1, 2012, and continued until February 2013, when all ARM equipment had to be off the ship before the *Spirit* went into dry dock for normal maintenance. During these several months properties of clouds, aerosols, and radiation and meteorological parameters were routinely sampled. Additionally, an intensive operational period (IOP) occurred in January 2013 in which radiosonde launches occurred every three hours for one round trip. The measurements made to date will be discussed, and some results will be highlighted.

http://www.arm.gov/campaigns/amf2012magic

MJO events observed from AMIE/DYNOMO/CINDY and ARM long-term measurements at TWP

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The Madden-Julian Oscillation (MJO) is an intraseasonal fluctuation in the global tropics with a cycle of 30–60 days (Madden and Julian 1971, 1972). It is characterized by eastward propagation of regions of enhanced and suppressed tropical rainfall, associated with distinct patterns of lower and upper atmospheric circulation anomalies in the tropics. The ARM MJO Investigation Experiment (AMIE) campaign is associated with the Dynamics of the Madden-Julian Oscillation (DYNAMO) and Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011 (CINDY2011) campaigns to fully characterize the ensemble of convection associated with MJO with ARM cloud radars.

AMIE has two components: AMF2 on Gan Island in the Indian Ocean (AMIE-Gan), where the MJO enhanced convective phase initiates and starts its eastward propagation, and the ARM Manus site (AMIE-

Manus) in the Tropical Western Pacific, which is in the general area where the MJO usually starts to weaken in climate models. We find very different correlation patterns between cloud field and thermodynamic structure for three MJO events observed at these two locations. MJO events at Gan have tilted relative humidity (RH) structure with time and height, which means lifting of moisture level at the pre-onset stage and low-level drying at the post-onset stage. Increases in high cloud lag behind low-level and middle-level clouds. These features are consistent with the discharge-recharge mechanism (Blade and Hartmann 1993, Maloney and Hartmann 1998). However, MJO events at AMIE-Manus do not have the obvious patterns observed at AMIE-Gan.

To further elaborate on the conclusions found during the AMIE campaign, ARM long-term cloud radar and radiosonde observations at the Manus and Darwin sites from 2005 to 2010, along with National Centers for Environmental Prediction (NCEP) reanalysis data, are investigated. We classify each local MJO event as strong-sustaining or weak according to its intensity and duration as indicated by the MJO index provided by the National Oceanic and Atmospheric Administration (NOAA)/ NCEP climate prediction center. We find significant differences in cloud field and thermodynamic structure between the strong-sustaining and weak MJO events.

Multiscale variability of the tropical tropopause layer during AMIE

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The interface between the troposphere and the stratosphere is best described as a transition layer with characteristics of both the troposphere and the stratosphere. In the tropics, this region is known as the tropical tropopause Layer (TTL). The TTL extends from the level of main convective outflow (~200 hPa) to the lower stratosphere (~70 hPa). It sets the boundary conditions for atmospheric tracers entering the stratosphere. Specifically, TTL temperatures control stratospheric water vapor concentrations, which play a key role in the radiative budget of the stratosphere. The ARM Madden-Julian Oscillation (MJO) Investigation Experiment (AMIE), along with companion field campaigns Dynamics of the Madden-Julian Oscillation (DYNAMO) and Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011 (CINDY2011), offers a broad suite of data sets in the location of the origin of the MJO to investigate tropical convective systems over wide-ranging time scales and their impact on the tropopause and TTL. Here we present initial analysis of the response of TTL temperatures and winds to the MJO passages based on the intense high-resolution sounding observations on Gan from October–December 2011. In particular we analyze the characteristics of the observed wave structures and their impact on TTL structure and relate these to the observed deep convective and cirrus clouds.

http://campaign.arm.gov/amie/

Nucleation modes and particle habits of cirrus particles in synoptic cirrus: results from SPARTICUS and MACPEX

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Eric Jensen, NASA Ames Research Center
Sara Lance, National Oceanic and Atmospheric Administration

In situ measurements from the Small Particles in Cirrus (SPARTICUS) and Midlatitude Airborne Cirrus Properties Experiment (MACPEX) airborne campaigns provide extensive data sets of midlatitude cirrus microphysical properties. Jensen et al. (2013) recently compared 2D-S airborne measurements of particle concentration with results from numerical simulations of the synoptically-forced cirrus cases. The cases are stratified into three temperature regimes (-68°C to -58°C, -58°C to -48°C, -48°C to -38°C), and the observations are compared with simulations. One-dimensional simulations with detailed treatments of cloud microphysical processes are driven by temperatures and vertical winds extracted from meteorological analyses. The computationally efficient modeling approach incorporates the key cirrus physical processes, such that thousands of cloud cases can be simulated and the model results can be statistically compared with observations. Cloud particle habits are automatically classified using cloud particle imager (CPI) data and summarized for each of the three temperature regimes. Implications regarding homogeneous and heterogeneous nucleation are discussed.

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Observations and modeling of melting-layer microphysical processes in MC3E

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Microphysical factors controlling cold-pool evolution are uncertain and lead to considerable uncertainty in simulations of aerosol effects on organized deep convection. In particular, microphysical processes in stratiform rain regions of mesoscale convective systems are not well understood, especially within and above the melting layer. In an effort to reduce these uncertainties we have analyzed in situ observations of cloud particle size distributions and particle shape during the Midlatitude Continental Convective Clouds Experiment (MC3E), with particular focus on aircraft spiral ascent/descents through the melting layer during stratiform and convective trailing stratiform events over the ARM Southern Great Plains (SGP) site. Through newly developed particle shape analysis we can detect details of the melting process, showing the evolution of melting from small particle sizes to large ones. In addition, improved estimates of particle fall velocity, number concentration, and mass flux through the melting layer have been developed. These observations are compared with results from quasi-idealized cloud system-resolving model simulations, focusing on the May 20, 2011, squall line case.

Transformation of organic aerosol in Sacramento during CARES

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Jerome Fast, Pacific Northwest National Laboratory
Rahul Zaveri, Pacific Northwest National Laboratory
Alexander Laskin, Pacific Northwest National Laboratory
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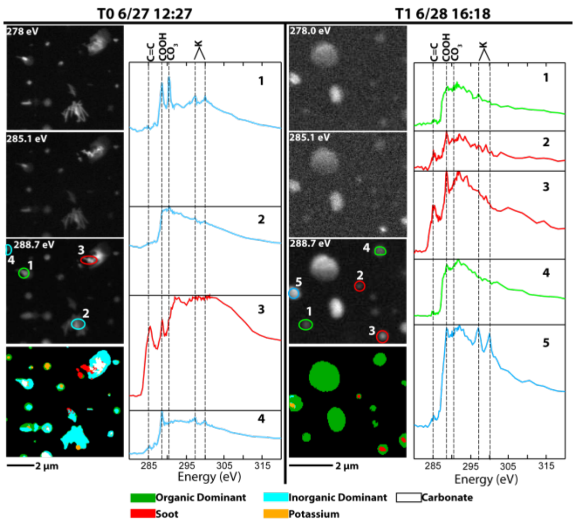

Fixed-site microscopy sampling during the Carbonaceous Aerosols and Radiative Effects Study (CARES) field campaign allowed for the observation of chemical changes within individual organic particles throughout a period of photochemical aerosol formation and build-up. To observe changes in the chemical composition of the particles with a 10–30 nm spatial resolution, a combination of scanning transmission X-ray microscopy/near-edge X-ray absorption fine structure spectroscopy (STXM/NEXAFS) and computer-controlled scanning electron microscopy/energy dispersive X-ray spectroscopy (CCSEM/EDX) was used. Scanning electron microscope (SEM) observations showed the characteristics of organic aerosol, sea salt, dust, and primary biogenic particles. STXM/NEXAFS measurements were used to show an increase in organic mass on individual particles in addition to changes in the detailed microstructure in internally mixed inorganic/organic particles.

The Two-Column Aerosol Project (TCAP): update and preliminary findings

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Jens Redemann, NASA Ames Research Center
Arthur Sedlacek, Brookhaven National Laboratory
Beat Schmid, Pacific Northwest National Laboratory
John Shilling, Pacific Northwest National Laboratory
Yohei Shinozuka, NASA
Stephen Springston, Brookhaven National Laboratory
Jason Tomlinson, Pacific Northwest National Laboratory
Jacqueline Wilson, Pacific Northwest National Laboratory
Alla Zelenyuk-Imre, Pacific Northwest National Laboratory
Carl Berkowitz, Pacific Northwest National Laboratory

The Two-Column Aerosol Project (TCAP) is designed to investigate changes in aerosol mixing state, cloud condensation nuclei (CCN) concentration, aerosol radiative forcing, and cloud-aerosol interactions in two atmospheric columns located at different distances from the coast of North America: over Cape Cod, Massachusetts, and a location approximately 200 km to the east. The primary reason for selecting this particular region is the large uncertainty in the aerosol optical depth (AOD) simulated by climate models near the edge of North America and a wide variety in the types of cloud cover over this region.

A surface supersite and two research aircraft were deployed during July 2012 for Phase 1 of the campaign. The surface site, which was deployed within the column located over Cape Cod, consists of the DOE Atmospheric Radiation Measurement (ARM) Climate Research Facility's Mobile Facility (AMF) and includes instruments to measure the aerosol chemical composition, size distribution, and optical properties. The AMF is providing continuous measurements until July 2013. The research aircraft included the DOE Gulfstream 1 (G-1) and the NASA Langley King Air B200 (Phase I only). The G-1 was equipped to make in situ observations of aerosol optical properties, chemical composition, particle size distributions, and measurement of AOD above the aircraft using the NASA spectrometers for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR). The NASA aircraft was equipped with the second-generation downward-looking (nadir) high spectral resolution lidar (HSRL-2) and research scanning polarimeter (RSP) to measure aerosol optical properties in the column of air between the aircraft and the ground. TCAP is the first science mission for both 4STAR and HSRL-2. Phase II of the campaign, conducted in February 2013, was designed to focus on cloud-aerosol interactions, in addition to the aerosol radiative forcing. To meet this need, the G-1 was equipped with a counter-flow virtual impactor (CVI) inlet in addition to the isokinetic inlet used in Phase I. The use of the CVI allows us to examine the chemical composition of the particles that have served as CCN.

Understanding sources and processes of submicron particles at an urban downwind location: results from DOE ALC-IOP at BNL

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Jian Wang, Brookhaven National Laboratory
Stephen Springston, Brookhaven National Laboratory
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Yin-Nan Lee, Brookhaven National Laboratory

The Department of Energy (DOE) sponsored the Aerosol Life Cycle Intensive Operational Period (ALC-IOP) field campaign, which took place at the Brookhaven National Laboratory (BNL) on Long Island, New York, from July 1 to August 15, 2011. An Aerodyne high-resolution time-of-flight aerosol mass spectrometer (HR-ToF-AMS) was deployed after a temperature-stepping thermodenuder during this study to acquire highly time-resolved, quantitative data on the mass-based size distribution, chemical composition, and volatility profile of the non-refractory fraction of submicron particles (NR-PM1). The average mass concentration of NR-PM1 was high (13.3 ±7.7) µg/m3, with organics (64.4%) and ammonium sulfate (31.6%) dominating the composition. Our results indicate that particles at Long Island were originated from different air masses, influenced by urban plumes from New York City, regional pollution enriched of ammonium sulfate, forest fire plumes transported from Canada, and oceanic emissions with elevated methanesulfonic acid concentrations. In addition, relatively high concentrations of metal species such as Na, Mg, K, Fe, Mn, Cu, Zn, Sb, Sn, and their adduct ions were observed from the night of July 4 to the early morning of July 5, indicating the detection of firework smoke arising from the Independence Day celebration. Due to the influences of different sources, organic aerosol composition and oxidation degree varied substantially during the campaign. Positive matrix factorization of the high-resolution mass spectra of organics identified three distinct OA factors: a low volatility, highly oxidized oxygenated OA (LV-OOA; O/C = 0.79); a semi-volatile OOA (SV-OOA; O/C = 0.41); and a nitrogen-enriched OOA (NOA; O/C = 0.15 and N/C = 0.185). The volatility of the LV-OOA is higher than that of ammonium sulfate but lower than that of ammonium nitrate. The volatility profiles of NOA and ammonium nitrate are similar, while SV-OOA is clearly more volatile than ammonium nitrate. The mass spectrum of NOA also indicates that it is likely composed mainly of amine salts. Based on these result, the sources and life cycle processes of OA at this urban downwind location will be discussed.

Validating NU-WRF simulations during MC3E field campaign

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Toshihisa Matsui, NASA Goddard Space Flight Center/University of Maryland, College Park Earth System Science Interdisciplinary Center
Christa Peters-Lidard, NASA GSFC Laboratory for Hydrospheric Processes
Arthur Hou, NASA Goddard Space Flight Center
Gail Jackson, NASA Goddard Space Flight Center
Lin Tian, Goddard Science and Technology Center University of Maryland
Gerald Heymsfield, NASA Goddard Space Flight Center
Walter Petersen, NASA Marshall Space Flight Center
Ann Fridlind, NASA Goddard Institute for Space Studies

The recent ARM supported/co-sponsored field campaign—Midlatitude Continental Convective Clouds Experiment (MC3E)—has provided excellent measurements that can be used for model validations.

In this study, we want to test Goddard microphysics through the validation for different precipitation systems. Three cases are selected from MC3E covering deep convective and widespread stratiform systems (May 1, 20, and 24, 2011).

Each case will be validated rigorously against available field campaign data sets with an emphasis on microphysics structure of the precipitating systems, such as brightness temperature, particle size distribution, and ice water content. In addition, by comparing simulations to similar types of observations those are widely available in different geophysical locations, such as radar reflectivity from Next-Generation Radar (NEXRAD) and precipitation from North American Land Data Assimilation System (NLDAS), we want to find out whether these model-observation differences are case-dependent or systematically biased across different precipitating systems in our current model. The above effort will be beneficial for algorithm development and model improvement.

8.0 Infrastructure & Outreach

ARM Climate Research Facility Data Quality Office

Sean Moore, Mission Research Corporation
Kenneth Kehoe, NOAA ESRL Global Monitoring Division
Justin Monroe, University of Oklahoma
Randy Peppler, University of Oklahoma
Adam Theisen, ARM Data Quality Office/University of Oklahoma Cooperative Institute for Mesoscale Meteorological Studies

The Data Quality Office coordinates the ARM Climate Research Facility's efforts to produce datastreams of quality suitable for scientific research. With the Data Quality Office, the Instrument Team, site scientists, and others within the ARM Facility regularly review and assess ARM's datastreams for problems. Data quality analysis results are then communicated to data users as well as to ARM's site operators and engineers. This data quality program helps minimize the amount of unacceptable data collected and helps ensure that informed decisions are made when people use the data.

The Data Quality Office has developed a wide variety of tools to assist those within the ARM infrastructure in their quest to improve data quality. These tools include interactive and pre-generated web-based graphics to explore data, long time-series of measurements to detect trends, frequency distributions to assess typical behavior, and color-coded metrics tables and graphics to convey problems. These tools are being upgraded to take advantage of machine-readable data quality reports, now available to data users via a publicly accessible web service. It is hoped that this immediate feedback of showing how data quality reports can assist in better filtering and use of ARM data will encourage more timely and more accurate reporting of future problems.

http://dq.arm.gov/

ARM Data Integration Group's roles and responsibilties

Chitra Sivaraman, Pacific Northwest National Laboratory
Sherman Beus, Pacific Northwest National Laboratory
Brian Ermold, Pacific Northwest National Laboratory
Todd Hull, Pacific Northwest National Laboratory
Krista Gaustad, Pacific Northwest National Laboratory
Nicole Keck, Pacific Northwest National Laboratory
Annette Koontz, Pacific Northwest National Laboratory
Matt Macduff, Pacific Northwest National Laboratory
Tonya Martin, Pacific Northwest National Laboratory
Yan Shi, Pacific Northwest National Laboratory
Timothy Shippert, Pacific Northwest National Laboratory
Katarina Younkin, Pacific Northwest National Laboratory

The ARM Data Integration (DI) Group at Pacific Northwest National Laboratory works to efficiently move data from the sites to the ARM Data Archive through multiple processing steps and reviews. They develop and support a variety of software components to accomplish this to ensure reliable data products. The ARM DI Group engages with instrument mentors, translators and developers from the External Data Center, the ARM Data Archive, and the Data Quality Office to complete the steps of data production:

- Planning new data
- Collecting instrument data
- Development of the software to process the data
- Creating software packages to process the data
- Processing data
- Reviewing data
- Reprocessing the data when there is an issue
- Archival of the data
- Discovery of the data.

This poster will provide an insight into the people and the work that goes on behind the scenes to keep the data flowing.

Campaigns for the new aerosol observing systems

Stephen Springston, Brookhaven National Laboratory
Arthur Sedlacek, Brookhaven National Laboratory

The next generation of aerosol observing systems (AOS) provides reliable platforms suitable for both intensive operational periods (IOPs) and long-term monitoring. They contain instrumentation for in situ measurements of aerosols and their precursors.

All AOS units have a basic suite of aerosol instrumentation with independent, free-standing aerosol sampling inlets based on earlier AOS units within the ARM Facility. Remote access for instrument mentors greatly reduces on-site operator needs. Basic scattering, absorbance, and concentration instruments are in all units. A local meteorology sensor at the inlet provides measurement context. Once on site with power and internet, most AOS operations can commence within 1–2 hours of set up (erection of the sampling towers and roof railings). The more complex Mobile AOS (MAOS A and C) consists of two SeaTainers and is also self-contained, but it requires more involved on-site mentor staging. MAOS has converters for labile compounds at the 10-meter sampling height, a separate fast-flow PFA inlet for a trace gas instrument suite, and enhanced instrumentation for aerosol chemical and microphysical characterization. The MAOS instrument suite includes aerosol and black carbon counters, optical and electro mobility classifiers, three measurements of aerosol absorbance, hygroscopicity measurements of aerosol growth and scattering, cloud condensation nuclei counters, two measurements of aerosol chemical composition, and an extensive suite of research-grade instruments for complementary measurements of trace gas aerosol precursors. A (sonic detection and ranging (SODAR) provides additional atmospheric state information.

As parts of the ARM Facility, these AOS units are physically contained in 20-foot SeaTainers custom adapted to provide a sheltered laboratory environment for operators and instruments even under harsh conditions. Largely independent, with separate data systems, inlets, and power distribution, the structures are designed for rapid deployment. All components are transported internally, protected by shock-mounted racks and in their operating configuration (plumbing, power, pumps, and data connections). All structures are suitable for extreme terrestrial conditions while maintaining laboratory conditions inside. In case of severe weather forecasts, the inlets can be quickly lowered. Inlets are deiced and guyed for winds up to at least ~50 m/s. In case of severe weather forecasts, the inlets can be quickly lowered.

Data Delivery Tracking Tool

Matt Macduff, Pacific Northwest National Laboratory
Sherman Beus, Pacific Northwest National Laboratory
Nicole Keck, Pacific Northwest National Laboratory

In 2012, the Data Delivery Tracking Tool was developed to help ARM Operations manage data flow from the sites to the ARM Data Archive. This tool queried databases and other sources from across the ARM infrastructure to provide a single view of the current data state. The intent was to create a tool that told the truth. This required the development of a flexible process to accommodate exceptions, ignore routine noise, and minimize cascading error reporting. The tool is currently used routinely across the ARM infrastructure.

https://dsview.arm.gov/ddtrack/#v::hi

DOE ARM Climate Research Facilities on the North Slope of Alaska: Barrow, Oliktok, Atqasuk, unmanned aerial vehicles, tethered balloons, field campaigns, and selected significant results

Mark Ivey, Sandia National Laboratories
Johannes Verlinde, Pennsylvania State University
Scott Richardson, Pennsylvania State University
Valerie Sparks, Sandia National Laboratories
Darin Desilets, Sandia National Laboratories
Fred Helsel, Sandia National Laboratories
Daniel Lucero, Sandia National Laboratories
Jeffrey Zirzow, Sandia National Laboratories
Robert Cook, Sandia National Laboratories
Larry Yellowhorse, Sandia National Laboratories
Martin Stuefer, University of Alaska, Fairbanks, Geophysical Institute
Christine Waigl, University of Alaska, Fairbanks

Since 1998, ARM facilities on the North Slope of Alaska (NSA) have provided data about cloud and radiative processes at high latitudes. The ARM NSA facilities are part of the ARM Climate Research Facility, a national user facility that provides scientific infrastructure and data archives to the international research community. The ARM NSA facilities are available for collaborative international research for both long- and short-term projects: weeks, months, or longer. Past campaigns studied boundary-layer clouds, mixed-phase Arctic clouds, and radiative heating in dry winter atmospheres. In 2011, we completed the installation of new instruments and upgrades to existing instruments in Barrow. A new ARM Mobile Facility, AMF3, is under development. Its first deployment is planned for Oliktok Point, Alaska, the site of previous ARM field campaigns. This poster will provide an update on new instruments at Barrow, current plans for Oliktok Point, and an update on development of AMF3.

www.arm.gov

DOE ARM Climate Research Facility—cloud, aerosol, and precipitation measurements for climate model evaluation and advancement

Jimmy Voyles, Pacific Northwest National Laboratory
James Mather, Pacific Northwest National Laboratory
Rolanda Jundt, Pacific Northwest National Laboratory
Jackie Marshall, Pacific Northwest National Laboratory

The Atmospheric Radiation Measurement (ARM) Climate Research Facility, a DOE national scientific user facility, has recently enhanced its observational capabilities at its fixed and mobile sites as well as its aerial facility. New capabilities include scanning radars, several types of lidars, an array of aerosol instruments, and in situ cloud probes. All ARM sites have been equipped with dual-frequency scanning cloud radars that will provide three-dimensional observations of cloud fields for analysis of cloud field evolution. Sites in Oklahoma, Alaska, and Papua New Guinea have also received scanning centimeter wavelength radars for observing precipitation fields. This combination of radars will provide the means to study the interaction of clouds and precipitation. New lidars include a Raman lidar in Darwin, Australia, and high spectral resolution lidars in Barrow and with the second ARM Mobile Facility. Each of these lidars will provide profiles of aerosol extinction while the Raman will also measure profiles of water vapor. Scanning Doppler lidars have been added to our Southern Great Plains, Darwin, and our first mobile facility. ARM has also expanded its capabilities in the realm of aerosol observations to include the second mobile facility. These aerosol systems principally provided measurements of aerosol optical properties. Additionally, a new Mobile Aerosol Observing System has been developed that includes a variety of instruments to provide information about aerosol chemistry and size distributions. Many of these aerosol instruments are also available for the ARM Aerial Facility (AAF). The AAF also now includes a variety of cloud probes for measuring size distribution and water content. Building on these new capabilities, ARM is adding two new research sites based on our expanded observational strategy and multidimensional measurements. A permanent research site will be added in the Azores and a third mobile facility will be deployed at Oliktok Point, Alaska. The new array of ARM instruments and sites are intended to build upon the existing ARM capabilities to better study the interactions among aerosol, clouds, and precipitation. Data from these instruments are now available, and the development of advanced data products is underway.

http://www.arm.gov

Eastern North Atlantic Graciosa Island ARM facility

Kim Nitschke, Los Alamos National Laboratory
Eduardo Azevedo, University of the Azores
Paul Ortega, Los Alamos National Laboratory
Amon Haruta, Los Alamos National Laboratory

The new ARM facility on Graciosa Island, the Azores, Portugal, is scheduled to be operational on September 30, 2013. This poster will outline the proposed capabilities, instrument configurations, and progress to date.

Exploring variability of radar backscattering cross-sections of dendrites at millimeter wavelengths

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Eugene Clothiaux, Pennsylvania State University
Kultegin Aydin, Pennsylvania State University
Johannes Verlinde, Pennsylvania State University
Giovanni Botta, Pennsylvania State University

Botta et al. (2012, in progress) developed a database of backscattering cross-sections at X-, Ka-, and W-bands of dendrites with different masses, maximum dimensions, and shapes. Based on this database we developed a two-parameter model that captures most of the variability within it. The first parameter is the sum of the phase across all parts of a particle as observed far from the particle, which relates to coherence effects between different parts of a particle. It captures most of the variability in the backscattering cross-sections that are due to differences in the masses, maximum dimensions, shapes and orientations of the dendrites. The second parameter relates to self-interactions between different parts of a dendrite that are relatively close together, which alter the electric field strength inside the particle. It explains secondary variability within the database of backscattering cross-sections due to different structures within the dendrites. Backscattering cross-sections estimated by a computationally inexpensive model based on these two parameters are compared with those from the database. Among all the backscattering cross-sections from dendrites with different mass, maximum dimension, shape and orientation, 94.83% of them have differences between model and GMM results that are less than 0.5 dB, 4.88% between 0.5 dB to 1.0 dB, and 0.29% larger than 1.0 dB, with a maximum error of 5.88 dB. We show that the variability within the database is due to the mass, maximum dimension, orientation, and internal structure of the dendrites. This implies that, amongst other things, ice microphysical models must predict these characteristics of dendrites, especially their internal structure, if their particle properties are intended for forward modeling of radar backscattering cross-sections with subsequent comparisons to radar observations. Observations of detailed ice crystal structures that illustrate the distribution of mass within them are ultimately necessary to guide the development of such ice microphysical models.

IDL and Python language bindings for the ARM Data Integrator (ADI)

Krista Gaustad, Pacific Northwest National Laboratory
Brian Ermold, Pacific Northwest National Laboratory
Jeff Daily, Pacific Northwest National Laboratory

This poster describes the Interactive Data Language (IDL) and Python language bindings that have been implemented to access the ARM Data Integrator (ADI) libraries. These bindings facilitate the development of ARM value-added products (VAPs) and other processes involving the consolidation of data from diverse input data sets in the IDL and Python programming languages. The core ADI modules and supporting data retrieval, transformation, and product creation functions were developed in the C programming language. The bindings that wrap these functions have been developed to provide users the look and feel of programming in the native languages through the use of object-oriented class, properties, and methods.

Precipitation estimation from the ARM distributed radar network during the MC3E field campaign

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Scott Giangrande, Brookhaven National Laboratory
Scott Collis, Argonne National Laboratory
Ali Tokay, University of Maryland, Baltimore County

The Midlatitude Continental Convective Clouds Experiment (MC3E) was the first demonstration of the Atmospheric Radiation Measurement (ARM) Climate Research Facility's scanning precipitation radar platforms. A goal for the MC3E field campaign over the Southern Great Plains (SGP) facility was to demonstrate the capabilities of ARM polarimetric radar systems for providing unique insights into deep convective storm evolution and microphysics. One practical application of interest for climate studies and the forcing of cloud-resolving models is improved Quantitative Precipitation Estimates (QPE) from ARM radar systems positioned at SGP.

This study presents the results of ARM radar-based precipitation estimates during the two-month MC3E campaign. Collocated ground disdrometer resources, precipitation profiling radars, and nearby surface Oklahoma Mesonet gauge records are consulted to evaluate potential ARM radar-based rainfall products and optimal methods. Rainfall products are also evaluated against the regional (Next-Generation Radar [NEXRAD])-standard observations.

Small cloud particle shapes in mixed-phase clouds

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Junshik Um, University of Illinois, Urbana-Champaign
Robert Jackson, University of Illinois, Urbana-Champaign

The shapes of cloud particles with maximum dimensions (Dmax) between 35 and 60 micrometers in mixed-phase clouds were studied using high-resolution particle images collected by a cloud particle imager (CPI) during the Mixed-Phase Arctic Cloud Experiment (M-PACE) and Indirect and Semi-Direct Aerosol Campaign (ISDAC). The area ratio (alpha), the projected area of a particle divided by the area of a circle with diameter Dmax, quantified particle shape. The differing optical characteristics of CPIs used in M-PACE and ISDAC had no effect on derived alpha provided Dmax > 35 micrometers and CPI focus > 45. The fraction of particles with 35 < Dmax < 60 micrometers with alpha > 0.8 increased with the ratio of liquid water content (LWC) to total water content (TWC). The average alpha_mean of small particles in each 10-second interval in mixed-phase clouds was correlated with LWC/TWC with a correlation coefficient of 0.60 for M-PACE and 0.43 for ISDAC. The stronger correlation seen during M-PACE was most likely associated with the presence of more liquid droplets larger than the CPI detection threshold contributing to alpha_mean; the modal effective radius was larger (11 micrometers compared to 6 micrometers), and drops with D > 35 micrometers had 6 times larger concentrations during M-PACE compared to ISDAC. This study hence suggests that area ratio can be used to identify the phase of particles with 35 < Dmax < 60 micrometers and questions the assumption used in previous studies that all particles in this size range are supercooled droplets. The impacts on the representation of mixed-phase clouds in numerical models are discussed.

Solar radiometric data assessment using ARM and NREL data quality tools for SKYRAD, GNDRAD and SIRS stations

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Mary Anderberg, National Renewable Energy Laboratory
Aron Habte, National Renewable Energy Laboratory
Mark Kutchenreiter, National Renewable Energy Laboratory
Peter Gotseff, National Renewable Energy Laboratory

The Atmospheric Radiation Measurement (ARM) Climate Research Facility provides quantitative radiometric data of known quality available to users based on pyranometer and pyrheliometer calibrations and measurements traceable to the World Radiometric Reference (WRR). The National Renewable Energy Laboratory (NREL) and the radiometer calibration facility at the Southern Great Plains provide calibration of broadband radiometers deployed in the sky radiometers on stand for downwelling radiation (SKYRAD), ground radiometers on stand for upwelling radiation (GNDRAD), and solar and infrared radiation station (SIRS) instrument platforms. In addition to radiometer calibration, the quality of broadband radiometric data depends on the installation, operation, and maintenance of the instruments. As the broadband radiometer instrument mentor for ARM, NREL addresses Data Quality Problem Reports (DQPR), Data Quality Reports (DQR), and related data quality actions by identifying radiometric data problems and providing solutions for the SKYRAD, GNDRAD, and SIRS data using available ARM data quality tools and NREL-developed methods. The poster summarizes the concepts for these tools and provides sample results from applications to SKYRAD, GNDRAD, and SIRS data from selected sites.

http://www.nrel.gov/solar_radiation/

Update, status, and characteristics of the AMF2 stable platform

Richard Coulter, Argonne National Laboratory
Timothy Martin, Argonne National Laboratory

AMF2's stable platform, developed to support the marine W-band ARM cloud radar (M-WACR) measurements, was placed into operation as part of the Marine ARM GPCI Investigation of Clouds (MAGIC) field campaign. The table (roll, pitch, and heave; RPH) is designed to compensate for the roll, pitch and vertical motion of the ship, in this case the *Horizon Spirit*. Control of the table is done either through a “straight” proportional, integral, derivative (PID) approach that requires no additional input beyond a tilt sensor mounted on the table or an “enhanced” PID approach that requires external input of the ship's roll and pitch. The response of the RPH table to either type of control was found to be very good so long as the feedback controls were appropriate. Initial results from the first seven voyages are presented, and suggestions for improved future operation are discussed.

Using statistical comparisons between simulations and ARM observations to understand physical processes controlling midlatitude cirrus bulk properties

Eric Jensen, NASA Ames Research Center
Paul Lawson, SPEC, Inc.
Leonhard Pfister, NASA Ames Research Center
Gerald Mace, University of Utah

The 2010 DOE Small Particles in Cirrus (SPARTICUS) and the 2011 NASA Midlatitude Cirrus Properties Experiment (MACPEX) provided extensive data sets of midlatitude cirrus clouds with new instrumentation designed to minimize shattering artifacts and with sufficient time response to image particles as small as 10 um. In addition, the long-term radar and lidar measurements at the ARM SGP site provide cirrus bulk properties (ice water content, extinction, and effective radius). We will first present statistics of midlatitude cirrus microphysical properties. Next, we will compare the measured cirrus microphysical property statistics with results from ensembles of detailed process-model simulations driven by meteorological analyses and including small-scale waves. Sensitivity studies will be used to evaluate the relative importance of different cloud physical processes (heterogeneous and homogeneous nucleation, deposition growth, sublimation, sedimentation, and aggregation) in controlling the ice concentrations, ice water content, extinction, and effective radius. We will show that small-scale waves that are not resolved in meteorological analyses are critical for producing high ice concentrations that are occasionally observed.

Value-added product highlights from the Cloud Life Cycle working group

Michael Jensen, Brookhaven National Laboratory
Scott Collis, Argonne National Laboratory
Shaocheng Xie, Lawrence Livermore National Laboratory
Maureen Dunn, Brookhaven National Laboratory
Edward Luke, Brookhaven National Laboratory
Karen Johnson, Brookhaven National Laboratory
David Troyan, Brookhaven National Laboratory
Renata McCoy, Lawrence Livermore National Laboratory

ARM value-added products (VAPs) provide an important translation between the measurements from ARM instrumentation and the geophysical quantities needed for scientific analysis, particularly model parameterization and development. VAPs are developed by the ARM infrastructure team (translators and developers) with guidance from each ASR science working group and individual science sponsors for each VAP. This poster will highlight the current status of ARM VAPs relevant to the ASR Cloud Life Cycle working group (CLWG) with an emphasis on new developments including precipitation and cloud radar-based VAPs, vertical velocity VAPs, and forcing data sets.

Value-adding the ARM precipitation radars

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Scott Giangrande, Brookhaven National Laboratory
Jonathan Helmus, Argonne National Laboratory
Adam Theisen, ARM Data Quality Office/University of Oklahoma Cooperative Institute for Mesoscale Meteorological Studies
Nitin Bharadwaj, Pacific Northwest National Laboratory
Kevin Widener, Pacific Northwest National Laboratory
Maureen Dunn, Brookhaven National Laboratory
Kirk North, McGill University

The ARM Climate Research Facility currently operates two 5-cm wavelength (C-band) and four 3-cm wavelength (X-band) scanning radar systems. The scientific goal is to capture the microphysics and kinematics of precipitating cloud systems. The radars, however, do not directly measure the pertinent geophysical parameters, but rather the properties of the backscattered beam. This presentation will outline the work being carried out by the radar products team and collaborators on producing a suite of quality-controlled geophysical retrievals from the ARM radar network including: quantitative precipitation estimates, Cartesian mapped radar moments, quality-controlled corrected moments in antenna coordinates, and variationally retrieved storm kinematics. Details regarding temporal and spatial coverage will be given as well as examples of applications and selected examples of future work.

http://www.arm.gov/

VAP highlights for the CAPI working group

Laura Riihimaki, Pacific Northwest National Laboratory
Sally McFarlane, U.S. Department of Energy
Chitra Sivaraman, Pacific Northwest National Laboratory
Tim Shippert, Pacific Northwest National Laboratory
Krista Gaustad, Pacific Northwest National Laboratory
Yan Shi, Pacific Northwest National Laboratory
Jennifer Comstock, Pacific Northwest National Laboratory

We will present an update on the development of value-added products (VAPs) associated with the Cloud-Aerosol-Precipitation Interactions (CAPI) working group. VAP highlights for this year include the following efforts:

- Initial development of a cloud droplet number (NDROP) product and submission of data to the ARM Data Archive evaluation area
- Processing Radiatively Important Parameters Best Estimate (RIPBE) and Broadband Heating Rate Profile (BBHRP) for initial ARM Cloud Retrieval Ensemble Data Set (ACRED) cloud retrievals as part of the Quantification of Uncertainty in Cloud Retrievals (QUICR) focus group
- Updating RIPBE and BBHRP to run with new versions of input data
- Extension of Cloud Optical Depth from MFRSR (MFRSRCLDOD) to Southern Great Plains (SGP) extended facility sites, TWP sites, and the ARM Mobile Facility (AMF) Azores deployment

- Adjusting the Raman Lidar Cloud Profile VAP to include cloud properties up to 20 km at the Tropical Western Pacific (TWP) Darwin site
- Extending the surface spectral albedo product to the North Slope of Alaska (NSA).

We will also discuss plans for future CAPI VAP efforts including continued work on the Planetary Boundary Layer (PBL) Height products, development of an Infrared Thermometer Sea-Surface Temperature (IRTSST) VAP for AMF2 ship deployments, and implementation of a new retrieval for the 3-channel microwave radiometers.

9.0 Instruments

Aerosol mass spectrometry of particles containing refractory carbon

Timothy Onasch, Aerodyne Research, Inc.
Ed Fortner, Aerodyne Research, Inc.
Paola Massoli, Aerodyne Research, Inc.
Leah Williams, Aerodyne Research, Inc.
Andrew Lambe, Boston College
John Jayne, Aerodyne Research, Inc.
Paul Davidovits, Boston College
Douglas Worsnop, Aerodyne Research, Inc.

Refractory black carbon (rBC)-containing particles, including energy-derived combustion particles, can affect climate directly by absorbing (and scattering) incoming light depending on particle composition and morphology and indirectly by influencing cloud droplet formation and lifetimes. The uncertainty in the climatic effects of rBC is driven, in part, by several important factors: poorly understood formation, poorly quantified atmospheric processing (e.g., hydrophobic into hydrophilic), and limited information on the UV-VIS-IR optical properties. These uncertainties are complicated by the lack of measurement techniques that can unambiguously measure properties of refractory carbon containing particles.

To help address these uncertainties, we have developed a soot particle aerosol mass spectrometer (SP-AMS) instrument capable of measuring the mass, size, and chemical composition of rBC particles. rBC particles are vaporized by a CW intracavity Nd:YAG laser vaporizer (1064 nm). The volatilized components are ionized by 70 eV electron impact ionization and detected by high resolution time-of-flight mass spectrometry. Laboratory studies demonstrate that the SP-AMS technique provides real-time mass spectra of refractory carbon ion cluster distributions for sampled aerosol particles containing refractory carbon materials. The mass spectra of rBC particles fall into categories that point toward distinct carbon atom bonding and structures from different types of rBC particles, with the potential for source apportionment. In addition, the SP-AMS provide a unique capability for real-time measurements of the amount and chemical composition of non-refractory components associated with refractory carbon containing particles. These measurements provide an additional constraint on methods for quantifying and modelling the interaction of solar radiation with rBC particles. Results from laboratory and field studies will be presented.

Airborne continuous CO_2 in the U.S. Southern Great Plains

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Margaret Torn, Lawrence Berkeley National Laboratory
James Smith, Atmospheric Observing Systems, Inc.
Colm Sweeney, NOAA Earth System Research Laboratory
Pieter Tans, NOAA Earth System Research Laboratory

We report on 10 years of airborne measurements of atmospheric CO_2 concentrations from continuous and flask systems, collected between 2002 and 2012 over the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) site. These observations were designed to quantify trends and variability in atmospheric concentrations of CO_2 and other greenhouse gases with the precision and accuracy needed to evaluate ground-based and satellite-based column CO_2 estimates, test forward and inverse models, and help with the interpretation of ground-based CO_2 concentration measurements. During flights, we measured CO_2 and meteorological data continuously and collected flasks for a rich suite of additional gases: CO_2, CO, CH_4, N_2O, $13CO_2$, carbonyl sulfide (COS), and trace hydrocarbon species. These measurements were collected approximately twice per week by small aircraft (first a Cessna 172, then Cessna 206) on a series of horizontal legs ranging in altitude from 460 meters to 5500 meters (above mean sea level). Since the beginning of the campaign, more than 400 continuous CO_2 vertical profiles have been collected (2007–2012), along with about 330 profiles from NOAA Earth System Research Laboratory 12-flask (2006–2012) and 284 from NOAA/ESRL 2-flask (2002–2006) packages for carbon cycle gases and isotopes. Averaged over the entire record, there were no systematic differences between the continuous and flask CO_2 observations when they were sampling the same air, i.e., over the one-minute flask-sampling time. Using multiple technologies (a flask sampler and two continuous analyzers), we documented a mean difference of ~0.1 ppm between instruments. However, flask data were not equivalent in all regards; horizontal variability in CO_2 concentrations within the 5–10 minute legs sometimes resulted in significant differences between flask and continuous measurement values for those legs, and the information contained in fine-scale variability about atmospheric transport was not captured by flask-based observations. The CO_2 concentration trend at 3000 meters (above mean sea level) was 1.91 ppm y-1 between 2008 and 2010, very close to the concurrent trend at Mauna Loa of 1.95 ppm y-1. The seasonal amplitude of CO_2 concentration in the free troposphere (FT) was half that in the planetary boundary layer (PBL) (~15 ppm vs. ~30 ppm) and twice that at Mauna Loa (approximately 8 ppm). The CO_2 horizontal variability was up to 10 ppm in the planetary boundary layer and less than 1 ppm at the top of the vertical profiles in the free troposphere.

Arctic high spectral resolution lidar measurements of aerosols and clouds

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Richard Ferrare, NASA Langley Research Center
Edwin Eloranta, University of Wisconsin
David Turner, National Oceanic and Atmospheric Administration

As part of the American Recovery and Reinvestment Act (ARRA) of 2009, the DOE ARM Climate Research Facility deployed a new ground-based Arctic high spectral resolution lidar (AHSRL) at the North Slope of Alaska (NSA) site. This lidar, which is based on the AHSRL that was part of NOAA's Study of Environmental Arctic Change (SEARCH) contribution to the Canadian Network for the Detection of Atmospheric Change (CANDAC) facility at Eureka, Nunavut Territory, is an autonomous lidar that provides calibrated profiles of particulate (i.e., aerosol and cloud) backscatter cross-section, optical thickness, and circular depolarization at 532 nm. The AHSRL provides measurements of both intensive and extensive particulate properties. The intensive parameters depend only on the nature of the particles (size, composition, shape), not on the quantity or concentration. Here we present AHSRL measurements and describe how these can be used to discriminate and identify ice, liquid water, and aerosol (e.g., dust, pollution) particles. The AHSRL measurements are also combined with additional NSA measurements to study the vertical distributions and properties of aerosols and clouds above the NSA.

A CAPS-based single-scattering albedo monitor

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We present data detailing the performance of a particle single-scattering albedo (SSA) monitor that incorporates both a Cavity Attenuated Phase Shift (CAPS)-based optical extinction measurement and an inverse nephelometer in the same measurement volume. Since an absolute extinction measurement is provided, the scattering channel can be calibrated with any non-absorbing particle (e.g., a polystyrene latex [PSL]) or gas (other than air). The monitor demonstrates noise levels (1 second sample time) of less than 1 Mm-1 in both channels. Measurements of the single-scattering albedo of bare and organic-coated soot particles using both this monitor (the CAPS PMssa) and another instrument that comprised a cavity ring-down-based extinction system with a photoacoustic particle absorption spectrometer (courtesy of C Cappa, UC Davis) showed excellent agreement between the two. The SSA monitor can be operated in any wavelength region compatible with the availability of high-reflectivity mirrors, LEDs, and photomultiplier tube (PMT) photocathodes. At present, the available wavelength band is restricted to the 400–700 nm region. The upper value is limited by the availability of a suitable PMT, while at the lower end, the lack of high-quality mirrors is the issue.

The challenges of shipborne weather balloon launches

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The second ARM Mobile Facility (AMF2) Marine ARM GPCI Investigation of Clouds (MAGIC) field campaign presented an abundance of new hurdles for collecting scientific data. This was the first ARM campaign to be aboard a ship. The *Horizon Spirit* container ship travels between Los Angeles and Honolulu each week. Managing data collection from the balloon-borne sounding system (BBSS) on a moving ship was a challenging task for the meteorological technicians, not only in maneuvering a large balloon in high winds, but logistically getting the radiosonde to clear the cargo within a large turbulent environment caused by the containers themselves. Due to the nature of the BBSS system, surface latitude and longitude needed post-flight corrections.

Characterization of the ARM Aerial Facility optically based aerosol instrumentation

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The ARM Aerial Facility (AAF) faces unique challenges when measuring aerosol physical properties. The DOE AAF G-1 does most sampling at speeds around 100 m/s. At this flight speed, sampling rates of 1 Hz or greater are required to acquire measurements with adequate spatial resolution of the in situ aerosol. Optically based measurement techniques comprise the most common basis to meet this need. AAF operates an ultra-high sensitivity aerosol spectrometer–airborne (UHSAS), passive cavity aerosol spectrometer (PCASP), and a cloud aerosol spectrometer (CAS) to make high-speed measurements of aerosol size distributions from 0.06 to 10 µm. However, the use of these instruments can lead to difficulty in the accurate sizing of the aerosol. The shape and chemistry changes the index of refraction of the particles, which shifts the measured size of the aerosol away from its actual size. If the shift is not quantified, optical closure studies or cloud condensation nuclei closure studies will have unknown errors and inaccurate results.

AAF is utilizing state-of-the-art facilities and instrumentation, available at the Atmospheric Measurements Laboratory at the DOE Pacific Northwest National Laboratory, to characterize the aforementioned instruments. With future field campaigns planned within biomass burning (Biomass Burning Aerosol Properties [BBOP]) and in heavily organic environments (Green Ocean Amazon [GOAMAZON]), it is imperative that the instruments are fully tested with representative aerosol from these environments. An overview of the testing methodology, preliminary lab results, and preliminary results from the Two-Column Aerosol Project (TCAP) will be presented.

Demonstration of the 2D MAX-DOAS instrument: comparison with HSRL, MFRSR, and in situ aerosol optical properties during TCAP

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The Two-Column Aerosol Project (TCAP) field intensive operational period (July 15– August 31) at Cape Cod, Massachusetts, provided an opportunity to evaluate a new passive remote sensor to measure trace gases and aerosol optical properties: the University of Colorado (CU) 2D scanning Multi-Axis Differential Optical Absorption Spectroscopy (2D-MAX-DOAS) instrument. 2D-MAX-DOAS features an azimuth- and elevation-angle scanning telescope to measure scattered and direct sun light radiance spectra. These spectra are analyzed by DOAS nonlinear least square fitting to retrieve trace gas slant column densities (SCD, i.e., NO_2, HONO, HCHO, CHOCHO, BrO, IO, O_4 SCDs, and Raman scattering probability). In a second step, aerosol extinction and trace gas vertical distributions are retrieved by constrained optimal estimation/regularization algorithms by inverse modeling of radiative transfer modeling (RTM).

The 2D MAX-DOAS was deployed and operated for six weeks at Cape Cod, Massachusetts, as part of TCAP. This deployment provides unique opportunities for comparisons with aerosol extinction profile measurements with in situ measured optical properties aboard the DOE's G-1 aircraft, NASA Langley's airborne high spectral resolution lidar (HSRL), and aerosol optical depth by a collocated NOAA multifilter rotating shadowband radiometer (MFRSR).

The 2D-MAX-DOAS instrument is presented, as well as a retrieval to invert effective radius and complex refractive index of particles for monomodal logarithmic normal distribution derived from Mie-scattering calculations in the size range of 0.1–1um. Aerosol extinction retrieved from MAX-DOAS measurements is compared with extinction predicted by Mie theory to test the assumption of particle homogeneity and sphericity. The synergy of data provided by the DOE and NASA aircrafts, DOE's ARM Mobile Facility (AMF), and Mobile Aerosol Observing System (MAOS) provide opportunities to evaluate 2D-GMAX-DOAS for use with (1) atmospheric radiation closure studies, (2) test retrievals of aerosol optical depth in the presence and absence of clouds, (3) measure trace gases and aerosol profiles in an often decoupled boundary layer, and (4) use 2D-MAX-DOAS to bridge between spatial scales probed by in situ sensors, aircraft, satellites, and those predicted by atmospheric models.

The Doppler lidar Boundary-Layer Turbulence Statistics value-added product

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The US Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility currently operates scanning coherent Doppler lidars at the Southern Great Plains (SGP) site, the Tropical Western Pacific site in Darwin, Australia (TWP Darwin), and the first ARM Mobile Facility (AMF). Procurement of two additional systems is also planned for new sites at Oliktok Point on the North Slope of Alaska and on Graciosa Island in the Azores. These Doppler lidar systems operate in the near-infrared (IR) at a wavelength of 1500 nm and provide measurements of attenuated aerosol backscatter, clear-air vertical velocities, and horizontal wind profiles. Vertical velocities are currently acquired with a height resolution of 30 m and a temporal resolution of about 1 second. Since the instruments are sensitive to aerosol backscatter, measurements are generally confined to the lower troposphere (< 3 km above ground level [AGL]); however, accurate measurements are also often obtained from cloud bases or through optically thin cloud layers, up to the maximum measurement height of 10 km AGL.

Recently, the science community has expressed an interest in developing a Boundary-Layer Turbulence Statistics (BLTS) value-added product (VAP) from the raw Doppler lidar observations in order to reduce the raw data volume and more readily facilitate certain process studies. The focus of this poster is to present results from the new BLTS VAP that is currently under development. The BLTS VAP produces daily files containing 30-minute averaged profiles of vertical velocity variance, skewness, kurtosis, updraft fraction, cloud-base height, cloud fraction, cloud-base vertical velocity, as well as profiles of horizontal wind magnitude and direction. In addition to these lidar-derived quantities, the VAP also incorporates surface turbulent flux information from the eddy correlation (ECOR) systems, precipitation data, and cloud-base height estimates from the ceilometers. Noise correction methods are described and sample results showing profiles of vertical velocity variance, skewness, kurtosis, and updraft fraction are presented. Statistical composites of the daily BLTS VAP files are used to investigate the mean (monthly averaged) diurnal variation in these quantities at the SGP and TWP Darwin sites. Additionally, cloud-base height and cloud fraction estimates from the Doppler lidar and the ceilometer are compared.

Effects of a ship's motion on the measurements of vertically pointing radars: the scientific basis and development of radar-based VAPs for the MAGIC AMF deployment

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The second ARM Mobile Facility was created with the intent to include deployments in marine environments. After initial land-based deployments in Steamboat Springs, Colorado, and Gan Island, Maldives, the first deployment at sea began in October 2012. The year-long MAGIC deployment consists of approximately 20 round-trip transects between Los Angeles, California, and Honolulu, Hawaii. Among the many challenges associated with this deployment is determining the impact of the ship's motion on the measurements of the vertically pointing radars. Development of two post-processing value-added products (VAPs)—”kazrshipcor1” VAP and the “mwacrshipcor1” VAP—is necessary to provide adjustments for the movement of the ocean-going ship.

The “kazrshipcor1” VAP will post-process data from the unstabilized Ka-band ARM zenith radar (KAZR). Since KAZR is unstabilized and will move with the ship, the radar beam will typically be off-zenith due to ship roll and pitch. This creates the need for two corrections: the radar range coordinate will often differ from the Earth-based vertical height above the radar, and observed mean Doppler velocities will often not be vertical velocities. The “kazrshipcor1” VAP will provide a time-varying height coordinate corresponding to the Earth-based vertical location of each radar range gate above sea level. It will also perform a geometric correction to the radar’s radial velocities to transform them to the Earth-based vertical coordinate. The VAP will also adjust for the height and velocity biases caused by the ship’s time-varying height (heave) and vertical velocity (heave velocity). An exploration of the influence that horizontal winds may play on radar-measured radial mean Doppler velocities will be included.

The “mwacrshipcor1” VAP will post-process data from the stabilized marine W-band ARM cloud radar (M-WACR). Placement on a stabilized platform ensures that the M-WACR will be collecting data at vertical incidence. First-order adjustments to the mean Doppler velocities will only require correction for ship heave velocity. A time-varying height above sea level coordinate will be produced, reflecting the time-varying ship heave. However, in the event of a known failure of the stabilized platform, M-WACR velocity observations and measurement heights can be corrected for roll and pitch-related offsets from vertical, similar to those from KAZR.

High-sensitivity simultaneous HNO_3 and NH_3 monitor using continuous wave quantum cascade laser IR absorption

Mark Zahniser, Aerodyne Research, Inc.
Scott Herndon, Aerodyne Research, Inc.
John Jayne, Aerodyne Research, Inc.

Aerosols play an important role in influencing the composition of the atmosphere, climate forcing, and human health. Secondary particles are formed and grow via gas to particle conversions in the atmosphere, including nucleation and condensation. We have developed a highly sensitive infrared absorption spectrometer using the latest developments in quantum cascade laser spectroscopy and an inlet system to enable quantitative and sensitive simultaneous measurements of gaseous nitric acid and gaseous ammonia, both of which are key aerosol precursors. The particle phase is measured using the Aerodyne aerosol mass spectrometer, a chemically speciated mass-based aerosol instrument. Measurements of nitric acid, ammonia, and particle ammonium nitrate will enable a better understanding of secondary aerosol formation and transformation in the atmosphere. These measurements will provide valuable data inputs for atmospheric models that predict the role of aerosols on radiative forcing and future climate. In this poster we describe the latest advances in instrument development and measurement precision for combination of HNO_3 and NH_3 that provide measurement capability at the low part-per-trillion levels for both species.

http://www.aerodyne.com

High-sensitivity simultaneous SO_2 using continuous wave quantum cascade laser IR absorption

Scott Herndon, Aerodyne Research, Inc.
John Jayne, Aerodyne Research, Inc.
Mark Zahniser, Aerodyne Research, Inc.

Aerosols play an important role in influencing the composition of the atmosphere, climate forcing, and human health. Secondary particles are formed and grow via gas to particle conversions in the atmosphere, including nucleation and condensation. We have developed a highly sensitive infrared absorption spectrometer using the latest developments in quantum cascade laser spectroscopy and an inlet system to enable quantitative and sensitive simultaneous measurements of sulfur dioxide. This species is the remote tropospheric source for production of sulfuric acid, a key aerosol precursor. Particulate sulfate is measured using the Aerodyne aerosol mass spectrometer, a chemically speciated mass-based aerosol instrument. Sensitive, direct measurements of sulfur dioxide will enable a better understanding of gas-phase sulfuric acid measurements and secondary aerosol formation in the atmosphere. In this poster, the spectroscopy, instrument performance, and verification during various mobile field campaigns will be discussed.

www.aerodyne.com

Improvements to the North Slope and AMF2 HSRL systems

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Joe Garcia, University of Wisconsin

The calibration stability of the ARM North Slope of Alaska (NSA) and second ARM Mobile Facility (AMF2) high spectral resolution lidar (HSRL) systems have been substantially improved by replacing the vendor-supplied seed laser controller with a unit of our own design. The seed lasers have also been modified to reduce sensitivity to environmental temperature and to provide feedback control of the pump diode power.

Additional improvement has been achieved with a new frequency-locking scheme in the AMF2 system. Modification of critical mirror mountings in the AMF2 transmitter appears to have eliminated a puzzling humidity-correlated optical alignment drift. We plan to implement these improvements in the NSA system on our next maintenance trip.

These upgrades and the resulting improvement in HSRL performance will be described.

http://lidar.ssec.wisc.edu

Is there evidence of Okmulgee Forest decline in ARM measurements?

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Tom Stoffel, National Renewable Energy Laboratory

The Okmulgee Forest, particularly oak trees, has declined in health in the past two years from a combination of damage caused by ice, wind, or stress from several years before, and a resulting fungus infestation. The associated condition is called hypoxylon canker. There is little that can be done to prevent it. In October 2012 about one-third of the oak trees in the vicinity of and upwind of the tower had died and another one-third were in significant decline. There was evidence of some decline two years earlier, but the progression of the decline was startling this past October. We use data from the ARM extended facility 21 (E21) site from the past five years to attempt to detect effects of the forest decline on radiation and eddy correlation flux data.

Measuring sea-surface temperature for the MAGIC field campaign

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Michael Ritsche, Argonne National Laboratory

The second ARM Mobile Facility has been deployed aboard the container ship *Horizon Spirit* for the Marine ARM GPCI Investigation of Clouds (MAGIC) field campaign. A critical measurement for this over-ocean field campaign is the upwelling infrared emission, which can be determined by measuring the temperature of the sea surface. Different instruments are capable of making this measurement, but most are relatively expensive, such as the infrared sea-surface temperature Autonomous Radiometer (ISAR) or the marine atmospheric emitted radiance interferometer. For MAGIC, an inexpensive and simple (but less accurate) method of measuring sea-surface temperature is provided with two standard ARM infrared thermometers (IRTs). The two IRTs are orthogonally mounted such that one is measuring the ocean surface and the other is measuring the sky brightness temperature, so that the upwelling radiance can be corrected for the reflection of the downwelling radiance. A value-added product is under development to derive sea-surface temperature from the new IRT datastream. We will discuss the method used to calculate sea-surface temperature and compare the measurements with those from the ISAR.

http://www.arm.gov/instruments/irt

New products from radar wind profilers

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The operation of an ARM radar wind profiler (UHF, 915 MHz) has been reconfigured (optimized) during the spring of 2012 to facilitate studies relevant to both planetary boundary layer (PBL) and precipitation physics (PR). New data products are being generated based on two modes of profiler radar operation. The PBL mode consists of a sequence of vertical and oblique beams for both short and long pulses, and the PR mode consists of a sequence of vertical-only short and long pulses. The PBL mode (estimated temporal resolution of 2 minute) observations are used to produce estimates of boundary-layer top heights, profiles of turbulent kinetic energy, and profiles of horizontal wind magnitude and direction. Initial results for boundary-layer estimates are presented over the ARM Southern Great Plains site (C1 profiler), in comparison with radiosonde-based estimates at the site.

The PR mode (estimated temporal resolution 12–14 seconds) observations will be used soon to produce calibrated radar reflectivities, unfolded Doppler velocity, spectral width, radar receiver noise time series, and calibration constant in an auxiliary datastream file.

PPP, Fourier transform, and spectrum width measurements of ARM scanning radars

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Nitin Bharadwaj, Pacific Northwest National Laboratory
Pavlos Kollias, McGill University

The first three radar Doppler moments (reflectivity, velocity, and spectrum width) are usually estimated from the Doppler spectrum that is obtained by Fourier transformation (FT) of the normalized autocorrelation function of the radar signals. The moments can also be calculated using the Pulse Pair Processing (PPP) method that uses the lagged 0 and lagged 1 autocorrelation functions. Recently, some researchers even use lagged 2 and lagged 3 autocorrelation functions to calculate the moments. Here, we are investigating the impact of the selected signal processing technique (FT or PPP) on the value and interpretation of the radar Doppler spectrum width, a parameter of great importance for retrieving microphysical and turbulence properties. For the PPP method, the scanning radar effective beam width is a function of the lagged time. It increases with lagged time increasing. Because effective beam width impacts spectrum width measurement, the shorter lagged time should be considered when designing new moment estimators. Using recorded I/Q time series from the scanning ARM cloud radars (SACRs), we will investigate the impact of the estimator (FT versus PPP) on the recorded radar Doppler spectrum width.

Providing diurnal hemispherical cloud fraction data at ARM sites

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Ronald Blatherwick, University of Denver
Victor Morris, Pacific Northwest National Laboratory

The Solmirus Corporation has been funded by the U.S. Department of Energy to develop a diurnal hemispherical cloud fraction (HCF) data product utilizing the infrared (IR) radiometrically calibrated data from their all-sky infrared visible analyzer (ASIVA) instrument. Nighttime HCF has long been a critical programmatic gap in ARM's observational data set and is an important factor in understanding the life cycle of clouds, one of the central themes of the ASR program. This poster paper describes a novel radiometric calibration procedure that has allowed accurate determination of the clear-sky IR radiance, paving the way to providing a superior diurnal HCF data product. The validity of the HCF algorithms developed under this award is being verified by direct comparison of daytime ASIVA data to cloud fraction data retrieved from the total sky imager (TSI). Comparison HCF data derived from Solmirus' ASIVA Campaign conducted at the ARM Southern Great Plains (SGP) site from May 21 to July 27, 2009, are presented. Radiometrically calibrated IR ASIVA data are also compared to concurrently observed AERI (atmospheric emitted radiance interferometer) radiances. In addition, Solmirus is developing a HCF data product utilizing ASIVA's visible channels that closely mimics results from the TSI instrument. This comparison is also presented.

http://www.arm.gov/campaigns/sgp2009solmirus

Raman lidar retrievals of mixed-layer heights over the TWP Darwin and SGP sites

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David Turner, National Oceanic and Atmospheric Administration
Rob Newsom, Pacific Northwest National Laboratory
Amy Scarino, NASA Langley Research Center

Accurate determination of the atmospheric mixing-layer (ML) height is important for modeling the transport of aerosols and aerosol precursors and forecasting air quality. Aerosol and water vapor profiles measured by the DOE ARM Southern Great Plains (SGP) and Tropical Western Pacific (TWP) Darwin ground-based Raman lidars provide direct measurements of the vertical structure of ML. We have developed automated algorithms to identify sharp gradients in aerosols, water vapor, and potential temperature at the top of the ML and have used these algorithms to derive ML heights for extended periods over the last few years. We evaluate these ML heights with those derived from coincident radiosondes. The Darwin Raman lidar measurements reveal a shallow, moist cloud-topped ML with little diurnal variability during the austral summer and deeper ML with more diurnal variability during the austral winter. The Darwin Raman lidar measurements of the diurnal and seasonal variabilities of ML heights and the aerosol and water vapor distributions relative to these ML heights will also be presented.

A real-time cloud optical depth sensor

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Ed Niple, Aerodyne Research, Inc.
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J.-Y. Christine Chiu, University of Reading

While working for the Air Force Research Laboratory, Aerodyne Research, Inc. has developed and successfully deployed a unique, real-time cloud optical depth sensor, dubbed the Three-Waveband Spectrally-agile Technique (TWST). It was developed to serve as a ground-based, portable, and reliable means for remote cloud monitoring. It uses the spectral radiance of scattered sunshine from a small area of overhead cloud and the MODTRAN5 model of atmospheric radiation transport to determine cloud optical depths (CODs). A real-time output assists with monitoring dynamic situations, and continuous data logging permits detailed post processing. The basic phenomenology of TWST is similar to that employed in Aerosol Robotic Network (AERONET) sensors running in cloud-mode, which provided direct validation of TWST during simultaneous TWST-AERONET data collections at Harvard Forest in Petersham, Massachusetts, during October 2012. Unlike AERONET, however, TWST is a dedicated, continuous cloud monitor with the ability to work in vegetated and non-vegetated terrains, in addition to being portable rather than a fixed installation like AERONET.

Numerous investigators have shown success in inferring cloud optical depth from passive optical measurements of solar-scattered radiance, either from below or above. The algorithms in these techniques are built around the ability to do forward modeling of the cloud radiance for various scenarios, so that one can search for the best fit to the data. One of the underlying problems with this approach is that the downwelling cloud radiance is a two-valued function of the COD. Therefore, the first problem with COD retrieval is to distinguish whether to use the “thin cloud” or “thick cloud” branch of the radiance. For TWST COD retrieval we adopted the O_2 A-band equivalent width as the means to overcome this ambiguity. Unlike water vapor, O_2 concentration in the atmosphere is quite stable. The strength of the O_2 absorption depends on the total photon path length and increases with more scattering events before reaching the sensor. Thus, the relative absorption from traversing a thin cloud (single scatter only) differs from that through a thick cloud. A number of other researchers have utilized this feature.

TWST's unique combination of features makes it ideal for ground truth measurements in support of airborne or satellite sensors. It has performed quite successfully in field tests covering a wide range of locations and diverse background conditions.

http://aeronet.gsfc.nasa.gov

Reducing and quantifying uncertainties in climatically relevant cloud microphysical parameters derived from optical array probes

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Jeff Stith, National Center for Atmospheric Research

Prior estimates of ice crystal number concentrations derived from 2D Cloud Probes (2DCs) have been artificially amplified by the detection of small ice crystals generated from the shattering of large ice crystals on the probe tips. Although shatter reducing tips and correction algorithms to remove shattering artifacts exist, there is considerable uncertainty in their effectiveness. In this presentation, the effect of shattering and the associated uncertainties on climatically relevant cloud microphysical properties, such as total ice crystal concentration (Ni), extinction (β), ice water content (IWC), effective radius (re) and median mass diameter (Dm), derived from 2DC data are quantified. The impact on mass-weighted terminal velocity and single-scattering properties, which are important for parameterizations of cloud microphysics in models with a myriad of temporal and spatial scales, are also examined. This is done by comparing bulk cloud properties derived from 2DCs with standard and shatter reducing tips used on the National Research Council of Canada Convair-580 during the 2008 Indirect and Semi-Direct Aerosol Campaign (ISDAC) and on the National Center for Atmospheric Research C-130 during the 2011 Instrumentation Development and Education in Airborne Science phase 4 (IDEAS-4) as a function of true air speed, pitch, roll, and attack angles, ice crystal habit, median diameter, and temperature. Additional comparisons of the size distributions (SDs) from the 2DCs against those measured by a 2D Stereo Probe provide further insight on the importance of small ice crystal concentrations in determining bulk cloud properties. The β and IWC from the 2DC with modified tips were about 20% smaller than β and IWC with standard tips, with larger differences noted in the presence of graupel. The true air speed, angle of attack, pitch and roll angle, median diameter and temperature did not affect the magnitude of the difference between the SD from the 2DC with standard tips and the SDs from the 2DC with modified tips. The shatter reducing tips were more effective than the application of the correction algorithms for removing shattered artifacts, but that neither alone was able to remove all artifacts. This study, using only one of many existing designs for modified probe tips, shows that further testing of alternate probe tip geometries is required to identify the optimum design and that measurement uncertainties still plague accurate estimates of small ice crystal concentrations.

Spectral albedo

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Joseph Michalsky, DOC/NOAA OAR Earth System Research Laboratory

The multifilter radiometer (MFR) mounted in the starboard wing tip of the Cessna 206 operating out of the Ponca City airport has been resurrected. The first flight with valid data occurred on October 27, 2012. As of January 2013 there have been 28 flights. Each flight typically occurs between 1800 UTC and 2100 UTC, with passes over the Southern Great Plains (SGP) Central Facility (CF) lasting about two hours. As with the SGP multifilter rotating shadowband radiometers (MFRSR) and tower-mounted MFRs, the Cessna MFR measures at 415, 500, 615, 673, 870, and 950 nm. In addition to the standard MFR measurements, latitude, longitude and altitude are also recorded. The sampling rate is 1 hz.

In this poster we compare spectral albedo calculated using the Cessna MFR and the SGP extended facility 13 (E13) MFRSR, with albedos calculated from the 10-m and 25-m MFRs located at the Central Facility. As with the Cessna data, the E13 MFRSR is also used for calculating albedo with the CF MFRs. To accomplish this comparison, each pass over the CF is averaged and compared with albedos from the fixed locations. The fixed MFRs and MFRSR sample every 20 seconds. Since we are comparing Cessna data with the CF data, we only use the portion of each pass that is close to the CF.

Statistical properties of cloud liquid water path at Barrow, Alaska, and at the Greenland Summit station

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Matthew Shupe, University of Colorado
Ralf Bennartz, University of Wisconsin
Von Walden, University of Idaho

Accurate knowledge of arctic clouds, their phase, and their microphysical properties are important to correctly model cloud forcing and the Earth's radiation budget. It is important therefore to be able to detect the presence of liquid water in clouds and to quantify the liquid water path (LWP) as accurately as possible. The retrieval of liquid water path in the Arctic is challenging due to the low amounts of water vapor and the fact that a majority of clouds have very small amounts of liquid water. In 2006 the Atmospheric Radiation Measurement Climate Research Facility deployed a high-frequency microwave radiometer in Barrow, Alaska, to help improve the retrieval of water vapor and liquid water path. The G-band vapor radiometer (GVR) has been collecting data for seven years now, and retrieval of water vapor and liquid water path from this instrument has been developed. The vapor retrievals have an uncertainty of ~0.3 mm, and the liquid water path retrievals have an estimated uncertainty of 8 g/m2 (compared to the 25 g/m2 of the two-channel microwave radiometer). The retrievals provide improved information on the presence of small amount of liquid water, especially in supercooled clouds.

In this poster we use data from the microwave radiometers, radiosondes, and Vaisala ceilometer and analyze seven years (2006–2012) of improved liquid water path in Barrow, Alaska from GVR measurements. We compare them with three years (2010–2012) of liquid water path derived from the microwave radiometers at the Summit station in Greenland. The estimated uncertainty of this retrieval is approximately 5 g/m2.

At both sites we examine how the presence of liquid water and the LWP depend on the cloud temperature. We also examine some seasonal characteristics of clouds where liquid water was not detected by the radiometers. The analysis shows some interesting similarities between the two sites, but also some noticeable differences. For example, in both locations water in liquid phase was detected in about 20% of the cases when the cloud temperature was between -25°C and -30°C. Differences in the seasonal LWP average are noticeable at the two sites, the average LWP at Summit being much less than at Barrow in all seasons, and especially in spring and fall. Overall, the two data sets provide valuable information on some important cloud properties at the two sites and underscore the importance of long-term observations to improve our knowledge of cloud properties.

A unified approach for reporting ARM measurement uncertainty

Douglas Sisterson, Argonne National Laboratory
Edwin Campos, Argonne National Laboratory

Uncertainty is often conceptualized to express one of two distinct parameters: either the estimate of the error of a measurement (accuracy) or the dispersion of the values that could reasonably be attributed to the measured variable (precision). The first uncertainty concept (accuracy) focuses on unknowable quantities, total error and true value, because knowing these quantities is impossible in an operational context. Therefore, the second uncertainty concept (precision) is becoming the current practice in metrology. The ultimate goal is to express all measurement uncertainties in accordance with the Guide for Uncertainty Measurements (GUM, Joint Committee for Guides in Metrology 2008), since it provides an internationally recommended protocol.

We tested these concepts by building a comprehensive inventory with current ARM uncertainty estimates, using inputs from each ARM instrument mentor, for each ARM instrument, and for the main ARM measured variables. Then we classified each uncertainty estimate either as instrument resolution, precision, accuracy, or non-standard estimate. For those cases where the uncertainty was reported as accuracy (i.e., calibration procedures), we further classified the calibration reference as a traceable standard, consensus procedure, or expert judgment. These methods provided a unified approach for reporting measurements uncertainties for all ARM instruments.

The results indicate the existence of measurement families that have common attributes of uncertainty type. Almost all of the ARM measurements have reported accuracy uncertainty. However, many of the measurements to date have not yet been characterized in terms of precision uncertainty. This will need to be done in order to match the higher metrology standards of the expression of uncertainty, which are consistent with GUM.

Update on the total precipitation "hot plate" sensor in Alaska

Jessica Cherry, International Arctic Research Center
Mark Ivey, Sandia National Laboratories

Estimation of solid precipitation in cold regions is incredibly challenging because of the effects of conventional gauge designs on the air flow over the gauge. The authors provide an update on the performance of the total precipitation sensor (TPS) installed at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's North Slope of Alaska (NSA) site in Barrow, as well as University of Alaska-managed sites at Atqasuk, Toolik, and Fox. The TPS design is intended to avoid the undercatch biases of traditional gauges, but may not detect smaller-sized snow particles. Output from the TPS is compared to that from the collocated National Oceanic and Atmospheric Administration's (NOAA's) Climate Reference Network (CRN) sites, snow particle counters, and changes from snow depth sensors. The CRN site has a Geonor gauge with a modified double fence, as per the national network standard. Output from the Vaisala FD12P present weather sensor (PWS) at the ARM NSA site is also considered. Recent results from wind tunnel testing with the manufacturer, Yankee Environmental Systems, have led to changes to the sensor algorithm as described here. Precipitation measurements in Barrow will be important for scanning radar data analyses and calibrations.

http://ine.uaf.edu/werc/projects/atpn/index.html

10.0 Modeling

1. RACORO-FASTER: case study generation

Andrew Vogelmann, Brookhaven National Laboratory
Ann Fridlind, NASA Goddard Institute for Space Studies
Satoshi Endo, Brookhaven National Laboratory
Wuyin Lin, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory
Yangang Liu, Brookhaven National Laboratory

As part of the FAst-physics System TEstbed and Research (FASTER) project, a series of case studies are being constructed to assess and improve model representation of continental boundary-layer clouds (stratus, stratocumulus, cumulus) using aircraft data from the Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO) field campaign and ARM ground-based remote sensing observations. Three 60-hour case study periods are selected that capture the temporal evolution of cumulus, stratiform, and drizzling boundary-layer cloud systems under a range of conditions, intentionally including those that are relatively more mixed or transitional in nature versus being of a purely canonical type. In each case study, boundary-layer systems are simulated from sunrise on day one to sunset on day three. Collectively, the case studies include: daytime stratus, stratocumulus, and cumulus formation and breakup under varying aerosol conditions; strong and weak nocturnal jets; and nighttime stratus formation and deepening within a residual layer. The aircraft data include aerosol number size distributions, which have been fit to lognormal modes for concise representation in models with two-moment microphysics. The case studies are being developed to run side-by-side using large-eddy simulation (LES) models (see Endo et al.) and single-column models (see Lin et al.). The goal is to provide a diverse set of observationally constrained cases of cloudy boundary-layer evolution for use by FASTER and the general modeling communities to improve our understanding of continental cloudy boundary layers, aerosol influences upon them, and their representation in cloud-scale and global-scale models (see Ackerman et al.). These continental case studies offer an important complement to previous case studies, which mainly focus on marine boundary-layer clouds. Additional unique features of these cases are: they address the temporal evolution of different/mixed cloud types (versus the steady state of canonical types); they include observed profiles of aerosol size distributions and cloud condensation nuclei; and they include a wide range of observed aerosol loadings. Overall, the periods sample a wide range of cloudy boundary-layer conditions, but all case studies use a modular specification, which makes it easy for modelers to run them all.

2. RACORO-FASTER: large-eddy simulations

Satoshi Endo, Brookhaven National Laboratory
Ann Fridlind, NASA Goddard Institute for Space Studies
Wuyin Lin, Brookhaven National Laboratory
Andrew Vogelmann, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory
Yangang Liu, Brookhaven National Laboratory

New case studies are being constructed in the FAst-physics System TEstbed and Research (FASTER) project, based on continental boundary-layer-cloud observation during the Routine AAF Clouds with Low

Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO) field campaign. This poster presents preliminary results from large-eddy simulations (LESs) for the three 60-hour case study periods (See Vogelmann et al. for the detail of the case generation and Lin et al. for single-column model [SCM] simulations). The initial runs are performed by the GISS Distributed Hydrodynamic Aerosol and Radiative Modeling Application (DHARMA) model and the Weather Research and Forecasting (WRF) model implemented with forcing ingestion and other functions for flexible LES (WRF-FASTER). The two LES models commonly capture the significant transitions of cloud-topped boundary layers in the three periods: daytime breakup of stratus and stratocumulus clouds, diurnal evolution of cumulus layers repeating over multiple days, and nighttime evolution/daytime diminution of thick stratus. Aircraft observations are then used to statistically evaluate predicted cloud droplet number concentrations under varying aerosol and cloud conditions. Sensitivity tests are presented that allow us to refine the model configuration for the combined use of observations with parallel LES and SCM simulations. We evaluate lognormal idealization of aircraft observation-derived aerosol size distributions. We test the effects of differing vertical grids and horizontal wind nudging versus geostrophic wind forcing on simulated nocturnal boundary layer and jets. We also test fixed versus time-varying model top radiative flux boundary conditions. The simulated cases provide the opportunity to examine a variety of research topics including cloud type/diurnal transition, cloud entrainment, aerosol impacts, nocturnal boundary layer with evolving wind shear, and various interactions between physical processes.

3. RACORO-FASTER: climate significance and single-column model simulations

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Hua Song, Brookhaven National Laboratory
Ann Fridlind, NASA Goddard Institute for Space Studies
Andrew Vogelmann, Brookhaven National Laboratory
Satoshi Endo, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory
Audrey Wolf, NASA Goddard Institute for Space Studies
Yangang Liu, Brookhaven National Laboratory
Leo Donner, Geophysical Fluid Dynamics Laboratory
Anthony Del Genio, NASA

This work places into climatological context the Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO)/FAst-physics System TEstbed and Research (FASTER) case studies to improve our understanding of continental boundary-layer clouds and their representation in climate models. The climatic significance is quantified for the case study regimes specifically and the RACORO-type clouds generally, in terms of occurrence frequency, radiative effects, and environmental conditions, using ARM and other complementary measurements, and under the guidance of an objective cloud regime classification. We then use single-column model (SCM) simulations to further investigate the climate model representation of the RACORO-type clouds. The SCM work contains two parts. Multi-year SCM simulations by Global Fluid Dynamics Laboratory (GFDL) AM2 and AM3, Goddard Institute for Space Studies (GISS), and Community Atmosphere Model 3, 4, and 5 (CAM3, CAM4, and CAM5) SCMs, driven by observationally constrained ARM large-scale forcings, are first used to assess typical GCM representation or misrepresentation of such clouds. The

SCM simulations for the newly developed RACORO-FASTER cases are then examined in greater detail, focusing on the development and evolution of the clouds, and the relative contribution of different model physical processes, in particular those that are responsible for the major model biases.

ACCESS evaluation of convective cloud system properties over the Northern Australian region

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Vickal Kumar, Monash University
Alain Protat, Australian Bureau of Meteorology

In order to evaluate the representation of clouds and convection in the Australian Community Climate and Earth-System Simulator (ACCESS) forecast model within different large-scale forcings, the variability of the statistical properties of convective clouds over Darwin is investigated in the context of different phases of the Madden-Julian Oscillation (MJO). This study makes use of data sets from the ACCESS model, cloud radar and lidar measurements from the ARM Facility's Darwin site, and the C-band polarimetric radar (C-POL) observations. Vertical profiles of the frequency of occurrence of the convective clouds over a two wet-seasons interval (2005–2007), together with the diurnal cycles, are composited onto these large-scale atmospheric regimes and phases of the MJO. The frequency of occurrence of convective clouds tends to peak too early in ACCESS compared to the ARM and C-POL observations, although the proportion of the vertical compared to the ARM and C-POL observations is in fairly good agreement. This strong bias is also observed in the diurnal cycle of the convective cloud system for all regimes. In addition, the diurnal cycle of model data reveals a notable occurrence of low-level clouds that is not seen in the ARM observations. These biases are observed as well in all of the large-scale regimes and MJO phases.

Aerosol reanalysis using a multiscale aerosol data assimilation system for the FASTER project

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Yangang Liu, Brookhaven National Laboratory
Wuyin Lin, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory
Andrew Vogelmann, Brookhaven National Laboratory

This research aims to support the aerosol-related tasks of the FAst-physics System TEstbed and Research (FASTER) project by developing an aerosol reanalysis product for the Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO) field campaign, using an advanced data assimilation scheme and both surface and aircraft aerosol measurements. The reanalysis product offers three-dimensional fields of both aerosol concentrations and size distributions. We have implemented a three-dimensional variational (3DVAR) data assimilation system with a WRF/Chem system for the Southern Great Plains (SGP) region. The MOSAIC scheme is used to represent aerosol processes. The MOSAIC scheme uses four size bins to represent size distributions and explicitly treats eight species, including elemental/black carbon, organic carbon, nitrate, sulfate, chloride, ammonium, sodium, and the sum of other inorganic, inert mineral and metal species. This 3DVAR scheme is formulated to provide analyses of both concentrations and size distributions of these eight species. We have produced a one-month aerosol reanalysis product during RACORO. The reanalysis product is produced by assimilating the surface PM2.5 from the Environmental Protection Agency (EPA) operational monitoring network and speciated measurements from the Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring network. The impact of aircraft measurements has been particularly explored. The framework and products offer a new avenue for using ARM aerosol-related measurements.

http://www.bnl.gov/faster/

Boundary-layer clouds in the Community Atmosphere Model with a unified PDF-based scheme

Peter Bogenschutz, University of Utah
Andrew Gettelman, National Center for Atmospheric Research
Hugh Morrison, National Center for Atmospheric Research
Vincent Larson, University of Wisconsin, Milwaukee

This presentation describes the coupling of the Community Atmosphere Model version 5 (CAM5) with a trivariate PDF turbulence scheme, known as Cloud Layers Unified by Binormals (CLUBB). This third-order turbulence parameterization replaces the planetary boundary-layer (PBL), shallow convection, and cloud macrophysics schemes in CAM5. The coupling of CAM with CLUBB (CAM-CLUBB) represents a more unified treatment of boundary-layer and shallow convective processes, which drives a single double-moment microphysics scheme. Therefore, this also leads to a more unified treatment of cloud-aerosol interactions compared to CAM5, which has separate shallow convective and stratiform microphysics parameterizations.

Results from both single-column and global simulations are presented and suggest that CAM-CLUBB can provide a better treatment of boundary-layer clouds and processes, when compared to CAM5. CAM-CLUBB especially excels in the representation of transitional cumulus under stratocumulus regimes found in the subtropical oceans. In addition, CAM-CLUBB appears to be more robust to changes in the horizontal, vertical, and temporal resolution, suggesting that CLUBB may provide a more scale-aware parameterization compared to conventional CAM5 physics. These improvements are owed in part to the more unified nature of the new turbulence scheme.

Characteristics of the atmospheric boundary-layer structure and cloud properties for precipitating convection with data assimilation

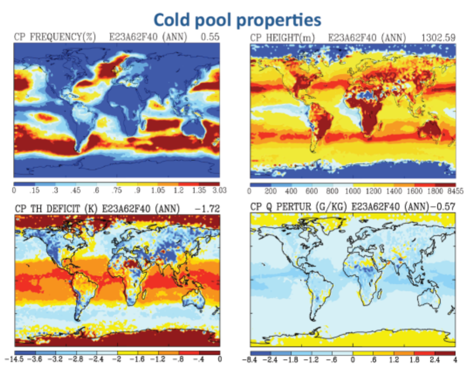
Zhaoxia Pu, University of Utah
Chao Lin, University of Utah
Steven Krueger, University of Utah

The major objective of this study is to create realistic estimates of high-resolution (~1-kilometer horizontal grid size) atmospheric boundary-layer structure and the characteristics of precipitating convection, including updraft and downdraft cumulus mass fluxes and cold-pool properties from analyses that assimilate the surface Mesonet observations of wind, temperature, and water vapor mixing ratio and available profiling data from single or multiple surface stations. Specifically, data assimilation experiments have been conducted for the major convective cases during the Midlatitude Continental

Convective Clouds Experiment (MC3E) using the mesoscale community Weather Research and Forecasting (WRF) model and its data assimilation system. The Oklahoma Mesonet observations and the data obtained from six MC3E sounding stations over the region around the Southern Great Plains (SGP) site have been assimilated. Results show that the data assimilation has resulted in realistic analyses and simulations of the initiation and evolution of precipitating convection. Then, these analyses and simulations obtained from the data assimilation are being used to characterize the convective properties and atmospheric boundary-layer structures associated with precipitating convections. The interaction between convectively generated cold pools and convection as well as the characteristics of vertical velocity statistics in the convective systems are being examined. In addition, the WRF high-resolution analyses are also being compared with the standard ARM large-scale forcing.

Cold pools – a first step in representing convective organization in GCMs

Anthony Del Genio, NASA
Mao-Sung Yao, Sigma Space Partners, LLC
Jingbo Wu, Columbia University
Audrey Wolf, NASA Goddard Institute for Space Studies



Most global climate models (GCMs) represent moist convection as an ensemble of convective cells determined by the instantaneous grid-scale environment. Most precipitation and cloud forcing in convective environments, however, comes from organized mesoscale clusters with life cycles that span many hours and a heating profile that shifts from full troposphere heating to a dipole structure of upper/lower level heating/cooling as the stratiform rain region develops. Parameterizing the organization of convection is a multi-step process:

- Initiation of convective downdrafts that inject cold air into the boundary layer
- Formation of cold pools that spread over time and remain distinct from ambient air
- Regeneration of convection by lifting of ambient air at the gust front
- Initiation of a stratiform cloud and rain region by detrained convective condensate
- Development and evolution of mesoscale updrafts and downdrafts.

We will describe initial efforts to account for the first three steps of convective organization in the Goddard Institute for Space Studies (GISS) global climate model (GCM). Cold pools are assumed to form when downdraft air with virtual potential temperature colder than that of ambient air enters the boundary layer. The cold pool spreads at a rate determined by the virtual potential temperature contrast, while its depth evolves according to the competition between spreading and further addition of downdraft air. Evolution of cold-pool thermodynamic properties is determined by the properties of subsequent downdrafts, offset by relaxation to ambient conditions over a specified time scale. After the cold-pool forms, further convection triggering utilizes properties of the undisturbed boundary layer and assumes parcel lifting up to the cold-pool top.

Initial GCM tests indicate that parameterized cold pools are ~1–2 km deep and are deeper over land than over ocean; have cold anomalies of ~0.5–2 K or more, with the largest values over drier continental areas; and usually have dry anomalies of ~0–1.5 g/kg, although cold pools at the edges of the continental Intertropical Convergence Zone (ITCZ) tend to be slightly wetter than ambient air. Although these characteristics qualitatively resemble those seen in field experiments and cloud-resolving models (CRMs), the frequency of occurrence (~0.5% globally) and duration (2 hours or less) of cold pools is not sufficient to shift the phase of the diurnal cycle of convection. We are performing single-column model tests of the Midlatitude Continental Convective Clouds Experiment (MC3E) field campaign data to try to understand how this limitation of the parameterization might be mitigated.

A computational method for riming ice crystals with varying habits

Anders Jensen, Pennsylvania State University
Jerry Harrington, Pennsylvania State University

Cloud and climate models require accurate estimates of phase-partitioning among ice, liquid, and vapor to predict precipitation processes, which help determine cloud lifetime and net cloud radiative forcing. Theoretical and computational advances have led to better vapor depositional growth of ice in cloud models, but improvements are needed in the treatment of aggregation and riming.

In a single-particle model, we grow ice crystals by vapor deposition and allow different habits to develop, which are approximated by spheroids with a reduced density. A theoretical method is developed and tested in which ice crystals are allowed to collect rime mass, which changes the ice crystal mass, aspect ratio, and density. Evolving ice crystals in the method removes the need for different ice categories like pristine ice and graupel and allows ice crystals to evolve in a mechanistic way depending on the environmental conditions.

Model output is compared to wind tunnel data, and the results compare well where significant mass increase due to riming occurs for ice crystals grown isometrically at liquid water contents less than 0.5 gm-3. Ice crystals with more extreme aspect ratios do not collect significant rime mass at liquid water contents less than 0.5 gm-3. This riming method will be parameterized for use in bulk microphysical models.

Determining resolution awareness of microphysics using the separate physics and dynamics experiment framework

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Heng Xiao, Pacific Northwest National Laboratory
Balwinder Singh, Pacific Northwest National Laboratory
Philip Rasch, Pacific Northwest National Laboratory
Jerome Fast, Pacific Northwest National Laboratory

This poster presents results from a recently submitted paper showing the utility of the Separate Physics and Dynamics Experiment (SPADE) framework for examining resolution dependencies within atmospheric model physics parameterizations. As a first demonstration of SPADE, an analysis has been performed comparing the resolution dependence of microphysics designed for a mesoscale model versus one designed for a global climate model. Specifically, the Morrison microphysics from the Weather Research and Forecasting (WRF) model is compared with the Morrison-Gettelman microphysics from the Community Atmosphere Model v5 (CAM5).

The comparison is done using a month-long, springtime simulation for the central United States coinciding with the Midlatitude Continental Convective Clouds Experiment (MC3E). Grid spacings of 4 and 32 km are compared to span the “gray zone” of cloud parameterization, which is in the range targeted for global cloud system resolving models and current state-of-the-art climate models. Understanding the resolution dependence of parameterizations within this range is critical for improving next-generation climate models with multi-resolution grids, as well as uniform high-resolution grids.

The SPADE framework complements traditional resolution-dependence comparisons. In a traditional comparison, the grid spacing is changed for all model components, and a comparison is done to see how model behavior changes with resolution. For SPADE, the grid spacing is held constant for most of the model while changing the grid spacing for specific components of interest. This allows one to isolate specific resolution dependencies within the model, making it easier to understand the dependencies for the tested components.

Development of integrative LES-CRM-SCM-NWP evaluation framework and demonstration with RACORO cases

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Satoshi Endo, Brookhaven National Laboratory
Zhanqing Li, University of Maryland
Andrew Vogelmann, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory
Hua Song, Brookhaven National Laboratory
Wuyin Lin, Brookhaven National Laboratory
Anthony Del Genio, NASA
Leo Donner, NASA Geophysical Fluid Dynamics Laboratory
Robin Hogan, University of Reading

Physical processes associated with the aerosol-cloud-precipitation system occur over a wide range of time-space scales and are often investigated using different types of models and for different purposes, including large-eddy simulations (LES), cloud-resolving models (CRM), numerical weather prediction (NWP) models, and single-column models (SCM). In view of the multiscale nature of the cloud processes and their parameterizations, it is desirable to have a comprehensive evaluation framework that integrates the different types of models. While still maintaining what individual models can accomplish, such an integrative-model evaluation framework also permits better understanding of multiscale processes and diagnosis of potential parameterization deficiencies. Further, the integrative model framework provides a unique way to better capitalize on the various detailed, high-temporal, and vertical-resolution ARM measurements designed for a domain of a global climate model (GCM) grid size.

Here we introduce a prototype of such a framework developed under the FAst-physics System TEstbed and Research (FASTER) project and demonstrate its utility and potential by applying it to cases from the Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations

(RACORO) field campaign. Also explored are the potentials of a Weather Research and Forecasting (WRF)-based multiscale data assimilation system in generating multiscale data and assisting the integrative model evaluation.

Double-moment cloud microphysics scheme for the deep convection parameterization in the GFDL AM3

Alexei Belochitski, University of Maryland
Leo Donner, NASA Geophysical Fluid Dynamics Laboratory

A double-moment cloud microphysical scheme originally developed by Morrision and Gettelman (2008) for the stratiform clouds and later adopted for the deep convection by Song and Zhang (2011) is being implemented in to the Geophysical Fluid Dynamics Laboratory's (GFDL) atmospheric general circulation model AM3. The scheme treats cloud drop, cloud ice, rain, and snow number concentrations and mixing ratios as diagnostic variables and incorporates processes of autoconversion, self-collection, collection between hydrometeor species, sedimentation, ice nucleation, drop activation, homogeneous and heterogeneous freezing, and the Bergeron-Findeisen process. Such detailed representation of microphysical processes makes the scheme suitable for studying the interactions between aerosols and convection, as well as aerosols' indirect effects on clouds and their roles in climate change.

As the first step of implementation, the scheme is tested in the single-column version of the GFDL AM3 using forcing data obtained at the U.S. Department of Energy Atmospheric Radiation Measurement Climate Research Facility's Southern Great Plains and Tropical Western Pacific sites. In the future, tests with the full atmospheric global climate model (GCM) will be conducted. In addition, sensitivity of the scheme to the parameterizations of some collection processes that were originally obtained for the stratiform cloudiness regime will be investigated. Specifically, these are formulations for autoconversion of cloud water and its accretion by rain as well as the formulation for self-collection of rain and self-collection of snow.

Morrison, H, and A Gettelman. 2008. “A new two-moment bulk stratiform cloud microphysics scheme in the Community Atmosphere Model, version 3 (CAM3). Part I: Description and numerical tests.” *Journal of Climate* 21: 3642–3659.

Song, X, and GJ Zhang. 2011. “Microphysics parameterization for convective clouds in a global climate model: Description and single-column model tests.” *Journal of Geophysical Research* 116: D02201, doi:10.1029/2010JD014833.

Drizzling low clouds at Graciosa Island—how does the ECMWF model perform?

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Richard Forbes, European Centre for Medium-Range Weather Forecasts

Comprehensive observations of clouds, precipitation, and surface radiation were gathered over a 19-month-long period during the ARM Mobile Facility (AMF) deployment on Graciosa Island. During this time, boundary-layer clouds were the most frequently observed cloud type, often associated with drizzling conditions.

A common problem in global models is an overestimate of light precipitation occurrence. The observations from Graciosa provide a ready opportunity to evaluate and improve the representation of low clouds and precipitation in models. We evaluate the occurrence of clouds, surface precipitation, and precipitation re-evaporation in the European Centre for Medium-Range Weather Forecasts (ECMWF) model, as well as cloud properties and biases in surface radiation.

The ECMWF model's monthly statistics of cloud occurrence and type are generally good and in reasonable agreement with the observations. However, systematic but compensating surface radiation errors exist and can be linked with broken and overcast low cloud conditions. This is a feature of the model previously identified at the continental ARM Southern Great Plains site.

As anticipated, the model's precipitation occurrence does not agree well with observations. Precipitation is produced too frequently at cloud base, and only a small fraction of it re-evaporates before reaching the surface, leading to an overestimate of surface precipitation frequency as well. The single-column model is used to test combined changes to the autoconversion/accretion and precipitation re-evaporation processes in the convection and cloud parameterizations to improve the model cloud-radiation impacts and precipitation statistics at Graciosa.

E-poster: displaying the parameterization's decision process in a CAPT-initialized CAM with organized convection scheme

Brian Mapes, University of Miami
Baohua Chen, University of Miami
Hsi-Yen Ma, Lawrence Livermore National Laboratory, Program for Climate Model Diagnosis and Intercomparison

Climate model parameterizations are often evaluated in a disconnected way. On the one hand, their conceptual basis and equation set is discussed for its reasonableness. On the other hand, highly statistical aspects of their performance are evaluated (climate simulation characteristics).

In between lies the code implementation and what is actually going on from timestep to timestep within the model's weather. These are harder to discuss because they are harder to communicate.

In this e-poster (a small poster and a laptop), initialized runs of our experimental organized-convection scheme version of Community Atmosphere Model 5 (CAM5) are displayed using the Integrated Data Viewer. The poster provides necessary information on the model and unique convection scheme. In the screen display, the parameterization's buoyancy, entrainment rates, and other interior variables, along with its tendencies, are displayed as plan views and cross-sections, within a rich, multi-layered display of the model weather. Convective processes can be scrutinized in the context of interactive skew-T profiler, which be dragged to any location and time. This unprecedented view inside the model's world has uncovered a few subtle bugs and highlights the challenges and partial successes of simulating organized convection with two plumes of different entrainment rates plus large-scale condensation.

An economical PDF-based turbulence closure model for cloud-resolving models and global climate models

Steven Krueger, University of Utah
Peter Bogenschutz, University of Utah

Many coarse-grid cloud-resolving models now use horizontal grid sizes that resolve deep convection but not boundary layer clouds. How can these subgrid-scale (SGS) clouds be better represented in an economical way?

Our solution is to integrate several existing components: a prognostic SGS turbulence kinetic energy (TKE) equation, the trivariate assumed PDF method, a diagnostic second- and third-moment SGS turbulence closure, and a turbulence length scale related to the SGS TKE and eddy length scales. Our turbulence closure requires only one prognostic equation. This makes it economical, portable, and well-behaved. Our closure also uses a novel turbulence length scale that allows results to be nearly independent of horizontal resolution.

We implemented our approach, called Simplified Higher-Order Closure (SHOC), in a cloud-resolving model (CRM) and tested it against large-eddy simulation (LES) results. We also implemented it in a global model based on the Multiscale Modeling Framework (MMF) and evaluated the results using global observations. The CRM that we used is SAM (System for Atmospheric Modeling) developed by Marat Khairoutdinov. SAM-SHOC incorporates our new turbulence closure model.

Several LES benchmark cases were used to test SAM-SHOC. Our evaluations show that SAM-SHOC can realistically represent many boundary-layer cloud regimes in CRMs with horizontal grid sizes of 0.5 kilometers or larger, with practically no dependence on horizontal grid size. We also performed a SHOC test within the SP-CAM (Super-Parameterized Community Atmospheric Model). In SP-CAM, the representation of shallow cumulus was improved, but subtropical stratocumulus were still severely under-represented, likely due to inadequate vertical resolution.

We are currently performing simulations of the Midlatitude Continental Convective Clouds Experiment (MC3E) field campaign with SAM-SHOC for a range of horizontal grid sizes.

Environmental controls on cloud populations in the Madden-Julian Oscillation during AMIE/DYNAMO

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Zhe Feng, Pacific Northwest National Laboratory
Chuck Long, Pacific Northwest National Laboratory
Kiranmayi Landu, Pacific Northwest National Laboratory
L. Ruby Leung, Pacific Northwest National Laboratory

Analysis of radar reflectivity data collected by Spol-Ka-Pol, Shared Mobile Atmospheric Research & Teaching Radar (SMART-R), and the Ka-band ARM zenith radar (KAZR) revealed that cloud populations evolving from isolated shallow clouds, to deep convective cores, to wide convective cores, and finally to broad stratiform regions during the passage of each of the two Madden-Julian Oscillation episodes observed during the ARM Madden-Julian Oscillation Investigation Experiment (AMIE)/Dynamics of the Madden-Julian Oscillation (DYNAMO) field campaign. We used cloudpermitting regional model simulations, which correctly capture the salient features of these episodes, to examine the large-scale environmental processes that determine the timing of these transitions. Specifically we tested the "stretched building block hypothesis" on the organization of convection by the large-scale environment and the role of environmental wind shear and cold-pool dynamics.

Evaluating and constraining cirrus parameterizations in GCMs with SPARTICUS observations

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Kai Zhang, Pacific Northwest National Laboratory
Jennifer Comstock, Pacific Northwest National Laboratory
Minghuai Wang, Pacific Northwest National Laboratory
Gerald Mace, University of Utah
David Mitchell, Desert Research Institute

Cirrus clouds composed of ice crystals play an important role in regulating the Earth's radiative budget and influencing the hydrological cycle. Although cirrus clouds are an important player in the global climate system, there are still large uncertainties in the understanding of cirrus cloud properties and processes and their treatments in global climate models. In this study we analyze the in situ cirrus measurements from various research campaigns, including the Small Particles in Cirrus (SPARTICUS) campaign (http://campaign.arm.gov/sparticus/). We use the derived statistical information to evaluate and constrain the cirrus cloud parameterizations in the Community Atmospheric Model version 5 (CAM5) with a focus on ice crystal formation through in situ ice nucleation and growth through water vapor deposition, and cirrus dynamics through vertical velocity. We compare modeled and observed ice crystal number concentration, ice water content, and relative humidity inside and outside cirrus and their covariance with temperature. We also evaluate the simulated vertical velocity in cirrus clouds and examine its impact on ice nucleation and the associated aerosol indirect forcing. Our results indicate that
(1) homogeneous ice nucleation on sulfate aerosol may play a dominant role in the ice formation compared to the heterogeneous nucleation in the midlatitude cirrus with temperatures less than -40°C over the ARM Southern Great Plains (SGP) site, as revealed from the analysis of observation data;
(2) heterogeneous ice nucleation has the potential to significantly perturb the cirrus cloud microphysical properties and radiative forcing if there is a sufficient number of ice nuclei (IN) in the upper troposphere, and thus a cooling of climate through the cirrus seeding of IN may be physically plausible; and
(3) subgrid vertical velocity is the most important factor for the large aerosol longwave indirect forcing in CAM5 through ice nucleation compared to other global climate models (GCMs).

FAst-physics System TEstbed and Research Project (FASTER) convective-stratiform precipitation and vertical velocity products

Tami Toto, Brookhaven National Laboratory
Scott Giangrande, Brookhaven National Laboratory
Michael Jensen, Brookhaven National Laboratory
Pavlos Kollias, McGill University
Mary Jane Bartholomew, Brookhaven National Laboratory
Xiquan Dong, University of North Dakota

In support of the FAst-physics System TEstbed and Research (FASTER) project, several convective/stratiform precipitation products have been developed using data from the ARM radars at the Southern Great Plains (SGP) site. For the period from 1999–2007, an attenuation-based algorithm has been applied to millimeter-wavelength cloud radar (MMCR) data to produce convective/stratiform precipitation and accumulation data sets. The algorithm has been evaluated using Next-Generation Radar (NEXRAD) data and results will be presented. Additionally, a novel approach combines UHF ARM zenith radar (UAZR), Ka-band ARM zenith radar (KAZR) from the KAZR-ARSCL VAP, and Joss-Waldvogel disdrometer (JWD) impact disdrometer data to produce time series profiles of calibrated and rain attenuation corrected reflectivity, vertical velocity, and specific echo classification. Constrained by disdrometer observations, the integrative analysis exploits the sensitivities of both radars to identify regions of cloud, stratiform precipitation, and associated bright band, drizzle, convective cores, and elevated convection. Initial results will be presented for select rain events of the 2011 Midlatitude Continental Convective Clouds Experiment (MC3E). The convective and stratiform properties available through the data sets, such as drop-size distribution, vertical velocity magnitude, horizontal extent, and spatial characteristics, are useful for model evaluation.

Improved hydrometeor simulations using cloud-resolving WRF and multiscale data assimilation and augmented forcing for single-column models

Sha Feng, UCLA Joint Institute for Regional Earth System Science and Engineering
Zhijin Li, University of California, Los Angeles/NASA Jet Propulsion Laboratory
Yangang Liu, Brookhaven National Laboratory
Wuyin Lin, Brookhaven National Laboratory
Tami Toto, Brookhaven National Laboratory
Andrew Vogelmann, Brookhaven National Laboratory

A set of numerical experiments for convective cloud and precipitation cases occurring over the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) site has been conducted using the WRF-based multiscale data assimilation system. This system was developed for the FAst-physics System TEstbed and Research (FASTER) project to examine the influence of the assimilating ARM surface meteorological observations and balloon-borne sounding (SONDE) profiles along with conventional and satellite radiance data processed by the National Centers for Environmental Prediction (NCEP). In addition to further improvements on meteorological fields, the results demonstrate significant impact of ARM observations on modeled clouds and precipitation. Assessments show that the data assimilation improves the fits of domain-averaged mixing ratios of both liquid- and frozen-phase hydrometeors to satellite observations, the vertical structure of clouds via comparisons to radar reflectivity at the SGP Central Facility, and the spatial structure and amount of precipitation. Hydrometeor-related quantities derived from the data assimilation system are used to initialize and drive single-column models (SCMs). The influences are assessed by comparison of the simulations to those by conventional SCM simulations that do not use the hydrometeor-related quantities derived from the data assimilation system.

Improving convective transport, wet removal, and vertical distribution of aerosols in CAM5

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Dick Easter, Pacific Northwest National Laboratory
Po-Lun Ma, Pacific Northwest National Laboratory
Qing Yang, Pacific Northwest National Laboratory
Balwinder Singh, Pacific Northwest National Laboratory
Jerome Fast, Pacific Northwest National Laboratory
Phil Rasch, National Center for Atmospheric Research

It is important to simulate the correct vertical distribution of aerosols in climate models. Some aerosol species in the mid- troposphere and upper troposphere may affect ice cloud formation, and the vertical distribution of light-absorbing aerosols like black carbon (BC) influences local radiative heating and, consequently, the thermodynamic structure and circulation. Aerosol lifetime increases with altitudes because dry and wet deposition processes operate more strongly at the surface, affecting aerosol transport and removal.

The vertical distribution of aerosols in the free troposphere depends strongly on vertical transport and wet removal by convective clouds. Many global aerosol and climate models, including the widely used Community Atmosphere Model version 5 (CAM5), have large biases in predicting aerosols in the upper troposphere. In the standard CAM5, convective transport and wet removal of aerosols are treated separately, and secondary activation of aerosols entrained into updrafts is ignored. We recently introduced into CAM5 a new unified scheme for convective transport and wet removal of aerosols, with explicit aerosol activation above convective cloud base. This new implementation reduces the excessive aerosol aloft and better simulates observed BC profiles, which show decreasing mixing ratios in the mid-troposphere to upper troposphere, especially in the tropics and midlatitudes. The improved aerosol distributions have other impacts on CAM5, improving the global mean liquid water path and cloud forcing.

We will use the Weather Research and Forecasting (WRF) modeling framework with CAM5 physics to study transport and scavenging of aerosols by deep convective clouds, with fine-resolution cloud-resolving simulations and coarser-resolution simulations employing convective cloud parameterizations. Measurements from recent field campaigns will be utilized for process-level evaluation of model simulations.

Intercomparison of large-eddy simulations of Arctic mixed-phase clouds

Mikhail Ovchinnikov, Pacific Northwest National Laboratory

An intercomparison of large-eddy simulations (LES) of mixed-phase stratus observed over the Arctic sea ice during Flight 31 of the Indirect and Semi-Direct Aerosol Campaign (ISDAC) has been conducted. Results from over a dozen model configurations submitted by nine research groups are analyzed to gain insight into the processes controlling the longevity of mixed-phase clouds and to investigate the origins for the diversity among LES results documented in previous studies. Three simulations are conducted with each model configuration: one without any ice processes included and two with different prescribed ice number concentration (1 and 4 per liter, respectively). In addition to prescribing ice particle number concentration, this study also constrains mass-size and fall speed-size relationships used in all models and employs a simple parameterization for the longwave radiative cooling rate. The imposed constraints reduce but do not eliminate the spread of LES results. Two principal sources of remaining inter-model differences are identified. First, even in the absence of any ice processes, simulations are shown to diverge due to differences in formulations of model dynamics (e.g., advection and turbulent mixing). The second major source of inter-model variability comes from differences in a representation of ice particle size spectrum. Although the rates for depositional growth and sedimentation on a single-particle basis are uniformly constrained across models, variability in assumed (in bulk models) and predicted (in bin models) ice size distributions leads to different integral rates for cloud ice growth and removal. Simulations using two of the models that have both (bulk and bin) microphysics options available show that predicted ice water paths differ by as much as a factor of two, depending on whether the shape of ice spectrum is predicted or assumed to be exponential.

Intercomparison of the phase partitioning of water in mixed-phase clouds among global climate models

Muge Komurcu Bauraltar, Yale University
Trude Storelvmo, Yale University
Ulrike Lohmann, No Affiliation
Yuxing Yun, University of Michigan, Ann Arbor
Joyce Penner, University of Michigan, Ann Arbor
T. Takemura, Kyushu University

Clouds are one of the major components of the Earth's energy budget. The magnitude of the radiative influence of clouds on the Earth's surface is highly dependent on the cloud water phase. It is well known that the magnitude and spatial distribution of the liquid water path (LWP) and ice water path (IWP) simulated by different global climate models (GCMs) have large differences and do not compare well with satellite observations. Modeling the phase partitioning between cloud liquid water and ice has been a challenging topic due to the unknowns in ice nucleation, growth, and ice-nucleating particles as well as the challenges related to the satellite retrievals. Although there have been numerous climate model intercomparison studies, none of these studies concentrate particularly on the phase partitioning of cloud water. In this study, we aim to investigate the influence of ice nucleation mechanisms on the model predicted differences in the phase partitioning of cloud water using six different GCMs. We perform two sets of sensitivity simulations, one with default model ice nucleation mechanisms and the other with each model's default ice nucleation replaced with a prescribed ice nucleation mechanism. We find that although the parameterization of ice nucleation leads to differences in cloud water phase among different GCMs, it is not the main factor leading to differences in model results.

Investigating the nondeterministic processes of boundary-layer clouds using ARM observations and high-resolution simulations

Ping Zhu, Florida International University

Cloud parameterizations are developed based on the parameterizability assumption: that is, the subgrid-scale (SGS) cloud processes can be solely determined in terms of the large-scale properties resolved by weather and climate models. In this framework, the effects of some important internal cloud processes, such as precipitation and cloud mesoscale organizations, are either neglected or simplified into a conceptual cloud model. Previous studies show that some important cloud processes and organizations are not fully controlled by large-scale forcings. The existence of the nondeterministic cloud processes indicates the limit of deterministic parameterizability of clouds. In this study, using the multiple-scale Weather Research and Forecasting (WRF) simulation featuring a large-eddy simulation in the hindcasting mode, we investigated the nondeterministic effect of precipitation on the parameterization of precipitating shallow cumuli and stratocumulus clouds based on the cloudy cases observed at the ARM sites. Two sets of simulations with full microphysics and with the precipitation turned off are executed to illustrate how the precipitation affects the deterministic parameterizability of the vertical fluxes induced by clouds.

Large-eddy and single-column model simulations of boundary-layer clouds over Southern Great Plains and the Azores

Andrew Ackerman, NASA Goddard Institute for Space Studies
Ann Fridlind, NASA Goddard Institute for Space Studies
Jasmine Remillard, McGill University
George Tselioudis, NASA Goddard Institute for Space Studies
Susanne Bauer, NASA Goddard Institute for Space Studies

Continental shallow cloud case studies are provided by the FAst-physics System TEstbed and Research (FASTER) project, using aircraft and ground-based measurements obtained doing the Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO) campaign over the Southern Great Plains (SGP) in 2009. The case studies that the FASTER project has selected are three multi-day periods populated by a variety of boundary-layer cloud types. A critical input for the model simulations is provided by aerosol size distributions obtained by the aircraft in situ. Other posters that describe these cases are provided by Vogelmann and co-workers and Endo and co-workers, and Lin and co-workers place these into climatological context.

Shallow maritime cloud case studies are based on observations obtained during the Clouds, Aerosol, and Precipitation in the Marine Boundary Layer (CAP-MBL) field campaign, an ARM Mobile Facility deployment during 2009–2010 in the Azores. Our focus will be on the commonly observed drizzling marine boundary-layer clouds (Remillard et al. 2012). What the Azores cases lack in aircraft observations is made up for in a rich set of drizzle properties obtained through the W-band ARM cloud radar (WACR) retrievals of Kollias et al. 2011. The Azores case studies are placed into synoptic and climatological context in the Tselioudis et al. poster.

This poster focuses on the development and comparison of cases simulated by the large-eddy simulation code Distributed Hydrodynamic Aerosol and Radiative Modeling Application (DHARMA) and the single-column model version of the Goddard Institute for Space Studies (GISS) general circulation model (GCM). The DHARMA simulations use the bin microphysics code of Ackerman et al. (1995) and the dual-moment scheme of Morrison et al. (2009), while the single-column model (SCM) simulations use the traditional treatment of the GISS GCM (Schmidt et al. 2006) as well as the recent implementation of the dual-moment scheme of Morrison and Gettelman (2008).

Glaring deficiencies expected in the comparisons among the observations and the variety of model simulations will serve as a target for needed improvements in model physics, with an initial focus on reproducing basic cloud microphysics features when dynamics are subject to strong constraints.

Mechanistic insights into secondary organic aerosol formation from particle growth characteristics

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Dick Easter, Pacific Northwest National Laboratory

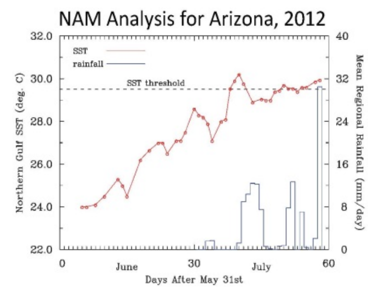
Several recent studies suggest that secondary organic aerosol (SOA) quickly becomes viscous and relatively non-volatile after formation, such that it does not evaporate upon dilution. However, the physical mechanism of SOA formation process itself still remains uncertain. SOA can form via three possible mechanisms:

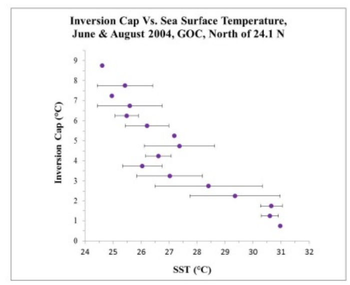
- irreversible condensation of low volatility organic vapors
- reactive uptake of organic vapors
- Raoult's Law-type absorption of organic vapors into pre-existing organic aerosol, followed by in-particle conversion to viscous, low-volatility products.

SOA formation via the first two mechanisms would be gas-phase diffusion-limited, and the growth will be controlled by aerosol surface area, while Raoult's Law-based absorption and particle-phase chemistry would be controlled by aerosol volume. The size distributions resulting from these processes would be quite different. In this study, we probe the mechanism of SOA formation from a-pinene photo-oxidation in an environmental chamber by interpreting the observed evolution of aerosol size distributions with the MOSAIC box-model, which treats aerosol size distribution evolution due to coagulation and dynamic, multicomponent gas-particle mass transfer. The poster will describe the experimental and modeling approaches and discuss the mechanistic insights gained from this type of analysis.

A mechanistic understanding of the evolution of the North American Monsoon

Ehsan Erfani, Desert Research Institute
David Mitchell, Desert Research Institute
Dorothea Ivanova, Embry-Riddle Aeronautical University





The North American Monsoon (NAM) is a large-scale synoptic feature having a strong impact on summer rainfall patterns and amounts over North America. For example, anomalously wet NAMs in Arizona are strongly anti-correlated with anomalously dry summers in the Midwest. Although regional climate models have succeeded in reproducing some features of the NAM, its onset, strength, and regional extent are not well predicted, and a physical understanding of key processes governing its evolution remains elusive. A correct physical understanding of the NAM is thus likely to improve the prediction of summer precipitation over North America in regional and global-scale models.

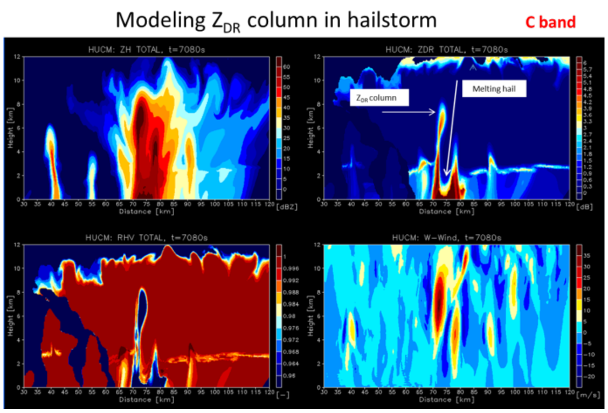
Here we propose a partial mechanistic understanding of the NAM incorporating local- and planetary-scale processes. The proposed hypothesis is supported with satellite observations of sea-surface temperature (SST), sea-surface height (SSH), and rainfall amount; temperature and humidity profiles from soundings launched over the Gulf of California (GC); climatologies of SST, outgoing longwave radiation (OLR), and 500 hPa streamline reanalysis; and regional-scale modeling of the NAM region.

On the local scale, these measurements and modeling demonstrate that relatively heavy summer precipitation in Arizona generally begins within several days after northern GC SSTs exceed 29°C. The mechanism for this relates to the marine boundary layer (MBL) over the northern GC. For SSTs < 29°C, GC air is capped by an inversion ~50–200 meters above the surface, restricting GC moisture to this MBL. The inversion weakens with increasing SST and generally disappears once SSTs exceed 29°C, allowing MBL moisture to mix with free tropospheric air. This results in a deep, moist layer that can be advected inland to produce thunderstorms.

On the synoptic scale, climatologies of NAM region SST, OLR, and NCEP/NCAR 500 hPa streamline reanalysis support the hypothesis that relatively warm SSTs (≥ 27.5°C) are generally required for widespread deep convection to initiate in the NAM region, and that the poleward evolution of the monsoon anticyclone during June–July is driven by the associated descending air north of the convective region. As warm Pacific SSTs propagate northwards up the Mexican coastline, deep convection follows this northward advance, advancing the position of the anticyclone. This evolution brings mid-level tropical moisture into the NAM region. This study may provide a basis for more productive NAM research.

Modeling and observations of deep convective updrafts using cloud models with with spectral microphysics and polarimetric radar measurements

Alexander Ryzhkov, National Severe Storms Laboratory
Alexander Khain, The Hebrew University of Jerusalem
Matthew Kumjian, National Center for Atmospheric Research



Polarimetric radar observations of convective storms routinely reveal the columns of positive differential reflectivity (ZDR) extending above the 0°C level, indicative of the presence of supercooled liquid raindrops lofted by the storm's updrafts and water-coated graupel /hail particles growing in the wet growth regime near the tops of the updrafts. Two cloud models with spectral microphysics of different complexity combined with the radar-scattering computations are used to simulate ZDR columns, including a one-dimensional model of raindrop freezing and a more sophisticated model of the Hebrew University of Jerusalem (HUCM), which takes into account both freezing of supercooled raindrops and wet growth of graupel/hail.

It is shown that the freezing and size sorting of raindrops is the major microphysical process responsible for generation of relatively shallow ZDR columns associated with weaker updrafts, whereas water-coated hailstones in the wet growth regime contribute significantly to the generation of taller ZDR columns related to stronger updrafts.

The study suggests a new approach for improving microphysical parametrization schemes in the storm-scale cloud models. According to this approach, individual microphysical processes such as stochastic drop nucleation by an immersed foreign particle and subsequent deterministic freezing are modeled and parametrized using a simplified, one-dimensional explicit bin microphysics model that is capable of reproducing realistic-looking ZDR columns consistent with polarimetric radar observations. Then the simplified model, which is optimized by direct comparison with radar data, is nested as a special module describing the processes of nucleation and refreezing into a more sophisticated HUCM model that also explicitly treats the processes of hail growth via accretion and takes into account collisions between the particles of different habits.

Utilization of the ZDR column as a proxy for a deep convective updraft (without the need to directly measure vertical air velocity) will effectively facilitate the use of the newly deployed operational polarimetric WSR-88D radars and research dual-polarization scanning cloud radars for better understanding convective development in the cloud life cycle.

Multiple-scale simulations of the impact of PBL and convection schemes on the initiation of convection in the tropics

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Samson Hagos, Pacific Northwest National Laboratory
Larry Berg, Pacific Northwest National Laboratory
Zhe Feng, Pacific Northwest National Laboratory
Maoyi Huang, Pacific Northwest National Laboratory

In this study, we performed a series of regional simulations based on the Weather Research and Forecasting (WRF) regional model using a wide range of spatial resolutions (2-km, 10-km, and 50-km grid spacing) to identify the weakness of current planetary boundary layer (PBL) and convection parameterizations in capturing the initiation of convection and intraseasonal variability of precipitation over the Indian Ocean. Two episodes of the Madden-Julian Oscillation (MJO) observed during the ARM MJO Investigation Experiment (AMIE)/Dynamics of the Madden-Julian Oscillation (DYNAMO) field campaign of the boreal winter of 2011 are selected as a case study. The work consists of four distinct parts:

- We evaluated the spatial pattern of simulated precipitation with different resolutions against Tropical Rainfall Measuring Mission (TRMM) data, as well as the simulated vertical profiles of cloud, humidity, and temperature against observations collected during AMIE.
- We conducted simulations with three different PBL schemes (i.e., Yonsei University, Mellor-Yamada-Janjic, and University of Washington) and compared the boundary-layer structure and the transition from clear to cloudy conditions within the simulations.
- We tested the different convective schemes (i.e., Kain-Fritsch versus Zhang-McFarlane and Kain-Fritsch versus Kain-Fritsch cumulus potential) to look at the responses of simulated PBL clouds to those schemes. All simulations conducted for (2) and (3) are free runs (without nudging) done at both 10-km and 50-km grid spacing. The cloud properties and their probability density function (PDF) obtained from the 2-km simulations are used to evaluate the initiation of convection in the 10-km and 50-km simulations.
- We conducted another set of simulations similar to (2) and (3) but with water vapor nudging. The nudging tendency terms are examined to help identify errors in the gradual moistening and heating processes that are believed to be critical for simulating low-frequency variability of PBL and clouds.

By comparing the results from different spatial resolutions, PBL schemes, convection schemes, and with or without nudging, we can investigate the scale-dependence of modeled PBL structure and initiation of convection in the tropics under an idealized scenario in which moisture supply from the surface is unlimited using different PBL and convection schemes commonly applied in community models.

A new algorithm to interface subgrid variability and microphysics

Vincent Larson, University of Wisconsin, Milwaukee

The interfacing of subgrid-scale variability and microphysics in climate models could be improved in several respects. For instance, present-day climate models often neglect within-cloud variability and correlations between hydrometeor species.

To address these problems, we have developed a new algorithm ("SILHS") that generates profiles of temperature, moisture, hydrometeors, and so forth that are drawn from a distribution of subgrid variability. These sub-column profiles are subsequently fed into a microphysics parameterization. Then microphysical process rates are computed for each sub-column profile, averaged together to form a grid box mean, and fed back into the mean evolution equations.

The new algorithm is tested in single-column simulations of drizzling shallow stratocumulus and cumulus clouds. Although the algorithm does inject statistical noise into the solutions, the time-averaged profiles match compare satisfactorily with a limited but exact analytic method that interfaces the subgrid variability and the microphysics.

The next generation of SOA models: development and application

John Seinfeld, California Institute of Technology
Chris Cappa, University of California, Davis

Three recent studies, 2D-VBS (Donahue et al. 2012), SOM (Cappa and Wilson 2012) and FGOM (Zhang and Seinfeld 2012) are directed at the next generation of secondary organic aerosol (SOA) models. SOA formation and evolution are represented in terms of the competition between functionalization and fragmentation. Each model contains a set of parameters that are to be determined by fitting the model to laboratory chamber data. This poster outlines the features of the Functional Group Oxidation Model (FGOM) and presents its implementation to describe SOA formation from C12 alkanes. The implementation of the FGOM is compared with that of the SOM model.

The North American monsoon: implications from WRF modeling

Dorothea Ivanova, Embry-Riddle Aeronautical University
David Mitchell, Desert Research Institute

The North American monsoon (NAM) is responsible for considerable summer cloud cover and precipitation. Satellite observations suggest that sea-surface temperatures (SST) in the northern Gulf of California (GC) may play a critical role in the onset and amount of summer rainfall over the U.S. southwest. In particular, the onset of relatively heavy rainfall occurs after these SSTs exceeded 29°C. Here we explore this idea in a modeling context using the Weather Research and Forecasting (WRF) model to simulate the onset of the North American monsoon in Arizona (AZ). This study explores the impact of GC SSTs on factors affecting deep convective precipitation: the regional atmospheric circulation, water vapor mixing ratio, convective available potential energy (CAPE), and convective inhibition (CIN). The impact of GC SSTs on rainfall is also addressed.

After analyzing the predicted evolution of the above properties and their dependence on GC SSTs in numerous WRF simulations, a new understanding emerges as to how the lower atmosphere over the GC interacts with SSTs to release moisture for monsoon rainfall. When the GC SST is 29°C or less, an inversion is present over the GC due to warmer air aloft. When GC SSTs reach 30°C or higher, moist marine boundary-layer (MBL) air may become buoyant relative to the drier overlying air. This buoyancy can erode the marine inversion and allow MBL air to mix with the free troposphere. This enhances the moisture content of low-level southerly winds during favorable synoptic conditions, enhancing the moisture flux into AZ. The predicted dependence of the AZ regional rainfall rate on the northern GC SST is remarkably similar to the observed dependence, featuring an abrupt increase in rainfall rate when the SST exceeds 29°C. Thus, both modeling and observations indicate the existence of a threshold SST in the northern GC responsible for the onset of relatively heavy rainfall over AZ.

A boundary-layer parameterization having high vertical resolution with an accurate treatment of physical processes appears essential for capturing the sensitivity of AZ rainfall to GC SSTs.

Optimizing a coated-sphere module

David Wong, U.S. Environmental Protection Agency
Francis Binkowski, University of North Carolina, Chapel Hill

A widely used coated-sphere module, BHCOAT (Bohren and Huffman 1983), has been adopted for applications in coupled Weather Research and Forecasting Community Multiscale Air Quality Model (WRF-CMAQ applications). This module calculates the efficiencies for extinction, total scattering, and backscattering and asymmetry factor for a particle consisting of an absorbing spherical surrounded by a shell of material with a different refractive index from the core. When the refractive indices are equal, then the particle is treated as homogeneous. Our starting base version had been implemented from Bohren and Huffman's listing by Professor Bruce T. Draine of Princeton University from whom we obtained the code. This version of the code was implemented in standard double precision complex number format.

We have optimized to improve computational performance for our application in the coupled WRF-CMAQ model. During the model testing phase, we have encountered numerous cases that caused the failure in the BHCOAT algorithm. We have tested the algorithm with 32 specific cases, and 4 of them failed. The reason of failure is that the denominator becomes zero due to subtraction of two similar numbers. One of the failed cases did not exceed the limits that Bohren and Huffman had suggested. We applied a classical approach that increases the real precision to 16 bytes and the complex precision to 32 bytes. The problem went away. However, the run increased time by 77.47% to 96.33%.

We have devised a simple approach to deal with this numerical precision issue but add no extra burden on computation. We will present example calculations to illustrate the optimization technique we used, the numerical precision issue, and our approach to handle it.

Bohren, CF, and DR Huffman. 1983. Absorption and Scattering of Light by Small Particles. Wiley-Interscience, New York, 530pp.

Perturbed-parameter simulations of the MJO with CAM5

Stephen Klein, Lawrence Livermore National Laboratory
Jim Boyle, Lawrence Livermore National Laboratory
Richard Neale, NOAA/CIRES Climate Diagnostics Center
Shaocheng Xie, Lawrence Livermore National Laboratory
Kenneth Sperber, Lawrence Livermore National Laboratory

The Madden-Julian Oscillation (MJO) is a dominant source of intraseasonal variability precipitation and is of a subject of strong interest to the ARM Climate Research Facility/Atmospheric System Research (ASR) program. In an attempt to understand and improve the typically poor simulations of the MJO by climate models, we examine perturbed-parameter simulations with the fifth version of the Community

Atmosphere Model. Our ensemble consists of over 700 6-year atmosphere-only simulations with prescribed sea-surface temperatures in which 22 parameters contained in the parameterizations of shallow convection, deep convection, and large-scale clouds from a predetermined range of their acceptable values have been perturbed with a latin hypercube sampling methodology. Initial analysis suggests that the MJO could be improved by having a small value to the time scale for adjustment in the deep convection scheme shorter, a large value to the entrainment for deep convection, and less efficient autoconversion of deep convective condensate to precipitation. The connection between the simulation of MJO in hindcast (i.e., Cloud-Associated Parameterizations Testbed [CAPT]) and free-running mode will also be discussed.

Preliminary results on implementing a third-order turbulence closure in the Community Atmosphere Model

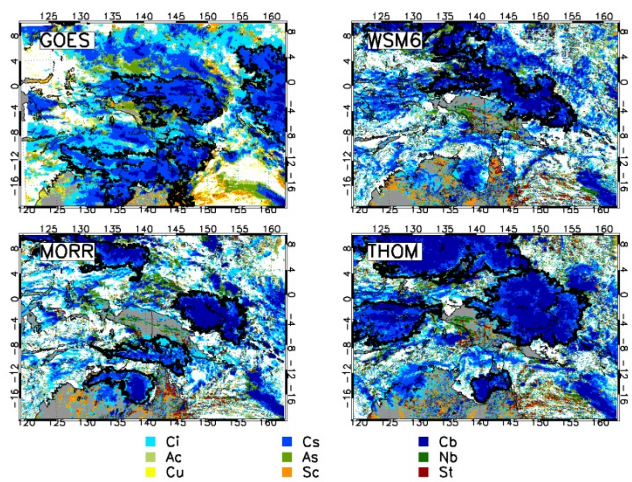
Anning Chen, NASA Langley Research Center
Kuan-Man Xu, NASA Langley Research Center

This presentation describes the implementation and testing of a higher-order turbulence closure, an intermediately prognostic higher-order turbulence closure (IPHOC), into the Community Atmosphere Model (CAM) version 5 (CAM5). The third-order turbulence closure introduces a joint double-Gaussian distribution of liquid water potential temperature, total water mixing ratio, and vertical velocity to represent any skewed turbulence circulations. The distribution is inferred from the first-, second-, and third-order moments of the variables given above and is used to diagnose cloud fraction and grid-mean liquid water mixing ratio, as well as the buoyancy term and fourth-order terms in the equations describing the evolution of the second- and third-order moments. In addition, a diagnostic planetary boundary layer (PBL) height approach has been incorporated in IPHOC in order to resolve the strong inversion above PBL for the coarse general circulation model (GCM) vertical grid spacing.

The IPHOC replaces PBL, shallow convection, and cloud macrophysics parameterizations in CAM5. The coupling of CAM5 with IPHOC (CAM5-IPHOC) represents a more unified treatment of boundary-layer and shallow convective processes. Results from global simulations are presented and suggest that CAM5-IPHOC can provide a better treatment of boundary-layer clouds and processes, when compared to CAM5. However, the representation of the cloud processes in the horizontal scale of 100 km is challenging for the IPHOC, which is normally used to parameterize the PBL processes in the horizontal scale of 1 km. The global annual mean low cloud fraction and precipitation are compared among CAM5, CAM5-IPHOC, and a multiscale modeling framework model with IPHOC. A few vertical cross-section plots along the GCSS/WGNE Pacific Cross-Section Intercomparison (GPCI) line and the south-east Pacific will also be shown in the poster.

The role of cloud microphysics parameterization in the simulation of mesoscale convective systems in the Tropical Western Pacific

Kwinten Van Weverberg, Brookhaven National Laboratory
Andrew Vogelmann, Brookhaven National Laboratory
Wuyin Lin, Brookhaven National Laboratory
Edward Luke, Brookhaven National Laboratory
Alice Cialella, Brookhaven National Laboratory
Patrick Minnis, NASA - Langley Research Center
Mandana Khaiyer, Science Systems and Applications, Inc.
Erwin Boer, LUEBEC
Michael Jensen, Brookhaven National Laboratory



High clouds, related to tropical convection, have been a challenge to climate modeling ever since its inception, even as the representation of clouds improved and grid spacings became smaller over the years. Progress in the representation of convective cloud structures within cloud-resolving models can only be achieved if the physical reasons for discrepancies between the different models are truly understood. This poster presents a detailed analysis of convection-permitting cloud simulations, aimed at increasing the understanding of the role of parameterized cloud microphysics in the simulation of mesoscale convective systems (MCSs) in the Tropical Western Pacific (TWP). Simulations using three commonly used cloud parameterizations with varying complexity have been compared against satellite-retrieved cloud properties. An MCS identification and tracking algorithm was applied to the observations and the simulations to evaluate the number, spatial extent, and microphysical properties of individual cloud systems. Different from previous studies, these individual cloud systems could be tracked over larger distances due to the large TWP domain studied. The analysis demonstrates that the simulation of MCSs is very sensitive to the parameterization of microphysical processes. The most crucial element was found to be the fall velocity of frozen condensate. Differences in this fall velocity between the experiments were more related to differences in particle number concentrations than to fall speed parameterization. Microphysics schemes that exhibit slow sedimentation rates for ice aloft experience a larger build-up of condensate in the upper troposphere. This leads to more numerous and/or larger MCSs with larger anvils. Surface precipitation was found to be overestimated and insensitive to the microphysical schemes employed in this study. In terms of the investigated properties, the performance of complex two-moment schemes was not superior to the simpler one-moment schemes, since explicit prediction of number concentration does not necessarily improve processes such as ice nucleation, the aggregation of ice crystals into snowflakes, and their sedimentation characteristics.

Van Weverberg, K, AM Vogelmann, W Lin, EP Luke, A Cialella, P Minnis, M Khaiyer, ER Boer, and MP Jensen. 2013. "The role of cloud microphysics parameterization in the simulation of mesoscale convective system clouds and precipitation in the Tropical Western Pacific." *Journal of the Atmospheric Sciences*, in press.

http://www.bnl.gov/faster/

Spatially resolved land-surface modeling using CLM for the ARM SGP site

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Margaret Torn, Lawrence Berkeley National Laboratory
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We have developed a modeling framework to ingest Mesonet climate forcing (solar radiation, humidity, temperature, precipitation, wind speed), U.S. Department of Agriculture (USDA) crop and vegetation cover at 30 m, and 1-km U.S. Geological Survey (USGS) soil characterization data into CLM4.5 (the land model integrated in the Community Earth System Model (CESM), the Department of Energy/National Center for Atmospheric Research (DOE/NCAR) climate model. CLM4.5, the new version of CLM to be released this summer, includes an explicit representation of several crops (corn, soy, pasture, summer wheat). We distributed the Mesonet climate forcing to 10-km resolution and ran CLM at that resolution with the dominant three vegetation cover types in each grid cell. Climate forcing has been generated for approximately the past ten years, and we continuously update these fields as information is passed to the ARM Data Archive. CLM4.5 lacks phenological, respiration, and photosynthetic parameterizations for winter wheat, as well as explicit water or fertilizer management. We have begun work to implement new parameterizations for these processes and compare to eddy covariance observations in the region. We report here on model performance and patterns in net ecosystem C, water, and sensible heat exchanges over the ten-year record.

Testing convection onset conditions in convective parameterization schemes using ARM observations at SGP and TWP

Guang Zhang, University of California, San Diego
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Convection initiation or onset is very important to climate, from diurnal cycle and intraseasonal variability to precipitation frequency and intensity climatology. Many global climate models (GCMs) do not simulate the diurnal cycle correctly, have weak intraseasonal variability, and produce too frequent convection with too weak intensity. All these biases are in one way or another related to the improper onset of convection in the models. In this work, we make extensive use of the ARM observations from intensive operational periods (IOPs) at the Southern Great Plains (SGP) and Tropical Western Pacific (TWP) sites together with the long-term single-column model forcing data from Atmospheric System Research (ASR) principal investigators to examine many convection trigger functions commonly used in GCMs. For each trigger function examined, the performance is stratified into three groups: correct prediction, over-prediction, and under-prediction of convection onset. A statistical skill score is used to quantify the performance of each trigger function. To further identify the critical factors responsible for the performance of a trigger function, for each group we further examine the composite profiles of moist static energy, temperature, moisture, and large-scale vertical velocity. It is found that there are systematic differences in these parameters among the three groups. These results will provide useful guidance to improving the convection trigger function and the simulation of convection onset in GCMs. More details will be presented at the meeting.

TRIP: the Turbulence Intercomparison Project

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Steven Krueger, University of Utah
Peter Bogenschutz, University of Utah
Anning Chen, NASA Langley Research Center
Marat Khairoutdinov, Stony Brook University
Vincent Larson, University of Wisconsin, Milwaukee
Chin-Hoh Moeng, National Center for Atmospheric Research

We have formed a multi-institutional partnership to implement, test, and evaluate four recently developed turbulence parameterizations, using a wide variety of methods and modeling frameworks together with observations including ARM data. The parameterizations are being compared and evaluated on the basis of their a priori conceptual merits, including closure assumptions; the realism of the results obtained in tests, including tests with global models; and their computational speeds. We will also undertake some modest model-development work to take advantage of what we learn from our tests. This poster will summarize the design of the project and progress to date.

Understanding the glaciating states of mixed-phase clouds with insight into ice particle habit evolutions

Kara Sulia, Pennsylvania State University
Jerry Harrington, Pennsylvania State University
Hugh Morrison, National Center for Atmospheric Research

Prior studies of mixed-phase clouds suggest that ice concentration plays a primary role in controlling the structure, phase partitioning, dynamics, and lifetime of these clouds. However, these prior studies assumed spherical particles or mass-size relations that lead to an overestimate of mixed-phase cloud lifetime. Ice and snow prediction has been improved though a new bulk parameterization that predicts bulk-averaged aspect ratio evolution with a historical tracking parameter. The method is used within a two-dimensional kinematic model and the Weather Research and Forecasting model to examine habit influences on the structure, lifetime, and dynamics of mixed-phase clouds. Studies show that predicting ice habits have strong effects on cloud and water phase partitioning. Cloud dynamics modify these results as vertical motions can support the simultaneous growth of both liquid and ice. Dynamics extend cloud lifetime when ice concentrations are low and when ice crystals grow at temperatures that promote isometric growth (around -10°C). Temperatures where growth is highly non-spherical (-15°C and -6°C) require higher vertical motions and lower ice concentrations to maintain the liquid phase. Moreover, our results show that supercooled liquid can be maintained when dendritic growth is predicted, which is in contrast to prior results using mass-size relations. Our results suggest a strong habit-based temperature dependence to supercooled liquid maintenance in Arctic clouds.

A unified probabilistic model of dry, shallow, and deep convection

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Fabio D'Andrea, Laboratoire de Meteorologie Dynamique, Ecole Normale Superi
Zhiming Kuang, Harvard University

We will present the probabilistic bulk coupled model (PBCM), a boundary-layer scheme based on a probabilistic framework. In the dry and shallow convection case an ensemble of plumes generated at the surface permit the growth of the boundary layer. The advantage of the probabilistic approach is twofold: the entrainment velocity of the mixed layer top and the cloud-base mass flux are described through a complementary relationship, based on the fraction of plumes overshooting a dry convective inhibition (corresponding to the subcloud layer) and the convective inhibition, generating active cloud cover.

The probabilistic framework accurately describes the diurnal course of convection and the triggering of deep convection. Once rain occurs, a probabilistic ensemble of cold pools organizes the mixed-layer turbulence and provides a mechanical and thermodynamic lifting to the environmental updrafts. The cold pools also increase the size of the updrafts, thus reducing their lateral entrainment.

The model favorably compares to large-eddy simulation results in various cases (ARM Southern Great Plains, Bomex, Amazon...), which will be presented.

Update on ARM climate modeling data development at Lawrence Livermore National Laboratory

Renata McCoy, Lawrence Livermore National Laboratory
Shaocheng Xie, Lawrence Livermore National Laboratory
Yunyan Zhang, Lawrence Livermore National Laboratory
Chuanfeng Zhao, Lawrence Livermore National Laboratory

The Lawrence Livermore National Laboratory (LLNL) ARM Infrastructure Team had been working on climate modeling ARM value-added products (VAPs) for many years now. We describe new additions, updates, and future plans of the VAPs being developed. The ARM showcase data set ARM Best Estimate (ARMBE, former Climate Modeling Best Estimate [CMBE]) product is presented. It is now part of the main ARM Data Archive and not an evaluation product; it has been updated to the most recent 2012 data, and the cloud fraction was updated with the new Active Remote Sensing of Clouds (ARSCL) algorithm. The work on a new ARMBE-Land data set that will facilitate use of ARM data in land-atmosphere coupling studies and the community land model development is presented. A new Quality-Controlled Eddy Correlation (QCECOR) VAP was developed and evaluated and is now transferring to the main ARM Data Archive. Another product developed at LLNL is the Variational Analysis (VARANAL) VAP also known as the large-scale forcing for cloud modeling studies. New variational analysis forcing data sets are being developed for several ARM field campaigns, namely: the Midlatitude Continental Convective Clouds Experiment (MC3E), Small Particles in Cirrus (SPARTICUS), and ARM Madden-Julian Oscillation Investigation Experiment (AMIE) field campaigns. We also discuss the cloud retrievals uncertainty quantification work and the ACRED (ARM Cloud Retrieval Ensemble Data Set) product updates. The future goals for all the LLNL ARM VAPs are also presented.

Using ARM data to investigate aerosol-cloud interactions for convective clouds in a global model

Lin Su, No Affiliation
Andrew Gettelman, National Center for Atmospheric Research
Shaocheng Xie, Lawrence Livermore National Laboratory
Xiaoliang Song, Scripps Institution of Oceanography
Guang Zhang, University of California, San Diego

We incorporate a physically based two-moment microphysics scheme for convective clouds in the latest National Center for Atmospheric Research (NCAR) and Department of Energy (DOE) Community Atmosphere Model version5 (CAM5). We evaluate the cumulus, aerosol, and climate interactions using a more robust single-column version of NCAR CAM5 framework that incorporates ARM field data sets and observation periods. We developed scripts for running CAM5 using available ARM field campaigns (ARM95, ARM97, GATE111, Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Response Experiment [TOGA-COARE], Mixed-Phase Arctic Cloud Experiment [M-PACE], Tropical Warm Pool-International Cloud Experiment [TWP-ICE], Small Particles in Cirrus [SPARTICUS]). The representations of convective clouds, aerosol-cloud interaction, and cloud radiative effect (CRE) in convective clouds have been improved based on two deep convection field campaign cases (TWP-ICE for tropical case and ARM97 for subtropical case). The aerosol-cloud interaction and its effect on cloud development such as the delay of precipitation, cloud freezing levels, the optimum aerosol load, convection invigoration, and extending cloud lifetime have been evaluated through several aerosol sensitivity experiments.

http://www.arm.gov/

Using TWP-ICE and MC3E observations to expose dynamical and microphysical causes of CRM and LAM simulated deep convection biases

Adam Varble, University of Utah
Edward Zipser, University of Utah

Ten 3D cloud-resolving model (CRM) simulations and four 3D limited area model (LAM) simulations of an intense mesoscale convective system observed on January 23–24, 2006 during the Tropical Warm Pool-International Cloud Experiment (TWP-ICE) field campaign are microphysically and dynamically compared with each other and observational retrievals in an attempt to explain results in Varble et al. (2011) and other studies showing a high bias in convective radar reflectivity aloft. Whereas several previous studies have focused on redistributing ice mass into different hydrometeor categories or smaller sizes to combat this high bias, our results suggest that it may be as much due to excessively large ice water content as ice category or size. These large ice water contents are a product of large, deep, strong convective updrafts that are nearly undiluted in some cases, allowing large rain water contents to be lofted and frozen.

The highest 10 percent of simulated deep updraft maximum vertical velocities from the surface to ~10 km are comparable in magnitude to the highest dual-Doppler derived updraft vertical velocities at those levels. However, average simulated updrafts from the surface to ~10 km, and all simulated updrafts in the upper troposphere are substantially stronger than the dual-Doppler derived updrafts and other tropical oceanic observations near coastlines in previous studies. We speculate that the large upper tropospheric difference is due to freezing of much more condensate in the simulations than in reality.

Aircraft penetrations into tropical oceanic convection during previous field campaigns between temperatures of 0 to -10°C show a select few vertical velocities of 15–17 m/s and questionable near adiabatic condensate contents on par with those simulated, but at much finer spatial scales than can be resolved by 1-km horizontal grid spacing. While observations are far from extensive, the ones available suggest that high vertical velocities and condensate contents simulated by the CRMs and LAMs may be possible over tropical oceans, but typically at lower frequencies and finer spatial scales than can be resolved by the simulations.

This research is now being extended to LAM simulations of Midlatitude Continental Convective Clouds Experiment (MC3E) cases for which superior observational retrievals exist. Our focus continues to be on the interactions of convective dynamics and different microphysics representations including how these interactions impact stratiform region properties, such as rain rate, which was biased low in TWP-ICE simulations.

11.0 Precipitation

Analysis of polarimetric signatures from the ARM MMCR Ka-band radar: calibration of the precipitation mode and a new model for raindrop shape

Michele Galletti, Brookhaven National Laboratory
Dong Huang, Brookhaven National Laboratory
Pavlos Kollias, McGill University

We focus on measurements of circular depolarization ratio (CDR) in rain with the Atmospheric Radiation Measurement (ARM) Climate Research Facility's millimeter-wavelength cloud radar (MMCR) in search of signatures due to non-axisymmetric oscillation of raindrops. If the depolarization ratio is obtained from the so-called polarimetric mode (5 main channel and 6 weak channel), CDR enhancements in the lower part of the troposphere are well visible, but are due to main channel saturation. If the depolarization ratio is obtained from the precipitation mode (4 main channel and 6 weak channel), then a correlation between CDR and max drop diameter and between CDR and rain rate can be observed. Potentially, the sensitivity of mm-wave radars to depolarization from oscillating raindrops may be used for quantitative estimation, provided the cross-polar isolation of the antenna is improved to better than -30 dB and the receiver architecture is designed to provide truly dual-polarization measurements (simultaneous reception of co-polarization and cross-polarization channels).

CDR measurements of rain are interpreted by means of T-matrix simulations of horizontally oriented oblate spheroids with a canting angle width between 7° and 10°. Surprisingly, such models cannot explain the observed depolarization. We then resorted to assuming ellipsoidal equilibrium raindrop shapes to account for the non-axisymmetric oscillations. The non-axisymmetric model for raindrop shape is substantiated by DDA (Discrete Dipole Approximation) simulations.

In the analysis, the invariance of the antenna ICPR (cross-polar isolation) is used to derive a method for the relative calibration of the precipitation mode with respect to the general mode. Relative calibration of the precipitation mode with respect to the general mode can be made with an accuracy of tenths of dBZ (~0.2 dBZ).

http://www.meteo.fr/cic/meetings/2012/ERAD/extended_abs/CR_100_ext_abs.pdf

Applications of ARM Southern Great Plains data sets to evaluating multiphase winter precipitating systems: thermodynamics and microphysics

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Lance Leslie, Ohio University
Peter Lamb, University of Oklahoma

The principal goal of the Atmospheric System Research (ASR) program is to reduce the uncertainty in future climate projections through improving process understanding of cloud, precipitation, and aerosol; their interactions; and the radiative budget. ASR draws from the unique observational capabilities of ARM Climate Research Facility sites around the world. The situation of the Southern Great Plains (SGP) facility was motivated by the wide variety of observed cloud systems, ranging from isolated convection to synoptic-scale disturbances. The ARM SGP site now has approximately 18 years of data, which is ideal for use in both interannual climatology and individual case study analysis. This poster demonstrates the current and potential future value of ARM data sets for improving understanding of multiphase synoptic-scale winter precipitating systems. Using a selection of case studies, a holistic approach to examining the evolution of the thermodynamic environment, as it relates to cloud phase, microphysics evolution, and precipitation growth, is considered. We highlight the use of ARM data in understanding the average thermal environment associated with mixed phase precipitation, we examine the evolution of the thermal profile associated with a specific winter weather case study, and we also consider the uses of in situ data sets in the validation of a WRF simulation. Finally, we identify some of the ways that the ASR program and the ARM Facility, with its recent addition of polarimetric radar capabilities, might be able to improve understanding of the microphysics of mixed-phase cloud and precipitation though dual-polarimetric techniques. The latter inquiry is based on a case study using the C-band OU-Prime precipitation radar.

Backscatter cross-section dependence on ice crystal habit in radar retrieval algorithms during STORMVEX

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Gerald Mace, University of Utah
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Tim Garrett, University of Utah
Gannet Hallar, Storm Peak Laboratory, Desert Research Institute
Ian McCubbin, Desert Research Institute

It is widely known that the presence of ice particles in clouds as well as snowfall and consequent snow cover at the Earth's surface play a critical role in the Earth's overall radiative energy budget. Determining the contribution to these radiative effects based on the specific ice particle habit, however, is much less understood. While a large part of this lack in physical understanding is due to remote sensing assumptions and parameterizations, recent progress has been made in ascertaining ice particle habit from the use of scanning W-band ARM cloud radar (SWACR) data collected during the Storm Peak Laboratory Cloud Property Validation Experiment (STORMVEX) held in Steamboat Springs, Colorado, during the winter of 2010/11. Originally shown in Matrosov et al. (2012), slant linear depolarization ratios (SLDRs) calculated from SWACR scanning periods can be used to deduce an ice particle habit when referenced in combination with backscatter relationships derived from T-matrix scattering calculations for oblate spheroid ice particles of varying aspect ratio. Extending from this most recent work and presented here, upon choosing an ice particle habit and corresponding backscatter parameterization, a comparison is made between SWACR retrievals calculated during vertical mode using a generic backscatter parameterization and scanning mode when the SLDR is being used to choose a habit-dependent backscatter parameterization. Tentative results from this study have thus far shown that radar reflectivity and hence the microphysical processes perceived to be taking place are much more sensitive to this backscatter parameterization than was perhaps previously thought. It is also expected that by choosing a more representative ice particle habit-based on the SLDR, we can reduce the optimal estimation uncertainty in snow microphysics retrieval schemes as well. This assumption will be tested with measurements collected at Storm Peak Lab and by the Wyoming King Air during the Colorado Airborne Multiphase Cloud Study (CAMPS) field campaign.

http://meteo04.chpc.utah.edu:8080/stormvex/

Investigation of raindrop breakup and evaporation using Doppler lidar-radar synergy: a feasibility study using MC3E observations

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Alessandro Battaglia, University of Bonn
Edward Luke, Brookhaven National Laboratory
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Recent modeling studies have indicated that the evolution of midlatitude precipitating systems critically depends on the parameterization of raindrop breakup (Morrison et al. 2012). Profiling radars have been traditionally been used to study the evolution of the raindrop size distribution (RSD). However, radar observations are sensitive to high moments (6th–7th) of the RSD, while microphysical processes influence and are parameterized as a function of lower moments (0th–3rd) of the RSD. We will demonstrate that the choice of the RSD shape in bulk microphysical schemes can have a large impact on our efforts to evaluate lower moments using radar observations. This raises the question: How can we use remote sensing to evaluate the presence and degree of raindrop breakup?

The Midlatitude Continental Convective Cloud Experiment (MC3E), a joint field program involving NASA Global Precipitation Measurement Program and ARM investigators, is the first field campaign conducted using the new Recovery Act ARM instrumentation. As part of the new instrumentation, observations from a profiling Doppler lidar and a multi-frequency profiling radar facility are available. In rain, the Doppler lidar receives coherent backscatter returns from aerosol particles and raindrops (Traumner et al. 2010). When raindrops dominate the Doppler lidar signal, the measurements depend on the 2nd–3rd moment of the RSD. This implies that the Doppler lidar measurements have the potential to be more sensitive than radar observables to raindrop breakup/evaporation. Here, we conduct a feasibility study using MC3E observations, a simple raindrop breakup model and a radar/lidar forward model.

Morrison, H, SA Tessendorf, K Ikeda, and G Thompson. 2012. “Sensitivity of a Simulated Midlatitude Squall Line to Parameterization of Raindrop Breakup.” *Monthly Weather Review* 140: 2437–2460.

Träumner, K, J Handwerker, A Wieser, and J Grenzhäuser. 2010. “A synergy approach for estimating raindrop size-distributions using Doppler lidar and cloud radar.” *Journal of Atmospheric and Oceanic Technology* 27: 1095–1100.

The mechanism of rain formation in deep cumulus clouds

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The formation of first raindrops in deep convective clouds is investigated. A combination of observational data analysis as well as 2D and 3D numerical bin microphysical simulations of deep convective clouds suggests that the first raindrops form in slightly diluted cloudy volumes at the tops of bubble cores. It is shown that droplet size distributions in the non-diluted and slightly diluted cores are wider and contain more large droplets than in diluted volumes. The results of the study indicate that process of raindrop formation is determined by the basic microphysical processes within ascending adiabatic volumes. It allows one to predict the height of the formation of first rain drops considering the processes of nucleation, diffusion growth, and collisions. The results obtained in the study explain observational results reported by Freud and Rosenfeld (2012) according to which the height of first raindrop formation depends linearly on the droplet number concentration at cloud base. The results also explain why a dynamically simple adiabatic parcel model can reproduce this dependence. The present study provides a physical basis for retrieval algorithms of cloud microphysical properties and aerosol properties using satellites proposed by Rosenfeld et al. (2012).

The study indicates that the role of mixing and entrainment in the formation of the first droplets is, supposedly, not of crucial importance. It is also shown that low variability of effective and mean volume radii along horizontal traverses that is regularly observed by in situ measurements can be simulated with cloud models, in which mixing is parameterized by a traditional 1.5 order turbulence closure scheme using the turbulent kinetic energy equation.

Mesoscale structure of a frontal snow system around Barrow, Alaska: an observational and modeling study

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Jerry Harrington, Pennsylvania State University
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Eugene Clothiaux, Pennsylvania State University
Hugh Morrison, National Center for Atmospheric Research

To elucidate the characteristics of Arctic frontal snow cloud systems, the mesoscale structure of a frontal system passing through Barrow from 16–18 October 2012 was analyzed, taking advantage of the new radar systems deployed at Barrow. This same frontal system is further analyzed using the Weather Research and Forecasting (WRF) Model version 3.4.1. During the passage of this system, the -10 dBZ echo-top heights measured by the Ka-band ARM zenith radar (KAZR) decreased from a height of 7 km. For the period of lower echo-top heights, the radar reflectivity below a height of 2 km reached peak values up to 20 dBZ. Vertical profiles of horizontal winds were estimated by a velocity azimuth display method using plan position indicator scans from the X-band scanning ARM precipitation radar (X-SAPR). These radar-estimated horizontal winds showed a predominance of northerly winds below a height of 3 km and southeasterly winds above a height of 4 km. The top of the layer of northerly winds decreased with height even as the winds above backed, becoming easterly. In order to understand the features observed in the radar measurements, the finest domain of WRF simulations utilized a 0.5-km horizontal resolution and 49 vertical levels with 15 levels in the lowest 1 km. The Morrison double-moment microphysical scheme was used. The 0.5-km simulations revealed that a high equivalent potential temperature (> 278°K) air mass overran a pre-existing lower equivalent potential temperature air mass from the east to west. The simulated frontal system formed in an environment of northerly winds below a height of 3 km and southwesterly winds above the height of 3 km. The frontal system moved towards the west. The simulated wind fields are in good agreement with radar-estimated vertical wind profiles. Moreover, the simulated snow mixing ratio dramatically increased below heights of 2 km. This is consistent with the measured radar reflectivity.

http://www.arm.gov/

Multiple-wavelength radar measurements for rain profile retrievals at ARM SGP Central Facility

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Pavlos Kollias, McGill University

The U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility sites now host continuous multiple-wavelength radar measurements with matched beams. Thanks to the recent reconfiguration and improved signal processing of the UHF wind profiler in a precipitation mode, triple wavelength profiles of rain events are now available at the Southern Great Plains (SGP) site.

Rain attenuation at the millimetre wavelength of cloud radars does represent a useful signal for the retrieval of precipitation characteristics. In particular, at Ka-band, the reflectivity gradient can be used to retrieve rain-rate profiles, assuming that the non-attenuated reflectivity profiles are constant within the vertical layer where the retrieval is applied. In order to improve or extend this method, a non-attenuated Rayleigh reference profile allows considering the more general case of vertical variability of hydrometeor profiles, while an additional attenuated cloud radar (e.g., W-band) permits extension of the retrievals to very low rain rates. The key step in this new methodology is to disentangle the contributions to the measured dual-wavelength ratios provided by rain attenuation and by non-Rayleigh effects that can be of the same order of magnitude for cloud radars. To achieve this goal, the retrieval of full drop-size distribution characteristics is mandatory.

This theoretical study aims at showing the feasibility of such retrievals. The improvement brought by the third wavelength will be evaluated, and the optimal combination of radar wavelengths will be determined depending on the rain-rate regimes. Finally, this methodology will be illustrated through different case studies using the UHF wind profiler and the Ka- and W-band cloud radars of the ARM SGP Central Facility.

Parsivel2 disdrometer intercomparison study in support of MAGIC

Mary Jane Bartholomew, Brookhaven National Laboratory

Observations of cloud and precipitation are primary goals for the Marine ARM GCPI Investigation of Clouds (MAGIC) field campaign, currently underway. Vertically pointing cloud radars are critical tools for this research. Typical radar calibration methods rely on collocated scanning cloud radars. A scanning radar will not be available during MAGIC; hence, the decision was made to deploy optical disdrometers to monitor and to try to constrain the quality of the radar data. From the available suite of ARM disdrometers, the Parsivel2 disdrometers manufactured by Ott Messtechnik were thought to have the chance to accurately measure rainfall and/or drop-size distribution under admittedly difficult conditions. Because no absolute calibration is available for the disdrometers, a side-by-side intercomparison study is being carried out at Brookhaven National Laboratory to evaluate Parsivel2 precision and feasibility to provide relative calibration for the cloud radars. In part the intercomparison is intended to determine the influence of ship motion on observed drop distributions and the equivalent reflectivity factor calculated from those distributions. A preliminary analysis of the data suggests that the minute-to-minute results of the disdrometers can be used to predict equivalent reflectivity factor to +- 1.5dBZ and +-2.5 dBZ for W- and K-band observations, respectively. Any attempt to use the results of the side-by-side study to as a basis for determining the precision of equivalent reflectivity factor as measured on ship must take into account two important caveats. First, the ship moves at a steady 10 meters/second and often experiences higher wind speeds. Those conditions cannot be recreated in the current side-by-side disdrometer intercomparison. Secondly, the disdrometers and the radars have very different sampling volumes.

12.0 Radiation

AERI profiling using GFS first guess

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Profiles of temperature and water vapor in the lower troposphere can be obtained from the atmospheric emitted radiance interferometer (AERI) infrared spectrometer under clear-sky conditions using the AERI Profiles (AERIPROF) physical retrieval developed at the University of Wisconsin Space Science and Engineering Center. The accuracy of the retrieval, however, is dependent of the quality of the first guess that is used. New automation is under development to provide first-guess profiles for the AERI physical retrieval using routinely received Global Forecast System (GFS) model output. As a result, deploying the AERI retrieval will be possible anywhere in the world where general internet access is available, using simple configuration including the latitude and longitude of the AERI observing site. Comparisons between AERI retrievals at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP), North Slope of Alaska (NSA), and Tropical Western Pacific (TWP) sites using both a GFS- and radiosonde-based first guess show good agreement. These results pave the way for autonomous deployment of the AERI instrument and high-quality temperature and water vapor profiling without the need for a collocated radiosonde station.

Analysis of spectra from the RHUBC-II campaign

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The mid-to-upper troposphere is an important driver of that region's dynamics. Surface measurements of thermal and solar radiation in typical conditions contain no pertinent information about these radiative processes due to absorption by water vapor in the intervening lower atmosphere. The resulting relatively high uncertainty in our knowledge of these processes is reflected in a corresponding uncertainty in climate models predictions for the mid-to-upper troposphere. In an initiative targeted at targeted at lowering these uncertainties, the ARM Climate Research Facility recently conducted the second Radiative Heating in Underexplored Bands Campaigns (RHUBC-II) from August–October 2009 at a site at 5400 meters elevation in the Atacama Desert of Chile. During RHUBC-II, precipitable water vapor values as low as 0.2 mm were observed during clear periods. This campaign included a number of instruments that provided spectrally resolved measurements in strong H_2O absorption bands, including two instruments that measure throughout the far-IR and one in the near-IR.

Analysis of RHUBC-II measurements requires accurate specification of the water vapor profiles in the radiating column above the site. Vaisala RS-92 radiosondes were regularly launched during operational periods of RHUBC-II, but these sondes have well-known accuracy issues in conditions of low humidity and during daytime. Previous ARM radiative closure studies have demonstrated that measurements associated with well-characterized H2O absorption lines in the microwave can provide information that improves the accuracy of water vapor profiles measured by sondes. This study has utilized an optimal estimation approach to refine the sonde profiles using observations from the RHUBC-II G-band vapor radiometer profiler (GVRP) instrument, which has 14 channels on the 183.3 GHz H_2O line, resulting in a best-guess water vapor profile for each RHUBC-II clear-sky case. These profiles allow analysis of near-IR spectrally resolved measurements of solar radiation by the absolute solar transmittance interferometer (ASTI), from which calibrated observations were obtained for two days at the end of the campaign.

Can we use observed cloud overlap in models?

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The assumption of subgrid cloud overlap used in global climate model (GCMs) is critical to the computed radiation budget. It has been suggested that cloudy layers that are contiguous have a maximum overlap, and other cloudy layers have a random overlap. Some recent parameterizations also use the decorrelation length scale to parameterize the transition from maximum to random overlap. Cloud overlap parameters are typically computed based on observed cloud masks, regardless of the optical thickness of each cloud layer. This study uses the radar data from the ARM Southern Great Plains (SGP), North Slope of Alaska (NSA), and Tropical Western Pacific (TWP) sites to examine possible biases in calculated radiation when observed cloud overlap is used. It is then proposed that effective cloud overlap parameter (e.g., weighted by optical thickness) or a subgrid Probability Distribution Function (PDF) representation of subgrid clouds (instead of the binary representation) should be used for radiation calculations.

Development and uses of the Python-ARM Radar Toolkit (Py-ART)

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The Atmospheric Radiation Measurement (ARM) Climate Research Facility routinely deals with large amounts of complex remote sensing data. The measured parameters from this remote sensing data as well as value-added products (VAPs) are made available to the cloud and climate modeling communities. Preparing this data for dissemination requires extensive use of computational resources and algorithms which are not well addressed by current software packages. Here we will report on our progress in the development of the Python-ARM Radar Toolkit (Py-ART) to address these needs.

Py-ART offers a powerful interpreted environment for ingesting radar data from a number of formats, correcting for aliasing and attenuation, mapping data to Cartesian grids, and performing a number of geophysical retrievals on the data. The package is also capable of writing data to Climate and Forecast (CF) standard netCDF files as well as the emerging CF-Radial format for antenna coordinate data. Py-ART is written in the Python programming language, taking advantage of the powerful scientific libraries

(NumPy, SciPy, matplotlib) available for the language as well as interfacing with legacy C and FORTRAN radar code. The package will be freely available under an open-source license. Here we will focus on our recent efforts to make the package more accessible to end users by simplifying the interface, increasing code readability, and developing high-quality documentation.

http://radar.arm.gov

Efficient numerical orientation average for calculations of single-scattering properties of small atmospheric ice crystals

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Cloud phase and composition have substantial impacts on vertical profiles of radiative heating. However, reliable retrievals of these quantities from remote sensing measurements are difficult. Furthermore, retrieval techniques using satellite radiance measurements are limited to at most a few viewing angles. During the 2004 Mixed-Phase Arctic Clouds Experiment (M-PACE) over the North Slope of Alaska (NSA) site, the Atmospheric Radiation Measurement Climate Research Facility's Unmanned Aerospace Vehicle's (UAV) diffuse field camera (DFC), consisting of a pair of nadir-mounted digital cameras with hemispheric field-of-view lenses with 620–670 nm and 1580–1640 nm pass filters, was mounted on the Proteus aircraft and measured cloud radiance and irradiance fields. In this study, DFC data are used to derive the complete directional dependence of cloud reflectance and hemispherical directional reflectance factor (HDRF), which is related to cloud phase and composition. The observed HDRF are compared with those calculated for water, ice, and mixed-phase clouds using the radiative transfer code libRadtran that uses the discrete ordinate radiative transfer solver DISORT version 2.0. Distinct features in the calculated HDRF with for varying phases (i.e., water, ice, or mixed), compositions (i.e., sizes and shapes of ice crystals), and cloud optical depths are examined to find the best match compared with the observed HDRF. For mixed-phase cloud simulations the fraction of solid ice and liquid water and the vertical inhomogeneity of clouds are varied to determine which best matches the observed HDRF; similarly, the idealized ice crystal habit that best matches the observed HDRF is identified for ice clouds.

Measurement-model intercomparison of long-term spectral and broadband infrared measurement trends at the ARM SGP site

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Trends and associated statistics in both spectral and broadband downwelling longwave radiation are determined from the atmospheric emitted radiance interferometer and the broadband radiometer station, respectively, at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) site. These measurements are compared against spectral and broadband simulations based on historical forcing runs from the Community Climate System Model (CCSM), versions 3 and 4. We find that the phase and amplitude of trends as measured and from the climate models do not differ statistically. In the spectra, we find that the increase in CO_2 over the time span of the measurements can be detected in the wings of the R-branch of v2 absorption feature around 13.5 μm. Additionally, the contributions of water vapor and clouds to trends in downwelling longwave radiation are compared between measurement and model using the differential sensitivity of the mid-infrared window band (8–12 μm). Finally, we discuss prospects for comparing long-term spectral and broadband measurements at ARM against the Coupled Model Intercomparison Project Phase 5 (CMIP5) archive.

Surface albedo derived from clear-sky and partly cloudy observations from CERES

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One of working groups of the Clouds and the Earth's Radiant Energy System (CERES) project, the Surface and Atmosphere Radiation Budget (SARB) working group, computes surface and atmospheric irradiances to understand surface and atmospheric radiation budget and interaction of clouds and aerosols with radiation. The CERES team is preparing for the next major algorithm revision, Edition 4. As a part of the effort, we revised the algorithm to derive clear-sky surface albedo from clear-sky CERES observations. The CERES instrument footprint size is approximately 20 km. When the entire CERES footprint is clear, based on MODIS radiances, we use a radiative transfer model to derive broadband surface albedo using top-of-atmosphere (TOA) broadband irradiance derived from CERES observations as an input. This algorithm requires the size of clear-sky scene to be larger than 20 km. To improve the sampling for the Edition 4 process, we use partly cloudy scenes in addition to the clear-sky scene. Using MODIS narrowband radiances observed over the clear-sky area of partly cloudy CERES footprint, we estimate broadband clear-sky radiance and apply CERES angular distribution model (ADM) to compute TOA irradiance. We then derive the broadband surface albedo using radiation transfer model, similar to the process used for CERES clear-sky footprints.

In this presentation, we will present surface albedo map derived from the Edition 4 process. The surface albedo derived around the ARM Climate Research Facility North Slope of Alaska (NSA) and Southern Great Plains (SGP) sites will be used in an ASR-funded projects, "Moving ASR cloud microphysical retrieval beyond the vertical column" (principal investigator Professor Eugene Clothiaux) in modeling 3D radiative transfer.

Top-of-atmosphere shortwave and longwave broadband fluxes derived over ARM SGP using improved techniques

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As part of an ongoing effort to provide a continuous satellite cloud and radiative property data set for climate studies over the ARM domains, the Visible Infrared Solar Split-Window Technique (VISST) satellite retrieval algorithm provides top-of-atmosphere (TOA) broadband shortwave (SW) and longwave (LW) fluxes from geostationary satellite data. These fluxes are currently calculated from empirically derived narrowband-to-broadband (NB-BB) conversion coefficients, derived from coincident geostationary satellite narrowband fluxes and Terra Clouds and the Earth's Radiant Energy Budget (CERES) broadband fluxes. The accuracy of these derived fluxes can be limited by a number of factors, including a lack of temporal and angular ranges in the coincident times, and the use of one representative narrowband wavelength to calculate broadband flux.

This study addresses some of the limitations inherent in the current NB-BB fits. While limited in data set length (January–August 1998), Tropical Rainfall Measuring Mission (TRMM) CERES data provide broadband fluxes along a precessing orbit, yielding diurnal variability in the data set. Terra, limited to two daily local observations, provides a wealth of data extending from March 2000 to the present. These two data sets are used to improve the derivation of SW and LW broadband fluxes from the Geostationary Operational Environmental Satellites (GOES) data. Additionally, a new 2-channel technique utilizing the 6.7 µm water vapor and 11 µm window channels (M. Sun et al. 2012) provides improvement in LW flux derivation. NB-BB fits are derived for GOES-8 and validated with CERES-Aqua observed broadband fluxes as well as modeled fluxes from Fu-Liou radiation code. These methods will be applied to other satellites and ARM domains.

13.0 Conclusion

Two hundred and forty-nine posters were presented during the Science Team Meeting. Abstracts for each poster are included here, sorted into the following subject areas: aerosol-cloud-radiation interactions, aerosol properties, atmospheric state and surface, cloud properties, dynamics/vertical motion, field campaigns, infrastructure and outreach, instruments, modeling, precipitation, and radiation.

Full-size and color versions of images are available at http://asr.science.energy.gov/meetings/stm/posters/2013.

To recognize the important contributions of students to ASR research, awards were presented for student-led posters. The student poster competition was judged by the chairs of the three working groups. Awards were based on content (scientific merit), clarity, and originality and were presented during Thursday morning's plenary sessions. Student Poster Awards were given to Mark Fielding, Robert Johnson, Yinghui Liu, Scott Powell, and Jian Tian.

ABOUT THE FRONT COVER

Images on the program cover highlight two recent field campaigns that address ASR scientific objectives. Please refer to the agenda for related topical sessions.

MAGIC: Let by principal investigator Ernie Lewis from Brookhaven National Laboratory, MAGIC deployed the second ARM Mobile Facility on the container ship Horizon Spirit. During approximately twenty trips between Los Angeles, California, and Honolulu, Hawaii, AMF2 obtained continuous on-board measurements of cloud and precipitation, aerosols, and atmospheric radiation; surface meteorological and oceanographic variables; and atmospheric profiles from weather balloons launched every six hours.

TCAP: Led by principal investigator Larry Berg from Pacific Northwest National Laboratory, TCAP used ARM Mobile Facility instruments gathered data for a 12-month period starting in the summer of 2012 in order to quantify aerosol properties, radiation, and cloud characteristics at a location subject to both clear and cloudy conditions, and clean and polluted conditions. These observations were supplemented by two aircraft intensive observation periods, one in the summer and a second in the winter.