Closure Studies in Arctic Mixed-phase Stratocumulus: How Do Aerosols Control Cloud Ice Formation?

Ann Fridlind and Andrew Ackerman, NASA GISS

Science Question

Arctic clouds contain ice crystals that form on unique aerosol referred to as ice nuclei (IN).
Does the IN aerosol account for observed ice?

Findings from Three ARM Field Campaigns

• ***M-PACE*** (autumn, cold-air outbreak with drizzle and riming): ***No***. IN concentration more than 10 times higher than observed required to reproduce observed ice, a finding subsequently reproduced by other groups. Novel formation mechanisms or surface IN source needed to explain observations. **Publications**: Fridlind et al. (JGR, 2007), van Diedenhoven et al. (JGR, 2009), Klein et al. (QJRMS, 2009).

• ***SHEBA*** (springtime over ice pack, with few microphysical processes active): ***No***. Again more than 10 times observed IN concentration required to account for observed ice. Simple mixed-layer model explains why IN concentrations above cloud layer exceed ice number concentrations by factor of ~100. **Publications**: Fridlind et al. (under review, JAS, 2011), Morrison et al. (JAMES, 2011), van Diedenhoven et al. (JAMC, in press).

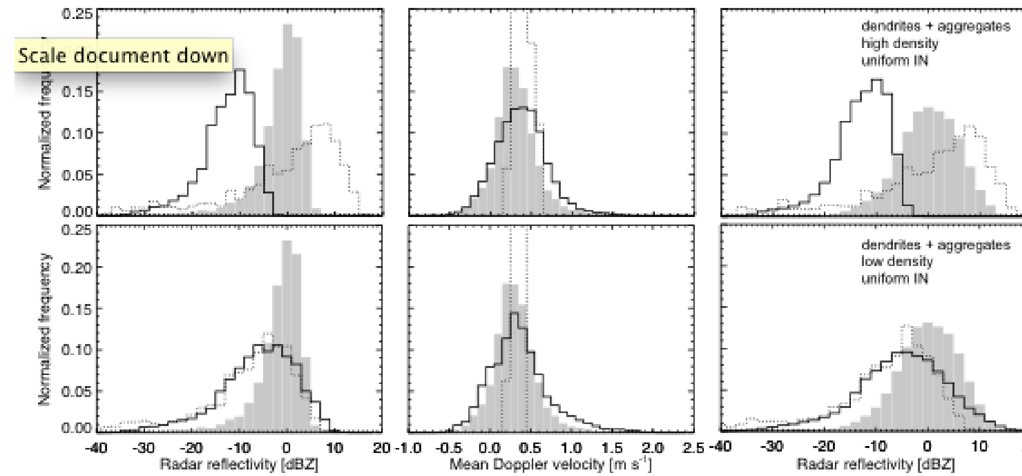


Figure: MMCR reflectivity and Doppler velocities and X-band reflectivities below cloud for ISDAC case: observed (shaded), model results (solid), and using in-situ size distributions (dotted) for simulations with high-density (top panels) and low-density (bottom) ice

• ***ISDAC*** (springtime over open ocean, aggregation of dendrites active): ***Maybe!*** With slow-falling crystal habit, IN concentration measured above cloud layer exceeds ice concentration. *If* there is an IN reservoir below or more IN under liquid supersaturated conditions (as may happen), agreement with measurements indicates that closure could be possible in some circumstances. **Publications**: Avramov et al. (under review, JGR, 2011), Botta et al. (JGR, in press).

Raman Lidar and HSRL Measurements of Aerosol and Water Vapor Variability

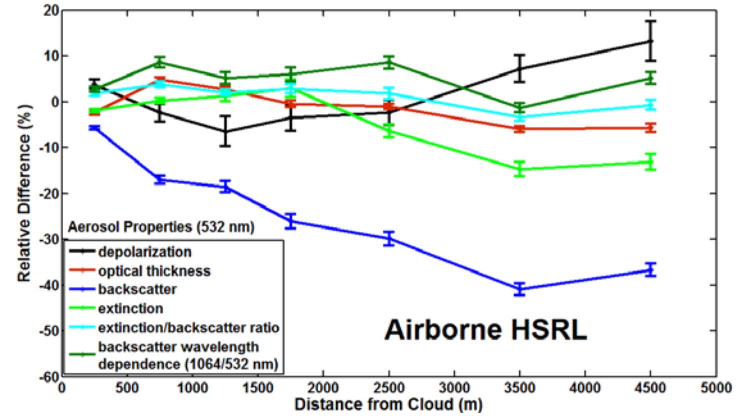
Rich Ferrare[1], Marian Clayton[2], Dave Turner[3], Chris Hostetler[3], John Hair[1], Mike Obland,[1] Ray Rogers[1]
[1]NASA/LaRC, [2]SSAI, [3]NOAA/NSSL

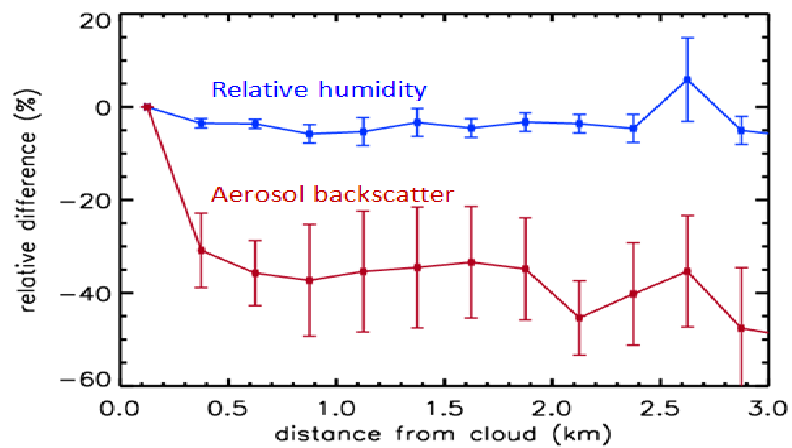
Science Questions

- How do aerosol optical and physical properties vary near clouds?
- How are these variations related to changes in relative humidity?
- How well can we use lidar to measure or infer these variations?

Approach

SGP Raman lidar aerosol and water vapor measurements and NASA Langley Research Center airborne High Spectral Resolution Lidar (HSRL) measurements acquired during the CHAPS and RACORO campaigns are used to investigate aerosol hygroscopicity and variations in aerosol properties near clouds in the daytime boundary layer.





Key Accomplishments

- SGP Raman measured increased relative humidity (5-10%) near clouds
- Raman lidar and HSRL measured increased aerosol backscatter (20-40%) and aerosol optical depth (5-10%) near clouds
- HSRL measured decreased aerosol depolarization near clouds (10-20%) indicating that aerosols become more spherical with higher RH near clouds
- Variations in aerosol properties and RH are largest at or within about 200 m below cloud base

An Investigation Into the Aerosol Semi-direct Effect at Barrow, AK

Zafer Boybeyi & John Lindeman
George Mason University, Fairfax, VA

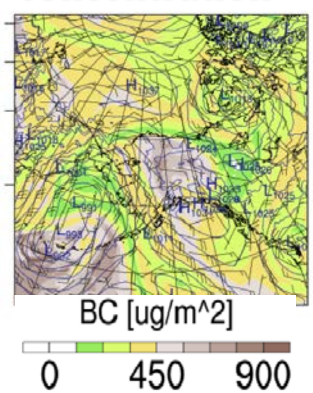
Science Question

How does the aerosol semi-direct effect influence atmospheric stability and cloud cover at Barrow, AK during an episode of Arctic haze? How sensitive is the atmosphere to variations in black carbon?

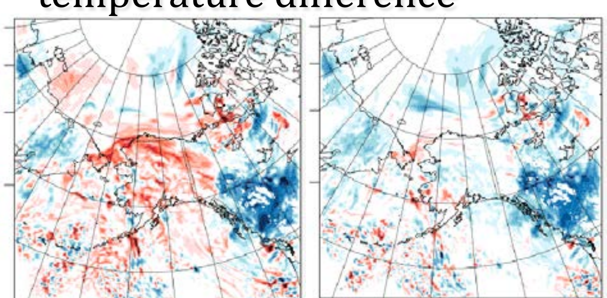
Approach

- WRF/Chem simulations of polluted conditions at Barrow during the ISDAC field experiment.
- Compare polluted case with identical baseline WRF/Chem run which does not include aerosol direct or semi-direct effects **(BASE)**.
- Sensitivity studies with WRF/Chem simulations containing twice the black carbon concentration **(BC)** and no black carbon **(no BC)**.

Black carbon concentration



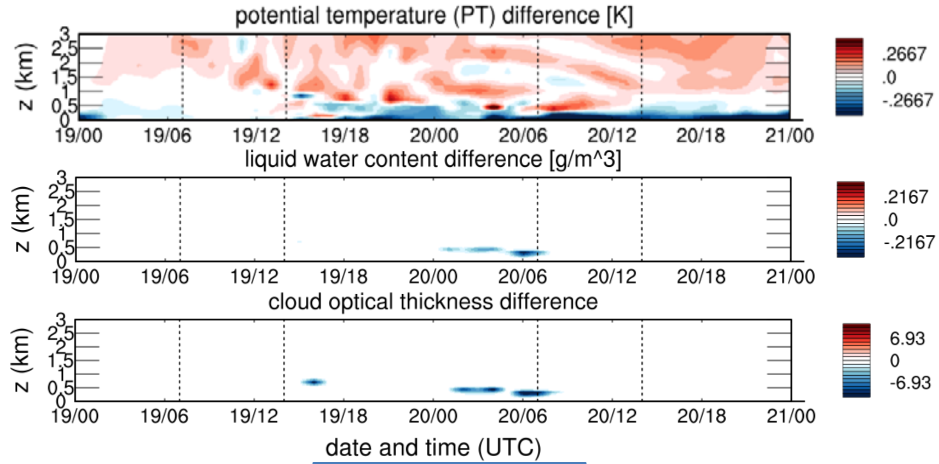
850 mb potential temperature difference



BC - BASE

no BC - BASE

Time series at Barrow, AK (April 19-21, 2008)



BC - BASE

Findings and Conclusions

The aerosol semi-direct effect increases stability and dries the lower troposphere at Barrow, AK. The atmosphere is particularly sensitive to the black carbon concentration, which enhances tropospheric warming substantially.

Publication

Lindeman, J. & Z. Boybeyi., 2011: An examination of the aerosol semi-direct effect for a polluted case of the ISDAC field campaign, *J. Geo. Res.*, under review.

Ice Nucleation Link to Aerosols: Improving Modeling of Aerosol Impacts on Clouds and Precipitation

Paul J. DeMott, Anthony J. Prenni /Colorado State University
Xiaohong Liu / Pacific Northwest National Laboratory

Science Question

Do simplified relations exist between aerosol physical and chemical properties and the number concentrations of **ice nuclei (IN)** for improving global modeling of mixed phase clouds and precipitation?

Approach

- Use large data base of IN measurements with co-sampled aerosol data to parameterize IN number concentration as a power law function of aerosol concentration at sizes >0.5 mm and temperature
- Use DOE ISDAC (Arctic) study data to test robustness of parameterization
- Implement in global model simulations

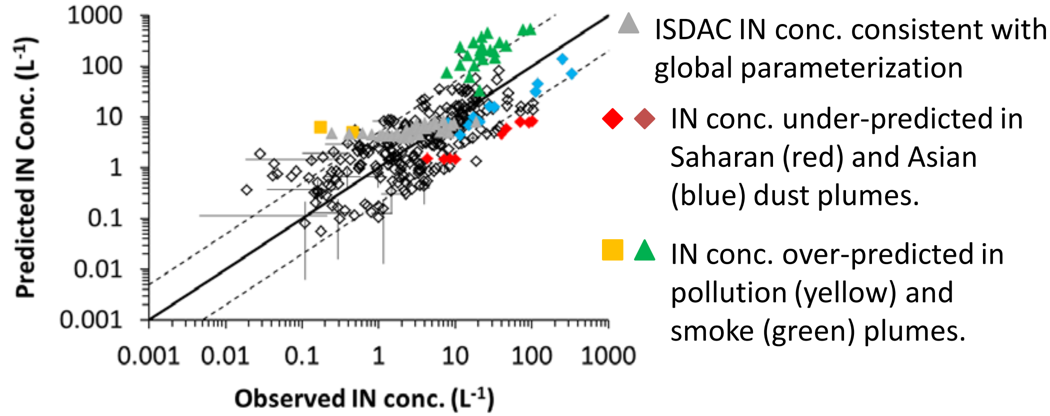
Results

- Parameterization agrees with ISDAC IN data. Need to incorporate chemical speciation of IN.
- Inclusion of aerosol size and T sensitivities strongly impacts mixed phase cloud properties and forcing in global simulations.

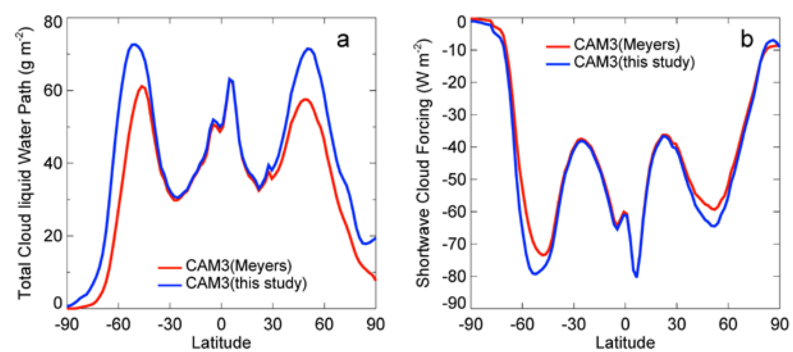
Publication

DeMott, P.J., A. J. Prenni, X. Liu, et al.,, 2010: Predicting global atmospheric ice nuclei distributions and their impacts on climate, Proc. Natnl. Acad. Sci., 107 (25), 11217-11222.

New Understanding of IN Variability in the Atmosphere



Strong Sensitivity to IN in Global model simulations



Net globally-averaged cloud forcing decreases compared to a previous aerosol-independent IN scheme. Reduced [IN] in regions with low concentrations of large particles inhibits cloud liquid conversion to ice, increasing high latitude cloud cover and reducing annual zonal mean downwelling shortwave radiation at the surface.

Aerosol Microphysical Effects on Deep Convective Clouds

Jiwen Fan/ Pacific Northwest National Laboratory

Science Question

- How aerosols impact convection and what are the important factors determining the relationship between aerosols and convection?
- What are the CCN and IN effects on tropical Anvils and water vapor content in the Tropical Tropopause Layer (TTL)? Which one is more important- boundary layer CCN and mid-tropospheric CCN?

Approach

- The cloud-resolving modeling simulations with Spectral-Bin Microphysics (SBM)
- Combined with the observations (in situ and ground-based remote sensing data)

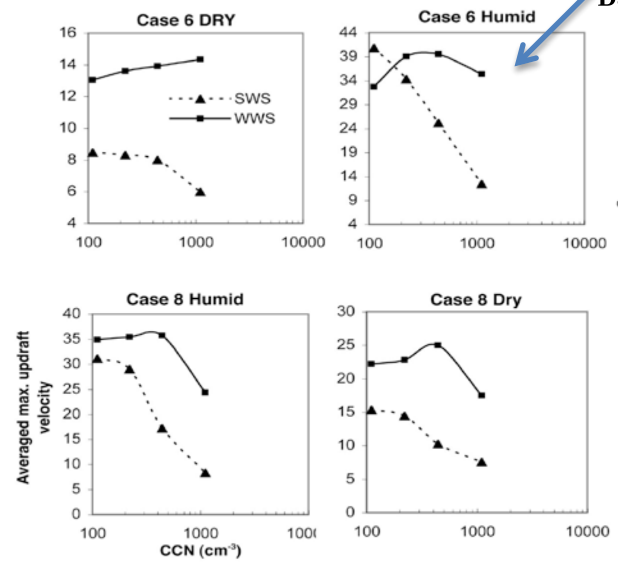
Publication

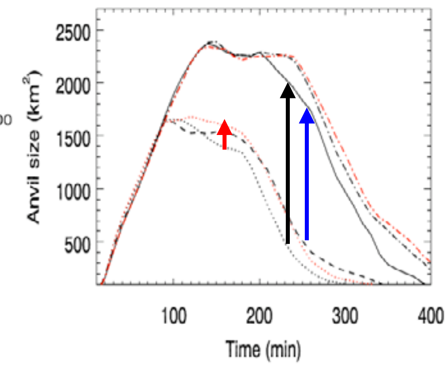
Fan, J., T. Yuan, J. M. Comstock, S. Ghan, et al.(2009), Dominant role by vertical wind shear in regulating aerosol effects on deep convective clouds, *J. Geophys. Res.*, 114, D22206, doi:10.1029/2009JD012352.

Fan, J., J. M. Comstock, M. Ovchinnikov (2010), The cloud condensation nuclei and ice nuclei effects on tropical anvil characteristics and water vapor of the tropical tropopause layer, Environ. Res. Lett., 5, 044005

Results

Solid line: weak wind shear
Dashed line: strong wind shear





Black arrow: CCN effect
Red arrow: IN effect
Blue arrow: effect of PBL CCN

Key Accomplishment

- Vertical wind shear qualitatively determines whether aerosols suppress or enhance convection. Increasing aerosols always suppresses convection under strong wind shear and invigorates convection under weak wind shear until this effect saturates at an optimal aerosol loading.
- Dominant effect of CCN on anvil size and lifetime relative to IN; significant role of PBL CCN in anvil size and lifetime; anvil size is increased by CCN

Aerosol Impacts on Clouds and Precipitation from a Systems-Based Perspective

Hugh Morrison and Wojciech Grabowski / National Center for Atmospheric Research

Science Question

What are the indirect effects of aerosols on deep convection and precipitation in a system of many interacting clouds over multiday timescales, as opposed to the effects on a single cloud considered in most previous studies?

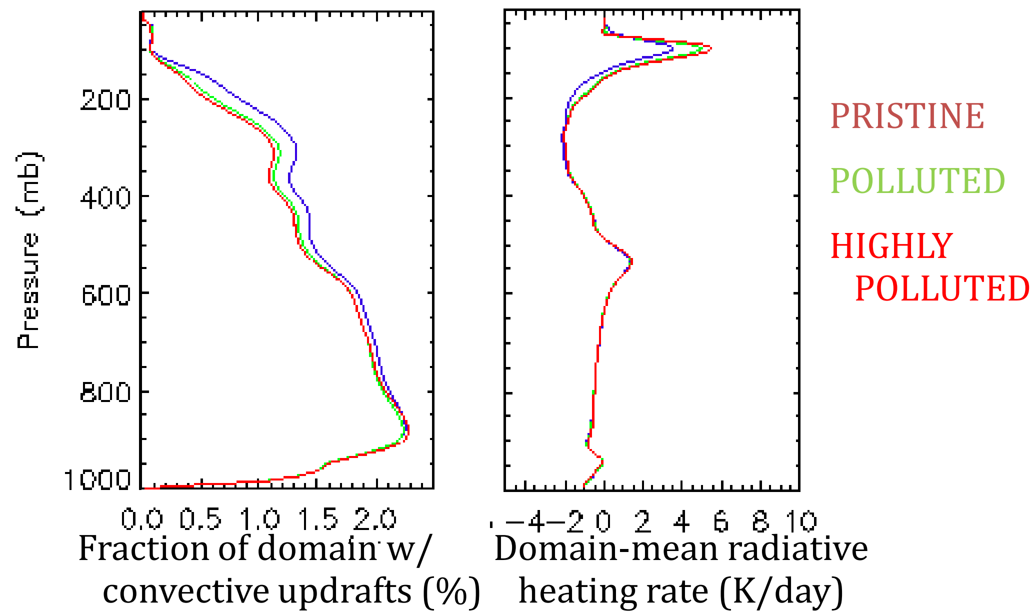
Approach

- Use a new microphysics scheme in a cloud system-resolving model to investigate aerosol impacts on clouds and precipitation in radiative-convective quasi-equilibrium.
- Extend this work to a case based on observations from the TWP-ICE field experiment.

Key Accomplishment

Feedback between convection and its thermodynamic environment is critical and results in aerosol effects that differ dramatically when a system of interacting clouds is considered, as opposed to the process-level effects on a single cloud.

Impact of aerosols on convection and radiative heating from TWP-ICE simulations



Publications

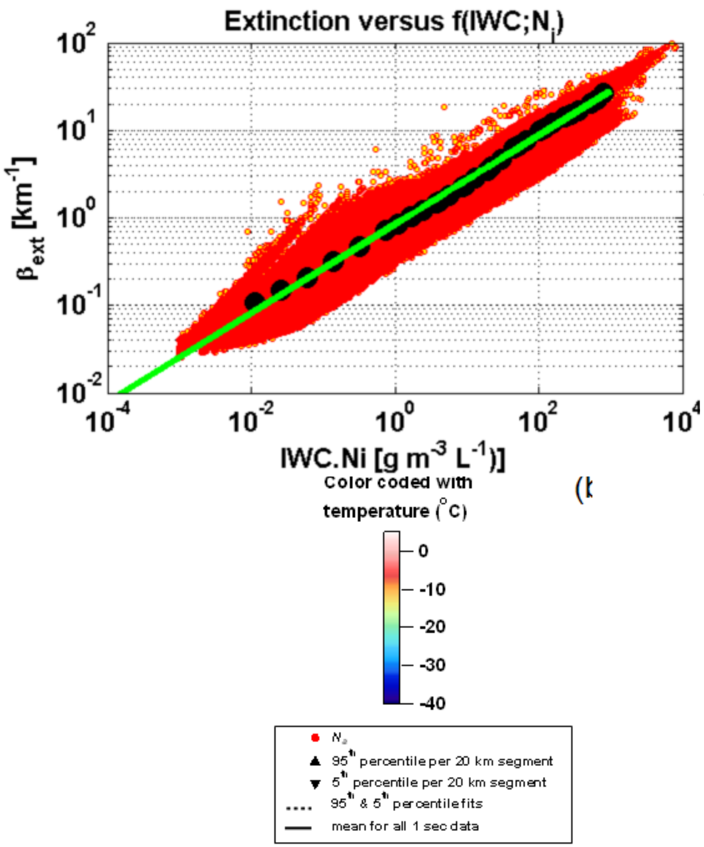
Grabowski, W. W., and H. Morrison, 2011: Indirect impacts of atmospheric aerosols in idealized simulations of radiative-convective quasi-equilibrium. Part 2: Double-moment microphysics. J. Climate, 24, 1897-1912.

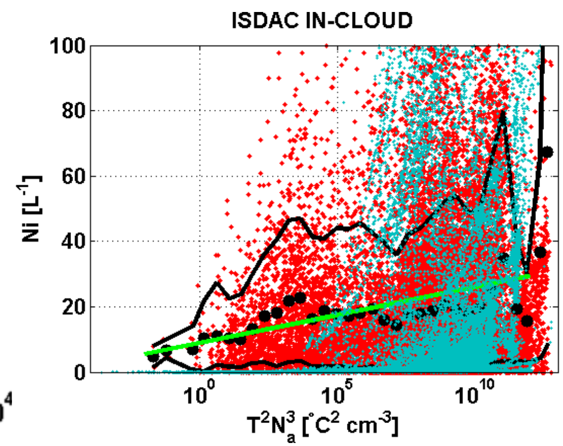
Morrison, H., and W. W. Grabowski, 2011: Cloud system-resolving model simulations of aerosol indirect effects on tropical deep convection and its thermodynamic environment. Atmos. Phys. Chem. Disc., 11, 15573-15629.

Polar Clouds Microphysics and Aerosols During ISDAC: Aerosol Indirect Effects

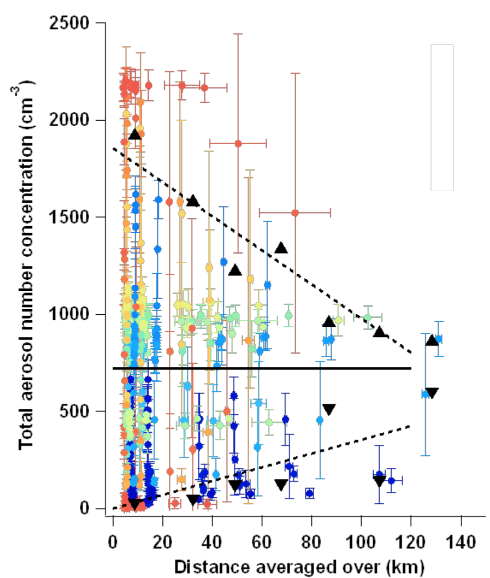
There were 3 important results obtained using observations from ISDAC project

1) parameterizations:
   - i) extinction versus f(IWC;Ni);
   - ii) Ni versus f(Na*T) using aircraft observations

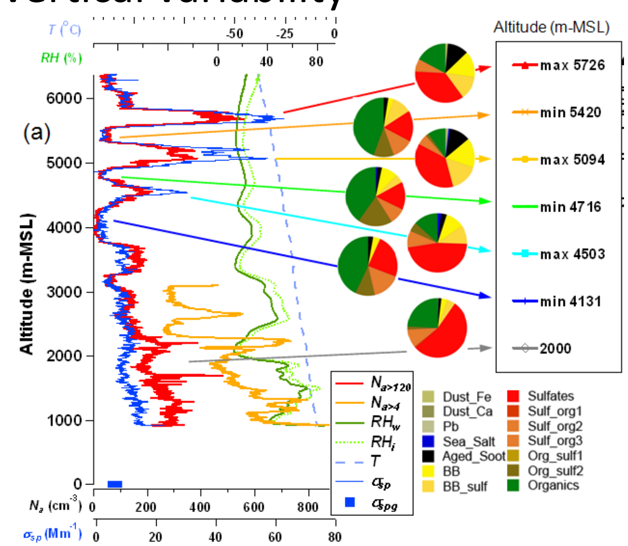




Aerosol effects on cloud microphysics can be due to aerosol composition effects, variability, and extinction of radiation. These effects include multicomponents that are summarized briefly here.



2.Aerosol composition and vertical variability



3. Aerosol properties during polluted conditions

Evaluating Forecasts of Central US Mesoscale Convective Systems in a GCM with Explicit Embedded Convection

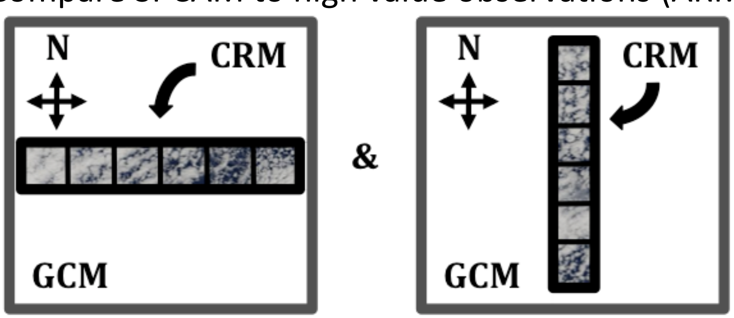
Gabe Kooperman, Mike Pritchard, Richard Somerville / SIO, UCSD

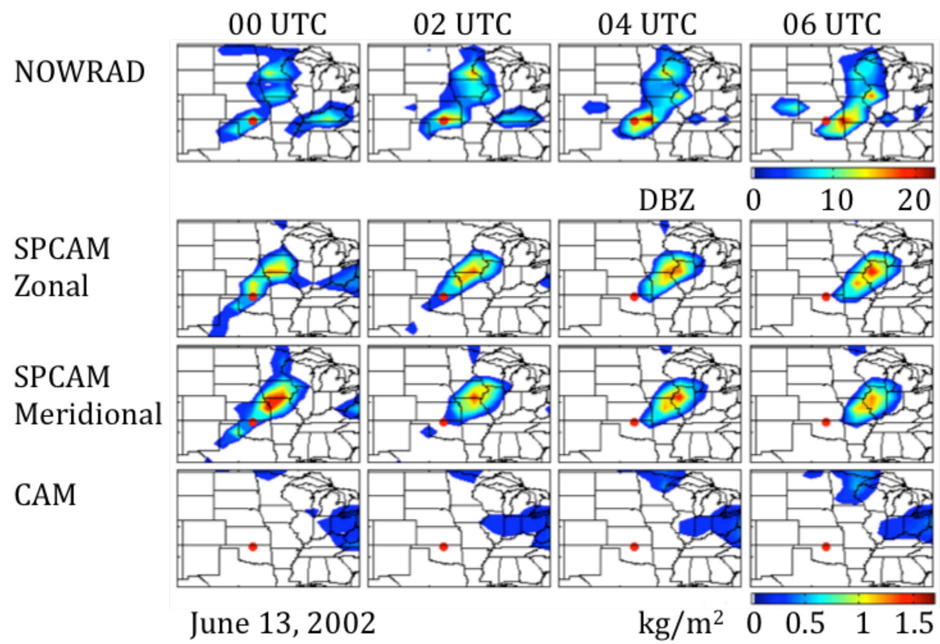
Science Question

Pritchard et al. (2011) demonstrated that the Central US organized nocturnal eastward propagating mode of convection can be captured in a prototype GCM which uses embedded cloud resolving models (CRM) instead of statistical parameterizations to handle sub-grid convection (superparameterization – SPCAM). But how important is CRM orientation and therefore the direction of shear organization for simulating these mesoscale convective systems (MCS)? And how well do simulated MCSs compare to observations?

Approach

- Develop a new technique to initialize both resolved scales for forecast simulations (GCM and 2D CRM).
- Run SPCAM in forecast mode initialized just prior to an MCS observed to pass over the ARM SGP site.
- Test sensitivity to zonal/meridional CRM orientation.
- Compare SPCAM to high value observations (ARM).





Key Accomplishments

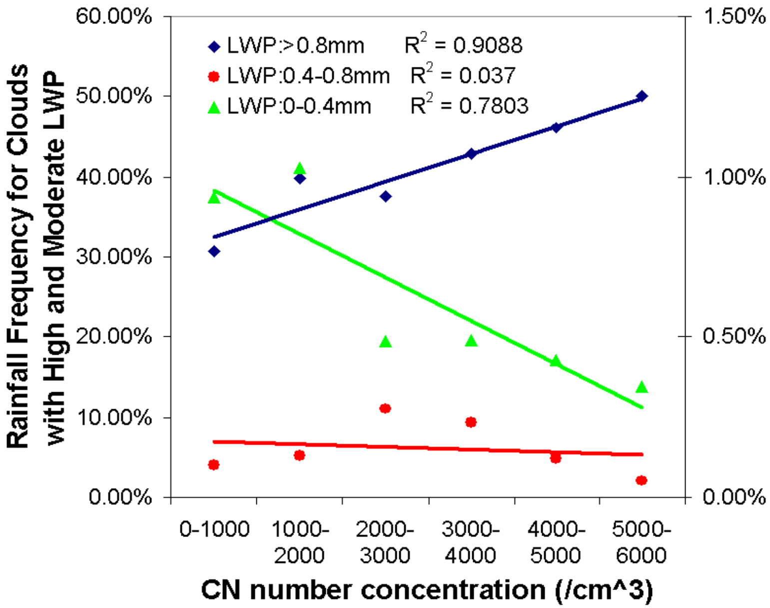
The challenge of initializing the CRM domain for SPCAM forecasts has been overcome. SPCAM is able to forecast a mode of convection that CAM cannot in both CRM orientations. SPCAM mis-positions the storm center location and over simulates IWP.

Publication

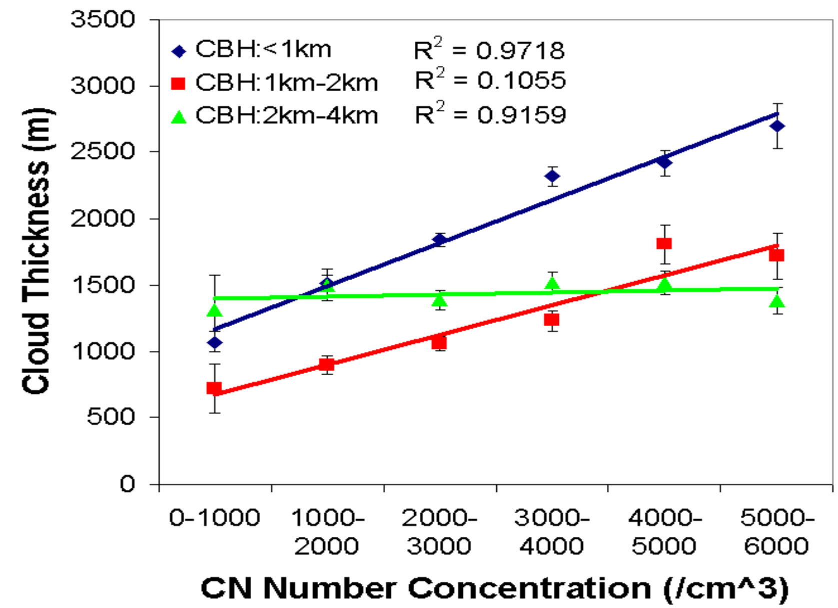
Pritchard, M., et al., 2011: Orogenic propagating precipitation systems over the US in a global climate model with embedded explicit convection, Journal of Atmospheric Science, in press.

Strongest Long-term Net Impact of Aerosols on Cloud & Precipitation is Revealed by the ARM Data

Rainfall Frequency



Cloud Thickness



Rainfall frequency is reduced by aerosols for low liquid water parth (LWP), but increased for large LWP.

Cloud thickness/top increases with aerosol concentration for low cloud height (CBH), but nil for high.

The Twomey Effect and Invigoration Effect are both at work !

Z. Li (University of Maryland)

The Deployment of the AMF in China Provides the First-Ever Information on Cloud Vertical Structure


nature 24 September 2009, Vol. 461
International weekly journal of science

Cloudy, with a chance of science

When American and Chinese scientists agreed to measure pollution and dust over China, nobody foresaw how difficult it would be. **Jane Qiu** reports.

The meteorological bureau in the sleepy town of Shouxian in eastern China was buzzing with excitement. It was May 2008, and the spacious courtyard was littered with sophisticated remote-sensing instruments that had just arrived on loan from the United States Department of Energy (DoE). The bureau had been expecting the equipment earlier, but it had been held up by Chinese customs officials for more than two months.

A group of climate researchers and government officials from China and the United States eagerly inspected the new arrivals, which included a cloud radar, a tailor-made lidar (a radar-like instrument that sends out laser beams rather than microwaves) and sensors for studying various features in the atmosphere and the radiation from the Sun. "We can do great things with these here," said Zhanqing Li, an atmospheric scientist at the University of Maryland at College Park, who was leading the Sino-American collaboration.

Over the next few months, these instruments would be pointed up into the Chinese sky to monitor and study aerosols — tiny airborne particles such as dust and soot. The researchers were particularly interested in tracing how aerosols alter the personality of clouds by influencing whether clouds produce rain, how high they extend, how much sunlight they reflect and how long they persist. At present, atmospheric researchers have only a rudimentary understanding of how aerosols affect clouds and that ignorance is one of the major sources of uncertainty in forecasts of future climate.

For aerosol experts, China's sky is close to heaven. The country has high concentrations of particles arising from pollution as well as natural dust blowing in from surrounding deserts. Researchers expected that data from such a particle-rich atmosphere would help to resolve major questions about aerosols and climate. At the same time, it was hoped that the project, staged at four sites across China (see map) would reap political rewards. The joint collaboration, conducted under the umbrella of the DoE's Atmospheric Radiation Measurements (ARM) programme, was viewed as a sign of China's movement towards openness. "This kind of collaboration would have been inconceivable ten years ago," says Thomas Ackerman, an atmospheric scientist at the University of Washington in Seattle.

The political winds did not, however, always blow favourably. With much frustration, the DoE had to alter its usual mode of operation and settle for lower-quality data and a smaller range of measurements than expected. "Between the heights of hope and the depths of despair, it was the most up-and-down deployment we have ever had," says Warren Wiscombe, ARM's chief scientist and an atmospheric scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

The stakes are high because the data collected by the ARM programme will be used to improve the way that climate models simulate clouds and aerosols. When the programme was created in 1989, it collected measurements only at fixed sites within the United States. "But it soon dawned on us that we need as much information as possible from diverse climate systems around the world to build up a complete picture of global climate change," says Wiscombe.

This resulted in a mobile facility, built in 2004, that contains most of the remote-sensing instruments present at the fixed sites. Each year,

MONITORING SITES
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Xianghe
Beijing
CHINA
Shouxian
Taihu
Shanghai

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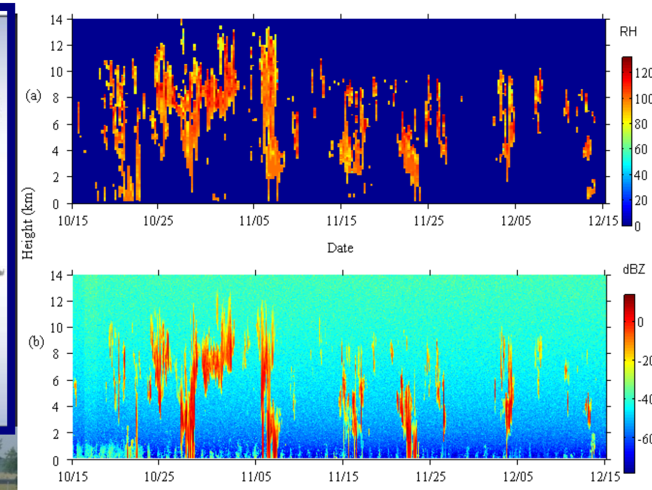
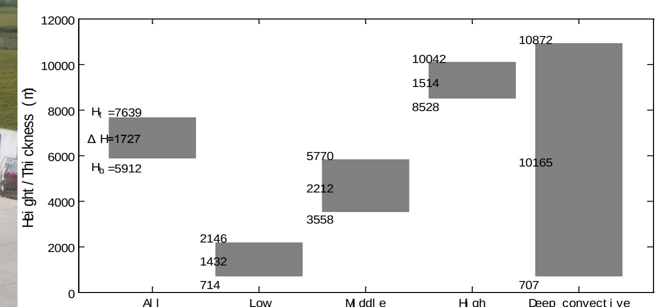




Some Major Findings from the AMF Are Reported in the Following Articles

Li, Z., K.-H. Lee, J. Xin, Y. Wang, 2009, First observation-based estimates of aerosol radiative forcing at the top, bottom and inside of the atmosphere, *J. Geophy. Res*., revised.

Li, C., N. A. Krotkov, R. R. Dickerson, Z. Li, K. Yang, and M. Chin (2009), Transport and evolution of a pollution plume from northern China: A satellite-based case study, J. Geophys. Res., doi:10.1029/2009JD012245, in press.

Guo, Z., Z. Li, J. Farquhar, A. J. Kaufman, N. Wu, C. Li, R. R. Dickerson, and P. Wang (2009), Identification of Sources and Formation Processes of Atmospheric Sulfate by Sulfur Isotope and SEM Measurements, *J. Geophys. Res*., doi:10.1029/2009JD012893, in press.

Lee, K. H., Z. Li, M.C. Cribb, J. Liu, L. Wang, Y. Zheng, X. Xia, H. Chen, and B. Li (2009), Aerosol optical depth measurements in Eastern China and a new calibration method, *J. Geophys. Res*., d oi:10.1029/2009JD012812, 2009, in press.

Zhang, J. H. Chen, Z. Li, X. Fan, L. Peng, Y. Yu, M. Cribb, Analysis of cloud layer structure in Shouxian, China using RS92 radiosonde data, *J. Geophys. Res*. Submitted.

Z. Li (UMD)

Observing Properties of Single-layer Arctic Stratocumulus Leads to Largest International Cloud Model Intercomparison

Greg McFarquhar, Hans Verlinde, Ann Fridlind and Steve Klein

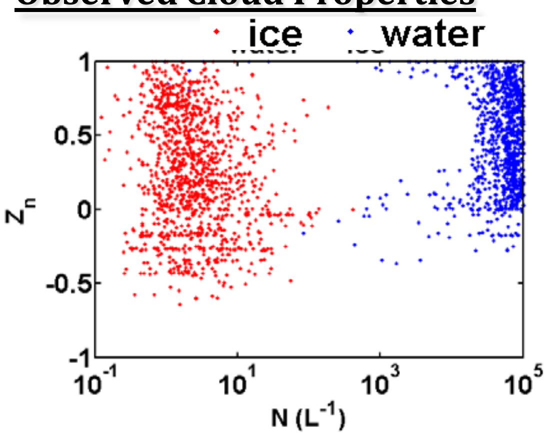
Science Question

What controls cloud microphysical properties in persistent mixed-phase Arctic stratocumulus, and how can these processes be represented in models?

Approach

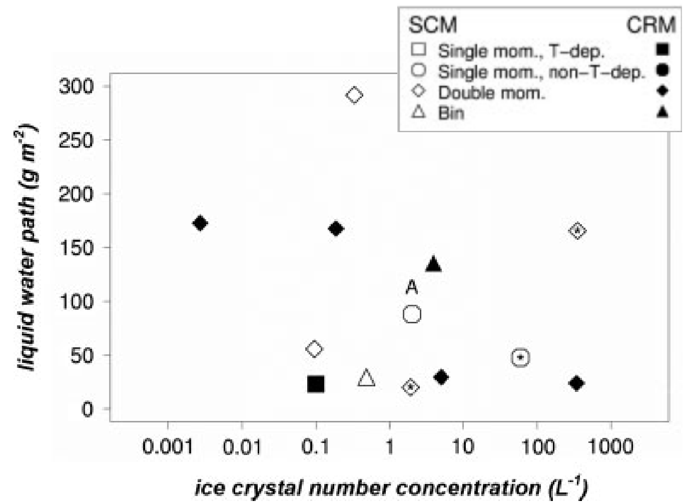
- Derive vertical profiles of cloud properties observed by instrumented aircraft that flew > 100 ramped ascents/descents through clouds over North Slope of Alaska
- Compare observed properties against those modeled using varying ice formation mechanisms to identify processes responsible for formation of ice
- Simulate cloud properties with 26 different models to determine which models & processes give optimum representation of observed microphysics

Observed Cloud Properties



Observed water droplet and ice concentration Ni as function of normalized cloud altitude used to assess models

Modeled Cloud Properties



Single-column model (SCM) and cloud-resolving model (CRM) Ni predictions vary by over five orders of magnitude under these common Arctic conditions. Observed values indicated by A.

Comparison suggests models with more sophisticated microphysics (bin-resolved) better match aircraft observed properties. Because of scatter, limitations of using 1 case study, and uncertainties in data, similar comparisons now being conducted using more comprehensive aircraft observations obtained in ASR 2008 Arctic cloud experiment.

Key Accomplishment

Synergy of ASR field observations and models shows advances in cloud microphysics schemes are necessary for modeling observed cloud properties; understanding of mechanisms responsible for ice in Arctic clouds will benefit representation of such processes in climate models.

Publications

Verlinde et al. (BAMS, 2007), McFarquhar et al. (JGR, 2007), Fridlind et al. (JGR, 2007), Klein et al. (QJRMS, 2009)

Effect of Marine Organic Aerosol on Regional and Global Climate

Nicholas Meskhidze/ North Carolina State University

Science Question

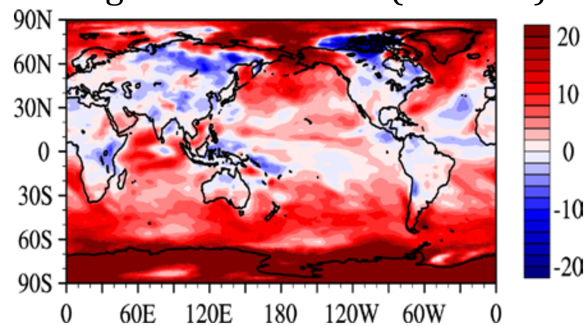
How do uncertainties in the emission rate and chemical composition of marine aerosol affect model-predicted extent of human-induced climate change?

Approach

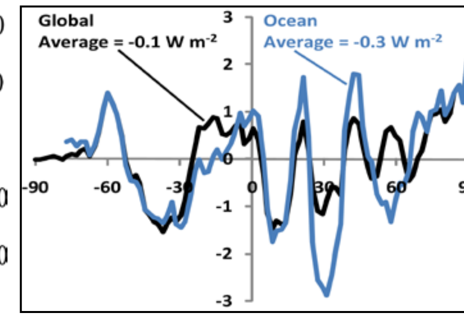
- Develop wind speed dependent size-resolved parameterization for the organic mass fraction of sea spray aerosol
- Develop parameterization for marine secondary organic aerosol production
- Implement marine organic aerosol source functions into CAM5 model and evaluate using in situ and remotely sensed data
- Conduct model simulations using present day and preindustrial emissions

Effect of marine organic aerosol on CAM5 predictions

Annual average percentage change in surface CCN (S= 0.2%)



Change in shortwave cloud forcing (W m^{-2})

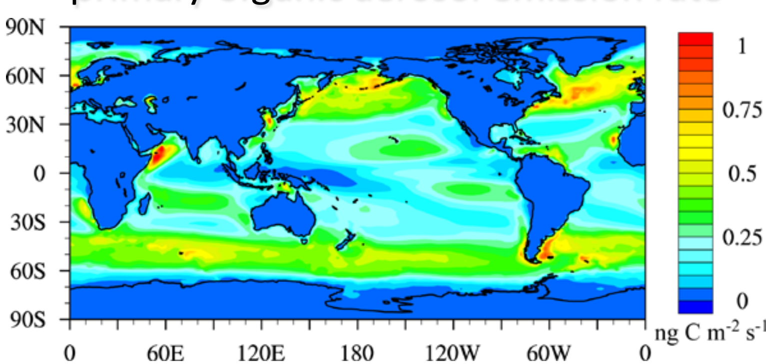


Key Accomplishments

Marine organic aerosol provide globally significant source of organics in the atmosphere with considerable cloud radiative forcing and climatic effects.

A special Issue was published on Marine Aerosol-Cloud-Climate Interaction (http://www.hindawi.com/journals/amet/2010/si.1/)

Annual average submicron marine primary organic aerosol emission rate



Selected publications

Meskhidze, N., et al. (2011), Global distribution and climate forcing of marine organic aerosol – Part 1: Model improvements and evaluation, Atmos. Chem. Phys. Discuss., 11, 18853–18899.

Gantt, B. et al. (2011), Wind speed dependent size-resolved parameterization for the organic enrichment of sea spray, *Atmos. Chem. Phys. Discuss.*, 11, 10525-10555.

Meskhidze N. and A. Nenes (2010), Effects of ocean ecosystem on marine aerosol-cloud interactions, *Advances in Meteorology*, Article ID 239808.

Gantt, B., et al. (2010), The impact of marine organics on the air quality of the western United States, Atmos. Chem. Phys., 10, 1–9.

Gantt, B., et al. (2010), The effect of marine isoprene emissions on secondary organic aerosol and ozone formation in the coastal United States, *Atmos. Environ*,. 44, 115–121.

ASR Atmospheric System Research

Ice Nucleation Processes and the Life Cycle of Cirrus Clouds

David L. Mitchell and Subhashree Mishra / Desert Research Institute

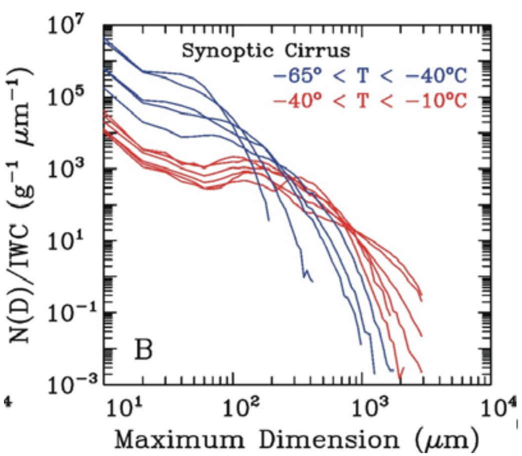
Science Question

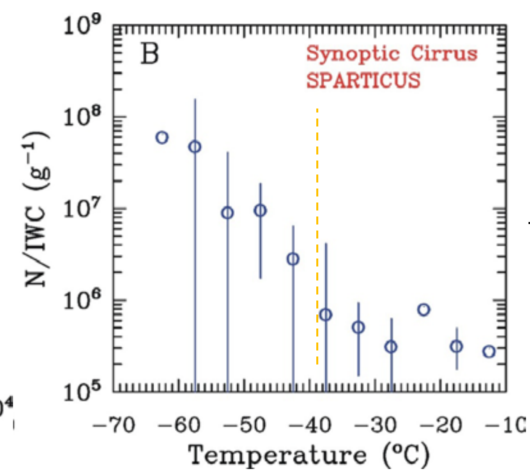
Does homogeneous freezing nucleation dominate ice production in mid-latitude synoptic cirrus clouds?

Approach

Process and analyze in situ measurements obtained during the SPARTICUS field campaign, where the problem of ice particle shattering was greatly reduced. Use new probes and methods to reveal changes in nucleation rate and ice particle morphology.

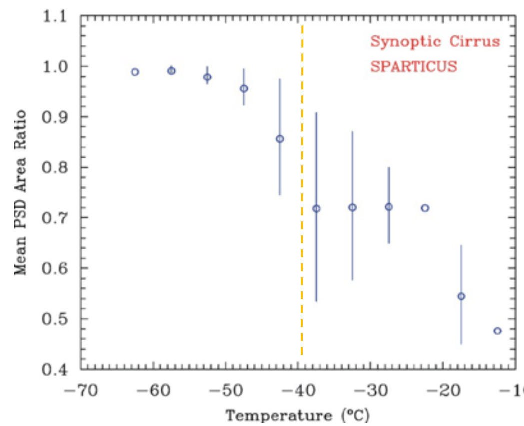
Results

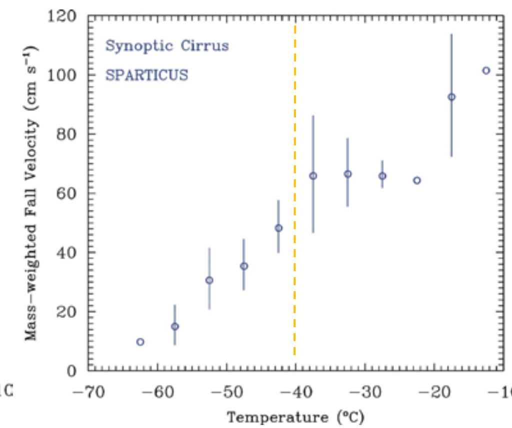




Results (continued)

Onset of homogeneous freezing is ~ - 38°C. The mean size distribution area ratio is a measure of ice particle shape.





Key Accomplishment

Homogeneous nucleation appears to strongly affect the size distribution shape, number concentration, ice particle shape and life cycle (i.e. fall speed) of synoptic cirrus clouds.

Publication

Mitchell, D. L., S. Mishra and R. P. Lawson, 2011: Cirrus clouds and climate engineering: New findings on ice nucleation and theoretical basis. In: *Global Warming*, Dr. Stefano Casalegno and Prof. Elias Carayannis (Eds.), book chapter under review.

ASR Atmospheric System Research

Modeling Aerosol Growth By Aqueous Chemistry

Mikhail Ovchinnikov and Richard Easter / Pacific Northwest National Laboratory

Science Question

How does chemistry inside cloud droplets affect aerosol size distributions?

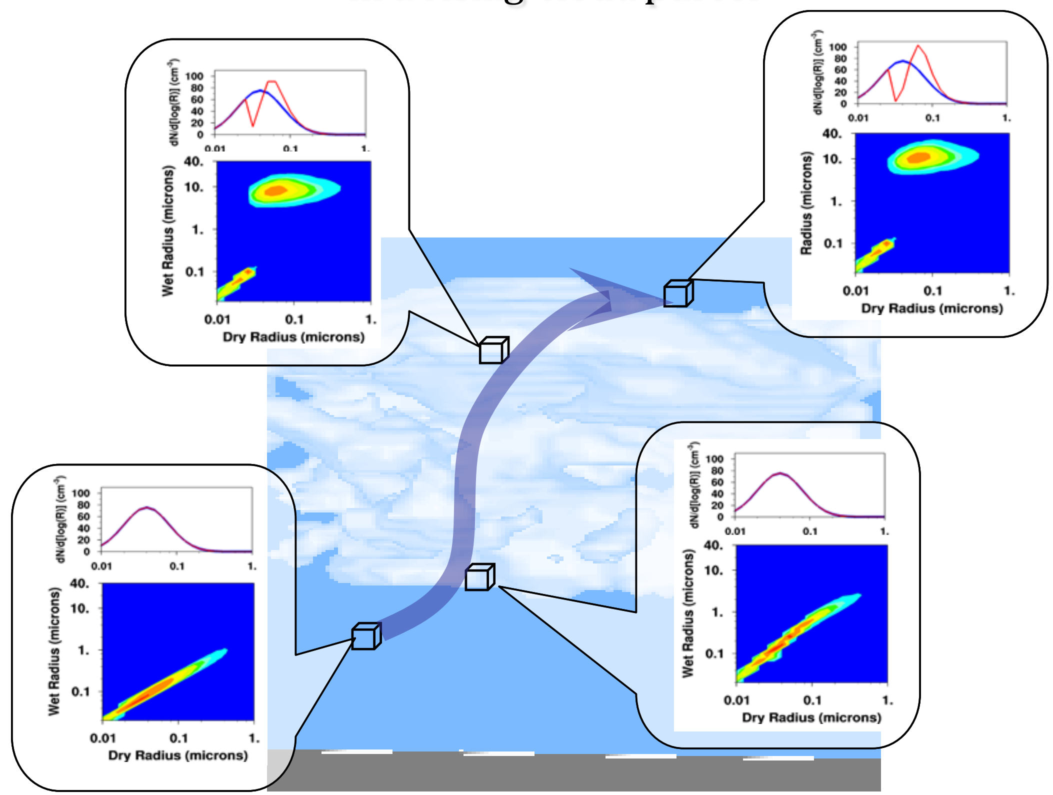
Approach

- Develop a novel model that tracks aerosol particles inside cloud droplets.
- Simulate aerosol processing by stratiform clouds
- Evaluate assumptions used in global models to relate aerosol size to cloud droplet size.

Key Accomplishment

Explicit simulations of aerosol transformations inside cloud droplets suggest corrections are needed to the aqueous chemistry treatment in global models.

Schematic of aerosol and droplet spectrum evolution in a rising cloud parcel



Publications

Ovchinnikov, M. and R. C. Easter, 2010: Modeling aerosol growth by aqueous chemistry in a non-precipitating stratiform cloud. *J. Geophys. Res.*, 115, D14210, doi:10.1029/2009JD012816.

Ovtchinnikov, M. and R. C. Easter, 2009: Nonlinear advection algorithms applied to interrelated tracers: Errors and implications for modeling aerosol-cloud interactions. *Mon. Wea. Rev.*, 137, 632-644, doi:10.1175/2008MWR2626.1

Quantifying the Contribution of Organic Aerosol to Cloud Condensation Nucleus Activity

Paul Ziemann, Sonia Kreidenweis, Markus Petters

Science questions

- How efficiently does secondary organic aerosol promote cloud droplet activation?
- How do molecular size and functional group composition influence CCN properties?

Key Accomplishment

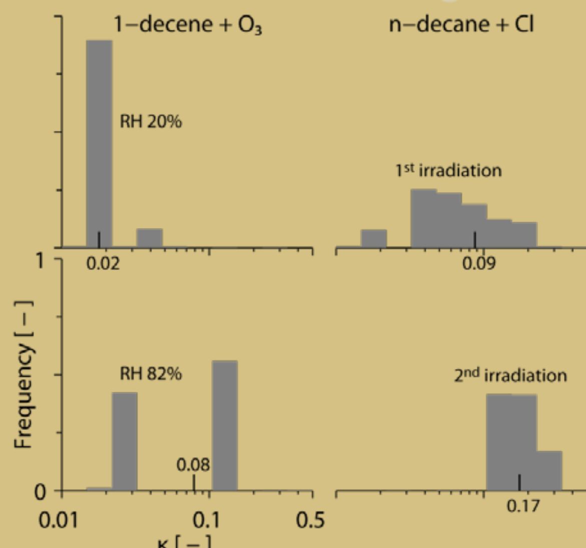
Quantified links between the chemical mechanism forming the SOA and the measured effect on CCN activity

Approach

- Generate model organic aerosol inside an environmental chamber.
- Measure the CCN activity of the combined (online) or separated products (offline) using high performance liquid chromatography.
- Find relationships between organic aerosol physicochemical properties and the hygroscopicity parameter κ, which describes the chemical contribution of a particle towards modeling its CCN activity.

Changes in the hygroscopicity distribution as result of modifying the chemical reaction leading to its formation

If the reaction proceeds at high RH, smaller more oxidized α-hydroperoxide (high κ) dominates over less oxidized secondary ozonide and peroxyhemiacetal molecules (low κ)



Increasing the extent of oxidation leads to a reduction of compounds with low κ values in the mixture

Publications

Suda et al., 2011: Hygroscopicity distribution of secondary organic aerosol, *in preparation for Atmos Chem Phys.*

Petters et al., 2009: Role of molecular size in cloud droplet formation, *Geophys Res Lett,* 36, L22801, doi:10.1029/2009GL040131.

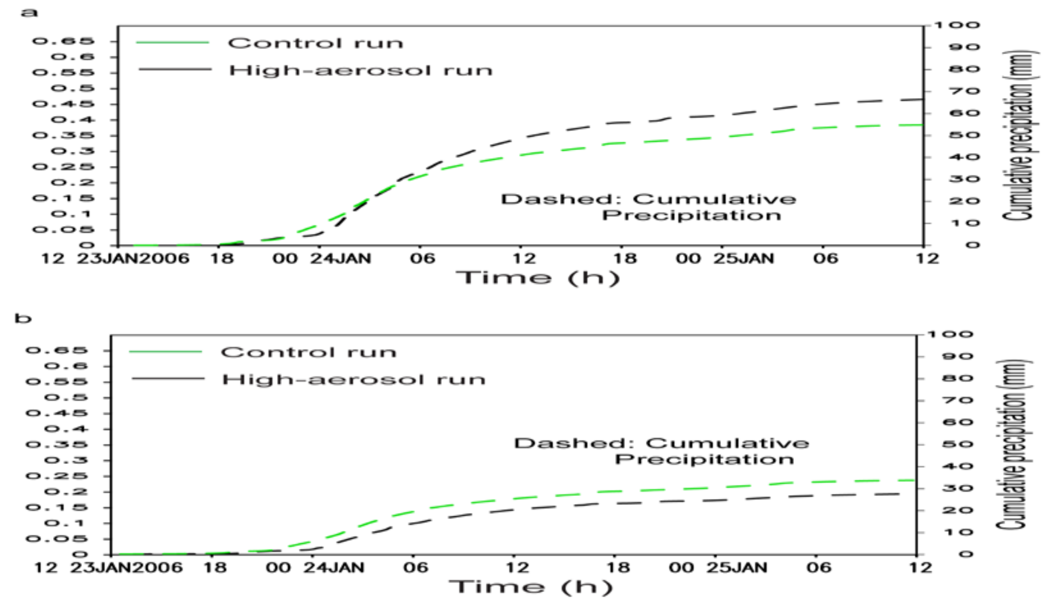
Prenni et al. 2007, Cloud droplet activation of secondary organic aerosol, *J Geophys Res*, 112, D10223, doi:10.1029/2006JD007963.

Petters et al., 2006: Chemical aging and the hydrophobic-to-hydrophilic conversion of carbonaceous aerosol, *Geophys Res Lett*, 33, L24806, doi:10.1029/2006GL027249.

Precipitating Cloud-System Response to Aerosol Perturbations

Seoung Soo Lee and Graham Feingold/ Earth System Research Laboratory

Cumulative precipitation (a) and (b) for convective and stratiform clouds



Goals

Explore precipitation and its interactions with aerosol in a mesoscale cloud ensemble (MCE) driven by deep convection

Approach

- Simulate an observed MCE of deep convection during TWP-ICE campaign over a tropical region
- The GCE model coupled with a two-moment microphysics is used on 256 km x 20 km domain
- Low-aerosol run (clean case) and high-aerosol run (polluted case) are performed to examine aerosol effects on clouds.

Key Accomplishment

A 10-fold difference in aerosol concentration results in very small 9% difference in precipitation between the two runs due to compensation or buffering among cloud types and microphysics processes.

Publication

Lee, S. S., and Feingold, G.: Precipitating cloud-system response to aerosol perturbations, Geophys. Res. Lett., 37, L23806, doi:10.1029/2010GL045596, 2010.

Multi-scale Modeling of Aerosol Impacts on Clouds and Precipitation

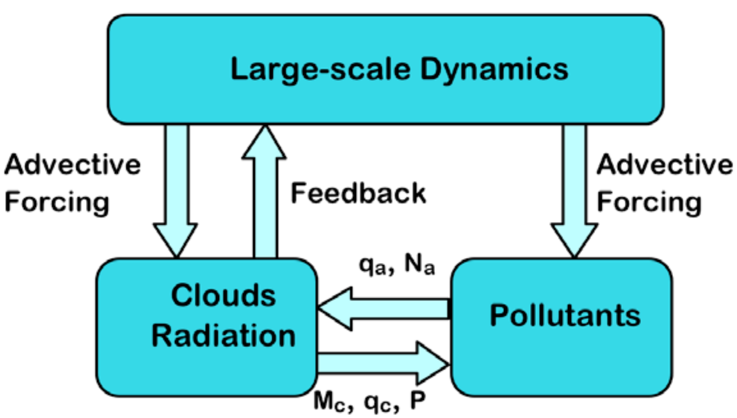
Minghuai Wang, Richard Easter, Mikhail Ovchinnikov, Steven Ghan

Science Question

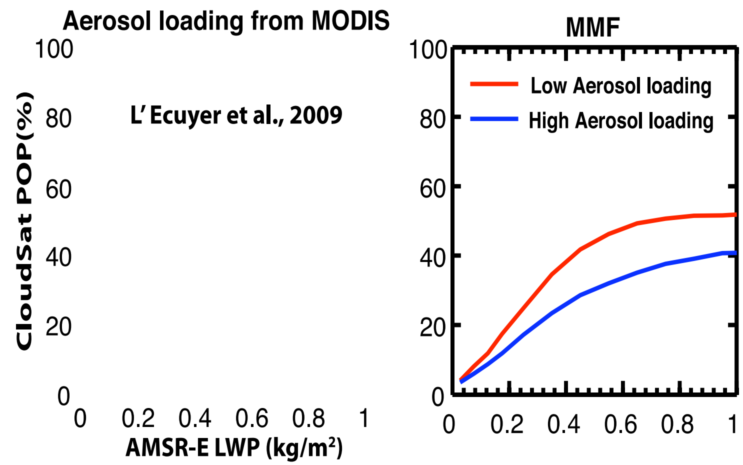
How do interactions between aerosols and clouds across scales from km to global influence precipitation and the global energy balance?

Approach

- Couple a cloud model with a global aerosol model
- Evaluate using in situ and remote sensing data
- Compare simulations using present day and preindustrial emissions



Probability of precipitation (POP) for warm clouds



Key Accomplishment

The first multi-scale estimate of cloud-aerosol interactions suggests weaker aerosol effects on clouds and precipitation than previous estimates with global models.

Publication

Wang, M., et al., 2011: Aerosol indirect effects in a multi-scale aerosol-climate model PNNL-MMF, *Atmos. Chem. & Phys.*, 11, 5431-5455, doi:10.5194/acp-11-5431-2011.

Quantifying the Indirect Effect of Ice Nuclei on Radiative Forcing in the Tropics and Mid-latitudes

Xiping Zeng, Wei-Kuo Tao / NASA Goddard Space Flight Center

Science Question

Is there a class of aerosols that can contribute positively to global warming? If yes, can its effect be quantified using ARM observations?

Approach

Ice nuclei (IN), which compose a small part of the 10^8 aerosol particles (at a temperature of -15°C), can impact clouds via super-cooled droplets that, in turn, affect radiation and climate. Under the constraint of the ARM observations as well as others (see Fig. 1 for campaign locations), the Goddard cloud-resolving model was used to quantify the indirect effect of ice nuclei on radiative forcing in the Tropics and middle latitudes, heading to an IN effect versus latitude (Fig. 2).

Fig. 1 Location of the field campaigns that provided data to drive and evaluate cloud-resolving model simulations.

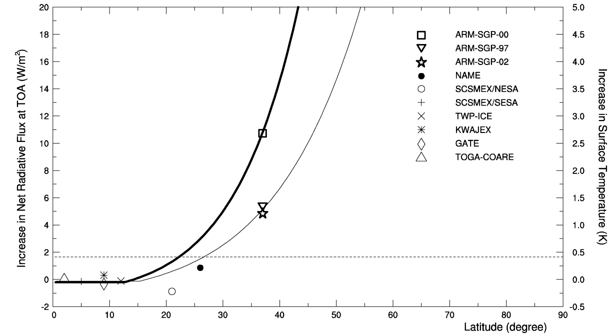


Fig. 2 The increase in the radiative forcing when IN concentrations are doubled varies with latitude. All the results obtained over the field campaigns are marked by symbols. Thick and thin solid lines are introduced to fit the results in spring and summer, respectively, based on ten-year TRMM observations. The dash line represents an increase in the radiative forcing when CO_2 concentration increases from zero to the current value.

Key Accomplishment

The indirect effect of doubling IN, as shown in Fig. 2, becomes stronger at higher latitude and is larger than that from doubling CO_2, which offers a new candidate for global warming.

Publication

Zeng, X., W.-K. Tao, M. Zhang, A. Y. Hou, S. Xie, S. Lang, X. Li, D. Starr, and X. Li, 2009: A contribution by ice nuclei to global warming. *Quart. J. Roy. Meteor. Soc.*, **135**, 1614-1629.

Award

Best Paper awarded by the Laboratory for Atmospheres at NASA Goddard Space Flight Center in 2010.

Influence of Ice Nucleation on Mixed-Phase Clouds and Climate

Xiaohong Liu/ Pacific Northwest National Laboratory

Science Question

How do ice nucleation and ice crystal growth influence mixed-phase cloud properties, and radiative balance?

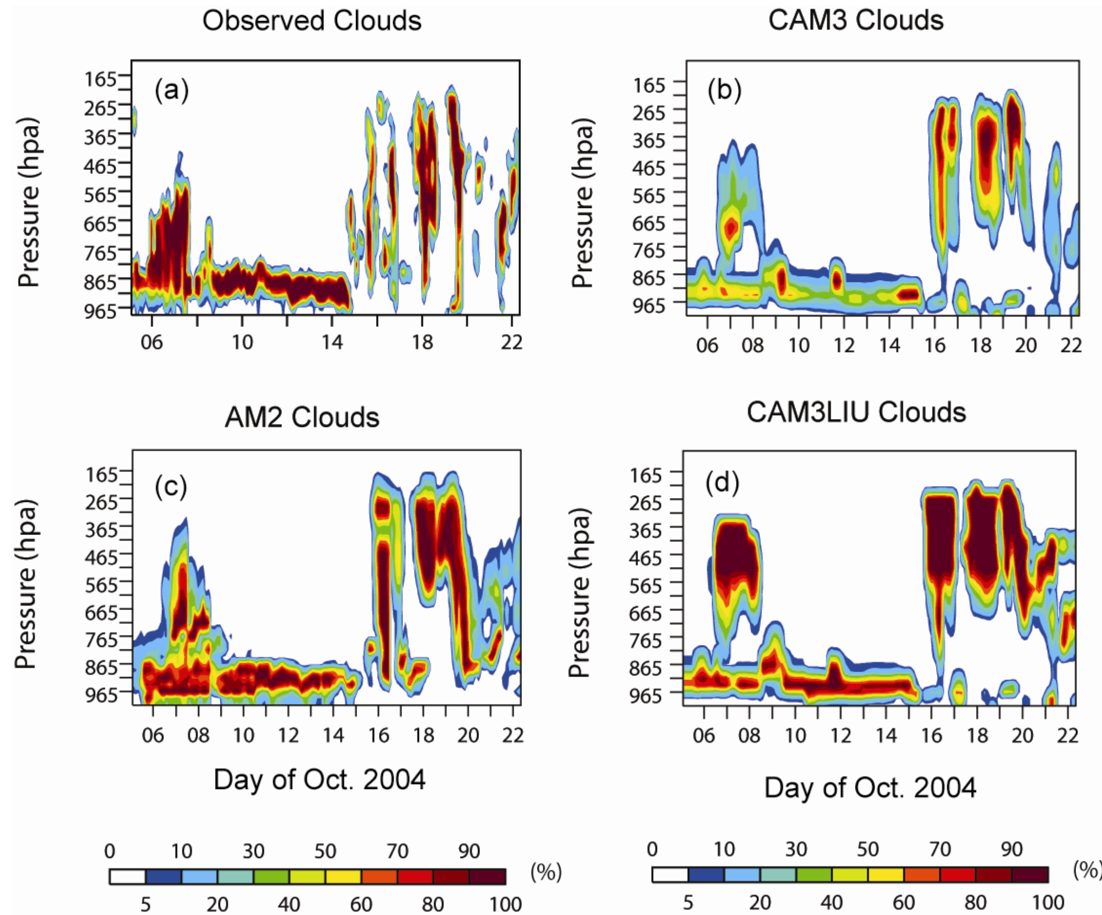
Approach

- Implement an ice nucleation parameterization (Liu et al. 2007) in CAM3
- Implement a new treatment of deposition growth of ice crystals in clouds
- Evaluate CAM simulations under the single column mode and CAPT testbed with ARM M-PACE observations

Key Accomplishment

Physical representation of ice nucleation and ice crystal growth for cold clouds in GCMs is important for realistic model simulations of mixed-phase cloud microphysics and radiative balance

Simulated and observed clouds during M-PACE



Publications

Liu, X., S. Xie, and S. J. Ghan (2007) Evaluation of a new mixed-Phase cloud microphysics parameterization with the NCAR single column climate model (SCAM) and ARM M-PACE observations. Geophysical Research Letter, 34, L23712, doi:10.1029/2007GL031446.

Xie, S., J. Boyle, S. A. Klein, X. Liu and S. Ghan (2008) Simulations of Arctic Mixed-Phase Clouds in Forecasts with CAM3 and AM2 for M-PACE. *Journal of Geophysical Research*, *113*, D04211, doi:10.1029/2007JD009225.

Changes of Aerosol Properties in Cumulus Humilis

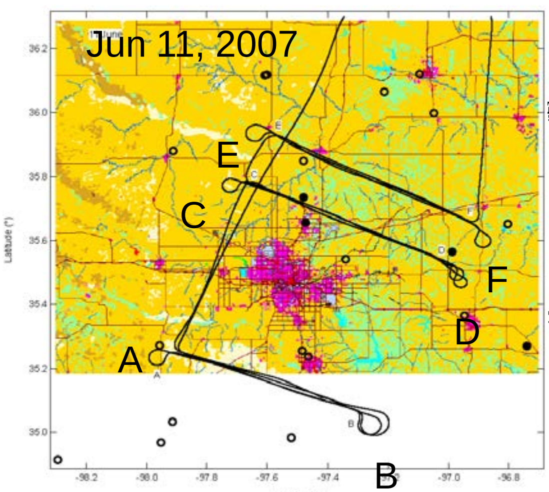
Xiao-Ying Yu/ Pacific Northwest National Laboratory

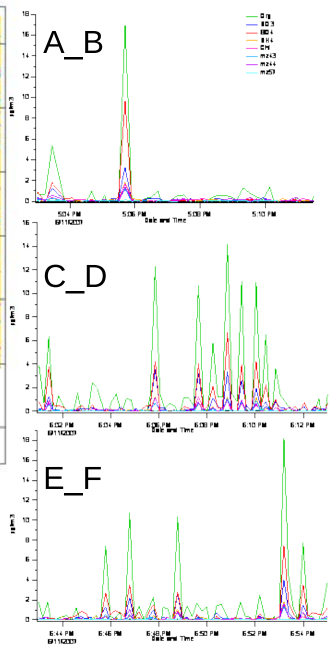
Science Questions

What is the difference between interstitial aerosol and activated CCNs? What mechanisms may contribute to the observations?

Approach

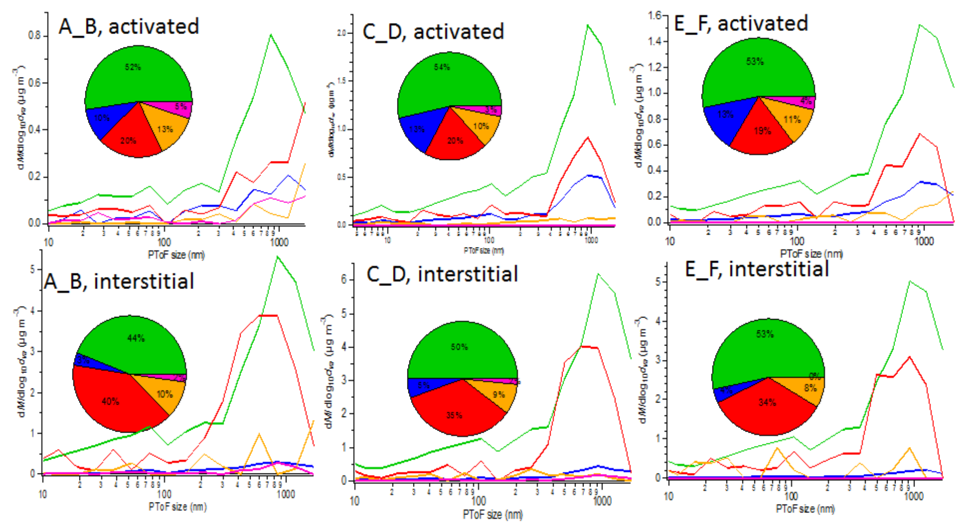
- Analyzed AMS data downstream of the isokinetic inlet (interstitial particles) and the counter-flow virtual impactor (activated CCN residues)
- Identified differences in size-resolved compositions between background particles and CCNs at different altitudes and pollutant transport scenarios





Left: Three parallel flight tracks in the vicinity of Oklahoma City; Right: Temporal profiles of activated CCN residues.

Enhanced NO_3, NH_4, Chl; Org enhanced 2 out of 3 legs; SO_4 not enriched in all 3 flight tracks.



Key Accomplishment

The first in situ observations of size-resolved interstitial and activated CCN residues in cumulus humilis reveal that clouds play an important role in processing aerosols and changing aerosol properties (composition, size distribution, and the ability to act as CCNs).

Publication

Yu, X.-Y. et al., 2011: Enriched nitrate, ammonium, and organics in cloud condensation nuclei residues in continental cumulus humilis, Geophys. Res. Lett., to be submitted, 2011

Ice Generation and Growth in Arctic Mixed-phase Clouds

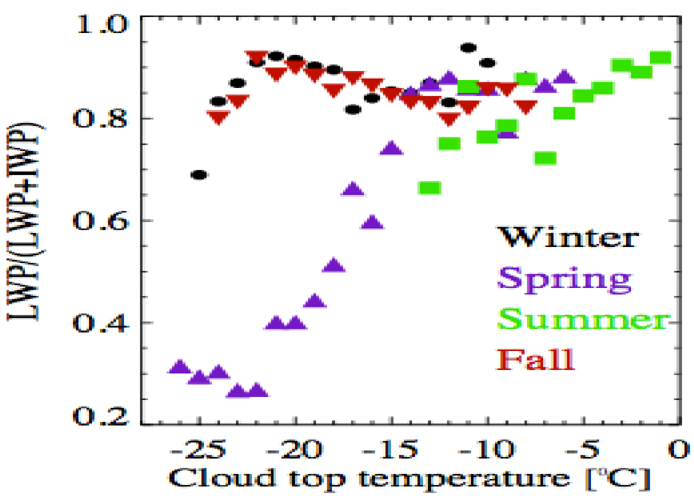
Zhien Wang/ University of Wyoming

Science Question

What controls ice generation and growth in arctic mixed-phase clouds and how do mixed-phase cloud properties impact the surface radiation budget ?

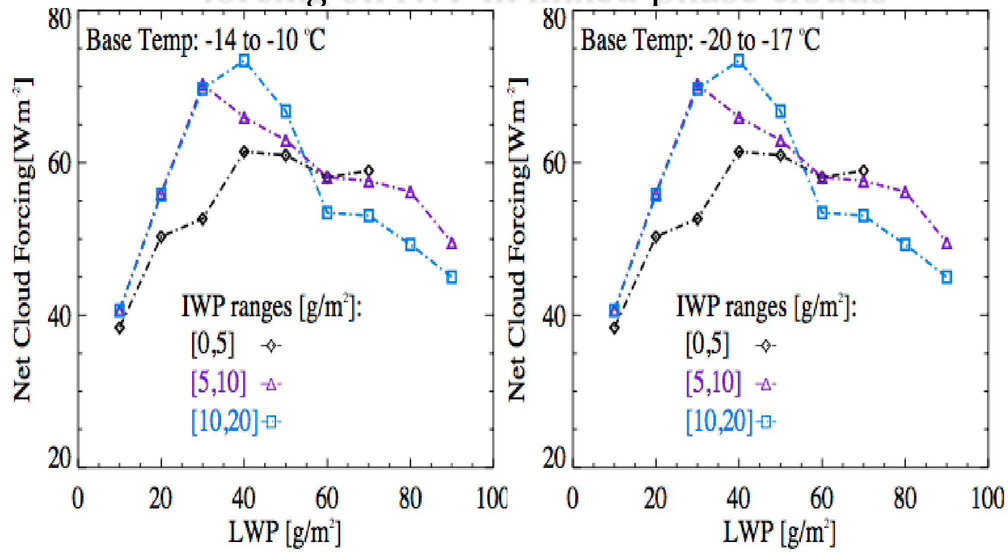
Approach

- Advanced multi-sensor retrieval algorithm development
- Long-term ARM data analyses
- Synergy model sensitivity studies with observational results



Long-term data show that the spring season has distinct ice-liquid mass partition in arctic mixed-phase clouds.

The sensitivity of surface long wave cloud radiative forcing on IWP in mixed-phase clouds



Key Accomplishment

Identified a strong seasonal dust impact on ice generation in arctic mixed-phase clouds, provided strong observational evidence for significant aerosol glaciation effects on arctic mixed-phase clouds.

Publication

Zhao, M., et al., 2011: The arctic clouds from model simulations and long-term observations at Barrow Alaska, PhD Dissertation, University of Wyoming .