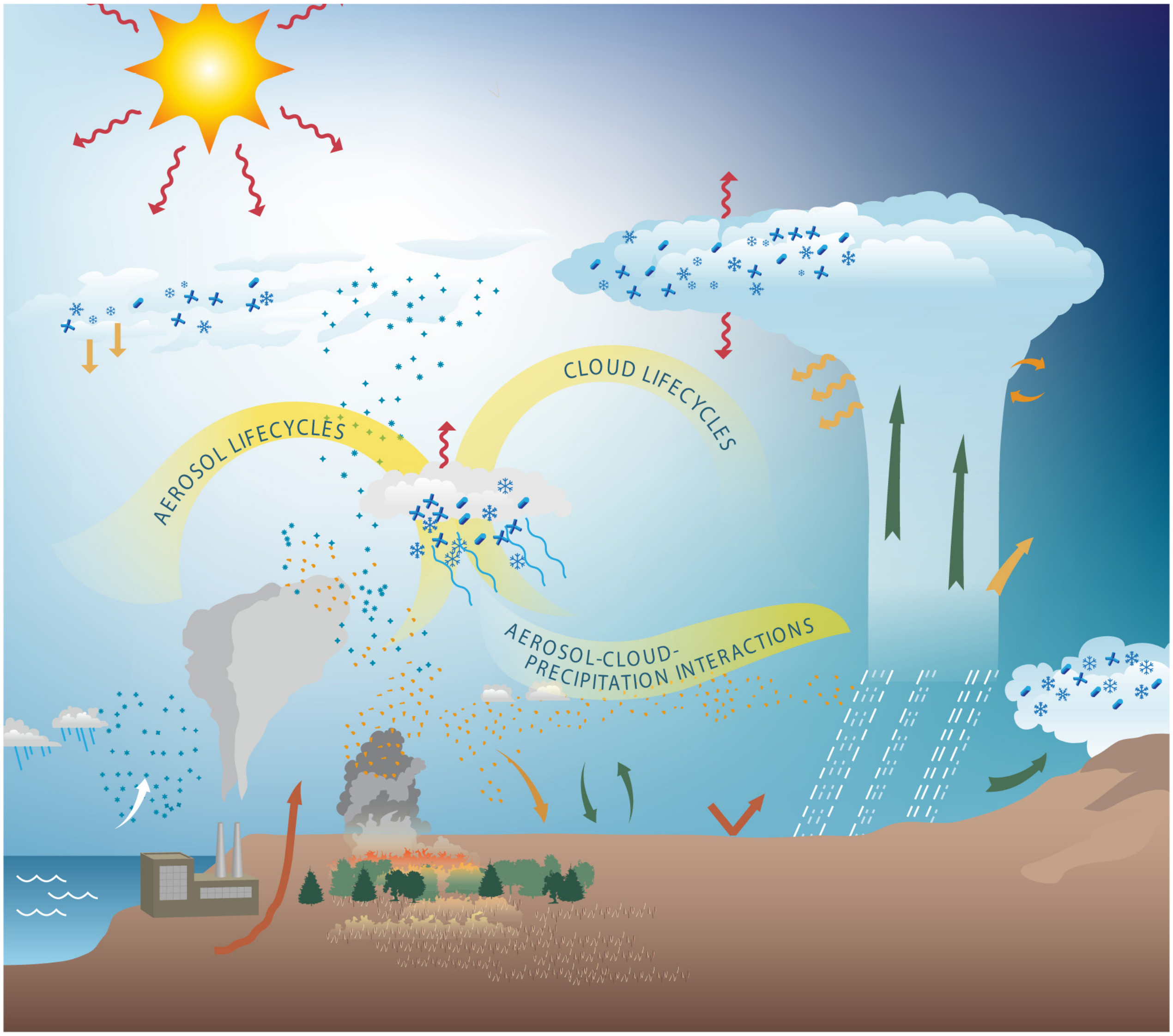
Atmospheric System Research

Science Team Meeting • March 15– March 19, 2010



U.S. DEPARTMENT OF ENERGY
Office of Science

ASR Atmospheric System Research

ABOUT THE FRONT COVER

The cover image illustrates the aerosol-cloud-precipitation continuum that 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. The defining objective of Atmospheric System Research is a detailed, process-level understanding of this system, leading to improved simulations by climate models.

The illustration was drafted by Matthew Shupe at a Science and Infrastructure Steering Committee meeting and rendered by Nathan Johnson, with contributions from many other scientists.

http://asr.science.energy.gov

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Atmospheric System Research (ASR) Science Team Meeting

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Contents

1.0 Executive Summary

Introduction

This document contains the summaries of papers presented in poster format at the March 2010 Atmospheric System Research Science Team Meeting held in Bethesda, Maryland. More than 260 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, field campaigns, infrastructure and outreach, instruments, modeling, and radiation. To put these posters in context, the status of ASR at the time of the meeting is provided here.

Background

For the past two decades the Atmospheric Radiation Measurement (ARM) Program and the Atmospheric Science Program (ASP) were the two research programs within the Biological and Environmental Research's Climate and Environmental Science Division (CESD) charged with conducting research on atmospheric processes pertinent to climate and climate change. These programs took coordinated and complementary approaches to quantify the effects of clouds and aerosols on the atmosphere's radiation balance. Both programs used laboratory studies, atmospheric measurements, and numerical modeling to examine processes that influence atmospheric radiative transfer in order to increase the fidelity of process representations in climate models. These programs supported the development and use of models on various scales, with domains that span the range from box models (order of meters) to global, to evaluate and improve the ability to make climate projections for assumed emissions scenarios. Thus, these programs provided data sets needed for the development of climate models in the United States and internationally and played a direct role in these model development activities.

At the beginning of FY2010, the ARM Program and ASP were merged. A major benefit of the merger is expected to be a strengthening of the programs by bringing together ARM expertise in continuous remote sensing measurements of cloud properties and aerosol influences on radiation with the ASP expertise for in situ characterization of aerosol properties, evolution, and cloud interactions.

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. The defining objective of ASR is a detailed, process-level understanding of this system that leads to improved simulations by climate models.

Recovery Act Upgrades

Through the American Recovery and Reinvestment Act of 2009, the U.S. Department of Energy's Office of Science received $1.2 billion, with $60 million allocated to the ARM Climate Research Facility. With these funds, ARM will purchase and deploy dual-frequency scanning cloud radars to all the ARM sites, enhance several sites with precipitation radars and energy flux measurement capabilities, and invest in new aerosol sampling and aerial instrumentation. In addition to new instruments for the ARM permanent and mobile sites, several instruments will be purchased for use throughout the facility and deployed as needed. Planned enhancements will result in 143 new instruments and increased research capabilities for the ARM user community, including the scientists of ASR.

References

Atmospheric System Research (ASR) Science and Program Plan. 2010. U.S. Department of Energy. http://www.sc.doe.gov/ober/Atmospheric%20System%20Research%20Science%20Plan.pdf.

2.0 Aerosol-Cloud-Radiation Interactions

Advancing an observational estimate of the cloud-albedo effect radiative forcing

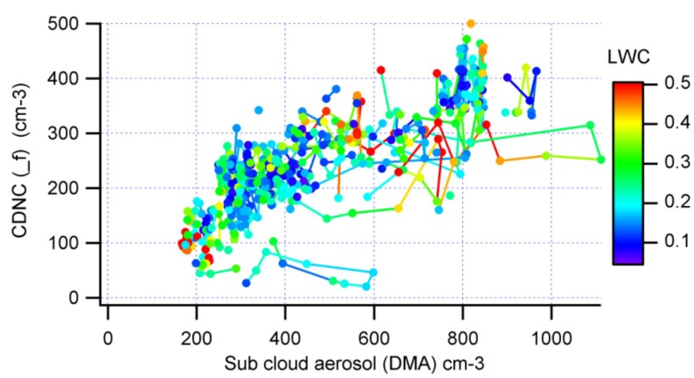
Allison McComiskey, CIRES/NOAA
Graham Feingold, NOAA Earth System Research Laboratory

Radiative forcing estimates of the cloud-albedo effect by the IPCC 4AR derive solely from model representations and are subject to high uncertainty. Observations of the cloud-albedo effect are not considered mature enough to provide a radiative forcing estimate; the uncertainty in existing observations may produce an uncertainty in radiative forcing several times that of the models. Several factors contribute to the difficulty in quantifying the cloud-albedo effect from observations. Foremost among these factors are: (1) variability in cloud liquid water path and failure to constrain this variability in calculations, (2) variability in vertical air velocities, and (3) variability in aerosol composition and size distribution. Failure to account for these factors tends to reduce the observed strength of aerosol impacts on cloud albedo and may be exacerbated by the observational platform or approach employed. We explore the impact of these factors, particularly their manifestation at different spatial scales, on the uncertainty in the observed cloud-albedo effect.

Aerosol-cloud interaction from aircraft observations in VOCALS

Larry Kleinman, Brookhaven National Laboratory
Peter Daum, Brookhaven National Laboratory
John Hubbe, Pacific Northwest National Laboratory
Yin-Nan Lee, Brookhaven National Laboratory
Arthur Sedlacek, Brookhaven National Laboratory
Gunnar Senum, Brookhaven National Laboratory
Stephen Springston, Brookhaven National Laboratory
Jian Wang, Brookhaven National Laboratory

During the VOCALS field campaign, the U.S. DOE G-1 aircraft was used to make cloud and aerosol measurements. Flight plans were designed so that cloud penetrations could be associated with pre-cloud (or sub-cloud) aerosol particles around which cloud droplets formed. This poster describes the aerosol size distributions and the relation between pre-cloud aerosol and cloud droplet number concentration. Sub-cloud aerosol typically had an Aitken and accumulation mode separated by a Hoppel minimum at 70 to 90 nm. Sub-micron aerosol had an average composition of 1/4 neutralized H2SO4 (i.e., H1.5(NH4)0.5SO4) with a 10% admixture of organics that reflected



Comparison of cloud droplet number concentration with sub-cloud aerosol for the entire VOCALS campaign. Data points that are connected are sequential in time. Breaks appear because aircraft flight patterns consisted of transects and vertical profiles in and out of cloud.

large SO2 emission rates from smelters and power plants located near the coast of Chile. Aerosol with this composition is expected to be easily activated as confirmed by CCN measurements. At a supersaturation of 0.2%, particles with a diameter greater than ~100 nm are on average activated. Variations in aerosol composition were minor. Cloud droplet number concentrations (CDNC) as a function of below-cloud aerosol are shown in the attached figure. Results are within the range of values obtained at different locations by other investigators. Measurements of dried interstitial aerosol from a DMA and PCASP in the cabin and from a PCASP mounted outside of the aircraft indicate a significant fraction of large particles in the size range 150–300 nm. Partially dried cloud droplets appear at larger sizes in the nose-mounted PCASP. Mechanisms for the creation of a population of large hygroscopic interstitial particles are discussed.

Aerosol-cloud interactions of secondary organic aerosols formed from the oxidation of linear, branched, and cyclic alkanes and alkenes

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Annelise Faulhaber, University of California, Riverside
Anthony Prenni, Colorado State University
Paul DeMott, Colorado State University
Roger Atkinson, University of California
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Christian Carrico, Colorado State University
Christopher Sullivan, Colorado State University

Secondary organic aerosols (SOA) formed from anthropogenic and biogenic precursors comprise a significant fraction of the atmospheric aerosol burden and play an important role in the Earth's radiation budget. To obtain a prognostic understanding of the impacts of SOA on clouds and climate, we must relate the chemical composition of the compounds that are found in the aerosol to their cloud forming potential. Unfortunately, the chemical mechanisms that govern SOA formation result in an intractable number of species. Therefore, models operating at any scale need to introduce optimally aggregated aerosol properties to minimize the number of classes that must be tracked. Towards this goal, we conducted measurements of the cloud condensation nuclei (CCN) and ice nuclei activity of secondary organic aerosol that was formed from the oxidation of linear, branched, and cyclic alkanes and alkenes. Aerosol-forming reactions were carried out in an FEP environmental chamber, including oxidation of the precursors with O3, NO3, and OH in the presence and absence of NOx. Ice nucleation experiments were performed only for the O3 reactions, and ice nuclei were not observed in detectable quantities for this subset of systems. When expressed as hygroscopicity parameter (kappa), CCN activity ranged from kappa=0.15 to kappa ~0, spanning the range from moderately CCN active to CCN inactive at atmospherically relevant sizes and supersaturations, respectively. The observed relationships between the organic aerosols' physical and chemical properties and its apparent cloud condensation nucleus activity allows us to constrain the organic aerosol behavior by grouping along the conceptual axes of precursor molecular size and types of functional groups associated with the carbon chain. The data suggest certain groupings that may provide a prognostic link between a source process (e.g., terpene emissions) and the effective behavior of the formed aerosol relevant to aerosol-cloud-climate interactions.

Aerosol effects on ice clouds: Can the traditional concept of aerosol indirect effects be applied to aerosol-cloud interactions in cirrus clouds?

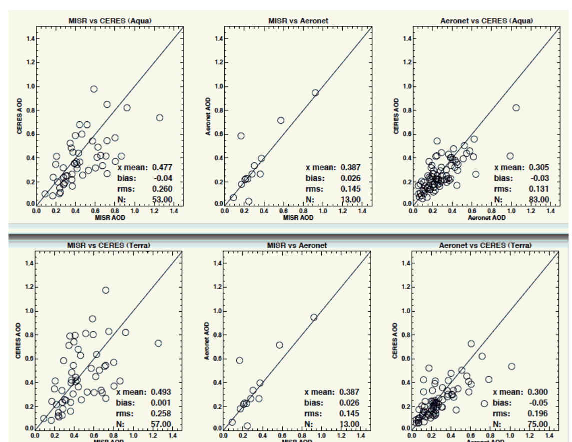
Seoung-Soo Lee, University of Michigan
Joyce Penner, University of Michigan

Cirrus clouds regularly cover 20–25% of the globe and thus play an important role in the Earth's radiation budget. This indicates that aerosol effects on cirrus clouds can have a substantial impact on the variation of global radiative forcing if ice-water path (IWP) changes. This study examines the aerosol indirect effect (AIE) through changes in the IWP in a case of cirrus clouds. We use a cloud-system resolving model (CSRM) coupled with a double-moment representation of cloud microphysics. Intensified interactions among the cloud ice number concentration (CINC), deposition, and dynamics play a critical role in the IWP increases due to aerosol increases. Increased aerosols lead to increased CINC, providing the increased surface area of ice crystals where water vapor deposits. This increases deposition and thus depositional heating to produce stronger updrafts, leading to the increased IWP. The conversion of ice crystals to aggregates through auto-conversion and accretion plays a negligible role in the IWP responses to aerosols, as does the sedimentation of aggregates. The sedimentation of ice crystals plays a more important role in the IWP response to aerosol increases than the sedimentation of aggregates, but not more than the interactions among the CINC, deposition, and dynamics.

Aerosol forcing at Niamey during RADAGAST from the CERES perspective

David Rutan, NASA Langley Research Center
Fred Rose, Science Systems and Applications, Inc./ NAS Langley Research Center
David Fillmore, National Center for Atmospheric Research
Thomas Charlock, NASA Langley Research Center

The ARM Mobile Facility (AMF), deployed at Niamey, Niger, during the RADAGAST experiment in 2006, accumulated a year-long set of detailed surface observations allowing for in-depth study of aerosol forcing to atmospheric radiation. NASA's Clouds and the Earth's Radiant Energy System experiment (CERES) instruments onboard the Terra and Aqua satellites measured top-of-atmosphere (TOA) radiation above the region and calculated flux profiles beneath CERES footprints simultaneously. Results are archived in the CERES Clouds and Radiative Swath (CRS) data product, which uses the Langley Fu and Liou two-stream radiation transfer model. Input for the model includes satellite remotely sensed variables such as clouds and aerosols and the Goddard Modeling and Assimilation Office GEOS-4 re-analysis for atmospheric conditions. Aerosol optical depth (AOD)



Comparison of independent surface (AERONET) and satellite (MISR) observations of column aerosol optical depth (AOD) near Niamey to values used in CERES radiation transfer modeling. AOD for CERES calculations over desert regions come primarily from the Model for Atmospheric Transport and Chemistry (MATCH), secondarily from retrievals from the MODIS instrument on board the Aqua and Terra satellites.

is specified, over deserts in particular, by the Model for Atmospheric Transport and Chemistry (MATCH) and AOD from the MODIS MOD04 data product. Aerosol properties are specified by the MATCH model. We show results from the CRS compared to surface observations for CERES footprints whose centers fall within 25 km of the AMF. Reported calculations are instantaneous at satellite overpass time, not daily averages (expect large RMSs) for all- and clear-sky conditions, and are presented with aerosol radiative forcing estimates from both satellites. On average, Aqua CRS all-sky results show mean insolation for the year of 756 W with a bias of 24 W and RMS of 91 W. Clear sky (defined as CERES footprint is cloud-free) results in mean insolation of 817 W, bias of 20 W, and RMS of 32 W. Mean shortwave aerosol forcing (calculated using clear-sky footprint results differenced from calculation without aerosol) is -51 W to surface insolation and +11 W reflection at TOA. The poster will show seasonal changes along with Terra results as well as consider impact of surface albedo on calculations. Key to these calculations is input AOD. The primary source for CRS calculations is the MATCH model with secondary source being MODIS MOD04. These estimates are compared to independent AOD observations from the ground (at 550 nm) from September–December 2006 using AERONET and to AOD derived from the MISR instrument onboard Terra for the entire year. Comparisons are relatively good and shown in accompanying image with biases of the CERES input values near 10% of MISR and AERONET observations with Aqua comparisons on top, Terra across the bottom.

http://www-cave.larc.nasa.gov/cave

Aerosol indirect effects in low LWP clouds: radiative-dynamical feedbacks

Jonathan Petters, The Pennsylvania State University
Jerry Harrington, The Pennsylvania State University
Eugene Clothiaux, The Pennsylvania State University

We compute cloud radiative heating through static plane-parallel adiabatic cloud layers, finding that integrated longwave radiative cooling and shortwave radiative heating are sensitive to LWP and droplet concentration Nd when LWP < 20 g m^-2. We examine feedbacks between radiative heating and dynamics within low-level low liquid water path (LWP) stratocumulus via large-eddy simulation (LES). We ran six-hour nocturnal simulations and sixteen-hour simulations of the diurnal cycle for the droplet concentrations of 50, 200, and 1000 cm^-3. Our simulations suggest that for low-level low LWP clouds, increasing droplet concentration leads to decreases in LWP and possible dissipation. Initial entrainment drying leads to more cloud breaks and lower LWPs when droplet concentration is high. Consequently, integrated radiative cooling is lessened for higher droplet concentrations in our nocturnal simulations. During the simulations, entrainment drying suppresses cloud growth when the droplet concentration is high (Nd = 1000 cm^-3) but is not strong enough to counteract cloud growth when the droplet concentration is low (Nd = 50 cm^-3). In our simulations of the diurnal cycle, integrated shortwave warming results in decreases in LWP and cloud fraction lowering. Consequently, radiative cooling decreases and circulations weaken, and LWP decreases further owing to the shortwave heating, creating a negative feedback loop. For Nd = 200 and 1000 cm^-3, integrated longwave cooling is reduced enough during the morning hours such that the cloud layer cannot be maintained against shortwave warming, and the cloud layer dissipates entirely. In contrast, for Nd = 50 cm^-3 the cloud layer is maintained throughout the day.

Analysis of aerosol-cloud interactions (ACI) in accordance with atmospheric stability

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You-Joon Kim, Gangneung-Wonju National University
Lim-Seok Chang, Global Environmental Research Center
Mark Miller, Rutgers University
Qilong Min, State University of New York at Albany

The subject of aerosol-cloud interactions (ACI) has received prominent attention because of still higher uncertainty in estimating its climatic forcings and its possible climate implications. Aerosol chemical and physical properties, cloud dynamic and turbulent characteristics, and the aerosol-cloud interactions should be considered together when evaluating the aerosol indirect effects. In this regard, ACI has been examined along with the distinctive different stability conditions between Pt. Reyes (PTR) and Southern Great Plains (SGP) in the similar low-level stratus/stratocumulus cloudy conditions. This study focuses on the role of static stability in the context of aerosol influences on the cloud microphysics. We found that stability appears to be critical in modifying aerosol-cloud interactions by suppressing cloud variability, with keeping the clouds being close to adiabatic especially in the PTR stratus clouds in comparison with SGP. We speculate that ACI could be possibly facilitated in the specific region and certain period, that is, low variability in the cloud macroscopic property (natural variability) largely suppressed by the static stability, certainly admitting a couple of possible inherent limitations in terms of measurement artifacts and discrepancy in aerosol properties in the comparisons of PTR and SGP.

Arctic cloud modeling and aerosol measurements: seasonal regime changes in aerosol particles and their role on cloud microphysics

Patrick Shaw, Scripps Institution of Oceanography
Lynn Russell, Scripps Institution of Oceanography

Cloud microphysical parameterizations are often based on comparisons with limited observational data sets. In this study, we will use the ARM data set to identify suitable regimes of similar observations with which the modeled microphysics can be compared. Two microphysical models will be tested for each regime by varying the complexity of parameterization schemes. For example, recent aerosol measurements at Barrow, Alaska, confirm seasonal changes in source regions and composition. Chemical signatures of anthropogenic pollutants were observed in particles during the springtime Arctic haze season, which differed dramatically from the summer and winter ocean-derived particles. In addition to these seasonal regimes, other regimes will be classified from the large data pool of ARM meteorology and radiation measurements using the results of Lubin and Vogelmann. We will monitor changes in simulated properties such as thermodynamic phase, growth rates, and size distributions and also develop methods to validate model performance with in situ ARM spectral data that is particularly sensitive to cloud microphysics. This framework will yield better characterization of Arctic sensitivity to cloud and aerosol feedbacks, and, if needed, allow us to modify the parameterizations. In this poster, a summary of the seasonal microphysical changes at Barrow is presented, along with a comparison of the two model cloud microphysics parameterizations that will be used.

Automatic detection of boundary layer by micropulse lidar (MPL)

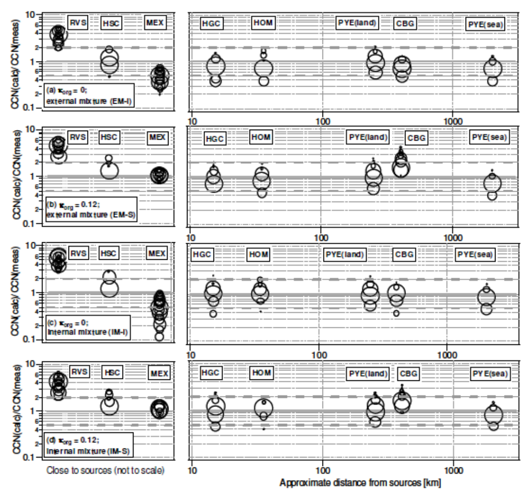
Virginia Sawyer, University of Maryland
Zhanqing Li, University of Maryland

The planetary boundary layer (PBL) is a feature of the lower troposphere that restricts mixing between the surface and the free atmosphere aloft. Its top height is often on the order of 1 km above the surface, but varies according to weather conditions. It has proved difficult to incorporate into global climate models, in which an accurate PBL parameter would help to simulate the global transport and distribution of aerosols. Although the boundary is defined by a buoyantly stable temperature inversion, the aerosol lidar backscatter signal is a desirable proxy measurement due to the high temporal resolution of ground-based, upward-directed MPL data. A PBL detection algorithm based on the Haar wavelet covariance transform (Davis et al. 2000, Brooks 2003) has been developed for MPLNET backscatter data. This algorithm was evaluated during the ICEALOT research campaign of March–April 2008. It is now adapted for MPL sites in China, demonstrating its ability to detect the PBL in a wide variety of locations and conditions.

CCN predictions using simplified assumptions of organic aerosol composition and mixing state: a synthesis from six different locations

Barbara Ervens, NOAA/CIRES

An accurate but simple quantification of the fraction of aerosol particles that can act as cloud condensation nuclei (CCN) is needed for implementation in large-scale models. Data on aerosol size distribution, chemical composition, and CCN concentration from six different locations have been analyzed to explore the extent to which simple assumptions of composition and mixing state of the organic fraction can reproduce measured CCN number concentrations. Fresher pollution aerosol as encountered in Riverside, CA (RVS) and the Ship Channel in Houston, TX (HSC) cannot be represented without knowledge of more complex (size-resolved) composition. For aerosol that has experienced processing (Mexico City [MEX], Holme Moss (UK) [HOM], Point Reyes (CA) [PYE], and Chebogue Point (Canada) [CBG]), CCN can be predicted within a factor of two assuming either externally or internally mixed soluble organics, although these simplified compositions/mixing states might not represent the actual properties of ambient aerosol populations. Under typical conditions, a factor of two uncertainty in CCN concentration translates to an uncertainty of ~15% in cloud drop concentration, which might be adequate for large-scale models given the much larger uncertainty in cloudiness.



Ratio of calculated to measured CCN number concentration for seven different data sets. The symbol size corresponds to the frequency of the respective ratio in the CCN closure. The dashed lines represent CCN (calc)/CCN (meas) = 0.5 and 2, respectively.

Cloud-aerosol-precipitation interactions

Steven Ghan, Pacific Northwest National Laboratory
Robert Wood, University of Washington

Aerosol particles, cloud particles, and precipitating particles form a continuum of particles that interact through a variety of complex mechanisms that affect the distribution and climate impacts of all particles. Aerosol particles affect clouds and precipitation by serving as the seeds for nucleation of droplets and crystals and by absorbing sunlight and thereby heating the air, suppressing condensation, changing the atmospheric circulation, and reducing turbulent transport of water from the surface into clouds. Clouds and precipitation affect the aerosol by transporting aerosol and their precursor gases upward and downward, by hosting aqueous chemistry that produces aerosol mass within cloud droplets, and by removing aerosol from the atmosphere when clouds precipitate. Observations and theoretical models suggest that full cloud-aerosol-precipitation interactions can lead to dramatic transitions from relatively polluted slowly precipitating clouds to much cleaner rapidly precipitating clouds, but these transitions are poorly understood. The Atmospheric Radiation Measurement (ARM) Climate Research Facility and the Atmospheric System Research (ASR) program together can provide the measurements, analysis, and modeling needed to address the many challenges of representing these interactions in climate models. In this poster/presentation we will summarize current understanding of cloud-aerosol-precipitation interactions and provide a vision for future directions of ARM and ASR measurements, analysis, and modeling to improve understanding and representation of the interactions in climate models.

Cloud chamber and single-particle mass spectrometry studies of aerosol-cloud interactions

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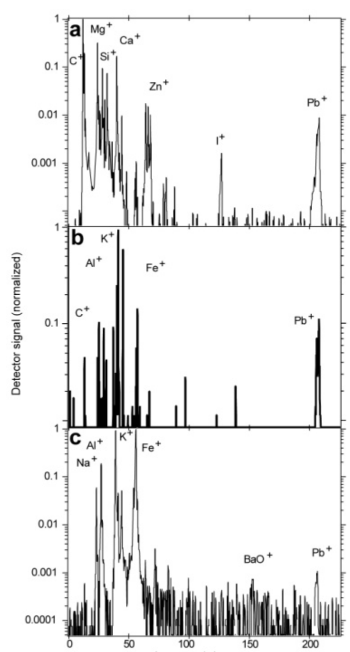
Mikhail Pekour, Pacific Northwest National Laboratory
Gourihar Kulkarni, Pacific Northwest National Laboratory
Kerri Pratt, Pacific Northwest National Laboratory

It is now highly certain that anthropogenic activities have caused a warming of the Earth's atmosphere. The addition of small aerosol particles has offset, to some extent, the warming attributed to greenhouse gases via the so-called "direct effect." Aerosol particles can also act as sites of condensation and lead to the formation of clouds, and this is termed an "indirect effect." Particles that form droplets are known as cloud condensation nuclei (CCN), and those that form ice are known as ice nuclei (IN). Our group has undertaken studies using commercial and custom



Mass spectra of ice crystal residual particles. (a) Spectrum obtained at the Storm Peak Laboratory in the Colorado Rocky Mountains when ambient aerosol was exposed to cirrus cloud conditions within an ice chamber. (b) Spectrum obtained at the Jungfraujoch Research Station of an ice crystal from a mixed-phase cloud. (c) Spectrum obtained when Arizona Test Dust was exposed to cirrus cloud conditions within a large cloud chamber. Reproduced from DJ Cziczo et al. 2009. "Inadvertent Climate Modification Due to Anthropogenic Lead." Nature Geosciences, doi:10.1038/ngeo499.

"cloud chambers," which mimic cloud formation conditions in the laboratory and at remote field sites. Droplets or ice crystals that are formed are then separated and analyzed with single-particle mass spectrometry to determine the initial aerosol size and composition and the role played by anthropogenic components. The effect of anthropogenic coatings is considered. Lead, an anthropogenic component that can have a significant impact on both precipitation and the Earth's radiative balance through perturbations to ice formation, will also be discussed.

http://www.pnl.gov/atmospheric/programs/atmos_measurement_lab.stm

Empirical predictions of CCN from aerosol optical properties

Anne Jefferson, NOAA ESRL Global Monitoring Division

Aerosol optical properties exhibit a close correlation with the CCN number concentration and can be used as a proxy for determining the CCN number concentration as a function of the percent supersaturation. An empirical method was developed to fit the aerosol single-scatter albedo and the backscatter fraction at 450 nm from in situ AOS measurements to the Twomey k and C power law fit parameters in the equation CCN = C*(%SS)k. The empirical model was run on data from four ARM surface sites: SGP, FKB, HFE, and GRA. A linear fit of the empirical fit vs. measured CCN at %SS from 0.2 to 0.85 gave slopes that range from 0.88 for Graciosa, Azores to 0.98 for the SGP site in Oklahoma. Correlation coefficients ranged from 0.59 for Graciosa and 0.77 for FKB in Germany. Error in the model is expected to result from measurement limitations of small particles by the nephelometer. Mie scattering calculations of the aerosol backscatter fraction at 450 nm indicate that the nephelometer has a lower size range of about 100–120 nm, while critical CCN activation diameters are predicted to be between 50–200 nm for ambient aerosol of mixed inorganic/organic concentration.

Evidence of the first indirect effect in clouds downwind of a mid-size North American city

Carl Berkowitz, Pacific Northwest National Laboratory
Larry Berg, Pacific Northwest National Laboratory
James Barnard, Pacific Northwest National Laboratory
Gunnar Senum, Brookhaven National Laboratory
Stephen Springston, Brookhaven National Laboratory

The first indirect effect refers to changes in the cloud droplet spectrum resulting from enhanced particle loading that provides additional cloud condensation nuclei on which droplets can form. While past observations have found this effect in stratiform clouds downwind of large urban areas or associated with ship plumes, we will present evidence of this feature occurring in shallow convective clouds downwind of a mid-size North American city. By binning observations of pollutant loading and updraft velocity made within hundreds of clouds sampled during the U.S. Department of Energy's Cumulus Humilis Aerosol Processing Study (CHAPS), we found an increase in the cloud droplet number concentration, CDNC, and a decrease in cloud droplet effective radius, r(eff), in polluted clouds relative to the CDNC and r(eff) measured in non-polluted clouds. Consistent with these observations was an increase in the total number of interstitial (non-activated) particles in polluted clouds relative to non-polluted clouds. Our presentation will include details of these observations and the analysis techniques used to arrive at these results. We will also present Mie calculations suggesting an increase in the scattering from the droplet spectra of polluted clouds. These results support the argument that to accurately simulate the microphysical properties of shallow cumuli requires treating both cloud dynamics and particle loading.

http://asp.labworks.org/index.stm

A global modeling study on carbonaceous aerosol microphysical characteristics and radiative forcing

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Surabi Menon, Lawrence Berkeley National Laboratory

Recently, attention has been drawn towards black carbon aerosols as a short-term climate warming mitigation candidate. However, the global and regional impacts of the direct, cloud-indirect, and semi-direct forcing effects are highly uncertain, due to the complex nature of aerosol evolution and the way that mixed, aged aerosols interact with clouds and radiation. A detailed aerosol microphysical scheme, MATRIX, embedded within the global GISS climate model is used in this study to present a quantitative assessment of the impact of microphysical processes involving black carbon, such as emission size distributions and optical properties on aerosol cloud activation and radiative forcing. Our best estimate for net direct and indirect aerosol radiative forcing between 1750 and 2000 is -0.56 W/m2. However, the direct and indirect aerosol effects are quite sensitive to the black and organic carbon size distribution and consequential mixing state. The net carbonaceous aerosol radiative forcing can vary between -0.32 to -0.75 W/m2, depending on these carbonaceous particle properties at emission. Assuming that sulfates, nitrates, and secondary organics form a coating around a black carbon core, rather than forming a uniformly mixed particle, changes the overall net aerosol radiative forcing from negative to positive. Taking into account internally mixed black carbon particles lets us simulate correct aerosol absorption. Black carbon absorption is amplified by sulfate and nitrate coatings, but even more strongly by organic coatings. Black carbon mitigation scenarios generally showed reduced radiative forcing when sources with a large proportion of black carbon, such as diesel, are reduced; however, reducing sources with a larger organic carbon component as well, such as bio-fuels, does not necessarily lead to negative radiative forcing change. This poster will give examples on how we plan to evaluate aerosol size and mixing state properties that are crucial to better understand their climate impacts.

Ice nucleation in mixed-phase clouds: parameterization evaluation with the ISDAC data and climate implication

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Jim Boyle, Lawrence Livermore National Laboratory
Stephen Klein, Lawrence Livermore National Laboratory
Paul DeMott, Colorado State University
Anthony Prenni, Colorado State University

There are still large uncertainties about ice nucleation mechanisms and ice crystal numbers in mixed-phase clouds, which affect modeled cloud phase, cloud lifetime, and radiative properties in the Arctic clouds in global climate models. In this study we evaluate model simulations with three mixed-phase ice nucleation parameterizations (Phillips et al. 2008, DeMott et al. 2009, Meyers et al. 1992) against the Atmospheric Radiation Measurement (ARM) Indirect and Semi-Direct Aerosol Campaign (ISDAC) observations using the NCAR Community Atmospheric Model Version 4 (CAM4) running in the single-column mode (SCAM) and in the CCPP-ARM Parameterization Testbed (CAPT) forecasts. It is found that SCAM and CAPT, with the new physically based ice nucleation schemes (Phillips et al. 2008, DeMott et al. 2009), produce a more realistic simulation of the cloud phase structure and the partitioning of condensed water into liquid droplets against observations during the ISDAC than the CAM with an oversimplified Meyers et al. (1992). Both SCAM simulations and CAPT forecasts suggest that the ice number concentration could play an important role in the simulated mixed-phase cloud microphysics and thereby needs to be realistically represented in global climate models. The global implication of different ice nucleation parameterizations also needs to be studied.

The impact of marine organic emissions on global climate and coastal air quality

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Dick Easter, Pacific Northwest National Laboratory
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The emissions of primary organic matter (POM) of marine biogenic origin and secondary organic aerosol (SOA) from the oxidation of phytoplankton-produced volatile organic compounds (VOC) can lead to changes in chemical composition and size distribution of marine aerosol, cloud droplet number concentration (CDNC), coastal air quality, and climate. Recent studies suggest that due to poor characterization of marine aerosols over remote regions, global climate models with prognostic treatment of CDNC could have up to 80% uncertainty in simulated aerosol indirect effect. Here the global and regional effects of marine biogenic trace gases and organic carbon (OC) aerosol emissions are explored using the NCAR Community Atmosphere Model, coupled with the PNNL Modal Aerosol Model (CAM-MAM) and the Community Multiscale Air Quality (CMAQ) modeling system Version 4.7. Ten-year CAM-MAM model simulations are conducted at a grid resolution of 1.9°×2.5° with 26 vertical layers. The CMAQ simulations are performed for the months of June–August, 2005 over the western U.S. at a horizontal resolution of 12×12 km2. Remotely sensed chlorophyll-a concentration, laboratory measurements, and model meteorology are used to calculate marine emissions of isoprene and monoterpenes. Marine POM emissions in sub- and super-micron modes are calculated by connecting organic mass fraction of sea spray with remotely sensed wind speed and the sea surface concentration of dissolved organic carbon (DOC). Both sub- and super-micron marine POM are assumed to be mostly water-insoluble, while marine SOA is assumed to be 50% water-soluble. Preliminary results show that different marine aerosol emissions and cloud droplet activation mechanisms yield 10%–20% increase in CDNC of global maritime shallow clouds. Changes associated with cloud properties raise shortwave forcing by -0.3Wm-2 to -0.7W m-2. Simulations suggest small effect of marine organic emissions on a regional scale with 0.1–0.2% increase in ozone and up to 3% increase in PM2.5 concentrations. Nevertheless, marine sources are shown to comprise 30% and 50% of the simulated average surface OC aerosol over the coastal areas and open ocean, respectively. By using different emission scenarios, SOA formation mechanisms, and droplet activation parameterizations, this study suggests that addition of marine primary aerosols and biologically generated reactive gases could reduce uncertainty in future global climate simulations and air quality studies.

The impact of surface forcing conditions on Arctic cloud-aerosol interactions

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Matthew Shupe, University of Colorado

In this study, we investigate how different surfacing forcing conditions observed during spring and fall in the Arctic produce differences in the microphysical and macrophysical properties of clouds and the surface energy balance, as well as different sensitivities to aerosol distributions. We present results from focused model studies identifying the impact of open water off the coast of Alaska on cloud formation processes and the sensitivity to Arctic aerosols over Barrow, Alaska. These studies use the Weather Research Forecast model run at 1-km-resolution and are validated with observations taken during April 2008 in the ARM Indirect and Semi-Direct Aerosol Campaign (ISDAC) and October 2004 during the Mixed-Phase Arctic Cloud Experiment (M-PACE).

Impacts of autoconversion scheme on simulated cloud properties and aerosol indirect effects using NCAR CAM3

Catherine Chuang, Lawrence Livermore National Laboratory
Jim Boyle, Lawrence Livermore National Laboratory
Shaocheng Xie, Lawrence Livermore National Laboratory

Estimates of the magnitude of aerosol radiative forcing vary widely, and aerosol indirect effects remain one of the most uncertain aspects in predicting the future climate variations. Aerosol-cloud interactions begin with the direct involvement of aerosols in cloud nucleation, followed by their indirect contribution to the formation of precipitation through collision and coalescence of cloud droplets. Since the treatments of cloud microphysics in climate models are highly parameterized, it requires a thorough study to examine the range of simulated properties from different parameterizations associated with aerosol-cloud interactions. Unlike previous studies focused on climate mode simulations, our interest is in short-range model response before the development of model bias and the compensation of multiple feedback mechanisms. In this study, we modified the RK98 cloud microphysics in NCAR CAM3 to explore the sensitivity of aerosol-cloud interactions to the treatments of autoconversion over the ARM SGP site. Our sensitivity experiments indicate that the simulated LWP is very sensitive to autoconversion scheme, and a factor of two differences is noted in the mean LWP. The negative feedback of a smaller autoconversion rate on cloud fraction outweighs the influence of increased LWP on cloud forcing, resulting in a larger net TOA SW. The maximum deviation of the averaged SW cloud forcing is up to 1.92 Wm-2 with different autoconversion schemes. Calculations of sulfate indirect effects indicate that microphysical feedbacks complicate the response of climate system and then possibly yield a positive second indirect sulfate forcing that counters to the expectation of increased aerosols on net TOA SW. The calculated total sulfate indirect effects vary widely, ranging from -0.1 to -2.1 Wm-2 over SGP during the Aerosol field campaign. Since the sensitivity of aerosol indirect effects to cloud parameterizations is temporal- and spatial-dependent, integration of results over different measuring sites helps to understand the foundational physics of aerosol-cloud interactions. More aerosol field campaigns to further explore the source of uncertainties are needed.

Inclusion of ammonium sulfate aerosols in McRAS-AC: an SCM Evaluation

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Lazaros Oreopoulos, NASA
Yogesh Sud, NASA Goddard Space Flight Center
Jun Wang, University of Nebraska–Lincoln
Ruixing Yang, George Mason University

Simulated ice clouds have large biases in present-day climate models, particularly GCMs that include aerosol-cloud interactions for nucleating cloud particles. Major gaps in our understanding of ice and mixed-phase clouds emanate from a lack of sufficient observations to better parameterize or evaluate them. Recent observational studies have led to the discovery of significant nucleating effects of ammonium sulfate (NH4)2SO4 aerosols found in the upper troposphere that were not included in the cloud physics of McRAS-AC, NASA's microphysical cloud scheme with Relaxed Arakawa Schubert cloud parameterization upgraded with aerosol-cloud interactions physics. Therefore, McRAS-AC was modified to invoke a realistic parameterization of (NH4)2SO4 aerosols and then used to evaluate its impact on clouds using a single-column model (SCM) employing the Southern Great Plains (SGP) and North Slope of Alaska (NSA) driver data sets. Twin simulations with and without (NH4)2SO4 aerosols were produced. The statistical behavior of the simulated clouds was evaluated against the available ground and satellite data to determine the influence of (NH4)2SO4 aerosols on cloud particle number densities, size, optical thicknesses, and the resulting longwave and shortwave cloud radiative forcings. The results show that inclusion of (NH4)2SO4 in the SCM mitigates some major biases in the simulated ice clouds while preserving the reasonable McRAS-AC simulation of liquid clouds. The detailed results of our poster will make a strong case for including (NH4)2SO4 aerosols not only in McRAS-AC, but in all interactive aerosol-cloud schemes.

Indirect impact of atmospheric aerosols in idealized simulations of convective-radiative quasi-equilibrium: double-moment microphysics

Wojciech Grabowski, National Center for Atmospheric Research
Hugh Morrison, National Center for Atmospheric Research

This poster will discuss an extension of the previous cloud-resolving modeling study (Grabowski 2006) concerning the impact of cloud microphysics on convective-radiative quasi-equilibrium over a surface with fixed characteristics and prescribed solar input, both mimicking the mean conditions on Earth. Current study applies sophisticated double-moment warm-rain and ice microphysics schemes (Morrison and Grabowski 2007, 2008a, 2008b) that allow for a significantly more realistic representation of the impact of aerosols on precipitation processes and on the coupling between clouds and radiative transfer. Two contrasting CCN characteristics are assumed, representing pristine and polluted conditions, as well as contrasting representations of the effects of entrainment and mixing on the mean cloud droplet size. As in the previous study, the convective-radiative quasi-equilibrium mimics the estimates of globally and annually averaged water and energy fluxes across the Earth's atmosphere. There are some differences from the previous study, consistent with the lower water vapor content in the troposphere and reduced lower-tropospheric cloud fraction in current simulations. There is also a significant reduction of the difference between pristine and polluted cases, from about 20 to about 4 W/m**2, with the difference between homogeneous and extremely inhomogeneous mixing reduced to about 2~W/m**2. An unexpected difference between previous and current simulations is the lower Bowen ratio of the surface heat flux, the partitioning of the total flux into sensible and latent components. It is shown that the change comes from the difference in the representation of rain evaporation in the sub-cloud layer between the single-moment parameterization used by Grabowski (2006) and the double-moment microphysics parameterization. Relatively small differences between results for pristine and polluted environments highlight the differences between the process-level approach to the impact of cloud microphysics on the quasi-equilibrium state with a more appropriate system-dynamics approach that includes interactions among all processes in the modeled system.

Investigation of the 2006 drought and 2007 flood extremes at the SGP through an integrative analysis of observations

Xiquan Dong, University of North Dakota

Hydrological years 2006 (HY06, 10/2005–09/2006) and 2007 (HY07, 10/2006–09/2007) provide a unique opportunity to examine climate extremes in the central United States because there are no other examples of two such highly contrasting precipitation extremes occurring in consecutive years at the Southern Great Plains (SGP) site in recorded history. The HY06 annual total precipitation amount in the state of Oklahoma, as observed by the Oklahoma Mesonet, is around 61% of the normal (92.84 cm, based on the 1921–2008 climatology), which results in HY06 being the second-driest year in the record. In particular, the total precipitation (3.7 cm) during the winter of 2005–06 is only 27% of the normal, and this winter ranks as the driest season. On the other hand, the HY07 annual mean precipitation over Oklahoma is 121% of the normal, and HY07 ranks as the seventh-wettest year for the entire state and the wettest year for the central region of the state. Summer 2007 is the second-wettest season for the state with a total precipitation of 40.8 cm, 68% higher than the normal. Precipitation is positively correlated with cloud fraction (corr=0.579), cumulus cloud thickness (0.654), cloud liquid water path (0.784), longwave flux (0.602), and atmospheric precipitable water vapor (0.64), but negatively correlated with shortwave flux (-0.645). The onsets of the SGP droughts and floods are triggered by persistent large-scale flow anomalies. For example, the winter precipitation deficit over the SGP is clearly linked to significantly suppressed cyclonic activity over the southwestern United States, which shows a robust relationship with the Western Pacific (WP) teleconnection pattern. From the Atmospheric Radiation Measurement (ARM) SGP observations, two positive feedback processes have been identified, which provide a physical basis for interpreting the observation that a drought or flood tends to “feed upon itself.” These observational results can serve as a baseline for future modeling studies that aim at simulating the onsets/demises of droughts and floods over the SGP and the multiple feedback processes involved in the formation of these hydrological extremes.

ISDAC cloud droplet number closure study: aerosol size distributions and case selection

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Michael Earle, Environment Canada
Steven Ghan, Pacific Northwest National Laboratory
J. Walter Strapp, Environment Canada
Richard Leaitch, Environment Canada
Alla Zelenyuk, Pacific Northwest National Laboratory
Don Collins, Texas A&M University
Mikhail Ovchinnikov, Pacific Northwest National Laboratory
Nicole Shantz, Environment Canada
Charles Brock, NOAA Aeronomy Laboratory
Ann Marie Macdonald, Environment Canada

A cloud droplet number closure study is initiated using observational data from the U.S. Department of Energy (DOE) Indirect and Semi-Direct Aerosol Campaign (ISDAC). Aerosol, cloud droplet, and atmospheric state measurements were obtained using the National Research Council of Canada (NRC) Convair-580 aircraft. Aerosol composition was determined using a Single Particle Laser Ablation Time-of-flight mass spectrometer (SPLAT), and aerosol concentration and size measurements were obtained using an Ultra-High Sensitivity Aerosol Spectrometer (UHSAS: size range 0.055–1.0 µm), Passive Cavity Aerosol Spectrometer Probe (PCASP-100X: size range 0.12–3.0 µm), and Forward-Scattering Spectrometer Probe (FSSP-300: size range 0.3–20 µm). The performance of the aerosol probes was assessed by comparison with ground-based measurements from the North Slope of Alaska (NSA) site during missed approaches at Barrow and/or measurements from the National Oceanic and Atmospheric Administration (NOAA) P-3 aircraft during periods of coordinated flying. The size distributions from the PCASP-100X compared well with independent measurements from the NSA ground site and NOAA P-3 and are used in the modeling component of the droplet closure study. Size distributions from the UHSAS and FSSP-300 are used in limited capacity; the former are subject to instrumental artifacts that depend on particle size, and the latter show significant variation in humid conditions. The present work details the determination of aerosol size distributions and identifies cases appropriate for droplet closure. A sample case is presented to demonstrate how the aerosol size and composition data are used to compute cloud droplet concentrations in an adiabatic parcel model. A preliminary representation of the vertical (updraft) velocity is used in the parcel model, which is guided by results from large eddy simulations (LES). In addition, since aerosol size distributions are of interest to the broader modeling community, selected distributions are provided for periods of interest throughout the ISDAC project.

Microphysical parameterizations based on ISDAC aircraft observations and aerosol-cloud effects on radiative fluxes

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Nicole Shantz, Environment Canada
Peter Liu, Environment Canada
J. Walter Strapp, Environment Canada
Eric Girard, University of Quebec at Montreal

The Indirect and Semi-Direct Aerosol Campaign (ISDAC) took place in Alaska in the vicinity of Barrow, Alaska, near the Atmospheric Radiation Measurement (ARM) North Slope of Alaska site from April 1–30, 2008. During this project, a Convair-580 aircraft flew through a variety of aerosol and cloud conditions. Aircraft observations obtained along constant altitude flights and profiles are used for microphysical parameterizations that include cloud fraction, total ice crystal number concentration, and total droplet number concentration as a function of one or more of the following parameters: temperature, vertical air velocity, effective size, aerosol total number concentrations, and relative humidity. Profiles of the total number concentration as well as the size distributions of aerosol particles are studied in a variety of conditions, including polluted and clean environments when there were no clouds or precipitation present. In situ broad band radiative fluxes (e.g., SW and IR) are then used to assess the aerosol and cloud effects on the surface heat budget. Overall, the results will be compared to these from the earlier studies, and applications to numerical modeling will be proposed.

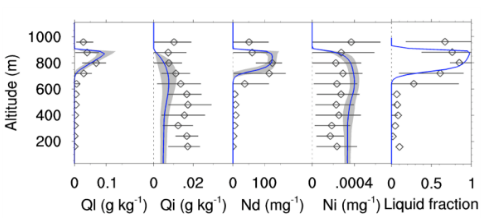
Overview of climate forcing research strategy at PNNL

William Shaw, Pacific Northwest National Laboratory
Jerome Fast, Pacific Northwest National Laboratory
Steven Ghan, Pacific Northwest National Laboratory
Sally McFarlane, Pacific Northwest National Laboratory

The Atmospheric System Research (ASR) science focus area at PNNL is an integrated research program designed to address key uncertainties in the physical processes that control the effects of clouds and aerosols on the climate system. The program comprises three principal objectives that address the aerosol life cycle, cloud-aerosol interactions, and cloud radiative forcing and feedback. The overall objective for the aerosol life cycle is to improve the understanding and representation of how the life cycle of aerosols determines the distribution of aerosols and their radiative and microphysical properties. For cloud-aerosol interactions, it is to improve understanding and representation of how cloud processes influence aerosol properties and how aerosols influence the radiative and microphysical properties of various types of clouds. Cloud-radiative forcing and feedback seeks to improve understanding and representation of the processes controlling the formation, structure, radiative and microphysical properties, and dissipation of cirrus and shallow clouds associated with convective cloud systems. These objectives are addressed in a framework that joins field and laboratory measurements with process, regional, and climate models. This poster will provide an overview of the ASR research effort at PNNL, describe the relationships between the three principal objectives, and highlight initial-year tasks currently underway.

A process study of mixed-phase Arctic stratus and associated aerosol effects

Mikhail Ovchinnikov, Pacific Northwest National Laboratory
Jiwen Fan, Pacific Northwest National Laboratory
Alexei Korolev, Environment Canada



Spectral bin microphysics model predicted (lines) and observed (diamonds) mean vertical profiles of mixed-phase cloud parameters (liquid, Ql, and ice; Qi, mass mixing ratios, droplet, Nd, and ice particles; Ni, number-mixing ratios, and liquid water condensate fraction) for Flight 31 on April 27, 2008. Shaded areas and horizontal lines indicate 15–85 percentile ranges for simulated and measured parameters, respectively. A good agreement in clouds suggests that the Bergeron-Findeisen process is reasonably reproduced in this simulation, while model underestimation of below-cloud ice (snow) water content indicates that the sedimentation rate may be overpredicted by this model configuration.

Comprehensive ISDAC measurements provide ample opportunities for evaluating and improving cloud models and parameterizations, particularly in simulating the mixed-phase cloud regime. The longevity on climatically important low-level Arctic stratus depends critically on cloud microphysics, which controls liquid-to-ice conversion and precipitation rates. We conduct high-resolution simulations of persistent mixed-phase stratus clouds observed over the sea ice on April 27, 2008 during ISDAC using a model with both spectral bin (SBM) and two-moment bulk liquid and ice microphysics. These simulations are compared and evaluated using aircraft measurements. Model parameters and corresponding process rates that result in a better agreement with observations are examined in detail. Aerosol effects on cloud micro- and macro-structure will also be discussed.

Significant impacts of aerosols on cloud and precipitation revealed from long-term ARM observations

Zhanqing Li, University of Maryland
Feng Niu, University of Maryland

Aerosols have numerous complex effects on cloud and precipitation that often offset each other. Most notable are the Twomey effect on cloud microphysics and the thermodynamic effect of aerosol-induced invigoration that tend to suppress and enhance precipitation respectively. Yet the dominant influence of atmospheric dynamics often conceals the aerosol signals, rendering an unknown net effect, especially on long time scales. The vast majority of observation-based studies were concerned with individual cases. Using 10 years worth of continuous, high-quality measurements pertaining to aerosol, cloud, and precipitation made at the U.S. Southern Great Plains (SGP) Atmospheric Radiation Measurement (ARM) Climate Research Facility site, compelling observational evidence emerges, revealing the significant net effects of aerosols on cloud and precipitation. Rain frequency is found to increase with increasing aerosol concentration for clouds with large liquid water paths (LWP), but decreases for low LWP. The relationships depend critically on cloud height, stronger for higher clouds than lower ones. A strong dependence is also found of cloud thickness on ground-level aerosol concentration. As the aerosol concentration increases, cloud thickness of low clouds (base < 1 km) increases substantially, but little effect is found for clouds of cloud base > 2 km. Using a conceptual model, the findings are explained by the competition between the Twomey effect and the invigoration, and their net influence is contingent upon their relative strength dictated by cloud height and water content. The observational major findings are reproduced by a full-fledged cloud resolving model.

Study of aerosol-cloud interactions in southeastern China during the AMF-China campaign

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L. Ruby Leung, Pacific Northwest National Laboratory
Zhanqing Li, University of Maryland
Hsiang-He Lee, University of Maryland
Yun Qian, Pacific Northwest National Laboratory

A deep convective and a stratocumulus cloud case observed during the AMF-China campaign are simulated using the Weather Research and Forecasting (WRF) Model with size-resolved cloud microphysics. Model results are being compared with satellite, surface radar, and rain-gauge measurements. Model simulations and sensitivity experiments are being analyzed to study aerosol effects on cloud properties and surface precipitation associated with onset time and spatial redistribution and their potential implications to weather and climate in China.

Study of mechanisms of aerosol indirect effects on glaciated clouds

Vaughan Phillips, University of Hawaii
John Kealy, University of Hawaii

Aerosol-cloud interactions account for some of the greatest uncertainties in global models' simulation of climate change. Aerosol indirect effects on glaciated clouds are particularly uncertain, partly because of the diversity of physical mechanisms for initiation of ice. For example, an offline intercomparison of various schemes of heterogeneous ice nucleation from the literature revealed five orders of magnitude of difference in predicted ice concentrations at -30°C (Phillips et al. 2008). It is thought that insoluble aerosols, by nucleating extra ice heterogeneously, can alter mixed-phase clouds' precipitation production (Phillips et al. 2003), lifetime, and potentially also, their phase. Conversely, extra soluble aerosols might alter the warm rain process in convective clouds, altering raindrop-freezing and supercooled cloud-liquid aloft, as well as homogeneous freezing and cirrus properties. Such influences, among others, may alter the properties and lifetime of mesoscale cloud systems, altering their impacts on the radiation budget. We have a model of the aerosol-cloud interaction with "double-moment" bulk microphysics, semi-prognostic treatment of multiple aerosol species, and representation of the known pathways for ice initiation (Phillips et al. 2009). In this current first year of the ASR project, the model is being enhanced. Relations for the size- and temperature-dependence of ice-particle morphology, partly predicted by a more detailed (spectral) model, are being incorporated into it. During subsequent years of the project, ARM cases from the Cloud and Land Surface Interaction Campaign (CLASIC; Oklahoma, 2007) and Tropical Warm Pool-International Cloud Experiment (TWP-ICE; Pacific Ocean, 2006) will be simulated by the model, with validation against ARM aircraft and satellite and ground-based observations. Sensitivity studies will elucidate the relative roles of mechanisms for the indirect effect from anthropogenic soluble and insoluble aerosol on glaciated clouds. Such process-level insights are needed if global models are to be improved by the community. In this presentation, our ongoing model enhancement will be described.

Understanding of the observed trend in radiation at the ARM SGP site

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Qilong Min, State University of New York at Albany
Daren Lu, Institute of Atmospheric Physics

The broadband radiometer measurements at the ARM SGP site show an increasing trend during the past 16 years, consistent with the global brightening. There are multiple reasons for the increased trend in radiation, such as changes in aerosols, clouds, aerosol-cloud interaction, and atmospheric dynamics. To better understand this phenomenon, we analyze optical properties of aerosols and clouds derived from the well-calibrated Multifilter Rotating Shadowband Radiometer (MFRSR) and Microwave Radiometer (MWR) measurements from 1993 to 2008, together with measurements of the BBSS and MMCR. We find that there is a long-term decreasing trend of cloud occurrence frequency, corresponding with the broadband radiation trend. Changes in aerosol loading and column water vapor amount cannot directly explain the observed trend in radiation. Further, we detect a decreasing trend in water vapor at the stratosphere and near the tropopause, and a reduction of cloud-top height. We speculate that our observed trend in broadband radiation could be due to the strengthening of the Hadley Circulation for the past

16 years. The strengthening of the Hadley Circulation dries up water vapor near the tropopause at the latitude of the SGP site that limits the high cloud formation and lowers the cloud-top height.

The vertical structure of cloud occurrence and radiative forcing at the ARM central facilities

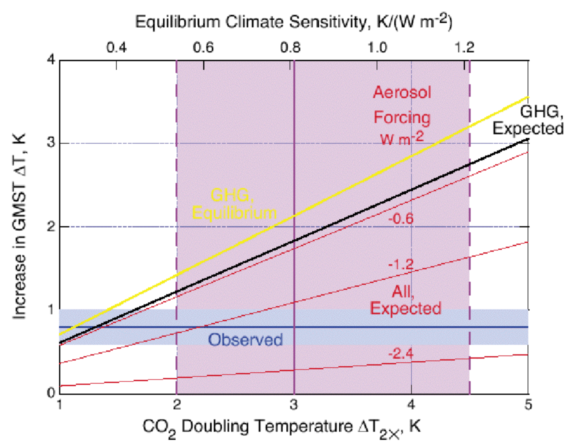
Gerald Mace, University of Utah
Sally Benson, University of Utah
Benjamin Foreback, University of Utah

Data collected at the Atmospheric Radiation Measurement (ARM) Climate Research Facility ground sites allow for the description of the atmospheric thermodynamic state, cloud occurrence, and cloud properties. This information allows for the derivation of estimates of the effects of clouds on the radiation budget of the surface and atmosphere. Using an updated analysis technique, 10 years of continuous data collected at the ARM Southern Great Plains (SGP) Climate Research Facility are analyzed, as well as data collected at the Tropical Western Pacific and North Slope of Alaska sites. The influence of clouds on the radiative flux divergence of solar and infrared energy on annual, seasonal, and monthly time scales will be presented, with an emphasis placed on comparisons and contrasts among the various locales.

Why hasn't Earth warmed as much as expected?

Stephen Schwartz, Brookhaven National Laboratory
Robert Charlson, University Of Washington
Ralph Kahn, NASA Goddard Space Flight Center
John Ogren, NOAA Earth System Research Laboratory
Henning Rodhe, Stockholm University

The observed increase in global mean surface temperature (GMST) over the industrial era is less than 40% of that expected from observed increases in long-lived greenhouse gases together with the best-estimate equilibrium climate sensitivity given by the 2007 Assessment Report of the Intergovernmental Panel on Climate Change. Possible reasons for this warming discrepancy are systematically examined here. The warming discrepancy is found to be due mainly to some combination of two factors: the IPCC best estimate of climate sensitivity being too high and/or the greenhouse gas forcing being partially offset by forcing by increased concentrations of atmospheric aerosols; the increase in global heat content due to thermal disequilibrium accounts for less than 25% of the discrepancy, and cooling by natural temperature variation



Equilibrium increase (yellow) and expected present increase (black) in global mean surface temperature (GMST) above pre-industrial temperature from the forcing by present (2005) incremental concentrations of long-lived greenhouse gases as a function of CO2 doubling temperature ΔT2×, (bottom axis) or equilibrium climate sensitivity S (top axis); expected increase accounts for global heating rate. Vertical purple solid and dashed lines denote IPCC (2007) best estimate and central 66% uncertainty range for equilibrium climate sensitivity. Red lines show expected increase in GMST, accounting for all forcings over the industrial period (IPCC, 2007, Figure SPM-2), for indicated values of forcings by anthropogenic aerosols. Blue line denotes observed increase in GMST of present climate relative to preindustrial, 0.8 K; blue band denotes estimated portion of increase in GMST that can be attributed to natural variability.

can account for only about 15%. Current uncertainty in climate sensitivity is shown to preclude determining the amount of future fossil fuel CO2 emissions that would be compatible with any chosen maximum allowable increase in GMST; even the sign of such allowable future emissions is unconstrained. Resolving this situation by empirical determination of Earth's climate sensitivity from the historical record over the industrial period or through use of climate models whose accuracy is evaluated by their performance over this period is shown to require substantial reduction in the uncertainty of aerosol forcing over this period. This paper is in press in the Journal of Climate.

3.0 Aerosol Properties

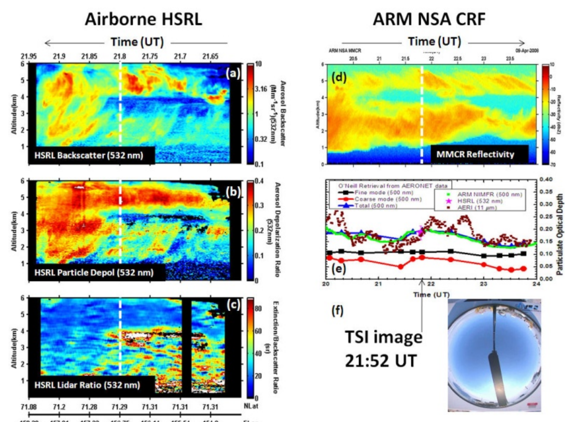
3-laser photoacoustic deployment at ARM SGP site in 2009

Bradley Flowers, Los Alamos National Laboratory
Manvendra Dubey, Los Alamos National Laboratory
Anne Jefferson, NOAA ESRL Global Monitoring Division
Pat Dowell, ARM Climate Research Facility
Claudio Mazzoleni, Michigan Technological University

We report the deployment of a new 3-laser photoacoustic instrument in the Aerosol Observing System at the ARM SGP site in 2009. We compare our measurements of absorption and scattering with collocated independent measurements made with a PSAP and a nephelometer, respectively. We find relatively good agreement between the two observational periods, made during relatively clean periods. We also share the challenges and opportunities of adding new instruments and measurement capabilities at any ARM sites. These will be valuable to facilitate the operation and mentoring of new ARRA-funded equipment that is being added in the new integrated ASR program.

Airborne HSRL aerosol, ice, and cloud observations during ARCTAS/ISDAC

Richard Ferrare, NASA Langley Research Center
Chris Hostetler, NASA Langley Research Center
John Hair, NASA Langley Research Center
Anthony (Tony) Cook, NASA Langley Research Center
David Harper, NASA Langley Research Center
Sharon Burton, Science Systems and Applications, Inc.
Michael Obland, NASA Langley Research Center
Raymond Rogers, Science Systems and Applications, Inc./NASA Langley Research Center
Amy Swanson, Science Systems and Applications, Inc./NASA Langley Research Center
David Turner, University of Wisconsin-Madison
Norm ONeill, Université de Sherbrooke
Peter Colarco, NASA Langley Research Center



Measurements acquired in the vicinity of the ARM NSA site on April 9, 2008 during the ARCTAS/ISDAC campaigns. (Left) Airborne HSRL measurements (532 nm) of particulate backscatter (a), particulate depolarization (b), lidar ratio (c). (Right) ARM NSA MMCR measurements of radar reflectivity (d), particulate optical depth measurements from various sensors (e), and TSI image (f). The white vertical dashed line represents when the HSRL measurements were acquired directly over the NSA site (21:52 UT). The NASA B200 King Air flew from east (right) to west (left). The HSRL measurements of high particle depolarization (> 0.3) and low lidar ratio (~20 sr) indicate the presence of ice. The MMCR measurements indicate cloud layers between ~1.5–5.5 km that are not obvious in the optical depth measurements or TSI image.

During the joint 2008 Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)/Indirect and Semi-Direct Aerosol Campaign (ISDAC) field campaign, the NASA Langley Research Center airborne High Spectral Resolution Lidar (HSRL) on the NASA B200 aircraft measured profiles of particulate extinction (532 nm), backscatter (532 and 1064 nm), and depolarization (532 and 1064 nm). Particulate intensive parameters derived from HSRL data are used to infer specific particulate types and mixtures of those types. Combining the HSRL observations of the spectral ratio of depolarization and the particulate extinction/backscatter ratio ("lidar ratio") are shown to help discriminate ice and dust. The HSRL measurements are used in conjunction with surface-based remote sensing measurements from the ARM Climate Research Facility's NSA site to investigate particles over Barrow. The HSRL measurements show that extensive layers of ice crystals can contribute significantly to particulate optical depth derived from surface-based passive measurements. During some instances, coincident MMCR radar observations indicated extensive cloud layers while Sun photometer, NIMFR radiometer, and TSI images showed little or no indication of clouds. The suite of active and passive remote sensing observations suggest that (1) ice crystals of various sizes were present, (2) coincident measurements from active sensors such as HSRL greatly aid in the interpretation of particulate optical depth measurements from passive instruments, and (3) coarse-mode aerosol optical depth derived from the Sun photometer data may provide an indication of the optical depth due to ice particles. In addition, the HSRL measurements are also used to evaluate the simulations of aerosol/cloud distributions from the NASA GEOS-5 general circulation model and assimilation system. The GEOS-5 median particulate extinction profiles are shown to be in good agreement with the corresponding median HSRL extinction profiles. The HSRL measurements indicated that particulate optical depth of elevated layers composed a much higher fraction (>40–50%) of total optical depth than observed in HSRL measurements acquired at lower latitudes on previous campaigns. Biomass burning smoke was found to provide the largest contribution to particulate optical thickness.

http://science.larc.nasa.gov/hsrl/index.html

Ambient and laboratory photoacoustic measurements of aerosol light absorption and scattering from 355 nm (new) to 1047 nm

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Pat Arnott, University of Nevada, Reno
Ramona Atherton, University of Nevada, Reno
Ian Arnold, University of Nevada, Reno
Rahul Zaveri, Pacific Northwest National Laboratory
Chen Song, Pacific Northwest National Laboratory

We present in situ and filter-based multi-spectral measurements of aerosol light scattering and absorption by ambient aerosols carried out in Reno, Nevada, during December 2009 and January 2010. We report new in situ photoacoustic and reciprocal optical characteristics of aerosol in the UV region (355 nm), as well as analysis of the simultaneous measurements at wavelengths 405 nm, 532 nm, 870 nm, and 1047 nm. Comparisons are presented for the spectra of aerosol collected on quartz fiber filters and analyzed with an optical spectrometer from 365 nm to 870 nm. Previous studies have shown that "brown" organic aerosols exhibit higher absorption towards the UV region. Although the UV region of the solar spectrum arriving at the Earth is only 12% of the total power, this part of the spectrum is vital to atmospheric photochemistry and the formation of aerosol mass that affects radiation transfer at all wavelengths. We present aerosol optical properties Ångström exponent of absorption and scattering, single-scattering albedo, and total extinction during strongly inverted and clean conditions. The absorption at 355 nm was found as high as 70 Mm-1 with scattering around 400 Mm-1. The comparison of the aerosol optics on strong temperature inversion days with that of California wildfires and of Mexico City indicates the closeness of the air pollution in these different events and locations. The wavelength dependence of the aerosol absorption from UV, visible, and infrared regions shows signatures of the presence of the significant amount of black carbon during the temperature inversion episodes. Laboratory calibrations with incense (strong brown carbon source), kerosene soot, and salt aerosol are also presented. This work is being carried out in preparation for the CARES project in summer 2010.

Analyses and modeling of relationships between ice nuclei concentrations, aerosol concentrations, and ice crystal number concentrations in clouds

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Paul DeMott, Colorado State University
Sonia Kreidenweis, Colorado State University

Our project involves the re-examination of field experiment data characterizing aerosols, ice nuclei, and ice formation in clouds. The goals are, first, to determine if ice nuclei measurements predict ice formation in clouds, and second, to determine how ice nuclei number concentrations may be simply related to species and variables prognosed in numerical models (e.g., aerosol type and number concentration, temperature). Our approach uses combined data from multiple field studies in which measurements of the number concentrations of ice nuclei were made using a continuous flow diffusion chamber; aerosol number concentrations (as a function of size) were obtained around clouds; and ice crystal number concentrations and size distributions were obtained in clouds. Our analyses indicate that ice nuclei were responsible for the first ice formation in dynamically simple clouds where ice crystal number concentrations could be well defined, within instrumental limitations. Additionally, we confirmed that ice nuclei number concentrations above the boundary layer vary strongly with the number concentrations of larger-diameter particles (larger accumulation mode and coarse particles) and with temperature. We also present preliminary findings on the effects of aerosol composition, which indicate that ice nuclei concentrations are enhanced when the ambient aerosol is enriched in mineral dust and particle types associated with biomass burning. Finally, we present a simple first parameterization approach based on relating ice nuclei to aerosol number concentrations and temperature and describe its application in a host of models for studies of atmospheric implications.

Can particle mass spectrometry be used to measure particulate organic nitrates?

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Veronique Perraud, University of California
Alla Zelenyuk, Pacific Northwest National Laboratory
Michael Ezell, University of California
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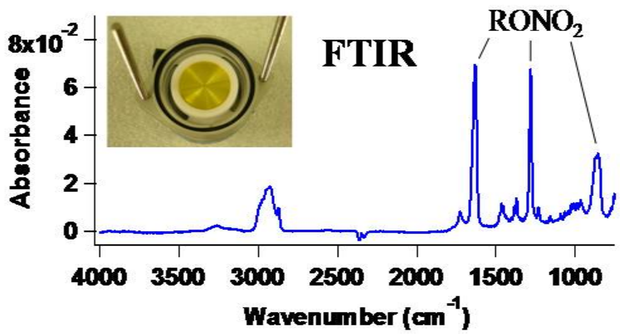
Barbara Finlayson-Pitts, University of California
Lizabeth Alexander, Pacific Northwest National Laboratory

Elucidating the composition of aerosols in the atmosphere is essential to understanding the effects of anthropogenic and biogenic emissions on climate. Organic nitrates are an important class of compounds formed through the oxidation of organic compounds in the presence of NOx. Because many of the expected organic nitrate products are semi-volatile and multifunctional, they partition between the gas phase and particles, making identification and quantification more difficult. Particle analysis traditionally involves the collection of particles on filters followed by extraction and analysis by techniques such as

FTIR and GC-MS. Although this provides specific composition and quantification information, it can introduce artifacts and does not provide real-time data. Particle mass spectrometry is one possibility for overcoming these issues; however, little is known about the response to organic nitrates. In this study, the response of a high-resolution time-of-flight aerosol mass spectrometer (HR-ToF-AMS) to particulate organic nitrate was investigated and compared to inorganic nitrate. FTIR spectroscopy on particles collected by impaction on ZnSe windows and single-particle laser ablation mass spectrometry (SPLAT II) was carried out for

comparison. Organic nitrates were formed from the NO3 radical reactions with α- and β-pinene, 3-carene, limonene, and isoprene, where products with sufficiently low vapor pressures form particles. Results from these studies will be presented to show that while all of these techniques have indicators for organic nitrates, identification of specific compounds in particles is not currently possible, and new approaches are needed. Currently under investigation is the application of atmospheric solids analysis probe mass spectrometry (ASAP-MS) to particulate organic nitrate analysis, for which preliminary results will be reported.



A typical FTIR spectrum of particles collected by impaction on ZnSe windows from the oxidation of biogenic organic precursors by NO3.

The chemical and physical characteristics of Asian outflow aerosols

Lim-Seok Chang, Global Environmental Research Center

Backrungdo site is the closest to China among several air quality super-sites in South Korea. The intensive monitoring has been routinely conducted since 2008 to characterize the physical and chemical properties of Asian outflow. The species, automatically monitored, are SO2, NOx, CO, O3, 55 VOCs, EC/OC, size-resolved ionic components, particle size distribution, and metals. In 2009 Backrungdo was the place with the best air quality in Korea. The aerosols were normally organic-rich, while Asian outflow aerosols were sulfate-rich with accompanying EC/OC and several metal components. Sulfate existed as ammonium sulfate below 1.8 micron in size, and the ratio of OC to EC ranged from 3 to 4. The source region of the Asian outflow was Beijing-Tianjin mega-cities based upon the backward trajectory analysis.

Chemically explicit model of secondary organic aerosol (SOA) formation in Mexico

Sasha Madronich, National Center for Atmospheric Research, Atmospheric Chemistry Division

Secondary organic aerosols are ubiquitous, with mass loadings comparable to and often larger than all other aerosols, and much larger than expected from traditional yields in chamber experiments. We developed a 0D model of the PBL in Mexico City, using MILAGRO measurements to prescribe a time-varying PBL height, vertical exchange with the free troposphere, horizontal ventilation based on city-averaged winds, and emissions of NOx and about 60 hydrocarbons. A nearly explicit chemical mechanism for the oxidation of hydrocarbons down to ultimate products CO2 and H2O was created using our code Generator of Explicit Chemistry and Kinetics of Organics in the Atmosphere (GECKO-A), resulting in ~6e6 reactions among ~1e6 chemical species, including estimates of associated thermal and photolytic rate constants as well as saturation vapor pressures for all initial and intermediate compounds. Secondary organic aerosols were formed by gas-particle partitioning using Raoult's law. We examined the contribution to SOA from different hydrocarbon classes. Aromatics provide only a small fraction of the observed SOA, via condensable intermediates such as nitro-catechols and multifunctional aldehydes. Long-chain alkanes (containing up to 20 carbon atoms in our simulations) give much more particulate mass, bringing the total into fair agreement with SOA mass and diurnal cycles observed during MILAGRO. The chemical speciation of particles generated from alkanes is largely the precursor hydrocarbons (esp. for C18 and larger alkanes), monofunctional nitrates, and delta-hydroxy carbonyls and nitrates. The latter result from 1.4 isomerization reactions of alkoxy radicals following OH abstraction of H atoms from the hydrocarbon chains is also observed in chamber experiments. For the NOx-rich conditions of Mexico City, nitrogen is predicted to be abundant in SOA formed from both aromatics (mostly as nitro groups) and alkanes (as nitrate groups) with N/C ratios of about 0.1. Comparisons of measured and model-predicted atomic ratios (N/C, O/C, H/C) offer key opportunities for elucidating the formation mechanisms of SOA. The importance of long-chain alkanes in our model is consistent with the proposal that evaporation of primary organic aerosols, followed by gas phase chemistry, is an important source of SOA in urban-influenced air. Several modeling studies have demonstrated the potential importance of this source using simple chemical parameterizations that treat all long-chain alkanes as generic semi-volatile organic compounds (S-VOC) or intermediate-volatility organic compounds (I-VOC). Our study is the first to consider the explicit chemistry of these alkanes and allows identification of the chemical nature of the nascent particles. We emphasize the nascent aspect, because we recognize that further chemistry currently not well understood may occur on the surface and interior of particles.

Cloud condensation nuclei in cumulus humilis—selected case study during the CHAPS campaign

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Carl Berkowitz, Pacific Northwest National Laboratory
Lizabeth Alexander, Pacific Northwest National Laboratory
Yin-Nan Lee, Brookhaven National Laboratory
Alexander Laskin, Pacific Northwest National Laboratory
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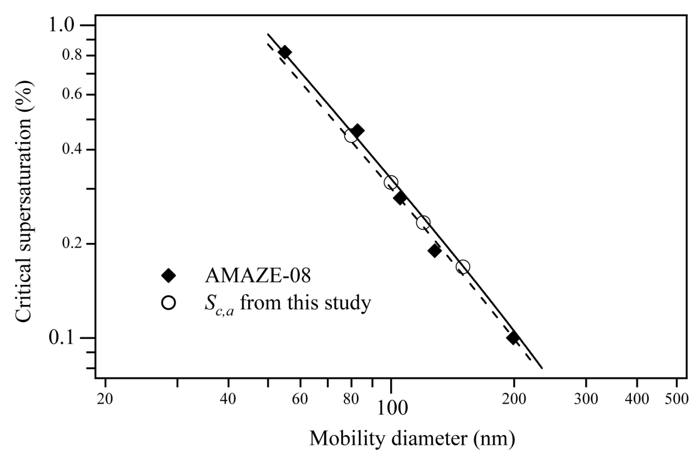
Elisabeth Andrews, NOAA Climate Monitoring & Diagnostics Laboratory

The Cumulus Humilis Aerosol Processing Study (CHAPS) provided a unique opportunity to study aerosol and cloud processing. Clouds play an active role in the processing and cycling of atmospheric constituents. Gases and particles can partition to cloud droplets by absorption and condensation as well as activation and impact scavenging. The U.S. Department of Energy (DOE) G-1 aircraft was used as one of the main platforms in CHAPS. Flight tracks were designed and implemented to characterize freshly emitted aerosols at cloud top and cloud base as well as within the cloud, i.e., cumulus humilis (or fair-weather cumulus), in the vicinity of Oklahoma City. Measurements of interstitial aerosols and residuals of activated condensation cloud nuclei were conducted simultaneously. The interstitial aerosols were measured downstream of an isokinetic inlet, and the activated particles downstream of a counter-flow virtual impactor (CVI). The sampling line to the Aerodyne Aerosol Mass Spectrometer (AMS) was switched between the isokinetic inlet and the CVI to allow characterization of non-activated interstitial particles outside of clouds in contrast to particles activated in clouds. Trace gases including ozone, carbon monoxide, sulfur dioxide, and a series of volatile organic compounds (VOCs) were also measured, as were key meteorological state parameters including liquid water content, cloud drop size, and dew point. We will report on the CCN properties in cumulus humilis. Several approaches will be taken. The first is single-particle analysis of particles collected by the Time-Resolved Aerosol Sampler (TRAC) by scanning electron microscopy (SEM) and transmission electron microscopy (TEM) coupled with energy disperse X-ray spectroscopy (EDX). Specifically, we examine differences between activated and interstitial ones, such as differences in chemical composition and morphology. The second analysis will link in situ measurements by AMS and PTRMS with the observations by TRAC. For instance, by comparing the characteristic m/z obtained by AMS and the CO or isoprene, one can gain more insight into the role of primary and secondary organic aerosols in CCN and background aerosols. Combined with observations of cloud properties, our goal is to provide an improved picture of CCN activation in cumulus humilis.

Cloud droplet activation of secondary organic material produced by the oxidation of biogenic volatile organic compounds

Scot Martin, Harvard University

The cloud condensation nuclei (CCN) properties of ammonium sulfate particles mixed with organic material condensed during the hydroxyl-radical-initiated photo-oxidation of isoprene (C5H8) were investigated in the continuous-flow Harvard Environmental Chamber. The experiments were designed to cover a range of atmospheric conditions, spanning the urban and rural southeastern U.S. during the summer to pristine background conditions of the Amazon Basin's wet season. The CCN activation curves were measured for organic particle mass concentrations of 0.5 to 10.0 ug m^-3, NOx concentrations from under 0.4 ppbv up to 38 ppbv, particle mobility diameters from 70 to 150 nm, and thermodenuder temperatures from 25°C to 100°C. At 25°C, the observed CCN activation curves were accurately described by a Kohler model with two internally mixed components: ammonium sulfate and secondary organic material. The modeled physicochemical parameters of the organic material were equivalent to an effective hygroscopicity parameter kappa (ORG) of 0.10 +/- 0.03, regardless of the C5H8:NOx concentration ratio for the span of > 200:0.4 to 50:38 (ppbv:ppbv). The volatilization curves (i.e., plots of the residual organic volume fraction against temperature) were also similar for the span of investigated C5H8:NOx ratios, suggesting a broad similarity of particle chemical composition. This suggestion was backed up by limited variance at 25°C



Size-resolved critical supersaturations measured in the Harvard Environmental Chamber (HEC) for the secondary organic material produced by the photo-oxidation of biogenic volatile organic compounds. The results are compared to observations during the Amazonian Aerosol Characterization Experiment (AMAZE-08) (diamonds). The comparison shows that the apparent critical supersaturations S(c,a) can be predicted using the results from the HEC (open circles).

among the particle mass spectra. For example, the signal intensity at m/z 44 (which can result from the fragmentation of oxidized molecules believed to affect hygroscopicity and CCN properties) varied weakly from 6–9% across the range of investigated conditions. In contradistinction to the results for 25°C, conditioning up to 100°C in the thermodenuder significantly reduced CCN activity. The altered CCN activity might be explained by chemical reactions (e.g., decomposition or oligomerization) of the secondary organic material at elevated temperatures. The study's results at 25°C, in conjunction with the results of other chamber and field studies for a diverse range of conditions, suggest that a value of 0.10 +/- 0.05 for kappa (ORG) is representative of both anthropogenic and biogenic secondary organic material. This finding supports the use of kappa (ORG) as a simplified yet accurate general parameter to represent the CCN activation of secondary organic material in large-scale atmospheric and climate models.

The effect of aerosol humic-like substances (HULIS) on aerosol absorption

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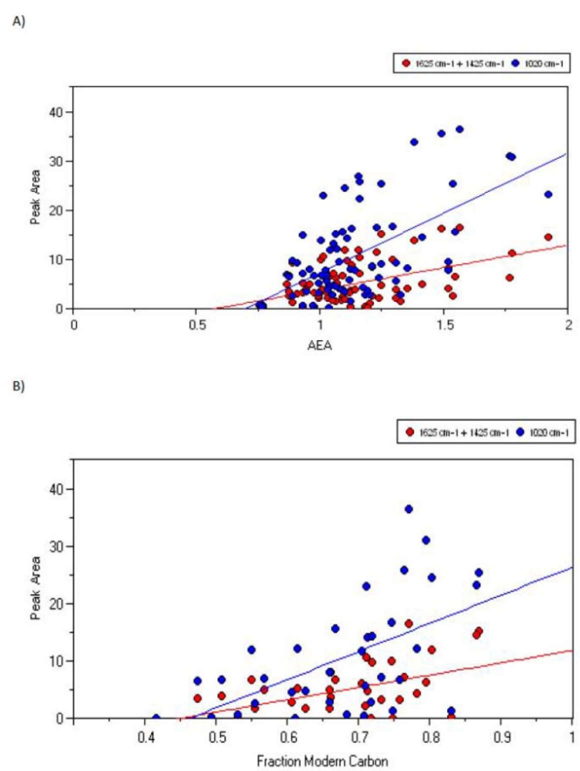
Kristi Kelley, University of Arkansas at Little Rock
Amrita Sarkar, University of Arkansas at Little Rock
Gail Bridges, University of Arkansas at Little Rock

In past work, black carbon (BC) produced from incomplete combustion has been assumed to be the only major absorbing species in atmospheric aerosols. BC absorption follows a broadband spectral profile with an inverse wavelength dependence (λ-1) from the UV to the near IR. This wavelength dependence is described by the Ångstrom absorption exponent (AAEs), which is 1 for BC. Recent work has identified other absorbing aerosol species that can add to the absorption of BC, resulting in enhanced absorption primarily at shorter wavelengths yielding AAEs greater than 1. The most important absorbing aerosol species other than BC is the water soluble humic-like substances, or HULIS. These aerosol species can become internally mixed with black carbon as the combustion aerosols age, resulting in larger AAEs, enhanced hygroscopicity, and removal of the aerosols through cloud formation and rainout. By using surface reflection spectroscopy, the absorption spectra of atmospheric aerosols were obtained in the UV-visible for accurate determination of aerosol AAEs. These results are compared to total aerosol carbon content, carbon isotopic analysis, and aerosol HULIS content measured by diffuse reflectance FTIR spectroscopy. These results indicate that the aerosol



The peak areas of the HULIS carboxylate (1620, 1420 cm-1) and polysaccharide (1020 cm-1) IR bands correlated with the enhanced aerosol AAEs and with the fraction of modern carbon as measured by 14C, indicating that the HULIS are of biogenic origin and are the source of the enhanced aerosol UV absorption.

HULIS content increases as the aerosols age and that this is primarily responsible for the observed enhanced UV absorption yielding overall aerosol AEAs from 1–2. In addition, carbon isotopic measurements show that the aerosol HULIS are biogenic in origin, arising from biomass burning and/or SOA formation from biogenic precursors.

The effect of metals on the evolved gas analysis of elemental and organic carbon

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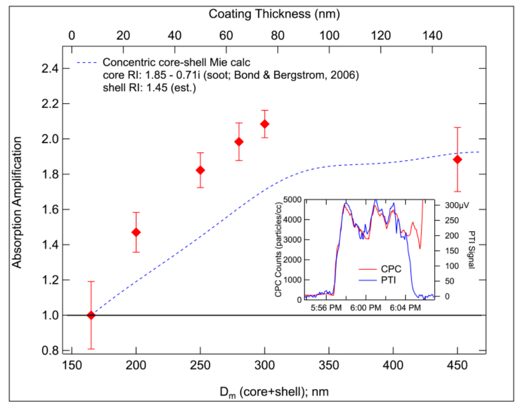
Uncertainties in quantification of elemental carbon (EC) and organic carbon (OC) are well known. Agreement between methods has been found repeatedly by intercomparison studies to be site-specific, presumably because of the site-to-site variation in aerosol chemical composition. In this study, we probe the effect of metals on evolution of organic and elemental carbon in thermo-optical analyses. Lab-generated metal salts were deposited on top of a layer of various mixed elemental and organic carbon samples, including diesel particles, secondary organic aerosols, and biodiesel particles, to investigate their effect on EC and OC quantification with evolved gas analysis (EGA). Investigated metals include alkaline metals (NaCl, KCl, Na2SO4), alkaline-earth metals (MgCl2, CaCl2), and transition metals (CuCl2, FeCl2, FeCl3, CuCl, ZnCl2, MnCl2, CuSO4, Fe2(SO4)3). Metals were observed to reduce the oxidation temperature of EC. The effect of Cu2+, Fe2+, Fe3+, Mn2+, K+, and Ca2+ on EC oxidation did not depend on the metal-to-carbon (M/C) ratio; Cu2+ resulted in the largest reduction, followed by Fe2+, Mn2+ > Fe3+, K+ > Ca2+. The effect of Cu+, Na+, and Mg2+ on EC oxidation did depend on M/C ratio, decreasing the oxidation temperature of EC as M/C increased. The amount of charred OC was determined by monitoring darkening of the filter spot. Metals were observed to affect the charring of OC, and this effect was highly dependent on the M/C ratio, and ranged from a -50% decrease to a 100% increase. For Cu2+, K+, Fe3+, Mn2+, Na+, Ca2+, and Mg2+, the charring of OC decreased as M/C increased. For Fe2+ and Cu+, the charring of OC increased as M/C increased. Metals were observed to affect the EC/OC ratio; this effect was highly variable and dependent on the M/C ratio. The resulting EC/OC ratio generally was increased by small amounts of metals, with the effect becoming smaller and eventually negative as M/C increased.



The measured light absorption amplification (AA) for a 165 nm mobility diameter flame-generated soot "core" as a function of dioctyl sebacate (DOS) shell thickness. As can be seen, light absorption enhancement occurs for all coating thicknesses, similar to what is observed in when coating black-dyed PSL particles. The blue line is a concentric core-shell model Mie calculation for a DOS-coated, 165 nm diameter soot particle. The inset is an example of the PTI signal and CPC number concentration count as a function of time.

Encapsulation effects on carbonaceous aerosol light absorption

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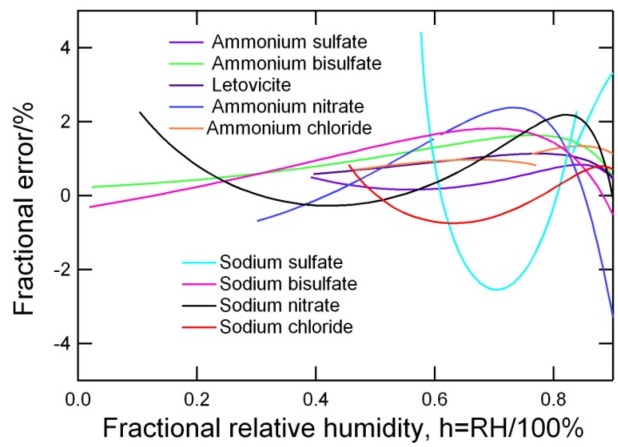
Timothy Onasch, Aerodyne Research, Inc.
Paul Davidovits, Boston College
Eben Cross, Boston College
Claudio Mazzoleni, Michigan Technological University

The contribution of aerosol absorption on direct radiative forcing is still an active area of research, in part because aerosol extinction is dominated by light scattering, and in part because the primary absorbing aerosol of interest, soot, exhibits complex aging behavior that alters its optical properties. The consequences of this can be evidenced by the work of Ramanathan and Carmichael (2008) who suggest that incorporating the atmospheric heating due to brown clouds (plumes containing soot byproducts from automobiles, biomass burning, wood-burning kitchen stoves, and coal-fired power plants) will increase black carbon (BC) radiative forcing from the Intergovernmental Panel on Climate Change best estimate of 0.34 Wm-2 (±0.25 Wm-2) (IPCC 2007) to 0.9 Wm-2. This noteworthy degree of uncertainty is due largely to the interdependence of BC optical properties on particle mixing state and aggregate morphology, each of which changes as the particle ages in the atmosphere and becomes encapsulated within a coating of inorganic and/or organic substances. In July 2008, a laboratory-based measurement campaign, led by Boston College and Aerodyne, was initiated to begin addressing this interdependence. To achieve insights into the interdependence of BC optical properties on particle mixing state and aggregate morphology, measurements of both the optical and physical properties of flame-generated soot under nascent, coated, and denuded conditions were conducted. This poster presents data on black carbon (BC) light absorption measured by Photothermal Interferometry (Sedlacek and Lee 2007). In addition to examining nascent BC—to provide a baseline measurement—encapsulation with varying thicknesses of either dioctyl sebacate (DOS) or sulfuric acid was conducted to glean insights into the interplay between particle mixing state and optical properties. Additionally, some experiments were carried out where BC was coated and then denuded. In the case of DOS-coated soot, a monotonic increase in light absorption to nearly 100% is observed as a function of DOS coating thickness. This observation is consistent with a coating-induced amplification in particle light absorption (Bond et al. 2006). In contrast, light absorption by sulfuric acid-coated soot displays unexpectedly complex behavior where the degree of amplification appears to be dependent upon the underlying soot core diameter.

Exact expressions and accurate approximations for the dependences of radius and index of refraction of solutions of inorganic solutes on relative humidity

Ernie Lewis, Brookhaven National Laboratory
Stephen Schwartz, Brookhaven National Laboratory

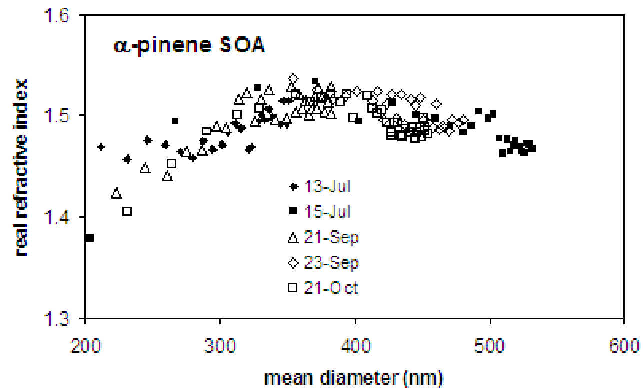


Fractional error in expression for radius ratio as a function of fractional relative humidity h=RH/100% for nine inorganic solutes of atmospheric importance.

Light scattering by aerosols plays an important role in Earth's radiative balance, and quantification of this phenomenon is important in understanding and accounting for anthropogenic influences on Earth's climate. Light scattering by an aerosol particle is determined by its radius and index of refraction, and for aerosol particles that are hygroscopic, both of these quantities vary with relative humidity (RH). Here exact expressions are derived for the dependences of the radius ratio (relative to the volume-equivalent dry radius) and index of refraction on RH for aqueous solutions of single solutes. Both of these quantities depend on the apparent molal volume of the solute in solution and on the practical osmotic coefficient of the solution, which in turn depend on concentration and thus implicitly on RH. Simple but accurate approximations are also presented for the RH dependences of both radius ratio and index of refraction for several atmospherically important inorganic solutes over the entire range of RH values for which these substances can exist as solution drops. For all substances considered, the radius ratio is accurate to within a few percent, and the index of refraction to within ~0.02, over this range of RH. Such parameterizations will be useful in radiation transfer models and climate models.

Genetic algorithm-determined real refractive indices of various secondary organic aerosols

Kim Hwajin, University of California, Los Angeles
Brian Barkey, University of California, Los Angeles
Suzanne Paulson, University of California, Los Angeles, Department of Atmospheric and Oceanic Sciences



GA-derived real refractive index of SOA particles generated from the ozonolysis of alpha-pinene in a solar reaction chamber as a function of SMPS-measured mean particle diameter. Each date represents the results from a separate experiment in which SOA particles are allowed to homogeneously nucleate and then grow over a period of 4 to 6 hours.

Real refractive indices (mr) of secondary organic aerosol (SOA) particles generated by oxidizing alpha-pinene, beta-pinene, and toluene in the UCLA solar reaction chamber are presented. The indices were derived from polar nephelometer measurements using 670 nm incident light polarized both parallel and perpendicular to the measurement scattering plane. Particles larger than about 200 nm gave sufficient signal to retrieve reliable refractive indices. A Genetic Algorithm (GA) optimization method is used to determine mr using the Mie-Lorenz scattering theory and particle size distributions measured with a scanning mobility particle sizer. As the measured size distribution often departs significantly from the expected lognormal distribution shape, a method to quantify and compensate for this distortion has been developed. The absolute error associated with the mr retrieval is ± 0.03, derived from an analysis of instrument electronic noise levels, errors arising from uncertainties in the calibration, and the efficacy of the GA method in determining the correct result from noisy data. The retrieved mr for the SOA studied indicate this property changes as particles grow and is different for each hydrocarbon precursor. For example, alpha- and beta-pinene SOA formed in the presence of NOx were similar, their mr increasing from 1.4–1.45 at 200 nm to 1.52 at 375–425 nm, and then declining gradually, reaching ~1.48 by 500 nm. Toluene SOA had a markedly different pattern and wider range of mr compared to the pinenes. Results for SOA from alpha- and beta-pinene reacted with ozone, as well as the dependence of retrieved mr on hydrocarbon precursor concentration, will also be presented.

A global perspective on aerosol from low volatility organic compounds

John Seinfeld, California Institute of Technology

Global organic aerosol is an important component of aerosol direct and indirect climate forcing. Organic aerosol formed from primary semi-volatile and intermediate volatility compounds is estimated in a global chemical transport model. Semi-volatile organic compound (SVOC) (saturation concentrations between about 0.1 and 10^4 ug/m3) oxidation is predicted to be a larger global source of net aerosol production than oxidation of traditional parent hydrocarbons (terpenes, isoprene, and aromatics). The yield of aerosol (defined as the ratio of the net mass of aerosol formed to the total mass of the parent hydrocarbon emitted) from SVOCs is about 75% on a global, annually averaged basis. Intermediate volatility compound (IVOC, saturation concentrations between about 10^4 and 10^6 ug/m3) emissions and oxidation are uncertain since they are not typically measured. The use of a naphthalene surrogate with different high-NOx and low-NOx parameterizations produces an aerosol yield of about 30%, or roughly 5 Tg/yr of aerosol from IVOC oxidation. We estimate a total global organic aerosol source between roughly 60 and 100 Tg/yr. This range reflects uncertainty in the parameters for SVOC emission volatility, SVOC oxidation, SVOC emissions, and IVOC emissions, as well as wet deposition. Additional information is needed to constrain the emissions and treatment of SVOCs and IVOCs, which have traditionally not been included in global models. Comparisons to winter organic carbon observations over the U.S. indicate that SVOC emissions are significantly underestimated by the traditional POA inventories. The degree to which IVOC emissions or other parameters are uncertain is not yet established.

Hygroscopic properties and CCN characteristics of the aerosols measured at an island at the northwestern end of South Korea

Seong Yum, Brookhaven National Laboratory
Lim-Seok Chang, Global Environmental Research Center

Aerosol total concentration (NCN), hygroscopic growth factor (GF), critical supersaturation (Sc), and CCN concentration (NCCN) were measured during August 8–30, 2009, at Baengnyeongdo (N 37°52', E 124°53'), an island located at the northwestern end of South Korea where local anthropogenic disturbance is small and therefore suitable for monitoring Asian continental outflow. The Sc for aerosols of 81 and 110 nm mobility diameter was measured; monodisperse aerosols classified by a DMA were fed into both DMT CCN counter, whose supersaturation (S) varied over 0.07–1.3% range, and TSI CPC 3010; then the S was found where the NCCN/NCN ratio was at the mid-point. Such instrumentation setting required about 70 minutes of sampling time to obtain Sc measurement for one diameter. Since the local disturbance was small, required sampling time was short enough to obtain reliable Sc for most of the samples. GF at around 90% RH was measured by H-TDMA for 53, 113, 163, and 225 nm mobility diameters. The average hygroscopicity parameter kappa obtained from GF and Sc agreed within ±0.1, and the value was around 0.4~0.5 for most of the campaign. It is substantially higher than that obtained at the mega-city of Seoul, which was within the range of 0.01–0.21. The average NCCN was 4016±1437 cm-3, and the average NCCN/NCN ratio was 0.80±0.13. Both values are high compared to the ones measured about a year ago at Gosan (1421±783 and 0.53±0.17), located at the west coast of Jeju Island about 650 km south of Baengnyeongdo. Since both sites were strategically chosen for monitoring Asian continental outflow and identical instruments have been used over the same season, it is quite surprising to find such large differences between the two sites. More detailed analysis will be shown at the meeting.

The importance of aerosol composition and mixing state on predicted CCN concentration and the variation of the importance with atmospheric processing of aerosol

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Michael Cubison, CIRES
Allison Aiken, Swiss Federal Institute of Technology
Jose Jimenez, University of Colorado
Don Collins, Texas A&M University
Jeffrey Gaffney, University of Arkansas at Little Rock
Nancy Marley, University of Arkansas

The influences of atmospheric aerosols on cloud properties (i.e., aerosol indirect effects) strongly depend on the aerosol CCN concentrations, which can be effectively predicted from detailed aerosol size distribution, mixing state, and chemical composition using Köhler theory. However, atmospheric aerosols are complex and heterogeneous mixtures of a large number of species that cannot be individually simulated in global or regional models due to computational constraints. Furthermore, the thermodynamic properties or even the molecular identities of many organic species present in ambient aerosols are often not known to predict their cloud-activation behavior using Köhler theory. As a result, simplified presentations of aerosol composition and mixing state are necessary for large-scale models. In this study, aerosol microphysics, CCN concentrations, and chemical composition measured at the T0 urban super-site in Mexico City during MILAGRO are analyzed. During the campaign in March 2006, aerosol size distribution and composition often showed strong diurnal variation as a result of both primary emissions and aging of aerosols through coagulation and local photochemical production of secondary aerosol species. The submicron aerosol composition was ~1/2 organic species. Closure analysis is first carried out by comparing CCN concentrations calculated from the measured aerosol size distribution, mixing state, and chemical composition using extended Köhler theory to concurrent CCN measurements at five supersaturations ranging from 0.11% to 0.35%. The closure agreement and its diurnal variation are studied. CCN concentrations are also derived using various simplifications of the measured aerosol mixing state and chemical composition. The biases associated with these simplifications are compared for different supersaturations, and the variation of the biases is examined as a function of aerosol age. The results show that the simplification of internally mixed, size-independent particle composition leads to substantial overestimation of CCN concentration for freshly emitted aerosols in early morning, but can reasonably predict the CCN concentration after the aerosols underwent atmospheric processing for several hours. This analysis employing various simplifications provides insights into the essential information of particle chemical composition that needs to be represented in models to adequately predict CCN concentration and cloud microphysics.

Laboratory measurements of hygroscopic growth factors, ethanol growth factors, and cloud condensation nuclei activity for oxidized soot and secondary organic aerosols

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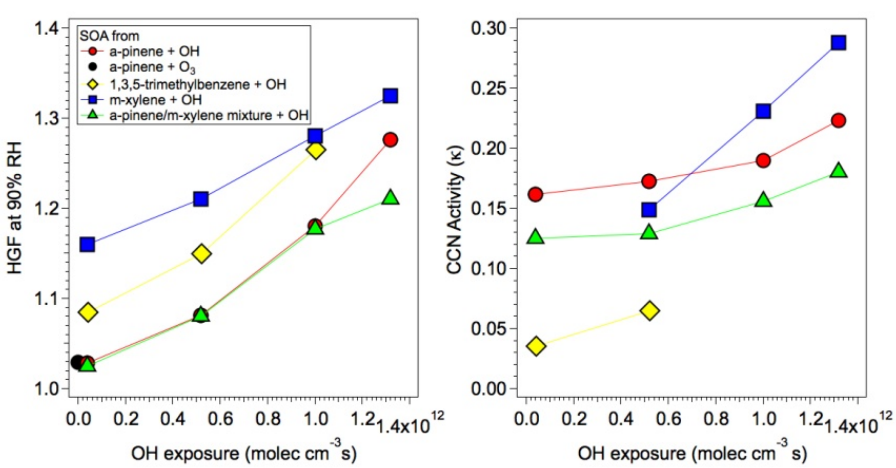
Adam Ahern, Aerodyne Research, Inc.
Paola Massoli, Aerodyne Research, Inc.
Timothy Onasch, Aerodyne Research, Inc.
Douglas Worsnop, Aerodyne Research, Inc.
Paul Davidovits, Boston College

Hygroscopic growth factors (HGF), ethanol growth factors (EGF), and cloud condensation nuclei (CCN) activity were measured for OH-oxidized soot aerosol and secondary organic aerosols (SOA) generated from common gas-phase biogenic and anthropogenic SOA precursors (α-pinene, m-xylene, 1,3,5-trimethylbenzene, and α-pinene/m-xylene mixtures). The species were oxidized in a laboratory aerosol flow reactor at OH radical concentrations that were varied from 4x10^8 molec cm^-3 to 1x10^10 molec cm^-3. The residence time in the flow tube was 120 sec; this combination of OH concentration and transit time (i.e., oxidant exposure) corresponds to 0.5 to 14 days assuming a 24-hour average OH concentration of 1x10^6 molec cm^-3. An Aerodyne aerosol mass spectrometer (AMS) was used to measure bulk aerosol chemical composition, which provided a measure of aerosol oxidation state. Hygroscopic and organic tandem differential mobility analyzers (HTDMA, OTDMA) were used to measure growth factors of oxidized aerosols. The HTDMA measures HGF by passing dry aerosols through water-humidified air (90% relative humidity) and measuring the wet-to-dry particle diameter ratio. The HTDMA therefore provides a measure of water-soluble organic compounds in the aerosol. The OTDMA measures EGF by passing dry particles through ethanol-laden air (80% relative to saturation of ethanol), providing a measure of water-insoluble organics. HGF in the range of 1.0–1.3 and EGF in the range of 1.1–1.3 were measured. The figure displays sample data showing that HGF and CCN activity are strongly correlated with extent of OH oxidation. These results suggest that model parameterizations between aerosol oxidation state, water solubility, and cloud-forming potential are possible.

Fourteen scientists from five institutions participated in the study. Only a partial list of authors is provided in this abstract; a full list of authors is shown on the poster.



HGF and CCN activity as a function of OH exposure for SOA generated by oxidation of α-pinene, m-xylene, 1,3,5-trimethylbenzene, and α-pinene/m-xylene mixtures.

A larger pool of secondary organic aerosol precursors in continental air

Paul Doskey, Michigan Technological University

Measurements of aerosol in urban and marine atmospheres suggest that production of secondary organic aerosol (SOA) cannot be explained by oxidation of organic gases that are routinely measured. Laboratory experiments demonstrated exhaust from diesel-powered vehicles (DPVs) produced more SOA than the amount predicted from oxidation of volatile organic compounds (VOCs) in the exhaust that are known precursors of SOA. A complex mixture of semi-volatile organic compounds (SVOCs) is suspected of producing the additional SOA. The SVOCs and suspected oxidation products are not routinely measured in ambient air or are measured with insufficient sampling frequency to evaluate SOA formation rates. Here, gas-aerosol partitioning characteristics of the likely semi-volatile precursors of SOA are evaluated, an SVOC emission profile for a roadway tunnel is developed, and the average contribution of SVOCs to SOA precursors emitted by vehicles in the United States is estimated. The results indicate approximately 81% and 12% of the suspected SOA precursors emitted by DPVs and gasoline-powered vehicles (GPVs), respectively, are semi-volatile. The magnitude of the OH reactivity of SOA precursor emissions from DPVs and GPVs are similar; however, approximately 82% and 15% of the OH reactivity from DPVs and GPVs, respectively, are contributed by SVOCs. The SVOCs from vehicle tailpipe emissions are more reactive with OH than VOCs, and thus, SVOCs will make a greater contribution to SOA formation near sources. In the high NOx conditions of urban areas, SVOC oxidation is likely to produce a complex mixture of δ-hydroxynitrates, dinitrates, and hydroxynitrates that are also poorly measured by current technologies. Using transportation statistics on annual DPV and GPV mileage in the United States, the emission profile of SVOCs in DPV and GPV exhaust, and the reported yield of SOA from photo-oxidation of diesel exhaust, we estimate the annual contribution of SVOCs to SOA precursors emitted by vehicles in urban areas of the United States might be as high as 20%. The SVOCs are expected to partition into the gas phase downwind of urban areas as total suspended aerosol concentrations diminish by dilution, and thus, the total contribution of SVOCs to SOA precursors is likely to be even greater.

Low-cost, fast-response aerosol optical extinction monitor

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We present laboratory and field measurements of aerosol light extinction performed at 445 nm and 632 nm using an instrument that employs Cavity Attenuated Phase Shift (CAPS) technique. The CAPS extinction monitor comprises a light-emitting diode (LED), an optical cavity that acts as the sample cell, and a vacuum photodiode for light detection. The particle extinction is determined from changes in the phase shift of the distorted waveform of the square-wave modulated LED light that is transmitted through the cavity. The detection limit (3σ) of the monitor under dry particle-free air is ~3 Mm-1 for 1 s integration time. Laboratory measurements of absolute particle extinction cross-sections using non-absorbing, monodisperse polystyrene latex (PSL) spheres were made with an average precision of ±2–4% (2σ); comparison of these results with Mie scattering calculations indicated that these results were accurate within the 10% uncertainty stated for the particle number density measurements. The CAPS extinction monitor was deployed twice in 2009 to test its robustness and performance outside of the laboratory. During these field campaigns, a collocated Multi-Angle Absorption Photometer (MAAP)

provided particle light absorption coefficient, allowing an estimate of the single-scattering albedo of the ambient aerosol particles by combining the CAPS-based extinction measurements at 632 nm with the MAAP-based absorption measurements at 635 nm. Our initial results show the high potential of the CAPS as a lightweight, compact instrument to perform precise and accurate extinction measurements of atmospheric aerosols in both laboratory and field conditions.

Measurements of optical properties of organic aerosols using photoacoustic instrumentation

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Light absorption and scattering by atmospheric aerosols has a considerable effect on the earth's direct and semi-direct radiative forcing. It is well known that light absorption by dust and black carbon aerosols (soot) has a warming effect on climate, while scattering by sulfate, nitrate, and sea salt aerosols has a cooling effect. However, there are large uncertainties associated with light absorption and scattering by various primary and secondary organic aerosols, especially in the near-UV and UV. Here, we present preliminary results from a recent laboratory study focused on measuring absorption and scattering properties of selected primary organic aerosol (POA) and secondary organic aerosol (SOA) systems using photoacoustic (PA) instruments at four wavelengths: 355, 405, 532, and 870 nm. In the POA category, we examined optical properties of lubricating oil (SAE15W-40) aerosol, black carbon aerosol (generated from India ink solution), and black carbon aerosol coated with lubricating oil. The results showed that light absorption of black carbon aerosol was significantly enhanced by the lubricating oil coating. In the SOA category, we examined light absorption properties of secondary organic aerosol (SOA) formed from the oxidation of α-pinene with ozone and nitrate radical in the presence of pre-existing neutral and acidic seed aerosols. Our results show that light absorption of α-pinene SOA is strongly dependent on the experimental conditions, such as relative humidity, oxidants, and acidity of the pre-existing inorganic seed aerosols. Strong absorption at 355 nm and 405 nm was observed for SOA from oxidation of α-pinene and nitrate (NO_3) radical in the presence of strong acidic inorganic seed aerosol at low RH (<3%). No light absorption was observed when RH was higher than 12% or in the presence of weak and neutral inorganic seed aerosols or when ozone was used as oxidant. Our results also indicate that α-pinene itself could be absorbed into strong acidic seed aerosols and enhance light absorption, possibly by forming oligomeric species via aerosol-phase heterogeneous reactions.

MFRSR-retrieved intensive aerosol properties under partly cloudy days: uncertainties and corrections

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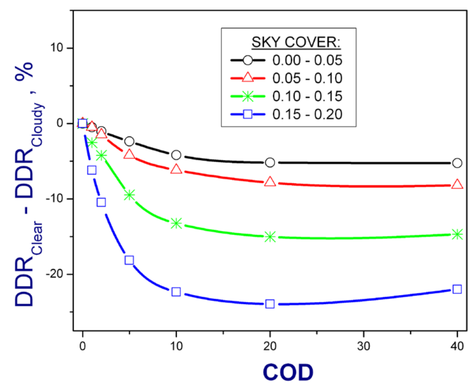

Cloud-induced bias of DDR as function of cloud optical depth (COD) and fractional sky cover (FSC).

Several studies have demonstrated that the aerosol single-scattering albedo and asymmetry parameter carry the largest uncertainty of any parameters associated with direct aerosol forcing (e.g., McComiskey et al. 2008). Under clear-sky conditions, these intensive aerosol properties can be provided quite accurately by Multifilter Rotating Shadowband Radiometers (MFRSRs) (e.g., Kassianov et al. 2007). The MFRSR-based aerosol retrieval, which is applied to accomplish this task, relies on the ratio of the diffuse and direct surface irradiances, so-called the diffuse-to-direct ratio (DDR). Broken clouds are observed frequently over the ARM SGP site, and they can substantially modulate the diffuse irradiance, and consequently the DDR. Thus, the cloud-induced changes to the DDR may significantly contaminate the MFRSR-derived intensive aerosol properties. Here we apply model simulations (attached figure) to quantify the cloud contamination and suggest corrections for reducing the contamination impact on the retrievals. The model results are accompanied by analyses of cloudy-sky data collected during the CHAPS/CLASIC campaigns.

McComiskey, A, SE Schwartz, B Schmid, H Guan, ER Lewis, P Ricchiazzi, and JA Ogren. 2008. “Direct aerosol forcing: Calculation from observables and sensitivities to inputs.” *Journal of Geophysical Research* 113: D09202, doi:10.1029/2007JD009170.

Kassianov, EI, CJ Flynn, TP Ackerman, and JC Barnard. 2007. “Aerosol single-scattering albedo and asymmetry parameter from MFRSR observations during the ARM Aerosol IOP 2003.” *Atmospheric Chemistry and Physics* 7: 3341–3351.

Modeling the formation of secondary organic aerosols from semi-volatile organic vapors in the Mexico City region

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Organic aerosols are an important component of ambient particulate matter affecting both climate and human health. Secondary organic aerosols (SOA) are formed in the atmosphere through oxidation of semi-volatile organic vapors emitted from a variety of combustion and biogenic sources. Many studies have shown that formation of anthropogenic and biomass burning SOA is highly under-predicted in current air quality models. Recent work has shown that evolution of organics in the atmosphere is highly dynamic, resulting from photochemical oxidation and gas-particle partitioning downwind of emission sources. The objective of this study is to improve the process representation of anthropogenic and biomass burning organic aerosols in models. The volatility basis-set framework has been coupled to the MOSAIC aerosol model and used to model the dynamic evolution of organics in the atmosphere. A box-model framework is used to do various sensitivity tests on the prediction of organic aerosols and relevant parameters, such as elemental oxygen-to-carbon ratios O:C of organics. In addition to the widely used equilibrium gas-particle partitioning scheme, a kinetics limited gas-particle mass transfer scheme is evaluated for the first time using the volatility basis-set approach. Sensitivity to parameters such as mass accommodation coefficients, volatility distribution, and reaction scheme on the kinetically limited gas-particle mass transfer rates are evaluated first in the box model. Results from these tests are used to infer the most relevant parameters for implementation of SOA treatment in the three-dimensional WRF-Chem model. WRF-Chem simulation results of SOA are evaluated against various measurements, such as those from Aerosol Mass Spectrometers (AMS), taken during the MILAGRO campaign in the vicinity of Mexico City during March 2006, to guide future research in predicting SOA in models. The improved process representation of organics in WRF-Chem will affect simulated light absorption and cloud condensation nuclei (CCN) formation and consequently shed light on the role of organics on direct and indirect forcing of climate. For example, the CCN formation has been recently shown to strongly correlate with O:C ratios that could be explicitly tracked as function of photochemical aging and kinetically limited gas-particle partitioning in WRF-Chem.

http://www.pnl.gov/atmospheric

Molecular characterization of organic aerosols using high-resolution mass spectrometry

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Characterization of composition and chemical transformations of OA is both a major challenge and the area of greatest uncertainty in aerosol research. Particularly, little is known about the fundamental relationship between the chemical composition and physicochemical properties of OA. The effect of atmospheric aging on these properties is also poorly understood. Applications of high-resolution electrospray ionization mass spectrometry (HR-ESI/MS) for structural characterization of OA constituents has been demonstrated recently, and currently this is a rapidly growing area of research in aerosol chemistry. We have conducted a number of field and laboratory studies that utilized HR-ESI/MS for comprehensive characterization of OA. We used HR-ESI/MS for characterization of the chemical composition of biomass burning aerosols (BBA). Our results indicated that BBA contained a variety of distinct, biomass-specific, characteristic peaks in ESI/MS spectra that can be used as unique markers for different types of biofuels. In addition to a large number of oxygen-containing polar organic compounds, we identified a significant number of N-heterocyclic compounds that have not been previously described in the literature. Because of the presence of non-bonding electrons and double bonds, N-heterocylcic compounds often contain chromophore moieties responsible for light absorption in the UV/Vis region. Our current projects focus on the application of high-resolution desorption electrospray ionization mass spectrometry (DESI-MS) for detailed chemical characterization and studies of chemical aging of OA collected on substrates. DESI-MS offers unique advantages both for detailed characterization of chemically labile components in OA that cannot be detected using more traditional ESI-MS approach, and for studying chemical aging of OA. DESI-MS combined with MS/MS experiments were used to examine chemical aging of SOA in the presence of gaseous ammonia. Exposure of SOA to ammonia resulted in measurable changes in the light absorption properties of the sample. We demonstrated that ammonia-mediated chemical aging results in formation of highly conjugated nitrogen-containing species that are responsible for light-absorbing properties of the aged SOA. That study presented an important step towards understanding the formation of light-absorbing OA (brown carbon) in the atmosphere.

Morphology of mixed primary and secondary organic particles and the adsorption of spectator organic gases during aerosol formation

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Primary organic aerosol (POA) and associated vapors can play an important role in determining the formation and properties of secondary organic aerosol (SOA). If SOA and POA are miscible, POA will significantly enhance SOA formation, and some POA vapor will incorporate into SOA particles. When the two are not miscible, condensation of SOA on POA particles forms particles with complex morphology. In addition, POA vapor can adsorb to the surface of SOA particles, increasing their mass and affecting their evaporation rates. To gain insight into SOA/POA interactions, we present a detailed experimental investigation of the morphologies of SOA particles formed during ozonolysis of α-pinene in the presence of dioctyl phthalate (DOP) particles, serving as a simplified model of hydrophobic POA, using a single particle mass spectrometer. Ultraviolet (UV) laser depth-profiling experiments were used to characterize two different types of mixed SOA/DOP particles: those formed by condensation of the oxidized α-pinene products on size-selected DOP particles, and those formed by condensation of DOP on size-selected α-pinene SOA particles. The results show that the hydrophilic SOA and hydrophobic DOP do not mix, but instead form layered phases. In addition, an examination of homogeneously nucleated SOA particles formed in the presence of DOP vapor shows them to have an adsorbed DOP coating layer that is ~4 nm thick and caries 12% of the particle's mass. These results may have implications for SOA formation and behavior in the atmosphere, where numerous organic compounds with various volatilities and different polarities are present.

A multi-year analysis of clear-sky aerosol optical properties and direct radiative forcing at Gosan, Korea (2001–2008)

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A seven-year analysis of clear-sky column-integrated aerosol optical properties and direct radiative forcing at Gosan in Korea is presented in this paper; the Gosan site is heavily impacted by aerosols emitted from the Asian continent. MODIS and AERONET sun/sky radiometer measurements showed significant seasonal and geographical variability in aerosol optical depth (AOD), with high AODs over the east coastal industrialized regions of China in spring and summer. At the Gosan site, the monthly mean AOD at 675 nm ranged between 0.12 and 0.36. High AODs were observed from April to June (> 0.33), while low-to-moderate monthly mean AODs were apparent during the remaining months. The single scattering albedo (SSA) exhibited relatively low values from February to May (< 0.93), indicating the presence of light-absorbing aerosols, whereas high values of SSA (> 0.93) were observed during the remaining months. The annual average clear-sky direct forcing (forcing efficiency) at the surface was -27.55 ± 9.21 W m–2 (-91.85 ± 11.12 W m–2 τ–1) and at the top of the atmosphere (TOA) was -15.79 ± 4.44 W m–2 (-53.76 ± 6.70 W m–2 τ–1), thereby leading to an atmospheric absorption of 11.76 ± 5.82 W m–2. From March to June, the surface aerosol radiative forcing (forcing efficiency) ranged between -27.29 (-85.33) and -34.76 W m–2 (-97.19 W m–2 τ–1), whereas at TOA it ranged between -16.84 (-51.82) and -19.10 W m–2 (-56.05 W m–2 τ–1), and the atmospheric forcing ranged between 10.45 and 16.41 W m–2. The atmospheric forcing (i.e., atmospheric absorption) caused an increase in atmospheric heating (about 1.5 to 3.0 K day–1). The strongest radiative heating was observed from April to May (> 2.5 K day–1).

Nucleation and growth mechanisms of daytime and nighttime new particle formation

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Observations suggest qualitative differences between daytime and nighttime nucleation events. The objective of the present study is to test the simple hypothesis that sulfuric acid-limited new particle formation (NPF) produces the classical banana-shaped particle size distributions (psds) suggestive of sharp nucleation pulses and seen in numerous daytime NPF studies for over a decade; while organics-limited NPF produces the more recently observed “tomato”-like psd features, suggestive of sustained nucleation events seen in nighttime NPF (Lee et. al 2008). Laboratory measurements on the ternary organic acid/sulfuric acid/water system show that these species strongly interact to enhance nucleation rate. A multi-component nucleation theory has been developed that successfully parameterizes the measurements and provides critical nucleus composition at the molecular level (McGraw and Zhang 2008). In this theory each condensable vapor is found to contribute a power-law factor to the overall nucleation rate. For sulfuric acid the power-law exponent ranges between 4 and 8, whereas for organics the exponent is considerably reduced, ranging between 1 and 2. These exponents quantify the sensitivity of nucleation rate to vapor phase species concentration. We show that narrow nucleation pulses are a natural consequence of the higher exponents, as is consistent with sulfuric acid limited nucleation and daytime NPF. By contrast, smaller exponents are found to result in sustained periods of nucleation characteristic of nucleation processes limited by organics and nighttime NPF. Modeled processes include a continuous source of condensable vapor; vapor and size-dependent scavenging of clusters by the surface of typical background aerosols and new particles; self-coagulation; and particle growth. Simulations were performed using the quadrature method of moments (QMOM) with tracking of vapor and four radial psd moments.

Lee, S-H, LH Young, DR Benson, T Suni, M Kulmala, H Junninen, TL Campos, DC Rogers, and J Jenson. 2008. “Observations of nighttime new particle formation in the troposphere.” *Journal of Geophysical Research* 113: D10210.

McGraw, R and R Zhang. 2008. “Multivariate analysis of homogeneous nucleation rate measurements: Nucleation in the p-toluic acid/sulfuric acid/water system.” *Journal of Chemical Physics* 128: 064508.

Nucleation and growth of atmospheric particles

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New particle formation (NPF) in the atmospheric is a two-step process: Nucleation leads to the birth of stable nuclei that subsequently grow to sizes that can be detected and affect the atmosphere's radiative properties. Our group is studying both of these processes. Our nucleation research is largely supported by NSF and involves measurements of neutral molecular clusters formed by nucleation with a new custom-designed mass spectrometer (the Cluster-CIMS) and measurements of nanoparticle size distributions as small as 1 nm with a new aerosol spectrometer (the DEG SMPS). These measurements are providing new insights into aspects of cluster behavior that affect nucleation rates. The U.S. DOE supports our research on nanoparticle growth rates. This research couples physical and chemical measurements of aerosol properties and behavior. The TDCIMS, which enables real-time measurements of composition for freshly nucleated particles as small as 8 nm and was developed with support from DOE, is the most important tool in this work. Our most important discoveries about processes that affect growth rates are summarized in a recent PNAS article (doi:10.1073/pnas.0912127107). In short, this work has shown that alkylammonium-carboxylate salts, formed, for example, by reactions between amines and carboxylic acids, account for 20–50% of the mass of freshly nucleated particles in locations that include Atlanta, Mexico City, Boulder, and Hyytiälä, while sulfates account for only about 10%. These newly discovered compounds help to explain the high growth rates of freshly nucleated particles that have been observed around the globe and help to explain why nucleation is an important atmospheric process, not just a scientific curiosity. Our poster will provide an overview of this work.

Optical remote sensing of aerosol characteristics

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Michelle Snyder, North Carolina State University
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Laser remote sensing techniques now provide an important tool for determining most of the characteristics of aerosols, including their physical and chemical properties. Examples are selected from measurements to show the types of information contained in the optical scattering signatures. Improvements in understanding the distribution of aerosols, their sources, their processes of formation and growth, and their role in establishing the planetary albedo and the radiative transfer into space are critically important for improving the predictions of our changing climate. Multi-wavelength backscatter measurements from Rayleigh and Raman lidar techniques provide signals that are used to profile the properties for describing the transmission of radiation through an atmospheric column. The Rayleigh lidar signals provide backscatter coefficients, and the Raman lidar signals backscattered from N2 and O2 provide true extinction profiles. The combination of these two sets of data gathered simultaneously makes a most important contribution to understanding the radiation transmission through the atmosphere. In addition, the same lidar beams can be used to make multistatic measurements of the polarization ratio of the scattering phase function. The multistatic measurements at several wavelengths are analyzed to determine profiles of the aerosol number density, size, size distribution, and type. These parameters can be determined for spherical particles in the size range between about 50 nm and 10 µm. Analysis of the size distribution requires adopting a mathematical shape function, usually a log-normal distribution. Information on aerosol type can be roughly determined based on chemistry and shape estimates from refractive index of the scatterers and depolarization of the scattered radiation as a function of wavelength. Raman and DIAL lidar measurements provide the opportunities for measuring the profiles of chemical species which absorb radiation, thereby reducing the atmospheric transmission, as in the case of the infrared region greenhouse gases. Multi-wavelength DIAL, hyper-spectral measurements, and the recent developments of supercontinuum lidar techniques (SAL, Supercontinuum Absorption Lidar, or SAS, Supercontinuum Absorption Spectroscopy) promise to provide the fundamental data to describe the optical absorption that influences the radiation balance between Earth and space.

Organic aerosol removal during precipitation events: climate implications

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Nancy Marley, University of Arkansas
Gail Bridges, University of Arkansas at Little Rock
Angie Marchany-Rivera, University of Arkansas at Little Rock
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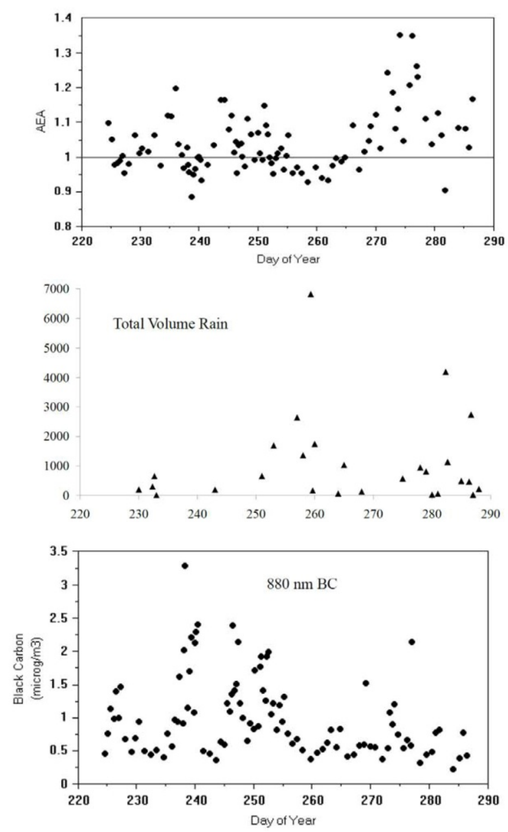
Atmospheric aerosols and their links to clouds are one of the main focus areas of the U.S. Department of Energy's Atmospheric System Research, particularly as they affect regional climate. Aerosol lifetimes depend on the aerosol's ability to uptake water and grow to sufficient size to be either removed by gravitational settling, act as cloud condensation nuclei, or be removed by precipitation scavenging. The investigation of UV-visible absorbing aerosols is underway using a seven-channel aethalometer to evaluate the change in optical absorption during precipitation events. Ångström absorption exponents (AAEs) are determined before, during, and after rain events to examine the changes in AAEs anticipated by removal of shortwave-absorbing organic species (i.e. carboxylates) that are produced by biogenic emissions (isoprene, monoterpenes, and sesquiterpenes). Black carbon data taken at the University of Arkansas at Little Rock and other sites



Rain impacts on AEAs and BC levels (absorption at 880 nm). Note that significant BC remains even during heavy rain events, while AEAs show loss of UV-absorbing compounds during rain events.

clearly show that a significant amount of absorbing carbon is not removed during rain events, and that the organic matter removed is likely secondary organics from biogenic sources as indicated by lower AAEs. The determinations of dissolved organic carbon (DOC) and natural radionuclides in precipitation are also used to help examine the carbonaceous aerosol removal during rain events. This work suggests that carbonaceous aerosols will have different lifetimes depending on their aqueous solubilities (non-polar or polar) and their morphologies (i.e., organic coatings on non-polar materials or polar materials or as separate organic aerosol species). The work also indicates that equilibrium may exist between semi-volatile water-soluble organics and aerosol surfaces that act to remove the oxidized organics while "black carbon" is not removed. The data are discussed in terms of the

potential impacts of anthropogenic enhancement of secondary organic aerosols that are absorbing radiation and adding to atmospheric heating, and their anticipated lifetimes.

Reduction of snow surface albedo by black carbon

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The black carbon deposited in snow and ice is thought to contribute to global warming and to the melting of snowpack, ice, and glaciers worldwide. Climate models' predictions are partly verified by black carbon concentrations measured in snow at a number of locations worldwide, but the snow albedo reduction by black carbon is based mainly on theory, because this effect is difficult to measure under natural conditions. This presentation is about laboratory experiments designed to examine the reduction of snow surface albedo by black carbon. Two types of experiments will be featured: one to quantify the dependence of snow spectral albedo on black carbon concentration and snow grain size, and the other to examine how black carbon is transported in melting snow. The process of creating and characterizing snow will be described, and experimental observations will be compared with the assumptions and predictions of climate models.

Regional climate forcing by carbonaceous aerosols: relating optical properties to chemical composition to improve predictions

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Bradley Flowers, Los Alamos National Laboratory
Claudio Mazzoleni, Michigan Technological University
Alla Zelenyuk, Pacific Northwest National Laboratory
James Schauer, University of Wisconsin-Madison
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The emissions, composition, and optical properties of carbon-containing aerosols are the largest source of uncertainty in estimates of direct aerosol radiative forcing, which vary by a factor of four amongst models. Using a state-of-the-art 3-laser photoacoustic instrument, we measured the aerosol absorption and scattering and combined it with chemical observations of long-range transport (LRT) pollution in the Arctic (ISDAC) and in Asia (CAPMEX) in 2008. Our analysis develops a process-level understanding of the optical properties as the aerosols mix and age during transport by linking them to changes in observed changes in chemical composition. In Asia we find that transport of mixed sulfate, carbonaceous, and nitrate aerosols from various pollution plumes to Jeju, South Korea, accounted for 74% of the deployment days, showing large variations in their measured chemical and optical properties. We show that episodes with high organic carbon/sulfate and nitrate/sulfate ratios exhibit lower single-scatter albedo at shorter wavelengths, significantly lower than predicted by an optical model that assumes constant complex index of refraction with wavelength. Organic carbon absorption accounts for up to 50% of the measured aerosol absorption at 405 nm. In Alaska, in April 2008 we intercepted and interrogated pervasive pollution layers aloft Alaska. The absorption and scattering signals occurred in layers from 1 to 6 km above the surface and approached 30 to 200 (Mm)-1 respectively. Alternating light and dark aerosol layers with single-scatter albedo ranging from 0.7 to 0.95 were evident, and they extended over vast areas. Real-time satellite data-assimilated transport models indicate that this pollution was imported from Chinese dust storms and Siberian fires as well as from Eurasian energy sectors. Our wavelength-dependent optical properties are used to diagnose the soot, dust, sulfate, and organic components of this complex soup of pollutants. They are then verified by analysis of size distributions and chemical compositions observed by a single-particle laser ablation spectrometer instrument. We use our optical observations to estimate a direct radiative forcing by pollution of the order of 40 of W m-2 and also significant atmospheric heating rates. We find that aerosols forcings and impacts in Asia and the Arctic are large. Our results underscore the need to predict changes in optical properties from aerosol aging during their long-range transport in models.

Size-resolved chemical composition of aerosol particles in multiple urban, rural, and remote atmospheric environments: an integrated view via aerosol mass spectrometry

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Size-resolved chemical composition of submicron particles in urban, urban downwind, high elevation, forested, coastal, and rural atmospheres was examined based on analyses of more than 30 ambient aerosol mass spectrometer data sets acquired from the Northern Hemisphere. The size distributions of sulfate, nitrate, ammonium, and organics are summarized and compared among different types of environments. The size distributions of major types of organic aerosols (OA), e.g., hydrocarbon-like and oxygenated OA (HOA and OOA), were extracted via multivariate analysis of the size distributions of main OA fragments, e.g., m/z's 44, 43, 55, and 57. These components are evaluated according to correlations with secondary inorganic aerosol species (e.g., sulfate and nitrate) and primary emission tracers such as elemental carbon, CO, and NOx. The HOA component in urban locations usually consists of an ultrafine mode and an accumulation mode that overlaps with those of OOA and sulfate. The size distributions of OOA and sulfate are overall similar; both are usually dominated with an accumulation mode that centers around 450–600 nm. Compared to that of sulfate, the size distribution of OOA tends to be slightly broader, extending more into the small size mode. The broader OOA size distribution is more obvious during periods when semi-volatile OOA (SV-OOA) is an important component of OA, which is consistent with surface-controlled partitioning of semi-volatile species. In addition, case studies will be conducted to evaluate the influence of new particle formation and growth events on the total and chemically resolved size distributions. The evolution of the size distributions of different aerosol species will also be examined for prominent particle growth cases.

http://www.envtox.ucdavis.edu/Faculty_Personal_Web_Pages/zhang/AMS_global_database.html

Soot particle studies—instrument intercomparison

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An intercomparison study of instruments designed to measure the microphysical and optical properties of soot particles was completed. The following mass-based instruments were tested: Couette Centrifugal Particle Mass Analyzer (CPMA), Time-of-Flight Aerosol Mass Spectrometer-Scanning Mobility Particle Sizer (AMS-SMPS), Single Particle Soot Photometer (SP2), Soot Particle-Aerosol Mass Spectrometer (SP-AMS), and Photoelectric Aerosol Sensor (PAS2000CE). The following optical absorption-measuring instruments were tested: Photoacoustic Spectrometer (PAS), Photoacoustic Soot Spectrometer (PASS-3), and Photo-Thermal Interferometer (PTI). Optical extinction measuring instruments tested were: Cavity Ring Down Aerosol Extinction Spectrometer (CRD-AES) and Cavity Attenuated Phase Shift Extinction Monitor (CAPS). The study covered an experimental matrix consisting of 318 runs that systematically tested the performance of instruments across a range of parameters including: fuel equivalence ratio ($1.8 \leq \varphi \leq 5$), particle shape (fractal dimension $1.8 \leq Df \leq 3.0$), particle mobility size ($30 \leq dm \leq 300$ nm), black carbon mass ($0.07 \leq mBC \leq 4.2$ fg), and particle chemical composition. In selected runs, particles were coated with sulfuric acid or di-octyl sebacate (DOS) ($0.5 \leq \Delta rve \leq 201$ nm). The effect of non-absorbing coatings on instrument response was determined. Changes in the morphology of fractal soot particles were monitored during coating and denuding processes, and the effect of particle shape on instrument response was determined. The combination of optical and mass-based measurements was used to determine the mass-specific absorption coefficient for denuded soot particles. The single-scattering albedo of the particles was also measured. An overview of the experiments and sample results are presented. As an example of the data obtained, the figure displays optical absorption cross section (σabs) at $\lambda = 532$ nm as a function of per-particle black carbon mass for denuded soot measured with the PASS-3, PTI, and PAS instruments. Three types of denuded particles are shown in the figure: DOS-coated-denuded (squares), H_2SO_4-coated-denuded (circles), and nascent-denuded (stars). The slope of each linear fit is the mass specific absorption coefficient (MAC) as noted in the figure.

Thirty scientists from fourteen institutions participated in the study. Only a partial list of authors is provided in this abstract. The full list of authors is shown in the poster.

Spectral shortwave radiative closure studies at SGP: improved treatment of aerosol properties

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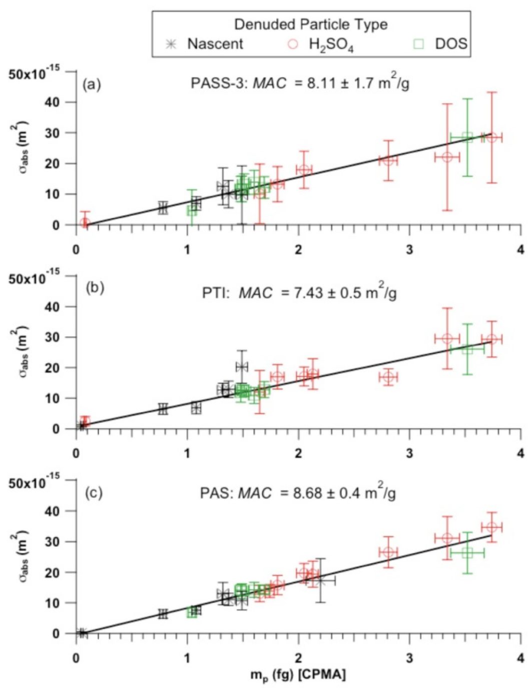
Krista Gaustad, Pacific Northwest National Laboratory

Understanding regional aerosol processes and precisely representing them in climate models is an essential requirement for producing accurate simulations of future climate. Over the past decade, the

Atmospheric Radiation Measurement (ARM) Program has put forth significant effort to characterize the radiative properties of atmospheric aerosols above the ARM Climate Research Facility sites. A ground-based Aerosol Observing System (AOS) continuously measures extensive aerosol properties from which intensive properties such as single-scattering albedo, asymmetry parameter, and Ångström exponent can be determined. These aerosol properties have been combined into value-added products (VAPs), such as the Aerosol Best Estimate, that are made available to the community. Ground-based radiometric measurements from the ARM Facility sites serve an equally important role in aerosol characterization. Not only is the aerosol optical depth derived from such measurements, but these measurements are used in radiative closure studies in which spectrally resolved measurements are compared with radiative transfer model calculations; the analysis of the measurement-model disagreement is targeted at resolving the source of the disagreement. This poster presents results from a continuing clear-sky radiative-closure study that utilizes Rotating Shadowband Spectroradiometer (RSS) measurements of the direct-normal, diffuse-horizontal, and total-horizontal irradiances from 360 to 1050 nm. The radiative transfer model for this study is the numerically accurate Code for High Resolution Accelerated Radiative Transfer with Scattering (CHARTS). A new aspect of this study is the utilization of recently updated aerosol products, which include a first evaluation of spectral hygroscopic growth factors and aerosol optical properties derived from the AOS measurements. Albedos from the Surface Spectral Albedo VAP will also be used for the first time in this shortwave radiative closure effort.



Absorption cross-sections (σabs) for denuded soot measured at λ = 532 nm for the (a) PASS-3, (b) PTI, and (c) PAS instruments as a function of the mass measured by the CPMA instrument. Soot particles were generated at φ = 2.0 0.2. The symbols indicate the different coating condition (prior to denuding): DOS-coated-denuded (squares), H2SO4-coated-denuded (circles), or nascent-denuded (stars). The linear regressions shown are fit through all three denuded particle types (weighted to the 1σ standard deviations shown). The slope of each linear fit is the mass specific absorption coefficient (MAC).

Spectro-microscopic characterization of carbonaceous particulates

Mary Gilles, Lawrence Berkeley National Laboratory
Ryan Moffet, Lawrence Berkeley National Laboratory
Shruti Prakash, Lawrence Berkeley National Laboratory
Alexander Laskin, Pacific Northwest National Laboratory

Carbonaceous particles formed by combustion account for a large fraction of light-absorbing aerosols. Understanding and characterizing the diversity of particulate matter produced from fossil fuel and biomass burn combustion is important for modeling radiative properties of the atmosphere. In recent years we have combined a variety of micro-spectroscopic techniques to probe carbonaceous particulates: specifically, scanning transmission x-ray microscopy, capable of performing near-edge x-ray fine-structure micro-spectroscopy, (STXM/NEXAFS), and computer-controlled scanning electron microscopy coupled with an energy-dispersive x-ray analyzer (CCSEM/EDX) for elemental analysis. STXM/NEXAFS is used to explore the diversity of bonding, carbon sp2 hybridization, and C/O atomic ratios of light-absorbing particulates. It has also been used to illustrate chemical and morphological differences in bonding between fractal soots and aged biomass burn particulates (tar balls). For the tar balls, examination of the carbonyl intensity as a function of particle size indicates the presence of a thin oxygenated interface layer. Additionally, in studies on controlled burns of biomass fuels, we observed a striking range in particulate matter produced. Current studies examine changes in carbon bonding during charring that could influence the determination of elemental carbon/organic carbon. These studies have formed the base for recent work on physical and chemical transformations of collected particles aged in the outflow from Mexico City. Such studies have the potential to improve our understanding of the composition of organic particles and their environmental processing.

Surface tension of dilute to highly concentrated inorganic electrolyte solutions at tropospheric and stratospheric temperatures

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

Knowledge of surface tension is central to accurate predictions of cloud droplet activation and nucleation. However, limited attention has been given to the value of surface tension for ubiquitous inorganic electrolyte solutions under atmospheric conditions, where instances of supersaturation or supercooling are present. In this work, a semi-empirical model for calculating surface tension of atmospherically relevant inorganic aqueous solutions has been developed, based on solution mixing and solute-structure formation properties. The resultant surface tension model for the inorganic electrolytes will be integrated with a study of aerosol density that has just been completed as part of our project, and then incorporated into the Extended Aerosol Inorganics Model and made available on the web (Clegg and Wexler, Wexler and Clegg 2002). The electrolytes studied are HCl, HNO3, H2SO4, NaCl, NaNO3, Na2SO4, NaHSO4, Na2CO3, NaHCO3, NaOH, NH4Cl, NH4NO3, (NH4)2SO4, NH4HCO3, NH4OH, KCl, KNO3, K2SO4, K2CO3, KHCO3, KOH, CaCl2, Ca(NO3)2, CaSO4, MgCl2, Mg(NO3)2, and MgSO4. With over 2000 experimental surface tension values from the literature for single salt solutions, the average error between the model and experimental surface tension is $< 1\%$. Model parameters for > 10 mixed electrolyte solutions were also determined, with an average error near 1.5 %. Unlike other models, this model extrapolates smoothly to temperatures as low as 150 K over the entire concentration range from infinitely dilute to the theoretical supercooled melt. Additionally, theoretical molten surface tension properties extrapolated to low temperatures for salts with no experimental molten data have been estimated by relating known molten salt surface tension properties to properties such as ion valency, melting temperature, salt molar volume, and ion radius.

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

Clegg, SL, and AS Wexler. Extended Aerosol Inorganics Model (E-AIM). http://www.aim.env.uea.ac.uk/aim/aim.php.

Wexler, AS, and SL Clegg. 2002. “Atmospheric aerosol models for systems including the ions H+, NH4+, Na+, SO42−, NO3−, Cl−, Br− and H2O.” Journal of Geophysical Research 107: D14.

Synergisms between ozone and nitrate radical chemistry in the formation and composition of secondary organic aerosol

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Michael Ezell, University of California
Stanley Johnson, University of California
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Lizabeth Alexander, Pacific Northwest National Laboratory
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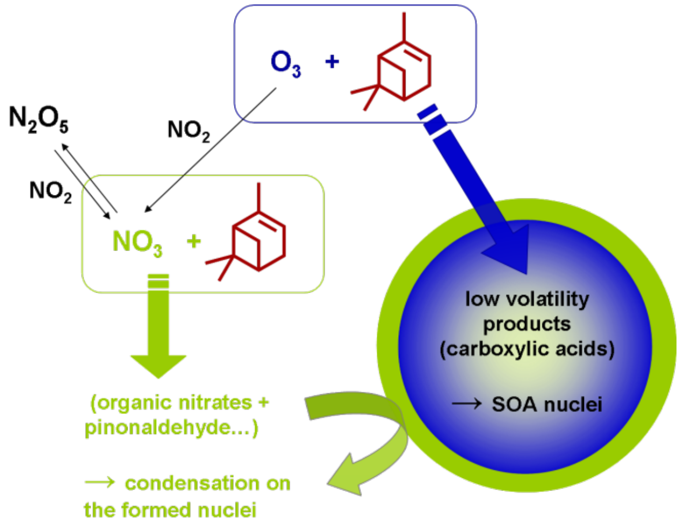
The three major atmospheric oxidants involved in the formation of SOA from biogenic volatile organic compounds are O3, OH, and NO3. While O3- and OH-initiated oxidation are most important during the day, NO3 radical-initiated oxidation is a major contributor to the nighttime chemistry of volatile organic compounds in the troposphere. The reaction of biogenic hydrocarbons with NO3 is relatively fast (for example, the lifetime of α-pinene is only ~11 min at 2.5 x 10^8 NO3 molecules cm-3), so this reaction is expected to be a major sink for organics at night and also to contribute to the removal of NOx from the atmosphere. Furthermore, it has the potential to form SOA of different composition (e.g., containing organic nitrates) than the ozone and OH oxidations. Previous studies by other groups have shown that the SOA yield from the NO3 reaction is relatively small due to the high volatility of the reaction products. However, studies to date have been in relatively simple systems where NO3 was the sole oxidant, which is not necessarily representative of atmospheric conditions. We report the results of experiments designed to probe the influence of O3 on particle formation and composition in the NO3 oxidation of α-pinene. The experiments were performed in a unique large diameter, high-volume, slow-flow tube using the reaction of NO2 with O3 as the source of NO3 radicals. Particle size distributions were measured using a scanning mobility particle sizer (SMPS) and an aerodynamic particle sizer (APS). Real-time aerosol mass spectrometers (SPLAT-II and AMS) as well as integrated collection of particles on ZnSe impaction disks and quartz fiber filters were used to characterize the chemical composition of the particles. Organic nitrates were major components of the particles at high ratios of NO2/O3 but decreased as this ratio decreased. The particle size distribution also shifted from a very few-but-large particle distribution to a numerous-much-smaller particle distribution. In addition, the formation of low vapor pressure products such as carboxylic acids was observed due to the increasing contribution from the ozonolysis of α-pinene. The results of these experiments suggest that organic nitrates may contribute more to SOA than expected, based on oxidations carried out using NO3 in the absence of other SOA-forming reactions such as ozonolysis reactions, and may potentially modify particle properties such as water uptake and their ability to act as CCN.



Schematic representation of the α-pinene oxidation reactions and resulting particle composition observed in this study using NO2+O3 as the source of NO3 radicals.

Thermodynamic properties and gas/particle partitioning of atmospheric amines

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

Amines can be emitted into the atmosphere from a variety of sources, such as animal husbandry, industrial operations, and oceans. They are also among one of the important groups of organic species in atmospheric aerosols and a rare class of bases (Saxena and Hildemann 1996). However, relatively little is known about the atmospheric chemistry of amines and how they may lead to particle formation. We present a general overview of the present knowledge of amines, with respect to atmospheric sources, emission fluxes, detection in ambient air, and atmospheric behaviors such as gas-phase reactions, gas-to-particle conversion, wet deposition processes, and health effects. Additionally, information about atmospheric occurrence and reactivity of amino acids and urea in the atmosphere are also reviewed since these are closely related compounds. 154 amines and 32 amino acids have been identified in the atmosphere. We evaluate the thermodynamic properties of atmospherically relevant amines with special regard to the gas/particle partitioning, such as Henry Law's constant, acid-dissociation constant, vapor pressure, solubility, and activity coefficient. Those data will be incorporated into our E-AIM web interface (Extended Aerosol Inorganic Model, Wexler and Clegg 2002), so that users can add additional amines to the model for the gas/aerosol partitioning calculations of their interests. Finally, we estimated the dissociation constants and their variation with temperature and relative humidity (RH) of atmospherically relevant aminium salts, such as aminium chloride and nitrates, and their likely competition with ammonium salts on gas/aerosol partitioning.

Saxena, P, and LM Hildemann. 1996. "Water-soluble organics in atmospheric particles: A critical review of the literature and application of thermodynamics to identify candidate compounds." *Journal of Atmospheric Chemistry* 24: 57-109.

Wexler, AS and SL Clegg. 2002. "Atmospheric aerosol models for systems including the ions H+, NH4+, Na+, SO42-, NO3-, Cl-, Br- and H2O." *Journal of Geophysical Research* 107(D14): 4207.

Toward closure of absorption and scattering by complex aerosols at high humidities: equipment benchmarking results

Benjamin Brem, University of Illinois at Urbana-Champaign
Tami Bond, University of Illinois
Mark Rood, Illinois State Water Survey

This project entails closure studies between predictions of optical properties, including absorption, for biomass combustion aerosols mixed with inorganic material. Novel components of this project include: (1) changes in both absorption and scattering with humidity; (2) optical properties at relative humidities up to 95%, which are usually extrapolated rather than being confirmed; and (3) examination of aerosol from wood pyrolysis—representative of most of the primary atmospheric organic carbon—mixed with inorganic particles. This year's activities focused on benchmarking the optical instrumentation, iterating those tests with improvements in optical instrumentation, obtaining stable humidification, developing automated interfaces for determining closure, and exploring measurements to characterize organic aerosol. This report outlines the benchmarking of the instrumentation under dry (8% RH) and wet conditions (up to 92% RH). The dry benchmarking results with ammonium sulfate aerosols show promising signal stability and an approximate light absorption detection limit of 42 Mm-1 at 532 nm. The wet benchmarking results show good performance of the extinction cell at high humidities. Measurement of scattering at high humidities has been hindered by a previously reported challenge: heating of the sample volume by the light source, limiting our measurement of scattering response to 78% RH. Remedies for this heating are currently under investigation. Work in the immediate future (remainder of the second project year) will include benchmarking and closure studies with well-characterized absorbing aerosol in addition to the first measurements of organic aerosols from biomass combustion.

4.0 Atmospheric State & Surface

Atmospheric characterization using ground-based and satellite infrared spectral radiance measurements

William Smith, Hampton University
Michael Howard, National Securities Technology
Jian Yongxiao, Hampton University
Melissa Yesalusky, Hampton University

The ASR-related research concerns the development and testing of new atmospheric profiling algorithms to be applied to: (1) ground-based U.S. DOE Atmospheric Sounder Spectrometer for Infrared Spectral Technology (ASSIST) and Atmospheric Emitted Radiance Interferometer (AERI) radiance spectral radiance measurements, and (2) the combination of downwelling radiance spectra measured with the ground-based instruments with the upwelling top of the atmosphere spectral radiance measurements obtained with the Aqua Advanced Infrared Sounder (AIRS) and MetOp Infrared Atmospheric Sounding Interferometer (IASI) satellite instruments. The objective is to obtain the highest possible vertical resolution atmospheric temperature and water vapor profiles from the surface to 50 km. The results are compared with those achieved by the ground-based measurements alone and with the satellite-alone measurements in order to identify the limitations of each type of profile input into atmospheric characterization models.

Comparative analysis of temperature inversion and influences of aerosols using ARM data in Shouxian and SGP

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Zhanqing Li, University of Maryland
Hongbin Chen, Institute of Atmospheric Physics, Chinese Academy of Sciences

Low-level atmospheric temperature inversions frequently occur at middle and high latitudes, and their heights are commonly lower than 700 hpa. They influence the depth of vertical mixing in the boundary layer, cloud formation, aerosol transport, and surface radiation balance. In 2008, the ARM Mobile Facility (AMF) was deployed in China and acquired high temporal and spatial resolution radiosonde data at Shouxian for nearly eight months. Through statistical analysis of radiosonde and aerosol data, we obtained statistical characteristics and monthly variation of temperature inversions and aerosols in Shouxian. We also analyzed the temperature inversions and aerosols using ARM data obtained at SGP during the same period. The results show that: (1) temperature inversion frequency in Shouxian is less than that of SGP, but Shouxian's inversions are more frequent in high altitude, (2) the layer of inversion near ground at Shouxian is thinner than that of SGP, and the rate of inversion temperature increased at Shouxian is greater, and (3) surface-based inversions directly affect aerosols transport and resulted in high concentrations of aerosols at both sites. At noon, the frequency of temperature inversions in Shouxian and SGP were 42% and 62%, respectively, under the clear-sky conditions, their heights near 2000 m.

Comparisons of Raman lidar water vapor measurements and aircraft data

Erin Wagner, University of Wisconsin-Madison
David Turner, University of Wisconsin-Madison
Larry Berg, Pacific Northwest National Laboratory

The Raman lidar at the Southern Great Plains (SGP) site measures water vapor mixing ratio, as well as other constituents, at a maximum sampling rate of 10 s and 7.5 m vertical resolution. This is averaged to produce low-noise 10-s, 75-m resolution measurements, which are capable of resolving the major portion of turbulent motions in the convective boundary layer. While it is important to maintain the maximum temporal sampling rate possible, there is a trade-off in the selected vertical resolution on sampling error vs. random noise. This study investigates the optimal vertical resolution of the Raman lidar for calculating higher order moments of water vapor mixing ratios in the turbulent boundary layer. In addition, we compare the SGP Raman lidar water vapor measurements and the derived moments (i.e., variance and skewness) as a function of altitude to the Diode Laser Hygrometer (DLH) measurements collected during the Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO) experiment. Of the numerous RACORO flights that occurred between January and June 2009, 16 were designed to capture turbulence information as a function of height through the boundary layer over the SGP site. Water vapor moments derived from the DLH data collected during these missions will be compared against the collocated Raman lidar measurements to evaluate the methodology used to derive the moments from the Raman lidar data.

Developing a testbed at the ARM Climate Research Facility for coupled climate-carbon cycle model evaluation

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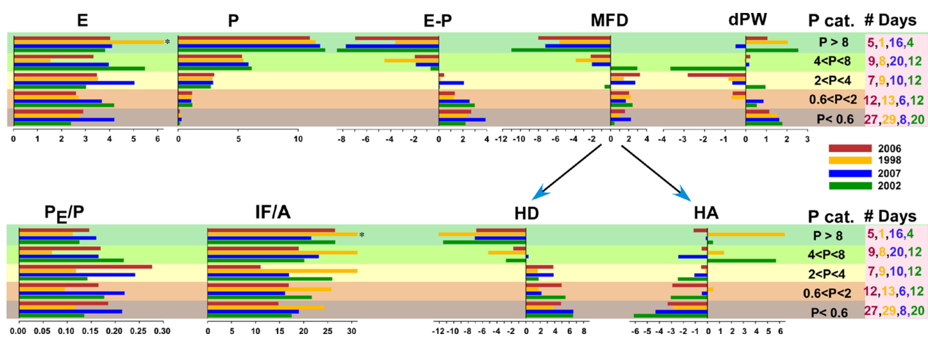
William Riley, Lawrence Berkeley National Laboratory
Sebastien Biraud, Lawrence Berkeley National Laboratory
Marc Fischer, Lawrence Berkeley National Laboratory
Dave Billesbach, University of Nebraska–Lincoln
Joseph Berry, Carnegie Institution of Washington

Climate simulations for the Fifth Assessment Report of IPCC (AR5) will utilize Coupled Climate-Carbon Cycle models (C4 models). Unfortunately, the terrestrial carbon components of these models are largely untested, particularly in coupled mode. Testing the coupled model performance requires both new data products and validation protocols. The Berkeley Lab/ARM Carbon is measuring terrestrial fluxes of CO2, water, and energy as well as concentrations of greenhouse gases and their isotopes from the surface to 15,000 feet above sea level, in the Southern Great Plains. We are also collaborating with NASA and JPL in estimating whole-column CO2 by upward-looking Fourier Transform Spectrometry. In this poster we describe our work to make the ARM Climate Research Facility a preeminent facility for evaluating C4 models by integrating carbon cycle observations, forcing data, site information, and modeling analysis. By combining our efforts with other ASR and ARM efforts, we will create a testing platform for many carbon and non-carbon components of C4 models. Our focus will be on daily to multi-year time scales rather than dynamic vegetation and other long-term processes. The model-testing data sets may become a value-added product (VAP) for the ARM Climate Research Facility. In the first phase of this work we are focusing on testing the land-surface component of C4 models. We have collected AmeriFlux type data in grassland, wheat, and other dominant land-cover types, and have tower and aircraft data for concentrations, as well as observations of soil temperature and moisture, plant biomass, and 13C in soil and vegetation. These data will be used to test model predictions of plant physiological function (e.g., water-use efficiency, light-use efficiency), diurnal and seasonal cycles in land-surface C and energy exchanges, Bowen ratio, and land-surface responses to cloud type and cover. The models will be compared to regional-scale estimates we have made using a highly tuned land-surface model. In the second phase, we will provide data to test the fully coupled models. Coupled runs will be performed in both regional (e.g., WRF-CLM) and global (e.g., CCSM) climate models. Consistent boundary forcing will be specified for all the regional climate models (e.g., from reanalysis). Predictions of trace-gas concentrations, temperature, humidity, and radiation will be compared to ARM's extensive atmospheric observations.

Investigation of Southern Great Plains atmospheric moisture budget for CLASIC

Peter Lamb, University of Oklahoma
Diane Portis, University of Oklahoma/CIMMS

The Cloud and Land Surface Interaction Campaign (CLASIC) was conducted over the Southern Great Plains (SGP) ARM Climate Research Facility during June 2007. One of the primary foci of the CLASIC Science Plan is to understand the interactive roles of horizontal moisture advection and land surface processes for cumulus convection.



Area-averaged daily moisture budget components for May–June periods stratified by precipitation category for larger-scale study region encompassing the SGP. The red (yellow) bars are for the dry 2006 (1998); the blue bars are for the wet 2007; and the green bars are for the average 2002. The number of days in a particular precipitation category for each May–June period is shown on the extreme right using the same color scheme. There was only one case in the extreme precipitation category of P > 8 for 1998. The asterisks indicate larger values than shown for E (7.8 mm/day) and IF/A (62.0 mm/day).

Our moisture budget analysis for CLASIC, conducted over an expanded region surrounding the SGP during CLASIC and three other contrasting May–June periods, provides a bulk approach for relating cloud properties to larger-scale atmospheric conditions. Record-breaking rainfall during CLASIC led to a uniformly saturated land surface, marking an extreme condition over the SGP that heavily damaged the maturing winter wheat crop. In our study, we included three other contrasting May–June periods: 2006 with extreme dryness over the SGP; 1998 with extreme upstream dryness over Texas; and 2002 with a more normal rainfall regime over our entire study area. Despite the large variation in rainfall and land surface cover among all four study periods, our investigation revealed fundamental commonalities among their moisture budget components and related variables. The figure shows these moisture budget terms composited by rainfall amounts (P). For daily P < 4 mm/day (the P categories of most relevance to CLASIC), there is moist horizontal advection (HA < 0) and horizontal velocity divergence in the presence of moisture (HD > 0). As P rises above this level, HD decreases dramatically and becomes convergent, indicating stronger synoptic forcing. This increase in the HD contribution to the total moisture convergence is accompanied by a decrease in the HA contribution. This paradoxical decrease in moist horizontal advection with increasing P can be explained by a very small phase difference between HA and P. Also shown in the figure is a recycling estimate (PE/P) that uses the equation developed in our recent Midwestern moisture budget study (Zangvil et al. 2004) where PE is the P derived from local evapotranspiration. Our moisture recycling methodology involves the advected and locally evapotranspired origins of P being expressed in terms of an inflow/outflow (“bulk”) formulation that is defined at the boundaries of the study area and not in terms of the more traditional moisture flux divergence (“process”) formulation. The recycling ratios for P < 4 mm/day are consistently higher for 2007 when there was copious rainfall and a saturated land surface.

Merged sounding VAP version 2.0

David Troyan, Brookhaven National Laboratory
Michael Jensen, Brookhaven National Laboratory
David Turner, University of Wisconsin-Madison
Larry Miloshevich, National Center for Atmospheric Research

The merged sounding value-added product (VAP) has been in the ARM and ASR pipeline since 2001. Output datastreams have been added to the Evaluation Products section of the ARM website for the past five years. Currently, there are data for all of the ARM fixed sites and all deployments of the Mobile Facility. Fifty-three years of merged sounding data is available as an evaluation product. The process of moving all data to the ARM Data Archive has been started and will be completed shortly. A second version of the merged sounding VAP was developed to address several concerns: (1) Vaisala radiosondes have inherent problems obtaining an accurate measurement of relative humidity, (2) the profile can be extended from 20 km to 60 km above ground level based upon the height achieved by ECMWF profiles, and (3) ECMWF temperatures require adjustments at high altitude (between 1 mb and 100 mb). Solutions to these issues have been incorporated in the new version of this VAP. Along with producing that second version of merged sounding, a secondary datastream—Sonde Adjust—was created. This VAP incorporates any humidity corrections to the Vaisala RS-80, RS-90, and RS-92 radiosondes. The algorithms used to perform these corrections are documented by Wang et. al. (2002), Turner et. al. (2003), and Miloshevich et. al. (2004, 2009).

A multi-year record of airborne continuous CO2 in the U.S. Southern Great Plains

Sebastien Biraud, Lawrence Berkeley National Laboratory

We report on two years of airborne measurements of continuous atmospheric CO_2 concentrations over the Atmospheric Radiation Measurement (ARM) Climate Research Facility in the U.S. Southern Great Plains. Measurements are made weekly from a small aircraft (Cessna 206) on a series of horizontal legs ranging from 5000 to 300 m above sea level. Since November 2007, more than 100 continuous CO_2 vertical profiles have been collected, along with NOAA/ESRL 12-flask (carbon cycle gases and isotopes) packages for cross-validation. Gradients between the mixed layer and free troposphere varied seasonally, reflecting variations in surface fluxes and large-scale vertical and horizontal transport. Horizontal variability in CO_2 concentration near the top of the boundary layer indicates that convective mixing may be more important than diurnal entrainment processes in vertical PBL-FT exchange. We focus on resolving vertical transport, which is poorly constrained in many atmospheric models.

New updraft retrievals for TWP-ICE and comparison with dual-frequency profiler measurements

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Alain Protat, Bureau of Meteorology
Peter May, Bureau of Meteorology
Christopher Williams, CIRES/NOAA Aeronomy Laboratory
Kao-Shen Chung, McGill University, Atmospheric and Oceanic Sciences

As the use of cloud-resolving models (CRMs) to verify parameterization schemes in global climate models increases, so does the importance of validating the dynamical and microphysical schemes within the CRMs. The Tropical Warm Pool-International Cloud Experiment (TWP-ICE) produced a data set for the initialization and forcing of numerical simulation of deep convective storms as well as an extensive set of measurements. Previously reported radar-based retrievals of updraft intensities from TWP-ICE indicated low (< 1m/s) vertical velocities within intense updrafts at cloud base. An enhanced retrieval technique, which includes a correction for sub-radar convergence, has been implemented, and initial retrievals over the wet monsoon period of TWP-ICE return more realistic cloud base vertical velocities, ~2 m/s within the intense convective cores. To provide some validation of the technique, a comparison between updrafts retrieved from the radar-based radial velocity measurements and those retrieved from a dual-frequency (920/50 MHz) profiler system was performed, showing good agreement. Percentile curves of retrieved vertical velocity show weaker updrafts than those produced in CRM simulations for the same period of TWP-ICE, a difference that is the subject of future investigation.

Pentad analysis of summer precipitation variability over the Southern Great Plains and its relationship with the land-surface

Sumant Nigam, University of Maryland

State-of-the-art atmospheric models are currently unable to simulate the multi-decade record of summer hydro-climate variations in an AMIP mode, even when anomalies are averaged over a large spatial domain (e.g., the million square-kilometer-plus Great Plains). At the center of the problem is the fact that when trying to explain summer precipitation variability, some of those models tend to prioritize local atmosphere-land-surface interactions, via evapotranspiration, over the remote effect of sea surface temperatures, via moisture fluxes. The problem is that observations indicate that at seasonal and monthly resolutions the priority of those processes is the other way around. Those differences are associated with different surface heat balances in models and observations. As a first step to understanding those differences, the present work focuses on the nature of atmosphere-land-surface interactions over the Great Plains in summer, but at pentad resolution, in order to better establish spatio-temporal relationships among the different variables. It is found that the interaction is characterized by more than one mode of variability at pentad resolution. One of those modes is associated with precipitation anomalies centered over the Southern Great Plains, although the maximum is slightly shifted to the east. When excessive precipitation occurs over the region, surface air temperature, evaporation, and net surface radiation are also reduced. An east-west gradient is apparent in the structure anomalies of evaporation and net surface radiation indicating the radiative control of evaporation.

Sources of tropical mid-tropospheric water vapor and its role in controlling deep convection

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Annette Foerster, Monash University
Laura Davies, Monash University

In recent years it has become apparent in numerous studies that the amount of rainfall in tropical regions is strongly non-linearly related to the vertically integrated water vapor content of the atmosphere. This relationship has prompted the development of a number of simple models of the interaction of water vapor and tropical convection. More recently it has been hypothesized that while low-level processes likely control the occurrence of convection, the amount of rainfall and by association the strength of convection is controlled by the amount of water vapor in the mid-troposphere. This raises the question of which processes are primarily responsible for moistening the middle troposphere and hence providing the environment for strong convection. Likely candidates are horizontal or vertical advection, and non- or weakly precipitating convection of limited vertical extent. In this study we use a long-term data set of the large-scale and subgrid-scale state of the atmosphere derived using the standard variational analysis technique developed at ARM's TWP Darwin site. Using this long-term data set, we first show that this location is representative for the earlier findings on the water-vapor rainfall relationship. We then demonstrate the main source of water vapor for the mid-troposphere prior to heavy rainfall is vertical advection by the mean flow, and not as is often postulated, moistening by non-precipitating convection. Our findings are consistent with the notion that heavy rainfall (and hence strong convection) requires significant dynamical "forcing" to occur.

Using ASR observations to quantify the seasonal influence of stratiform mixed-phase clouds on Arctic sea ice growth rates

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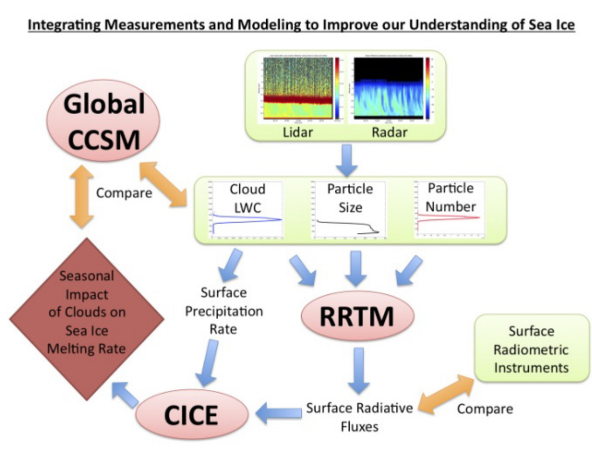
William Collins, Lawrence Berkeley National Laboratory
Edwin Eloranta, University of Wisconsin
Surabi Menon, Lawrence Berkeley National Laboratory
Elizabeth Hunke, Los Alamos National Laboratory

Single-layer stratiform clouds are commonly observed at high latitudes (de Boer et al. 2009, Shupe et al. 2006, others). Recently several papers have linked record minimum sea ice coverage in part to anomalous patterns in low cloud coverage (e.g., Kay et al. 2008). Low-level mixed-phase clouds may impact sea ice growth/melting rates via their influence on the atmospheric radiation budget as well as through frozen precipitation they produce. These influences are naturally variable by season, dependent largely upon sun angle and atmospheric temperature. In this study, we plan to utilize multiple years of cloud observations from



A graphical overview of the proposed study.

surface-based remote sensors at Barrow, Alaska (United States Department of Energy Atmospheric Radiation Measurement [U.S. DOE ARM] North Slope of Alaska site) and Eureka, Canada (National Oceanographic and Atmospheric Administration and Canadian Network for the Detection of Arctic Change/Study for Environmental Arctic Change [NOAA/CANDAC SEARCH] program) to derive seasonal estimates of surface radiative and precipitation fluxes using measured cloud properties such as liquid water content, ice water content, precipitation rate, temperature, and cloud depth. The radiative flux estimates are obtained with the help of an atmospheric radiative transfer model (RRTM, Clough et al. 2005) and tested for a limited number of cases using radiometer data from the NSA site. Finally these fluxes, along with relevant temperature and precipitation information, are used to drive the Los Alamos Sea Ice Model (CICE, Hunke and Lipscomb 2008) to determine the influence of these clouds on sea ice growth rates. We will present an overview of the proposed work, along with some preliminary results and a vision for future investigations involving other cloud types.

5.0 Cloud Properties

A 4D cloud water content product derived from operational satellite data for ARM

William Smith, NASA Langley Research Center
Patrick Minnis, NASA Langley Research Center
Mandana Khaiyer, Science Systems and Applications, Inc.
Rabindra Palikonda, Science Systems and Applications, Inc./NASA Langley Research Center
Douglas Spangenberg, Science Systems and Applications, Inc.
Helen Yi, Science Systems and Applications, Inc./NASA Langley Research Center
Kris Bedka, NASA

Together, the CALIPSO lidar and the CloudSat cloud profiling radar are providing unprecedented data describing the vertical structure of cloud systems across the Earth. While these instruments provide excellent vertical resolution along the satellite track, they are non-scanning, and by themselves do not provide the three-dimensional representation of clouds over large areas needed for a variety of applications. Thus, it is desirable to try and extend the unique information provided by CloudSat and CALIPSO in time and space in order to improve the characterization of clouds in four dimensions. In the approach taken here, characteristic or climatological cloud water content (CWC) profiles are derived from CloudSat data for a variety of cloud types. A future version of this analysis will incorporate new data products from CALIPSO. The cloud types are defined by cloud parameters typically retrieved from operational satellite data, such as the cloud temperature (Tc), cloud water path (CWP), and geometric thickness (DZ). This information is used in a retrieval system to derive CWC profiles from operational satellite imager data that are constrained by the retrieved CWP and DZ. The technique is demonstrated over the SGP using cloud properties derived routinely for ARM from Geostationary Operational Environmental Satellite (GOES) data and tested with independent CloudSat data. This encouraging new 4D product has a number of potential applications for the ARM community, including the improved description of atmospheric radiative heating and the evaluation of cloud process models on regional scales. Because the product can be produced in near real-time, it also has potential for assimilation into forecast models. A strategy for accomplishing this will also be discussed.

Analysis of cloud condensation nuclei concentrations measurements during the AMF deployment in China

Jianjun Liu, University of Maryland

Cloud microphysical properties, as well as optical and radiative properties, depend on atmospheric concentrations and spectra of cloud condensation nuclei (CCN). CCN concentration is the most important factor affecting cloud microphysics properties. During the ARM Mobile Facility (AMF) deployment in China in 2008, cloud condensation nuclei (CCN) measurements were made at the Shouxian site, which is located in eastern China, from 26 July to 31 October. The average CCN concentrations were 215±132, 369±178, 454±275 1/cm3 at a supersaturation of 0.20 for August, September, and October, respectively. Corresponding CCN/CN ratios were 0.125±0.078, 0.158±0.106, 0.074±0.098 at SS=0.20. During the whole observation period, the air masses over Shouxian were continental. The diurnal variation of CN and CCN showed that there were two peaks at about 8:00 am and 18:00 pm and 9:00 am and 19:00 pm, respectively, when human activities were intense. A significant increase in CCN concentration with increasing CN was measured, especially at higher SS. The relationship between CN, CCN, and CCN/CN are found to be significantly influenced by air mass and meteorological conditions.

Analysis of cloud layer structure using radiosonde and cloud radar data in China

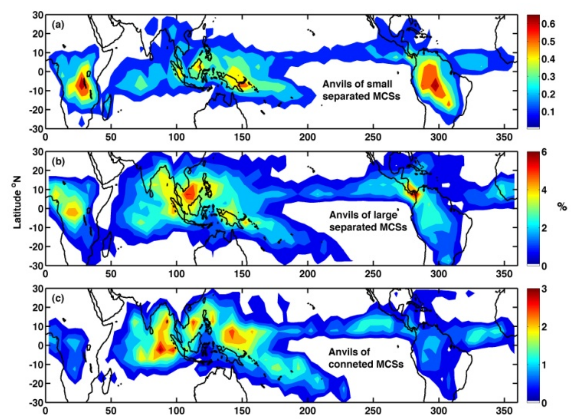
Jinqiang Zhang, Nanjing University of Information Science & Technology
Hongbin Chen, Institute of Atmospheric Physics, Chinese Academy of Sciences
Zhanqing Li, University of Maryland

The Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF) was deployed in Shouxian, Anhui Province, China, from May 14 to December 28, 2008. With reference to the cloud structure as detected by ground-based 95 GHz radar operated for 2.5 months, radiosonde data obtained during the AMF campaign are used to analyze cloud vertical structure over this area for the entire 8-month period of AMF deployment. Single-layer, two-layer, and three-layer clouds account for 28.0%, 25.8%, and 13.9% of all cloud configurations, respectively. Low, middle, high, and deep convective clouds account for 20.1%, 19.3%, 59.5%, and 1.1% of all clouds found at the site, respectively. The average cloud-base height, cloud-top height, and cloud thickness for all clouds are 5912 m, 7639 m, and 1727 m, respectively. The thicknesses of all layers in two-layer and three-layer clouds are less than that of a single-layer cloud with an average difference of -867 m. The maxima of cloud-top height and cloud thickness occurred at 13:30 Local Standard Time (LST) for single-layer and uppermost-layer of multiple layers. They occurred at 19:30 LST for the lower-layer clouds in multiple-layer cloud systems. The diurnal variations in the thickness of upper-level clouds are larger than those of lower-level clouds. In general, the thickness of cloud layers does not change from summer to autumn, but multi-layer clouds occurred more frequently in the summer. The absolute differences in cloud-base heights from radiosonde and those from the micropulse lidar (MPL) and ceilometer are less than 500 m for 77.0%/69.4%, respectively.

Anvil clouds of mesoscale convective systems and their effects on the radiative heating structure

Jian Yuan, University of Washington
Robert Houze, University of Washington

Mesoscale convective systems (MCSs) are objectively identified from the combination of three A-Train satellite instruments: MODIS, AMSR-E, and CloudSat. Active MCSs consisting of rain cores and anvil clouds are further divided into two types: separated MCS (SMCS) and connected MCS (CMCS). Combining these three types of A-Train data allows us not only to identify MCSs, but also to separate their non-raining anvils from their raining regions. By separating anvils from the raining regions of MCSs, we are able to have quantitative



Annual mean (2007) climatology of anvil clouds associated with (a) small separated MCSs (< 12000 km^2, the smallest 25%), (b) large separated MCSs (> 40000 km^2, the largest 25%), and (c) connected MCSs. The color indicates percentage of area covered by MCS anvil clouds for each 5°x5° grid.

global maps of anvil coverage (see figure). These maps show that anvil clouds associated with small SMCSs are often found over land areas including continents and large islands, but the total coverage is small with maxima (~0.6%) over Africa and South America. In contrast, anvil clouds from large SMCSs are favored over warm oceans, and they cover several times more area overall than do small SMCSs. Anvil clouds from CMCSs are also common over open ocean areas, with most of them occurring over the Indian Ocean, Bay of Bengal, South China Sea, and West Pacific warm pool. CloudSat radar data are used to characterize the vertical and internal structures of anvil clouds. With the CloudSat data we find that anvil cloud profiles from MCSs are of two major types: light rain and non-raining profiles. The former consist of a deep-cloud mode and a multiple-layers mode with raining clouds below high-topped clouds. The latter are dominated by thinner high-topped clouds with elevated bases. In addition to MCSs, we have determined the global pattern of non-MCS anvil clouds. The mapping of anvils accomplished in this study lays a foundation for calculations of radiative effects of these anvil clouds. Preliminary radiative heating calculations applied to the anvil clouds identified in this study, as expected, show net radiative warming in the upper troposphere over areas covered by anvil clouds. This warming is a combination of shortwave warming concentrated in the upper part of anvil clouds and longwave cooling in the upper portion of the anvil and some warming near cloud base. More comprehensive investigations of the radiative heating structure of tropical anvil clouds from both MCSs and non-MCSs are in progress and, when applied to the maps of anvil coverage, will show the global pattern of anvil-cloud radiative heating.

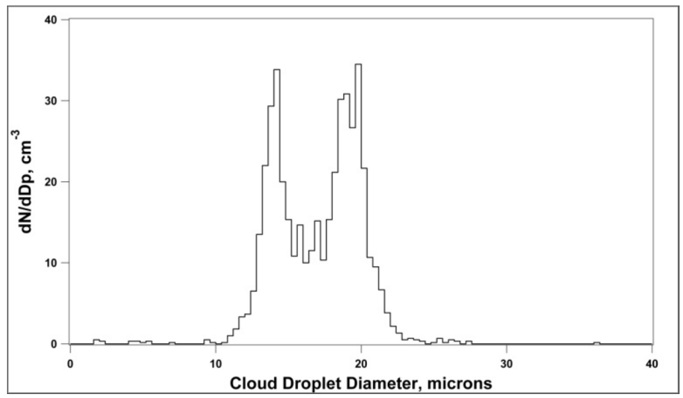
Atmospheric classification at Darwin

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

Unlike numerical weather prediction models, general circulation models do not make predictions of what the weather will be at a particular point in time, thus making direct moment-to-moment comparison to observations impossible. Instead, observations and model output must be temporally averaged over long periods to create statistical distributions of both observations and model output, which can then be compared to each other. While comparing these averages is often effective in determining the presence of errors in the model, it generally provides little insight on the source of the errors. Not being able to identify when or under what conditions the errors occur makes it difficult to understand which physical processes are not being properly represented in the model and, in turn, what corrective measures should be taken. To avoid this problem, we classify observations into a number of large-scale atmospheric states, as defined by a neural network pattern recognition program. Averaging of both observations and model output is then done within each category. With this method, when errors appear between the observed and modeled averages for a particular atmospheric state, the physical circumstances which produced the error are known, helping to identify the physical processes which are insufficiently represented by the model. Previous work by Marchand and coauthors (*Journal of the Atmospheric Sciences* 2006 and *Journal of Climate* 2009) has shown that the approach works well over the U.S. Southern Great Plains. However, the classifier struggled to find statistically meaningful states during the summer. This raised questions as to the effectiveness of the technique for convective atmospheres. Here, we apply the classification to Darwin, Australia, and explore the sensitivity of the method to a variety of inputs. We use two years of ECMWF reanalysis data for a region surrounding Darwin as our input to the classifier, and then create vertical cloud occurrence profiles for each state using data from the vertically pointing millimeter radar at the U.S. Department of Energy ARM Climate Research Facility site at Darwin as a diagnostic tool. In particular, we explore the importance of domain size, horizontal resolution, and input variable selection to the states created. We show that, with only minor variations, this method produces a robust set of states independent of the precise input configuration.

Bimodal cloud droplet distributions in marine stratus clouds observed in VOCALS 2008

Gunnar Senum, Brookhaven National Laboratory



A bimodal cloud droplet distribution, the small-sized distribution at 13.9 μ (diameter) and the larger at 18.9 μ. Both have a relative dispersion of about 0.07. This a 100-meter long sample taken on 10/18/2008 near cloud top at 1320 feet at -18.5 lat and -75.3 long. The LWC was 0.54 g/m3. The bimodal distribution regions of the marine stratus clouds extend up to 12 km in spatial extent.

The spectral or relative dispersion (ε) of cloud droplet distributions affects the formation of precipitation, cloud lifetime, and cloud albedo. Presently there are many differing models relating the relative dispersion to these cloud microphysical properties, but none with bimodal distributions. Bimodal cloud droplet distributions (as shown in the figure) were observed in many instances in the marine stratus clouds in the east Pacific off the coast of Chile during the VOCALS 2008 campaign. These bimodal distributions were measured by a CAPS probe with an improved particle-by-particle (PbP) feature. This allowed the size of every cloud droplet to be measured, supplanting the binned data channel of the CAPS probe. The bimodal cloud droplet distributions were discovered by the increased PbP cloud droplet sizing resolution. These bimodal cloud droplet distributions tended to be present in low turbulence and minimal vertical velocity regions, that is, acquiescent regions, of the marine stratus clouds. These bimodal distributions had individual relative dispersions of about 0.07 in the droplet size maxima distribution. The overall dispersion was more than twice that of the individual peaks. They were observed near cloud top. As the liquid water content (LWC) increases, the smaller-sized distribution decreases in cloud particle number and larger increases until at some LWC, the smaller distribution completely disappears. The opposite occurs with decreasing LWC. The smaller cloud droplet diameter ranged from 13 to 17 μ and the larger from 18 to 23 μ. They also were seen only in regions with LWC between 0.3 and 0.6 g/m3. Other microphysical properties also play a role in the formation and properties of these bimodal distributions, such as interstitial aerosol concentration and drizzle. The formation of these bimodal distributions has been thought to be caused by collisional coalescence and/or entrainment and mixing processes in marine stratus clouds. Further work will examine the various models to see if these bimodal distributions significantly change the formation of precipitation, cloud lifetime, and albedo of marine stratus clouds compared to the previous assumed unimodal cloud particle distributions.

Browsing a wealth of millimeter-wavelength Doppler spectra data

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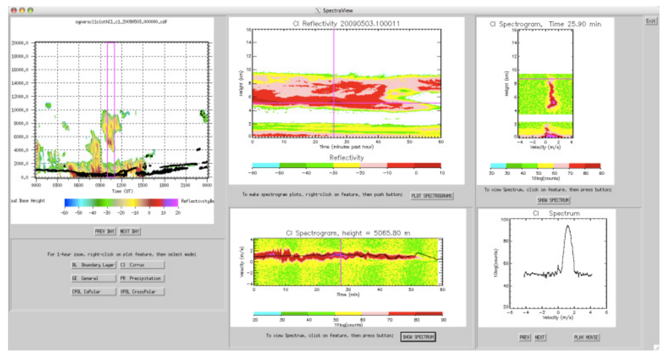
Kevin Widener, Pacific Northwest National Laboratory
Michael Jensen, Brookhaven National Laboratory

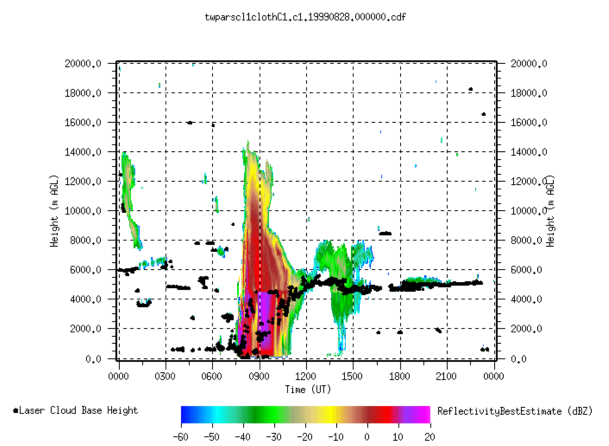
The ARM Climate Research Facility has collected an extensive archive of vertically pointing millimeter wavelength Doppler radar spectra at both 35 and 95 GHz. These data are a rich potential source of detailed microphysical and dynamical cloud and precipitation information. The recording of spectra, which is ongoing, began at the Southern Great Plains site in September of 2003, at the North Slope of Alaska site in April 2004, and at Tropical Western Pacific sites in 2006. Spectra are also being collected during ARM Mobile Facility deployments. The data's temporal resolution is as high as two seconds, at height intervals of 45 to 90 m. However, the sheer volume of available data can be somewhat daunting to access and search for specific features of interest. Here we present a user interface for spectra browsing, which allows the user to view time-height images of radar moments, select a time or height of interest, and then "drill down" through images of spectrograms to individual Doppler spectra or time- and height-sequences of spectra. Also available are images summarizing spectral characteristics, such as number of spectral peaks, spectral shape information (skewness and kurtosis), moment uncertainty estimates, and hydrometeor vs. clutter identification as produced by the ARM MicroARSCL (Microphysical Active Remote Sensing of Clouds) value-added product. In addition to the access and visualization tools, we are developing a Doppler spectra simulator capable of generating Doppler spectra from liquid, mixed-phase, and solid cloud constituents and precipitation. The Doppler spectra simulator can be used as an interface between explicit microphysics models and Doppler spectra observations from the ARM radars. The plan is to ultimately make the spectra simulator available from within the spectra browser, allowing a user to associate observed spectra with the microphysical conditions capable of producing them.



Snapshot of Spectra Browser application.

Characterization of melting-level clouds over the Tropical Western Pacific warm pool

Michael Jensen, Brookhaven National Laboratory
Jacob Billings, Florida Agricultural and Mechanical University
Karen Johnson, Brookhaven National Laboratory
David Troyan, Brookhaven National Laboratory
Chuck Long, Pacific Northwest National Laboratory
Jennifer Comstock, Pacific Northwest National Laboratory



ARSCL best estimate radar reflectivity above the ARM site on Manus Island. Note the attendant shelf cloud situated between approximately 1700 and 2300 hours.

A cursory examination of historical ARSCL data indicates a common cloud feature in the tropics are thin detrainment shelves (Attendant Shelf Clouds, or ASCs) near the melting level (see figure for example). We use the ARSCL product to identify ASCs by defining them as cloud layers with bases above 4 km, a corresponding top below 6 km, and a thickness of less than 1 km. In order to prevent biases in determination of the diurnal cycle of cloud occurrence, we require that both the MMCR and MPL are operating well. In this study we use a total of 55 months of data collected over 14 years of deployments at the Manus, Nauru, and Darwin ARM sites in the Tropical Western Pacific to define the frequency of occurrence (~14% of the time) and diurnal cycle of these clouds, along with the atmospheric thermodynamic profile. We further investigate the horizontal extent, cloud radiative forcing, and cloud particle phase through a series of “golden cases” where there is a general absence of additional cloud types in the column and nearby deep convection. These cases indicate that the clouds can cover horizontal areas on the order of a GCM gridbox, have significant (but not always) cloud radiative forcing, and may be composed of liquid or ice water.

A climatology of tropical mid-level clouds

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Sally McFarlane, Pacific Northwest National Laboratory
Jennifer Comstock, Pacific Northwest National Laboratory

Tropical mid-level clouds are challenging to observe, but rich in possibilities for increasing our scientific understanding. The ARM TWP measurement sites are well suited for studying these clouds because of the frequency of mid-level clouds at these locations and the instrumentation available. Here we use a new merged lidar and radar data set to present a climatology of tropical mid-level clouds. This combined instrumentation allows a comprehensive picture of the frequency and macrophysical characteristics of mid-level clouds. Mid-level clouds fall in the mixed-phase region and have a complex relationship between mid-level cloud occurrence, the stable layers at the freezing/melting level, and convection. We examine the properties of clouds that are detected by both the radar and lidar and those that can only be detected by the lidar separately. These cloud types have different microphysical and macrophysical properties. Both cloud types show multiple peaks in cloud top and base height distributions. Preliminary results show that both cloud types are more predominant at night than during the day, though this varies by season.

Cloud-mode optical depth observations—example of adaption of ARM to AERONET

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Alexander Marshak, NASA Goddard Space Flight Center
Warren Wiscombe, Brookhaven National Laboratory
Yuri Knyazikhin, Boston University
C. Stefani Huang, NASA Goddard Space Flight Center/Science Systems and Applications, Inc.
Ilya Slutsker, NASA Goddard Space Flight Center/Sigma Space Corporation
David Giles, NASA Goddard Space Flight Center/Sigma Space Corporation
Brent Holben, NASA Goddard Space Flight Center

Cloud optical depth is one of the most poorly observed climate variables. A dramatic increase in the number and accuracy of cloud optical depth observations is crucial both for validation and improvement of climate model predictions. The ARM sunphotometer, identical to those used in AERONET, was originally designed to measure aerosol properties. When clouds block the sun, the radiometer is placed into sleep mode. We propose to use some of this idle time to monitor clouds and have dubbed this new operational mode “cloud-mode.” We will compare cloud-mode optical depth retrievals with those from the MODIS satellite instrument and from ARM ground-based shortwave flux, microwave, and cloud radar measurements. We will also show how cloud-mode is being adapted to work within AERONET, which will expand observations of cloud optical properties to the global scale.

Cloud-scale vertical velocity composites of fair-weather cumuli at the SGP ARM Climate Research Facility

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Pavlos Kollias, McGill University
Bruce Albrecht, University of Miami

Over land, shallow cumuli coverage is small, yet significantly affects the global radiation budget. This shallow mode of convection over land also plays an important role in the preconditioning of deep convection through the regulation of the heat and moisture transport in the lower troposphere. Records of vertical velocity measurements in fair weather cumuli from aircraft penetrations and ground-based cloud radars have exhibited great variability in 1D and 2D with often an updraft core and downdrafts near cloud edges reported. Our aim here is to develop composites (observational models) of the dominant (most frequently observed) vertical velocity structures in fair-weather cumulus (e.g., investigate if downdrafts are prominent near the cloud edges, if penetrative downdrafts are present, or if updraft structure extends from the cloud base to the cloud top). This study uses high temporal and spatial resolution cloud radar (35/94 GHz) measurements at the Southern Great Plains (SGP) ARM Climate Research Facility during summer months. This study differs from previous studies that look at macroscopic properties of fair-weather cumuli by documenting several vertical velocity statistics per cloud entity using normalized cloud depth and width. This detailed documentation could lead to the development of a scheme for the classification of shallow clouds to active/passive and to investigate the impact of entrainment of cloud structure.

Cloud macrophysical and optical properties derived from micropulse and Raman lidar over SGP Site

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Active remote sensing such as lidars or radars can be used with other data to quantify the cloud properties at regional scale and at global scale (Dupont et al. 2009). Lidar remote sensing is sensitive to very thin and high clouds but has a significant limitation due to signal attenuation in the ability to precisely quantify the properties of clouds with a cloud optical thickness larger than 3. In this study, 10 years of backscatter lidar signal data are analyzed by a unique algorithm called STRAT (Morille et al. 2006). We apply the STRAT algorithm to data from both the collocated micropulse lidar (MPL) and a Raman lidar (RL) at the ARM SGP site between 1998 and 2009. Raw backscatter lidar signal is optimized, and dead-time, overlap, and after-pulse corrections are taken into account. The cloud properties for all levels of clouds are derived, and distributions of cloud base height (CBH), top height (CTH), physical thickness (CT), and optical thickness (COT) from regional statistics are compared. The goal of this study is (1) to establish a climatology of macrophysical and optical properties for all levels of clouds observed over the ARM SGP site and (2) to estimate the discrepancies induced by the two remote sensing systems (pulse energy, sampling, resolution, etc.). Our first results tend to show that the MPLs, which are the primary ARM lidars, have a distinctly limited range of usable lidar signal, especially during summer daytime period (only 50% of usable lidar signal at an altitude of 7 km). Consequently, the MPL-derived annual cycle of cirrus cloud base (top) altitude is biased low, especially for daylight periods, compared with those derived from the RL data, which ranges from 7.5 km in winter to 9.5 km in summer (from 8.6 to 10.5 km). The optically thickest cirrus clouds (COT > 0.3) reach 50% of the total population for the Raman lidar and only 20% for the micropulse lidar due to the difference of pulse energy and the effect of solar irradiance contamination. A complementary study using the cloud fraction derived from the micropulse lidar for clouds below 5 km and from the Raman lidar for cloud above 5 km allows for better estimation of the total cloud fraction between the ground and the top of the atmosphere. The study presents the diurnal cycle of each cloud fraction for each season in comparisons with the Long et al. (2006) cloud fraction calculation.

A comparison framework to evaluate TWP-ICE cloud-resolving simulations with observations

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Edward Zipser, University of Utah
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Ping Zhu, Florida International University
Jean-Pierre Chaboureau, University of Toulouse/CNRS, France
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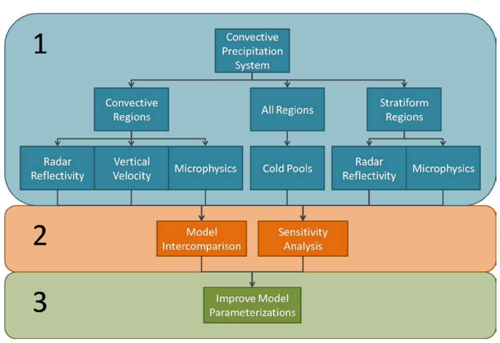
Jimy Dudhia, National Center for Atmospheric Research
Adrian Hill, NOAA

A range of different model simulations have been performed for the monsoon period of the Tropical Warm Pool-International Cloud Experiment (TWP-ICE) as part of the Cloud Resolving Model (CRM) Intercomparison Study (Fridlind et al. 2009) and Limited Area Model (LAM) Intercomparison Study. A model-versus-observations comparison framework, shown in the figure, has been developed to establish inconsistencies between simulated and observed oceanic tropical convective properties. This framework is unique in that convective scale and mesoscale properties are compared as opposed to domain-averaged quantities. C-band polarimetric radar (CPOL) reflectivity is compared to simulated radar reflectivity in six CRM simulations and two LAM simulations for convective and stratiform regions separately. Three CRM simulations employ one-moment microphysics schemes: DHARMA, Meso-NH, and UKMO. There are also a Meso-NH simulation and SAM simulation that use a two-moment scheme and one DHARMA simulation that uses a bin scheme. For the LAM simulations, one run employs the new Thompson microphysics scheme in WRF, and the other uses the WSM6 scheme. Differences between observed reflectivity and model-simulated reflectivity are then further investigated in two ways. First, updraft and downdraft vertical velocity statistics are compared with dual Doppler radar results. Second, microphysics characteristics are compared with the CPOL microphysics species algorithm and drop-size distribution (DSD) retrievals. Cold pool and gust front properties are also compared with surface station observational data. Section 1 of the framework can be made more robust as more observations and model analyses are added, which is one objective going forward. A second aim is to begin Section 2 of the analysis, which involves model-versus-model comparisons of several properties to aid understanding of the results of Section 1. Ultimately, the third and final goal is to utilize results from Sections 1 and 2 to improve model parameterizations on all scales, especially within but not limited to bulk microphysics schemes, for use in modeling tropical oceanic convection.



The model-versus-observations comparison framework consists of three sections, the first of which is addressed in this study. In Section 1, the model precipitation systems are separated into convective and stratiform regions. Radar reflectivity, vertical velocity, and microphysics are compared in the convective regions, while radar reflectivity and microphysics are compared in stratiform regions. Cold-pool properties spanning both regions are also examined. Yet to be started are Sections 2 and 3. Section 3 consists of further examining results of Section 1 through model-versus-model comparisons and sensitivity analyses. The ultimate goal is to improve model parameterizations in Section 3.

A comparison of cloud microphysical quantities with forecasts from cloud prediction models

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Robin Hogan, University of Reading
Ewan O'Connor, University of Reading
Michael Jensen, Brookhaven National Laboratory
Dong Huang, Brookhaven National Laboratory

Numerical weather prediction models (ECMWF, NCEP) are evaluated using ARM observational data collected at the Southern Great Plains (SGP) site. Cloud forecasts generated by the models are compared with cloud microphysical quantities, retrieved using a variety of parameterizations. Information gained from this comparison will be utilized during the FASTER project, as models are evaluated for their ability to reproduce fast physical processes detected in the observations. Here the model performance is quantified against the observations through a statistical analysis. Observations from remote sensing instruments (radar, lidar, radiometer, and radiosonde) are used to derive the cloud microphysical quantities: ice water content, liquid water content, ice effective radius, and liquid effective radius. Unfortunately, discrepancies in the derived quantities arise when different retrieval schemes are applied to the observations. The uncertainty inherent in retrieving the microphysical quantities using various retrievals is estimated from the range of output microphysical values. ARM microphysical retrieval schemes (Microbase, Mace) are examined along with the CloudNet retrieval processing of data from the ARM sites for this purpose. Through the interfacing of CloudNet and ARM processing schemes, an ARMNET product is produced and employed as accepted observations in the assessment of cloud model predictions.

A comparison of GOES cloud optical property retrievals with ground- and satellite-based reference data from SGP

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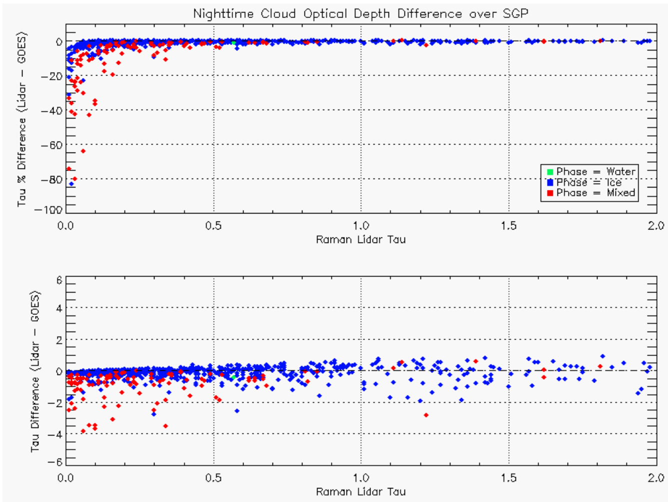
Patrick Minnis, NASA Langley Research Center
Mandana Khaiyer, Science Systems and Applications, Inc.
Patrick Heck, University of Wisconsin

Daytime and nighttime cloud optical properties (optical depth, effective radius, and liquid/ice water path) have been retrieved from geostationary satellite data starting with GOES-8. The retrievals are based on a legacy algorithm that was developed at NASA Langley Research Center for the CERES (Clouds and the Earth's Radiant Energy System) project and have been applied to data from GOES, AVHRR, MODIS, MTSAT, and MSG. In addition to being available in real time from NASA, these products are available from the ARM Data Archive at pixel-level resolution over a 10 degree by 14 degree lat/lon area centered over the SGP Central Facility at Lamont, Oklahoma. This poster summarizes the efforts currently underway at NASA Langley to assess the accuracy and reliability of both the daytime and nighttime cloud optical property retrievals from GOES. Comparisons are made with ground-based reference data from SGP (Raman Lidar and Microwave Radiometer), as well as retrieval products from other satellite platforms (CLOUDSAT, CALIPSO). Results are separated by day/night, satellite platform, and cloud phase.



Nighttime cloud optical depth from GOES-8 and GOES-10, compared with Raman lidar data from the SGP Central Facility. Included are nearly 800 data points from May 1998 through January 2004. This comparison suggests reasonable agreement between the Raman lidar and satellite retrievals for ice clouds; however, it highlights that there are some difficulties with water clouds.

Comparison of the CALIPSO satellite and ground-based observation of cirrus clouds at the ARM Tropical Western Pacific (TWP) sites

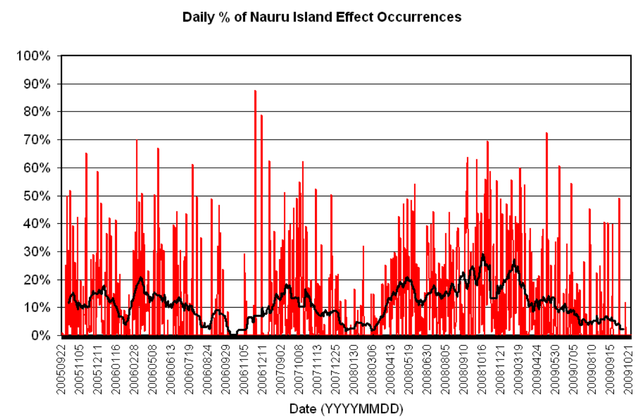
Tyler Thorsen, University of Washington
Jennifer Comstock, Pacific Northwest National Laboratory
Qiang Fu, University of Washington

A reliable data set of cirrus cloud properties is necessary in order to quantify cloud radiative effects in the tropical tropopause layer (TTL). Thin cirrus clouds occur frequently in the TTL region, and their optical depths are commonly below the minimum detectable threshold of imaging radiometers and radars. Therefore, lidar observations are required to obtain a complete set of TTL cirrus cloud properties. In the TWP, we have two lidar options for observing the region: the ground-based ARM micropulse lidar (MPL) and the CALIOP instrument on board the CALIPSO satellite. Data sets from the ground-based MPL at the ARM TWP sites Manus, Nauru, and Darwin and data sets from the CALIPSO satellite are examined for consistency in ice and TTL cloud properties. Included in our comparison are cloud top and base heights, cloud thickness, number of cloud layers per profile, and optical depth. We will explore potential causes of the noted discrepancies between the two data sets.

Detection of the occurrence and impacts of the Nauru Island effect

Chuck Long, Pacific Northwest National Laboratory
Sally McFarlane, Pacific Northwest National Laboratory

During the Nauru99 Experiment (http://www.arm.gov/campaigns/twp1999nauru), results indicated that Nauru Island had some influence on the Nauru ARM Climate Research Facility measurements that are intended to represent the surrounding oceanic environment. These results spurred the Nauru Island Effect Study campaign (Long 2001) where data were used to determine the character of the Nauru Island influence (Matthews et al. 2007) and develop a methodology given "upwind" measurements to detect when an island influence was occurring (McFarlane et al. 2005). The two largest cloud effects are shown to be a high bias in the frequency of occurrence of low-level cloudiness and a low bias on the downwelling shortwave irradiance (with a corresponding increased variability), both occurring during daylight hours, since the island effect is primarily driven by solar heating of the island. To provide long-term measurements needed for detection of the island effect occurrence, a set of Licor pyranometers were installed at a location near the airport on the southern part of Nauru Island, with the data record starting on September 22, 2005. A system failure resulted in an 8-month data gap from January into August 2007 and another 3-month gap from late November 2008 into mid-February 2009. We have coded up the island effect detection algorithm and processed the available data through October 2009. A plot of the percent of daily daylight-detected island effect occurrence is shown here. A primary intent of these efforts is for the TWP Site Scientist's office to provide ARM data users with information on the occurrences and impacts of the island effect as an aid in understanding and using the Nauru data. We will present an updated analysis of the occurrence of the Nauru Island effect, as well as analyses of the impact on various measurements at the Nauru ARM site.



Time series (September 2005–September 2009) of the daily relative percent of occurrence (red) of an island influence on the measurements at the Nauru ARM site as determined by the McFarlane et al. (2005) methodology. Black line represents a 30-day running mean.

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Development of a data set to explore properties of tropical convection and anvil cirrus

Sally McFarlane, Pacific Northwest National Laboratory
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Tropical convective clouds are important elements of the hydrological cycle and produce extensive cirrus anvils, which strongly affect the tropical radiative energy balance. In most current climate models, the optical properties of anvil cirrus are only weakly linked to the properties of the convective clouds that generate them. To improve simulations of the global water and energy cycles and accurately predict cloud radiative feedbacks, models need more realistic links between the relationships between the properties of convective clouds and the cirrus clouds they generate. We will present a data set developed by identifying and tracking tropical convective systems (and their associated anvils) in the tropical western Pacific using geostationary satellite observations. The database will also contain information on the macrophysical properties of the convective system (size, age, intensity) and microphysical properties of the associated anvil (water path, particle size). For systems that cross over the ARM sites, information on convective intensity (from C-Pol) and anvil properties (from MMCR/MPL) will also be obtained. Once the data set has been compiled, relationships between the properties of convection and cirrus clouds in the observations and those simulated by regional and global models can be examined to evaluate the model parameterizations.

Dissecting diabatic heating profiles from TWP-ICE

Courtney Schumacher, Texas A&M University
Shaocheng Xie, Lawrence Livermore National Laboratory
Sally McFarlane, Pacific Northwest National Laboratory

Observations made during the Tropical Warm Pool-International Cloud Experiment (TWP-ICE), which took place in Darwin, Australia, in early 2006, are used to estimate the latent, radiative, and sensible heating profiles associated with the convective systems that occurred during the active and break periods of the Australian monsoon. The heating components are further isolated by storm type (MCS, hector, etc.) and dominant radar echo type (shallow convective, deep convective, stratiform, and non-precipitating anvil), as well as over the land and ocean regions surrounding Darwin, to highlight heating profile variations associated with storm and environmental properties. The goal of this work is to have a more comprehensive understanding of the different components of total diabatic heating of tropical cloud systems and how they relate to one another.

The diurnal cycle of the boundary layer, convection, clouds, and surface radiation in a coastal monsoon environment (Darwin, Australia)

Peter May, Bureau of Meteorology
Alain Protat, Bureau of Meteorology
Chuck Long, Pacific Northwest National Laboratory
James Mather, Pacific Northwest National Laboratory

The diurnal variation of convection and associated cloud properties remains a significant issue in climate models. This study analyzes observed diurnal variability of convection in a coastal monsoonal environment, examining the interaction of convective rain clouds, their associated cloud properties, and the impact on the surface radiation and corresponding boundary layer structure. The analysis uses data from TWP-ICE as well as routine measurements from the Darwin Bureau and ARM measurements. Both active monsoonal and large scale suppressed (break) conditions are examined.

The effect of aerosols on the onset of precipitation

Kathryn Boyd, Colorado State University, Atmospheric Science Department
Christian Kummerow, Colorado State University

This work examines the theory of the Second Indirect Effect of Aerosols by analyzing cloud properties at the onset of precipitation. Using data from three ARM mobile and permanent facilities, cloud properties are statistically correlated with several environmental factors, including CCN (cloud condensation nuclei) concentration and dynamical attributes such as stability and wind speed, in order to determine the effects of aerosols on the onset of precipitation, as well as whether these effects are dependent on dynamical situations. Cloud lifetimes and thicknesses are tracked alongside CCN concentrations in order to determine their effect on these cloud properties. Drop-size distributions, liquid water contents, water vapor contents, and rain rates within the cloud (retrieved from a W-band radar reflectivity) are statistically correlated with CCN concentrations to determine any possible relationships between them. In order to increase the robustness of the results, these analyses will be performed on many cases from three sites spaced around the globe, therefore also testing the robustness of the Second Indirect Effect Theory.

Effects of ice nucleation and crystal habits on the dynamics of Arctic mixed-phase clouds

Muge Komurcu, The Pennsylvania State University
Jerry Harrington, The Pennsylvania State University

Both climate and weather prediction models produce results that are inconsistent among them and that do not match the observations in the Arctic. Some prior studies suggest that ice nucleation parameterizations are a primary reason for the mismatch between the observed and modeled cloud water contents. Recent findings also show that the choice of ice crystal habit in models leads to large differences in the partitioning of phase between liquid water and ice. In order to improve model predictions in the Arctic, it is important to identify the processes responsible for mixed-phase cloud development and persistence. In our study we examine the complex interactions between microphysics and dynamics that lead to persistent mixed-phase clouds. We investigate and inter-compare the impacts of different ice nucleation mechanisms and ice crystal habits on mixed-phase cloud evolution. Our preliminary studies show that although different nucleation mechanisms lead to different water paths, the difference in water paths caused by the choice of habits is greater. The amount of radiative cooling at cloud top and ice precipitation at the surface changes as the strength of ice production changes for different nucleation mechanisms, or as the in-cloud lifetime of an ice crystal changes for different habits. As a result, the cloud dynamics and cloud evolution differ for each habit and nucleation mechanism.

Estimating rain evaporation in convective systems from cold pool surface pressure perturbations

Steven Krueger, University of Utah
Andrew Lesage, University of Utah

Because convective cloud systems generally have strong interactions with boundary-layer circulations and thermodynamics, the boundary-layer wind and thermodynamic fields contain a great deal of information about convective cloud systems and their interactions with the boundary layer. We are in the process of “retrieving” this information from 15 years of 5-minute Oklahoma Mesonet data and hourly Arkansas Basin River Forecast Center (ABRFC) gridded precipitation data. We have already demonstrated that estimates of cloud base updraft and downdraft mass fluxes can be retrieved from the surface divergence field. We are currently developing a method to estimate rain evaporation in convective systems from cold pool surface pressure perturbations. In the 1950s, Fujita identified meso-highs in his mesoanalyses and linked them to cold pools produced by rain evaporation (Fujita 1959). We are extending Fujita’s (1959) method for estimating rain evaporation from the hydrostatic surface pressure anomaly and testing it with 3D cloud-resolving model simulations. CRM simulations (Krueger 1988, Tompkins 2001) suggest that the air in cold pools is partly ambient boundary-layer air and partly air from downdrafts. The air from both sources has been cooled by rain evaporation. In order to better understand the relationships between cold pools and downdrafts, we would like to determine the sources of cold pool air and their relative contributions. To do this, we need to estimate the amount of rain evaporation. Information about the sources of cold pool air may be gained by analysis of T, q, and h (moist static energy) of the cold pools, combined with knowledge of the downdraft source level and its thermodynamic properties, and the downdraft mass flux. Unfortunately, it is not easy to determine the downdraft source level(s). However, knowledge of the amount of rain evaporation can be used to close this problem.

Evaluation and improvement of NCEP global forecast system (GFS) using satellite retrievals

Hyelim Yoo, University of Maryland

There are several studies that reveal the horizontal distribution of clouds from the surface and from space-borne sensors. However, the vertical distribution and internal structure of clouds have not been resolved on global scales. As such, the majority of models were evaluated by comparing radiation measurements at the top of atmosphere (TOA) and total column cloud amounts instead of layered clouds. The objective of this study is to diagnose the performance of the NCEP GFS (global forecast system) model using different types of satellite retrievals. Comparisons were made against the merged CloudSat and Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) data and Atmospheric InfraRed Sounder (AIRS) for July 2007 and 2008. Several cloud parameters and meteorological variables were evaluated, including Cloud Vertical Fraction (CVF), atmospheric temperature vertical profile, the lowest cloud top, base height and its thickness, and relative humidity (RH). In general, the GFS captures reasonably well the patterns of hydrometeors and follows the general trends of satellite measurements, but has large discrepancies in vertical temperature and RH profiles. GFS model results are most comparable with the observation at upper level in the troposphere but overestimated approaching the surface.

Evaluation of cloud fraction parameterizations using long-term ARM observations

Zhenduo Zhu, Florida International University
Ping Zhu, Florida International University

Relative humidity (RH) is often used as a predictor for parameterizing sub-grid cloud fraction in general circulation models, such as CAM3. In this study, the cloud fraction parameterization based on RH is evaluated using 12-year ARM observations over Southern Great Plains (SGP) and Tropical Western Pacific (TWP). The atmospheric profiling is obtained from the ARM sounding. The diagnosed cloud fraction is then compared with the cloud fraction obtained from ARM Climate Modeling Best Estimate (CMBE). The diurnal, seasonal, and annual variations of the RH-based cloud fraction parameterization are examined. It is shown that the parameterization produced reasonable low and middle cloud fraction compared with the CMBE data. However, the parameterization significantly underestimates the cloud fraction of high clouds. We also explored how to use the long-term ARM data to evaluate other types of cloud fraction parameterizations.

An evaluation of GOES microphysical property retrievals at anvil regions of deep convection by using MMCR and NEXRAD

Zhe Feng, University of North Dakota
Xiquan Dong, University of North Dakota
Baike Xi, University of North Dakota
Patrick Minnis, NASA Langley Research Center

A new algorithm has been developed to perform automatic classification of deep convective systems by using data from U.S. DOE ARM measurements. The algorithm has been tested on major deep convective events of summer 2007 at the ARM SGP site. The major components of the data include ARSCL best-estimated and precipitation mode reflectivity, Doppler velocity from MMCR, rain rate from rain gauges close to MMCR, and merged sounding temperature from value-added products. The classification is performed every minute, giving a total of seven classes, including shallow cumulus, convective, stratiform with bright band, stratiform without bright band, transition from precipitating to non-precipitating cloud, mixed-phase anvil, and ice anvil. The similar technique developed from ARM instruments is then applied to the scanning radars (NEXRAD). The NEXRAD data are first objectively analyzed onto a Cartesian grid, followed by a two-step precipitation-cloud classification. While the MMCR classification provides accurate time-series profiles for NEXRAD to separate the precipitating and non-precipitating portion of the convective systems, the NEXRAD classification can provide a three-dimensional field of such systems. Direct time-series comparison between the MMCR and two nearby NEXRAD is performed to evaluate classification from NEXRAD. Applications of the NEXRAD classification to GOES satellite macrophysical and microphysical cloud property retrievals in regions of the mixed-phase anvil and ice anvil of deep convection will be shown to illustrate the potential of this technique to study continental deep convections.

Factors controlling boundary layer cloud fraction and mass flux at the ARM Nauru site

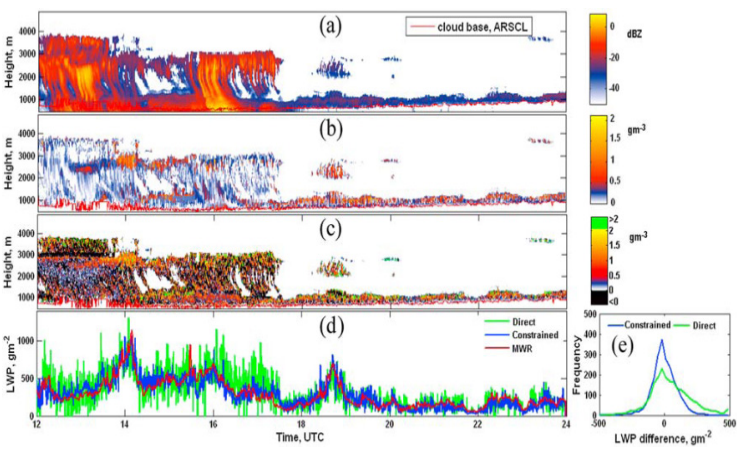
Bruce Albrecht, University of Miami
Virendra Ghate, Rutgers University
Pavlos Kollias, McGill University

The climatology of nighttime boundary layer clouds and surface turbulent fluxes estimated at the ARM Nauru site from January 1999–2001 has been studied within the context of a simple atmospheric mixed-layer representation of the sub-cloud layer applied to monthly averages. The period for this analysis is chosen since the nighttime winds observed at Nauru are very steady from the east during the entire observing period and very little precipitation was observed. It is shown that the mixed-layer formulation provides an excellent framework for representing the close coupling among sea surface temperature, wind speeds, atmospheric mixed-layer properties, and the sub-cloud layer radiative cooling. The monthly averaged low-cloud fractional cloudiness estimated from the ceilometer varies from 0.09–0.21 during this period. The fractional cloudiness is negatively correlated (-0.66) with the convective velocity scale (the Deardorff velocity) estimated from the surface fluxes and the sub-cloud layer depth. There is a positive correlation (0.60) between the monthly fractional cloudiness and the lower tropospheric stability (difference between the 700 mb and 1000 mb potential temperature) estimated using the soundings from the site; but there is a stronger negative correlation (-0.86) between the fractional cloudiness and the SST (upstream from Nauru). The cloud base cumulus mass fluxes for this time period have been calculated using the MMCR Doppler observations. The relationships between these fluxes and the fractional cloudiness, the convective velocity scale, and static stability at the top of the sub-cloud layer are being explored.

High-resolution retrieval of cloud liquid water profiles using the collocated ARM Ka- and W-band radars

Dong Huang, Brookhaven National Laboratory
Karen Johnson, Brookhaven National Laboratory
Yangang Liu, Brookhaven National Laboratory
Warren Wiscombe, Brookhaven National Laboratory

Most of the existing radar algorithms for retrieving cloud liquid water content (LWC) make use of empirical Z-LWC relationships that are based on various questionable assumptions. They work poorly under precipitating conditions, and the uncertainty in the retrievals is difficult to quantify. We have not seen much progress on these approaches for decades. On the other hand, the dual-frequency radar attenuation approach makes no assumptions about the cloud drop size distribution and is based on simple physics. Thus, this approach can provide accurate (unbiased) retrieval of cloud LWC. Previous studies showed that, however, the precision of the dual-frequency retrieval is very poor; either a long radar dwell time or averaging over many range gates is needed to improve the retrieval precision. This poster shows that, by virtue of advanced mathematical inversion techniques like total variation regularization, accurate retrieval of vertically resolved cloud LWC at high temporal and spatial resolution is achievable using operational cloud radars. The validity of this dual-frequency approach is demonstrated using the co-located Ka-band and W-band cloud radars operated by the Atmospheric Radiation Measurement (ARM) Climate Research Facility. The liquid water path calculated from the radars agrees closely with that from a microwave radiometer, with mean difference of 70 gm-2 for precipitating clouds and 30 gm-2 for non-precipitating clouds. Comparison with lidar measurements reveals that the dual-frequency retrieval also reasonably captures the cloud base height of drizzling clouds—something that is very difficult to determine from radar reflectivity alone. We have applied the dual-frequency approach to the ARM radar observations from 2006 to 2008 and have produced a three-year cloud LWC vertical profile data set.



Dual-frequency radar observations at the Southern Great Plains Central Facility site on May 6, 2006: (a) radar reflectivity factor at 95 GHz by the WACR with the ARSCL lidar cloud base shown as red line; (b) the dual-frequency radar cloud LWC retrieval using the constrained approach present in this letter; (c) the retrieval using the direct approach (Hogan et al. 2005). For better visualization, negative values are shown in black, and values larger than 2.0 gm-3 are shown in green. Note that the direct approach is designed only for high signal-to-noise ratio cases, or equivalently, low resolution. The comparison is only to show the benefits of the constrained approach for high-resolution retrievals. (d) Time series of the radar LWPs in comparison with the reference LWP from the microwave radiometer; (e) the histograms of the corresponding difference in LWP (radar LWP-MWR LWP).

Ice cloud microphysics and heating rate statistics at the tropical Darwin site

Jennifer Comstock, Pacific Northwest National Laboratory
Alain Protat, Bureau of Meteorology
Sally McFarlane, Pacific Northwest National Laboratory
Julien Delanoe, University of Reading
Min Deng, University of Wyoming

Tropical clouds play an important role in the radiative energy balance and can impact water vapor transport in the Tropical Tropopause Layer (TTL). Forecasting the future climate invariably depends on accurate prediction of clouds and their associated radiative feedbacks. Long-term data sets provide the cloud properties statistics needed to evaluate and improve climate model simulations. In this study, we present statistics of cloud microphysical properties and computed heating rates in ice clouds over a 3.5-year period at the ARM Darwin site. We will compare microphysical properties derived from several independent lidar-radar retrieval algorithms to understand the uncertainty associated with these properties and evaluate the impact of this uncertainty on our knowledge of the radiative forcing of tropical ice clouds.

Ice clouds size distributions (SDs), ice water content (IWC), and their dependence on temperature—what thousands of SDs tell us

Dorothea Ivanova, Embry-Riddle Aeronautical University

Ice clouds are an important factor affecting climate, and statistical properties of ice cloud microphysical parameters are of great importance for climate modeling. Cloud temperature is expected to be one of the main parameters governing cloud microstructure (Korolev et al. 2001). Ice cloud SDs' behavior and IWC values versus temperature were evaluated to demonstrate this sensitivity, using in situ data from several U.S. DOE ARM field campaigns. Ice particle size spectra parameters and IWC were averaged into five-degree temperature bins. Next, the effective diameter (Deff) was estimated as a function of temperature with ice particle shape assumptions for different cirrus cloud types. Several scenarios will be presented, dependent on geographic location where the measurements were made. SD shape (the dispersion, the degree of bimodality) for all scenarios will be specified, from which ice cloud radiative properties can be determined. These results may help improve the mid-latitude and tropical ice cloud parameterization schemes for GCMs.

Improvements in characterizing ARM cloud and radiation fields using satellite data

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William Smith, NASA Langley Research Center
J Ayers, NASA Langley Research Center/Science Systems and Applications, Inc.
Fu-Lung Chang, National Institute of Aerospace
Gang Hong, Science Systems and Applications, Inc.
Mandana Khaiyer, Science Systems and Applications, Inc.
Rabindra Palikonda, Science Systems and Applications, Inc./NASA Langley Research Center
Douglas Spangenberg, Science Systems and Applications, Inc.
Helen Yi, Science Systems and Applications, Inc./NASA Langley Research Center
Chris Yost, Science Systems and Applications, Inc.

Cloud and radiation properties derived from satellite data at NASA Langley Research Center provide an essential component of the ARM ensemble of measurements used for characterizing the radiation budget at a variety of scales. With the availability of ARM instruments in new locations, new value-added products (VAP), and new models of cirrus ice crystals, as well as new satellite data, it is possible to develop improved techniques for retrieving cloud properties. These properties include cloud vertical structure, liquid or ice water path, and optical depth. This paper summarizes improvements in the cloud retrievals over the fixed and mobile ARM sites. Multi-layer cloud retrievals have been implemented to analyze GOES-12 and Meteosat data. Cirrus cloud optical depths have been improved with changes in the retrieval code. MODIS data are being analyzed for the North Slope of Alaska. Variable snow-surface albedos are being tested to improve retrievals over snow surfaces. These and other changes are evaluated using other satellite data and comparisons with ARM surface-based measurements and aircraft in situ data. This paper will summarize the changes, potential new products, and assessments of the data quality.

http://www-angler.larc.nasa.gov/

Insights on water-ice partition in stratiform mixed-phase clouds based on long-term ARM observations

Zhien Wang, University of Wyoming
Ming Zhao, NOAA

Our poor understanding of ice generation in the atmosphere results in large uncertainties in simulating ice and mixed-phase clouds in weather and climate models. Recent analyses on global distribution of mixed-phase cloud distributions and IPCC inter-model differences in simulated cloud radiative forcing under doubling CO2 condition indicate that mixed-phase cloud representations in climate models contribute significantly to current climate predication uncertainties. A novel multi-sensor retrieval algorithm is applied to long-term ARM observations at the NSA site and provides an important data set to better understand stratiform mixed-phase clouds. Statistical results show that widely used temperature dependence of water-ice partition based on in situ observations from frontal clouds cannot represent the water-ice partition in this type of mixed-phase clouds. Significant difference in temperature dependence of water-ice partition is found between the spring season and the other seasons, which can be attributed to more effective ice generation and/or growth linked to high aerosol loading during the spring season over the Arctic region. Although temperature is an important controlling factor on water-ice partition in mixed-phase clouds, the water-ice partition in these stratiform mixed-phase clouds also depends on cloud

microphysical properties. These new insights provide important guidance on developing new mixed-phase cloud parameterization for large-scale models.

Likelihood function construction and Bayesian data fusion for analyzing cloud fraction data

Samuel Shen, San Diego State University
Jeff Ledahl, San Diego State University
Richard Somerville, Scripps Institution of Oceanography

Bayesian data analysis methodology has become popular in various fields, including climate science, for analyzing observed and modeled data, because it allows relaxed assumptions on the data distribution compared to the least squares approach, and because it outputs a probability density function called the posterior distribution. The posterior distribution is calculated from a prior distribution of the objective parameter under analysis, and a likelihood function, which may be regarded as a conditional distribution based on known data. This paper will discuss the construction of a likelihood function for cloud fraction observations derived from different instruments. In particular, ARSCL (Active Remotely-Sensed Clouds Locations) and TSI (Total Sky Imager) data over the ARM Southern Great Plains (SGP) site from 2001–2007 will be considered. It will be shown that the likelihood function can be modeled by a linear regression procedure and hence is a normally distributed function. However, the prior distribution of the cloud fraction is modeled by a two-parameter Beta distribution, due to the high frequencies of either near-complete coverage (overcast) or near-zero coverage (clear sky) of the clouds over the SGP. The posterior distribution yields not only the median value of the cloud fraction, but also the confidence set that quantifies the errors of merged data from multiple observational sources. The procedure has been applied to revise the cloud fraction data from CAM3 and hence to produce an approximation of a global cloud fraction climatology based on the fusion of the modeled and observed data by the Bayesian approach.

Measurement of ice crystal precipitation at cloud base

Edwin Eloranta, University of Wisconsin

Thin mixed-phase clouds are frequently observed in the Arctic. These often persist for days with nearly continuous, light precipitation. Models have difficulty maintaining these clouds and are very sensitive to micro-physical assumptions. Changes in microphysics yield variations of the removal of cloud water by ice crystal precipitation. This poster will describe the use of high spectral resolution lidar (HSRL) and millimeter wavelength cloud radar (MMCR) data to estimate ice water and ice particle number fluxes from cloud base. Sample data will be shown. A ratio formed from HSRL and MMCR backscatter cross sections provides a robust measurement proportional to the fourth root of the average mass-squared over the average area of the ice crystals. Using these ratios and Doppler velocities with an equivalent spheroid model for ice particles, we compute the ice water content in the precipitating ice. Multiplying the ice water content by the Doppler velocity generates the precipitation rate. The measured velocity is a sum of the particle fall velocity and the vertical air motion. Because these are both order 1 m/s, in the past, time averaging was necessary to suppress the air motion. However, slowly varying vertical motions, often caused by gravity waves, could not be removed by while maintaining structure in the ice fall streaks. Following the lead of previous investigators, we assume that the lowest frequency contributions to the MMCR Doppler spectra are produced by particles with negligible fall velocities so that they trace air motion. Time-average profiles of the vertical air motion show limitations of this approach. In regions of high turbulence, the Doppler spectrum is broadened by velocity variations within a single radar range bin.

This produces a small apparent mean upward vertical velocity. In regions where the radar return is very small, the vertical velocity shows a small mean downward motion. This indicates the absence of small-particle radar returns. To reduce these errors, we use a 1-hour mean vertical air motion profile to correct individual air motions. The derived air motions are subtracted from the Doppler velocities to derive the corrected fall velocity. This correction eliminates the need for time averaging and improves the capture of structure in ice fall streaks.

Microphysical relationships of clouds observed during March 2000 Cloud IOP at SGP site and important implications

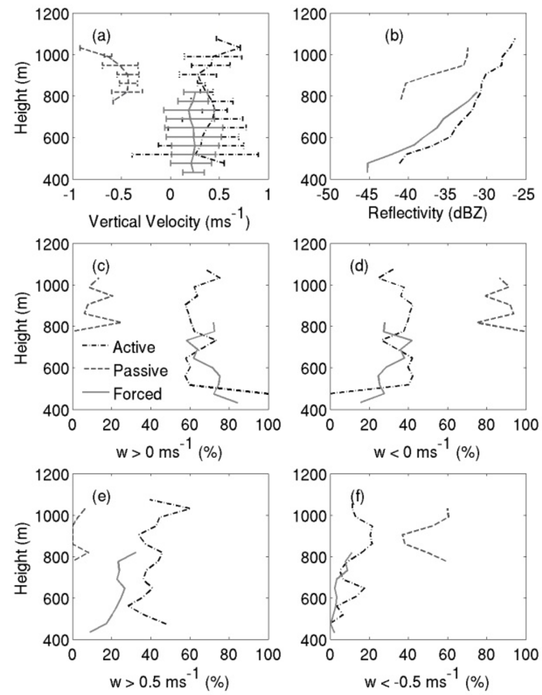
Chunsong Lu, Brookhaven National Laboratory
Yangang Liu, Brookhaven National Laboratory

Cloud droplet size distributions—hence the key microphysical quantities of climate importance (e.g., the total droplet concentration, liquid water content, relative dispersion, mean-volume radius, radar reflectivity, and effective radius)—are determined by different physical mechanisms such as pre-cloud aerosols, cloud updraft, and turbulent entrainment-mixing processes. Therefore, the relationships among these microphysical properties are expected to behave differently in response to aerosols, cloud updrafts, and turbulent entrainment-mixing processes. Identifying and quantifying the influences on these microphysical relationships of the various mechanisms is critical for accurately representing cloud microphysics in climate models and for reducing the uncertainty in estimates of aerosol indirect effects. This study first examines the characteristics of the relationships between relative dispersion droplet concentration, liquid water content, mean-volume radius, effective radius, and radar reflectivity calculated from in situ measurements of cloud droplet size distributions collected during the March 2000 Cloud IOP at the SGP site. The relationships are further analyzed to dissect the effects from different mechanisms/factors (aerosols, updraft, and different turbulent entrainment-mixing processes). Potential applications to improve radar retrievals of cloud properties will be explored as well.

Morphology and dynamics of non-precipitating marine fair weather cumulus clouds

Virendra Ghate, Rutgers University
Mark Miller, Rutgers University

Non-precipitating marine fair-weather cumulus clouds, or cumulus humilis, have a large impact on the boundary layer structure and on the earth's radiation budget. Due to their marine location, short lifetime, and small spatial scales, their observations still remain sparse. These clouds are further classified as forced, active, and passive clouds, based on their role of venting mixed-layer air into free troposphere, with each type having a distinct morphological and dynamical structure. The current deployment of Atmospheric Radiation Measurement (ARM)'s Mobile Facility (AMF) on the island of Graciosa in the Azores gives an opportunity to sample this important component of the climate system. Data from the vertically pointing W-band ARM Cloud radar (WACR) collected during a 10-hour period on 26 June 2009 are analyzed to understand the morphology and dynamics of these clouds. The WACR-observed cumuli are classified to identify 85 forced, 3 active, and 4 passive clouds. The mean in-cloud vertical velocities are found to be 0.22 ms-1, 0.38 ms-1, and -0.48 ms-1 within forced, active, and passive clouds, with an updraft fraction near cloud base of 80%, 60%, and 20%, respectively. Although the preliminary results are based on few samples, they are remarkably consistent with the expectations based on theory and highlight the need to distinguish between different fair-weather cumulus cloud types. The data available at the end of the two-year deployment offer the opportunity to characterize the morphology and dynamics of these clouds under variety of aerosol concentrations.



(a) Mean vertical velocity and the associated standard deviation, (b) mean reflectivity, (c) updraft fraction, (d) downdraft fraction, (e) updraft fraction conditionally sampled at 0.5 ms-1, and (f) downdraft fraction conditionally sampled at -0.5 ms-1 as a function of height for active, passive, and forced clouds.

Observing mixed-phase cloud microphysical-dynamical processes at Barrow

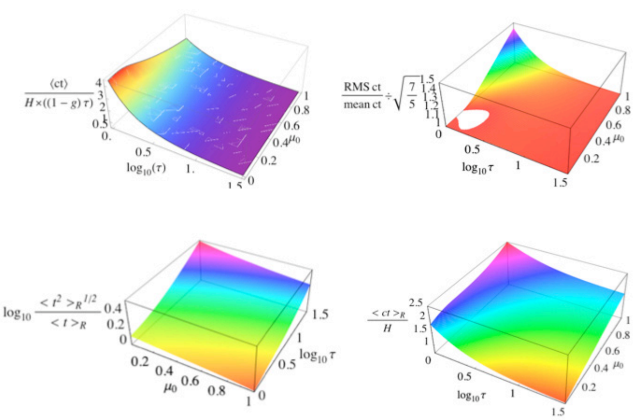
Matthew Shupe, University of Colorado

Low-level Arctic clouds are subject to a complex array of microphysical and dynamical processes that often result in layers of cloud liquid water that can persist for long periods of time, at temperatures well below freezing, even in the presence of cloud ice. These microphysical-dynamical processes, which operate at cloud scales, play a key role in determining the overall partitioning of condensate between liquid and ice phases and thereby determine the cloud microphysical composition. Phase partitioning and microphysical composition ultimately define the impact that clouds have on climatically significant processes such as the atmospheric radiation and hydrologic budgets. A suite of retrieval methods based on cloud radar, lidar, microwave radiometer, infrared spectrometer, and radiosondes have been applied to observations at the North Slope of Alaska site in Barrow to characterize important microphysical and dynamical properties of stratiform mixed-phase clouds. Signatures in derived vertical velocity and turbulence fields reveal important information about the forcing mechanisms that generate buoyancy-driven motions within the clouds. It is found that the characteristic scales-of-motion and the microphysical properties in these clouds are dependent upon the forcing mechanisms. Moreover, relationships between the liquid and ice microphysical properties and the vertical velocity suggest that ice formation within these clouds occurs through droplet-size-dependent mechanisms.

Oxygen A-band spectroscopy as a remote sensing capability for clouds, from both sides

Anthony Davis, Jet Propulsion Laboratory

Differential optical absorption spectroscopy (DOAS) of oxygen in its “A” band (~760 nm) has been demonstrated theoretically and observationally (e.g., field campaigns at the ARM SGP facility) as an exquisite diagnostic of spatial complexity in cloudiness. “Complexity” captures here any mix of multiple and/or horizontally broken layers, the essence of large-scale cloud “3Dness.” This makes O2-DOAS a powerful diagnostic of cloud-radiation interactions in the solar spectrum for the most challenging scenarios, e.g., for GCM shortwave radiation schemes. This has lead ARM to invest in the development of fieldable high-resolution A-band instruments, through both Science Team and SBIR efforts. Overlooked in this development is the opportunity for O2-DOAS to become a new modality in cloud property remote sensing, either stand-alone or in synergy with other cloud-probing sensors. The basic physics for the cloud 3Dness detection and remote sensing are the same. O2-DOAS is used to infer low-order moments of the integrated paths that sunlight takes between its source and its detection, either above or below the cloud. The length of this path is random, with a distribution determined primarily by the number of scatterings suffered in the clouds. For a



Let <(ct)^q>_F be the q-th moment of pathlength in transmission (F=T) or reflection (F=R). The upper left panel shows the ratio of _T to the product of cloud thickness H and scaled optical thickness, (1-g)tau, as function of SZA cosine (u_0) and log_10(tau); g is the phase function’s asymmetry factor. Knowing any two, one can compute the third quantity in the ratio. The upper right panel is the non-dimensional ratio of the root-mean-square (RMS) path, <(ct)^2>_T^(1/2), to its mean, further divided by its asymptotic value √7/5. We see here that the mean is a very good predictor of the RMS, so now new cloud parameters can be gleaned from higher moments for ground-based O2-DOAS, at least in this simple cloud geometry. Lower panels show RMS(ct)_R/_R and _R/H. The former ratio of O2-DOAS observables can be used to derive tau, knowing g and u_0, and the later can then be used to derive H from mean path length. O2-DOAS can thus be used as a standalone cloud probing modality from space.

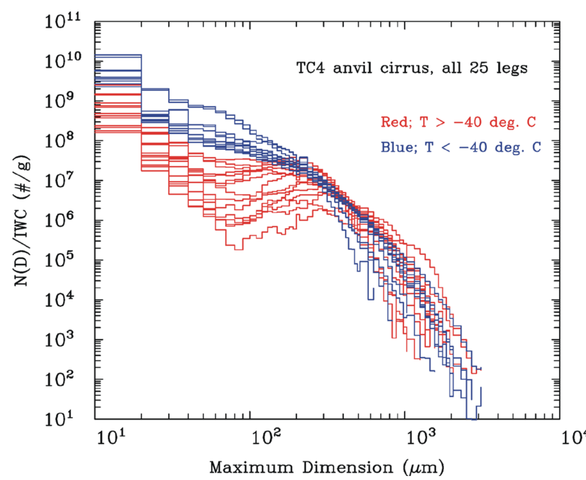
single unbroken deck, reasonably well-approximated by a plane-parallel slab, low-order moments of solar photon path length are known quantities. In diffusion regimes (optical thickness >~10), we have analytical functions of cloud thickness and optical depth. The present author has recently added to these expressions the effects of solar zenith angle, the presence of an overall internal gradient in cloud opacity, small-scale random fluctuations of droplet concentration, and gross deviations from slab geometry. The top panels in the figure demonstrate that, for ground-based O2-DOAS, one can confidently infer cloud thickness knowing its optical depth, or vice versa. When ARM acquires continuously operating A-band instruments, it will add robustness to its cloud profiling under all conditions. In contrast, from above, using diffusely reflected rather than transmitted light, stand-alone cloud property remote sensing is a possibility, since various path-length moments bring new pieces of information (cf. lower panels in figure). We are therefore excited about the re-flight of NASA's Orbiting Carbon Observatory (OCO), which has its own reasons for having hi-resolution O2-DOAS capability. It could be a cloud probe as well as CO2 monitor.

http://climate.gsfc.nasa.gov/publications/fulltext/Chap5_LSR4+ToC.pdf

Parameterizing anvil cirrus size distributions and ice sedimentation rates

David Mitchell, Desert Research Institute
Paul Lawson, SPEC Inc.

The life cycle of cirrus clouds depends strongly on their ice sedimentation rates, which have been difficult to characterize due to uncertainties in the concentration of small ice crystals. The 2D-S probe has the capability to remove ice artifacts (e.g., small ice particles produced by larger particles that shatter on the probe tips). The technique uses software processing and has measured the size-resolved number, area, and mass concentration of anvil and in situ cirrus particles during two recent field campaigns. These measurements have been used to develop the relationships needed for parameterizing Vf, the median mass-flux fall speed of the ice particle size distribution (PSD): (1) the ice particle projected area- and mass-dimension relationships and (2) a parameterization of the PSD. Regarding (1), these relationships appear fairly insensitive to temperature and cloud type (i.e., anvil cirrus, aged anvils, in situ cirrus, and turrets). Since ice water contents (IWCs) measured by the 2D-S agreed well with CVI-measured IWCs, IWCs predicted by these relationships should also be consistent with CVI measurements. Regarding (2), the PSD parameterization allows for bimodality, following the method published in Mitchell et al. (*Journal of the Atmospheric Sciences* 2010). The observed (aircraft leg-averaged) and parameterized PSD fall into two



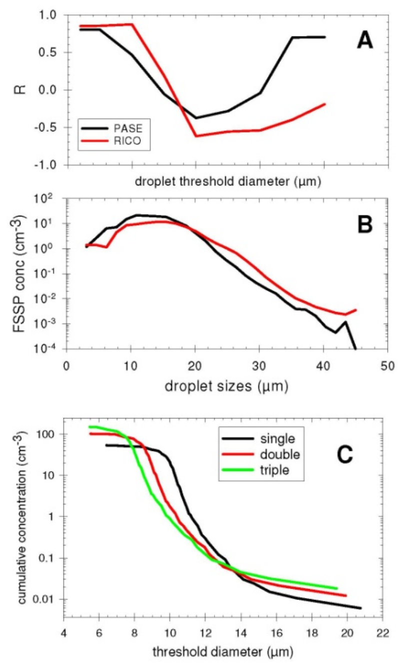
Ice particle size distributions (PSDs) for fresh anvil cirrus sampled during the TC4 field campaign. PSD were normalized by their ice water content (IWC) to compare number concentrations directly. The threshold for homogeneous freezing nucleation is ~ -40°C, precisely where the PSDs transition from monomodal to bimodal. This appears consistent with the higher nucleation rates predicted from homogeneous freezing, increasing the concentration of the smaller crystals.

categories: (1) monomodal for temperature T < -40°C, and bimodal for T > -40°C. The secondary maximum for the bimodal PSD occurs ~D = 220 µm. For smaller particles, the number concentration in the monomodal PSDs is ~10 times larger relative to bimodal PSDs of similar IWC, resulting in lower Vf relative to the bimodal PSDs. This suggests that recently formed anvil cirrus colder than -40°C will have longer lifetimes than warmer cirrus. The clean separation of PSD type at -40°C suggests a physical mechanism may be responsible. Size-sorting by fall velocity from higher to lower levels could possibly explain the PSD evolution. If the ice crystals formed at temperatures similar to sampling conditions (questionable for anvil cirrus), then a transition in dominant nucleation mechanism, from heterogeneous to homogeneous freezing, may explain the observations. The PSD for in situ cirrus clouds were colder than -40°C and were monomodal, consistent with this reasoning. Moreover, PSD number concentration normalized by IWC for T < -40°C was a factor of 7 higher on average relative to the warmer concentrations.

Positive and negative correlations between CCN concentrations and cloud droplet concentrations

James Hudson, Desert Research Institute

Correlations between CCN concentrations and cumulative cloud droplet concentrations have shown consistent patterns in four aircraft field projects in diverse environments. Panel A in the figure illustrates the pattern of positive, then negative, and then less negative or positive correlation coefficients (R) with increasing size thresholds. The positive R between CCN concentrations and total cloud droplet concentrations (i.e., small size thresholds) is expected because droplet concentrations should be in proportion to the concentrations of preexisting aerosol that they condensed upon. The negative R between CCN and larger droplets concentrations arises because of the smaller droplet sizes when concentrations are higher. The maximum absolute value of negative R occurs just beyond the average mode of the droplet distributions (panel B), because this is where the effect of competition among droplets is the greatest, especially when concentrations are higher. For larger threshold sizes, R decreases in negative absolute value and can even become positive for larger droplet thresholds. This is explained by the diminished competition at larger droplet sizes where concentrations are lower. This causes the concentrations of larger droplets to revert to proportionality with the nuclei upon which they condensed. These are the CCN concentrations at lower S. If CCN



Panel A displays correlation coefficients (R) between CCN concentrations at 1% S and cumulative droplet concentrations larger than the abscissa threshold sizes for averages of 11 Pacific Sulfate Experiment (PASE) and 16 Rain in Cumulus Over the Ocean (RICO) flights. PASE was done in very small clouds over the mid-Pacific. RICO was done in taller cumulus clouds over the eastern Caribbean. Panel B shows the average differential spectra from the two projects. Panel C shows a separate example of model predictions of cumulative droplet spectra grown on three CCN spectra that are exact multiples of each other (identical shapes). For sizes less than eight µm, cumulative droplet concentrations are positively correlated with the CCN concentrations. For sizes between 9 and 13 µm, cumulative droplet concentrations are inversely (negatively) correlated with CCN concentrations. For sizes larger than 14 µm, cumulative droplet concentrations are again positively correlated with CCN concentrations.

concentrations at various S are in proportion, this can result in the positive or decreased negative R values that have been observed for larger threshold cumulative droplet concentrations. Intermediate R are due to the conflict between the original positive R between CCN and droplet concentrations and the negative R due to competition reducing droplet sizes. An adiabatic model that predicts droplet spectra from CCN spectra and updraft speed is consistent with these observations. This is especially the case for CCN spectra that are multiples of each other, i.e., identical concentration ratios at all S (identical spectral shapes) as in panel C. Variations in actual relative shapes of the CCN spectra cause variations in the relative droplet spectra that can result in differences in the R patterns. Real clouds are seldom adiabatic because entrainment effects on droplet sizes and concentrations are usually independent of CCN concentrations. Nevertheless, the general pattern of the R predictions was even found for considerably sub-adiabatic clouds, which indicates a persistent aerosol influence on cloud microphysics. These observations and model simulations indicate that droplet spectra are subject to greater CCN influence than merely determining total cloud droplet concentrations. The relative concentrations of large nuclei (CCN with low critical S; Sc) and giant nuclei (CCN with extremely low Sc) can influence the concentrations of large cloud droplets and drizzle drops, which then affect precipitation and thus the second indirect aerosol effect.

Predictability of convective precipitation

Todd Jones, Colorado State University
David Randall, Colorado State University

Cumulus parameterizations predict the expected values of the convective precipitation rate, and the convective heating and drying rates, as functions of the large-scale sounding and the resolved-scale forcing. These predictions are statistical and have uncertainties that depend on the model's grid spacing and also on the rate at which the resolved-scale weather situation is changing. We will present an analysis of the results of a large number of numerical experiments with a three-dimensional cloud-resolving model designed to investigate the dependence of the uncertainty of grid spacing and other parameters.

Preliminary results from Learjet investigations of cirrus clouds during SPARTICUS

Paul Lawson, SPEC Inc.
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Jennifer Comstock, Pacific Northwest National Laboratory
Eric Jensen, NASA Ames Research Center
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Beat Schmid, Pacific Northwest National Laboratory
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SPEC Learjet and photos of microphysical sensors.

From a mass-weighted perspective, cirrus clouds exert an enormous influence on the radiative energy budget of the earth's climate system. Owing to their location in the cold upper troposphere, cirrus can reduce significantly the outgoing longwave radiation while, at the same time, remain relatively transmissive to solar energy. Thus, cirrus clouds are the only cloud genre that can exert a direct radiative warming influence on the climate system. The Small Particles in Cirrus (SPARTICUS) field campaign is scheduled to take place from 4 January through 15 April 2010. The SPEC Learjet (see attached figure) has been instrumented with state-of-the-art microphysical sensors (see attached figure) and will collect data in cirrus clouds over the ARM Climate Research Facility site near Lamont, Oklahoma. The overarching scientific goal of SPARTICUS is to document the nature and variability of the particle size distribution in cirrus. Given the uncertainty in previous measurements, SPARTICUS aims to determine to what degree small particles (i.e., < 50 microns diameter) contribute to the mass and radiative properties of mid-latitude cirrus. Characterization of the contribution of small particles to the total number concentration is critical for developing and evaluating model parameterizations and improving algorithms to retrieve microphysical properties using remote sensors. SPARTICUS measurements will reshape our understanding of the bimodality of the ice crystal size distribution. Improving and evaluating cloud property retrieval algorithms is fundamental to utilizing the long-term time record of remote sensing observations at the ARM sites. Preliminary results from in situ microphysical measurements in cirrus will be presented, including fast FSSP, CDP, CPI, 2D-S, 2DP, and Nevzorov measurements of particle size, area, and mass distribution.

http://www.specinc.com

A remote sensing approach to retrieve fair-weather cumulus entrainment rates

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David Turner, University of Wisconsin-Madison
Larry Berg, Pacific Northwest National Laboratory

Cumulus entrainment is an active area of research due to the changes it induces on cloud development and, by extension, the radiative and thermodynamic characteristics of the local environment. We are developing an algorithm named Retrieval of Entrainment and Droplet Density In Cumulus (REDDIC) that promises to retrieve the entrainment rate through ground-based remote sensing observations and thus provide insight into the entrainment process without the use of in situ measurements. Due to the inability to determine life cycle stage or cloud geometry from a fixed point on the surface, REDDIC retrieves a bulk characteristic entrainment rate for an afternoon rather than an individual rate for a specific cloud. Time-averaged thermodynamic profiles from instruments based at the ARM Southern Great Plains site are used as inputs into a cloud parcel model that treats entrainment events explicitly. Effective radius and liquid water path are calculated from the model output and compared to a distribution of those parameters measured during the observation period. Through iterative adjustment, the cloud droplet number concentration and entrainment rate are modified until the modeled properties converge to observations. Initial results will be presented.

Results of the TWP-ICE CRM model intercomparison: general trends and comparisons with field data

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Adrian Hill, NOAA
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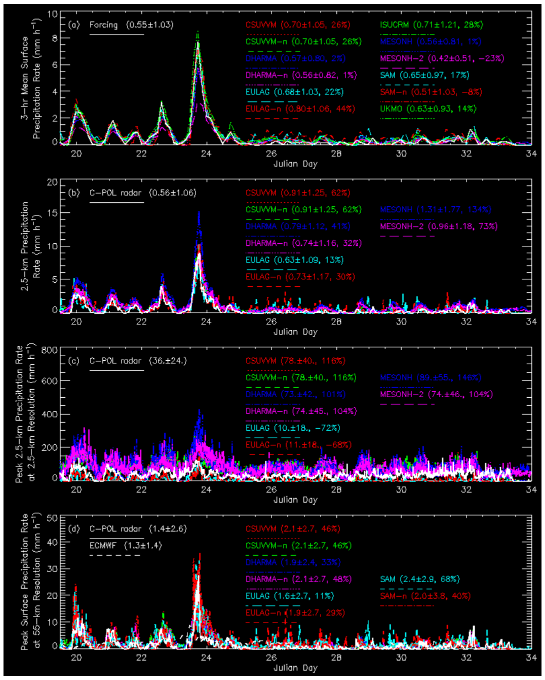
Xiaoqing Wu, Iowa State University

An idealized cloud-resolving model (CRM) intercomparison specification was based on observations obtained under active and suppressed monsoon conditions over 16 days during the Tropical Warm Pool-International Cloud Experiment (TWP-ICE). Results of eight CRM simulations were submitted for the baseline case described in the specification. Sensitivity test results were also submitted for half of the eight models, wherein nudging to observed thermodynamic fields with a six-hour timescale was included. Results from the eight different models generally exhibit a wider spread than between baseline and sensitivity results from any single model. Considering all of the simulations together, predicted values of precipitation rate and liquid and ice water path, cloud optical thickness, and the ratio of upwelling over downwelling shortwave radiative flux all vary by about a factor of two. As a function of total predicted condensate path, liquid and ice water path and surface precipitation rate all tend to increase with a similar trend. While cloud optical thickness also exhibits the same general trend, scatter is much greater. By contrast, the ratio of upwelling to downwelling shortwave radiative flux at top of atmosphere is both widely scattered and poorly correlated with total condensate path, and instead closely correlated with the ratio of liquid water path to total condensate path, consistent with the dominant contribution of liquid to cloud optical thickness. We investigate the liquid water fraction and radiative flux differences in the context of simulated cloud macrophysical and microphysical structure. We present evidence that uncertainties in large-scale forcing fields are likely to produce differences in model results comparable to the spread in most reported values (e.g., precipitation rate) but can still identify various likely outlying simulation results through comparison of a wide range of reported diagnostics with disparate datastreams, such as cloud optical thickness range observed at the surface, upwelling longwave radiative flux range measured by satellite, and reflectivity fields measured by scanning precipitation radar.

http://science.arm.gov/wg/cpm/scm/scmic6/index.html



Precipitation rate statistics at the surface and at 2.5-km elevation from eight cloud-resolving model simulations and four sensitivity tests are compared with the large-scale forcing data set, which is based on the scanning C-POL radar at Darwin, and with ECMWF re-analysis at three grid cells considered representative of local conditions. Mean value and standard deviations are listed, followed by percentage difference between forcing and C-POL data.

Routine cloud boundary algorithm development for ARM micropulse lidar

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Connor Flynn, Pacific Northwest National Laboratory
Zhien Wang, University of Wyoming
Karen Johnson, Brookhaven National Laboratory

Lidar cloud boundaries are a useful tool for identifying cloud base height, as well as cloud thickness in optically thin clouds, and are a necessary input for popular ARM data products, such as the Active Remotely Sensed Cloud Locations (ARSCL) product. The ARM LIDAR focus group has been tasked with the development of an operational lidar cloud boundary algorithm to help alleviate bottlenecks in cloud mask generation. While this task seems straightforward, an operational data product must work most of the time under all atmospheric conditions, which proves difficult as instrument health and lidar corrections vary over time. To work towards a solution, we have evaluated and compared three different cloud boundary algorithms to help choose the most robust method. We will present results from this comparison and describe our progress and path forward for implementation into a standard ARM data product.

Scanning cloud radar observations at Azores: preliminary 3D cloud products

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Ieng Jo, McGill University
Aleksandra Tatarevic, McGill University
Scott Giangrande, McGill University
Karen Johnson, Brookhaven National Laboratory
Kevin Widener, Pacific Northwest National Laboratory
Nitin Bharadwaj, Pacific Northwest National Laboratory
James Mead, ProSensing Inc.

The deployment of the scanning W-Band ARM cloud radar (SWACR) during the AMF campaign at Azores signals the first deployment of an ARM Facility-owned scanning cloud radar and offers a prelude for the type of 3D cloud observations that ARM will have the capability to provide at all the ARM Climate Research Facility sites by the end of 2010. The primary objective of the deployment of scanning ARM cloud radars (SACRs) at the ARM Facility sites is to map continuously (operationally) the 3D structure of clouds and shallow precipitation and to provide 3D microphysical and dynamical retrievals for cloud life cycle and cloud-scale process studies. This is a challenging task, never attempted before, and requires significant research and development efforts in order to understand the radar's capabilities and limitations. At the same time, we need to look beyond the radar meteorology aspects of the challenge and ensure that the hardware and software capabilities of the new systems are utilized for the development of 3D data products that address the scientific needs of the new Atmospheric System Research (ASR) program. The SWACR observations at Azores provide a first look at such observations and the challenges associated with their analysis and interpretation. The set of scan strategies applied during the SWACR deployment and their merit is discussed. The scan strategies were adjusted for the detection of marine stratocumulus and shallow cumulus that were frequently observed at the Azores deployment. Quality control procedures for the radar reflectivity and Doppler products are presented. Finally, preliminary 3D-Active Remote Sensing of Cloud Locations (3D-ARSCL) products on a regular grid will be presented and the challenges associated with their development discussed. In addition to data from the Azores deployment, limited data from the follow-up deployment of the SWACR at the ARM SGP site will be presented. This effort provides a blueprint for the effort required for the development of 3D cloud products from all new SACRs that the program will deploy at all fixed and mobile sites by the end of 2010.

Simultaneous cloud, precipitation, and vertical motions with dual-frequency Doppler spectra: getting ready for the new radars

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Gerald Mace, University of Utah
Stephanie Houser, University of Utah

Understanding the processing of water within the climate system is central to atmospheric prediction on most space and time scales. Documenting from observations the properties of cloud and precipitation as they exist within vertical motion regimes is a key element in developing this understanding. Up to now, it has been difficult to use ARM data to simultaneously document these key parameters. In response to this need, the Atmospheric System Research (ASR) program will field an unprecedented suite of radars at the ARM Climate Research Facility sites over the next several years. The centerpieces of this new suite of radars will be dual-frequency millimeter wavelength systems that will record full Doppler spectra when

pointing vertically. We explore the capacity for these dual-frequency systems to provide simultaneous information regarding cloud and precipitation microphysics and vertical motion statistics using both theoretically derived synthetic data as well as existing measurements.

The skill of cloud fraction and condensate decorrelation lengths to reproduce cloud field statistics according to a high resolution MICROBASE data set

Lazaros Oreopoulos, NASA
Peter Norris, NASA Global Modeling and Assimilation Office/UMBC Goddard Earth Sciences & Technology Center

The exponential-random paradigm has been recently proposed as a good representation of cloud fraction overlap. In this paradigm, the degree of overlap can be expressed simply in terms of a decorrelation length (scale). A version of the MICROBASE data set with very high horizontal (10 sec) and vertical (45 m) discretization in cloud condensate and extending seven years allows us to test the validity of this framework at the ARM SGP site. Similarly, the appropriateness of exponential decreases in the condensate rank correlations (a measure of the degree of vertical alignment of relatively thin and thick parts of cloud layers) can also be examined. The decorrelation climatology analysis shows a conspicuous seasonal cycle for both overlap and rank decorrelation lengths with peaks in the summer months and a significantly faster tendency towards randomness for condensate rank correlations. The purpose of the presentation is to examine whether decorrelation length scales are capable of reproducing via cloud generators the statistical properties of the condensate field (e.g., total cloud fraction, profiles of cumulative cloud fraction, variance of water path) with acceptable fidelity. We investigate the level of spatial and temporal detail needed in the specification of decorrelation lengths in order for this capability to be realized while maintaining the simplicity needed for actual implementation in cloud parameterizations. We attempt to address this question with a variety of tests that reveal decorrelation length dependencies and sensitivities to specific choices in the analysis methodology.

Small ice particle observations in tropospheric clouds: fact or artifact? Airborne Icing Instrumentation Evaluation experiment

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Edward Emery, NASA Glenn Research Center
J. Walter Strapp, Environment Canada
Stewart Cober, Environment Canada
George Isaac, Meteorological Service of Canada
Mohammed Wasey, Environment Canada
Brad Baker, SPEC Inc.
Paul Lawson, SPEC Inc.

Understanding the formation and evolution of small ice particles in clouds has been a long-standing problem in cloud physics. Debates around this problem extend well over three decades and began when optical particle size spectrometers became accepted instruments for airborne cloud-particle sampling. Early airborne measurements suggested that in glaciated clouds, the number concentration of ice particles is dominated by small particles with sizes less than 100 μm. Recently, increasing evidence has suggested that in many cases, concentrations of small ice particles may be the consequence of larger particle impacts on probe tips and inlets followed by shattering into small fragments. Environment Canada has recently undertaken efforts to modify cloud particle probes' inlets to deflect bouncing particles and shedding water away from the sample volume and optical field apertures, thereby mitigating the effect of shattering on measurements. The performance of the modified and standard probe tips was then studied in the Cox wind tunnel using high-speed video recording. In the spring of 2009, Environment Canada conducted the Airborne Icing Instrumentation Evaluation (AIIE) flight campaign, which attempted to quantify the effect of shattering on ice measurements and improve our understanding of the problem of small ice particles in clouds. The evaluation of this shattering effect was focused on the CIP, FSSP, and OAP-2DC probes installed on the National Research Council of Canada Convair-580. The results of the AIIE project demonstrate that the contamination of particle size distributions by shattering is a significant problem for the airborne microphysical characterization of ice clouds. Shattering may contaminate the ice crystal spectrum up to sizes of ~500 µm, particularly when large ice particles are present, resulting in overestimation of the total number concentration of particles of up to 100 times or more. Existing data processing algorithms cannot effectively filter out all shattering events on all probes.

Statistics of vertical velocity and drop-size distribution parameters in large-scale precipitation

Scott Giangrande, McGill University
Edward Luke, Brookhaven National Laboratory
Pavlos Kollias, McGill University

As traditionally viewed from a weather radar perspective, large-scale precipitation is often characterized by prominent melting-layer signatures (radar bright band) and gentle-varying radar reflectivity gradients beneath. When observed, these same sorts of radar features are often indirectly associated with the presence of weak (downward) vertical air motions and slow-evolving drop-size distribution parameters. Aircraft penetrations, wind profiler measurements, and other in situ instrumentation have been previously deployed to validate such beliefs; however, these approaches have several known limitations including space/time sampling and accuracy issues. Here, this study employs a well-established, novel technique to retrieve high-resolution, high-quality vertical air motion and drop-size distribution parameters in large-scale precipitation fields. This cloud-radar-based technique capitalizes on non-Rayleigh backscattering signatures at 94 GHz for an extended data set. The existing data set includes a diverse sampling from long-term deployments in the Southern Great Plains (SGP) region, as well as ARM Mobile Facility (AMF) deployments in the regions of Niamey, Niger (NIM) and Germany's Black Forest (FKB). These data are classified with respect to location and surface rainfall intensity. Mean and standard deviations of the retrieved distributions of vertical air motion are used to test the assumption of near-zero mean vertical air motion in large-scale precipitation and to document the occurrence of large vertical air motion magnitudes. Decorrelations in time and height of the retrieved drop-size distribution parameters (e.g., slope, shape) are introduced to study the scales of microphysical variability. The high-resolution data set is also re-sampled to coarser spatial and temporal resolutions so as to assess physical process (sorting) noise and the sub-sampling volume variability of these parameters as compared to other ground-based (e.g., NexRad, disdrometer) and satellite-based (e.g., TRMM/GPM) efforts.

A study of cloud and drizzle properties in the Azores using Doppler radar spectra

Edward Luke, Brookhaven National Laboratory
Jasmine Rémillard, McGill University
Pavlos Kollias, McGill University

Understanding the onset of coalescence in warm clouds is key in our effort to improve cloud representation in numerical models. Coalescence acts at small scales, and its study requires detailed high-resolution dynamical and microphysical measurements from a comprehensive suite of instruments over a wide range of environmental conditions (e.g., aerosol loading). The first AMF is currently in its second year of a two-year deployment at Graciosa Island in the Azores, offering the opportunity to collect a long data set from a stable land-based platform in a marine stratocumulus regime. In this study, recorded WACR Doppler spectra are used to characterize the properties of Doppler spectra from warm clouds with and without drizzle, and from drizzle only, in an effort to observe the transition (onset) to precipitation in clouds. A retrieval technique that decomposes observed Doppler spectra into their cloud and/or drizzle components is applied in order to quantify drizzle growth.

Sub-visual cirrus effect on the brightening of surface clear-sky downwelling shortwave irradiance

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The recent decadal clear-sky brightening of downwelling shortwave irradiance at the ARM SGP site is about +2.9 Wm-2/decade (Long et al. 2008). This trend is composed of -0.3 Wm-2/decade and +3.2 Wm-2/decade for direct and diffuse irradiance, respectively. This tendency is also observed at SURFRAD sites over the continental United States. The Long et al. results show that the clear-sky changes are correlated with increased commercial aircraft flight hours over the continental U.S. In the traditional classification of "clear sky," an inherent limit must be included that allows some amount of condensed water in the column to be included in the "clear sky" category. Dupont et al. (2008) show that traditional clear-sky classification allows up to 0.15–0.2 optical depth of primarily cirrus-level ice crystals. Here we attempt to quantify the effect of this "clear-sky" condensate on the clear-sky brightening of downwelling shortwave irradiance. In this study, we use a 10-year data set of lidar remote sensing (micropulse and Raman lidar) to derive the high-level ice (here named "residual condensates") properties, such as altitude, optical thickness, and occurrence, using the STRAT algorithm (Morille et al. 2006). We combine this information about residual condensates with radiative flux measurements to quantify the tendency of residual condensates not traditionally classified as cloud, using the radiative flux analysis methodology (Long and Ackerman 2000). Our results show that overall 50% of the residual condensates have an optical thickness stronger than 0.1, and 70% are higher than 5 km. In 1999, only 10% of the clear-sky periods include residual condensates compared with an almost 50% occurrence in 2006. The residual condensates layers thinner than 0.5 km represent 40% and 65% of the cases in 1999 and 2006 respectively. This study classifies three types of situations: all cases, pristine, and turbid period. The first correspond to all the situations detected as clear by the radiative flux algorithm, the second to the pristine clear-sky periods (lidar signals and Long et al. algorithm indicate 0%), and the third to condensate situations detected by lidar but classified as clear-sky by the radiative flux analysis. The radiative effect of residual condensates is also quantified, and the increase reaches 10 W m-2 for the shortwave diffuse irradiance at 45° solar zenith angle.

Synergetic use of MMCR and C-POL radars for retrievals of cloud and rainfall parameters

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A combined radar approach for retrieving cloud and rainfall parameters in the vertical column above the ARM TWP Darwin site is suggested. This approach uses vertically pointing radar measurements from the MMCR and scanning radar measurements from the C-POL radar above Darwin. Rainfall retrieval constraints are provided by data from a surface impact disdrometer. The approach is applicable to stratiform precipitating cloud systems when a separation between the liquid hydrometeor layer, which contains rainfall and liquid water clouds, and the ice hydrometeor layer is provided by the radar bright band. Absolute C-band reflectivities and Ka-band vertical reflectivity gradients in the liquid hydrometeor layer are used for retrievals of the rain water path (RWP) and cloud liquid water path (CLWP) in this layer. Mean-layer rain rate is also estimated. C-band reflectivities from C-POL are then used to estimate ice water path (IWP) in cloud regions above the melting layer. The retrieval uncertainties of CLWP and IWP for typical stratiform events are around 500–800 g/m^2 (for CLWP) and about 50–70% (for IWP). The CLWP retrieval uncertainties increase with rain rate. The expected uncertainties of layer mean rain rate retrievals are around 20%, which is due in part to the constrains available from disdrometer data. The applicability of the suggested remote sensing approach is illustrated by two characteristic events observed at the ARM Darwin site during the wet season of 2007. Rain rates during these events were averaging at about 2-4 mm/h with some brief periods of heavier rainfall. Typical retrieved values of CLWP were between 1 and 2 kg/m2. IWP values were generally significantly higher. Future use of W-band radar at the ARM Darwin site can improve retrieval accuracies.

Towards a statistical climatology of the relationship between updraft velocity, liquid water path, and cloud droplet number density: preliminary analysis from MASRAD and COPS

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Mark Miller, Rutgers University
Maureen Dunn, Brookhaven National Laboratory

The AMF deployment at Point Reyes, California, and in the Black Forest of Germany provided numerous measurements of thin (< 300 m thick) layer clouds from the microwave radiometer, AERI, MMCR, and laser ceilometer. Thin clouds are notoriously difficult to measure, and these data sets afford an opportunity to establish the foundation for a climatology of thin layer clouds at all ARM sites and to examine the viability of various techniques used to quantify thin cloud structure. The thin clouds at Pt. Reyes and in the Black Forest are shown to exhibit a wide range of liquid water paths, but a relatively narrow range of updraft velocities. The significance of this narrow range of updraft velocities lies in the aerosol-to-cloud-droplet nucleation process, which lies at the heart of the first aerosol indirect effect. These observations lead us to hypothesize that the dynamic structure of thin clouds, which in many cases are in the process of decaying and evaporating, may be insufficient to support the nucleation of aerosols in highly polluted air masses, thereby providing immunity from the first aerosol indirect effect. To estimate the potential consequences of this narrow range of velocities, we employ a technique using the surface-based measurements of the CCN activation spectrum to estimate the number of cloud droplets present in these thin clouds. Clouds are subsequently classified according to liquid water path, and a climatology of the relationship between updraft velocity and droplet number concentration is created.

Using Doppler spectra to separate hydrometeor populations and analyze ice precipitation in multilayered mixed-phase clouds

Mahlon Rambukkange, The Pennsylvania State University
Johannes Verlinde, The Pennsylvania State University

Multimodality of Doppler spectra is used to partition cloud phases and to separate distinct ice populations in the radar volume, thereby facilitating analysis of individual ice showers in multilayered mixed-phase clouds. A 35-GHz cloud radar located at Barrow, Alaska, during the Mixed-Phase Arctic Cloud Experiment collected the Doppler spectra employed in this study. Data from a pair of collocated depolarization lidars confirmed the presence of liquid in two cloud layers that were analyzed. Surprisingly, both of these cloud layers were embedded in ice precipitation yet maintained their liquid. Our spectral separation of the ice precipitation yielded two distinct ice populations: ice initiated within the two liquid cloud layers and ice precipitation formed in higher cloud layers. Ice fall velocity versus radar reflectivity relationships derived for distinct showers show that a single relationship might not properly represent the ice showers during this period.

Validation of a radar Doppler spectra simulator using measurements from the ARM cloud radars

Jasmine Rémillard, McGill University
Edward Luke, Brookhaven National Laboratory
Pavlos Kollias, McGill University

The use of forward models as an alternative approach to compare models with observations contains advantages and challenges. Radar Doppler spectra simulators are not new; their application in high-resolution models with bin microphysics schemes could help to compare model output with the Doppler spectra recorded from the vertically pointing cloud radars at the ARM Climate Research Facility sites. The input parameters to a Doppler spectra simulator are both microphysical (e.g., particle size, shape, phase, and number concentration) and dynamical (e.g., resolved wind components and sub-grid turbulent kinetic energy). Libraries for spherical and non-spherical particles are then used to compute the backscattering cross-section and fall velocities, while the turbulence is parameterized as a Gaussian function with a prescribed width. The signal-to-noise ratio (SNR) is used to determine the amount of noise added throughout the spectrum, and the spectral smoothing due to spectral averages is included to reproduce the averaging realized by cloud radars on successive returns. Thus, realistic Doppler spectra are obtained, and several parameters that relate to the morphological characteristics of the synthetically generated spectra are computed. Here, the results are compared to the new ARM microARSCL data products in an attempt to validate the simulator. Drizzling data obtained at the SGP site by the MMCR and the AMF site at Azores using the WACR are used to ensure the liquid part and the turbulence representation part of the simulator are properly accounted in the forward model.

The variability of the tropical ice cloud properties from ground-based radar-lidar observations over Darwin, Australia

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Julien Delanoë, University of Reading
Mick Pope, Bureau of Meteorology
Peter May, Bureau of Meteorology
Ewan O'Connor, University of Reading
John Haynes, Colorado State University
Christian Jakob, Monash University

In the present paper the statistical properties of non-precipitating tropical ice clouds (deep ice anvils resulting from deep convection and cirrus clouds) over Darwin, Northern Australia, are characterized using ground-based radar-lidar observations from the ARM Climate Research Facility. The ice cloud properties analyzed are the frequency of ice cloud occurrence, the morphological properties (cloud-top height, base height, and thickness), the microphysical and radiative properties (ice water content, visible extinction, effective radius, terminal fall speed, and concentration), and the internal cloud dynamics (in-cloud vertical air velocity). The variability of these tropical ice cloud properties is then studied as a function of different large-scale environmental conditions: the large-scale cloud regimes derived from the International Satellite Cloud Climatology Project (ISCCP), the amplitude and phase of the Madden-Julian Oscillation (MJO), and the large-scale atmospheric regime as derived from a long-term record of radiosonde observations over Darwin. The rationale for characterizing this variability is to provide an observational basis to which model outputs can be compared for the different regimes or large-scale characteristics and from which new parameterizations including the large-scale context can be derived.

6.0 Field Campaigns

A 3D comparison of WRF forecasts with observations during the RHUBC-II campaign

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The Radiative Heating in Underexplored Bands Campaigns (RHUBC) are a set of field experiments that aim to better understand the radiative processes in spectral regions with strong water vapor absorption. The RHUBC-II campaign was held at Cerro Toco (~5300 m of altitude) in the Atacama Desert in Chile from August to October 2009. These months show very low daily climatological precipitable water vapor (PWV) values that can range between 0.1 and 1.0 mm. The large number and diversity of data collected during the campaign provide a great opportunity to assess numerical weather forecasts over a complex orography and for very dry atmospheric conditions. In addition, this is a region relatively little studied, where meteorological observations are scarce and several astronomical observatories operating there need accurate forecasts. Forty-eight hours of forecast from the Weather Research and Forecasting (WRF) model are compared with RHUBC-II and satellite measurements for the period August–October 2009. Temperature, humidity, and wind speed and direction at and above the boundary layer will be presented. The PWV evolution and several cloud properties will also be shown.

Aerosol composition, chemistry, and source characterization during the 2008 VOCALS experiment

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Chemical composition of fine aerosol particles over the northern Chilean coastal waters was determined onboard the U.S. DOE G-1 aircraft during the VOCALS (VAMOS Ocean-Cloud-Atmosphere-Land Study) field campaign between October 16 and November 15, 2008. SO42-, NO3-, NH4+, and total organics (Org) were determined using an Aerodyne aerosol mass spectrometer, and SO42-, NO3-, NH4+, Na+, Cl-, CH3SO3-, Mg2+, Ca2+, and K+ were determined using a particle-into-liquid sampler-ion chromatography technique. The results show the marine boundary layer (MBL) aerosol mass was dominated by non-sea-salt SO42- followed by Na+, Cl-, Org, NO3-, and NH4+ in decreasing importance; CH3SO3-, Ca2+, and K+ rarely exceeded their respective limits of detection. The SO42- aerosols were

strongly acidic as the equivalent NH4+ to SO42- ratio was only ~0.25 on average. NaCl particles, presumably of sea-salt origin, showed chloride deficits but retained Cl- typically more than half the equivalency of Na+ and are externally mixed with the acidic sulfate aerosols. Nitrate was observed only on sea-salt particles, consistent with adsorption of HNO3 on sea-salt aerosols, responsible for the Cl-deficit. Dust particles appeared to play a minor role, judging from the small volume differences between that derived from the observed mass concentrations and that calculated based on particle-size distributions. Because SO42- concentrations were substantial (~0.5–~3 µg/m3) with a strong gradient (highest near the shore), and the ocean-emitted dimethylsulfide and its unique oxidation product, CH3SO3-, were very low (i.e., ≤ 40 parts per trillion and < 0.05 µg/m3, respectively), the observed SO42-aerosols are believed to be primarily of terrestrial origin. Back trajectory calculations indicate sulfur emissions from smelters and power plants along coastal regions of Peru and Chile are the main sources of these SO4- aerosols. However, compared to observations, model calculations appeared to underestimate sulfate concentrations based on an existing emission inventory. The agreement between observations and model predictions of CO as well as total sulfur is reexamined in this work with a new emission inventory made available recently.

Aerosol particle number concentration measurements during ISDAC flights

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The Indirect and Semi-Direct Aerosol Campaign (ISDAC) took place in Alaska in the vicinity of Fairbanks and Barrow, near the Atmospheric Radiation Measurement (ARM) North Slope of Alaska site during April 1–30, 2008. Profiles of the total number concentration and size distributions of aerosol particles at different altitudes are studied in a variety of conditions, including polluted and clean environments when there were no clouds or precipitation present. Averaging all clean scenario profiles reveals a mean aerosol number concentration of 120 with a standard deviation (s.d.) of 40 cm-3, over the vertical altitude range 500–6500 m. The polluted days, April 18–22, have a mean aerosol number concentration of 720 with an s.d. of 360 cm-3 over the altitude range 500–6500 m. Horizontally, there is also large variation over constant altitude legs. For example, a polluted case, flight 25 on April 19, 2008, has the aerosol total number concentrations 656 with an s.d. of 191 cm-3 at 5500 m, 636 with an s.d. of 292 cm-3 at 4500 m, and 1029 with an s.d. of 446 cm-3 at 2900 m. Aerosol size distributions at various altitudes are also presented. Future work includes determining the aerosol effects on different types of clouds encountered during flights. Cloud and aerosol physical and chemical properties are used for comparing and contrasting ice, liquid, and mixed-phase clouds.

Airborne high spectral resolution lidar and research scanning polarimeter measurements during RACORO

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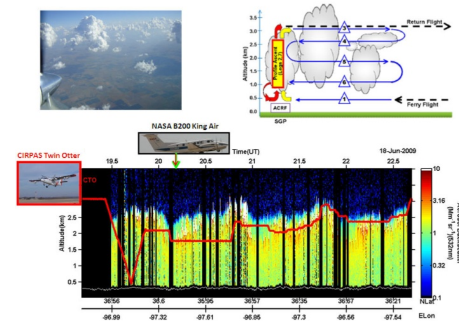
The NASA Langley Research Center (LaRC) airborne high spectral resolution lidar (HSRL) and the NASA Goddard Institute for Space Studies (GISS) research scanning polarimeter (RSP) were deployed on the NASA B200 King Air aircraft that participated in the RACORO mission during June 2009. The HSRL measured profiles of aerosol extinction (532 nm), backscatter (532 and 1064 nm), and depolarization (532 and 1064 nm). The RSP instrument measured total and linearly polarized radiance in nine spectral bands that were used to retrieve column aerosol optical thickness, size distribution, and refractive index, as well as cloud optical thickness and cloud droplet effective radius. The HSRL and RSP collected data during 19 science flights during June 2009; of these, 15 flights were coordinated with the CIRPAS Twin Otter, and 16 flights included overpasses of the SGP Central Facility. The HSRL profiles have been used to determine the vertical context for the Twin Otter measurements, characterize the boundary layer and distribution of aerosols within the boundary layer, examine the impact of relative humidity on aerosol parameters, and examine the variability of aerosols near clouds. Aerosol intensive parameters derived from HSRL data are used to infer specific aerosol types and mixtures of those types. An aerosol type associated with urban pollution was found to provide the largest contribution to aerosol optical thickness measured during the campaign. The RSP measurements are being used to derive cloud-drop effective radius and width of cloud-drop size distribution as well as to derive aerosol properties. Cloud-drop effective radius derived from RSP on June 18 was found to be between 5–7.5 micrometers and in excellent agreement with cloud- drop effective radius derived from coincident forward scattering



During the Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO) campaign conducted over the ARM Climate Research Facility's SGP site during June 2009, the CIRPAS Twin Otter and NASA B200 King Air conducted coordinated flights in order to investigate aerosol-cloud interactions, improve cloud simulations in climate models, and validate ARM remotely sensed cloud properties. Measurements from the airborne high spectral resolution lidar (HSRL) on board the B200 are being used to identify location of Twin Otter measurements relative to cloud and aerosol locations and to provide the vertical context for the Twin Otter in situ measurements. This figure shows the aerosol backscatter profiles measured by the HSRL on June 18 and shows the altitude of the Twin Otter relative to aerosol and clouds during this joint flight.

spectrometer probe (FSSP) measurements of cloud-drop size distribution near cloud top. RSP retrievals of aerosol properties and coincident ground-based Raman lidar aerosol profiles will also be presented.

http://science.larc.nasa.gov/hsrl/index.html

ATML: a new Atmospheric and Terrestrial Mobile Laboratory for GHG measurement

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Thomas Guilderson, Lawrence Livermore National Laboratory
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A new mobile laboratory for multi-signature, greenhouse gas measurement and source attribution is under construction in support of a three-lab (LANL-LLNL-SNL) program in Climate Modeling, Carbon Measurement, and Uncertainty Quantification. The Atmospheric and Terrestrial Mobile Laboratory (ATML) will provide measurement capabilities to attribute CO2 emissions to their diverse sources, quantify fluxes of CO2 in the terrestrial biosphere, and improve our ability to scale from ground-based to satellite-based GHG measurements. This poster will describe the unique suite of instruments on the ATML, including a proton transfer mass spectrometer and laser-based analyzers for field sampling and rapid, high-precision analysis of CO2 and water vapor concentrations and isotopics, as well as CH4 concentration. The ATML is also outfitted with a portable tall tower, flask sampler for collection of air samples for 14C analysis, EC Flux system, photoacoustic aerosol sampler, flask sampling system, and standard air quality and meteorological instruments. A separate, transportable high-resolution solar tracking Fourier transform spectrometer (FTS) that operates in the near-IR and vis-uv is being acquired for retrievals of columnar concentrations of CO2, CH4, N2O, CO, NO2, and other absorbing species. We plan to assemble and deploy the ATML and transportable FTS for a series of short-term, focused experiments in FY2010 for GHG measurement and attribution, emphasizing intercomparison and cross-validation of new analytical techniques, real-time measurement of multiple parameters for the attribution of CO2 sources, as well as test scaling hypotheses that connect ARM data to satellite products. This poster will summarize the ongoing construction of the ATML and timelines for its deployment later this year.

Cloud life cycle observed during the 2009 cloud tomography Field Campaign

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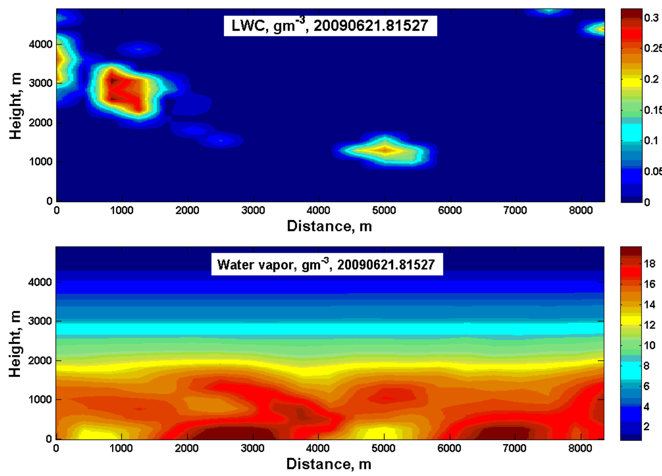
The major objective of the cloud tomography field campaign, conducted during the summer of 2009, is to demonstrate the feasibility of the cloud tomography method for long-term 3D observation of cloud and water vapor. During the two-month experiment, five scanning microwave radiometers were deployed along an eight-kilometer line and programmed to continuously scan the upper hemisphere. The quality of the radiometric data is evaluated by examining radiation closure during clear-sky conditions. The calculated brightness temperatures agree with the observed ones within 1.0°K when concurrent radiosonde measurements are used. Using a constrained cloud tomography retrieval algorithm, we are able to obtain a 2D snapshot of both the cloud liquid and the water vapor fields every two minutes. We will present the cloud and water vapor retrieval results for a variety of sky cover conditions. The high-resolution tomographic retrievals provide a unique opportunity for investigating the life cycle of warm clouds, the diurnal evolution of water vapor fields, and the interaction between them.



Tomographic retrievals of cloud liquid water content (LWC) and water vapor content at 23 UTC June 21, 2009. Top: the LWC field. Bottom: the water vapor field.

Comparing models and observations of boundary-layer clouds at Graciosa Island

Robert Wood, University of Washington

We use the Atmospheric Radiation Measurement Mobile Facility (AMF) data set at Graciosa Island, Azores, spanning May 2009–December 2010, to evaluate the performance of two numerical weather prediction models in predicting boundary-layer clouds in this subtropical marine environment. We are particularly interested in quantifying how well these models can simulate the diurnal cycle as well as synoptic-to-seasonal variability in low clouds. We compare the AMF observations to column predictions by the National Centers for Environmental Prediction Forecasting System (NCEP GFS) and the European Center for Medium-Range Weather Forecasting (ECMWF), as well as to satellite observations. Preliminary results indicate that model errors in winds are larger than expected, possibly due to island effects. Errors in temperature occur primarily due to errors in the boundary-layer depth. Relative humidity errors are large.

Dual-frequency profiler vertical air motions retrieved during TWP-ICE

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Scott Collis, Centre for Australian Weather and Climate Research
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Wind profilers are often called “clear-air” wind profilers because they can directly measure the wind motion by backscattering radar energy off of gradients in the turbulent refractive index. This Bragg scattering process enables 50-MHz wind profilers to directly measure the vertical air motion when precipitation is directly overhead. But 50-MHz wind profilers are also sensitive to Rayleigh scattering from raindrops and snow/ice particles that will bias the vertical air motions downward if the hydrometeor motion is not removed from the observed Doppler velocity power spectra. Thus, a dual-frequency profiler technique has been developed that uses the collocated 920-MHz wind profiler observations to identify and mask out the Rayleigh scattering signal in the 50-MHz wind profiler spectra. The poster will present the dual-frequency vertical air motion technique applied to the 50-MHz and 920-MHz wind profiler observations collected during the Tropical Warm Pool–International Cloud Experiment (TWP–ICE). Since the dual-frequency profiler retrievals provide accurate vertical air motion estimates in a vertical column but without any spatial context, these columnar estimates provide a reference measurement for state-of-the-art scanning radar retrievals as presented by the Collis et al. poster.

Forecasting for field campaigns at the Southern Great Plains ARM site

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Specialized operational forecasts typically are required during more intensive field campaigns, especially when aircraft attempt to penetrate specific cloud types. Our intention is to discuss the lessons learned over the past few years of forecasting field campaigns at the SGP by the Site Scientist Team, as well as the different techniques used to make these specific forecasts. The recent campaigns for which forecasting duties were necessary include CLASIC/CHAPS (June 2007), RACORO (January–June 2009), and SPARTICUS (currently ongoing). The forecasts have included specific cloud types ranging from fair-weather cumulus and boundary layer clouds with low optical water depths to upper-level cirrus. A recent shift also has been ongoing from Intense Operation Periods to less intensive and more routine flights over extended periods of time. Plans also are underway to upgrade the forecast and nowcast capabilities on site by adding real-time displays of data from some instrument systems (radars, lidar, ceilometers, etc.).

Global climate model performance in West Africa: realizing the goals of RADAGAST

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The ARM Mobile Facility (AMF) was deployed in West Africa during 2006 in support of the Radiative Atmospheric Divergence Using AMF, GERB data, and AMMA Stations (RADAGAST) campaign. The principal goal of RADAGAST was to measure the cross-atmosphere radiative flux divergence using data from the ARM Mobile Facility (AMF) and the Geostationary Earth Radiation Budget Experiment

(GERB). This configuration enabled the controls of this flux divergence to be determined using measurements from the AMF (Slingo et al. 2009). The ultimate goal of the RADAGAST campaign was to determine whether the radiative flux divergence and the factors that control it are properly simulated in the current generation of GCMs. To realize this goal, we compared the RADAGAST measurements with three GCMs used in the most recent IPCC report (GISS Model-e, HADGEM1, and AM2) and the NCAR Community Climate Model Version 3 (CCM3). The surface and top-of-atmosphere radiative fluxes, cross-atmosphere radiative flux divergence, surface energy budgets, and the clouds and precipitation simulated by each model were compared with the observations from RADAGAST. A decadal window centered on the year 2006 was used to compute averages and extremes for each variable in the model. To assess the performance of the cloud parameterizations, the ability of each model to reproduce an observed relationship between the surface lifting condensation level and the structure of clouds and precipitation is examined. It is shown that models that reproduce the radiative structure tend to exhibit sub-par performance in simulating clouds and precipitation, and vice versa. Models that more faithfully represent the radiative structure are shown to possess cloud fields that are strongly modulated by tuning to satellite data from the International Satellite Cloud Climatology Project (ISCCP). These models are shown to underperform models not tuned to ISCCP when the figure of merit is the ability to faithfully represent the clouds and precipitation observed in 2006.

Influence of Arctic cloud thermodynamic phase on surface shortwave flux

Dan Lubin, National Science Foundation
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As part of the Indirect and Semi-Direct Aerosol Campaign (ISDAC), an Analytical Spectral Devices (ASD, Inc.) spectroradiometer was deployed at the Barrow NSA site during April and May of 2008 and in April–October of 2009. This instrument recorded one-minute averages of surface downwelling spectral flux in the wavelength interval 350–2200 nm, thus sampling the two major near-infrared windows (1.6 and 2.2 microns) in which the flux is influenced by cloud microphysical properties, including thermodynamic phase and effective particle size. Aircraft in situ measurements of cloud properties show mostly mixed-phase clouds over Barrow during the campaign, but with wide variability in relative liquid versus ice water content. At fixed total optical depth, this variability in phase composition can yield an order 5–10 of watts per square meter in surface flux variability, with greater cloud attenuation of the surface flux usually occurring under higher ice water content. Thus, our data show that changes in cloud phase properties, even within the “mixed-phase” category, can affect the surface energy balance at the same order of magnitude as greenhouse gas increases. Analysis of this spectral radiometric data provides suggestions for testing new mixed-phase parameterizations in climate models.

Integrated database of cloud microphysical properties derived from in situ observations obtained during M-PACE, TWP-ICE, ISDAC, and RACORO

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Comprehensive databases of cloud microphysical properties are required for evaluation of model simulations and remote sensing retrievals, for process-oriented studies of how aerosols impact clouds, and for studies of fundamental cloud-radiation interactions. In this study, the development of such databases for arctic boundary-layer clouds, arctic and tropical cirrus, and low-level mid-latitude boundary layer clouds is described using in situ data collected during the Mixed-Phase Arctic Cloud Experiment (M-PACE), the Tropical Warm Pool-International Cloud Experiment (TWP-ICE), the Indirect and Semi-Direct Aerosol Campaign (ISDAC), and the Routine AAF Clouds with Low Optical Water Depths Optical Radiative Observations (RACORO). Distributions of microphysical quantities (i.e., total number concentration of water drops and ice crystals, effective radii of water drops and ice crystals, ice and liquid water contents, ice and liquid extinctions, size distributions and representations of size distributions as modified gamma functions, mean diameters and median mass diameters of ice and liquid clouds, equivalent reflectivity, and habit distributions) are calculated using data from both size-resolved and bulk cloud probes. Consistency tests and closure tests, whereby mass and extinction computed from size-resolved measurements are compared against comparable values measured by bulk probes, are used to determine the optimum combinations of probes for determining the microphysical parameters. Uncertainties in the derived parameters are estimated from the variability of the probe data, paying particular attention to the possibility of artificial amplification of small crystal concentrations from the shattering of large ice crystals on probe inlets and shrouds. Parameters such as the mean fall velocities and single-scattering parameters are derived from the database. Applications to cloud modeling and remote sensing studies are discussed.

The Midlatitude Continental Convective Clouds Experiment (MC3E)

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The Midlatitude Continental Convective Cloud Experiment (MC3E) will take place in central Oklahoma during April–May 2011. MC3E is a collaborative effort between the U.S. DOE Atmospheric Radiation Measurement (ARM) Climate Research Facility and the NASA Global Precipitation Measurement (GPM) mission. MC3E leverages existing observing infrastructure in the central U.S., augmented by an extensive sounding array, ground and airborne in situ observations, and new ARM instrumentation purchased with American Recovery and Reinvestment Act funding. The overarching goal of MC3E is to provide the most complete characterization of convective cloud systems ever obtained, the result being data sets that constrain model cumulus parameterizations and spaceborne precipitation retrieval algorithms. Different components of convective processes are targeted, such as pre-convective environment and convective initiation, updraft/downdraft dynamics, condensate transport and detrainment, precipitation and cloud microphysics, influence on the environment and radiation, and a detailed description of the large-scale forcing. MC3E will employ a multi-scale observing strategy leveraging a network of distributed sensors (both passive and active). The approach is to document the full spectrum of precipitation and cloud physical characteristics as a function of feedbacks to/from the environment. This will be accomplished via use of existing, external, and developing instrumentation deployed in and around the ARM SGP Central Facility. NASA will provide scanning multi-frequency dual-polarimetric radar systems at three different frequencies (Ka/Ku/S), high-altitude remote sensing (ER-2) and in situ aircraft (UND Citation), wind profilers, and a dense network of surface disdrometers. These platforms will augment a complement of DOE instrumentation including a sounding array, three networked scanning X-band radar systems, a C-band scanning radar, a dual-wavelength (Ka/W) scanning cloud radar, a Doppler lidar, and upgraded vertically pointing millimeter cloud radar (MMCR) and micropulse lidar (MPL). Within the envelope of this considerable ground-based observation system, an in situ aircraft will provide observations of precipitation-sized particles, ice freezing nuclei, and aerosol concentrations in coordination with a high-altitude satellite simulator platform carrying a Ka/Ku band radar and passive microwave radiometers (10-183 GHZ).

An overview of the upcoming 2010 Carbonaceous Aerosol and Radiative Effects Study (CARES) field campaign

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The primary objective of the Carbonaceous Aerosol and Radiative Effects Study (CARES) in 2010 is to investigate the evolution of carbonaceous aerosols of different types and their optical and hygroscopic properties in central California, with a focus on the Sacramento urban plume. Carbonaceous aerosol components, which include black carbon (BC), urban primary organic aerosols (POA), biomass burning aerosols, and secondary organic aerosols (SOA) from both urban and biogenic precursors, have been shown to play a major role in the direct and indirect radiative forcing of climate. However, significant knowledge gaps and uncertainties still exist in the process-level understanding of: (1) SOA formation, (2) BC mixing state evolution, and (3) the optical and hygroscopic properties of fresh and aged carbonaceous aerosols. Several specific science questions under these three topics will be addressed during CARES 2010. During summer the Sacramento-Blodgett Forest corridor effectively serves as a mesoscale (~100 km) daytime flow reactor in which the urban aerosols undergo significant aging as they are transported to the northeast by upslope flow. The CARES campaign observation strategy will consist of the U.S. DOE G-1 aircraft sampling upwind, within, and outside of the evolving Sacramento urban plume in the morning and again in the afternoon. The NASA B-200 aircraft carrying a high spectral resolution lidar (HSRL) and a Research Scanning Polarimeter (RSP) will also be deployed to characterize the vertical and horizontal distribution of aerosols and aerosol optical properties. The aircraft measurements will be complemented by a well-instrumented ground site within the Sacramento urban area and a downwind site in Cool, California, to characterize the diurnal evolution of meteorological variables, trace gases/aerosol precursors, and aerosol composition and properties in freshly polluted and aged urban air. The sampling strategy during CARES will be coordinated, to the extent possible, with CalNex 2010, a major field campaign that is being planned in California in 2010 by CARB, NOAA, and CEC. In addition to obtaining new observation-based understanding from the anticipated field data, the CARES campaign strategy is centered on using the data in various focused model evaluation exercises, so that the resulting new knowledge can be integrated into regional and global climate-chemistry models.

The RHUBC-II campaign: analysis of water vapor profiles

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Radiative heating and cooling are important drivers of Earth's climate. In the mid-to-upper troposphere, the dominant radiative processes in both the solar and thermal regimes are due to water vapor. These processes are imperceptible from the ground in typical conditions due to absorption by water vapor in the intervening lower atmosphere. A set of field experiments, the Radiative Heating in Underexplored Bands Campaigns (RHUBC), has been conducted as part of the Atmospheric Radiation Measurement (ARM) Climate Research Facility in order to provide a robust and complete data set that would allow radiative transfer models to be evaluated in spectral regions where water vapor absorbs strongly. RHUBC-II was held from August–October 2009 near the summit of Cerro Toco in the Atacama Desert in Chile—during this period of austral late winter/early spring, clear conditions were pervasive and the water vapor loading was as low as 0.2 mm. Measurements of spectrally resolved radiances throughout the infrared and sub-millimeter regions were obtained from a number of different instruments; the analysis of these measurements critically depends on accurate water vapor profiles. 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. This study will analyze candidate RHUBC-II water vapor profiles: the raw radiosondes, radiosonde profiles that have been modified using the method of Miloshevich et al., sonde profiles that have been uniformly scaled using coincident microwave measurements by the G-band vapor radiometer profiler (GVRP), and profiles that have been obtained from a multi-parameter retrieval from GVRP measurements. The poster will present direct comparisons of the water vapor profiles from these different methods. Also, the impact of their use on comparisons with measured radiances in other spectral regions will be shown.

Status of CALIPSO data products

David Winker, NASA Langley Research Center

The CALIPSO satellite, launched in April 2006, carries a two-wavelength polarization lidar, providing the global aerosol profiles during both day and night. Profiles of aerosol and cloud extinction, backscatter, aerosol type, and cloud ice-water phase are among the primary parameters produced. CALIPSO Version 2 data products including aerosol extinction have been available since 2008. An improved Version 3 data product is now available. New features of the Version 3 product and improvements relative to the Version 2 products will be presented.

The Storm Peak Lab Cloud Property Validation Experiment (STORMVEX)

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The core goals of the ARM Climate Research Facility include improving the representation of clouds in global models. To accomplish this, ARM has invested considerably in creating long-term data sets from ground-based remote sensors at climatically important locations around the world. However, the ability to convert the remote sensing measurements to cloud properties is hampered by a critical shortage of correlative data that can be use for validation and development of new algorithms. Such correlative data sets are normally created by episodic and expensive aircraft measurements. We will conduct a field deployment of the AMF2 that

STORMVEX science team at AMF2 radar site with Storm Peak Lab in background.

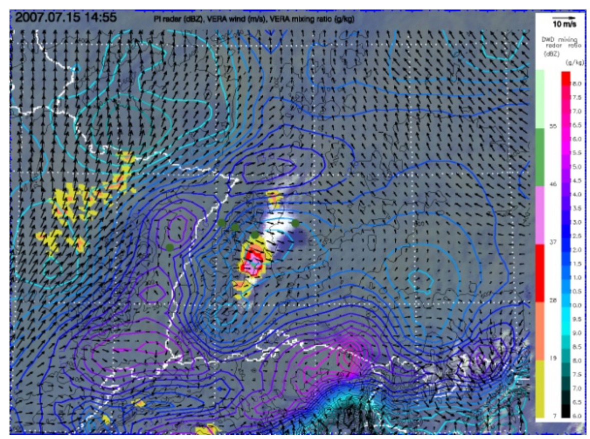
has the potential to create a correlative data set equivalent to between 200 and 300 aircraft flights in liquid and mixed-phase clouds. This will be achieved by placing the AMF2 in close proximity to an elevated platform heavily instrumented with aerosol, cloud, and precipitation sensors. The Storm Peak Lab (SPL), located east of Steamboat Springs, Colorado, is a well-established cloud and aerosol research facility operated by the Desert Research Institute. SPL is located at 3210 m above sea level and is above cloud base 25% of the time during the winter season. SPL will collect in situ cloud and precipitation property measurements while the AMF2 operates at a location approximately 2.4 km west and 500 m in elevation below SPL during a winter season extending from approximately October 2010 through May 2011. This deployment will address three long-standing ARM objectives: (1) From a cloud property retrieval perspective, the type of clouds that will be observed during this period will range from stable liquid-phase boundary-layer clouds to mixed-phase clouds to heavily precipitating snow. These cloud types represent some of the most unique challenges for cloud property retrievals, and the full Doppler spectra from the scanning cloud radar combined with other AMF2 measurements correlated with continuous in situ data will facilitate development of new algorithms and statistically significant validation of the algorithm results. (2) The data set will be collected in a region of complex terrain. Collecting such a data set has been a long-standing goal of ARM, and it will present a unique challenge and opportunity for modeling groups. (3) The extensive aerosol data set that will be collected at SPL will allow for investigation of the role of natural and anthropogenic aerosol in cloud and precipitation processes.

http://stormpeak.dri.edu

Understanding clouds and precipitation in complex terrain: the Convective and Orographically Induced Precipitation Study (COPS)

Volker Wulfmeyer, Hohenheim University

For weather forecasts and climate simulations, correct modeling of clouds and precipitation is crucial. Particularly over the land surface in complex terrain, excellent performance is required for many applications such as protection of crops, flash flood forecasting, and land-use management in the future. However, from nowcasting to medium-range weather forecasting to decadal climate simulations, the performance of models by far does not meet the needs of end users and decision makers. For instance, with respect to precipitation, weather forecasts suffer from high false-alarm ratios and low probabilities of detection. Both weather and climate simulations show substantial systematic errors, such as windward-lee effects and large phase errors in the diurnal cycle. The World Weather Research Programme (WWRP) Research and Development Project (RDP) Convective and Orographically Induced Precipitation Study (COPS) was designed and performed to understand and to remove these



Synergetic observation of convection initiation in the COPS domain. Overlaid are a three-channel composite of the MSG satellite and a radar composite as well as mixing ratio and wind fields from a densified surface station network. These results are used to study the interaction between thermally induced flows in the region and convection initiation. Here, the development of a convergence line over the southern crest of the Black Forest was caused by flow splitting of southwesterly flow and slope and valley flows from the western side of the Black Forest.

errors by combination of extensive observational and modeling efforts. COPS was strongly supported by ARM, e.g., the operation of the ARM Mobile Facility for nine months in the center of the COPS region in southwestern Germany/eastern France. We present highlights of the COPS research along the chain of processes leading to precipitation. These include observations of land-surface exchange processes in dependence of land-use and soil moisture; thermally induced slope flows in complex terrain leading to a modulation of moisture, CAPE, and CIN across convergence lines; initiation of convection and clouds; and aerosol-cloud-precipitation microphysics. These observations are accompanied by various data assimilation and ensemble modeling studies on the convection-permitting scale. The following main conclusions can be derived from these results. Extreme care has to be taken in the description of land-surface properties and processes, but still the relationship between latent and sensible heat fluxes on soil moisture is not resembled by models. Convection-permitting simulations remove several systematic errors caused by the parameterization of deep convection so that this resolution should be aimed for the next generation of weather and climate simulations. Advanced data assimilation systems in combination with new observations from surface networks and satellites have a huge potential to approach further the limits of predictability of key processes in the Earth system such as precipitation.

http://www.uni-hohenheim.de/cops

http://www.wmo.int/pages/prog/arep/wwrp/new/mesoscale_new.html

7.0 Infrastructure & Outreach

American Recovery and Reinvestment Act upgrades to the ARM Data Management Facility

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

The Data Management Facility (DMF) is the hub of ARM instrument data flow and also provides resources for VAP development. The American Recovery and Reinvestment Act provided money to ensure that the DMF could support the large number of new instruments and their data volumes, as well as plan for the expected continued growth in VAP development needs over the next few years. This poster presents the new hardware architecture of the DMF, the planned data flow, and proposed changes to data policies. The poster will generate feedback to help tune the policies. It will also serve to communicate the capabilities that are available to infrastructure data users.

AMF2 status: plans and progress

Richard Coulter, Argonne National Laboratory
Brad Orr, Argonne National Laboratory
Michael Ritsche, Argonne National Laboratory
Timothy Martin, Argonne National Laboratory
Richard Eagan, Argonne National Laboratory
David Cook, Argonne National Laboratory
Donna Holdridge, Argonne National Laboratory

The second ARM Moble Facility (AMF2) is scheduled for its first deployment to the Storm Peak Laboratory during the winter of 2010–2011. Designed for deployment to harsh environments, including at sea, this system faces a number of challenges. The addition of two scanning radars, a high spectral resolution lidar, and an aerosol observing system create challenges to the original concept of a small, highly mobile facility. This poster reports on approaches and solutions to motion compensation at sea, data communications over extended ranges, and extreme climate conditions. An up-to-date status report is provided.

ARM Climate Research Facility: outreach tools and strategies

Rolanda Jundt, Pacific Northwest National Laboratory
Lynne Roeder, Pacific Northwest National Laboratory

Sponsored by the U.S. Department of Energy, the ARM Climate Research Facility is a global scientific user facility for the study of climate change. To publicize progress and achievements and to reach new users, the ARM Facility uses a variety of Web 2.0 tools and strategies that build off of the program's comprehensive and well-established News Center (www.arm.gov/news). These strategies include: an RSS subscription service for specific news categories; an email "newsletter" distribution to the user community that compiles the latest News Center updates into a short summary with links; and a Facebook page that pulls information from the News Center and links to relevant information in other online venues, including those of our collaborators. The ARM Facility also interacts with users through field campaign blogs, like Discovery Channel's EarthLive, to share research experiences from the field. Increasingly, field campaign Wikis are established to help ARM researchers collaborate during the planning and implementation phases of their field studies and include easy-to-use logs and image libraries to help record the campaigns. This vital reference information is used in developing outreach material that is shared in highlights, news, and Facebook. Other Web 2.0 tools that ARM uses include Google Maps to help users visualize facility locations and aircraft flight patterns. Easy-to-use comment boxes are also available on many of the data-related web pages on www.arm.gov to encourage feedback. To provide additional opportunities for increased interaction with the public and user community, future Web 2.0 plans under consideration for ARM include: evaluating field campaigns for Twitter and microblogging opportunities, adding public discussion forums to research highlight web pages, moving existing photos into albums on Flickr or Facebook, and building online video archives through YouTube.

Twitter is the latest social media tool being used by the ARM Climate Research Facility.

http://www.facebook.com/pages/ARM-Climate-Research-Facility/110470104224

Collaborations for improved atmospheric humidity and temperature profiles

Douglas Sisterson, Argonne National Laboratory
Howard Diamond, NOAA National Climatic Data Center
Holger Vömel, DWD
Raymond McCord, Oak Ridge National Laboratory
Jimmy Voyles, Pacific Northwest National Laboratory
Michael Ritsche, Argonne National Laboratory

At a data management workshop held in September 2009, agreement between U.S. Department of Energy (DOE), the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC), the Global Change Observing System (GCOS) Reference Upper Air Network (GRUAN) lead center, and the Lindenberg Meteorological Observatory in Germany was reached on a data management strategy for the GRUAN. GRUAN is envisaged as a network of 30–40 high-quality, long-term, upper-air observing stations, building on existing observational networks expected to provide long-term, highly accurate measurements of the atmospheric profile. The DOE Atmospheric Radiation Measurement (ARM) Climate Research Facility will concurrently launch cryogenic frost-point hygrometers (CFH) and the ARM standard rawinsondes. The resulting data product will provide ARM users with improved humidity profiles in the upper regions of the troposphere and lower regions of the stratosphere. NCDC will provide (as budgets allow) the incremental funding required to conduct GRUAN operations (e.g., expendables such as CFH radiosondes and other related materials) at the seven U.S. GRUAN sites (including all five ARM sites). In return, the ARM Facility will process Vaisala (RS-92) rawinsonde data from all GRUAN sites (currently 15) and send the ARM-processed data to the Lindenberg Meteorological Observatory where error bars will be determined from individual site metadata and added to the individual data files. This GRUAN-branded rawinsonde will be archived at NCDC and made freely available to all users. The significance of this agreement is twofold: it allows rawinsonde data from

15 different worldwide sites to be directly comparable, and it will be the first time that a major observational network will provide error bars as part of its data. This activity is expected to begin mid-FY2010.

From EAST-AIRE to the ARM Mobile Facility deployment in China: an overview of data status

Maureen Cribb, University of Maryland
Zhanqing Li, University of Maryland

As the most populated and fastest-developing country in the world, China is undergoing drastic changes in many respects, including changes to its environment and climate. Unraveling the impact of environmental changes on weather and climate requires a good knowledge and understanding of atmospheric aerosols and precursor gases and their interactions with key meteorological variables such as radiation, clouds, and precipitation. Towards meeting these goals, the East Asian Study of Tropospheric Aerosols: an International Regional Experiment (EAST-AIRE) has collected radiation and aerosol data at two sites in China since its inception in the fall of 2004. The deployment of the ARM Mobile Facility at a third site during most of 2008 greatly expanded the scope of geophysical data obtained in China. This poster will summarize the datastreams available from all sites, as well as issues encountered along the way.

Infrastructure and domain changes at the SGP

Brad Orr, Argonne National Laboratory
Dan Rusk, Cherokee Nations Distributors, LLC
Douglas Sisterson, Argonne National Laboratory

Significant changes are underway at the SGP that will continue through the next year. The combined effects of budgetary constraints, the influx of significant American Reinvestment and Recovery Act (ARRA) money, and changing scientific requirements have all shaped these changes. The most notable is a reduction in the SGP domain that will be routinely serviced. It will go from the original 56,000 square miles down to an estimated 10,000 square miles (approximately 150 km x 150 km). The size of the reduced SGP domain was chosen as representative of a modern climate model grid cell, the same criteria used to establish the original SGP domain nearly 20 years ago. This service domain change will produce a notable reduction in operational costs that were associated with servicing the very remote and widely spaced sites. At the same time ARRA money has been designated for the installation of new surface characterization sites (i.e., new EFs) within this reduced domain. This will produce a much more dense network than the original domain (nearly as many EF sites within an area one-fifth the size), providing much better sub-grid surface characterization. ARRA money has also been made available for significant infrastructure and capital improvements at the SGP. Five new radar systems will be installed, including a dual-frequency scanning cloud radar and three X-band and one C-band precipitation radars. Combined with existing SGP instrumentation, these new systems will provide unique three- and four-dimensional data sets for cloud and atmospheric process studies and model validation. Other improvements at the SGP include new offices, an expanded electronics repair lab, and increased shipping and receiving storage.

Metadata standards—a key for data discovery and data interoperability: tapping the ARM Archive metadata database

Giri Palanisamy, Oak Ridge National Laboratory
W Christopher Lenhardt, Oak Ridge National Laboratory
Raymond McCord, Oak Ridge National Laboratory
Stefanie Hall, Oak Ridge National Laboratory

The ARM Archive users depend on the creation of structured metadata for search and discovery, sharing and interoperability, management, and reuse of data. Metadata also helps users answer questions about the data, helps publish the data for secondary access, and can facilitate provenance and attribution. Metadata following extended standards further improve the data search and discovery process and allow data providers to publish their metadata in distributed scientific discovery systems, which provides more visibility to the data products. Many different metadata schemes are being developed as standards for disciplines that span Earth and ecological sciences, libraries, education, archiving, e-commerce, and arts. Metadata standards applicable to ARM data are ISO 19115, Federal Geographic Data Committee's (FGDC) Content Standard for Digital Geospatial Metadata (CSDGM), Earth Science Markup Language (EML), NASA's Global Change Master Directory's (GCMD) Directory Interchange Format (DIF), and Dublin Core. The ARM Archive contains a rich metadata database. Exporting these metadata values into standards-based metadata records allows the Archive to build better data discovery tools. For example, standards-based metadata can enable users to discover data using various advanced search capabilities such as fielded, temporal, and spatial search. Standardized metadata also allows users to filter the search results based on logical grouping. Creating standardized metadata records will allow the ARM to publish the metadata in various scientific data discovery tools such as Global Earth Observation System of Systems (GEOSS), Earth System Grid (ESG), data.gov, science.gov, and Geospatial One Stop (GOS). The ARM Archive recently created metadata records in FGDC format. The poster will demonstrate some of the new data discovery concepts using these standardized metadata records. It will also demonstrate the discovery of ARM data using other distributed data search systems such as GEOSS and data.gov. Other advantages such as provenance and attribution will also be explored.

Model-measurement interaction: the development of model-like data from the ARM scanning radar network

Scott Collis, Centre for Australian Weather and Climate Research
Kevin Widener, Pacific Northwest National Laboratory
Nitin Bharadwaj, Pacific Northwest National Laboratory
Pavlos Kollias, McGill University
Annette Koontz, Pacific Northwest National Laboratory
Douglas Sisterson, Argonne National Laboratory
Brad Orr, Argonne National Laboratory

The implementation of multi-frequency dual-polarization scanning radar platforms at the fixed and mobile ARM sites will generate a large volume of data. The routine synthesis of geophysical parameters for comparison with cloud-resolving models and accurately describing the state of the atmosphere in three dimensions is a challenging task. In order to achieve this, a modular framework for manipulating scanning radar data will be developed based on a five-phase process: quality control and product generation in radar coordinates, gridding onto a Cartesian grid, simple product generation in Cartesian coordinates, retrievals involving constraining and adjoint models, and finally, statistical descriptions of data from the previous four phases. The system is being developed in a manner that allows interaction between the ARM Climate Research Facility infrastructure, the Atmospheric System Research (ASR)

working groups, and the scientific community such that the integration of modules written by third parties is straightforward through careful definition of the NetCDF file structure. The continuous operation of this system presents an exciting opportunity to generate long-term records of the three-dimensional structure of precipitating and non-precipitating systems from the tropics to the Arctic.

The new ARM.gov

Sherman Beus, Pacific Northwest National Laboratory
Rolanda Jundt, Pacific Northwest National Laboratory
Katarina Younkin, Pacific Northwest National Laboratory
Lynne Roeder, Pacific Northwest National Laboratory

The U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program developed a website in 1994 to support the science and infrastructure communication needs of the program. With an estimated 10,000 pages on servers maintained at Brookhaven National Laboratory, Pacific Northwest National Laboratory, and Oak Ridge National Laboratory, the ARM website provides climate change information and data to scientists, government officials, university researchers, and the public, as well as ARM participants. As a scientific user facility, the ARM Climate Research Facility provides web-based services, such as the data archive, publications database, research highlights, field campaign system, and wiki environments. On October 1, the ARM science component was merged with another DOE science program. This programmatic development required a redesign of the ARM website to reflect the changes in program structure, while also presenting an opportunity to change the way the site is managed. More than half of the site was maintained by an unconnected series of custom, database-driven content systems. Until the summer of 2008, news and program information were maintained the old-fashioned way—static HTML. In 2008, WordPress was installed to build a new database with RSS (really simple syndication) feed capability. Through the News Center, the custom systems developed for research highlights and publications were then connected, and RSS feeds could be offered to users. With a redesign underway, we moved the rest of the static HTML pages into WordPress. Now, through several interfaces of web forms, all content is accessible to all the ARM writers and editors, allowing them to update web pages without sending their content to web programmers. This allows the web application developers and programmers to better control the website HTML code, scripting, and cascading style sheets.

http://www.arm.gov

Overview of the ARM Aerial Facility

Jason Tomlinson, Pacific Northwest National Laboratory
John Hubbe, Pacific Northwest National Laboratory
Jennifer Comstock, Pacific Northwest National Laboratory
Beat Schmid, Pacific Northwest National Laboratory
Stephen Springston, Brookhaven National Laboratory
Gunnar Senum, Brookhaven National Laboratory

The AAF G-1 aircraft is shown in the center. Images from the ISDAC and RACORO campaigns are shown along the sides.

The ARM Aerial Facility (AAF) provides airborne measurements to answer science questions proposed by the ASR Science Team and the external research community. The AAF operates a Gulfstream-1 (G-1) turboprop aircraft and has access to a multitude of research aircraft operated by other agencies. The G-1 is currently undergoing a number of improvements that will increase the flight time, increase the available research power, enable the aircraft to carry a total of eight external probes, enable it to carry radiometers, and update the onboard data system. The AAF is in the process of acquiring 17 state-of-the-art cloud probes, aerosol instruments, and gas phase instruments through Recovery Act funding. An overview of these improvements and acquisitions will be presented.

http://www.arm.gov/sites/aaf

Quality control tools at the ARM Climate Research Facility Data Quality Office

Justin Monroe, ARM Data Quality Office/CIMMS/University of Oklahoma
Sean Moore, Mission Research
Randy Peppler, ARM Data Quality Office/CIMMS/University of Oklahoma
Kenneth Kehoe, CIMMS/University of Oklahoma

The ARM Climate Research Facility Data Quality (DQ) Office develops and utilizes a wide range of tools and analysis methods to support the needs of the Atmospheric System Research (ASR) Program. Now in our tenth year of operation, we ensure that data users receive the highest possible level of research-quality data. Some of these tools include Data Quality Health and Status (DQ HandS) to provide diagnostic data plots and quality-control (QC) metrics; NCVweb to allow users to interactively inspect and plot NetCDF files; and ARM*STAR to generate longer time-series plots and statistics. Of these tools, DQ HandS facilitates the majority of routine DQ Office analyses by automatically processing over 5,000 measurements and creating roughly 3,000 plots per day. Due to this exceptional volume of data, the DQ Office constantly researches different methods to better streamline the QC process. A vital component of this research is collaboration with ARM instrument mentors and other members of the ASR scientific community. Recent collaborations have led to the development of products that enable the DQ Office to detect irregularities with the millimeter wavelength cloud radar, compute liquid and vapor retrievals from the G-Band vapor radiometer, and transform infrared sky temperatures from the atmospheric emitted radiance interferometer. Examples of these newer products will be shown.

Radiatively Important Parameters Best Estimate (RIPBE) value-added product (VAP)

Timothy Shippert, Pacific Northwest National Laboratory
Sally McFarlane, Pacific Northwest National Laboratory
James Mather, Pacific Northwest National Laboratory
Connor Flynn, Pacific Northwest National Laboratory
Eli Mlawer, Atmospheric and Environmental Research, Inc.
Jennifer Delamere, Atmospheric and Environmental Research, Inc.
Michael Jensen, Brookhaven National Laboratory
Lazaros Oreopoulos, NASA
David Turner, University of Wisconsin-Madison
Shaocheng Xie, Lawrence Livermore National Laboratory

Currently, to calculate radiative heating rate profiles for the Broadband Heating Rate Profile (BBHRP) product, radiatively important parameters (water vapor, ozone, surface albedo, aerosol properties, and cloud properties) from multiple VAPs and datastreams are combined into input text files that are then used to run the RRTM radiative transfer codes. These input parameters have different temporal and spatial scales and are difficult to extract from the text files to be used for other purposes such as running other radiative transfer codes, analyzing results, or error tracking. The purpose of the Radiatively Important Parameters Best Estimate (RIPBE) VAP is to improve this process by creating a clearly identified set of inputs for BBHRP (and other radiation codes) on a uniform vertical and temporal grid. This process will decouple the input/output portion of the BBHRP from the core physics (the RRTM radiative transfer model) and will add error tracking and version information to the input data set. Critical parameters (which must exist for the radiation code to be run) will be designated; for other parameters, climatological or fixed values will be used when the preferred values are missing. This should increase the number of cases for which radiative transfer calculations can be run. In all cases, flags will clearly identify the source for each parameter. RIPBE will serve multiple functions: (1) it will provide a clearly identifiable set of inputs for BBHRP, (2) it will facilitate the use of BBHRP as a retrieval and radiation code development testbed by providing a vehicle for easily extracting and swapping input parameters needed to conduct radiative transfer calculations, and (3) it will be a complement to the Climate Modeling Best Estimate (CMBE) VAP and will provide a significantly expanded set of parameters for model evaluation in a showcase data set form. At the ASR meeting, we will present examples and evaluation of the initial RIPBE dataset at SGP.

Recovery Act-funded additions to the U.S. Department of Energy's Atmospheric Radiation Measurement Climate Research Facility sites on the North Slope of Alaska

Mark Ivey, Sandia National Laboratories
Jeffrey Zirzow, Sandia National Laboratories
Valerie Sparks, Sandia National Laboratories
Bernard Zak, Sandia National Laboratories
Johannes Verlinde, The Pennsylvania State University
Scott Richardson, The Pennsylvania State University
Jessica Cherry, International Arctic Research Center
Martin Stuefer, University of Alaska Fairbanks Geophysical Institute

The U.S. Department of Energy (DOE) provides scientific infrastructure and data archives to the international Arctic research community through a national user facility, the ARM Climate Research Facility, located on the North Slope of Alaska. The ARM sites at Barrow and Atqasuk, Alaska, have been collecting and archiving atmospheric data for more than 10 years. These data have been used for scientific investigation as well as remote sensing validations. Funding from the Recovery Act (American Recovery and Reinvestment Act of 2009) will be used to install new instruments and upgrade existing instruments at the North Slope sites. These instruments include: scanning precipitation radar; scanning cloud radar; automatic balloon launcher; high spectral resolution lidar; eddy correlation flux systems; and upgraded ceilometer, AERI, micropulse lidar, and millimeter cloud radar. Information on these planned additions and upgrades will be provided in our poster. An update on activities planned at Oliktok Point will also be provided.

Recovery Act instruments: deployment and data processing plans

Jimmy Voyles, Pacific Northwest National Laboratory
James Mather, Pacific Northwest National Laboratory

Through the American Recovery and Reinvestment Act of 2009, the U.S. Department of Energy's Office of Science allocated $60 million to the ARM Climate Research Facility for the purchase of instruments and improvement of research sites. With these funds, ARM is in the process of purchasing a broad variety of new instruments that will greatly enhance the measurement capabilities of the facility. New instruments being purchased include dual-frequency scanning cloud radars, scanning precipitation radars, Doppler lidars, a mobile Aerosol Observing System, and many others. A list of instruments being purchased is available at http://www.arm.gov/about/recovery-act. Orders for nearly all instruments have now been placed, and activities are underway to prepare for the next phase of the project, deployment. The deployment phase includes the physical installation of instruments as well as providing for the transfer of data from the sites to the archive. This data transfer also includes the development of data products for the many new instruments. An overview of instrument deployment and data processing plans will be presented.

http://www.arm.gov/about/recovery-act

Surviving the deluge (part I): learning from an analysis of data extraction patterns from the ARM Climate Research Facility Data Archive

W. Christopher Lenhardt, Oak Ridge National Laboratory
Stefanie Hall, Oak Ridge National Laboratory
Raymond McCord, Oak Ridge National Laboratory
Giri Palanisamy, Oak Ridge National Laboratory
Sean Moore, Mission Research

The ARM Climate Research Facility Data Archive supports the Atmospheric System Research program through the storage, management, and distribution of ASR data. To support growing demand for data from a growing supply, the Archive has developed a data extraction utility for its interfaces that enables users to find and selectively access relevant data for their research. Future usage of the large volumes of data anticipated from the new 3D observations is anticipated to be very dependent on data extractions. The Archive recently implemented a capability to log usage of these extractions. Usage logs of end-user data extraction represent a rich source of potential information about the data needs and usage patterns of the ARM Climate Research Facility Data Archive. This usage information gives the Archive developers a snapshot and a hint at usage trends and the needs for additional similar features. This poster will present an analysis of Archive data extractions that examines measurement themes and the frequency and extent of data extractions. The goal will be to better understand how our end users approach data extractions and to infer their typical data needs and analysis patterns. Understanding these patterns is important as a guide to the allocation of resources within the Archive and as a reality check to make sure the Archive is meeting the needs of its users as science needs evolve. Evaluating this analysis at this time is particularly important for the insights it may provide for developing the specifications of the user interfaces, data extraction, and data processing for the new instruments expected to come online in the future. Another objective for the poster will be to gain additional validation in the form of feedback from Science Team Meeting participants.

Surviving the deluge (part II): planning the ARM "Big Data" system for infrastructure and research processing of terabyte-scale data volumes

Raymond McCord, Oak Ridge National Laboratory
Giri Palanisamy, Oak Ridge National Laboratory
W. Christopher Lenhardt, Oak Ridge National Laboratory
Karen Gibson, Oak Ridge National Laboratory
Matt Macduff, Pacific Northwest National Laboratory
James Mather, Pacific Northwest National Laboratory

In 2010, ARM will be installing many new radar and lidar instruments for 3D atmospheric measurements. These instruments generate very large volumes of data (>10 GB and 100s data files per day) for basic data products. These data sizes will increase the overall data collection rate for ARM by a minimum of 4x. Processing tasks requiring more than a few months of these data result in terabyte scale problems. To meet the expected data deluge, the ARM infrastructure will be implementing at the Archive a new data system specifically designed for very large-scale data tasks. Part of the historical experiences and trends in managing and delivering ARM data is relevant to this new installation. However, the Big Data system will have many additional requirements. Accordingly, this poster will have two main goals: (1) to outline

current thinking on the problem (hardware, software, and policies) and (2) to engage users in the design process for a better understanding of the issues. The poster will be organized around the following themes: (1) What will the Big Data system look like? (2) What tasks will the new system be required to support? (3) Will the system support visualization, data extraction, and analysis? (4) What are the user expectations? In this context, key points from the recent survey conducted by ARM management about the ARM Computing Environment will be presented. For example; what kind of analysis facility will this system need to provide to researchers and infrastructure? (5) Key policy and operational issues and alternatives will also be presented. For example, will the system need to operate in batch mode? If so, how will tasks be defined and submitted for processing? During the STM meeting the presenters of this poster will actively seek additional feedback on these issues from ASR Science Team members.

A web-based aerosol calculator for research and education

Scot Martin, Harvard University

This poster introduces a web-based computational tool for the practical implementation in research and education of several popular examples of aerosol calculations. The user of the AerosolCalculator begins by discretizing a lognormal distribution into a group of size bins. The user selects particle chemistry among the possibilities of ammonium sulfate, sodium chloride, sulfuric acid, and polystyrene latex. The user can then view the distribution in number, surface, volume, or mass space with respect to volume-equivalent diameter. Alternatively, the user can view the distributions with respect to aerodynamic (e.g., to simulate an aerodynamic particle sizer) or vacuum-aerodynamic diameter (e.g., to simulate an aerosol mass spectrometer). The user can apply a Boltzmann charge distribution and then view distributions with respect to mobility diameter or particle electric mobility. The user can pass the particles through a differential mobility analyzer to filter for particles of selected mobility (including diffusing and nondiffusing transfer functions). The user can simulate CCN activation at a particular supersaturation. The user can choose to apply deliquescence, efflorescence, and hygroscopic growth (with Kelvin effect) to the size distributions. The particle size distributions at each stage of the simulation can be downloaded in Excel format. Online tutorials accompany the simulations. Careful records are kept of the data sources of the physical and chemical properties of the particles. At present, the AerosolCalculator is of research-quality value to scientists working on CCN activation and HTDMA hygroscopic growth.

http://www.seas.harvard.edu/AerosolCalculator

8.0 Instruments

Aerosol observing system platform integration and AAF instrumentation

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

As part of the federal government's 2009 American Recovery and Reinvestment Act (ARRA), the U.S. DOE Office of Science allocated funds for the capital upgrade of the Atmospheric Radiation Measurement (ARM) Climate Research Facility to improve and expand observational capabilities related to cloud and aerosol properties. The ARM Facility was established as a national user facility for the global scientific community to conduct a wide range of interdisciplinary science. Part of the ARRA-funded expansion of the ARM Facility includes four new Aerosol Observing Systems (AOS) to be designed, instrumented, and mentored by BNL. The enclosures will be customized SeaTainers. These new platforms ([AMF2]: ARM Mobile Facility-2; [TWP-D]: Tropical Western Pacific at Darwin; and [MAOS-A]/[MAOS-C]: Mobile Aerosol Observing System-Aerosol/Chemistry) will provide a laboratory environment for fielding instruments to collect data on aerosol life cycle, microphysics, and optical/physical properties. The extensive instrument suite includes both established methods and initial deployments of new techniques to add breadth and depth to the AOS data sets. The platforms are designed: (1) to have all instruments pre-installed before deployment, allowing a higher measurement duty cycle; (2) with a standardized configuration improving the robustness of data inter-comparability; (3) to provide remote access capability for instrument mentors; and (4) to readily accommodate guest instrumentation. The first deployment of the AMF2 platform will be at the upcoming STORMVEX campaign held at Steamboat Springs, Colorado, October 15, 2010–March 31, 2011, while the TWP-D AOS will be stationed at the ARM Darwin site. The maiden deployments of the MAOS-A and MAOS-C platforms will be during the Ganges Valley Experiment (GVAX) scheduled for April 2011–April 2012. In addition to the ground-based AOS platforms, thee major instrument builds for the AAF are also being undertaken (new trace gas package [NO, NOx, NOy, CO, O3, and SO2]; Scanning Mobility Particle Sampler [SMPS]; and Particle into Liquid Sampler [PILS]). The current status of the AOS platforms, instrument suites, instituted QA/QC activities, projected AOS VAPs, and inlet design, as well as still-unresolved issues, will be presented.

Comparison of microwave radiometer profiler (MWRP) and radiosonde in Taihu and Shouxian Sites

Hsiang-He Lee, University of Maryland
Zhanqing Li, University of Maryland

One aim of the ARM Mobile Facility (AMF) deployment in China in 2008 is to study the aerosol indirect effects. Shouxian and Taihu are located along the Meiyu front and convergence zone of the eastern monsoon system. They separated by about 500 km and are generally influenced by similar weather systems but with different types of dominant aerosols. This discrepancy provides a good opportunity to understand the cloud-aerosol interaction and the results of the indirect effects with various aerosol species. The microwave radiometer profiler (MWRP), one of the ground observation instruments of the AMF, provides vertical profiles of temperature, humidity, and cloud liquid-water content as a function of height or pressure. The radiosonde provides in situ measurements (vertical profiles) of both the thermodynamic state of the atmosphere and the wind speed and direction. These parameters lead to understanding the cloud formation in dynamic and microphysical processes. In order to obtain useful meteorological parameters from ground-based observation instruments, evaluation of the accuracy of the AMF instruments is essential. The comparison of MWRP and radiosonde can help eliminate the bias of MWRP-retrieved data from different algorithm retrieval methods. At the Taihu site, MWRP temperature and relative humidity (RH) retrievals in the lower atmosphere are consistent with the sounding profiles from neighboring Nanjing, Hangzhou, and Shanghai sounding stations. MWRP-retrieved temperature is generally lower than sounding temperature in the lower atmosphere (except surface temperature), but higher in the upper troposphere. The temperature differences are within ±2°C. Relative humidity shows opposite bias compared to temperature. Negative bias happens at 2000~5000 m height. Temperature and RH retrievals from the MWRP deployed at Shouxian have less bias compared to the Taihu site, because there is no spatial distinction for MWRP and sounding profile. Retrieved temperature is about 1°C higher, and RH is ~10% lower in the low atmosphere.

A demonstration of the Solmirus All Sky Infrared Visible Analyzer

Victor Morris, Pacific Northwest National Laboratory
Dimitri Klebe, Denver Museum of Nature and Science

The Infrared Sky Imager Intercomparison Study was conducted in September 2007 at the ARM Climate Research Facility Southern Great Plains (SGP) site to compare measurements of cloud fraction from five different types of infrared sky imagers. However, the results did not provide a clear solution for obtaining nighttime cloud fraction. After the field campaign, one of the participants, Solmirus Corporation, made significant improvements to the hardware and retrieval algorithms of their All Sky Infrared Visible Analyzer (ASIVA). A filter wheel was also added to determine color temperature from which cloud height can be estimated. The improved ASIVA was demonstrated at the SGP site from May to July 2009. The instrument captures hemispheric infrared images of the sky during both the day and night and provides values of cloud fraction and cloud height. The daytime values were compared with the operational Total Sky Imager, which provides visible images and real-time processing of daytime sky conditions.

The Solmirus All Sky Infrared Visible Analyzer on the Guest Instrument Facility platform at the ARM SGP site.

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

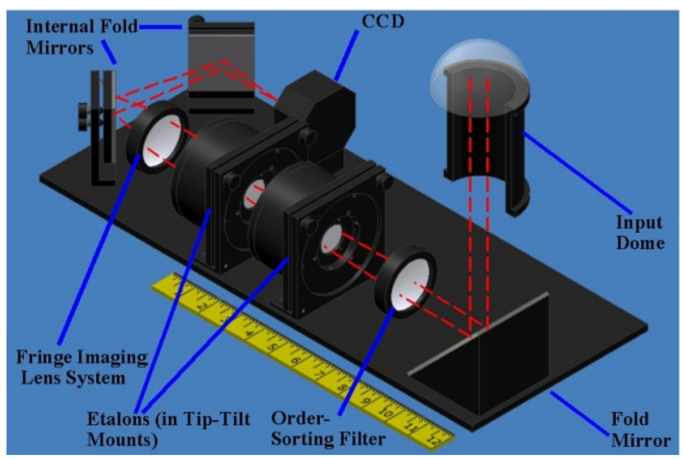
Detecting fault conditions in distributed sensor networks using dynamic Bayesian networks

George Chin, Pacific Northwest National Laboratory
Sutanay Choudhury, Pacific Northwest National Laboratory
Lars Kangas, Pacific Northwest National Laboratory
Sally McFarlane, Pacific Northwest National Laboratory
Kevin Widener, Pacific Northwest National Laboratory

A Bayesian network (BN) is a probabilistic graphical model, where nodes represent random variables and directed edges represent conditional dependencies. A dynamic Bayesian network (DBN) models the stochastic evolution of a set of variables over time. We are developing DBN models for identifying and analyzing fault conditions occurring in atmospheric radiation and measurement sensor networks. In these models, the different variables represent the various measurements that may be taken across a distributed sensor network. The variables are linked in the DBN to convey both causal and temporal relationships. Using the DBN, we may then compute the probabilities that particular measurements are unexpected or anomalous and detect whether parts of the sensor network are behaving unusually or erratically. A full set of DBNs of varying complexities is currently under construction to cover different collections and ranges of measurements and time frames.

FABSOAR—an instrument for measurement of solar shortwave forcing

Steven Watchom, Scientific Solutions, Inc.
John Noto, Scientific Solutions, Inc.



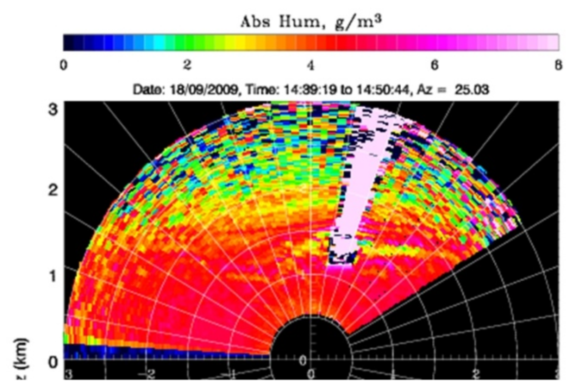
Scaled conceptual representation of the FABSOAR instrument, with a double Fabry-Perot represented.

Many atmospheric processes are driven by the infusion and dispersion of solar energy. The amount of shortwave (SW) solar radiation absorbed is of particular interest, regarding the terrestrial climate and atmospheric photochemistry. Some recent estimates of the SW budget, inferred from measurements, suggest that there are still major uncertainties in the levels predicted by atmospheric models in cloudy sky conditions, by up to 100 W/m2 for instantaneous measurements and 35 W/m2 in the diurnal mean. The problem may lie in radiative transfer models that, for relative ease of computation, treat the clouds as plane-parallel entities, ignoring three-dimensional cloud effects. While some sophisticated models—such as independent pixel and Monte Carlo simulations—have been developed, there have only been a few measurements of path lengths (or direct absorption measurements) with which to test them. The FABSOAR instrument will provide many more such measurements and probe the question of which situations are amenable to a simple plane-parallel cloud model. FABSOAR—a FABry-Perot Spectrometer for Oxygen A-band Research—is a high-throughput, high-resolving power, imaging, tandem Fabry-Perot spectrometer targeted particularly for the oxygen A-band (760–780 nm), though other nearby emissions can also be studied if they are also useful for the scientific goals. Designed for ground and airborne use, it gives high resolution in a much more compact package than a grating spectrometer, and combines that with high throughput, giving the performance of a refrigerator-sized grating spectrometer in a shoebox package. It also requires no moving parts for scanning, making it much more robust than conventional grating spectrometers. Development of FABSOAR has begun via a U.S. DOE SBIR Phase I grant. Under this contract, Scientific Solutions has developed a mechanical and optical design for the FABSOAR etalons, obtained and analyzed test images of a Helium-Neon laser source with an etalon with equivalent gap spacing, and begun work on a forward model to use FABSOAR data to obtain PDF-GP values for Solar shortwave. All of these results will be presented, along with a look ahead to projected work for a soon-to-be-proposed Phase II.

First 3D water-vapor measurements with differential absorption lidar

Andreas Behrendt, Hohenheim University
Volker Wulfmeyer, Hohenheim University
Sandip Pal, Hohenheim University

We present the first water-vapor differential absorption lidar (DIAL) system that is able to perform 3D measurements. The system is based on a high-power Ti:Sapphire laser transmitter with excellent spectral properties. 3D measurements are realized by simultaneous scans of an 80 cm telescope in so-called Coude configuration in which field-of-view of the laser output is transmitted and fixed by a high-power fiber. The performance of the system is discussed with respect to vertical pointing and scanning measurements. In vertical pointing mode, a unique combination of spatial and temporal resolutions (15 m, 1 s), respectively, is achieved even during daytime. This permits the investigation of turbulent transport processes in the convective boundary layer with "large-eddy resolution." Various PPI and RHI scans demonstrate that the system is capable of studying land-surface exchange processes in heterogeneous terrain as well as detrainment and entrainment processes around clouds.



First RHI scan of the humidity field around clouds using water-vapor DIAL. Streakline structures around the clouds likely indicate interaction of aerosol-cloud microphysics as well as detrainment and entrainment processes.

http://www.uni-hohenheim.de/www120

Meteorological instrumentation performance and data quality using temperature, relative humidity, and wind-speed sensors in Barrow, Alaska

Jenni Prell, Argonne National Laboratory

A recent instrument change at the Atmospheric Radiation Measurement (ARM) Climate Research Facility in Barrow, Alaska, has provided an effective backdrop for developing a new automated method to identify issues with data collection and quality. The parameters used for the comparison include minute averages of temperature, relative humidity, and wind speed, providing real-time error assessment. The variables were inter-compared between tower levels in effort to isolate instrument failures to specific instruments. Not only were discrepancies identified, but this methodology proved useful in accurately identifying erroneous and biased data elements using statistical procedures.

MMCR fourth-generation upgrade

Andrew Pazmany, ProSensing Inc.

Since the mid-1990s, MMCR has been the primary radar system used by the ARM Climate Research Facility for fundamental research on the effects of clouds and precipitation on the climate. Through the 2009 American Recovery and Reinvestment Act, the U.S. DOE's Pacific Northwest National Laboratory recently funded ProSensing Inc. of Amherst, Massachusetts, to carry out the fourth-generation upgrade of the five existing MMCR systems. Upgrades to MMCR include a redesigned, wide dynamic range IF section; state-of-the-art PC-based data system; and new processing software. The upgrade will include an embedded arbitrary waveform generator, allowing use of custom pulse compression waveforms with predicted range sidelobe suppression of greater than 60 dB. Simultaneous transmission of a linear FM chirp and short pulse will allow the General Mode to sample both the boundary layer and high-level clouds. The PC-based data acquisition system, using a high performance 16-bit, 120 MS/s digital receiver, has a single-sample dynamic range of approximately 85 dB. Combined with 30:1 or 60:1 pulse compression waveforms, the expected dynamic range of the system is close to 100 dB, potentially eliminating the need for the specialized precipitation mode used in the current MMCR system.

Modeling of microwave scattering from ice crystal aggregates and melting aggregates: a new approach

Giovanni Botta, Sapienza University of Rome
Kultegin Aydin, The Pennsylvania State University
Johannes Verlinde, The Pennsylvania State University

Ice crystal aggregates and their melting process are modeled with a new approach for determining their microwave scattering characteristics and are compared with those obtained using effective dielectric constant representations. The aggregates are constructed from columnar crystals of random lengths (the width being a function of the length), which are composed of a string of touching ice spheres with diameters equal to the column's width. The aggregates are melted using a model that incorporates the primary aspects of experimentally observed features of the melting process. The Generalized Multiparticle Mie (GMM) method is used for computing the scattering cross sections of the dry and melting aggregates. The T-matrix method is used for the calculations involving the effective dielectric constant models with oblate spheroidal shapes. The results obtained for 3 GHz and 35.6 GHz frequencies show significant differences in the backscattering cross sections. For sizes larger than 5 mm, these differences range from several dB at 3 GHz to well over 10 dB at 35.6 GHz. Significant differences are also observed in the extinction cross sections during the melting process. It is concluded that the effective dielectric constant models of dry and melting ice crystal aggregates may not be representative of the interaction between the constituent crystals of the aggregates. Hence, bulk models must be used with caution depending on the electromagnetic wave frequency and the aggregate size range.

A new aerosol flow system for photochemical and thermal studies of tropospheric aerosols

Michael Ezell, University of California
Stanley Johnson, University of California
Yong Yu, California Air Resources Board
Veronique Perraud, University of California
Emily Bruns, University of California
Lizabeth Alexander, Pacific Northwest National Laboratory
Alla Zelenyuk, Pacific Northwest National Laboratory
Donald Dabdub, University of California
Yan Li, University of California
Barbara Finlayson-Pitts, University of California

Photo of large-volume, slow-flow stainless-steel flow tube for aerosol studies.

For studying the formation and photochemical/thermal reactions of aerosols relevant to the troposphere, a unique, high-volume, slow-flow, stainless steel aerosol flow system has been constructed and characterized experimentally. This apparatus fills a gap between high-speed, short residence-time flow tubes and large, continuous flow chambers that have residence times of many hours or even days. The flow tube is equipped with ultraviolet lamps for photolysis and the residence time is of the order of an hour. Five sampling ports located along the length of the flow tube allow for time-resolved measurements of aerosol and gas-phase products. This system has many advantages, including a surface-to-volume ratio of 10 m-1 and total volume of 1.2 m3, sufficiently large flows to allow a number of analytical techniques to be applied simultaneously, ease of disassembly for cleaning, and easily varied residence times. Analytical techniques applied to this system include analyzers for NOx and ozone, as well as GC-MS and PTR-MS for other gas-phase products; an integrating nephelometer for light scattering measurements; SMPS and APS for particle size distributions; integrated particle collection on filters and impactors; and real-time particle mass spectrometry (AMS and SPLAT(II)). This system has been applied to photochemical studies of nitrite and nitrate aerosols as well as formation of secondary organic aerosol from alpha-pinene reactions (NOx photooxidation and ozonolysis). Selected results from these studies, including the effects of organic coatings on light scattering by particles, will be presented to demonstrate the capabilities of this new system.

New ECOR systems (TWP, NSA) and surface energy balance systems

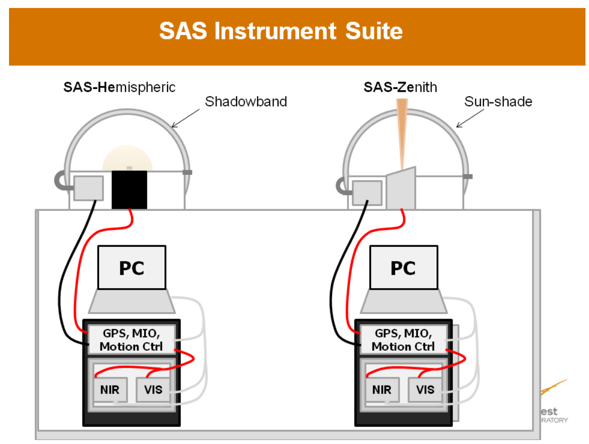
David Cook, Argonne National Laboratory

ECOR (eddy correlation) systems are being added to the Tropical Western Pacific (TWP) and North Slope of Alaska (NSA) sites of the ARM Climate Research Facility in order to provide surface-to-air exchange measurements of heat, water vapor, and carbon dioxide. Furthermore, all ECOR systems, including those already installed at the ARM Southern Great Plains (SGP) site and in the ARM Mobile Facilities (AMF1, AMF2), will be supplemented with a new instrument system that will allow the surface energy balance to be estimated. This poster shows photos of some of the potential ECOR installation sites at TWP and NSA and provides information on the new surface energy balance system.

New shortwave array spectrometers for the ARM Climate Research Facility

Connor Flynn, Pacific Northwest National Laboratory
James Barnard, Pacific Northwest National Laboratory
Patrick Disterhoft, NOAA Earth System Research Laboratory
Derek Hopkins, Pacific Northwest National Laboratory
Piotr Kiedron, NOAA
Albert Mendoza, Pacific Northwest National Laboratory
Joseph Michalsky, DOC/NOAA Earth System Research Laboratory
Dan Nelson, Pacific Northwest National Laboratory
Randy Norheim, Pacific Northwest National Laboratory
John Schmelzer, Pacific Northwest National Laboratory

Shortwave array spectrometers (SAS) providing full spectral measurements of zenith radiance, direct solar irradiance, and hemispheric diffuse irradiance from 350 nm to 1700 nm are being designed under funding from the American Recovery and Reinvestment Act. The SAS will be provided as a suite of two systems. Zenith radiance will be measured by the SAS-Ze while direct solar and diffuse hemispheric irradiance will be measured by the SAS-He (for "hemispheric"). We present the instrument design, measurement strategy, and lab results for these novel solar radiometers.



Shortwave array spectrometer instrument suite.

NSA Evaluation of Heated Ventilators in the Arctic

Scott Richardson, The Pennsylvania State University
Jeffrey Zirzow, Sandia National Laboratories
Martin Stuefer, University of Alaska Fairbanks Geophysical Institute
Walter Brower, University of Illinois at Chicago/ARM North Slope of Alaska
James Ivanoff, ARM North Slope of Alaska
Mark Ivey, Sandia National Laboratories
Chuck Long, Pacific Northwest National Laboratory
Johannes Verlinde, The Pennsylvania State University

Due to the harsh conditions at the ARM North Slope of Alaska site, the broadband radiometers have been equipped with electric heaters inside the ventilators to keep hoarfrost and snow from accumulating on the pyranometer domes and affecting the measurements. The amount of heat used and the location of the heater within the sensor housing, to date, have been chosen based on limited tests of ventilators and sensor heating performed prior to the Surface Heat Budget of the Arctic (SHEBA, 1997–1998) project. The NSA Evaluation of Heated Ventilators in the Arctic field campaign was designed to gain a more complete understanding of the effects of ventilator heaters on domed radiometric measurements.

Radiometer dome frosting on 24 March 2009.

Throughout the field campaign various combinations of heater type, ventilator flow, and AC- vs. DC-powered ventilator fans were performed to optimize the ARM broadband measurement strategy for the NSA site. In an effort to eliminate the hazards posed by 110 V AC electricity, lower-voltage DC fans were tested as a replacement. The field campaign was targeted at improving both our understanding and the quality and accuracy of the ARM NSA radiometer measurements. This field campaign built on the results of the NSA Pyranometer IR Loss Study field campaign conducted from August 2006 to July 2007. Information from Daily Rounds as well as digital pictures will be combined with heater and fan configuration information and synoptic weather information to show which configurations are most effective at eliminating errors due to frost buildup on the radiometer domes.

Quantification of diesel fuel semi-volatile organic compounds by PTR-MS

Matt Erickson, Washington State University
Bertram Jobson, Washington State University

The formation of secondary organic aerosol (SOA) in urban areas is not well understood, with models underestimating organic mass loadings by up to a factor of 10. It is thought that there is a large pool of organic carbon that goes unmeasured in urban areas due to its semi-volatile nature and the inherent difficulty in measuring low mixing ratios of such species by gas chromatographic techniques. It has been proposed that components of organic particulate matter emitted from diesel exhaust might partition back to the gas phase as the exhaust plume becomes diluted, creating a pool of reactive semi-volatile compounds that act as precursors for SOA. For the upcoming CARES field experiment in Sacramento, California, we will deploy a new sampling method to measure long-chain alkanes and other constituents of diesel exhaust that may contribute to SOA. The approach will be to use a proton transfer reaction mass spectrometer (PTR-MS) to measure organics coupled to a custom-built thermal desorption system that pre-concentrates SVOC from the air. Laboratory experiments show that the PTR-MS has an equivalent sensitivity to n-alkanes larger than C12, indicating that direct protonation of these species by the H3O+ reagent ion. For n-alkanes with fewer than seven carbon atoms, there is no apparent reaction with H3O+. The response to n-alkanes > C12 was measured to be 1/5 of that of toluene. The alkanes were shown to fragment to a common set of ions, allowing for the total n-alkane and iso-alkane abundance to be determined from the measurement of six ion fragments. Analysis of diesel #2 fuel by PTR-MS shows the fuel is dominated by alkanes, as expected, but with significant abundance of alkylbenzenes (up to mass of 232 amu) that may be important urban air SOA precursors. The poster will describe the lab experiments to quantify PTR-MS response to n-alkanes and other diesel exhaust components and describe initial results of the thermal desorption sampling of SVOC by PTR-MS.

Recovery Act radars—what, where, and when

Kevin Widener, Pacific Northwest National Laboratory
Jimmy Voyles, Pacific Northwest National Laboratory
Nitin Bharadwaj, Pacific Northwest National Laboratory

The ARM Climate Research Facility received $60 million from the 2009 American Recovery and Reinvestment Act (Recovery Act). Approximately half of this funding is being spent on radars. Currently under contract are: scanning C-band precipitation radars, scanning X-band precipitation radars, scanning X-band cloud radars, scanning Ka-band cloud radars, scanning W-band cloud radars, and upgrades to all of the millimeter wavelength cloud radars (MMCRs). This will significantly enhance ARM's 3D measurement capabilities at sites around the world. It also brings with it challenges in handling large volumes of data and making the data readily available for users. We will present what types of radars are going to which sites along with the schedules for the deployments.

RSS overhaul and redeployment at SGP in August 2009

Scott Stierle, NOAA ESRL Global Monitoring Division Radiation Group
Piotr Kiedron, NOAA

An overhaul of the rotating shadowband spectroradiometer (RSS) was approved after it was discovered that its responsivity had periodic time and wavelength dependencies. After finding the problem, we increased the frequency of radiometric calibrations to bi-weekly calibrations to reduce the measured irradiance errors due to responsivity changes. We speculated that the nature of the responsivity behavior was either from etaloning caused by the spacing between two filters used for responsivity compression or from etaloning caused by the variable thickness in the coating that was cumulating on the chilled CCD due to outgassing from the casting that served as the main optical chamber. During the overhaul we resolved that the outgassing was responsible for the instability. We considered several approaches to fixing the problem within the limits of the RSS's design. Eventually, we decided to build a vacuum chamber around the CCD that could be inserted into the optical chamber. We were able to achieve a vacuum in the chamber of less than 2 x 10-7 Torr. This also improved the thermoelectric cooling, because heat dissipation by convection was reduced. The RSS was redeployed in August 2009 and has operated continuously since. Prior to the redeployment, the RSS was carefully re-characterized at the NOAA Central Ultraviolet Calibration Facility, which can execute both UV and visible calibrations and characterizations. Currently, the RSS signal and processed data are closely monitored. New QC plots have been generated to facilitate our diagnostic abilities. They are available on ARM's RSS website. While it is too early to evaluate the degree of success of the overhaul, all external parameters are within the specifications. We expect to apply Langley-generated calibrations to the new RSS data within the next few months.

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

Scanning ARM cloud radar development

Ivan PopStefanija, ProSensing Inc.
James Mead, ProSensing Inc.
Andrew Pazmany, ProSensing Inc.
Kevin Widener, Pacific Northwest National Laboratory

Through the 2009 American Recovery and Reinvestment Act, the U.S. DOE's Pacific Northwest National Laboratory recently funded ProSensing Inc. of Amherst, Massachusetts, to build six dual-frequency cloud radar systems. These radars will be used by the Atmospheric Radiation Measurement (ARM) Climate Research Facility for fundamental research on the effects of clouds and precipitation on the climate. Four cloud radar systems will be permanently installed in Oklahoma, Alaska, Australia, and Papua New Guinea, while two portable systems will be deployed with ARM's mobile facilities (AMF1 and AMF2) at sites around the world. The scanning ARM cloud radar (SACR) systems will deployed in pairs operating at X-band and Ka-band or at Ka-band and W-band. The X-band systems will employ a high average power (200 W) travelling wave tube amplifier while the Ka-band and W-band systems will use an extended interaction klystron amplifier, with average powers of 100 W and 15 W, respectively. The X- and Ka-band systems will be deployed on separate pedestals at the ARM sites in Darwin, Australia and Manus Island, Papua New Guinea and with AMF1. The paired Ka/W-band system will be deployed at the Southern Great Plains and Barrow, Alaska, ARM sites and with AMF2. The Ka/W-band system will use beam-matched antennas deployed on a common heavy-duty scanning pedestal. The SACR RF units will include an embedded arbitrary waveform generator (AWG), allowing use of custom pulse compression waveforms. A separate AWG is used for frequency hopping to speed estimation of spectral moments. The RF units each have an integrated PC-based data acquisition system, using a high-performance 16-bit, 120 MS/s digital receiver. Custom processing features are being developed, including frequency hopping, staggered PRF, and optimally weighted pulse compression filters.

Scanning W-Band ARM cloud radar development

Chad Baldi, ProSensing Inc.
James Mead, ProSensing Inc.
Kevin Widener, Pacific Northwest National Laboratory

The W-band ARM cloud radar (WACR), previously deployed in a vertically pointing mode at the ARM SGP site since 2005, was recently modified for volume scanning operation. The scanning WACR (SWACR) system, built by ProSensing Inc of Amherst, Massachusetts, was deployed in September 2009 as part of the AMF1 deployment on Graciosa Island, Azores. SWACR generates a 1.5 kW peak power pulse, with 15, 45, or 90 m range resolution with a beam width of 0.4 degrees. The antenna, RF unit, and video camera are mounted on an elevation over azimuth pedestal with a maximum scan rate of 36 degrees per second. A remote chiller is used to maintain the temperature of the RF unit to within +/-3 degrees C. The chiller, dry air purging unit for the antenna, and data system are rack-mounted and located in the AMF shelter. The cable carrying power, coolant, dry air, control, and signal lines between the pedestal and data system rack is supported by a chain-flex cable housing that protects the cable bundle from wear during rotation of the pedestal. Following its deployment with AMF1 in the Azores, SWACR was installed at the ARM SGP site in February 2010. While at the ARM SGP site, SWACR will be calibrated and prepared for deployment with AMF2 in the fall of 2010 for the STORMVEX experiment near Steamboat Springs, Colorado.

Temperature profiling capability of the ARM Raman lidar

Rob Newsom, Pacific Northwest National Laboratory
David Turner, University of Wisconsin-Madison

The Atmospheric Radiation Measurement (ARM) Climate Research Facility has operated a Raman lidar (RL) at the Southern Great Plains (SGP) site since 1996. This turn-key, nearly autonomous system transmits at a wavelength of 355 nm and incorporates 10 detection channels that measure both elastic and Raman-shifted backscatter returns from the atmosphere. The signals from the various detection channels are processed to generate a number of value-added products (VAPs), including water vapor mixing ratio, aerosol scattering ratio, aerosol backscatter, aerosol extinction, and depolarization ratio. In October 2005, two detection channels were added to the system to enable temperature profiling. These channels sense Raman-shifted backscatter arising from rotational energy state transitions in atmospheric N2 and O2 molecules. Each channel measures a slightly different portion of the rotational energy spectrum such that the ratio of the two signals exhibits a very well-defined, nonlinear dependence on the air temperature of the scattering volume. Recently, significant progress has been made on the development of a new operational algorithm that derives temperature profiles from these two rotational Raman signals. The goal of this poster is to present results from a study to validate the RL temperature measurements. Calibrated RL temperature data are compared to temperature retrievals from a collocated AERI instrument. Calibration of the RL temperature data and estimation of the RL overlap function is achieved using data from radiosondes launched at the SGP Central Facility. By contrast, the AERI algorithm uses a physical retrieval approach that does not make direct use of the radiosonde data. For altitudes below 3 km AGL, the AERI retrievals provide a source of essentially independent temperature profile measurements, with time and height resolutions comparable to the RL data. Comparisons between the RL and AERI temperature data were performed over the span of one complete annual cycle. Preliminary results indicate good agreement between the two data sets. The correlations between time series of RL and AERI temperatures are better than 0.97 below 3 km, and median relative differences are less than 0.5% in this height layer. We also show that error estimates associated with individual RL data samples provide an effective means of quality control.

Upgrades and additions to the ARM Climate Research Facility balloon-borne sounding systems

Donna Holdridge, Argonne National Laboratory
Michael Ritsche, Argonne National Laboratory
Jenni Prell, Argonne National Laboratory
Richard Coulter, Argonne National Laboratory
Douglas Sisterson, Argonne National Laboratory

Several new additions and improvements to the ARM Climate Research Facility balloon-borne sounding systems have either been completed in the past year or are scheduled for completion during the coming year. Chipset upgrades were made to all the DigiCORA-I and DigiCORA-II backup systems to provide the latest radiation correction codes used with the redesigned radiosonde temperature booms. DigiCORA-III software was upgraded to the latest version to assure each system is current. A new DigiCORA-III system is being purchased and will be installed at the SGP, freeing up the current DigiCORA-III system to be used as a backup. A Vaisala Autosonde system has been purchased for installation at NSA-Barrow in June 2010 to allow for an increased launch schedule with less burden on the local observers. Monthly or twice-monthly launches of cryogenic frost point hygrometers (CFH) will begin at the SGP in June

2010 as part of the GRUAN network. The additional data products from the CFH will provide improved humidity profiles in the troposphere and lower stratosphere.

Using sun and aureole measurements to check MODIS COD and Reff retrievals for cirrus

John DeVore, Visidyne, Inc.

Cirrus is an important element in the atmospheric climate system. In situ measurement of cirrus is difficult, as evidenced by need for the SPARTICUS and MACPEX programs. Remote measurement is also difficult because of the complex shapes and strong forward-scattering properties of cirrus ice crystals. Sun and aureole measurement provides a new tool for validating remote retrieval of cirrus optical properties. Several examples are shown illustrating the use of sun and aureole measurements to check optical properties retrieved by the MODIS MOD06 algorithm. Monte Carlo scattering calculations of the solar aureole and disk radiance profile using the MODIS-retrieved optical depth and the phase function corresponding to the retrieved effective particle size are compared with radiance measurements at 670 nm made with Visidyne's SAM (Sun and Aureole Measurement) imaging sun photometer. The comparisons suggest that (1) the MODIS phase functions should be reviewed and (2) the strength of forward scattering needs to be properly accounted for in-cirrus property retrievals involving transmittance measurements.

http://www.visidyne.com/SAM/index.htm

9.0 Modeling

Analysis of subgrid cloud variability in a year-long CRM simulation over the ARM SGP

Xiaoqing Wu, Iowa State University
Sunwook Park, Iowa State University

General circulation models (GCMs) predict cloud cover fractions and hydrometeor concentrations only in discrete vertical layers where clouds are assumed to be horizontally homogeneous in a coarse grid. They do not explicitly specify vertical geometric associations or horizontal optical variations of clouds. Subsequently, clouds within a GCM grid are simulated as a single effective volume that impacts radiation using various vertical overlap assumptions. The parameterization of cloud vertical overlap and horizontal inhomogeneity in the radiation schemes of GCMs has been a long-standing challenge. The inclusion of subgrid cloud variability in the radiation calculation for GCMs requires the knowledge of cloud distribution under different climate regimes, which is not yet available from observations. The year-long cloud-resolving model (CRM) simulation forced with the ARM large-scale forcing provides a unique data set to document the characteristics of cloud horizontal inhomogeneity and vertical overlap and to evaluate and represent their effects on the radiative fluxes and heating rates over a GCM grid. The analysis of inhomogeneity parameter defined as the ratio of the logarithmic and linear average of cloud liquid and ice path distribution shows that relatively larger inhomogeneous clouds occur in summer and spring than in fall and winter. The inhomogeneity parameter also shows a large variation in the vertical. Significant radiative effects of cloud inhomogeneity are quantified by the diagnostic radiation calculation with horizontally homogeneous clouds in comparison with the CRM simulations. To account for the cloud inhomogeneity effect, the approach used in some GCMs is by scaling the cloud water paths with a constant reduction factor. The evaluation of this approach using the CRM simulations suggests that the parameterization with the vertically varied reduction factors represents the radiative effects of cloud inhomogeneity better than a constant reduction factor. Three cloud overlap assumptions (i.e., maximum, minimum, and random overlap assumptions) are currently used in GCMs. The analysis using the vertical profile of CRM cloud fractions indicates that none of these assumptions is able to reproduce the total cloud fraction. The maximum overlap assumption systematically underestimates the total cloud fraction, while the random and minimum overlap assumptions systematically overestimate the total cloud fraction.

Assessment of ECMWF model bias in the AMMA region with observations from the ARM Mobile Facility at Niamey

Maike Ahlgrimm, European Centre for Medium-Range Weather Forecasts
Anna Agusti-Panareda, European Centre for Medium-Range Weather Forecasts
Anton Beljaars, European Centre for Medium-Range Weather Forecasts

The ARM Mobile Facility was deployed to Niamey, Niger, in 2006 in the wider context of the African Monsoon Multidisciplinary Analysis (AMMA). The short-term forecast of the ECMWF model quickly develops biases, intensifying the Saharan heat low, placing the ITCZ further south than observed, and underestimating the frequency and intensity of the intermittent deep convection and associated precipitation in the Sahel region. Observations from the ARM Mobile Facility at Niamey provide an opportunity to assess how physical processes in the model contribute to the developing bias. The incoming shortwave radiation is overestimated in the model. A combination of lacking aerosol optical depth and cloud cover contribute to this overestimation. The net radiation absorbed by the surface is also overestimated. The model develops a warm and dry bias at the surface, which is adjusted in the analysis increments by increasing soil moisture and thus enhancing evaporation. As a result, the model's surface latent heat flux is unrealistically high during the dry months of the year. The model develops a deep, well-mixed boundary layer. Analysis increments adjust the temperature profiles to reduce the near-surface warm bias. Since radiosonde locations are sparse in the Sahel, this localized cooling induces a secondary circulation resulting in subsidence and further suppression of convection.

Assessment of radiation options in the Advanced Research WRF weather forecast model

Michael Iacono, Atmospheric and Environmental Research, Inc.

The broadband, correlated k-distribution model, RRTMG, developed at AER with ARM support for application to climate and weather forecast models, was released during 2009 as a radiative transfer option in the Advanced Research WRF (Weather Research and Forecasting) model. An assessment among RRTMG longwave and shortwave radiative transfer and the other radiation options in WRF will be presented for several forecast cases. Evaluation of the results and radiative closure are accomplished by comparison to surface measurements from the ARM Climate Modeling Best Estimate (CMBE) data set for the SGP and TWP sites and at the top of the atmosphere by comparison to several satellite data sets. In addition to radiation fields, the simulation of cloud amounts and cloud optical properties will also be assessed. The result of sensitivity studies relating to the frequency of the radiative transfer calculation and the application of the Monte-Carlo Independent Column Approximation (McICA) technique in WRF forecasts will also be described.

http://www.rtweb.aer.com

Assessment of the SCM/CRM forcing data derived from North American regional reanalysis

Shaocheng Xie, Lawrence Livermore National Laboratory
Yunyan Zhang, Lawrence Livermore National Laboratory
Stephen Klein, Lawrence Livermore National Laboratory
Aaron Kennedy, University of North Dakota
Xiquan Dong, University of North Dakota
Minghua Zhang, State University of New York at Stony Brook

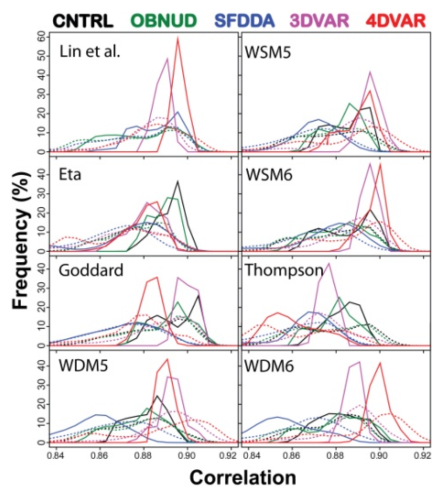
One concern about using the large-scale forcing data (i.e., vertical velocity and advective tendencies) obtained through data assimilation to drive single-column models (SCMs) and cloud-resolving models (CRMs) is that the forcing data themselves are affected by deficiencies of the model physical parameterizations used in generating the data. As shown in earlier studies, errors in such forcing are particularly large over periods where surface precipitation is not well simulated by the forecast model used in data assimilation. The quality of analysis data has been improved in recent years with improvements in data assimilation techniques and forecast models, as well as more observations (including precipitation) being assimilated. This has motivated us to revisit the issue on the suitability of the analysis forcing for SCM/CRM studies by examining the quality of the latest analysis data. In this study, we assessed the quality of the large-scale forcing diagnosed from the North American Regional Reanalysis (NARR), which has successfully assimilated precipitation into its data assimilation system.

The assessment was performed by comparing the NARR forcing with the ARM observed forcing and the ARM 1999–2001 three-year continuous forcing, which were respectively derived from ARM sounding measurements and the NOAA's Rapid Update Cycle (RUC) analyses constrained with surface and top-of-the-atmosphere (TOA) observations through a constrained variational analysis method. We compared the forcing fields and relevant surface and TOA fluxes between ARM and NARR over both wet and dry periods. We also compared the correlation between the ARM-observed cloud fraction and the vertical velocity field obtained from these forcing data sets. Since cloud fraction is not a constraint used in both the variational analysis and the NARR, this correlation provides an independent check on the quality of these forcing data sets. Detailed results from this study will be discussed in the meeting.

Assimilating surface and rawinsonde data in WRF microphysics simulations of warm-season convection for SGP Central Facility

Zewdu Segele, University of Oklahoma/CIMMS
Lance Leslie, Ohio University
Peter Lamb, University of Oklahoma

Several high-resolution (3-km) nested simulations were performed to examine the ability of the Weather Research and Forecasting (WRF) model microphysics schemes to reproduce the observed cloud properties and convection characteristics in the vicinity of the SGP Central Facility (CF) for the warm-season heavy precipitation case of May 27–31, 2001. The results showed substantial differences in simulated cloud water content, cloud ice concentration, and reflectivity profiles at the SGP CF for all WRF microphysical parameterizations. To minimize differences in observed and simulated convection onset and cloud microphysical properties, SGP surface and SGP CF upper-air sounding data were assimilated in SGP WRF microphysics experiments. Accordingly, simulations without data assimilation (CNTRL) for eight WRF microphysics schemes were compared to corresponding simulations with surface analysis nudging (SFDDA), upper-air observation nudging (OBSNUD), three-dimensional variational data assimilation (3DVAR), and four-dimensional variational data assimilation (4DVAR). Evaluation of the performance of the data assimilation experiments involved direct comparisons of simulated grid point values and observed CMBE and Mace et al.'s (2006) best estimates of SGP CF atmospheric state/cloud properties. To allow for a possible spatial grid point mismatch between simulated and observed variables, model performance also was assessed using the probability distributions of the correlations between observed atmospheric



Probability distributions of correlations between observed (CMBE) and simulated precipitable water vapor for eight WRF microphysics simulations with (colors) and without (black) data assimilation for 27–31 May 2001 warm-season heavy precipitation event over the SGP. Correlations are computed for the inner nested domain within 7x7 (solid lines) and 35x35 (dashed lines) grid boxes surrounding SGP CF. CNTRL, OBNUD, SFDDA, 3DVAR, and 4DVAR denote no data assimilation, observation nudging, surface analysis nudging, three-dimensional variational data assimilation, and four-dimensional variational data assimilation, respectively.

state variables and corresponding simulated values of the inner nested domain within 7x7 and 35x35 grid boxes surrounding SGP CF. The correlation analysis reveals that the 3DVAR/4DVAR experiments showed improved reproduction of the observed precipitable water vapor for Lin et al., WRF Single Moment 6-class (WSM6), WRF Double Moment 5-class (WDM5), and WRF Double Moment 6-class (WDM6) microphysics schemes, with the 4DVAR WDM6 simulation achieving the highest modal correlation exceeding +0.9. Compared to the CNTRL experiment, both the 3DVAR and 4DVAR runs perform poorly for the Eta and Thompson microphysics schemes because of increased convection early in the simulations. Although the SFDDA simulations produced increased LWC/IWC that compared favorably with the observed values, the correlation between observed and simulated PWV showed no improvement for many of the microphysics runs. Results of model sensitivity experiments to radiation schemes also will be presented.

A case study of three-dimensional cloud-resolving model simulations using a double-moment cloud microphysics parameterization

Zheng Liu, University of Washington
Thomas Ackerman, University of Washington
Hugh Morrison, National Center for Atmospheric Research

The Morrison double-moment microphysics parameterization used in this study predicts both the number concentration and mixing ratio for five hydrometeor species: cloud water, cloud ice, rain, snow, and graupel, along with the mass mixing ratio of water vapor. With the explicitly predicted hydrometeor number concentration, we expect the double-moment microphysics scheme to improve the simulation of microphysical processes and cloud properties. In this study, this microphysics scheme is utilized in a cloud-resolving model, called the System for Atmospheric Modeling (SAM), to simulate cloud evolution during the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) 1997 summer Intensive Observation Period. We perform sensitivity studies of parameters for immersion freezing of droplets, which are critical for the properties of detrained ice from deep convection. We also investigate the snow auto-conversion threshold. Simulated precipitation and cloud properties are compared against the observations from the ARM instruments during this period. To understand the extent of the model-inherent uncertainty and its impact on the microphysics sensitivity studies, we also perform an ensemble of simulations by using the same model configurations and large-scale forcing and only varying initial soundings. Because of the computational cost of the three-dimensional simulations, we only apply these ensemble runs to a short period of time (four days) to examine the model bifurcation after precipitation, which is frequently seen in two-dimensional simulations.

Cloud model simulations of TWP-ICE deep convection using a new bulk ice microphysics scheme

Hugh Morrison, National Center for Atmospheric Research
Wojciech Grabowski, National Center for Atmospheric Research
Sally McFarlane, Pacific Northwest National Laboratory
Jennifer Comstock, Pacific Northwest National Laboratory

A two-dimensional cloud model coupled with a new bulk ice microphysics scheme (Morrison and Grabowski 2008, *Journal of the Atmospheric Sciences*) is applied to the Tropical Warm Pool-International Cloud Experiment (TWP-ICE) and compared against available observations and microphysical retrievals. The model setup is the same as that of the ARM TWP-ICE cloud model intercomparison. A number of simulations are performed to compare sensitivities to various aspects of microphysics and modeling framework (e.g., horizontal grid length, domain size). It is found that the simulated anvil cloud macrophysical and microphysical characteristics and hence TOA upward solar and longwave radiative fluxes are highly sensitive to representation of graupel density and heterogeneous freezing of cloud droplets.

Cloud vertical distribution in extratropical cyclones

Catherine Naud, Columbia University/NASA Goddard Institute for Space Studies
Anthony Del Genio, NASA Goddard Institute for Space Studies

Using two consecutive winters of CloudSat-CALIPSO observations, NCEP-2 reanalysis atmospheric state parameters over the northern and southern hemisphere oceans (30°–70° N/S) between November 2006 and September 2008, and an automated front detection algorithm, we examined how clouds are distributed along the vertical across warm and cold fronts in extratropical cyclones. These distributions generally resemble those from the original model introduced by the Bergen School in the 1920s, with the following exceptions: (1) substantial low cloudiness that is present behind and ahead of the warm and cold fronts; (2) ubiquitous high cloudiness, some of it very thin, throughout the warm-frontal region; and (3) upright convective cloudiness near and behind some warm fronts. One winter of GISS general circulation model simulations of fronts at 2°x2.5°x32L resolution gave similar cloud distributions but with much lower cloud fraction, a shallower depth of cloudiness, and a shorter extent of tilted warm-frontal cloud cover in the cold sector. A close examination of the relationship between the cloudiness and relative humidity fields indicated that upward transport of water vapor is too weak in modeled mid-latitude cyclones, and this is related to weak vertical velocities in the model. The model also produced too little cloudiness for a given value of vertical velocity or relative humidity. For global climate models run at scales coarser than tens of kilometers, we suggest that the current underestimate of modeled cloud cover in the storm track regions, and in particular the 50°–60°S band of the southern oceans, could be reduced with the implementation of a slantwise convection parameterization. We will discuss how these results can be expanded to investigate modeled cloud properties (e.g., LWC, IWC, optical thickness) within cold and warm fronts using long-term ground-based ASR observations at the Southern Great Plains site.

Convective buoyancy and entrainment rate estimated from A-Train data: an observational basis for evaluating GCM cumulus parameterization

Zhengzhao (Johnny) Luo, City College of New York

A new satellite-based method to simultaneously estimate convective buoyancy (B) and entrainment rate (λ) was recently developed by the authors. Initial results of the new method applied to A-Train data in the tropics are presented and discussed in light of our current understanding of tropical convection. Inherent uncertainties are also estimated. Similar analysis can be conducted based on ARM Climate Research Facility data. This new database provides an important observational basis against which GCM cumulus parameterization can be evaluated. Examples will be presented.

www.sci.ccny.cuny.edu/~luo

Critical evaluation of the ISCCP simulator using ground-based remote sensing data

Stephanie Houser, University of Utah
Gerald Mace, University of Utah
Sally Benson, University of Utah
Stephen Klein, Lawrence Livermore National Laboratory
Qilong Min, State University of New York at Albany

Given the known shortcomings in representing clouds in Global Climate Models (GCM), comparisons with observations are critical. The International Satellite Cloud Climatology Project (ISCCP) diagnostic products provide global descriptions of cloud-top pressure and column optical depth that extend over multiple decades. The necessary limitations of the ISCCP retrieval algorithm require that before comparisons can be made between model output and ISCCP results, the model output must be modified to simulate what ISCCP would diagnose under the simulated circumstances. We evaluate one component of the so-called ISCCP simulator in this study by comparing ISCCP and a similar algorithm with various long-term statistics derived from ground-based sensors at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) site. We find that were a model to simulate the cloud radiative profile with the same accuracy as can be derived from the ARM data, then the likelihood of that occurrence being placed in the same cloud-top pressure and optical depth bin as ISCCP of the nine bins that have become standard is on the order of 50%. While the ISCCP simulator clarified interpretation of the comparisons, we find minor discrepancies due to the parameterization of cloud-top pressure in the ISCCP simulator. The primary source of error seems to be related to discrepancies in visible optical depth that are not accounted for in the ISCCP simulator. We show that the optical depth discrepancies are largest when the assumptions necessary for plane parallel radiative transfer optical depths retrievals are violated.

Custom data support for the Fast-Physics System Testbed and Research (FASTER) project

Tami Toto, Brookhaven National Laboratory
Michael Jensen, Brookhaven National Laboratory
Andrew Vogelmann, Brookhaven National Laboratory
Richard Wagener, Brookhaven National Laboratory
Yangang Liu, Brookhaven National Laboratory
Wuyin Lin, State University of New York at Stony Brook

The multi-institution Fast-Physics System Testbed and Research (FASTER) project, funded by the U.S. DOE Earth System Modeling program, aims to evaluate and improve the parameterizations of fast processes (those involving clouds, precipitation, and aerosols) in global climate models, using a combination of numerical prediction models, single-column models, cloud-resolving models, large-eddy simulations, full global climate model output and ARM active and passive remote sensing, and in situ data. This poster presents the Custom Data Support effort for the FASTER project. The effort will provide tailored data sets, statistics, best estimates, and quality control data, as needed and defined by FASTER participants, for use in evaluating and improving parameterizations of fast processes in GCMs. The data support will include custom gridding and averaging, for the model of interest, using high time resolution and pixel-level data from continuous ARM observations and complementary data sets. In addition to the FASTER team, these data sets will be made available to the ASR Science Team. Initial efforts with respect to data product development, priorities, availability, and distribution are summarized

here with an emphasis on cloud, atmospheric state, and aerosol properties as observed during the Spring 2000 Cloud IOP and the Spring 2003 Aerosol IOP at the ARM Southern Great Plains site.

The dependence of CAM cloud and precipitation simulations on horizontal and vertical resolution

Stephen Klein, Lawrence Livermore National Laboratory
Jim Boyle, Lawrence Livermore National Laboratory
Sungsu Park, University of Washington

We examine how Community Atmosphere Model (CAM) simulations of clouds and precipitation vary with changes in the model's horizontal and vertical resolution. For horizontal resolution, we examine simulations of tropical precipitation in models with resolution as fine as 0.25 degrees latitude-longitude. We utilize the CAPT weather forecasting approach and analyze simulations for the period of the ARM TWP-ICE campaign utilizing both ARM and satellite data. For vertical resolution, we contrast climate simulations of cloud and boundary-layer properties in climate simulations with 80 instead of the default 30 vertical levels. Particular quantities sensitive to vertical resolution include the simulation of marine stratocumulus clouds, tropical water vapor, and the stable boundary layer over ice sheets.

http://www-pcmdi.llnl.gov/projects/capt/index.php

Development of ensemble neural network convection parameterizations for climate models using ARM data

Michael Fox-Rabinovitz, University of Maryland
Vladimir Krasnopolsky, NOAA
Philip Rasch, Pacific Northwest National Laboratory
Yefim Kogan, University of Oklahoma/CIMMS
Alexei Belochitski, University of Maryland

The neural network (NN) approach is formulated and used for development of a NN ensemble stochastic convection parameterization for climate models. This fast parameterization is built based on data from cloud resolving model (CRM) simulations initialized with and driven/forced by observational (TOGA-COARE and ARM) data. The observational data are also used for validation of model simulations. The SAM (System for Atmospheric Modeling), developed by D. Randall, M. Khairoutdinov, and their collaborators, has been provided by M. Khairoutdinov and used for CRM simulations. CRM-emulated data have been averaged and projected onto the GCM space of atmospheric states to implicitly define a stochastic convection parameterization. This parameterization is emulated using an ensemble of neural networks (NN). An ensemble of NNs with different architecture, i.e., with different inputs and outputs, has been trained and tested. The inherent uncertainties of the stochastic convection parameterization are described and estimated. Due to these inherent uncertainties, their ensemble is used to constitute a stochastic NN convection parameterization. The major challenges of development of stochastic NN convection parameterizations based on our initial results are discussed. At the next step of the project, the stochastic NN convection parameterizations will be included into the NCAR SCM CAM and/or CAM in diagnostic and prognostic modes and tested in climate simulations using data from the SGP (Southern Great Plains) and TWP (Tropical Western Pacific) ARM sites and TOGA-COARE data.
Acknowledgments: The investigators would like to thank Prof. Marat Khairoutdinov (SUNY) for providing SAM and consultations and Dr. Peter Blossey (UWA) for consultations on SAM.

Diabatic heating and mesoscale vertical motion in cumulus anvils

Yonghua Chen, Columbia University
Anthony Del Genio, NASA Goddard Institute for Space Studies

Areally extensive cumulus anvil clouds dominate tropical cloud forcing and account for ~30–70% of the total rainfall in convective systems. Given the different heating profiles of convective cores and stratiform anvils, errors in convective-stratiform rain partitioning in a GCM imply errors in its tropical circulation. Most GCM cumulus parameterizations include the effect of stratiform anvils only via the condensate detrained from the convective updraft. However, anvils create their own mesoscale updrafts in response to diabatic (radiative plus latent) heating, and the properties of the anvils can be expected to evolve over their life cycle. To place some observational constraints on mesoscale vertical motions in convective clusters, we are combining geostationary satellite data and ASR data for the SGP and TWP. The ISCCP Convection Colocator, which identifies convective systems in IR data and tracks their propagation and evolution, is first used to select times when a convective cluster passed over one of the sites. Each system is classified as being in either the developing, mature, or decaying stage of its life cycle at the time of ASR observation. Radiative heating profiles are obtained from either the BBHRP product (at SGP) or the Mather-McFarlane product (at Manus), and composite profiles for the various life cycle stages are created. Initial results for the SGP suggest that longwave cooling peaks near 13 km during the developing stage, but descends to 10 km by the time systems decay; that shortwave heating is strong between 5–10 km during the developing stage, creating a net cooling/heating dipole above/below 10 km during the developing stage; and that shortwave heating is weaker later in the life cycle, creating little net heating/cooling below 8 km. Manus storms also show the net cooling/heating dipole during the developing stage but differ from the SGP in several ways, e.g., stronger longwave and shortwave heating during the developing and mature stages and heating extending to higher levels during the mature stage.

Diagnosing causes of cloud parameterization deficiencies using ARM measurements over the SGP site

Wei Wu, Brookhaven National Laboratory

Decade-long continuous surface-based measurements at Southern Great Plains (SGP) collected by the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility are first used to evaluate the three major reanalyses (i.e., ERA-Interim, NCEP/NCAR Reanalysis I, and NCEP/DOE Reanalysis II) to identify model biases in simulating surface shortwave cloud forcing and total cloud fraction. The results show large systematic lower biases in the modeled surface shortwave cloud forcing and cloud fraction from all three reanalysis data sets. Then we focus on diagnosing the causes of these model biases using the Active Remote Sensing of Clouds (ARSCL) products (e.g., vertical distribution of cloud fraction, cloud-base and cloud-top heights, and cloud optical depth) and meteorological measurements (temperature, humidity, and stability). Efforts are made to couple cloud properties with boundary processes in the diagnosis.

Dynamic and thermodynamic balances in Madden-Julian Oscillation

Samson Hagos, Pacific Northwest National Laboratory

In order to identify the simplest set of balances that govern the dynamics of the Madden-Julian Oscillation (MJO), scale analysis is performed on the various components of the wind, moisture, and potential temperature tendencies from an observationally constrained WRF simulation that realistically simulates the 2007–2008 MJO signal over the eastern hemisphere. First, the performance of the WRF simulation in reproducing the observed propagation characteristics is evaluated. Then, from the budget analysis of the governing equations, the contributions of smaller-scale convective processes, radiation, surface fluxes, and interactions with subtropical systems are quantitatively assessed. Finally, the results of the analysis are used to construct a simplified paradigm for MJO propagation.

Establishment of an NWP testbed using ARM data

Ewan O'Connor, University of Reading
Robin Hogan, University of Reading
Yangang Liu, Brookhaven National Laboratory

The aim of the FAst-physics System TEstbed and Research (FASTER) project is to evaluate and improve the parameterizations of fast physics (involving clouds, precipitation, and aerosol) in numerical models using ARM measurements. One objective within FASTER is to evaluate model representations of fast physics with long-term continuous cloud observations by use of an "NWP testbed." This approach was successful in the European Cloudnet project. NWP model data (NCEP, ECMWF, etc.) is routinely output at ARM sites, and model evaluation can potentially be achieved in quasi-real time. In this poster, we will outline our progress in the development of the NWP testbed and discuss the successful integration of ARM algorithms, such as ARSCL, with algorithms and lessons learned from Cloudnet. Preliminary results will be presented of the evaluation of the ECMWF, NCEP, and UK Met Office models over the SGP site using this approach.

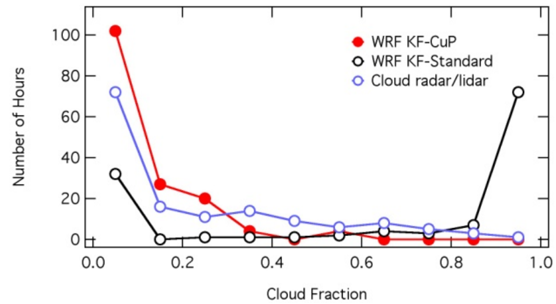
Evaluating the effective stability and springtime clouds simulated in the CAM at the SGP

Minghua Zhang, State University of New York at Stony Brook
Jingbo Wu, Columbia University
Shaocheng Xie, Lawrence Livermore National Laboratory
Wuyin Lin, State University of New York at Stony Brook

Atmospheric moist processes act to reduce the resistance of air to vertical displacement. We define the effective vertical stability of the moist atmosphere as the sum of dry stability and the compensation due to diabatic heating, which is parameterized in climate models. The effective stability is a controlling factor of the potential vorticity of the atmosphere, and it affects the propagation speed of synoptic systems. The ARM variational analyses of vertical velocity and diabatic heating at the SGP are used to evaluate the effective stability simulated in the Community Climate Model CAM4. We show that during the March 2000 ARM IOP, the model simulated smaller effective stability due to large compensation of the adiabatic cooling and diabatic heating, and thus faster cyclone propagation than in observations. The cyclone propagation error can largely explain the biases of cloud amount in the CAM simulation that was initialized using operational analysis.

Evaluation of a new parameterization of shallow cumuli

Larry Berg, Pacific Northwest National Laboratory
William Gustafson, Pacific Northwest National Laboratory
Evgueni Kassianov, Pacific Northwest National Laboratory



Frequency of occurrence of observed (blue) and WRF-predicted cloud fraction using the KF scheme (black) and KF-CuP scheme (red) during the summer of 2004.

A new parameterization for shallow cumuli, called the Cumulus Potential (CuP) scheme, has been developed. This new scheme explicitly links boundary-layer turbulence with shallow clouds and has been coupled with the Kain Fritsch (KF) cumulus parameterization in the Weather Research and Forecasting (WRF) model. In its default configuration, the KF scheme uses an ad-hoc temperature perturbation as a trigger function to determine if convection occurs. In the coupled KF-CuP scheme, that temperature perturbation is been modified to more realistically account for both sub-grid temperature and humidity variations. In order to evaluate the performance of WRF, two specially constructed data sets have been completed. The first documents the macroscale properties of shallow cumuli over the ARM Southern Great Plains Central Facility, while the second investigates the surface radiative forcing due to shallow cumuli. Both data sets make use of the Active Remotely Sensed Cloud Locations (ARSCL) value-added product (VAP) to estimate cloud boundaries and to help identify days with single-layer shallow cumuli. The surface shortwave forcing due to shallow clouds is determined using data from the Shortwave Flux Analysis VAP. Simulations using both the default KF and KF-CuP scheme have been completed for the summer (May–August) of 2004. Overall, the modified scheme does a much better job predicting the cloud properties than does the default scheme. As shown in the figure, the default scheme under-predicts the frequency of small amounts of cloud fraction and over-predicts the frequency of large amounts of cloud fraction. The cloud fraction predicted by the modified scheme is in much better agreement with the observations made at the Central Facility, leading to better estimates of the radiative impact of shallow clouds.

Evaluation of vertical structure of cloud fraction simulated by IPCC AR4 models over TWP

Yun Qian, Pacific Northwest National Laboratory

Cloud Fraction (CF) is a critical variable in determining the radiation flux through the atmosphere and at the surface in the climate models. Previous studies in evaluating Global Climate Model (GCM) performance revealed that the model biases for both atmosphere and surface shortwave absorption are largest at lower latitude areas, suggesting a poor performance of GCMs in simulating CF over tropical regions. Combined CF data sets that represent both the vertical and horizontal CF are generally not available for evaluating the CF in large-scale models. Current techniques generally use either satellite or ground-based hemispheric measurements to estimate horizontal CF. Alternatively, vertical cloud occurrence is determined using time series of narrow-beam active remote sensors. In this study, we first inter-compare four CF-related data sets over TWP, i.e., the total sky cover based on Total Sky Imager, the Active Remote Sensing of Clouds Layers (ARSCL), the total sky cover derived from surface shortwave radiometers, and effective sky cover derived from longwave radiometers. We integrate these data sets and generate a new composite CF data set that includes vertical structure. We use the integrated CF data set to evaluate the CF, including its vertical structure, predicted by IPCC AR4 GCMs.

FASTER: a new DOE effort to bridge ESM and ASR sciences

Yangang Liu, Brookhaven National Laboratory

In order to better use the long-term ARM measurements to evaluate parameterizations of fast processes used in global climate models, mainly those related to clouds, precipitation, and aerosols, the U.S. DOE Earth System Modeling (ESM) program funds a new multi-institution project led by the Brookhaven National Laboratory, FAst-physics System Testbed and Research (FASTER). This poster will present an overview of this new project and its scientific relationships to the ASR sciences and ARM measurements.

Fast Physics Testbed for the FASTER project

Wuyin Lin, Brookhaven National Laboratory
Yangang Liu, Brookhaven National Laboratory
Robin Hogan, University of Reading
Roel Neggers, Royal Netherlands Meteorological Institute (KNMI)
Michael Jensen, Brookhaven National Laboratory
Ann Fridlind, NASA Goddard Institute for Space Studies
Yanluan Lin, National Center for Atmospheric Research/Geophysical Fluid Dynamics Laboratory
Audrey Wolf, NASA Goddard Institute for Space Studies

This poster describes the Fast Physics Testbed for the new FAst-physics System Testbed and Research (FASTER) project. The overall objective is to provide a convenient and comprehensive platform for fast turn-around model evaluation against ARM observations and to facilitate development of parameterizations for cloud-related fast processes represented in global climate models. The testbed features three major components: a single-column model (SCM) testbed, an NWP-Testbed, and high-resolution modeling (HRM). The web-based SCM-Testbed features multiple SCMs from major climate modeling centers and aims to maximize the potential of SCM approach to enhance and accelerate the evaluation and improvement of fast physics parameterizations through continuous evaluation of existing and evolving models against historical as well as new/improved ARM and other complementary measurements. The NWP-Testbed aims to capitalize on the large pool of operational numerical weather prediction products. Continuous evaluations of NWP forecasts against observations at ARM sites are carried out to systematically identify the biases and skills of physical parameterizations under all weather conditions. The high-resolution modeling (HRM) activities aim to simulate the fast processes at high resolution to aid in the understanding of the fast processes and their parameterizations. A four-tier HRM framework is established to augment the SCM- and NWP-Testbeds towards eventual improvement of the parameterizations.

Fog increases and the effects of aerosols in China

Feng Niu, University of Maryland
Zhanqing Li, University of Maryland

Fog is a severe weather hazard that greatly influences traffic and daily life with potentially heavy economic loss. An increasing number of traffic accidents caused by fog have been reported in China in recent years. In this study, we show that the frequencies of fog events in wintertime over eastern-central

China have doubled over the past three decades. For the same period, surface wind speeds have dropped from 3.7 m/s to about 3 m/s, and the mean number of cold air outbreaks has decreased from 7 to around 5 times per winter; relative humidity and the frequency of light wind events have also increased significantly. Weakening of the East Asian winter monsoon system appears to be responsible for these changes, which is further linked to global warming and regional increases in atmospheric aerosol loading. Both trends reduce the thermal contrast between high and low latitudes, weaken the East Asian winter monsoon circulation, and favor the formation of fog. This hypothesis is tested using the National Centers for Environmental Prediction (NCEP) reanalysis data and model simulations with the National Center for Atmospheric Research Community Climate Model (NCAR/CCM3). The analyses show that the 500-mb trough in East Asia has shallowed over the past three decades. Meanwhile, the surface Siberian high has weakened, which is likely the cause for the diminishment in speed of the prevailing northwesterly winds and the reduction in intrusions of dry and cold air from the northwest. The increase in atmospheric aerosols was shown to weaken the East Asian winter monsoon as well. The reduced thermal contrast between China and Siberian regions caused by the cooling effect of aerosols over China also leads to a reduction in the influx of dry and cold air over eastern-central China. These effects are responsible for the increased convergence of water vapor there. All these changes favor the formation and maintenance of fog over this region.

High-resolution simulations of the December 2007 ice storm in the Southern Great Plains region: comparison of microphysics schemes with ARM observations

Esther White, University of Oklahoma/CIMMS
Lance Leslie, Ohio University
Peter Lamb, University of Oklahoma

High-resolution (4 km) simulations of a severe winter weather event in the Southern Great Plains are conducted using the Advanced Research WRF model. At this resolution convection is explicitly resolved, but cloud microphysical processes remain parameterized. The WRF-ARW has a number of microphysics schemes able to simulate cold season precipitation processes. A sensitivity study is conducted, where the evolution of the event is compared across all applicable microphysics parameterizations and observations of cloud properties from ARM instruments and the NEXRAD radar. Modeled cloud properties and vertical structure also are considered for a specific period within the event. Finally, methodology and early results are discussed, from nested simulations at cloud resolving resolutions (1 km), for the same case study.

Impact of vertical stratification of inherent optical properties on radiative transfer in a plane-parallel turbid medium

Minzheng Duan, Institute of Atmospheric Physics, Chinese Academy of Sciences
Qilong Min, State University of New York at Albany
Knut Stamnes, Stevens Institute of Technology

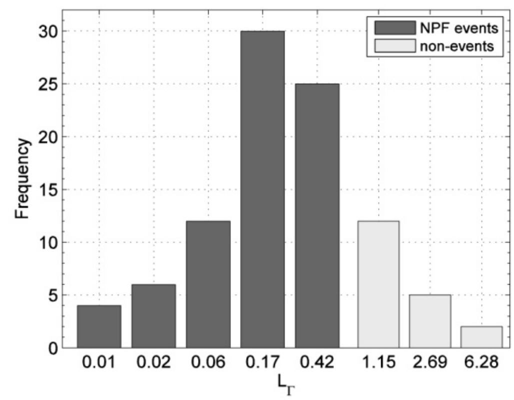
The atmosphere is often divided into several homogeneous layers in simulations of radiative transfer in plane-parallel media. This artificial stratification introduces discontinuities in the vertical distribution of the inherent optical properties at boundaries between layers, which results in discontinuous radiances and irradiances at layer interfaces, which lead to errors in the radiative transfer simulations. To investigate the effect of the vertical discontinuity of the atmosphere on radiative transfer simulations, a simple two-layer

model with only aerosols and molecules and no gas absorption is used. The results show that errors larger than 10% for radiances and several percent for irradiances could be introduced if the atmosphere is not layered properly.

An improved criterion for new particle formation in diverse environments

Chongai Kuang, Brookhaven National Laboratory
Ilona Riipinen, Carnegie Mellon University
Sanna-Liisa Sihto, University of Helsinki
Markku Kulmala, University of Helsinki
Alon McCormick, University of Minnesota
Peter McMurry, University of Minnesota

A dimensionless theory for new particle formation (NPF) was developed, using an aerosol population balance model incorporating recent developments in nucleation rates and measured particle growth rates. Based on this theoretical analysis, it was shown that a dimensionless parameter Lg, characterizing the ratio of the particle scavenging loss rate to the particle growth rate, exclusively determined whether or not NPF would occur on a particular day. This parameter determines the probability that a nucleated particle will grow to a detectable size before being lost by coagulation with the pre-existing aerosol. Cluster-cluster coagulation was shown to contribute negligibly to this survival probability under conditions pertinent to the atmosphere. Data acquired during intensive measurement campaigns in Tecamac (MILAGRO), Atlanta (ANARChE), Boulder, and Hyytiälä (QUEST II, QUEST IV, and EUCAARI) were used to test the validity of Lg as an NPF criterion. Measurements included aerosol size distributions down to 3 nm and gas-phase sulfuric acid concentrations. The model was applied to 77 NPF events and 19 non-events (characterized by growth of pre-existing aerosol without NPF) measured in diverse environments with broad ranges in sulfuric acid concentrations, ultrafine number concentrations, aerosol surface areas, and particle growth rates (nearly two orders of magnitude). Across this diverse data set, a nominal value of Lg = 0.7 was found to determine the boundary for the occurrence of NPF, with NPF occurring when Lg < 0.7 and being suppressed when Lg > 0.7. Moreover, nearly 45% of measured Lg values associated with NPF fell in the relatively narrow range of 0.1 < Lg < 0.3.



Histogram of measured Lg values associated with 77 new particle formation (NPF) events and 19 non-events from the MILAGRO (Tecamac), ANARChE (Atlanta), Boulder, QUEST II (Hyytiälä), QUEST IV (Hyytiälä), and EUCAARI (Hyytiälä) measurement campaigns. The dimensionless parameter Lg, characterizing the ratio of the particle scavenging loss rate to the particle growth rate, exclusively determines whether or not NPF can occur on a particular day. A boundary value of Lg = 0.7 separates NPF events and non-events, with values of Lg ranging from 0.0075–0.66 for NPF events and from 0.76–9.4 for non-events.

Improved simulated diurnal hydrologic cycle in a GCM with super-parameterized clouds

Michael Pritchard, Scripps Institution of Oceanography
Richard Somerville, Scripps Institution of Oceanography

We show that the Multi-scale Modeling Framework (MMF) approach to climate modeling results in improved simulations of small-scale daily rainfall variability. MMFs are GCMs with cloud super-parameterizations replacing conventional statistical parameterizations. That is, MMFs represent sub-grid cloud and boundary layer processes using an array of nested cloud resolving models in each GCM grid volume. The MMF (SPCAM3) and GCM (CAM3) compared in this study are identical except for this difference. Analysis of the vertically integrated diurnal composite moisture budget provides several new clues to the physical processes involved. Daytime entrainment humidification resolved by the embedded cloud-resolving model (CRM) in the Super-Parameterized Community Atmosphere Model v3.0 (SPCAM3) tempers the amplitude and fixes the timing of the overly vigorous CAM3 diurnal rainfall cycle over land. Diurnal water budget analysis shows that at night, and over the ocean, substantially different representations of diurnal moisture convergence in the two models play a major role in differentiating daily tropical rainfall. In CAM3 a large-scale equatorial planetary wave of diurnal moisture convergence and storage connects the vigorous over-land rainfall cycle to the diurnal rainfall cycle over open ocean thousands of kilometers away. The absence of this wave in SPCAM3 is another, more subtle reason for its improved diurnal rainfall cycle. Only a few MMFs exist. They are untuned, and development is still in its infancy. MMFs are extremely expensive computationally, typically about 200 times more demanding than a conventional GCM. Data from the ARM Climate Research Facility will be invaluable in improving the realism of MMFs.

Improving numerics of bulk microphysics schemes in WRF model: warm rain processes

Igor Sednev, Lawrence Berkeley National Laboratory
Surabi Menon, Lawrence Berkeley National Laboratory

We are developing an adaptive sub-stepping (ADSS) technique based on analytic stability and positive definiteness criteria to analyze numerics of warm rain processes in different bulk microphysics (BLK) schemes implemented in the Weather Research and Forecasting (WRF) model. We implement description of warm rain processes based on Eulerian explicit (EE) time integration in WRF BLK schemes into our microphysics package as a standalone program. We use results of sensitivity runs with EE and ADSS schemes for a wide range of cloud and rain water contents and droplet concentration to calculate auto-conversion and accretion growth rates as well as maximal time step permitted to keep the positivity of the solution. We highlight that all WRF BLK schemes are not positive definite and might show better performance for finer spatial resolutions when time steps used to advance microphysical prognostic equations have an order of magnitude from seconds to tenths of seconds. For coarser spatial resolutions, time steps are usually increased from hundredths up to thousandths of seconds, but it might lead to degradation of WRF BLK schemes performance because of corrections such as “mass adjustment” (for single-moment schemes) and additional “concentration adjustment” (for double- moment schemes). We analyze spatial and temporal distribution of accumulated precipitation and time series of maximal surface precipitation rates obtained in idealized large-scale WRF simulations. Differences between the control run (Morrison-Curry-Khvorostyanov BLK scheme with standard EE time integration) and runs with ADSS time integration will be presented during the meeting.

Improving the parameterization of cloud and precipitation in the ECMWF global numerical weather prediction model

Richard Forbes, European Centre for Medium-Range Weather Forecasts

The current cloud and precipitation parameterization scheme in the ECMWF global numerical weather prediction model is based on Tiedtke (1993), parameterizing the sources and sinks of cloud condensate and cloud fraction due to the main generation and destruction processes from convection and microphysics. The cloud condensate is diagnostically separated into liquid and ice as a function of temperature, and rain and precipitating snow are treated diagnostically. Although the scheme has performed well in the ECMWF global model, it is clear that a number of important cloud microphysical processes cannot be well-represented, particularly for mixed-phase clouds. Recent developments to the cloud scheme have introduced separate prognostic variables for liquid and ice and rain and snow with corresponding changes to the parameterization of microphysical processes. Preliminary evaluation of the new scheme shows an improved representation of mixed-phase clouds, ice water path, and the advection of snow. The potential for further evaluation with remote sensing data from CloudSat/CALIPSO and the ARM site facilities is highlighted.

An investigation of the cloud and convection scheme impacts on tropical clouds and radiation

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Jean-Christophe Golaz, Geophysical Fluid Dynamics Laboratory/University Corporation for Atmospheric Research
Leo Donner, Geophysical Fluid Dynamics Laboratory
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Stephen Klein, Lawrence Livermore National Laboratory
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To understand why GCMs predict up to one order of magnitude different ice water path while maintaining top of atmosphere (TOA) radiation balance, AMIP simulations using GFDL AM2 with high frequency output (every three hours) are used to investigate the effect of different cloud and convection schemes on the tropical clouds, precipitation, and TOA radiation balance. Model cloud fraction and ice water content are evaluated using ISCCP, CloudSat, and ARM observations. Simulations using the University of Washington (UW) scheme predict ~4 times larger IWC over the tropics than that using the relaxed Arakawa Schubert (RAS) and compare well with CloudSat and ARM IWC retrievals. By compositing the tropical cloud properties (cloud fraction, IWC, and LWC) by large-scale and convective precipitation respectively, we found the Tiedtke scheme underestimates the cloud fraction near freezing level and around 250 mb. IWC associated with convective precipitation is much smaller than that associated with large-scale precipitation. As a result, the partition of tropical precipitation between large scale and convection significantly regulates the tropical IWC. Using the standalone radiation calculation, the relative contribution of cloud fraction and IWC to TOA radiation flux is evaluated. For example, a doubling of IWC in AM2 RAS simulation induces a net TOA radiation flux of ~1.5 w m-2 in the tropics due to the cancellation of shortwave and longwave radiation. Large scale precipitation efficiency (defined as precipitation divided by the column total condensed water content) and its variation with cloud phase is also investigated. Impacts of prognostic or diagnostic cloud fraction in the Tiedtke scheme are also investigated. Compared with simulations using prognosed cloud fraction, simulations diagnosing cloud fraction using a fixed variance PDF for total water reduce the middle and low-level cloud fraction and large-scale precipitation over the deep tropics. Alternative experiments with the total water PDF variance dependent on surface subgrid inhomogeneity, vertical motion, and height are also conducted to explore the sensitivity of model tropical cloud and hydrological cycle to cloud fraction parameterization.

Large-scale parameter sweeps procedures for developing condensed aerosol schemes for climate models

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Aerosol physical and chemical process models involve multiple physical parameters, chemical pathways, multiple components, and microphysical processes. Representation of aerosols in climate models has proved to be particularly challenging as a result. The increased computational burden as a result of including aerosol processes models in all its details has not yet been justified. A need exists for developing approximate approaches to develop and represent condensed forms of aerosol formation, portioning between various chemical compositions and the effect of atmospheric parameters on these processes. In addition, there is a need to develop a condensed chemical mechanism for representing secondary organic aerosols from all the currently hypothesized organic gas precursor chemical pathways. Here we have implemented a large-scale parameter sweep procedure on a modern high-performance computing facility using a 1D atmospheric chemistry and aerosol chemistry-physics model. The chemistry schemes implemented include RACM, CB4, and SAPRC-99 for the chemistry of volatile organic compounds; JPL for inorganic chemistry; SORGAM for secondary organic aerosols; FAST J for photolysis rates; and ISOROPIA for thermodynamic equilibrium calculations for inorganic aerosols. In addition, this 1D model includes a PBL dynamics model based on k epsilon theory, achieving a 2.5 level closure for the Reynolds stress in calculating turbulence in the PBL. The PBL is very finely resolved in this 1D model, which has been used to investigate fast reactions and interactions with PBL turbulence. The coupling of this model with the climate model radiation code CRM allows us to investigate radiative feedbacks from selected aerosols for direct calculation of radiative forcing. The parameter sweep procedure uses a workflow management tool known as SWIFT in combination with a latin hypercube-sampling procedure implemented for a multi-parameter aerosol system describing the NH3-NO3-SO4 inorganic system. Results from these parameter sweeps, ranging over 1000 to 100,000 simulations and covering a wide range of physical, chemical, and input parameters to this aerosol processes in the 1D model, will be presented. Methods for developing a condensed parametric representation of this process for climate model applications will be discussed.

Lawrence Livermore, Los Alamos, and Sandia collaboration on climate modeling and carbon measurement

Michael Ebinger, Los Alamos National Laboratory
Doug Rotman, Lawrence Livermore National Laboratory
John Mitchiner, Sandia National Laboratories

Through a one-time funding opportunity, scientists from Los Alamos, Lawrence Livermore, and Sandia National Laboratories will contribute to the overall CCRP mission to “advance the forefront of climate change research to provide the nation with the scientific knowledge it needs about the effects of greenhouse gas (GHG) emissions on Earth’s climate and biosphere to support effective energy and environmental decision making." This one-year program is designed to integrate climate modeling advances with carbon measurement innovations to advance the understanding of GHG emissions on climate. New methods in climate modeling and uncertainty quantification and integrated, mobile measurements technology will be described, and their integration will be illustrated. The integrated effort will allow Sandia, Los Alamos, and Lawrence Livermore researchers to contribute to ongoing BER programs without affecting continuing funding for those programs.

A limited-area model (LAM) intercomparison study of the TWP-ICE case

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Ann Fridlind, NASA Goddard Institute for Space Studies
Jimy Dudhia, National Center for Atmospheric Research
Paul Field, UK Met Office
Kathrin Wapler, DWD
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Edward Zipser, University of Utah
Zhenduo Zhu, Florida International University
Ming Chen, National Center for Atmospheric Research
Jon Petch, UK Met Office

The limited-area model (LAM) intercomparison described in this study is a unique component of the joint modeling study on tropical deep convective clouds organized by ARM/GCSS/SPARC. Multiple model configurations from three LAMs, namely WRF, UKMO-LAM, and COSMO, are used to simulate the TWP-ICE cloud case. The models are initialized and forced with ECMWF analyses. All models with different configurations are able to reproduce and maintain the observed thermodynamic structures. The diurnal variation of the convective cloud systems initiated by the mainland and islands is reasonably captured by the simulations. Models somehow also reproduced the observed cyclone genesis during the event C. However, models with different configurations show a substantial discrepancy on the simulated cloud fields despite the similar potential temperature and moisture profiles. The difference of ice water content, liquid water content, and rain water can be as large as a factor of 10. The dynamic field, particularly the vertical velocity, also shows a marked difference among the models. The sensitivity tests show that the simulated cloud fields and properties depend strongly on cloud microphysics schemes and vertical resolution.

Modeling mesoscale convective systems in a highly simplified environment

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Wei-Kuo Tao, NASA Goddard Space Flight Center
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A three-dimensional cloud-resolving model (CRM) is used to simulate mesoscale convective systems (MCSs) in a highly simplified environment, addressing how cloud microphysics, vertical wind shear, and radiation impact the cloud organization in radiative-convective equilibrium (RCE). Sensitivity experiments reveal that the clouds at RCE become aggregated in two forms: (1) cloud envelopes that span ~100 km wide and propagate at ~4 m/s and (2) convective lines that are embedded in the former. These two forms are associated with cloud microphysics (e. g., ice processes) and vertical wind shear, respectively. Besides, the prevalence in modeled cloud envelope as well as observed MCS suggests that tropical cloud systems favor mesoscale too, which is beyond the Bjerknes theory that conditional instability favors the smallest possible scale of cumulus clouds.

Modeling study of relative importance of macrophysics and microphysics in determining cloud properties

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Yangang Liu, Brookhaven National Laboratory
Wuyin Lin, State University of New York at Stony Brook

It has been well recognized that both macrophysics (e.g., lower tropospheric stability) and microphysics (e.g., droplet concentration) affect boundary layer clouds; however, their relative importance has not been well understood and quantified. For example, Lin et al. (2009) investigated the seasonal differences of mean properties of marine boundary-layer clouds off the California coast and found that in comparison with wintertime clouds, the summertime clouds have a larger cloud fraction and liquid water path, lower cloud-top and cloud-base height, and similar cloud thickness and inversion strength. They found that most of these macrophysical features can be explained by the similarity to the downstream stratocumulus-to-cumulus transition theory. On the other hand, Liu (2010) showed that the same data exhibit striking microphysical differences between the summer and winter clouds, with the former having a higher liquid water content and cloud droplet concentration but smaller effective radius and drizzle rate. To discern the relative roles of macrophysics and microphysics, in this study, we perform idealized simulations using the LES mode of WRF model with a double-moment cloud microphysics scheme and vertical profiles from Lin et al. Extension of the results to the general boundary clouds such as those at the SGP site is explored.

Modeling the distribution of sub-grid moisture variability for cloud parameterizations in large-scale models

Peter Norris, NASA Global Modeling and Assimilation Office/UMBC Goddard Earth Sciences & Technology Center
Lazaros Oreopoulos, NASA
Arlindo Da Silva, NASA Goddard Space Flight Center

Large-scale models (LSM) with statistical sub-grid cloud parameterizations require realistic parametric forms for the distribution of sub-grid moisture. A vertical column of such distributions, together with vertical overlap assumptions, can be used to generate an ensemble of sub-column cloud fields for each LSM grid-column. These can then be operated on by Independent Column Approximation (ICA) radiative transfer to yield more accurate radiative averages for each grid-column. We examine various candidate layer probability density functions (PDFs) for modeling total moisture content from cloud-resolving model (CRM) simulations over the ARM SGP site. We include both symmetric and skewed distributions. We also consider the effect of grid-scale trends on these PDFs. Such trends can sometimes dominate sub-grid small scale variability, particularly outside of the boundary layer. Finally, we examine the use of ARM MICROBASE condensate retrievals to constrain the parameters of candidate total water PDFs via a maximum likelihood tail-fitting procedure.

Nature versus nurture in shallow convection

David Romps, Harvard University
Zhiming Kuang, Harvard University

We use tracers in a large-eddy simulation of shallow convection to show that stochastic entrainment, not cloud-base properties, determines the fate of convecting parcels. The tracers are used to diagnose the correlations between a parcel's state above the cloud base and both the parcel's state at the cloud base and its entrainment history. We found that the correlation with the cloud-base state goes to zero a few hundred meters above the cloud base. On the other hand, correlations between a parcel's state and its net entrainment are large. Evidence is found that the entrainment events may be described as a stochastic Poisson process. We construct a parcel model with stochastic entrainment that is able to replicate flux profiles and, more importantly, the observed variability. Turning off cloud-base variability has little effect on the results, which suggests that stochastic mass-flux models may be initialized with a single set of properties. The success of the stochastic parcel model suggests that it holds promise as the framework for a convective parameterization.

A new multi-scale modeling framework with an advanced higher-order turbulence closure

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

Annual and seasonal mean state, diurnal cycle, and MJO-like variability in a new multi-scale modeling framework (MMF) are analyzed, in which the cloud processes are represented by a two-dimensional (2D) cloud-system resolving model (CRM) with an advanced higher-order turbulence closure (HOC) at each general circulation model (GCM) grid box. The Community Atmosphere Model (CAM3.5) is used as the host GCM, while the CRM is the system for atmospheric modeling (SAM). The results from the new MMF are compared with those from the MMF with a first-order turbulence closure implemented in SAM. The global distribution of low cloud amount and the representation of the middle-level clouds in mid-latitude storm track regions show substantial improvement compared with those from the old MMF. Some improvements can also be seen from the diurnal cycle and MJO-like variability.

A numerical case study during ISDAC

John Lindeman, George Mason University
Zafer Boybeyi, George Mason University
Priyanka Roy, George Mason University
Eric Stofferahn, George Mason University

Numerical simulations with a mesoscale meteorological model are compared to ground-based and upper-air sounding observations in Point Barrow, Alaska, as part of the Indirect and Semi-Direct Aerosol Campaign (ISDAC) field campaign. The Weather, Research, and Forecasting (WRF) model is run at varying horizontal resolutions to analyze the importance of local forcing processes such as land surface and topography on the local weather conditions at Point Barrow. The WRF model, initialized with NCEP Global Forecast System (GFS) reanalysis data, is run over a period of several days for selected cases in the winter and spring of 2008. Idealized experiments with WRF and its chemistry module (WRF/Chem) are also run to analyze direct and indirect aerosol forcing effects on the surface radiation budget and meteorological parameters such as temperature and precipitation.

A numerical study of aerosol-cloud interaction during a deep convective episode

Priyanka Roy, George Mason University
Zafer Boybeyi, George Mason University
John Lindeman, George Mason University
Eric Stofferahn, George Mason University

The coupled Weather Research and Forecasting-Chemistry (WRF-Chem) model is used here to study the extent of the indirect effect of aerosols on deep convective precipitation. The focus of the study is the Midwestern United States of America, where the squall lines produce intense weather during the warm summer months. Since precipitation is a highly non-linear process and involves many processes, getting the state variables right is of utmost importance. The results suggest that the choice of vertical and horizontal resolution has a large contribution while simulating a deep convection. Comparisons with ground-based observations made at the ARM SGP site also support this point. Sensitivity analysis using the 2005 National Emission Inventory (NEI) emission data sets allows the indirect effect to be studied with the emissions for a typical summer day. The hypothesis being tested is the increase of convective strength and large-scale formation of clouds with increase in aerosols. Convection is driven by the increase in the updraft; the rapid transfer of aerosols and water vapor to higher levels causes them to release latent heat at higher levels, thus strengthening the convection.

On the parameterization of ice crystal growth in numerical cloud models

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Hugh Morrison, National Center for Atmospheric Research
Kara Sulia, The Pennsylvania State University
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The growth of ice crystals from vapor constitutes an important physical process within ice-containing, or cold, clouds. Ice crystals can grow rapidly to precipitation sizes through vapor growth alone; their growth constitutes an important sink of vapor which has potentially important impacts for the vapor budget of the upper troposphere. In addition, vapor growth produces complex crystal shapes that depend on temperature and supersaturation. While much is understood about crystal growth from vapor, cloud models generally contain simplified parameterizations that are formulated based on equivalent density spheres or specified mass-dimensional relationships based on aircraft data. We present a possible method to improve the prediction of primary crystal habit (a and c axis length) in bulk microphysical models. As an advantage, the new method is able to track the history of the particle's growth, allowing for the prediction of bulk a and c axis lengths. This method thus allows the axis ratios and primary habits to evolve in time and space. Tests of the new method in comparison with a detailed, Lagrangian ice crystal growth model will be shown. This new method is based on the capacitance model for ice crystal growth, which fails at low ice supersaturations when surface kinetics dominate the growth process. However, we show that it is possible to re-derive the capacitance model so that surface kinetic effects for non-spherical particles are included in a consistent fashion. Tests in comparison with detailed ice crystal growth models show that this method of including surface kinetic effects is accurate, and thus provides a simplified way to improve ice crystal growth in cloud models at both low and high ice supersaturations.

On the summertime shallow cumulus clouds at Southern Great Plains

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Stephen Klein, Lawrence Livermore National Laboratory
Pavlos Kollias, McGill University
Arunchandra Chandra, McGill University

Shallow cumulus clouds are important for surface radiation budget and vertical moisture transport. They occur very often during summertime over large areas near Southern Great Plains (SGP). This study aims to gain more insights on shallow cumulus cloud dynamics and life cycle with the help of both the modeling tools, such as large-eddy simulations (LES), and the ARM observations, especially the newly developed retrieval data of vertical velocity of air motions inside and beneath shallow cumulus clouds (Kollias et al. 2001, Kollias et al. 2003, Chandra et al. 2009). Based on long-term observations at the ARM SGP site, we develop composite cases of typical shallow cumulus clouds, which are closely related to surface heat fluxes and atmospheric boundary layer development. To develop composites, we investigate the ARM observations on cloud macrophysics, such as cloud base, fraction, thickness, and diurnal variation, and the associated meteorological conditions. These composite cases will help to generate statistics for cloud dynamics, such as mass flux, an important variable for cloud and convection parameterizations in large-scale models. These composite cases will further serve as testbeds for LES and single-column models to validate and explain observations and to test and improve parameterizations in large-scale models.

Organization of a plume ensemble

Brian Mapes, University of Miami

In order to ameliorate some shortcomings of convection schemes based on a single plume, or on an ensemble of plumes that compete for instability in their common large-scale column, we describe a treatment in which plumes can interact. The index of the ensemble is called a plume's generation. First-generation plumes mix their way up in the mean large-scale environment, detraining some mass flux along the way. The detrained mass tends to have greater moisture and entropy than ambient air, so higher-generation plumes that entrain it gain an advantage in their buoyancy and thus vertical growth. The succession is terminated when additional plumes do not reach higher altitudes (typically just a few generations). The closure for this plume ensemble therefore involves an interaction probability, which we treat via a single scalar: the "organization" of the cumulus cloud field (denoted org). The paper first describes single-column tests using the Bretherton et al. (2004) entraining-detraining plume, plus specified cooling and simple surface-flux and mixed-layer treatments. Plume interaction allows shallow and deep plumes to coexist with the same specified lateral-mixing strength. When org is defined functionally as a linear ramp from random (org=0) to maximum plume overlap (org = 1), varying org causes the mix of shallower and deep plumes to vary. With robust lateral mixing, the first generation has significant sensitivity to environmental dryness, yet late-generation plumes in high-org conditions can reach tropopause altitudes without such severe dilution.

Quantifying sub-grid variability of trace gases and aerosols

William Gustafson, Pacific Northwest National Laboatory
Yun Qian, Pacific Northwest National Laboratory
Jerome Fast, Pacific Northwest National Laboratory

Sub-grid treatments exist for meteorological processes in atmospheric models, such as clouds and turbulence. However, little effort has gone into understanding the impact of sub-grid processes on trace gases and aerosols. In addition to the impact of sub-grid meteorological conditions on aerosol mixing, there are also trace gas and aerosol-specific processes that could contribute to errors in simulated values if these processes are neglected. Two examples are the spatial variability of emissions and the nonlinearity of chemical rate constants with concentration. Using a series of model simulations with varying resolution, we have quantified the amount of variability present for meteorology, trace gases, and aerosols in and around Mexico City during the 2006 MILAGRO field campaign. Our results indicate that the amount of sub-grid variability is greater for trace gases and aerosols than for meteorological variables due to the large gradients in the former. We find distinct differences between the sub-grid variability of trace gases and aerosols that are mostly inert versus those that are secondary in origin. And, as intuitively expected, the sub-grid variability is less for locations remote from large emission regions. Emissions can account for up to 50% of the sub-grid variability over urban areas, and the variability is stronger during daytime than nighttime.

Radar simulator for validating a two-moment cloud microphysical model applied to TWP-ICE

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Hugh Morrison, National Center for Atmospheric Research
Sally McFarlane, Pacific Northwest National Laboratory
Wojciech Grabowski, National Center for Atmospheric Research
Jennifer Comstock, Pacific Northwest National Laboratory
Szymon Malinowski, University of Warsaw

We present results of a cloud radar simulator coupled with the two-moment liquid and ice microphysics scheme of Morrison and Grabowski (2007, 2008a, 2008b, *Journal of the Atmospheric Sciences*) and applied to two-dimensional cloud model (Dx = 1km) simulations of the Tropical Warm Pool-International Cloud Experiment (TWP-ICE). The simulator uses pre-computed look-up tables in which radar reflectivity and beam attenuation are calculated from the predicted temperature and hydrometeor number concentrations, mixing ratios, and in the case of ice, the predicted rime mass fraction (ratio of ice mass grown by riming and riming plus vapor diffusion). The observational data set used for validating the model is from the Jan 18–Feb 3, 2006 period of TWP-ICE, and the model setup is the same as the ARM TWP-ICE cloud model intercomparison.

Regional and cloud-scale modeling of Tropical Western Pacific clouds using WRF

Jimy Dudhia, National Center for Atmospheric Research

In the previous year, we have produced an initial analysis of December 2007 using an Ensemble Kalman Filter data assimilation method including COSMIC GPS for thermodynamic profiles over this data-sparse region. The analysis has revealed several areas for improvement in WRF that are relevant to regional climate model parameterizations. In this poster we will demonstrate some solutions to the problems we have found, particularly in the radiation and moist physics parameterizations applied to mesoscale models, and this will be part of an improved analysis planned for this year. The first of the problems relates to how ice clouds, in particular, are interacting with the radiation schemes. It was found that the new RRTMG longwave radiation scheme produced too little cloud effect in outgoing longwave radiation (OLR), an important climate parameter. This was traced to the assumption that the main effect of ice clouds came from the microphysics ice array. A better assumption was to add the ice and snow arrays to use in the radiation scheme, and this is a modification that will be in the 3.2 release of WRF due in 2010. Different microphysics schemes have this problem to different degrees depending on their relative amounts of snow and ice that represent the tropical convective anvils. A clear-sky problem we are currently addressing relates to the use of lower model tops in regional/mesoscale models than in global/climate models. Typical tops are in the 100 hPa to 10 hPa range (16–50 km), often being restricted by the height of commonly available analyses that are used for lateral boundary conditions. It has been noticed, particularly in the long simulations used for regional climate or data assimilation, that the top level cools unrealistically, possibly having impacts at lower levels and making satellite data assimilation difficult. This was traced to the downwelling radiation at the model top being calculated with an assumption of an isothermal layer between model top and the top of atmosphere. Better assumptions using observation-based lapse rates in the stratosphere improve the radiation, and this will also be available in the next WRF release. We have also participated in the TWP-ICE limited-area-model (LAM) intercomparison. Two three-day simulations with nesting down to cloud-permitting 1-km grids were carried out, and selected results may also be shown on the poster.

Respective roles of shallow convection and stratiform rainfall on the simulation of Madden-Julian Oscillation

Joshua Fu, University of Hawaii International Pacific Research Center

Reducing systematic errors of state-of-the-art general circulation models (GCMs) will increase our confidence on the projection of future climate change and improve our forecast skills of present-day weather and climate variability. One systematic error of conventional GCMs is the failure to simulate a dominant tropical atmospheric variability: Madden-Julian Oscillation (MJO). Through downscale and upscale influences, MJO modulates the occurrence of extreme hydro-meteorological events (e.g., hurricane, flood, and drought, etc.) and the onset and development of ENSO. This common model error not only hinders the achievement of seamless forecasts, but also undermines our confidence on the projection of future climate change. In this proposed study, we aim to improve the representation of MJO in conventional GCMs. As a first step toward the proposed goal, two sets of sensitivity experiments with ECHAM GCM have been carried out to unravel the respective roles of shallow convection and stratiform rainfall on the simulation of the MJO. First, a series of retrospective forecast experiments, targeting a prominent MJO event observed during TOGA-COARE, has been conducted to assess the impact of shallow convection on the dynamical MJO forecast skill. It is found that the boundary-layer moistening from shallow convection plays a critical role on the eastward propagation of model MJO. On the other hand, a series of long-term free integrations reveal that an appropriate portion (> 30%) of stratiform rainfall (vs. total rainfall) is necessary to sustain a robust MJO in ECHAM GCM. Present findings highlight the need to improve the representations of both stratiform clouds and shallow convection in conventional GCMs. We are now developing a high-resolution dynamically consistent regional data set for the TWP-ICE field campaign period using advanced data assimilation techniques. We plan to use this data set to diagnose the interactions among shallow convection, deep convection, and stratiform clouds.

The diagnostic results will be used to improve current cumulus parameterizations. Eventually, the improved parameterizations will be tested and implemented in ECHAM and other GCMs.

The role of gravity waves in the formation and organization of clouds during TWP-ICE

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Todd Lane, The University of Melbourne
Christian Jakob, Monash University
Andrew Heymsfield, National Center for Atmospheric Research

All convective clouds emit gravity waves. While it is certain that convectively generated waves play important parts in determining the climate, their precise roles remain uncertain, and their effects are not generally represented in climate models. There are at least three ways in which convectively generated gravity waves affect climate. First, gravity waves have the potential to lift moist layers in the upper troposphere to produce extensive layers of cirrus. The vertical velocity and temperature perturbations associated with such waves may lead to supersaturation near the tropopause, which in turn leads to cirrus nucleation. This process has the potential to very significantly control the transport of water in to the lower stratosphere, since the cirrus crystals will grow, fall, and dehydrate the upper atmosphere. Conversely, the formation of cirrus layers may increase the temperature at upper levels by a degree or two, which in turn would increase the saturation mixing ratio with respect to ice, promoting greater transport of water into the lower stratosphere. Either way, the effect of thin cirrus clouds on the distribution of water in the upper troposphere and lower stratosphere, and hence the radiative budget, is almost certainly large. Second, it is known that the gravity waves emitted by deep convective clouds may themselves trigger and organize further convection, although the frequency with which this occurs and its significance remain uncertain. Third, gravity waves transport momentum and energy very large distances from the site of their generation, exerting a stress on the atmosphere wherever they dissipate. In this way, convectively generated gravity waves play a very influential role in determining the climate, and in particular the large-scale circulation, as they couple the troposphere to the upper atmosphere through the redistribution momentum and energy. This research project has only just begun, and the poster will describe the research plan and some preliminary results. The project will investigate the part played by convectively generated gravity waves in the formation of cirrus, in the initiation and organization of further convection, and in the subgrid-scale momentum transport and associated large-scale stresses imposed on the troposphere and stratosphere. This will be achieved through a combination of detailed numerical simulation and analysis of the observations taken during TWP-ICE.

Seasonal distribution of radiative contributions to climate feedback strengths

Patrick Taylor, NASA Langley Research Center
Robert Ellingson, Florida State University

The 2xCO_2 climate sensitivity is controlled by the strength of climate feedbacks, which can act to amplify or dampen the CO_2 forcing. Traditionally, model climate feedback sensitivity parameters are defined in terms of global annual mean TOA net flux radiative perturbations driven by model climate responses: water vapor, temperature, cloud properties, and surface albedo. Little attention has been given to the distributions of these radiative perturbations throughout the annual cycle. Therefore, the annual cycle of radiative contributions to climate feedbacks will be investigated here using the partial radiative perturbation (PRP) methodology. Monthly mean model output was generated from a simulation of the NCAR CCSM3.0 forced with the SRESA1B emissions scenario. It was found that the TOA radiative perturbations show significant month-to-month variability with different annual cycle structures for each feedback. In addition, it was found that April and December are the least and most sensitive months, respectively, indicating that the simulated annual cycle influences the final climate sensitivity. The representativeness of model-derived annual cycle of climate feedback radiative perturbation to the expected climate system response is contingent on the model's ability reproduce the observed annual cycle. As a result, the annual cycle of various NCAR CCSM3.0 radiative quantities will be compared against satellite radiometric observations from the Clouds and Earth Radiative Energy System (CERES) instrument in conjunction with radiative flux measurements from the ARM SGP site. Comparing observations with model annual cycle in conjunction with radiative perturbations and feedback strengths allows for the investigation of possible links between monthly variability, climate feedbacks, and climate sensitivity.

Solar radiative transfer in a 3D CSRM simulation of a "mock-Walker" circulation

Jason Cole, Canadian Centre for Modelling and Analysis
Howard Barker, Environment Canada

Most, if not all, cloud system-resolving models (CSRMs) use the independent column approximation (ICA) for computation of radiative transfer. Many studies have shown that there can be locally large instantaneous biases between radiative fluxes computed using 3D methods and fluxes computed using the ICA, especially for solar wavelengths. What is not clear is if these systematic biases can in turn affect systematic biases within the simulations performed with CSRMs. Previous work using 2D CSRM simulations of a large domain atop an ocean with prescribed sinusodially varying sea surface temperatures suggested that computing solar radiative transfer using 3D or ICA produced very similar results for several diagnostics. This implies that the impact of using the more complicated 3D solar radiative transfer was minimal. To examine if these results are a byproduct of using a 2D CSRM domain, simulations were repeated using a 3D CSRM domain in which the solar radiative transfer was computed using either 3D or ICA radiative transfer. Results from these 3D CSRM simulations will be presented.

Statistical summary products for the CMBE data set

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Shaocheng Xie, Lawrence Livermore National Laboratory
Stephen Klein, Lawrence Livermore National Laboratory
Richard Neale, NOAA/CIRES Climate Diagnostics Center
Jean-Christophe Golaz, Geophysical Fluid Dynamics Laboratory/University Corporation for Atmospheric Research
Yanluan Lin, National Center for Atmospheric Research/Geophysical Fluid Dynamics Laboratory

We present the new addition to the Climate Modeling Best Estimate (CMBE) data set that comprises a statistical summary of the CMBE data. It includes both monthly mean and monthly mean diurnal cycle and their climatologies for all the geophysical quantities contained in the CMBE datasets. The CMBE was created to serve the needs of climate model developers. It is a multi-year data set over the five primary ARM Climate Research Facility sites at the Southern Great Plains (SGP), North Slope of Alaska (NSA), and Tropical Western Pacific (TWP). It consists of cloud fraction (narrow field-of-view and total sky), liquid water path, precipitable water, and surface radiation fluxes; and (currently for SGP site only) soundings, surface precipitation, surface turbulent fluxes, surface meteorology fields, top-of-the-atmosphere radiative fluxes, and Numerical Weather Prediction (NWP) model analysis data. The purpose of the new summary data sets is to further increase the use and make it even easier to use the CMBE data for model comparison to the observational ARM data. The statistical summary data have been significantly quality control-screened, to exclude the outliers suspected to be due to an instrument calibration or other data problems. The quality controls are described, and the use of these new statistical CMBE data sets is demonstrated in the comparison to the National Center for Atmospheric Research (NCAR) climate model and the Geophysical Fluid Dynamics Laboratory (GFDL) model.

http://science.arm.gov/workinggroup/cpm/scm/best_estimate.html

Studying aerosol-cloud interaction by solution adaptive modeling technique

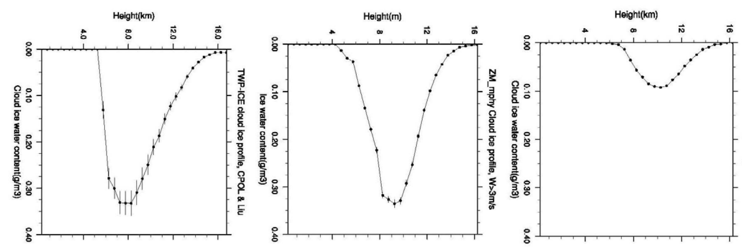
Zafer Boybeyi, George Mason University
John Lindeman, George Mason University
Priyanka Roy, George Mason University
Eric Stofferahn, George Mason University
Ismail Gultepe, Environment Canada
Nicole Shantz, Environment Canada

Solution adaptive numerical modeling using unstructured grid techniques is a relatively new concept for atmospheric modelers and will be discussed in this talk. Adaptive unstructured grids facilitate the use of very high resolutions only where needed by the evolving numerical solution. The rationale for using adaptive unstructured grid technique is that there is general consensus that the atmospheric processes at all relevant scales together is an intractable problem. One obvious method to improve the prediction of numerical models is to enhance the spatial grid resolution. However, introducing fine spatial resolution throughout a simulation domain is not always practical since the size of the modeling domain, the numerous interactions between the various atmospheric processes that span a multitude of spatial and temporal scales, and the complexity of the numerical algorithms place restrictions on the grid resolution that can be achieved using current computers. These limitations prohibit the use of a uniform high spatial grid resolution that is appropriate to resolve the smallest scales of interest. One alternative is to develop methodologies capable of providing local refinement in certain key regions where a high degree of resolution is required, such as shorelines and areas of large terrain gradients (i.e., static grid adaptation). In addition, solution-adaptive simulations can be run to improve the solution by dynamically adapting the mesh to physical features, such as clouds and aerosols (i.e., dynamic grid adaptation).

Test of microphysics treatment in convection parameterization using TWP-ICE data and NCAR SCAM and CAM3

Guang Zhang, University of California, San Diego
Xiaoliang Song, Scripps Institution of Oceanography

As part of an effort to improve the convection parameterization scheme for the NCAR CAM3 using ARM/ASR observations, we incorporated a cloud microphysics parameterization into the Zhang-McFarlane convection scheme. The scheme is then evaluated against observations of cloud ice and water during the TWP-ICE experiment using the NCAR SCAM. It is found that this physically based treatment of convective microphysics yields more realistic vertical profiles of convective cloud ice and liquid water contents. Cloud water and ice budgets are calculated to estimate the role of cloud water and ice detrainment from convection as water source for large-scale clouds. The new microphysics treatment is further implemented into CAM3 to test its effect on GCM simulations of clouds. Results indicate that increase in ice and water contents in convective clouds leads to a moderate increase in tropical cloud amount and ice/liquid water path.

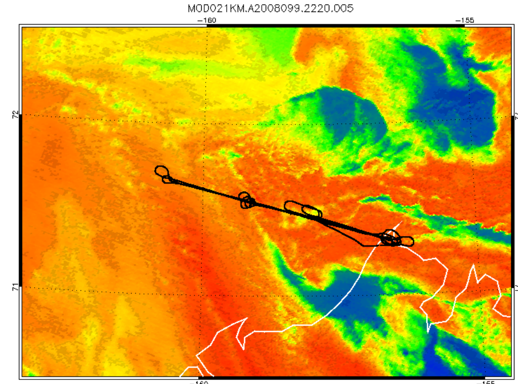


Vertical profiles of cloud ice content inside convective cells from (top) NCAR SCAM control run, (middle) NCAR SCAM with new microphysics for convection, and (bottom) TWP-ICE observations.

Towards ice formation closure in mixed-phase boundary layer clouds during ISDAC

Alexander Avramov, Columbia University
Andrew Ackerman, NASA Goddard Institute for Space Studies
Ann Fridlind, NASA Goddard Institute for Space Studies
Alexei Korolev, Environment Canada
Sarah Brooks, Texas A&M University
Andrew Glen, Texas A&M University

Mixed-phase stratus clouds are commonly found during winter and transition seasons in the Arctic and through various feedback mechanisms exert a strong influence on Arctic climate. Despite their important role, however, they are still difficult to represent correctly in cloud models. In particular, models of all types experience difficulties reproducing observed ice concentrations and liquid-ice water partitioning in these clouds. Previous modeling studies of arctic mixed-phase clouds have shown that simulated ice concentrations and ice water content are very sensitive to ice nucleation modes and ice crystal habit assumed in simulations. Here, we use large-eddy simulations with size-resolved microphysics to determine whether uncertainties in ice nucleus concentrations, ice nucleation mechanisms, ice crystal habits, and large-scale forcing are sufficient to account for the difference between simulated and observed quantities. We focus on a case study from the Indirect and Semi-Direct Aerosol Campaign (ISDAC)—April 8, 2008 (Flight 16)—in which the full suite of instrumentation on the Convair-580 was operational (including the Nevzorov probe, which measures ice water content) and during which the aircraft overflew the Barrow ground site. We present analysis of the consistencies (and lack thereof) between the measurements and an extensive comparison of model results with the in situ observations and remote sensing measurements.



Level 1 (1 km at nadir) radiances in MODIS band 20 (3.7 um) during flight 16 with flight track and coastline overlaid respectively in black and white.

http://acrf-campaign.arm.gov/isdac/

Tracking tropical cloud systems—observations for the diagnosis of simulations by the Weather Research and Forecasting (WRF) model

Andrew Vogelmann, Brookhaven National Laboratory
Wuyin Lin, State University of New York at Stony Brook
Alice Cialella, Brookhaven National Laboratory
Edward Luke, Brookhaven National Laboratory
Michael Jensen, Brookhaven National Laboratory
Minghua Zhang, State University of New York at Stony Brook

To aid in improving model parameterizations of clouds and convection, we examine the capability of models, using explicit convection, to simulate the life cycle of tropical cloud systems in the vicinity of the ARM Tropical Western Pacific sites. The cloud life cycle is determined using a satellite cloud-tracking algorithm (Boer and Ramanathan 1997), and the statistics are compared to those of simulations using the Weather Research and Forecasting (WRF) model. Using New York Blue, a Blue Gene/L supercomputer that is co-operated by Brookhaven and Stony Brook, simulations are run at a resolution comparable to the observations. Initial results suggest a computational paradox where, even though the size of the simulated systems are about half of that observed, their longevities are still similar. The explanation for this seeming incongruity will be explored.

Boer, E, and V Ramanathan. 1997. "Lagrangian approach for deriving cloud characteristics from satellite observations and its implications to cloud parameterization." *Journal of Geophysical Research* 102: 21,383-21,399.

Wildfire smoke aerosol modeling in the Arctic

Martin Stuefer, University of Alaska Fairbanks Geophysical Institute
Georg Grell, NOAA
Saulo Freitas, Center for Weather Forecast and Climate Studies

Wildfires in Siberia, Alaska, and Northern Canada are a major source of air pollution in the Arctic. We have been able to successfully predict the atmospheric effects of wildfire smoke. WRF/Chem Version 3.1 represents the core of the so-called UAFSmoke system. The system accounts for modeling of the chemistry and aerosol transport in online fashion with the meteorological forecast model. UAFSmoke includes detection of wildfire location and area using data from direct and airborne observations and thermal anomalies from the MODIS instrument. In addition, the sub-grid scale plume rise dynamics above fires have been embedded online in WRF/Chem as a further major progress in modeling wildfire effects in the atmosphere. The plume model is initiated with fire emissions derived from above-ground biomass fuel load data in 1-km resolution. Smoke concentration from UAFSmoke runs coincide well with measured particulate concentrations. Aerosol and radiation measurements at the ARM North Slope of Alaska (NSA) sites of Barrow and Atqasuk clearly show a strong wildfire smoke signal during extreme wildfire years. In 2004 the aerosol optical depth (AOD) at ARM NSA increased by orders of magnitude due to smoke transported from interior Alaska to the Arctic. The ARM measurements constitute a reference for WRF/Chem evaluation in support of modeling aerosol effects over the Arctic.

http://smoke.arsc.edu/

10.0 Radiation

Annual variability of white- and black-sky spectral albedo at the Central Facility

Gary Hodges, NOAA ESRL Global Monitoring Division/CIRES
Joseph Michalsky, DOC/NOAA Earth System Research Laboratory
Ellsworth Dutton, NOAA Earth System Research Laboratory

We explore the annual variability of both white- and black-sky albedo at the Southern Great Plains Central Facility using lamp-calibrated data from the E13 and C1 MFRSRs and the 10m and 25m MFRs. These instruments measure at six narrowband channels: 415, 500, 615, 673, 870, and 940 nm. White- sky albedo is the reflectance of the surface under diffuse-sky conditions. Black-sky albedo, also known as directional-hemispherical reflectance, is the reflectance of the surface from direct-beam illumination only. Using the surface albedo measured under overcast conditions, the components of the upwelling signal can be separated under black-sky conditions. The primary assumption for this analysis is that the diffuse albedos are comparable under both cloudy and clear-sky conditions.

Cloud edges: the spectral-invariant relationship between ratios of zenith radiances near them

Alexander Marshak, NASA Goddard Space Flight Center
Yuri Knyazikhin, Boston University
J.-Y. Christine Chiu, University of Maryland Baltimore County
Warren Wiscombe, Brookhaven National Laboratory

The transition zone between cloudy and cloud-free areas is where strong aerosol-cloud interactions take place. We have discovered a surprising spectral-invariant relationship between ratios of zenith radiance spectra measured by the ARM shortwave spectrometer (SWS) in this transition zone. This relationship demonstrates, as a consequence, that the shortwave spectrum within the transition zone is fully determined by zenith radiance spectra of fully cloudy and fully cloud-free regions. We also report the results of radiative transfer calculations that confirm the spectral invariance and show how the spectral-invariant relationship is affected by factors such as cloud thermodynamic phase, underlying surface types, aerosol properties, and the finite field-of-view of the spectrometer. Finally, we illustrate the dependence of spectral-invariant characteristics of the transition zone on aerosol properties using measurements from the AMF two-channel narrow field-of-view radiometer (2NFOV).

Development of a high-resolution oxygen A-Band spectrometer (HABS)

Qilong Min, State University of New York at Albany
Jerry Berndt, State University of New York at Albany Atmospheric Sciences Research Center
Piotr Kiedron, NOAA
Bangshen Yin, State University of New York at Albany

A high-resolution oxygen A-band spectrometer (HABS) has been developed to study the applicability of photon path length statistics in the remote sensing of clouds and aerosols. The HABS has the capability to measure both zenith and direct-beam radiances with a field of view of 2.7 degrees. The direct-beam measurements can be used to calibrate the spectrometer and construct the retrieval kernels for the zenith

measurements. The HABS also measures polarizations of A-band spectra with four polarizers, which substantially enhances the retrieval ability for aerosols and ice clouds. This spectrometer successfully achieves an out-of-band rejection of better than 10^-5, a resolution of better than 0.5 cm^-5, and a high signal-to-noise ratio, which are crucial to retrievals of atmospheric information through high-resolution spectrometry in the oxygen A-band. This spectrometer will provide a basis for the applications of path length distribution in the development and validation of remote sensing and radiative transfer parameterizations that account for the cloud 3D effects.

Evaluation of uncertainties affecting the retrievals of cloud liquid water using microwave frequencies at 90 and 150 GHz

Maria Cadeddu, Argonne National Laboratory
David Turner, University of Wisconsin-Madison

The Atmospheric Radiation Measurement (ARM) Climate Research Facility is in the process of deploying new microwave radiometers that use frequencies at 90 and 150 GHz to improve the retrieval of cloud liquid water path. One of these radiometers has been operating at the Southern Great Plains site for one year, and the new datastream is about to be released to the archives. A considerable effort has been devoted to the development of reliable calibration procedures and to the improvement of absorption models at these frequencies. Accurate calibration of the instrument and modeling are essential elements to ensure the highest accuracy of LWP retrievals. We present the new datastream, evaluate the calibration of the instrument, and compare model computations with observations. With the help of infrared measurements we retrieve cloud liquid water path for several cases of thin clouds, and we use the IR-derived LWP as input to a radiative transfer code to compute microwave brightness temperatures with four different cloud absorption models. The focus of the study is to analyze the model behavior for cases of very cold clouds ($T < -10°$ C) where the microwave absorption models are known to suffer from the lack of laboratory measurements and where the largest discrepancies between the models are expected. Modeled brightness temperatures are then compared to observations, and the results are used to infer the accuracy of the models and the level of uncertainty that can be expected in the retrievals. Examples of liquid water path retrievals from the new instruments are provided and compared to existing LWP retrievals from the ARM two-channel microwave radiometers (MWR).

An extensive variable-weather comparison of pyrheliometers

Stephen Wilcox, National Renewable Energy Laboratory
Ellsworth Dutton, NOAA Earth System Research Laboratory
Afshin Andreas, National Renewable Energy Laboratory
Peter Gotseff, National Renewable Energy Laboratory
Daryl Myers, National Renewable Energy Laboratory
Donald Nelson, NOAA
Ibrahim Reda, National Renewable Energy Laboratory
Tom Stoffel, National Renewable Energy Laboratory
Joseph Michalsky, DOC/NOAA Earth System Research Laboratory

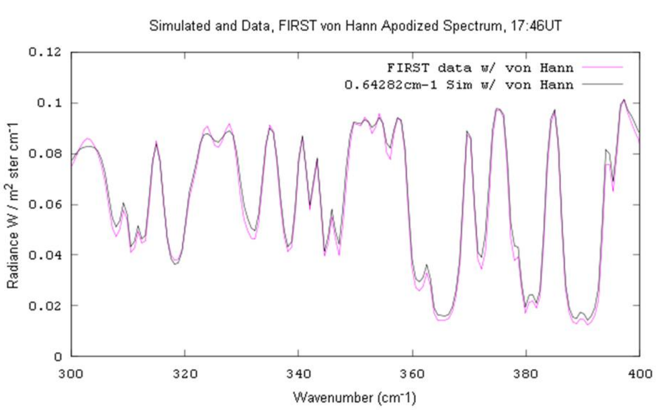
Thirty-three commercially available pyrheliometers were compared over more than nine months between November 2008 and September 2009 at the NREL Solar Radiation Research Laboratory near Golden, Colorado. Included among the 33 instruments were four all-weather absolute cavity radiometers, which proved to be as stable as the open cavities that were used to calibrate all pyrheliometers at several points during the study. The average of the four all-weather cavities was chosen as the standard irradiance to which the other 29 pyrheliometers were compared. The 95% confidence in the cavity standard was

± 1.2 W/m2. In addition to the four all-weather cavities, there were seven sets of three pyrheliometers of the same make and model plus an additional eight prototypes in the study. These test instruments include those most widely used by the international community along with these new production models. Instruments were cleaned every work day. Analysis was performed by a non-participant in the experiment who had no knowledge of the identification of the instruments except for the cavity radiometers; the analyst also knew which three pyrheliometers formed a set. If the manufacturer provided temperature corrections, they were applied. The early analysis suggests four groupings of pyrheliometers; windowed cavity radiometers are the most accurate; followed by pryheliometers that have 95% uncertainties around ± 5 W/m2; followed by pyrheliometers with uncertainties around ± 10–15 W/m2; and then two prototypes that were clear outliers. The results will be illustrated; the identity of the instruments is pending completion of the analysis. The comparison was organized under the auspices of the Baseline Surface Radiation Network with instruments donated from many sources. NREL staff members were responsible for most of the observational activity.

FIRST observations of far-infrared spectra from the RHUBC-II campaign

Martin Mlynczak, NASA Langley Research Center
Richard Cageao, NASA Langley Research Center
Dave Johnson, NASA Langley Research Center
John Alford, NASA Langley Research Center
Dave Kratz, NASA
Joseph Lee, NASA Langley Research Center
Glenn Farnsworth, NASA Langley Research Center

The Far-Infrared Spectroscopy of the Troposphere (FIRST) instrument was one of three instruments measuring downwelling infrared spectra during the Radiative Heating in the Underexplored Bands Campaign II (RHUBC-II), carried out at an altitude of 5.5 km on Cerro Toco, Chile from August to October 2009. FIRST is a Michelson interferometer covering the spectral range from 80 to 2000 wavenumbers at a nominal resolution of 0.643 wavenumbers. In this poster we will present far-infrared spectra observed over the course of the mission. These will be compared with radiative transfer calculations developed from the temperature and moisture profiles observed simultaneously by radiosonde during the campaign.



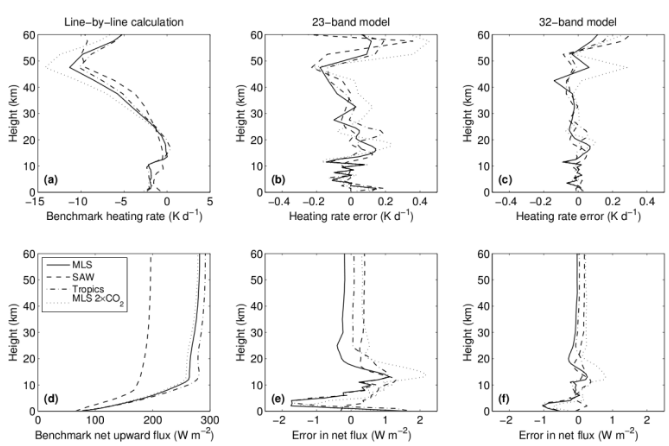
FIRST-observed spectra (red curve) compared with radiative transfer calculations (blue curve) in the 300 to 400 wavenumber interval. Data observed on September 19, 2009, on Cerro Toco, Chile, at an altitude of 5.5 km.

The full-spectrum correlated k method for longwave atmospheric radiative transfer: treatment of gaseous overlap

Robin Hogan, University of Reading

The correlated k-distribution (CKD) method is widely used in the radiative transfer schemes of atmospheric models and involves dividing the spectrum into a number of bands and then reordering the gaseous absorption coefficients within each one. The fluxes and heating rates for each band may then be computed by discretizing the reordered spectrum into of order 10 quadrature points per major gas and performing a monochromatic radiation calculation for each point. In this poster it is shown that for clear-sky longwave calculations, sufficient accuracy for most applications can be achieved without the need for bands; reordering may be performed on the entire longwave spectrum. The resulting full-spectrum correlated k (FSCK) method requires significantly fewer monochromatic calculations than standard CKD to achieve a given accuracy. The concept is first demonstrated by comparing with line-by-line calculations for an atmosphere containing only water vapor, in which it is shown that the accuracy of heating-rate calculations improves approximately in proportion to the square of the number of quadrature points. For more than around 20 points, the root-mean-squared error flattens out at around 0.015 K/day due to the imperfect rank correlation of absorption spectra at different pressures in the profile. The spectral overlap of m different gases is treated by considering an m-dimensional hypercube where each axis corresponds to the reordered spectrum of one of the gases. This hypercube is then divided up into a number of volumes, each approximated by a single quadrature point, such that the total number of quadrature points is slightly fewer than the sum of the number that would be required to treat each of the gases separately. The gaseous absorptions for each quadrature point are optimized such that they minimize a cost function expressing the deviation of the heating rates and fluxes calculated by the FSCK method from line-by-line calculations for a number of training profiles. This approach is validated for atmospheres containing water vapor, carbon dioxide, and ozone, in which it is found that in the troposphere and most of the stratosphere, heating-rate errors of less than 0.2 K/day can be achieved using a total of 23 quadrature points, decreasing to less than 0.1 K/day for 32 quadrature points. It would be relatively straightforward to extend the method to include other gases.

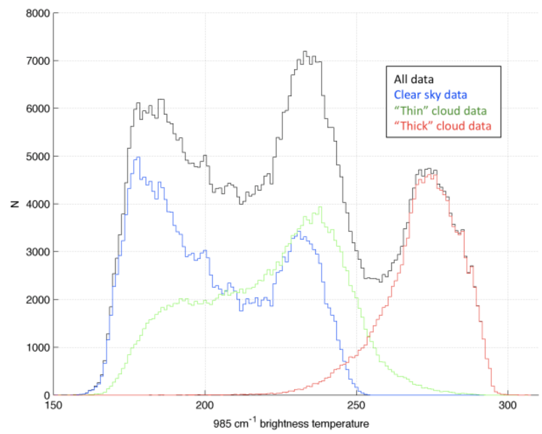
http://www.met.reading.ac.uk/clouds/publications/fsck.pdf



Evaluation of the 23- and 32-point FSCK models on four different McClatchey et al. (1972) standard atmospheres (indicated by the legend in panel d, where MLS is the mid-latitude summer atmosphere and SAW is the sub-arctic winter atmosphere) containing only H2O, CO2, and O3. (a) Longwave heating rate calculated at full spectral resolution, (b) the error in heating rate of the 23-point FSCK model, (c) the error in heating rate of the 32-point FSCK model, and (d)–(f) the same but for net longwave flux (upwelling minus downwelling).

Investigating climate trends in 14 years of AERI data at the ARM SGP site

Jonathan Gero, Space Science and Engineering Center
David Turner, University of Wisconsin-Madison



The distribution of brightness temperature at 985 cm-1 observed by the AERI at the SGP site from 1996 to 2008 (black). The clear and cloudy subsets were determined by a neural network trained using Raman lidar data and then subsequently applied to the entire data set.

The ARM Climate Research Facility has collected Atmospheric Emitted Radiance Interferometer (AERI) data at the SGP site since the mid 1990s. The AERI regularly views a high-accuracy blackbody calibration target that has been tested against NIST standards, and thus the accuracy of the AERI-observed infrared radiance is robust over the past decade. Any statistically significant trend in the AERI data over this time can be attributed to changes in the atmospheric composition, not to changes in the sensitivity or response of the instrument. We have analyzed AERI radiance data from 1996 to 2008 to see if any statistically significant climate trends could be identified over this nearly 14-year period. If the entire record of AERI observations is analyzed, then no significant climatic trends are identified in any of the spectral regions observed by the AERI (e.g., the far-infrared channels at wavelengths above 15 µm, the CO2 absorption band at 15 µm, the atmospheric window channels from 8-13 µm, etc.). However, it is possible that a significant trend in the downwelling infrared radiance may exist under certain conditions (e.g., clear-sky scenes) that is countered by a trend in other conditions. We have used a neural network, trained using Raman lidar observations over a 14-month period in 2007-2008, to identify clear vs. cloudy conditions from the AERI radiance data. This classification scheme was used to separate the AERI data set into clear-sky and cloudy conditions, where the latter category was further broken down into optically thin and thick classifications. These three subsets of data are further analyzed, as functions of the entire data set, seasonally and diurnally, for statistically significant climatic trends. Initial results demonstrate that there is a trend towards higher radiance in optically thick cloud scenes, which suggests that either the atmosphere is getting warmer in these conditions or that the clouds are becoming lower.

Monitoring of geoengineering strategies for remediation of global warming using radiative forcing

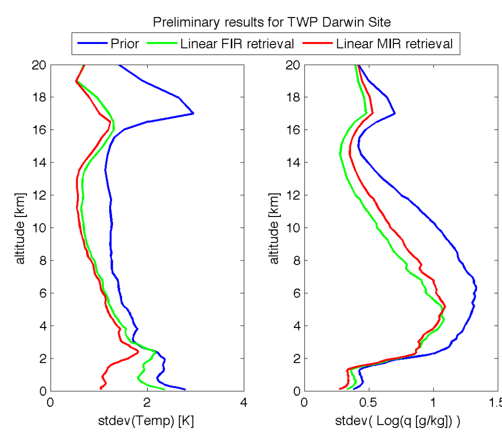
Wayne Evans, NorthWest Research Associates

The importance of having an accurate monitoring system before commencing geoengineering (GEOE) projects such as SRM has been overlooked. The recent "Climategate affair" has demonstrated that temperature is not adequate as the monitoring variable for global warming. Extensive debates over the accuracy of the temperature records have taken place. Ice melting has been used recently to demonstrate global warming but has a 25-year time lag. A variable with a fast response is needed to determine the current state of the global warming problem, let alone for modifications. The immediate response of adding greenhouses gases or aerosols to the atmosphere is a change in the climate radiative forcing (RF). This produces a temperature increase that lags behind RF by over 25 years due to the thermal inertia of water bodies. For GEOE the monitoring problem is more severe; the 25-year lag in temperature would make it difficult to monitor how effective a particular strategy would be. The time lag between RF and temperature response will be demonstrated. The noise in the temperature record further complicates its use to monitor the effectiveness of GEOE strategies. Similarly, water vapor lags RF by years since it is controlled by temperature. RF of gases can be measured at the surface with the AERI FTS instrument and at the top of the atmosphere with satellite instruments such as IASI. The shortwave spectral flux is also altered by aerosols. The use of current and planned satellites to monitor these changes will be described. The OSIRIS satellite results demonstrate that it would be feasible to set up an effective monitoring system for aerosol RF. GEOE should not be attempted without a monitoring system for RF in place. One might be working in the dark for 25 years without feedback from a fast-monitoring system. It is proposed to monitor the RF of global warming by GHG with a new network. The calibrated spectrum of greenhouse radiation at the surface has been measured and the RF flux from each greenhouse gas extracted. Fourteen AERI instruments, manufactured by ABB BOMEM, are deployed around the world. This network will provide a new experimental data set to complement the calculated RFs from climate models used for policy determination of safe levels of GHG. This network would support the U.S. DOE's long-term goal to deliver improved scientific data and models on the potential response of climate to increased GHG levels. The analysis of the data from ARM AERI sites would expedite a network to monitor RF. Although DOE has these valuable records of the ARM AERI data, it needs to process them into RF, a form suitable for release to the world community. The usefulness of RF over temperature is demonstrated by evaluating the present climate on the timeline of global warming. Our measurements show a total RF of 3.3 W/m2 from all GHG. Converting the 2 K Copenhagen target into RF shows that this is not achievable since only eight years are left before RF will exceed the target.

Objective comparison of high-resolution far- and mid-infrared spectral observations for atmospheric retrievals

Aronne Merrelli, University of Wisconsin
David Turner, University of Wisconsin-Madison

High-spectral-resolution observations of the atmospheric emission spectrum in the infrared have proven utility for atmospheric thermodynamic state retrievals. Current and future operational satellite instruments (AIRS, IASI, CrIS) produce these measurements in the mid-infrared (MIR) portion of the spectrum (roughly 4–15 µm) on a routine basis. In comparison, the far-infrared (FIR) portion of the spectrum (wavelengths longer than 15 µm) is poorly observed, mainly due to sensor limitations in this wavelength region. In this study we are investigating the differences between retrievals based on MIR and FIR measurements to understand how FIR measurements will improve our ability to sense the atmosphere. Water vapor, liquid water, and ice all have different absorption properties in

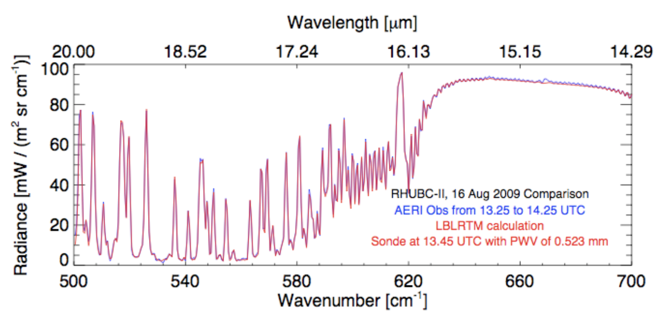


Preliminary results using the measured climatology from the TWP Darwin site. We used LBLRTM to model the infrared spectra and compute Jacobian matrices at the mean state. The results shown are from a simple linear retrieval, which directly uses the mean state Jacobian to estimate the profile.

the MIR and FIR spectral regions. For example, the FIR contains the rotational absorption band of water vapor, with no significant interference from minor atmospheric constituents, while the MIR contains the vibrational-rotational absorption band of water vapor, along with interference from minor atmospheric constituents such as methane. We are developing a modeling framework to simulate high-spectral-resolution observations and retrievals using both FIR and MIR spectra, using an optimal estimation approach (C Rodgers 2000). Our initial work focuses on clear-sky atmospheres, but the performance in cloudy conditions, especially ice clouds, is the primary objective of our research due to the markedly different absorption characteristics of ice and liquid in the FIR and MIR. The simulation and retrieval framework is based on climatological priors generated from radiosonde profiles collected at the ARM ground sites. The retrieval algorithm is applied consistently on the simulated observations from both spectral regions. With this approach, we can compare the available information content in the MIR and FIR for temperature and water vapor retrievals. Although the high-altitude temperature retrievals will be very similar for both spectral regions (each contains half of the carbon dioxide absorption band at 15 μm), the water vapor retrievals will have different information due to the different absorption bands.

The RHUBC-II campaign: analysis of downwelling infrared radiance

David Turner, University of Wisconsin-Madison
David Tobin, University of Wisconsin-Madison
Eli Mlawer, Atmospheric and Environmental Research, Inc.
Jennifer Delamere, Atmospheric and Environmental Research, Inc.



A comparison between the AERI-observed downwelling infrared radiance from 14.3 to 20 μm during RHUBC-II and a calculation using the line-by-line radiative transfer model LBLRTM. The LBLRTM incorporates the knowledge learned during the RHUBC-I experiment in 2007. The precipitable water vapor in this case is 0.52 mm, which is about 2 times drier than the driest case observed during RHUBC-I.

Radiative heating and cooling are important drivers of Earth's climate. In the mid-to-upper troposphere, the dominant radiative processes in both the solar and thermal regimes are due to water vapor. In order to properly model the atmospheric circulation, the radiative transfer models used within GCMs in the strong water vapor absorption bands, which are spectral regions that drive mid-to-upper tropospheric heating, must be accurate. The Radiative Heating in Underexplored Bands Campaigns (RHUBC-I and RHUBC-II) were conducted under the auspices of the ARM Climate Research Facility to collect the data needed (e.g., accurate water vapor profiles and spectrally resolved radiance observations) to evaluate and improve detailed radiative transfer models in the strong water vapor bands. This study will focus on the analysis of the radiance observations in the 6.7 μm vibrational water vapor band and the rotational water vapor band in the far-infrared (wavelengths longer than 15 μm) using data collected during RHUBC-II, which was conducted at an altitude of 5380 m in northern Chile. The precipitable water vapor was as low at 0.2 mm (approximately 100 times less than a typical SGP value), which resulted in the normally opaque far-infrared region of the spectrum being semi-transparent from 16-43 μm. This provides a unique opportunity to evaluate the water vapor absorption line parameters and the water vapor continuum absorption model in this region of the spectrum.

Statistics and parameterization of shortwave horizontal photon transport effects

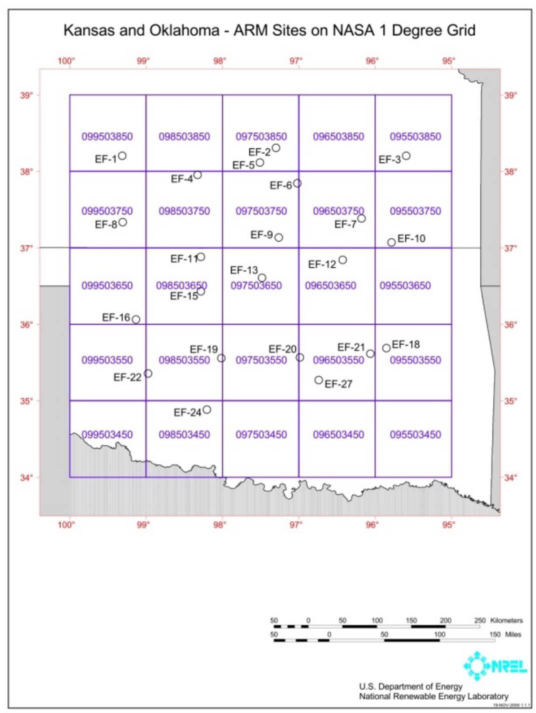
Tamas Varnai, UMBC Joint Center for Earth Systems Technology
Jerry Harrington, The Pennsylvania State University

The ultimate goal of our project is to help improve the accuracy of radiative heating calculations in regional and global cloud resolving simulations, and to better understand the role of horizontal photon transport in cloud development and in the Earth's radiative budget. For this, we are developing a neural network-based algorithm to provide corrections to the currently used 1D radiative calculations of cloud-resolving models, which cannot include horizontal photon transport effects. The first step of developing a correction algorithm was to create a data set of observed cloud structures and corresponding simulated radiation fields that are suitable for training a neural net. The poster includes new results from our statistical analysis of this data set, discussing the typical magnitude of 2D radiative effects over three ARM sites: NSA, SGP, and TWP. In addition, the poster also reports on our progress toward parameterizing horizontal photon transport effects. This includes examining both the effectiveness of the "Tilted Independent Column Approximation" to incorporate some horizontal processes into 1D radiative calculations and the effectiveness of a neural net to estimate horizontal photon transport effects using cloud texture parameters.

Validating surface solar flux estimates from satellite-based models for renewable energy applications

Tom Stoffel, National Renewable Energy Laboratory
Mary Anderberg, National Renewable Energy Laboratory

Measurements of downwelling shortwave solar irradiance collected by the Solar Infrared Station (SIRS) instruments at the Southern Great Plains (SGP) site have been used to compare two satellite-based models for estimating solar radiation resources for renewable energy applications. These "ground-truth" measurements are represented by the Best Estimate Flux value-added product (BEFlux) and SIRS data from up to 18 extended facilities active during the period July 1998 through June 2005. Model performance evaluations are based on comparisons of monthly averaged daily total (MADT) values of global horizontal solar irradiance. The SIRS station network and the Central Facility offer excellent geospatial representation of the modeled data available from NASA's Surface meteorology and Solar Energy (SSE) with 1 deg x 1 deg resolution and the modeled data produced with the State University of



SIRS station locations relative to the NASA SEE satellite 1 deg x 1 deg grid (SUNY model based on 0.1 deg x 0.1 deg grid resulting in 100 cells for each NASA SEE data value).

New York (SUNY) with 0.1 deg x 0.1 deg resolution (see figure). The SUNY model is the basis for the solar resource data available from the National Solar Radiation Database (NSRDB). NASA SSE data are available on a global scale. Preliminary analyses of the MADT for the entire period of record indicate model bias errors of -15% (SSE) and -2% (SUNY). The results of our comparison will be used to improve the data quality assessment of two models important for estimating renewable energy resources for national and global applications.

Validation of improved TOA shortwave and longwave broadband fluxes over the ARM TWP domain

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As part of a continuing effort to provide improved large-scale satellite coverage for climate research, cloud and radiative properties covering the ARM Tropical Western Pacific domain have been derived from GOES9 and MTSAT. Narrowband-to-broadband (NB-BB) fits specific to each satellite and season, as well as day-night differences in the LW, have been derived with respect to CERES (Clouds and the Earth's Radiant Energy Budget) onboard the Terra satellite. The NB-BB fits have been implemented within the VISST framework, and the improved TOA broadband shortwave and longwave fluxes will be validated with respect to CERES and the Fu-Liou model. Results from cases between May 2003 and December 2007 will be presented.

11.0 Conclusion

More than 260 posters were presented during the Science Team Meeting. Abstracts for each poster are included here, sorted by the following subject areas: aerosol-cloud-radiation interactions, aerosol properties, atmospheric state and surface, cloud properties, field campaigns, infrastructure and outreach, instruments, modeling, and radiation.

Full-size and color versions of images are available at http://asr.science.energy.gov/meetings/stm/posters/2010.

People's Choice Poster Awards, voted on by meeting attendees, were presented to Christopher Lenhardt and Raymond McCord, from Oak Ridge National Laboratory, and Alla Zelenyuk, from Pacific Northwest National Laboratory.

To recognize the important contributions of students to ASR research, three awards, one for each working group, 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 the Thursday working group sessions. Working group chairs presented Student Poster Awards to Partha Bhattacharjee, Jianjun Liu, Emily Bruns, Matt Erickson, Stuart Evans, and Tyler Thorsen.

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