“Ice Nucleation” breakout session

Wednesday, March 20, 10:30 p.m.–12:00 p.m.

1. Xiaohong Liu: Motivation to the session
2. Gourihar Kulkarni: Laboratory investigation of ice nucleating properties of bare and coated dust particles
3. Paul DeMott: Investigations of marine ice nuclei
4. Raymond Shaw: Is contact nucleation more efficient because of the existence of a three-phase contact line?
5. Zhien Wang: Explore Ice Generation Dependency on Aerosol Properties with Remote Sensing
6. David Mitchell: Evidence of homogeneous nucleation during SPARTICUS using in situ measurements
7. Jennifer Comstock: Factors influencing cirrus lifecycle using SPartICus data
8. Jiwen Fan: Dust effects on clouds and precipitation by serving as ice nuclei (IN)
9. Chuanfeng Zhao: Sensitivity of CAM5 Simulated Clouds to Ice Nucleation Parameterizations and the Climate Impacts in the Arctic and Southern Ocean Regions
10. Open Discussion/focus group (45 mins)

Proposed "Ice Nucleation" Focus Group

Motivation

- Ice nucleation processes involving aerosols are key to the formation and properties of ice and mixed-phase clouds, and thereby can impact both the atmospheric radiative energy distribution and precipitation processes.
- Compared to droplet formation in warm clouds, ice nucleation is more complicated and much less understood.
- large uncertainties in the representation of ice nucleation processes in climate models, and aerosol effects on ice and mixed-phase clouds.

Objectives

- Identify and collect key data needed to improve understanding of IN sources and heterogeneous ice nucleation mechanisms and their relationship to overall aerosol properties and environmental conditions;
- Develop the general framework for ice nucleation parameterization; and inter-compare different approaches and different formulations (derived from laboratory versus field data) of parameterizations for different aerosol types;
- Reduce uncertainties in aerosol impacts on cold clouds, precipitation and climate forcing.

Approaches

- Laboratory experiments provide details of the fundamental processes of ice formation under controlled conditions. A focused laboratory workshop on ice nucleation measurement is encouraged.
- Field measurements will allow us to understand the ice nucleation mechanisms occurring in the real atmosphere and, in some cases, to validate cloud impacts. Both in situ and laboratory measurements will provide data for parameterization development and model evaluation.
- Remote sensing (ground-based and satellite) will scale up in situ measurements while in situ measurements will provide information for improving remote sensing retrieval algorithms and developing new capability. Both remote sensing and in situ measurements will provide data for model validation.
- New parameterizations will be implemented into cloud models and GCMs to improve the representation of ice microphysics and to examine the roles of ice nucleation on cloud and precipitation, and climate forcing.

Items identified at the CAPI working group meeting last November

Near-term Action and Work in Progress

- Quantify marine sources of IN (P. DeMott, S. Burrows, K. Prather)
- Explore relationship between Ni and temperature, relative humidity and updraft velocity from existing measurements (e.g., SPARTICUS) (X. Liu, J. Comstock)
- Use remote sensing measurements to quantify dust impact (Z. Wang, X. Liu)
- Estimate ice number concentration with remote measurements (Z. Wang)
- Explore dependence of ISDAC Ni simulations on dust speciation (X. Liu)

Items identified at the CAPI working group meeting last November

New measurements needed (ideas):

- Conclusive temperature-dependence of immersion nucleation on BC (G. Kulkarni)
- CVI that distinguishes between droplets and ice crystals (G. Kulkarni)
- IN GOAMAZON 2015 (G. Kulkarni, P. DeMott)
- IN measurements that more clearly identify mode of ice nucleation
- Updraft velocity in cirrus clouds (J. Comstock)

Items identified at the CAPI working group meeting last November

New field experiments (ideas):

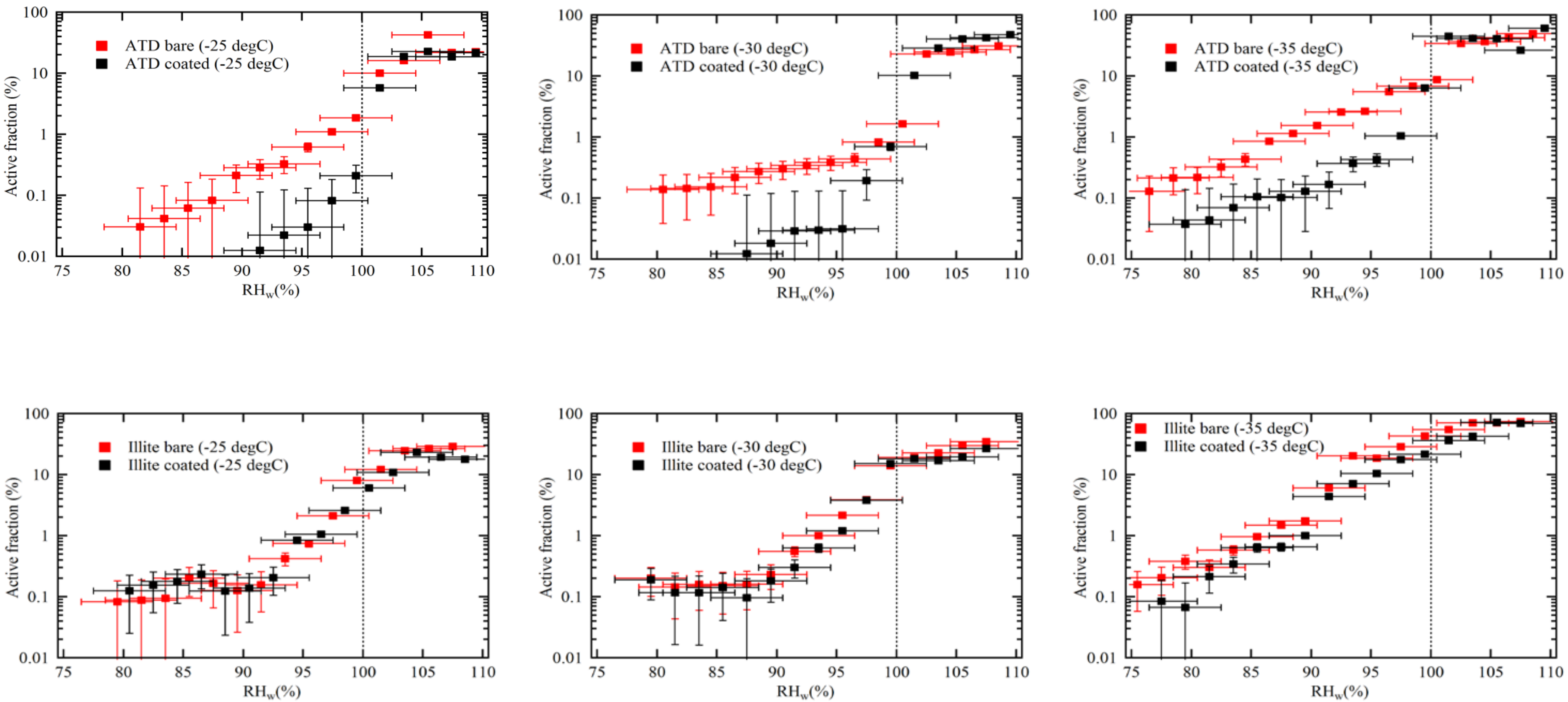
- Laboratory intercomparison of IN measurements (G. Kulkarni)
- IN closure in laboratory with CFDC>pCVI>SPLAT (G. Kulkarni, A. Zelenyuk)
- IN, Ni closure at surface multiple months (G. Kulkarni, A. Zelenyuk)
- IN measurement in Southern Hemisphere Cloud-Aerosol Experiment

G. Kulkarni at PNNL:

Laboratory investigation of ice nucleating properties of bare and coated dust particles

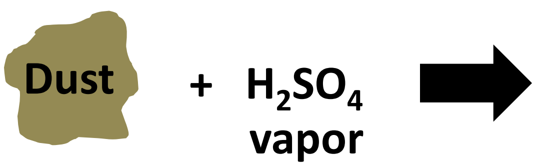
Laboratory investigation of ice nucleating properties of bare and coated dust particles

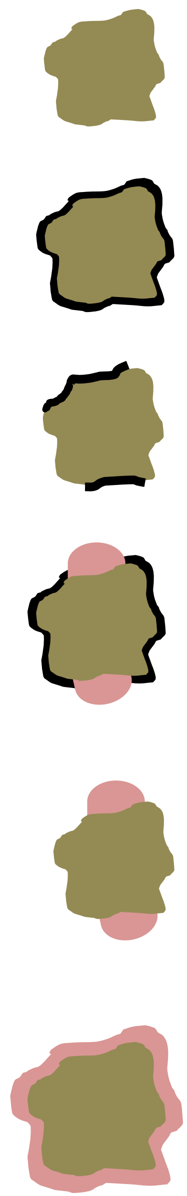
Role of dust ageing in the atmosphere on IN properties?



General consensus is that surface modification by sulfuric acid leads to reduction in the IN ability. However, some studies show the deactivation depends upon the dust mineralogy, coating thickness and surface morphology and suggest no reduction.

Hypothetical scenarios of interactions between dust and sulfuric acid vapor, and possibility of such interactions deduced from their deposition IN activity understanding.





Scenario	ATD	Other dust
No modification	no	yes
Complete surface modification (due to acid digestion)	no (hydrophobic surface like soot ; see CCN measurements)	no
Partial surface modification	yes/no (depends upon the coating efficiency)	yes/no
Partial surface modification and acid condensation (island effect)	no (hydrophobic surface and deliquescence inhibit ice nucleation)	no
Partial acid condensation (island effect)	yes/no (depends upon the coating efficiency and deliquescence limit)	yes/no
Complete acid condensation	no (deliquescence inhibit ice nucleation)	no

Such detailed measurements are urgently needed to accurately represent the ice nucleation processes in the cloud models.

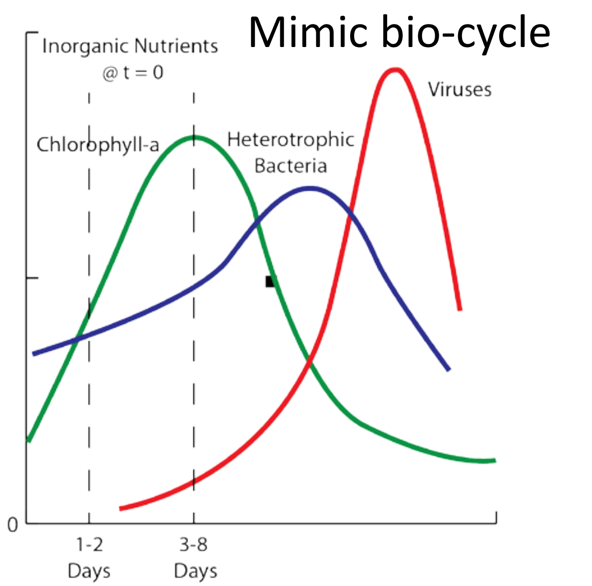
(See poster for more details)

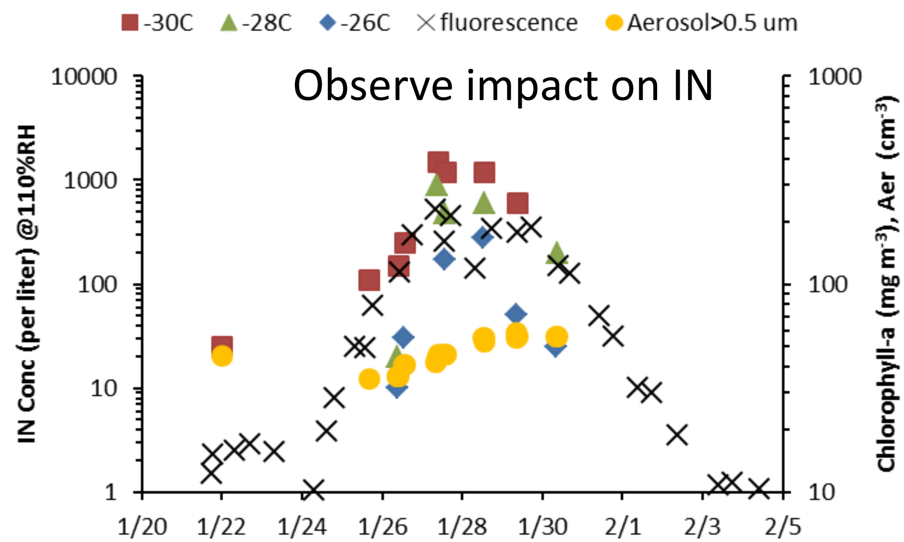
Paul DeMott at CSU:

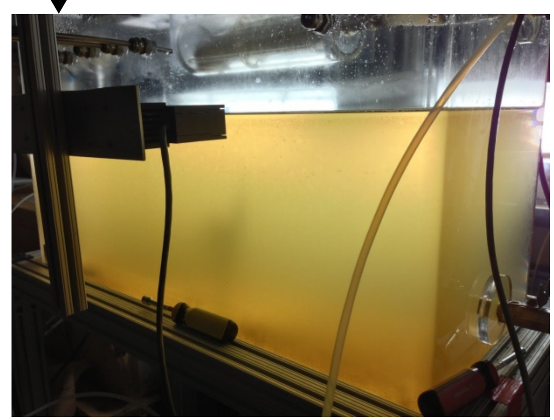
Investigations of marine ice nuclei

January 2013 UCSD lab experiments: Evidence that biology impacts the emission of IN from sea spray

Mimic bio-cycle





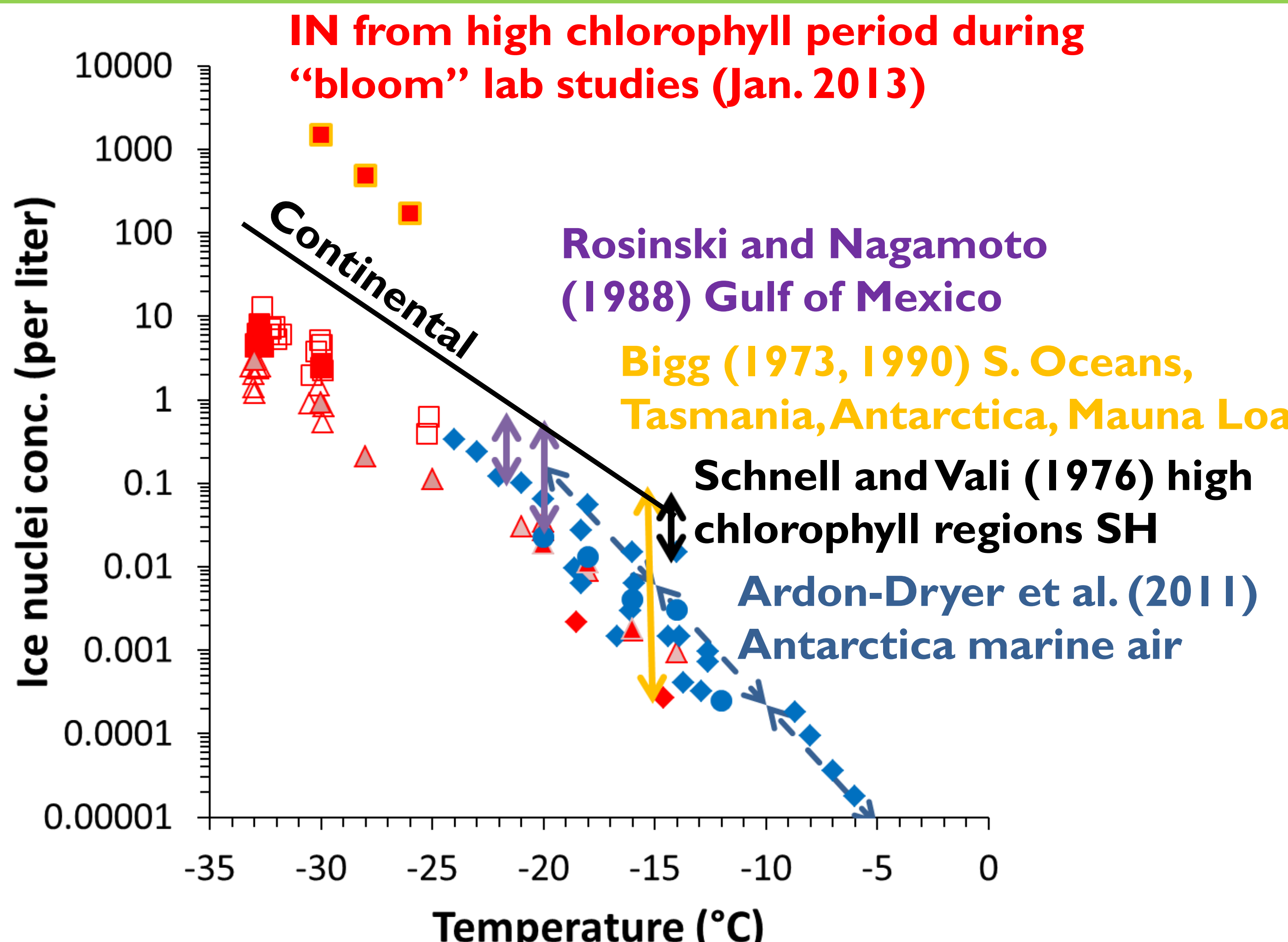


NSF

Colorado State University

Seaspray IN (lab = red ; ICE-T (diamond) and cruise (circle) field = blue) vs. historical (arrows) marine IN

Colorado State University

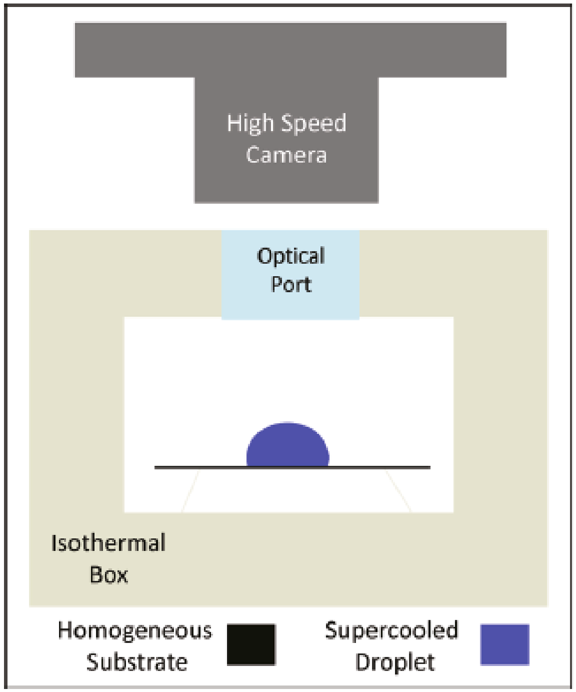


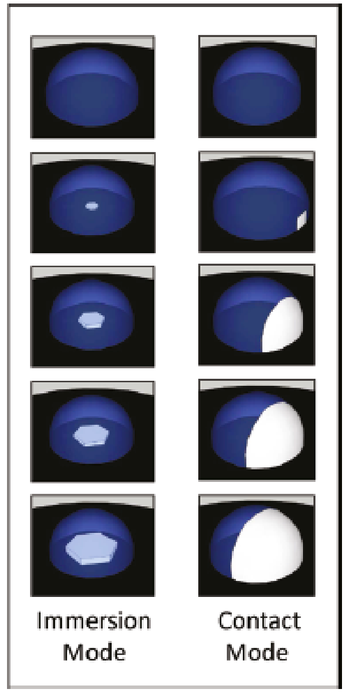
Need: Surface and aircraft measurements to validate lower average IN sources over oceans, high IN at bloom times, identify nuclei source, numerical modeling studies.

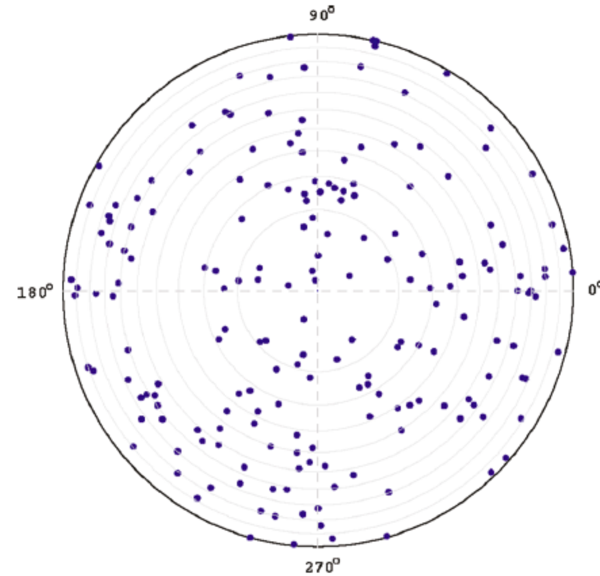
Raymond Shaw at Michigan Tech:

Is contact nucleation more efficient because of the existence of a three-phase contact line?

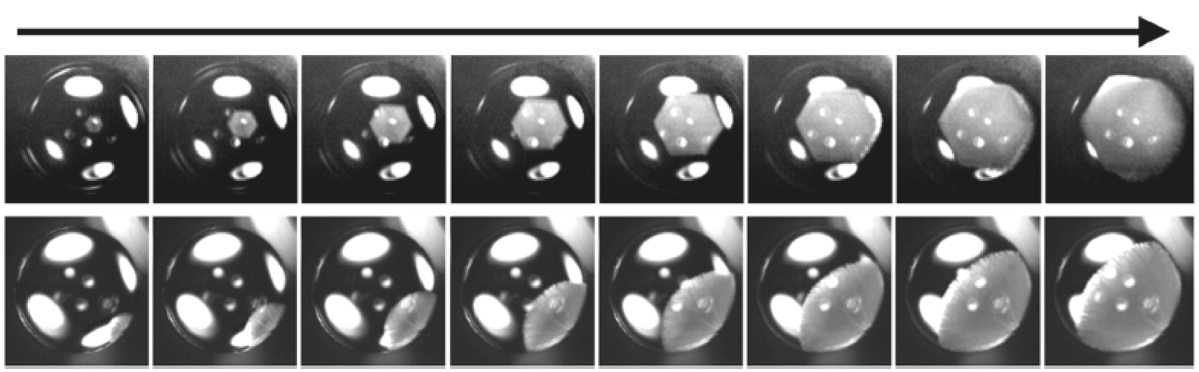
Is contact nucleation more efficient because of the existence of a three-phase contact line?







No preference for contact line observed.



New result: even when we vary the contact angle on the substrate or the rate of cooling, still no preference for contact line.

Gurganus et al. 2011 (J Phys Chem Lett); Gurganus et al. 2013 (J Phys Chem C)

New Cloud chamber facility...

Cloud chamber with capability to reach upper tropospheric conditions, with controlled turbulence conditions (e.g., thermal convection).

Contact: R. Shaw (rashaw@mtu.edu)

Zhien Wang at University of Wyoming:

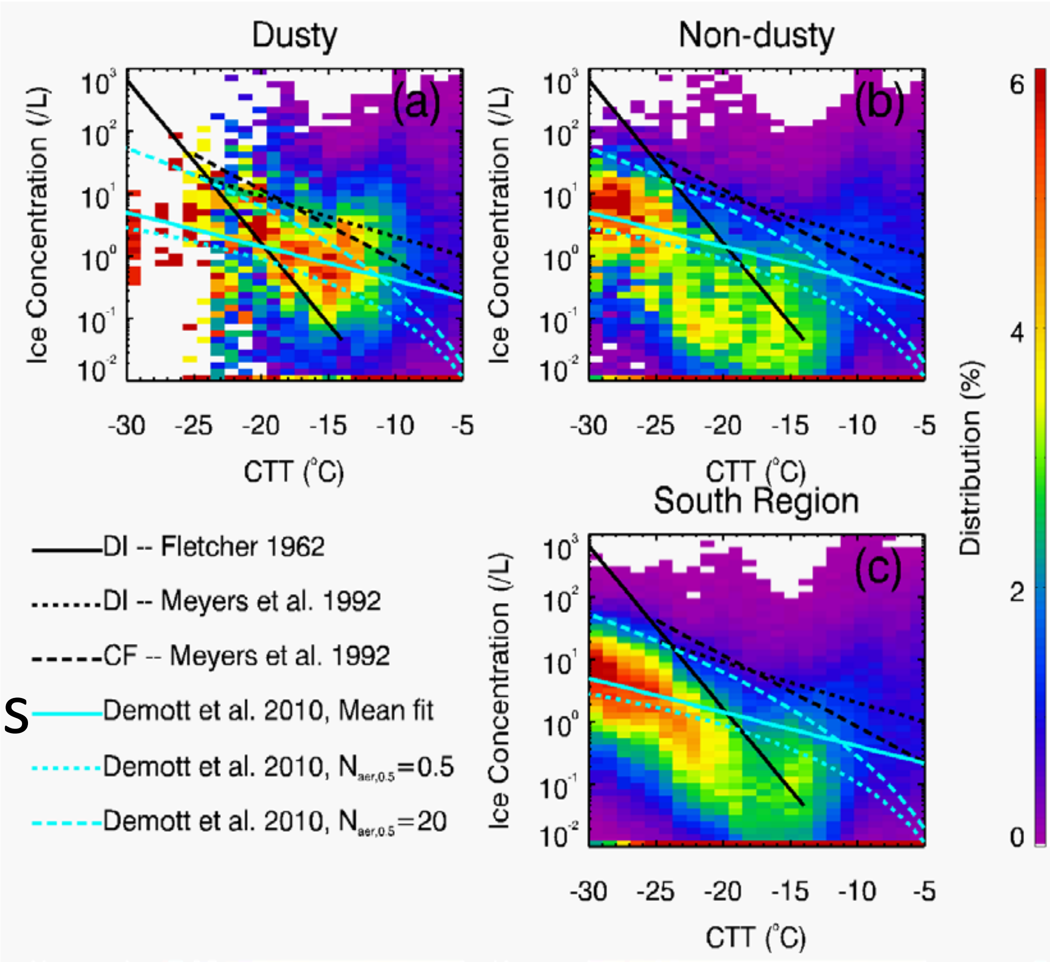
Explore Ice Generation Dependency on Aerosol Properties with Remote Sensing

Dust Impacts in the Context of Different Parameterizations

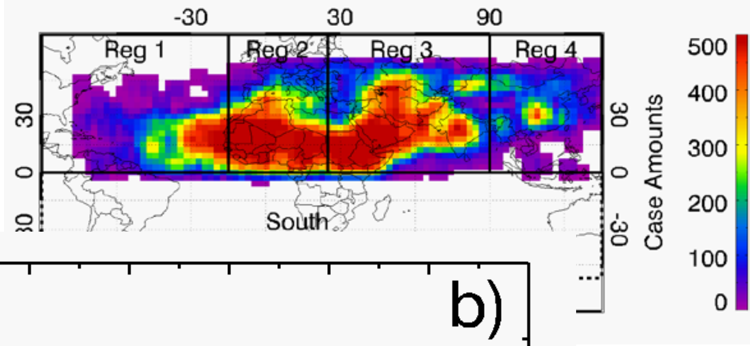
• Large variations in ice concentrations.

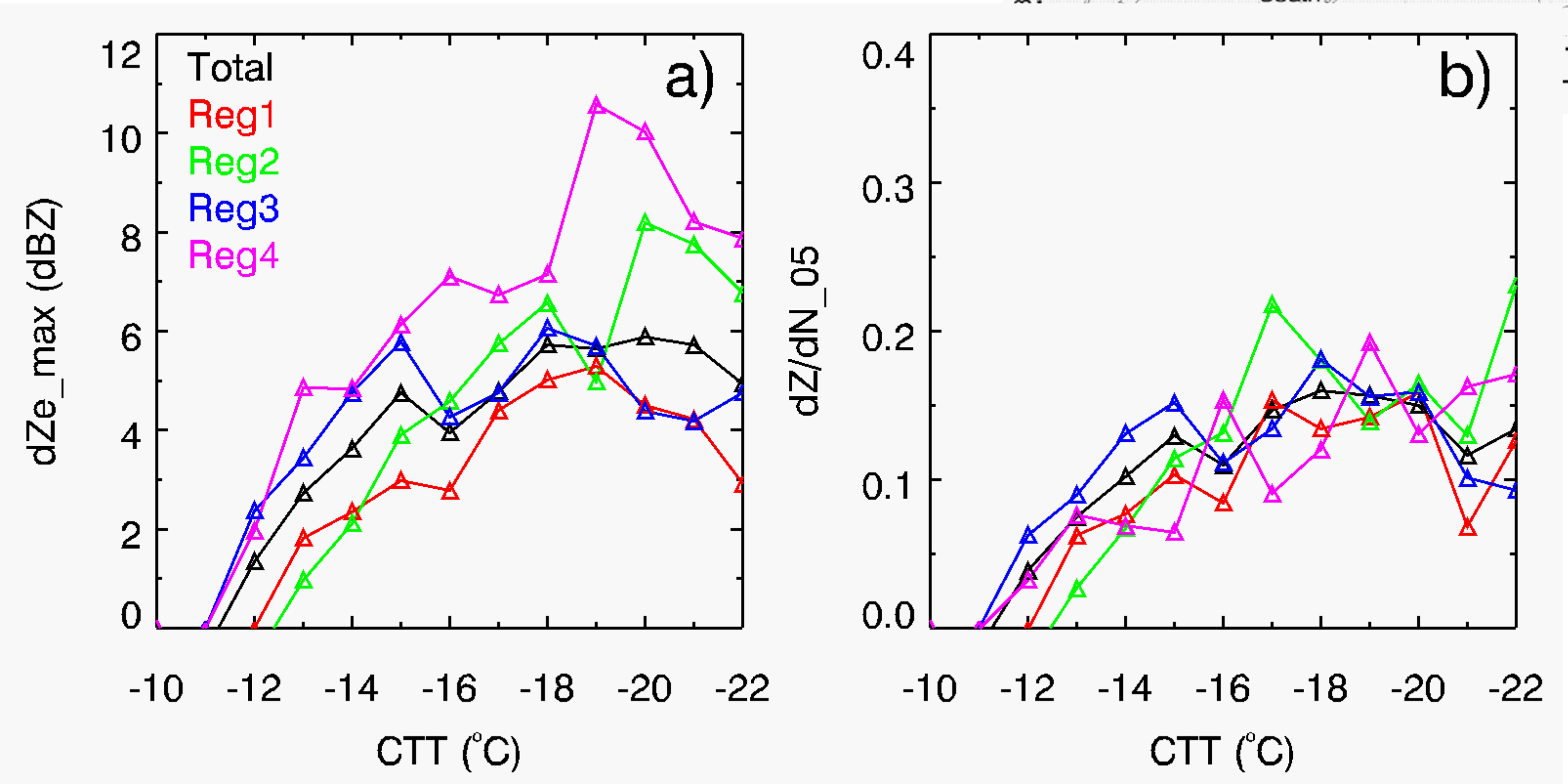
• Need a better understanding of aerosol property variations with ice concentration variations !

•Use CALIPSO measurements to estimate dust size and concentration.



Regional Dust Impact Differences

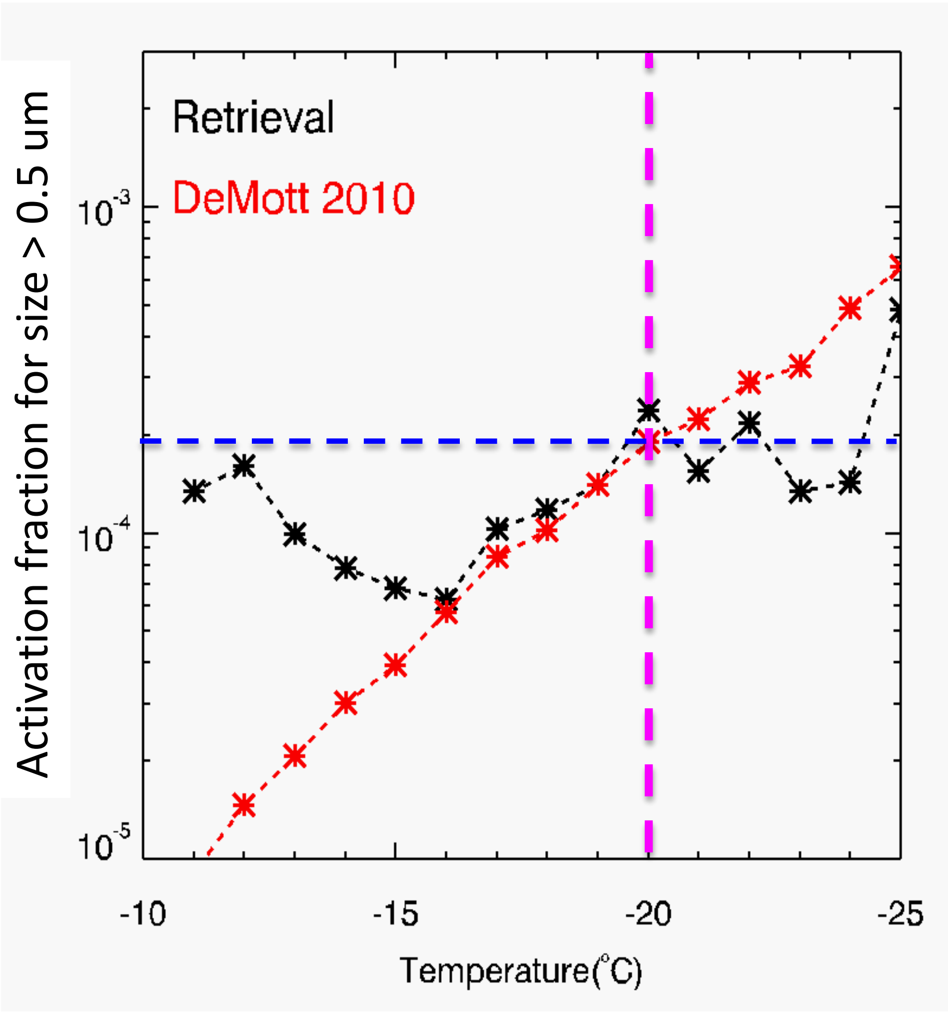




a) Z_e differences (dusty-south) indicate noticeable regional differences of dust impacts.

b) The normalized Z_e differences (with estimated larger than 0.5 µm dust concentration) indicate smaller regional differences of dust impacts.

Dust Activation Fraction



Working in progress.

PHILLIPS ET AL. 2013

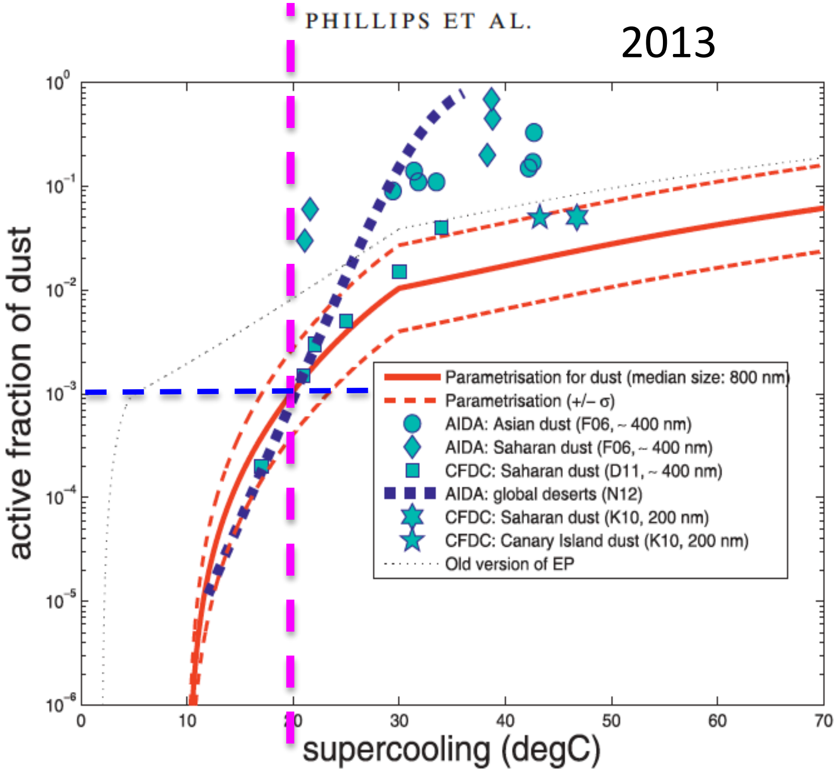


FIG. 5. Comparison of the frozen fraction of dust predicted by the parameterization with laboratory results from the AIDA chamber for immersion and condensation freezing from F06. The AIDA data are filtered to be close to water saturation ($S_i > S_i^w - 0.15$, where S_i^w is the saturation ratio with respect to ice at water-saturated conditions). Error lines are displayed for the scheme's prediction, based on uncertainties (relative errors) in its parameters, using a statistical model as clarified by Ph08. Also shown is laboratory data (CFDC) for Saharan soil dust from D11 and K10, who also observed Canary Island dust. The fit, for ice number (∝ surface area) by N12, to AIDA observations of dust from Israeli, Saharan, and Asian deserts is shown. This fit is applied to the same size distribution assumed for the EP. The original version of the EP from Ph08 is also plotted (thin dotted line).

David Mitchell at DRI:

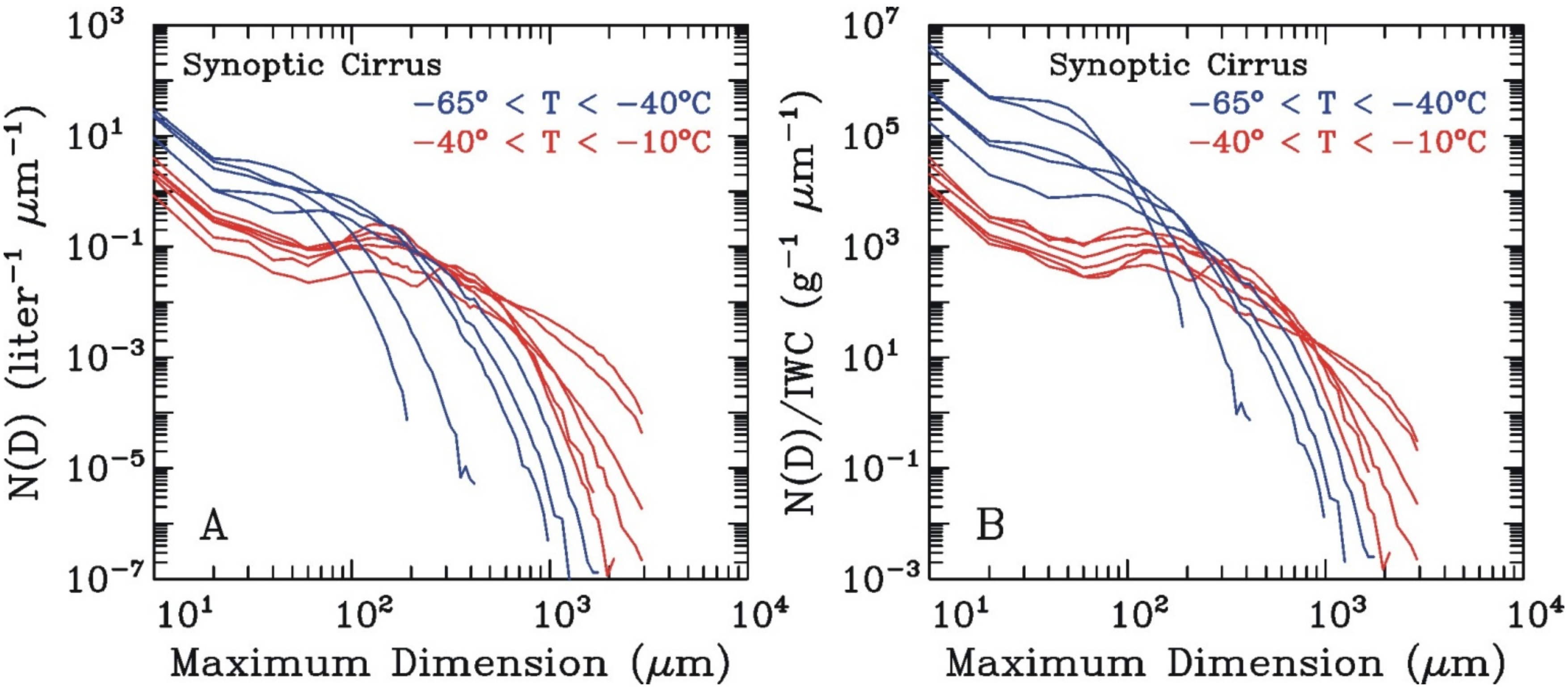
Evidence of homogeneous nucleation during SPARTICUS using in situ measurements

Evidence of Homogeneous Nucleation During SPARTICUS Using In Situ Measurements

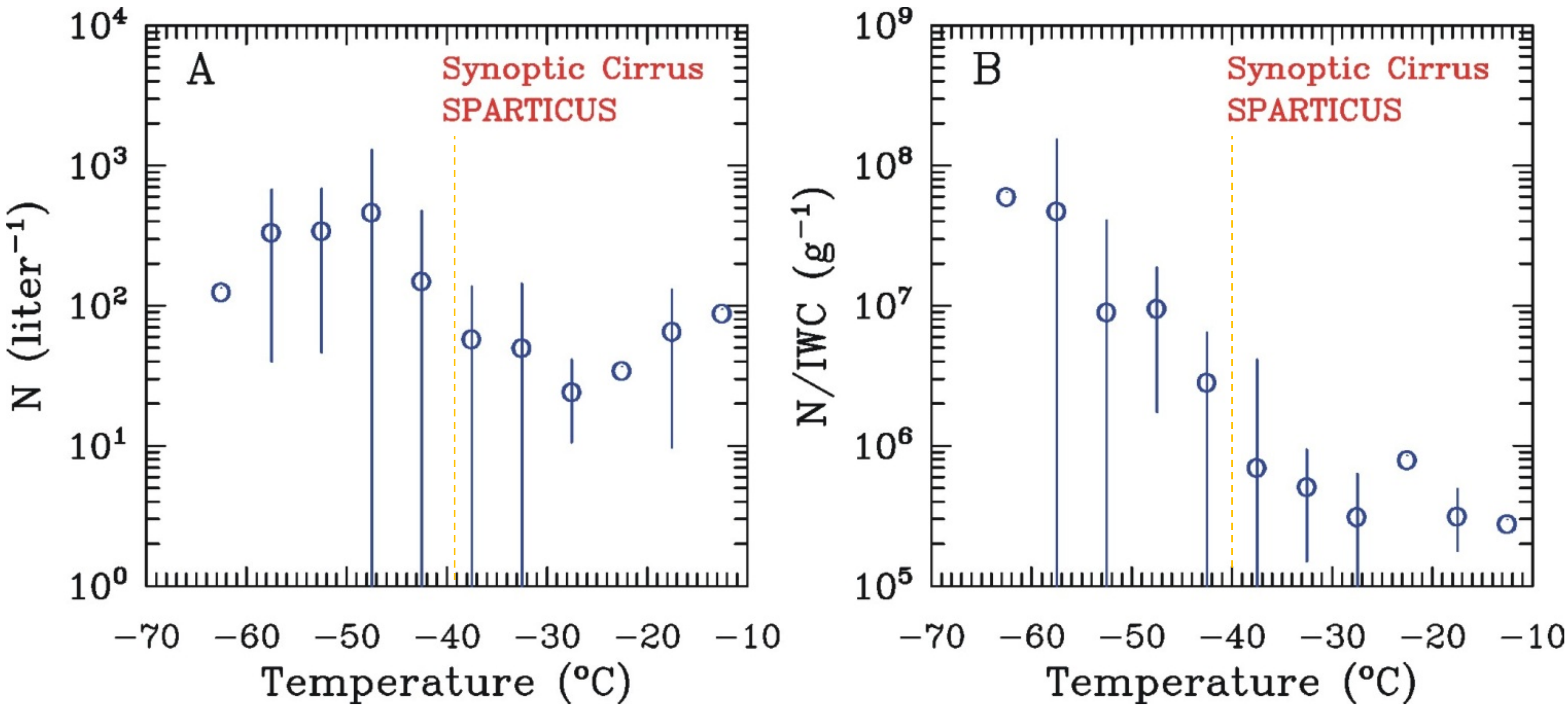
David L. Mitchell[1], Jennifer Comstock[2], Subhashree Mishra[3]

1. Desert Research Institute, Reno, Nevada
2. PNNL, Richland, Washington
3. CIMMS, Univ. Oklahoma, Norman Oklahoma

Temperature Dependence of Synoptic SPARTICUS PSD



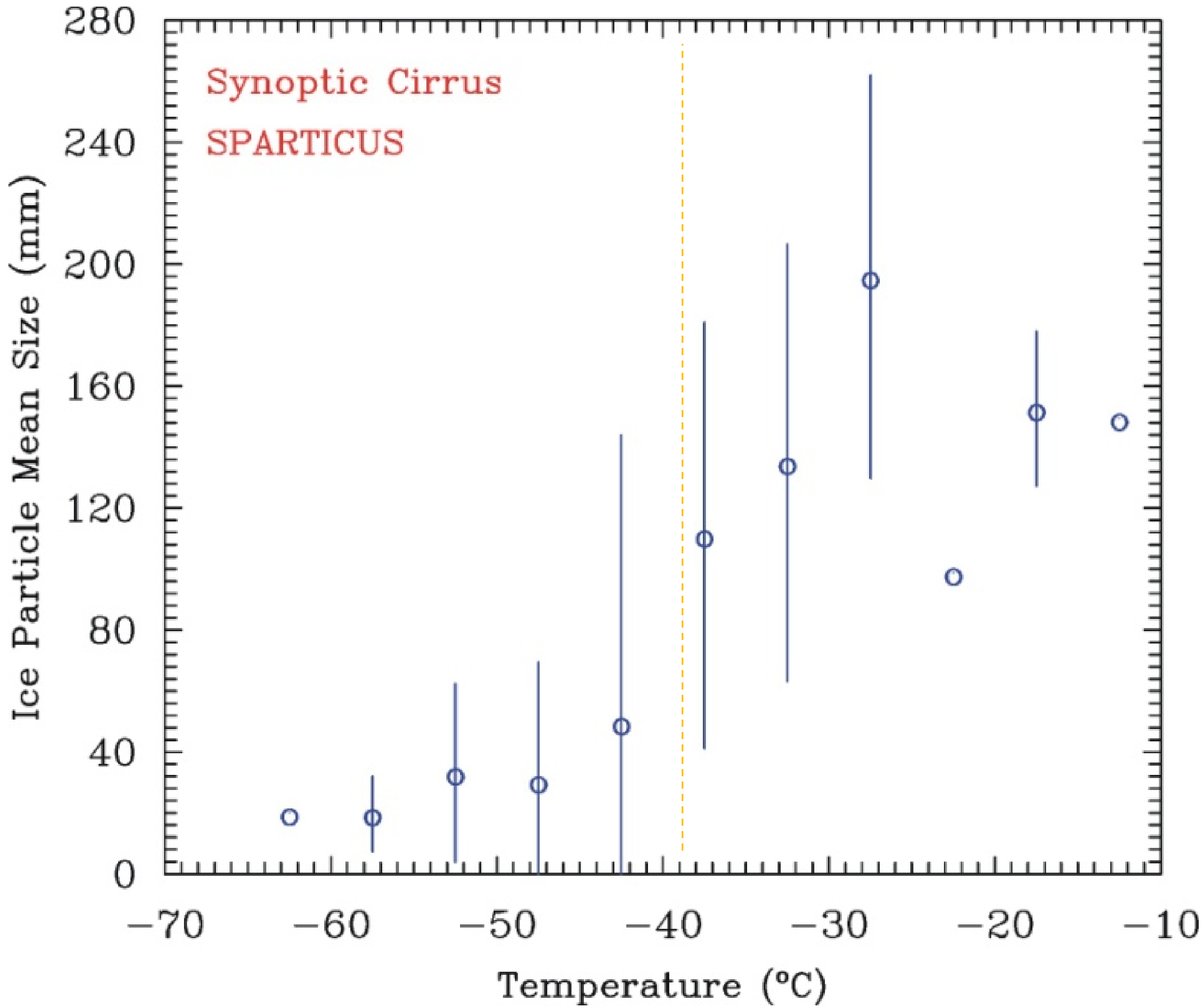
Evidence of homogeneous freezing nucleation?



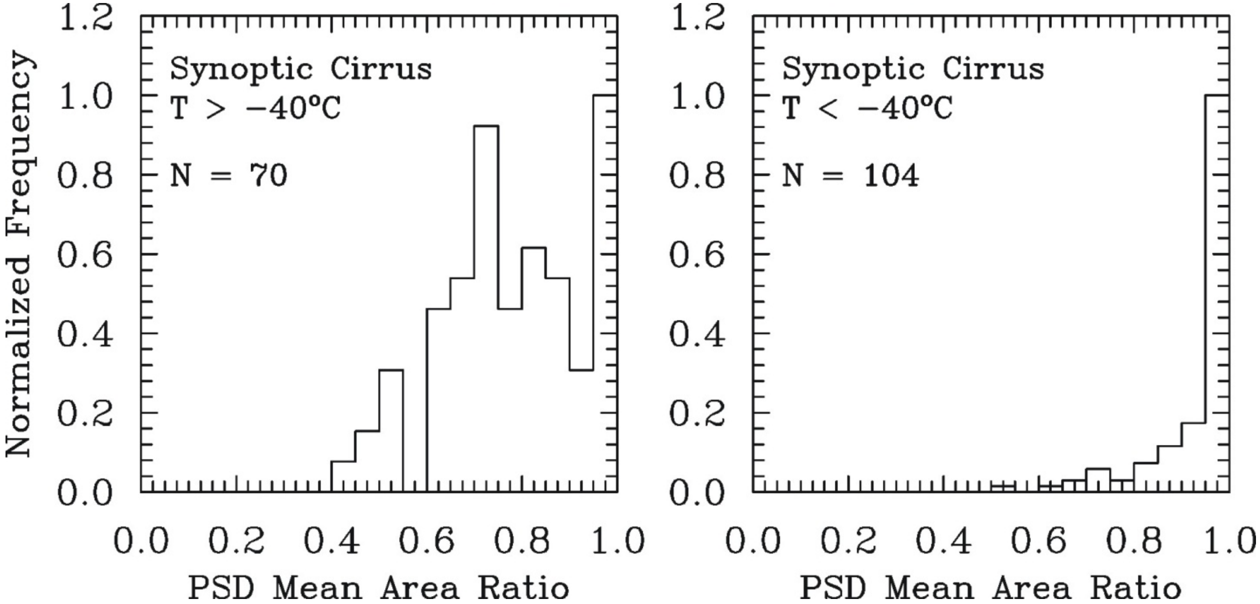
Ignoring aggregation & advection, the ratio N/IWC appears related to the nucleation rate coefficient J (# g^{-1} s^{-1}): $N/IWC \equiv \int_{t_o}^{t_f} J(t)\,dt$

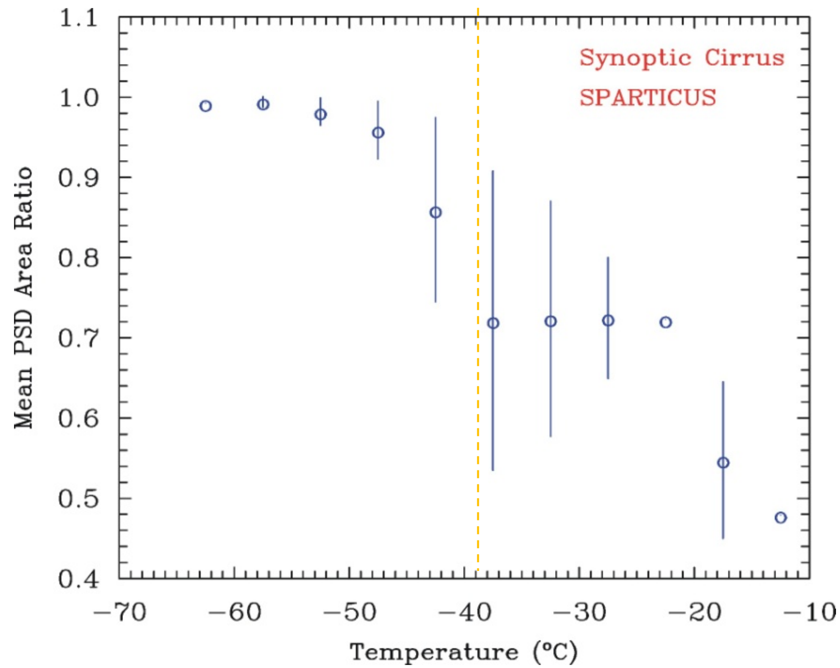
where t_o = ice initiation and t_f = sampling time of ascending parcel.

Temperature dependence of ice particle size

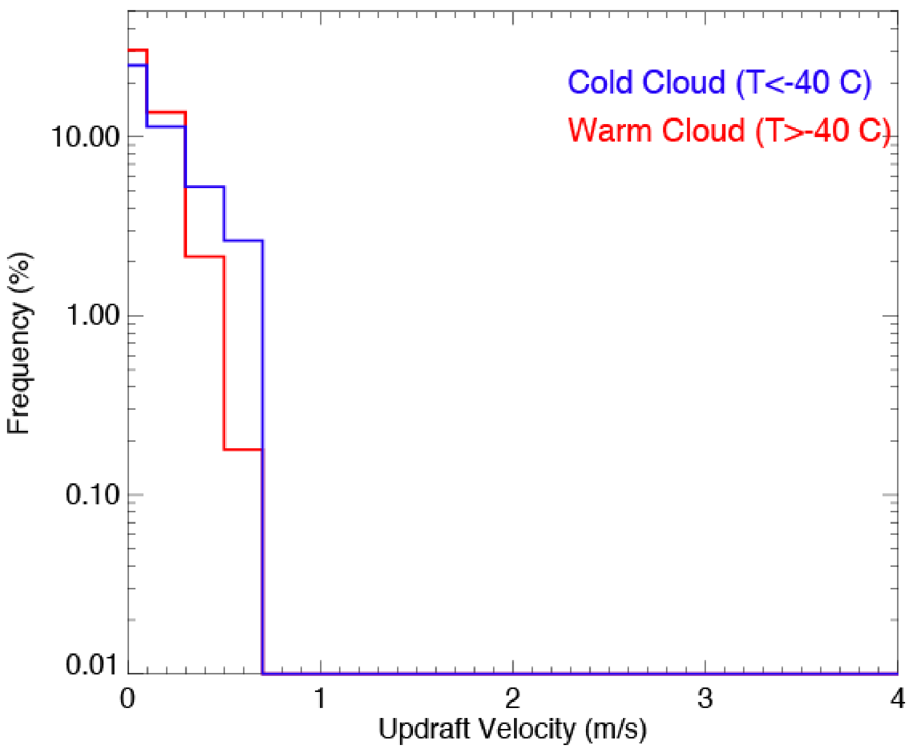


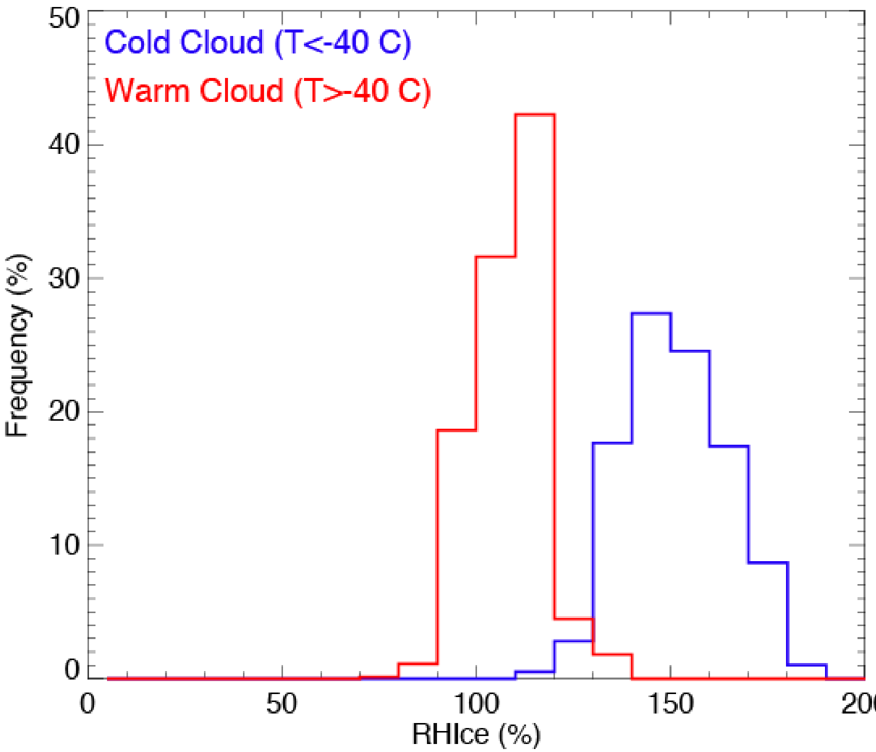
Temperature dependence of ice particle shape





Synoptic Cirrus PDFs for Updraft Velocity and RHi





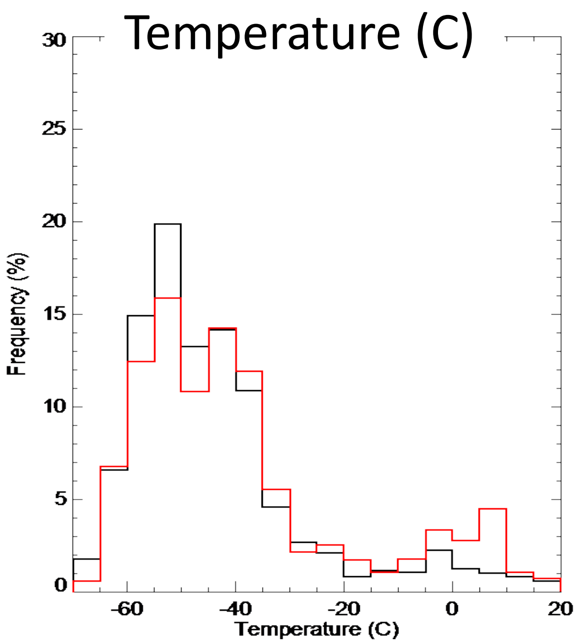
Updraft PDF confirms proper discrimination in selection of synoptic cirrus cases. RHi PDF shows remarkable separation between heterogeneous nucleation region (warm cloud) and region where homogeneous nucleation may occur. While homogeneous nucleation requires RHi > 140%, RHi may be < 140% when sampling ice crystals produced through homogeneous nucleation.

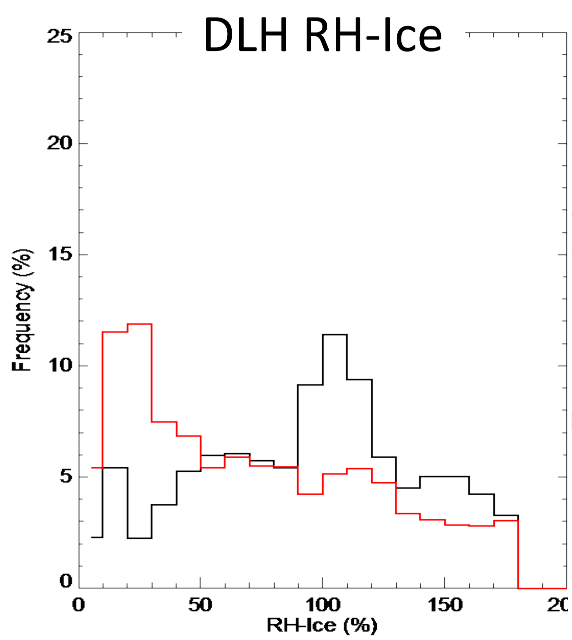
Jennifer Comstock:

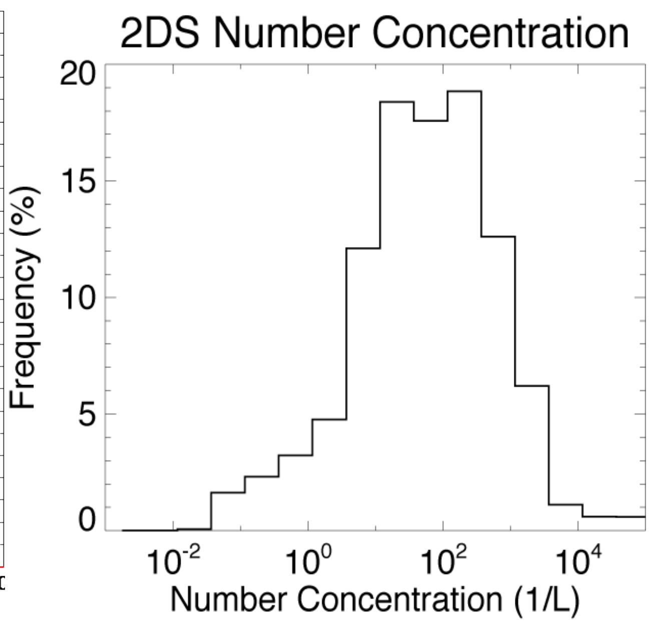
Factors influencing cirrus lifecycle using SPartICus data

Factors influencing cirrus lifecycle using SPartICus data (J. Comstock)

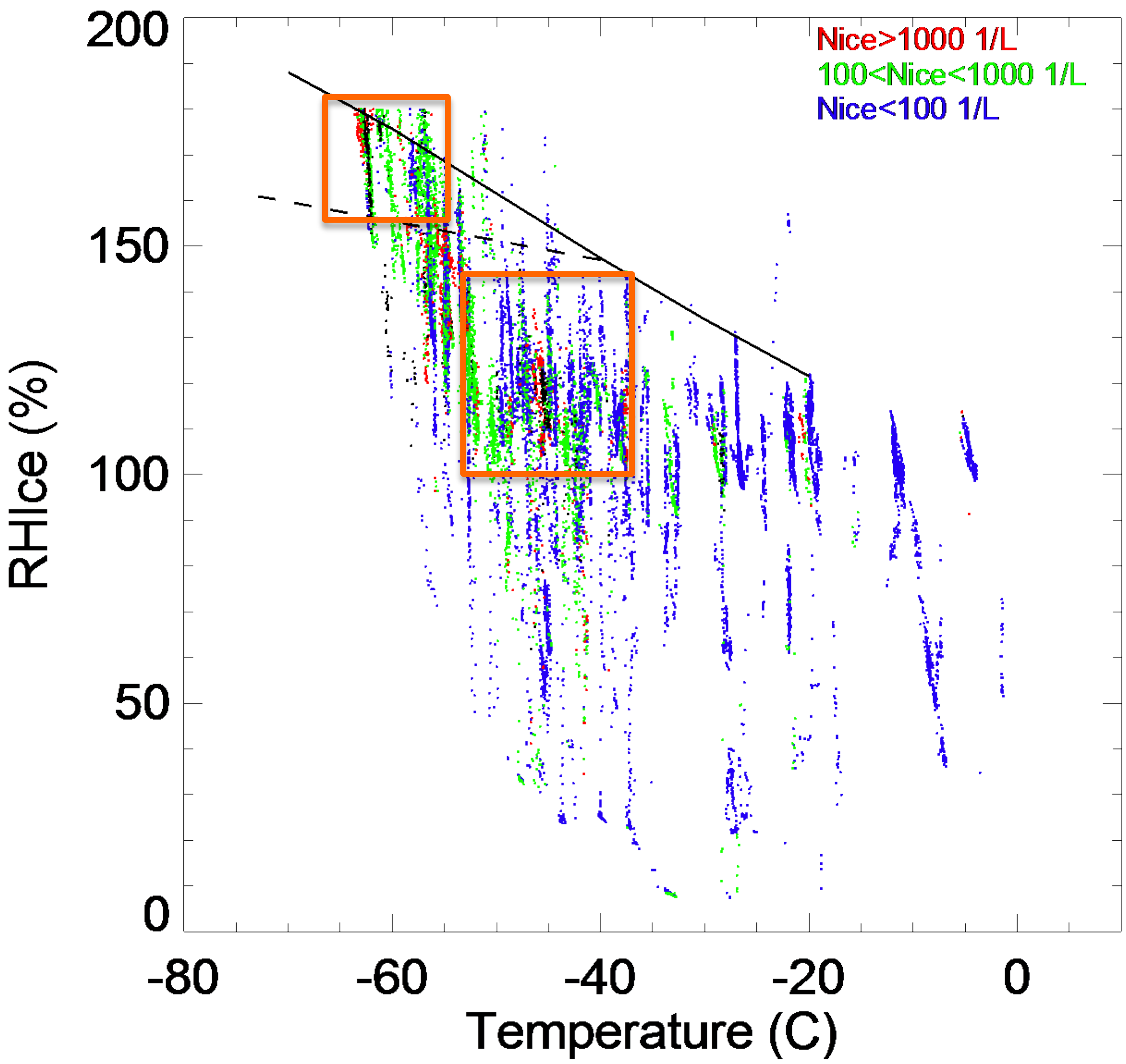
- Thermodynamic properties (temperature, humidity)
- Nucleation Mechanisms
- Vertical velocity variability
- Ice crystal number concentration



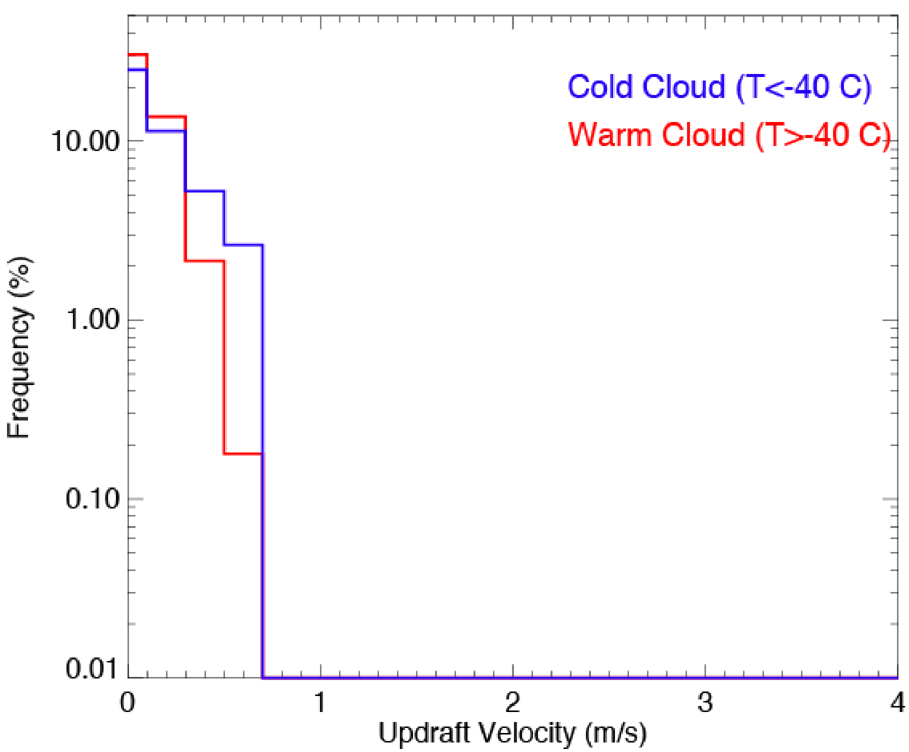


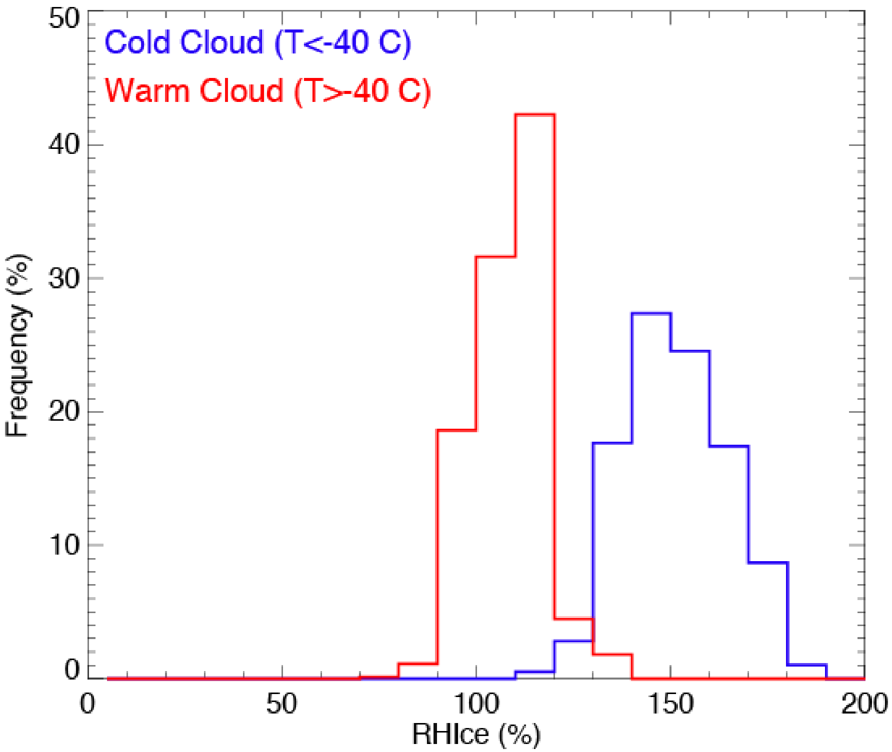


Thermodynamic Relationships



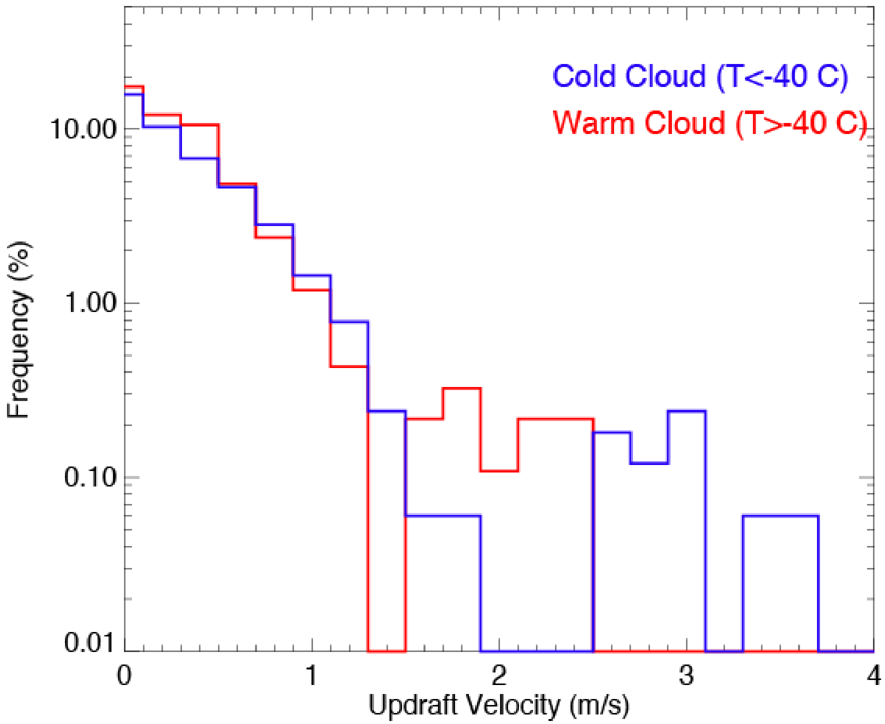
Synoptic Cirrus - Updraft Velocity and RHi

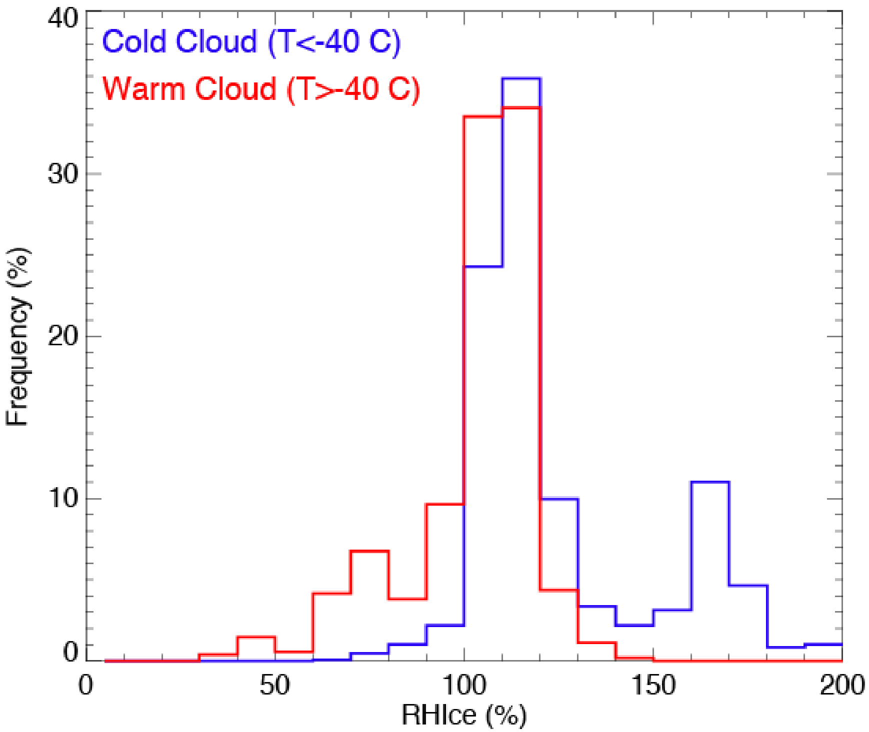




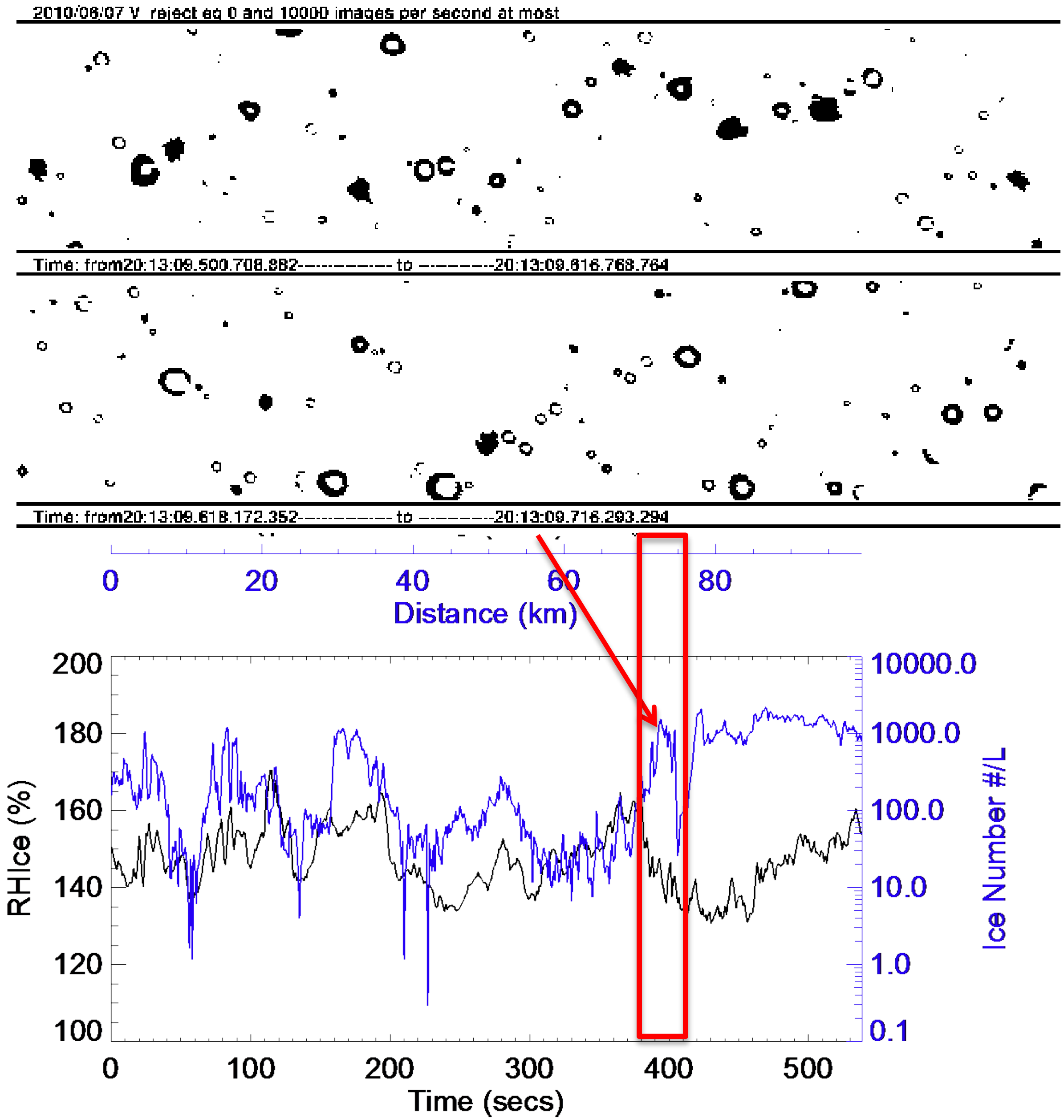
- Updraft velocity < 1 m/s
- RH-ice: larger separation for warm and cold clouds suggests homogeneous vs heterogeneous regimes

Anvil Cirrus PDFs for Updraft Velocity and RHi





- Updraft velocity is stronger, and less dependent on temperature (<1 m/s)
- RH-Ice: primary model 100-120%; secondary mode >150% (cold clouds)



Vertical Velocity
σ=0.5 m/s

Updraft=0.43 m/s
max=1 m/s

High N_{ice}
σ=548.2

T=-53 C

Jiwen Fan at PNNL:

Dust impacts on cloud and precipitation by serving as IN

1. Dust Impacts on California Winter Clouds and Precipitation in CalWater 2011

- **Background**

Enhanced precipitation is observed in the cases with dust compared with those without dust. The hypothesis from the observational study is that dust enhances ice formation and precipitation (Ault et al. 2011).

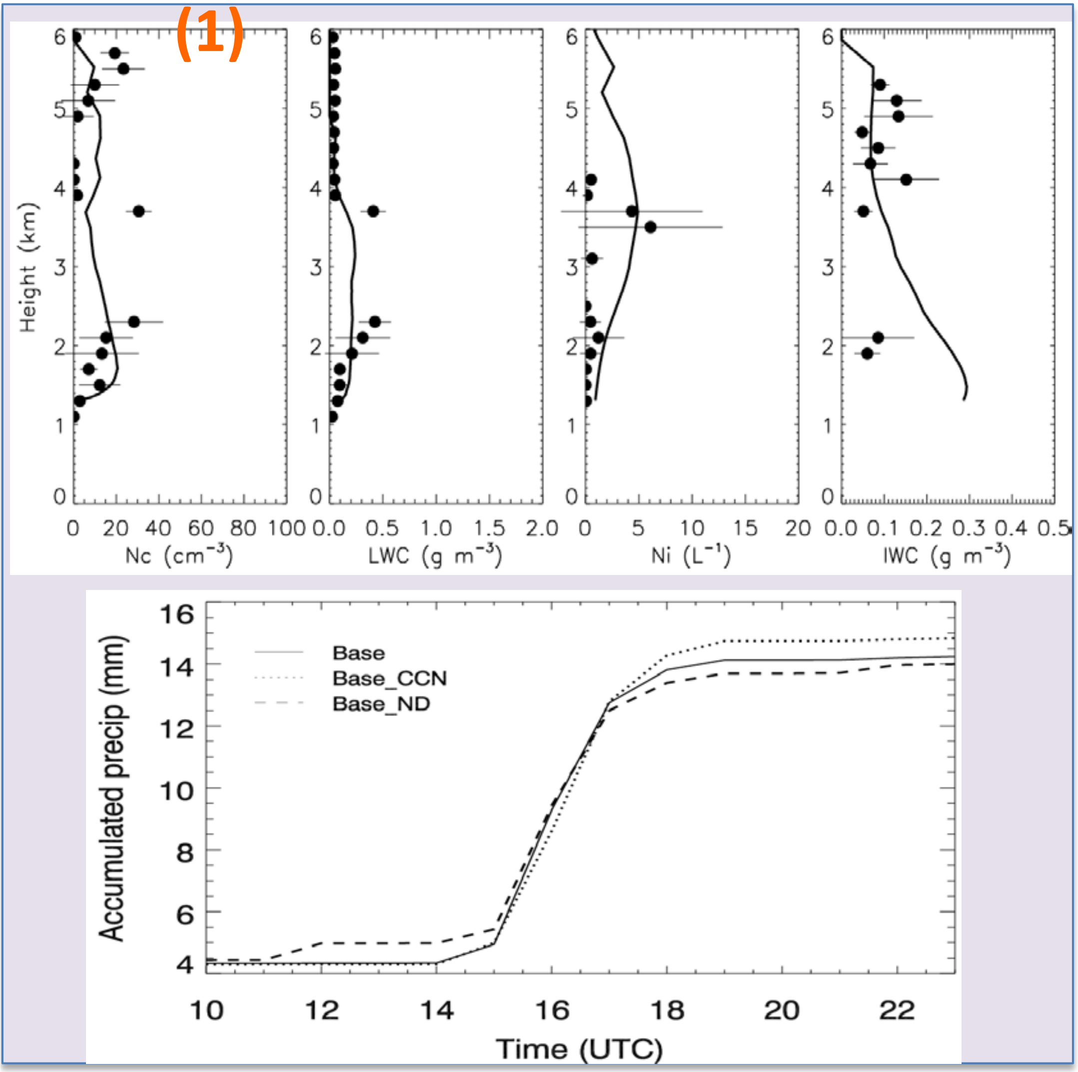
- **Goal**

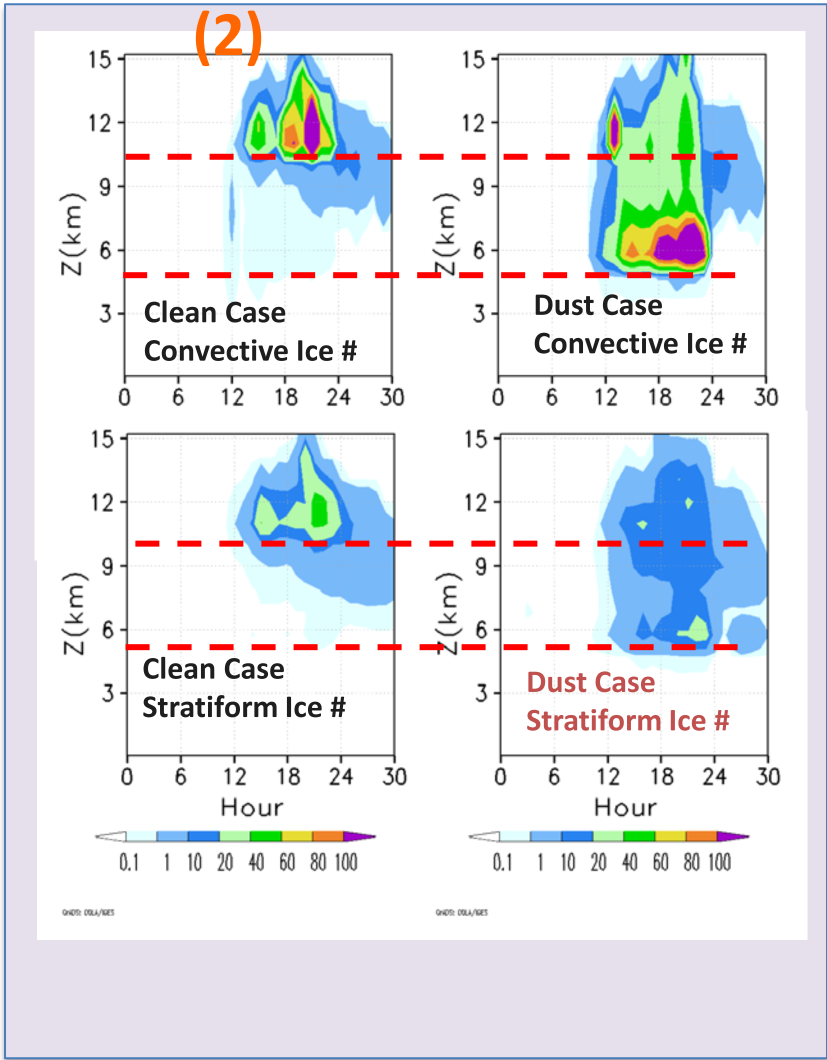
- To validate the hypothesis by simulating the cloud cases with dust during CalWater field campaign (Feb-Mar, 2011), and examine how the mountain precipitation is susceptible to increases in aerosols and long-range transport dust.

2. Impact of Sahara Dust Layer on Convective Cloud Development and Precipitation over the Tropical Eastern Atlantic Ocean (EAO)

- **Hypothesis**: For storms at EAO, dusts are transported to the upper layers through convective updrafts and then serve as effective IN, leading to stronger stratiform rain (Min et al. 2009).
- **Goal:** to evaluate the hypothesis by simulating MCS with dust layer, and understand impacts of the Sahara dusts on cloud properties and precipitation regimes over the region of the tropical (EAO)

Results


(1)
Height (km)
Nc (cm^{-3})
LWC (g m^{-3})
Ni (L^{-1})
IWC (g m^{-3})
Accumulated precip (mm)
Base
Base_CCN
Base_ND
Time (UTC)


(2)
Z(km)
Clean Case
Convective Ice #
Dust Case
Convective Ice #
Clean Case
Stratiform Ice #
Dust Case
Stratiform Ice #
Hour
0.1 1 10 20 40 60 80 100

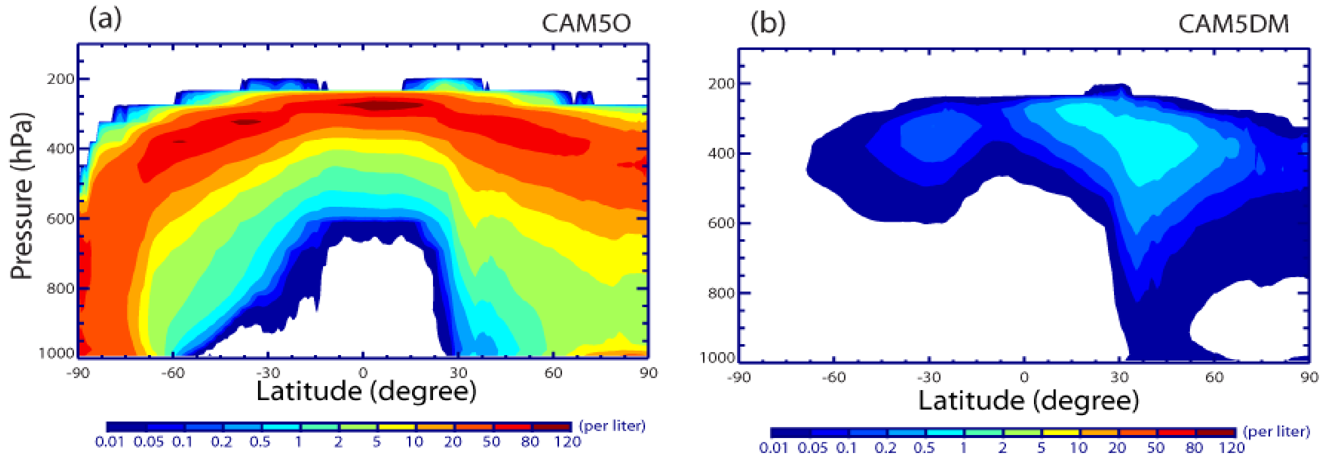
Chuanfeng Zhao at LLNL:

Sensitivity of CAM5 Simulated Clouds to Ice Nucleation Parameterizations and the Climate Impacts in the Arctic and Southern Ocean Regions

Sensitivity of CAM5 Simulated Clouds to Ice Nucleation Parameterizations and the Climate Impacts in the Arctic and Southern Ocean Regions (Xie, S., X. Liu, C. Zhao*, Y. Zhang, 2013, *J. Climate*)

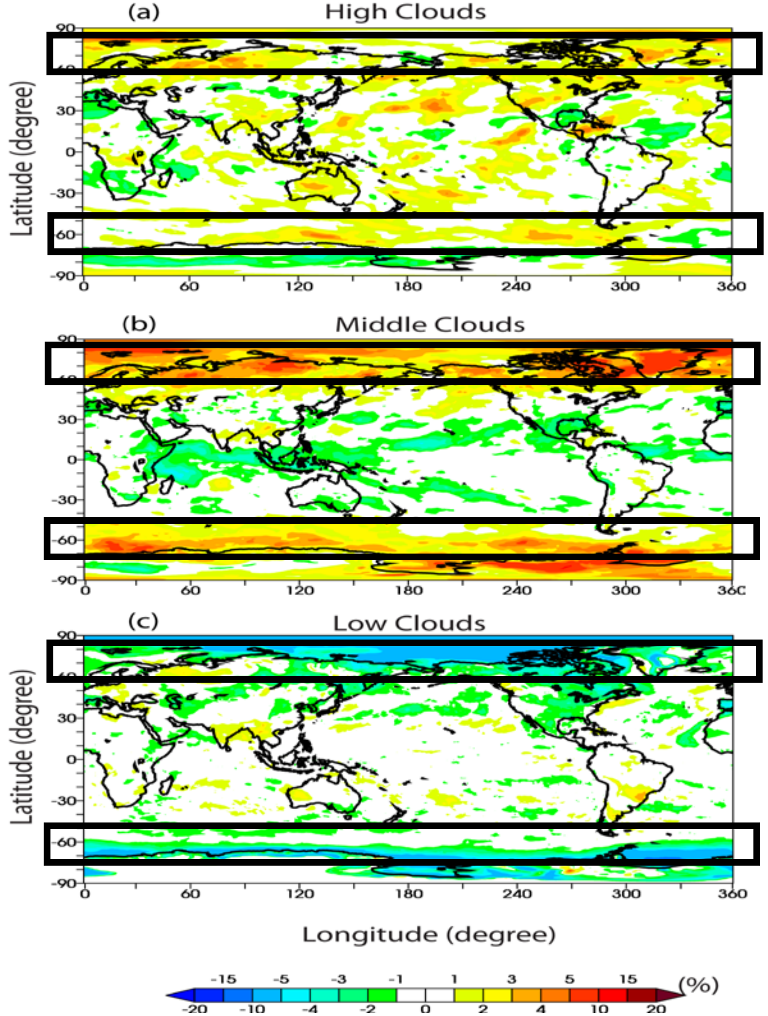
1. **Meyers et al. (1992):** $N_{IN} = \exp\{a+b*[100*(S_i-1)]\}$
2. **DeMott et al. (2010):** $N_{IN} = a*(273.16-T)^{b}(N_{aer,0.5})^{(c*(273.16-T)+d)}$

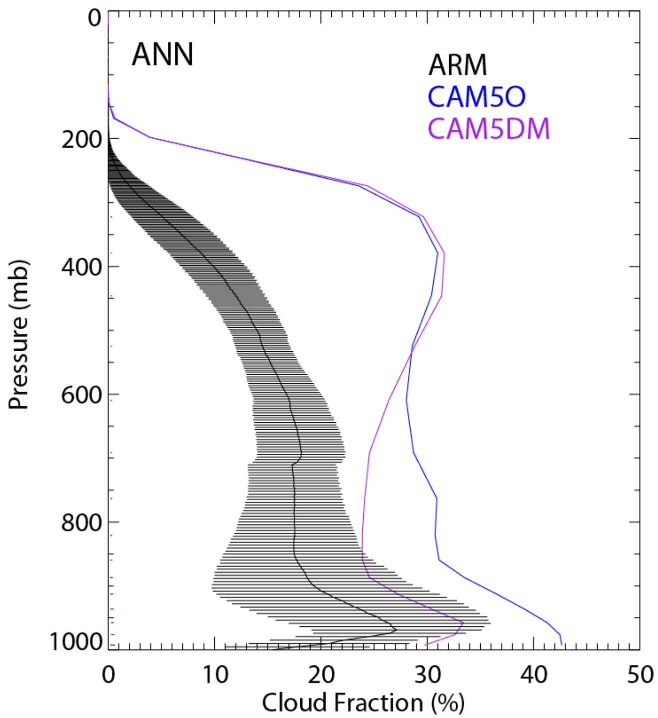
IN concentrations in mixed-phase clouds (-37°C<T<0°C)



Large Cloud Fraction Changes Seen in Mid- and Low- level Clouds for the two regions

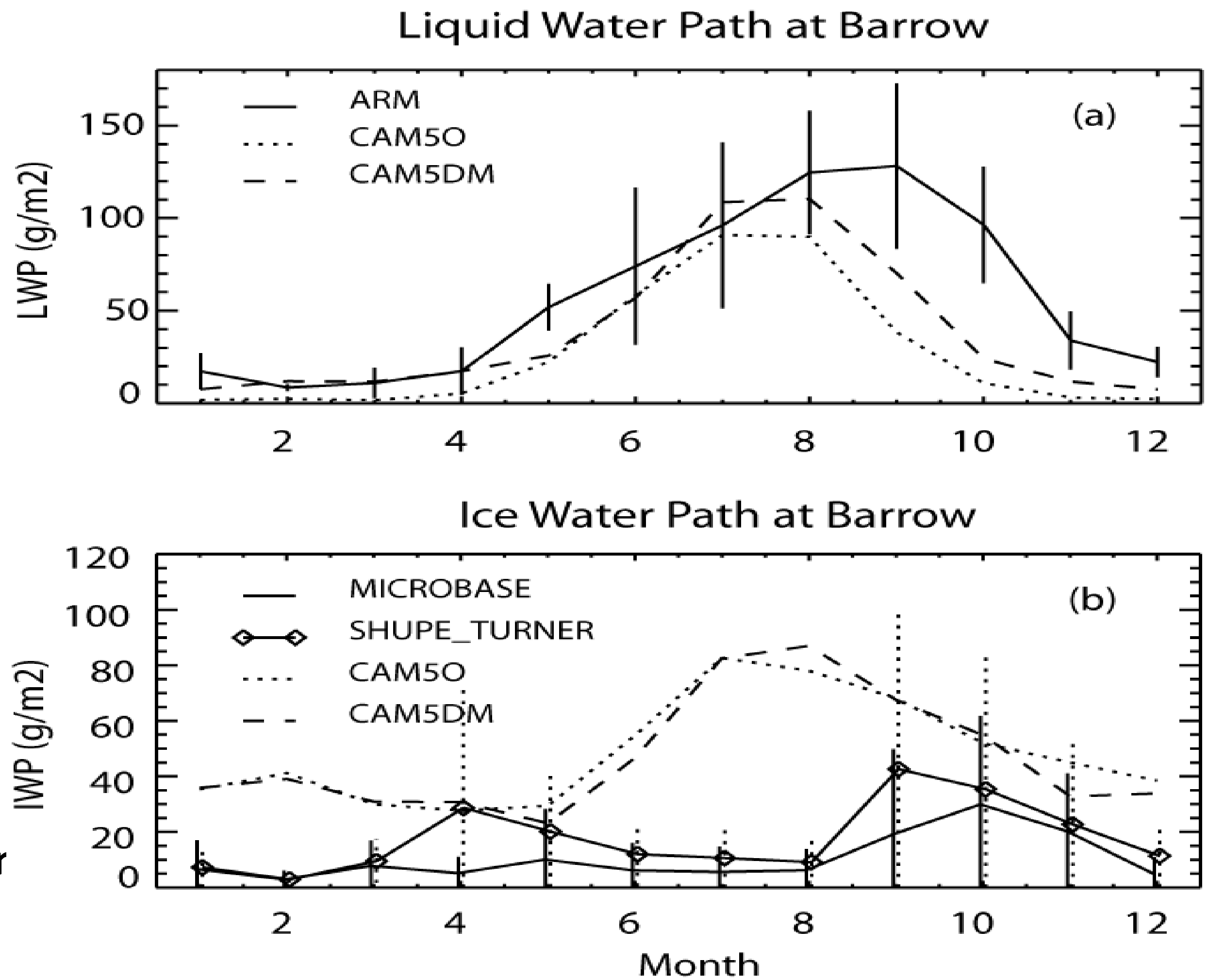
Differences in CF (CAM5DM – CAM5O)





Improved Low-level Cloud Simulation Compared to ARM at Barrow

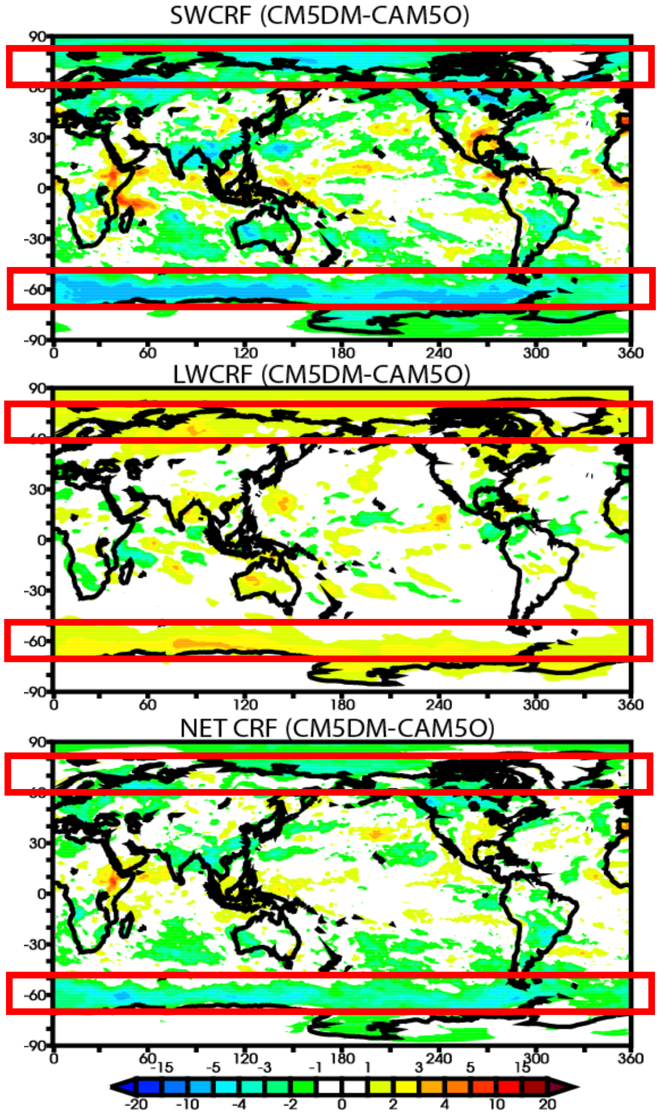
Large Impact Seen in Cloud Condensates



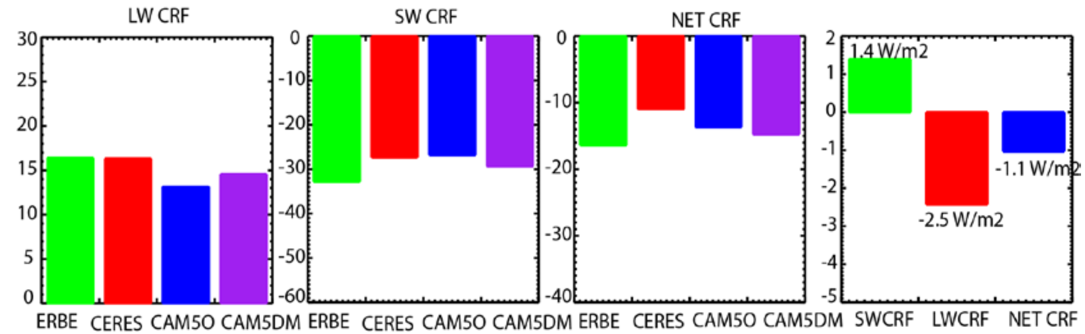
Ir

Noticeable Improvements in LWP and IWP compared to ARM observations

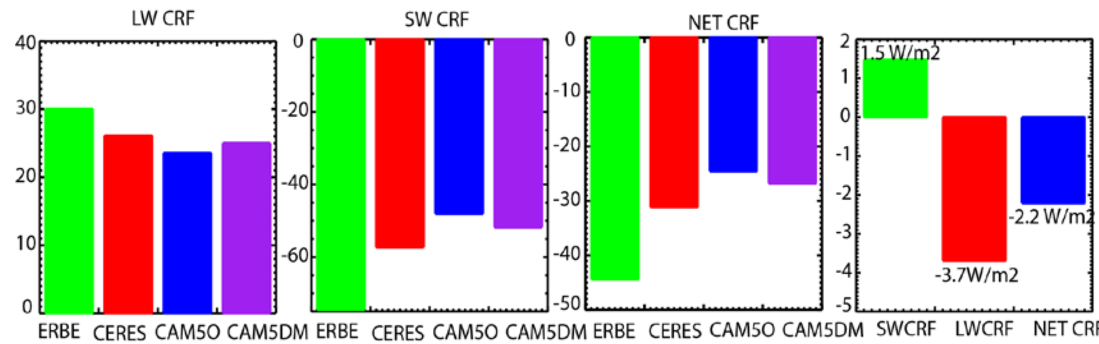
Stronger Cloud Radiative Forcing at TOA



Arctic: Both are comparable to Satellite Obs.



Southern Ocean: Noticeable Improvement



Measurable and Significant Progress on a 5-Year Time Scale

- Identify the uncertainty and nucleation mode with ice nuclei measurements (participate in International IN chamber Intercomparison Workshop, Kulkarni, DeMott)
- Conclusively explore the temperature-dependence of immersion nucleation on black carbon from different combustion sources (Kulkarni)
- Quantify marine sources of ice nuclei and their relationship with marine biogeochemistry (DeMott, Burrows)
- Understand the dominant nucleation mode (homogeneous versus heterogeneous nucleation) in cirrus clouds and its dependence on aerosol properties and updraft velocity (Liu, Comstock, Mitchell)
- Quantify the impact of ice nuclei (e.g., dust, biological aerosol) on clouds and precipitation using in situ and remote sensing measurements (Z. Wang, DeMott, Southern Ocean Proposal SOCRATES)
- Significantly improve the representations of ice nucleation and its optical and microphysical effects on clouds and precipitation in regional and global models (Liu, Fan, Xie)