Direct Comparisons of Ice Microphysical Properties Simulated by the Community Atmosphere Model CAM5 with ARM SPartICus Observations

Xiaohong Liu[1], Chenglai Wu[1], Kai Zhang[2], Minghui Diao[3], Andrew Gettelman[4]
[1]University of Wyoming [2]Pacific Northwest National Laboratory
[3]San Jose Sate University [4]National Center for Atmospheric Research

Introduction

- Cirrus clouds are one of the key components in the climate system, and are vital to global energy and hydrologic cycles;
- There are large uncertainties in the model representations of clouds and aerosol-cloud interactions, especially for cirrus clouds, e.g., ice crystal properties, ice nucleation, autoconversion of ice to snow;
- Cloud micro-physical properties vary greatly in time and space. In-situ observations are valuable for providing insights into the discrepancies in model simulations of cirrus clouds.

SPartICus observations

SPartICus: Small Particles in Cirrus January-June 2010

- **Routine** aircraft in situ measurements in cirrus over ARM SGP
- new generation of probes designed to minimize artifacts due to ice shattering
- **Resolution: ~150 m; Duration: ~155 hr**
- **Cirrus analysis restricted to T≤-40°C;** Ice crystals (10.0 - 3000 µm);
- ***in situ* cirrus** observed over SGP (6°×6°).

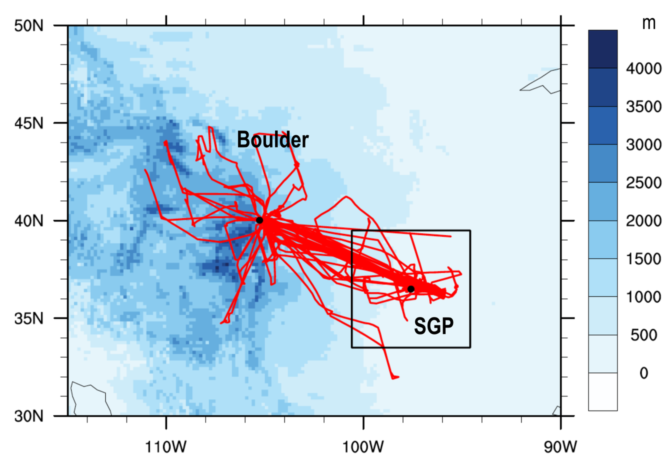


Figure 1. Aircraft trajectories during the SPartICus field campaign. Color shading shows the surface elevation. The square indicates a 6°×6° (~600 km×600 km) area centered at SGP, within which the measurements are used.

- Evaluate modeled statistics of Ni, IWC, Di, etc.
- Constrain the formation mechanism of ice crystals
- Constrain the aggregational growth of ice crystals

CAM5.3+ experimental design

- CAM5.3 + MG2 cloud microphysics (Gettelman and Morrison 2015) is run from Jan 2010 to June 2010 with specified dynamics. Offline meteorology (T, U, V) from GEOS5 analysis are used to drive the model, while water species (water vapor, clouds, aerosols) are calculated by CAM5.3+. Anthropogenic aerosol and precursor gas emissions for the year 2000 are used. The physics timestep is 1800 s. The horizontal resolution is 0.9°x1.25°, and the number of vertical layers is 56.
- To be collocated with HIPPO flights, CAM5.3+ is set to output the column results along or around the flight tracks. Model results for the four columns nearest to each flight track position are averaged to be compared with the observation at the track.

CAM5.3+ simulations

Simulation	Wsubi upper limiter	Preexisting ice	Ice nucleation	Dcs
Control	yes	no	Hom/Het	150 µm
PRE-ICE	no	yes	Hom/Het	150 µm
HET	yes	no	Het	150 µm
DCS	yes	no	Hom/Het	250 µm

- **Wsubi upper limiter**: vertical velocity variance from TKE is limited to 0.2 m/s
- **Pre-existing ice:** consider the effect of pre-existing ice on ice nucleation so as to remove artificial Wsubi limiter (Shi et al. 2015)
- **Hom/Het:** Liu & Penner (2005) ice nucleation parameterization
- **Dcs:** threshold size for autoconversion of cloud ice to snow

Results

Correlation of ice number Ni with T and σ_w

Observed Ni shows the increasing trend at lower temperatures, and Ni is > 100 L^{-1} at T<-60 °C, indicating the homogeneous nucleation. Observed Ni also increases with larger vertical velocity variance (σ_w) at different spatial scales.

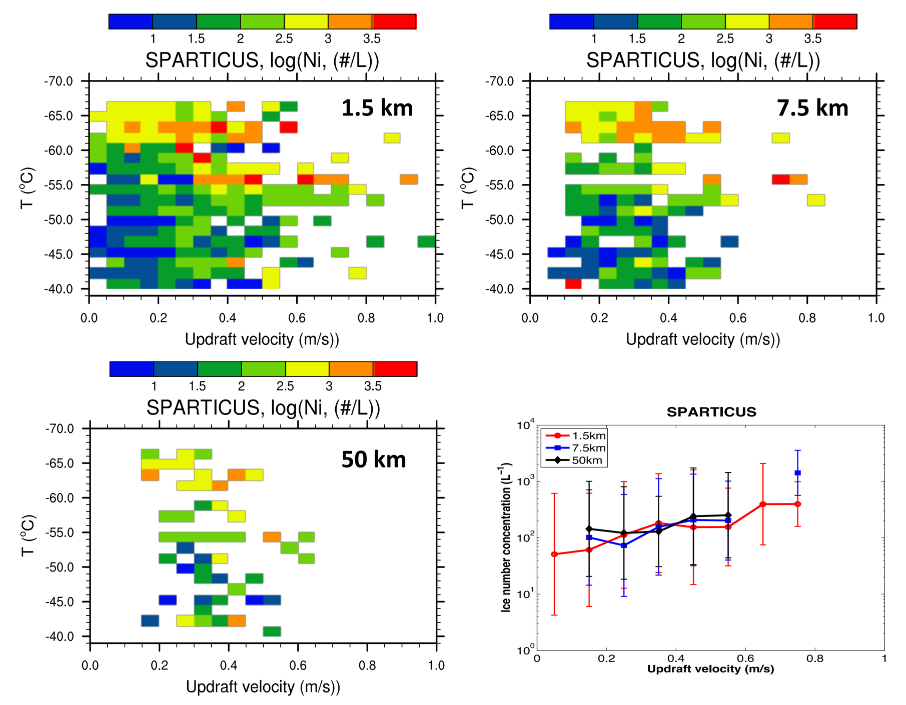


Figure 2. Observed relationship of ice crystal concentration (Ni) to temperature T (binned 1.5°C) and vertical velocity variance σ_w (binned 0.05 m/s) at 1.5 km, 7.5 km and 50 km spatial scales, and Ni variation with σ_w

Model broadly captures observed correlations between Ni and T and σ_w (only when the artificial limit is removed)

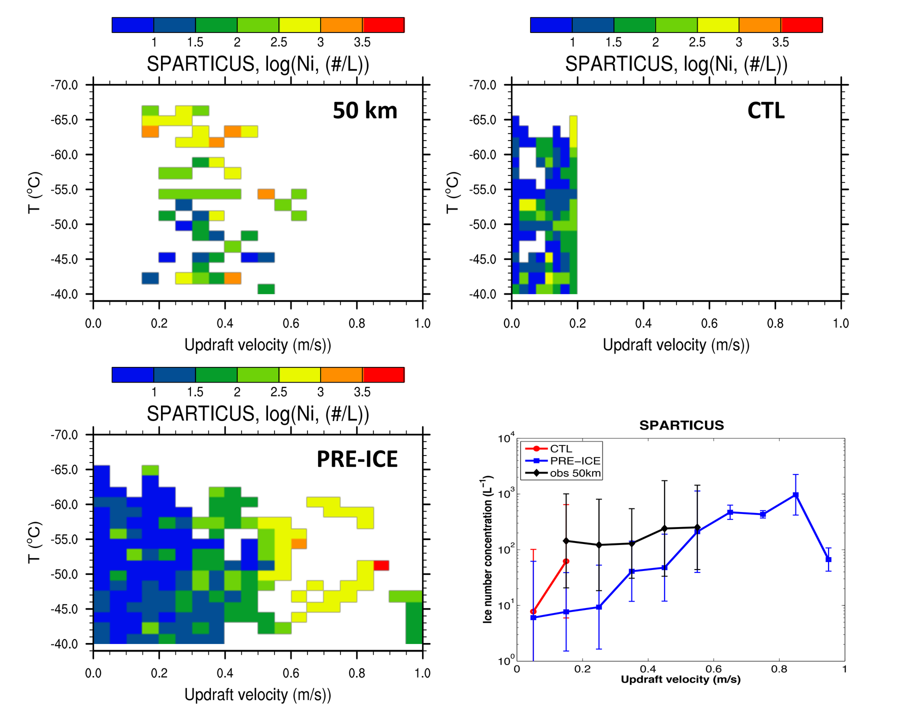


Figure 3. Comparison of observed relationship of ice crystal concentration (Ni) to temperature T (binned 1.5°C) and vertical velocity variance σ_w (binned 0.05 m/s) at 50 km spatial scale with model simulations (CTL and PRE-ICE)

Validation of modeled IWC, Ni, Di with observations

Model captures the observed increase of IWC with temperature. However, modeled IWC is significantly lower by 2-5 than observation. A higher Dcs (25 µm) increases modeled IWC.
Modeled Ni is also generally lower than observations.
As a result, modeled Dnm agrees well with observation, and model also captures the larger Dnm at higher temperatures.

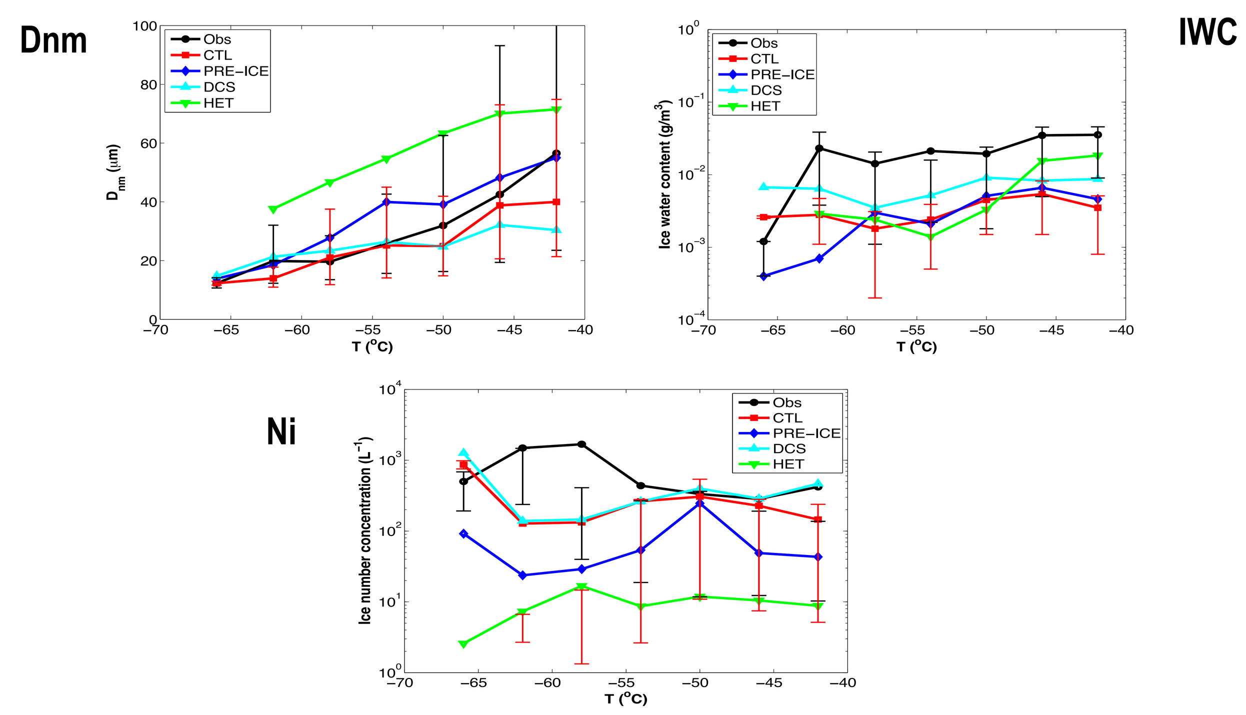
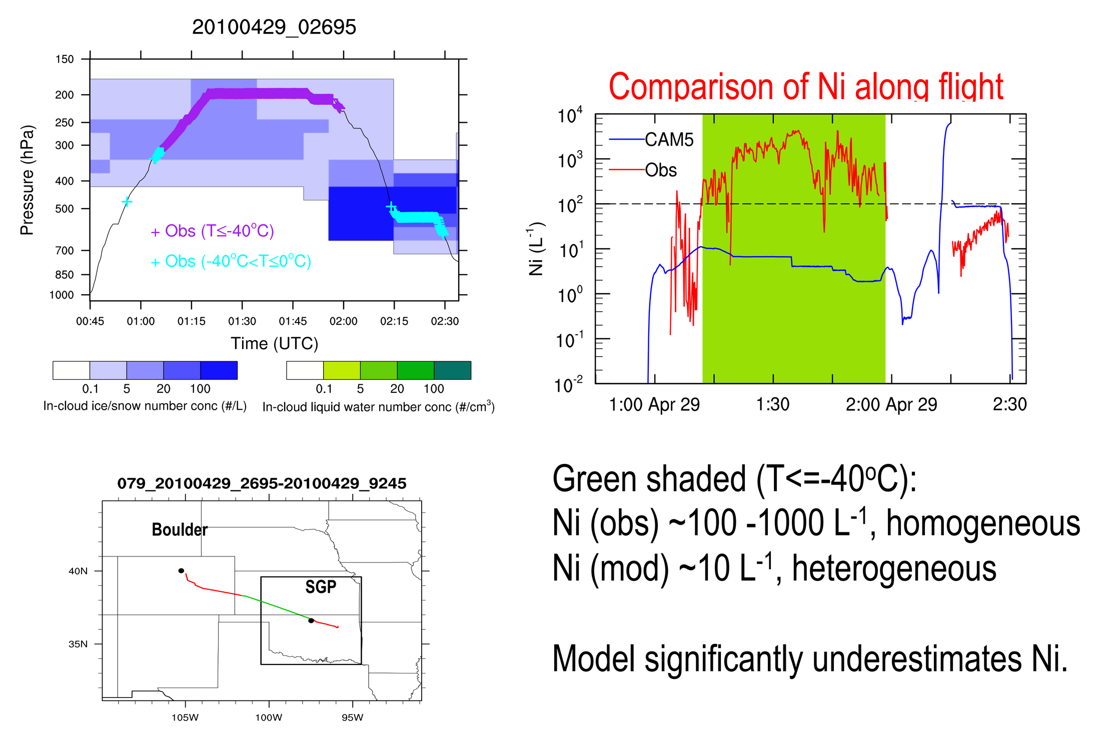


Figure 4. Comparison of observed ice crystal number mean diameter (Dnm), IWC, and Ni as a function of temperature with model simulations (CTL, PRE-ICE, HET, DCS).

Cloud occurrences during the flight on April 29, 2010



Green shaded (T<=-40°C):
Ni (obs) ~100 -1000 L^{-1}, homogeneous
Ni (mod) ~10 L^{-1}, heterogeneous

Model significantly underestimates Ni.

Figure 5. Comparison of modeled Ni with observation during a case study

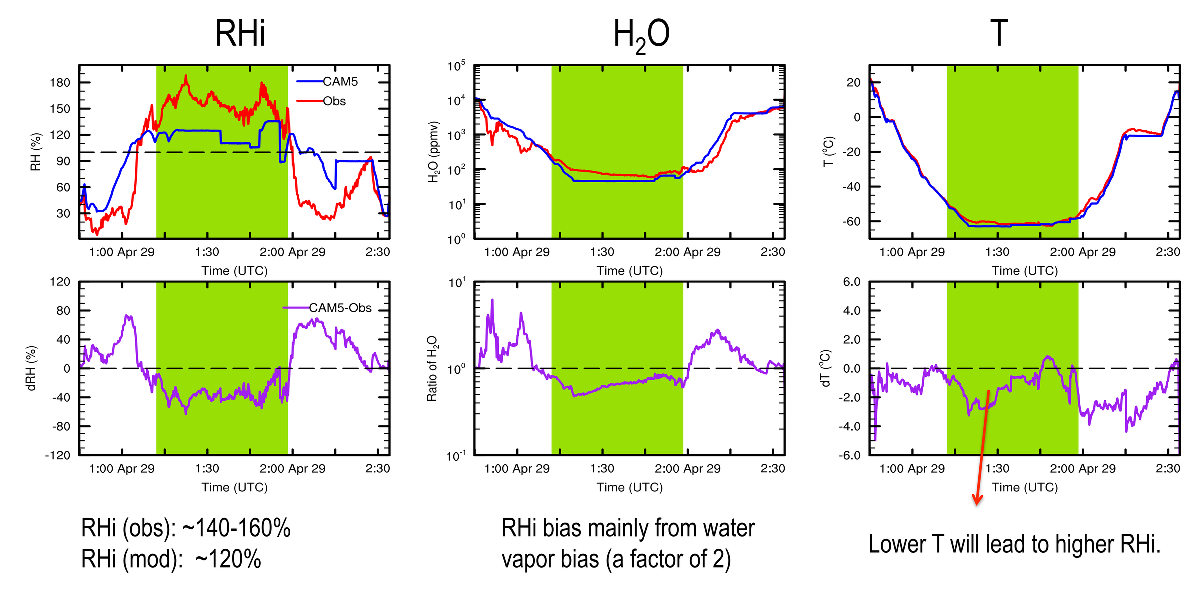


Figure 6. Comparison of modeled RHi, H_2O and T with observation during a case study

Summary

- Direct comparison of CAM5.3+ simulated ice clouds against SPartICus observations is conducted by collocating model output with aircraft flight tracks.
- CAM5.3+ can broadly capture the relationships of ice number N_i and environmental variables (T, w-variance).
- CAM5.3+ underestimates IWC and N_i by a factor of 2 to 5, although produces much better ice particle sizes compared to observations.
- Model low bias in N_i is often due to the RH bias attributed mostly to the bias of water vapor, not in T.