Direct comparisons of ice cloud macro- and microphysical properties simulated by CAM5.4 with HIPPO aircraft observations

Xiaohong Liu, Chenglai Wu
University of Wyoming
Minghui Diao
San Jose State University
Andrew Gettelman
NCAR

ASR
Atmospheric System Research

2016 Atmosphere Model Working Group Meeting
8 – 10 February 2016

Motivations

- Cirrus clouds are one of the key components in the climate system, and are vital to global energy balance and hydrologic cycles.
- There are large uncertainties in the model representations of clouds and aerosol-cloud interactions, especially for cirrus clouds.
- Cloud macro- and 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.

NSF HIAPER Pole-to-Pole Observations (HIPPO) Global flight campaign #1-5 (2009-2011) *(Wofsy et al., 2011)*

- **Latitudinal: 67°S to 87°N**
- **Vertical: ~600 transects** from surface to the upper troposphere and lower stratosphere (UT/LS)
- **Resolution: ~200 m; Duration: ~400 hr**
- **Cirrus analysis restricted to T≤-40°C;** Ice crystals (restrict to 75.0 μm - 3200 μm);
- Most cirrus clouds observed in HIPPO were extratropical *in situ* cirrus.

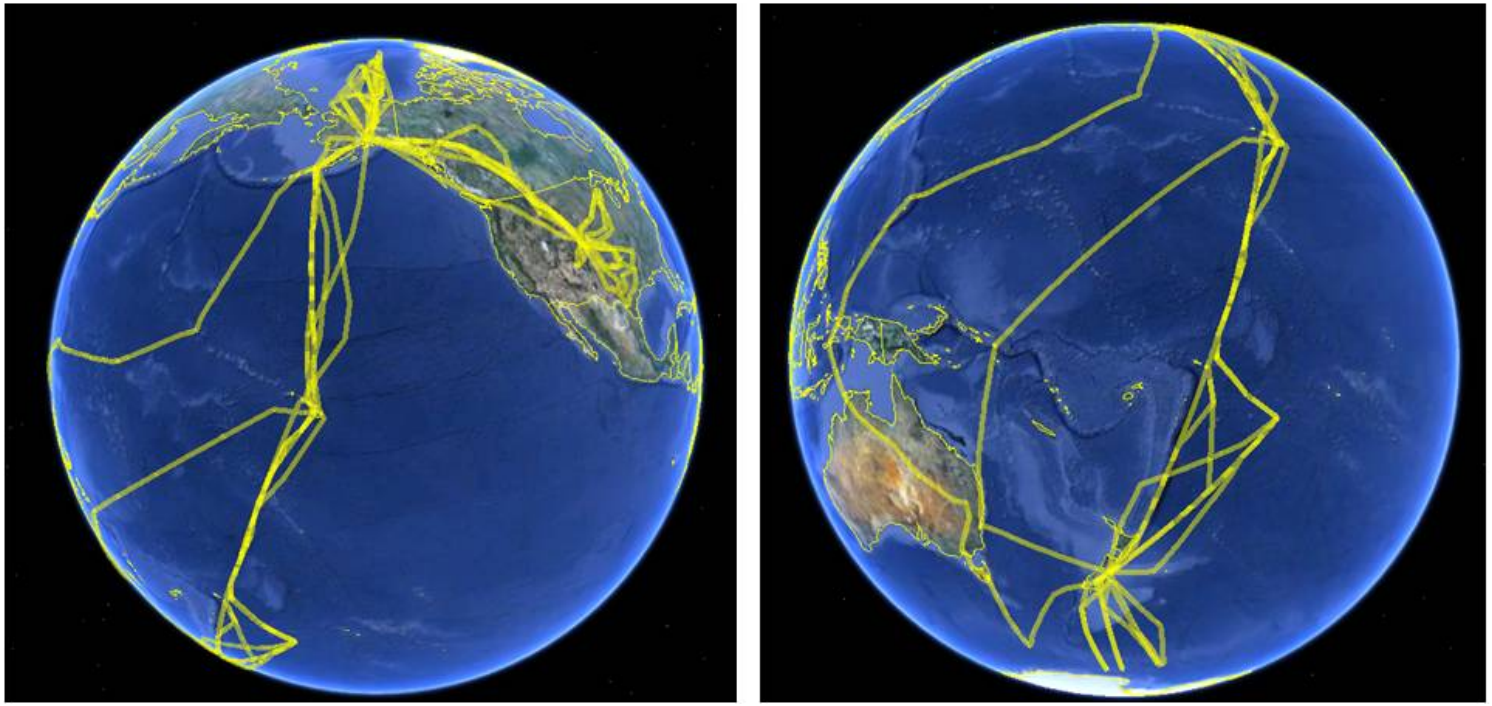


Figure from Dr. Minghui Diao

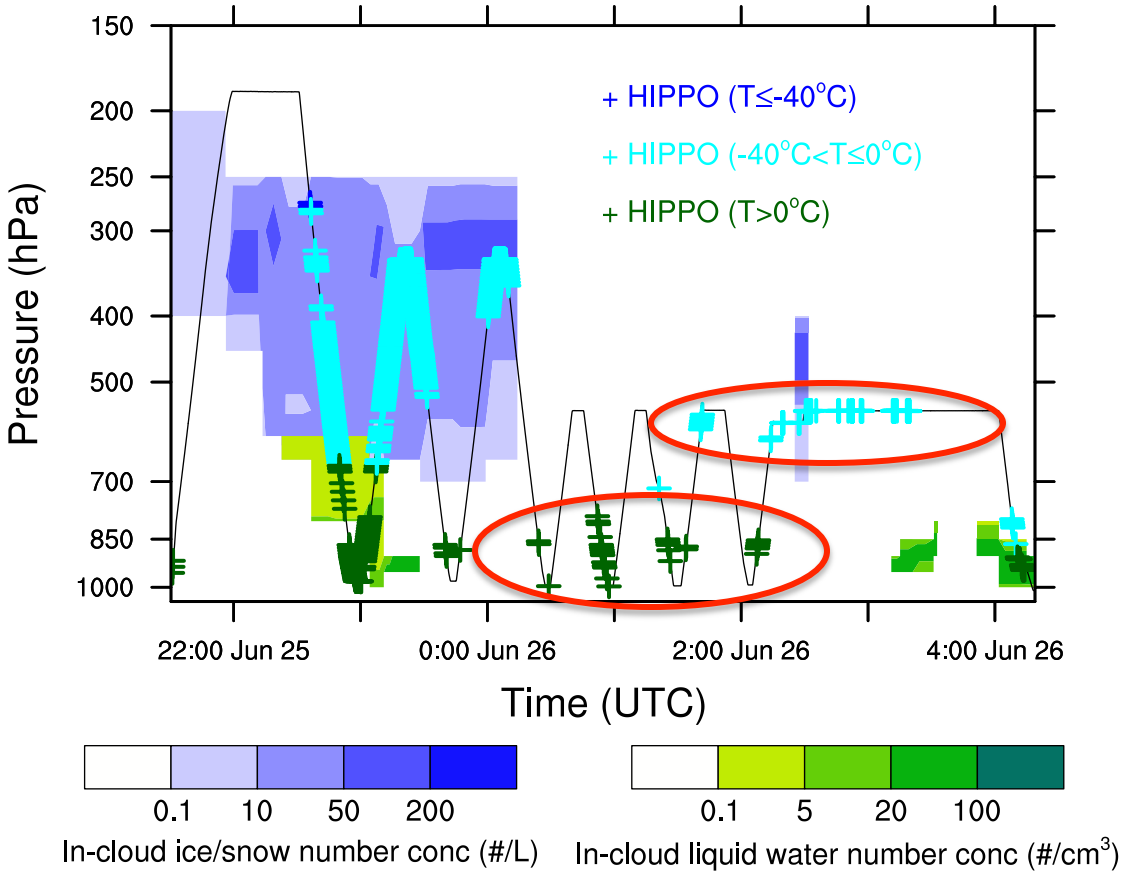
Community Atmospheric Model (CAM5)

- **Model: CAM5.4** (1.9°×2.5°) with MG2 cloud microphysics (Gettelman et al. 2015).
- **Direct comparisons** are made by:

  (1) nudging model meteorology (*U*, *V*, *T*) towards NASA MERRA reanalysis for HIPPO periods (2009-2011);

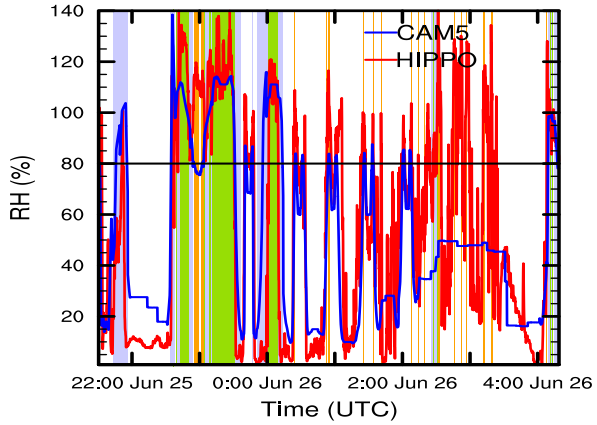
  (2) collocating model output with aircraft flight tracks.

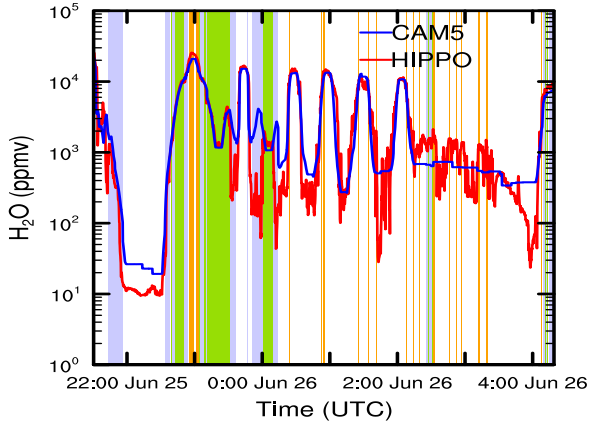
Cloud occurrences during the flight on June 25-26, 2011 (HIPPO)

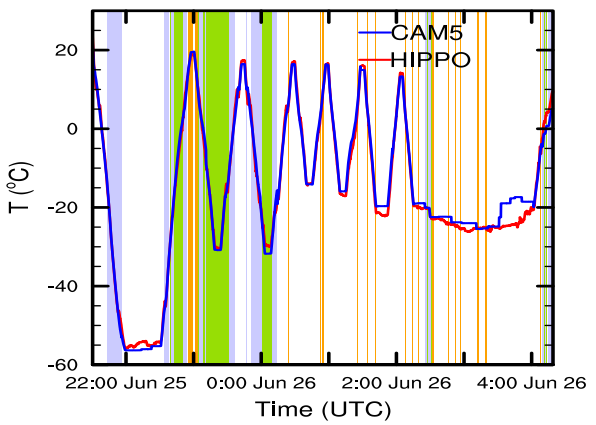


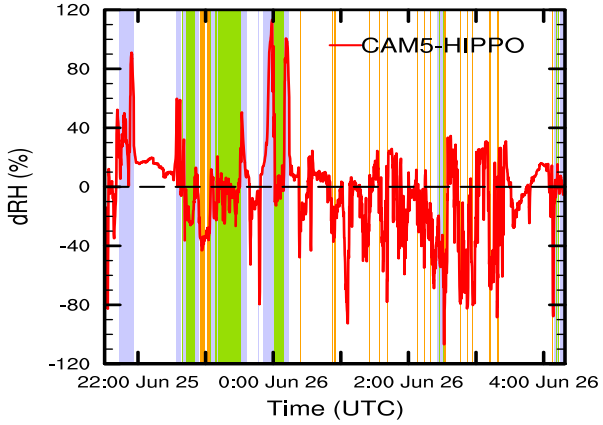
- **Good:** Model captures well the ice clouds in terms of vertical configuration and horizontal extension on June 25, 2011.
- **Bad:** Model misses a large portion of low-level liquid and mixed-phase clouds.

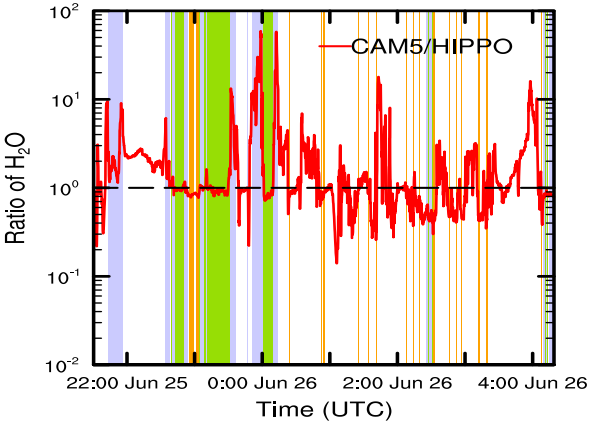
Variations of RH, H_2O, and *T* (top), and biases (bottom)

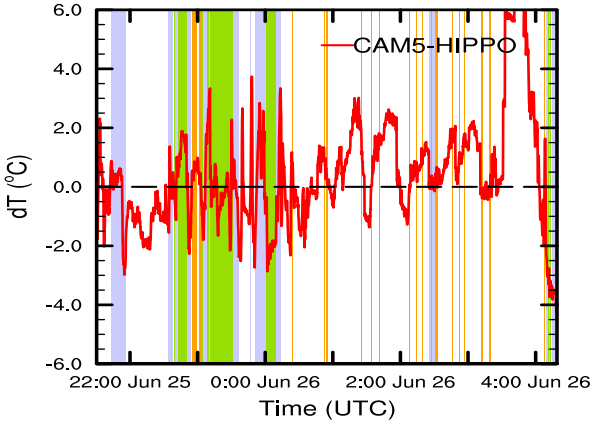










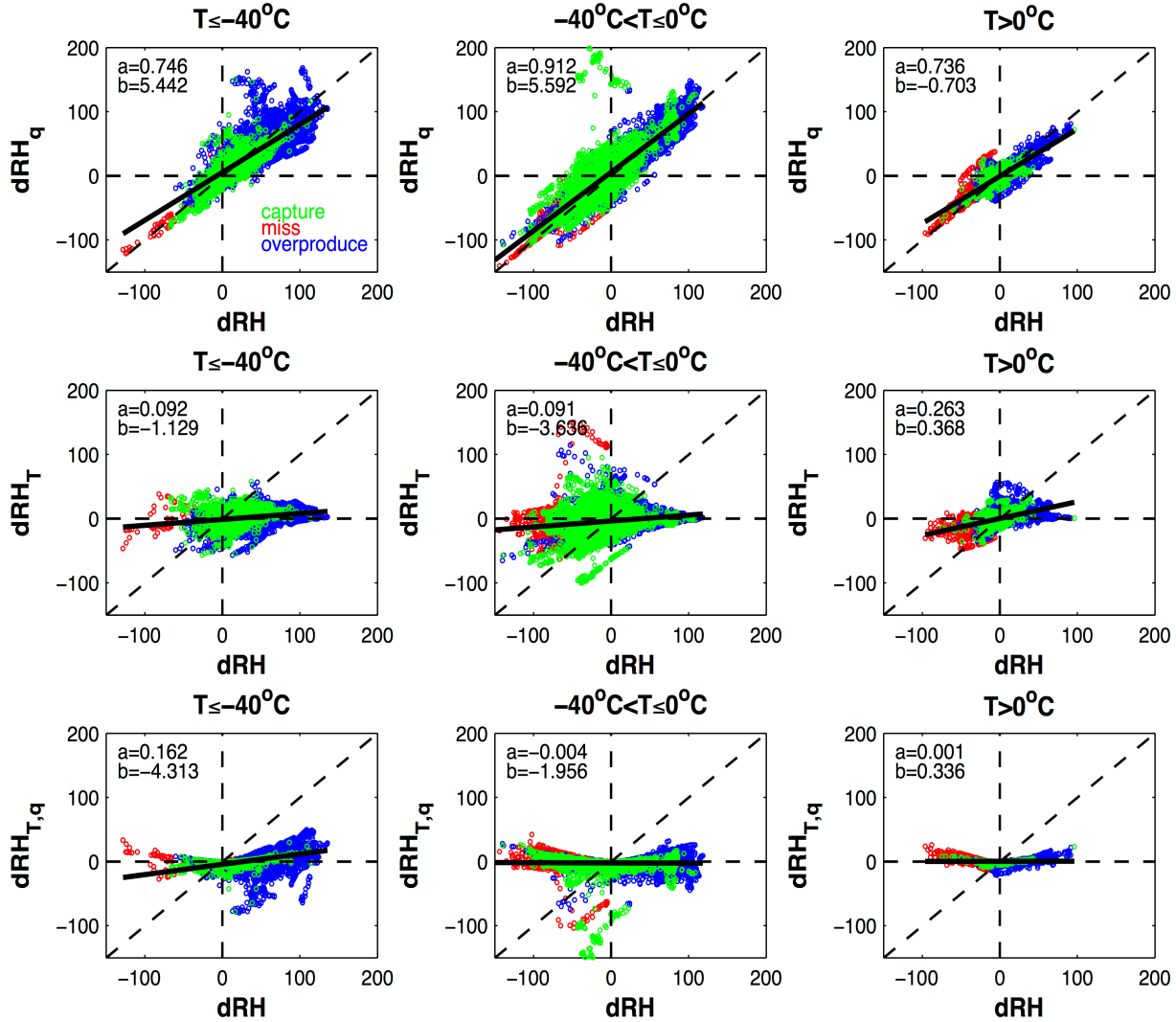


Model performance is shaded in **green** (‘**capture**’), **red** (‘**miss**’), and **blue** (‘**spuriously produced**’)

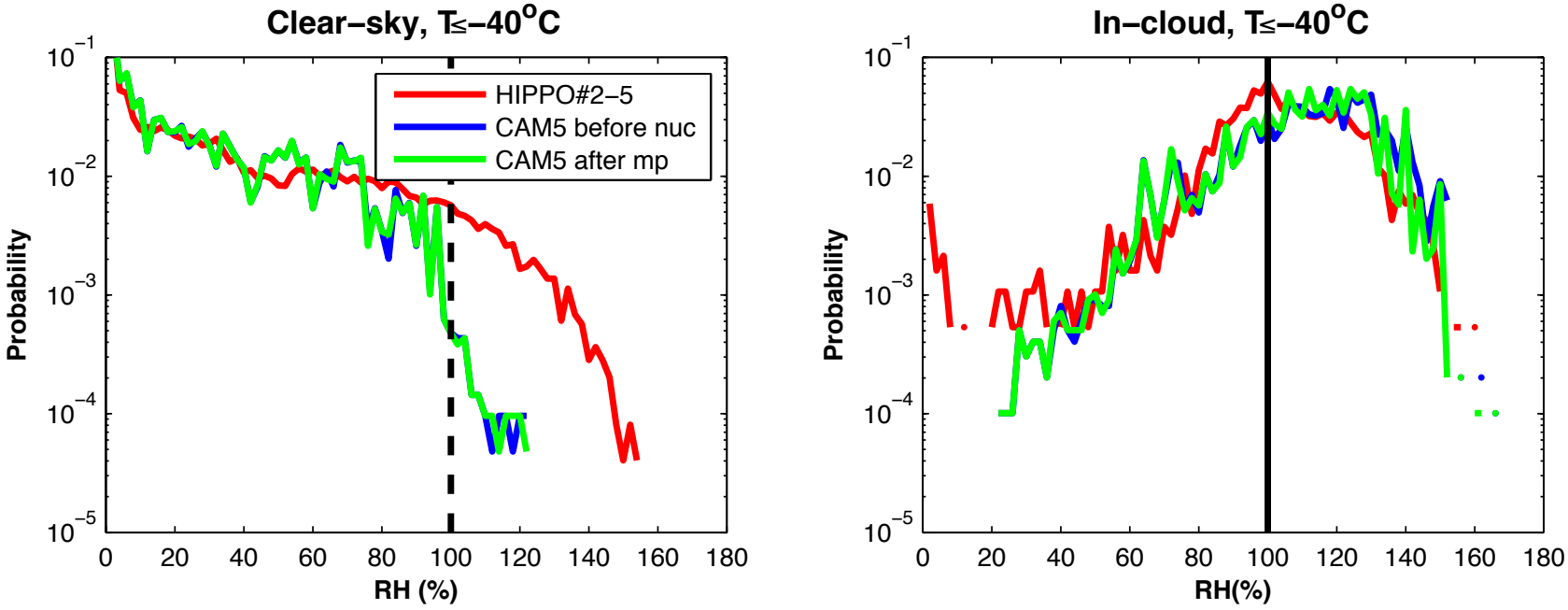
Contribution of biases in T and H_2O to RH biases (*d*: model-obs; *o*: obs):

$$dRH = de \cdot \frac{1}{e_{s,o}} + e_o \cdot d(\frac{1}{e_s}) + de \cdot d(\frac{1}{e_s}) = dRH_q + dRH_T + dRH_{T,q}$$

Diao et al. (2014)



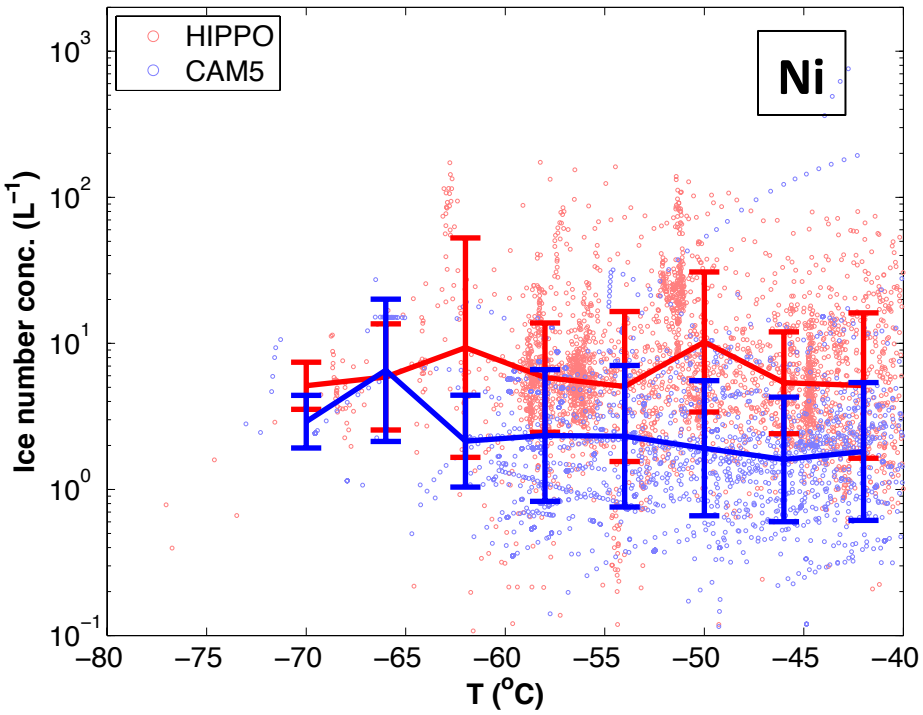
PDF of RH: HIPPO vs. CAM5.4

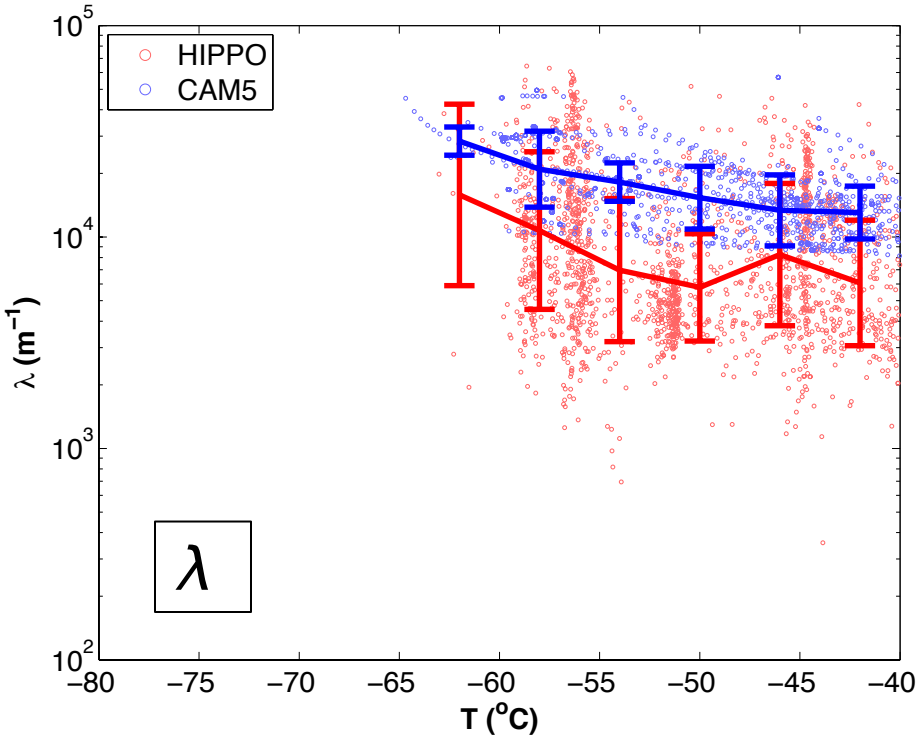


Model simulates a weaker ice supersaturation in clear-sky conditions.

HIPPO#2-5 vs. CAM5

Ice crystal concentration (Ni) and ice particle size distribution (gamma)

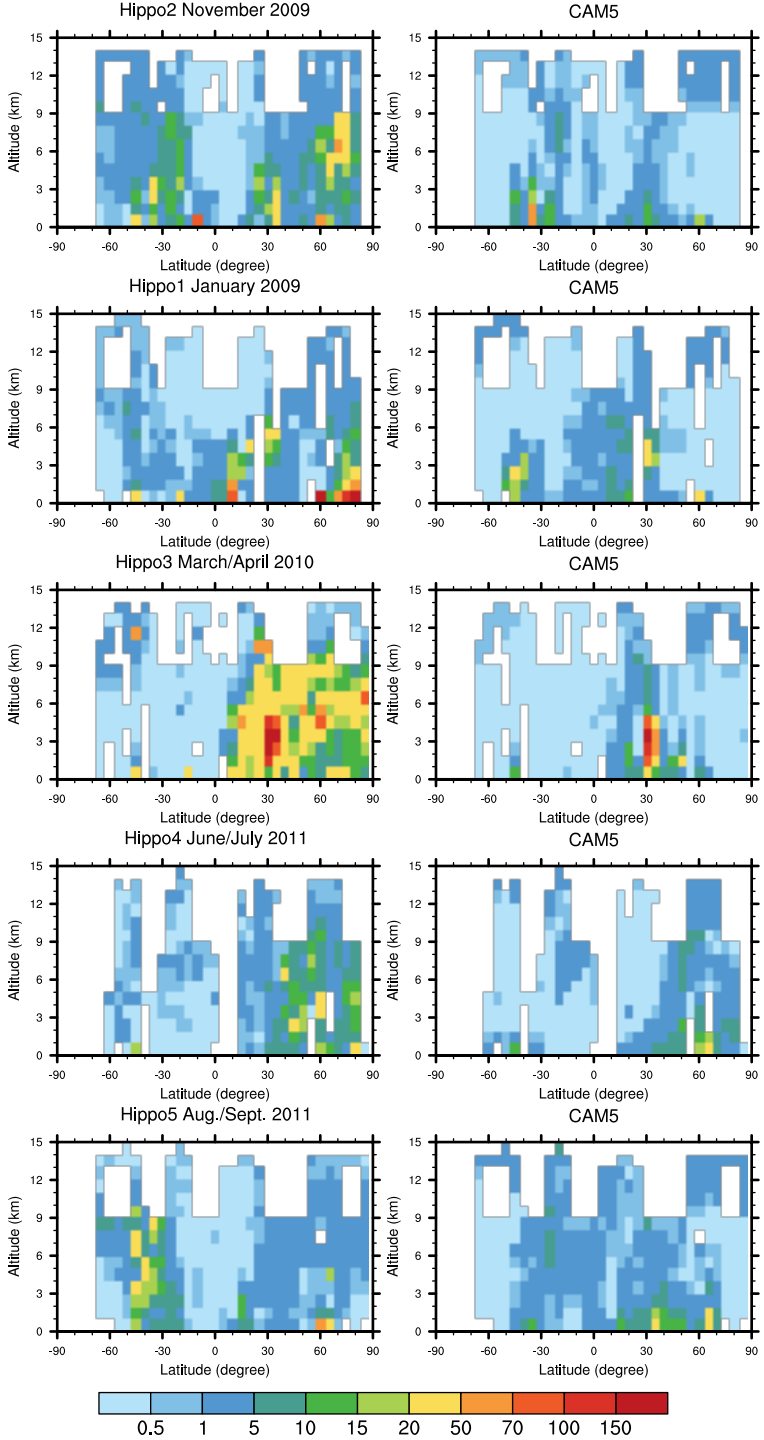




- CAM5.4 underestimates N_i (combined ice and snow) by a factor of 2 to 5, but overestimates λ by a factor of 2 to 3 indicating smaller ice particle size.

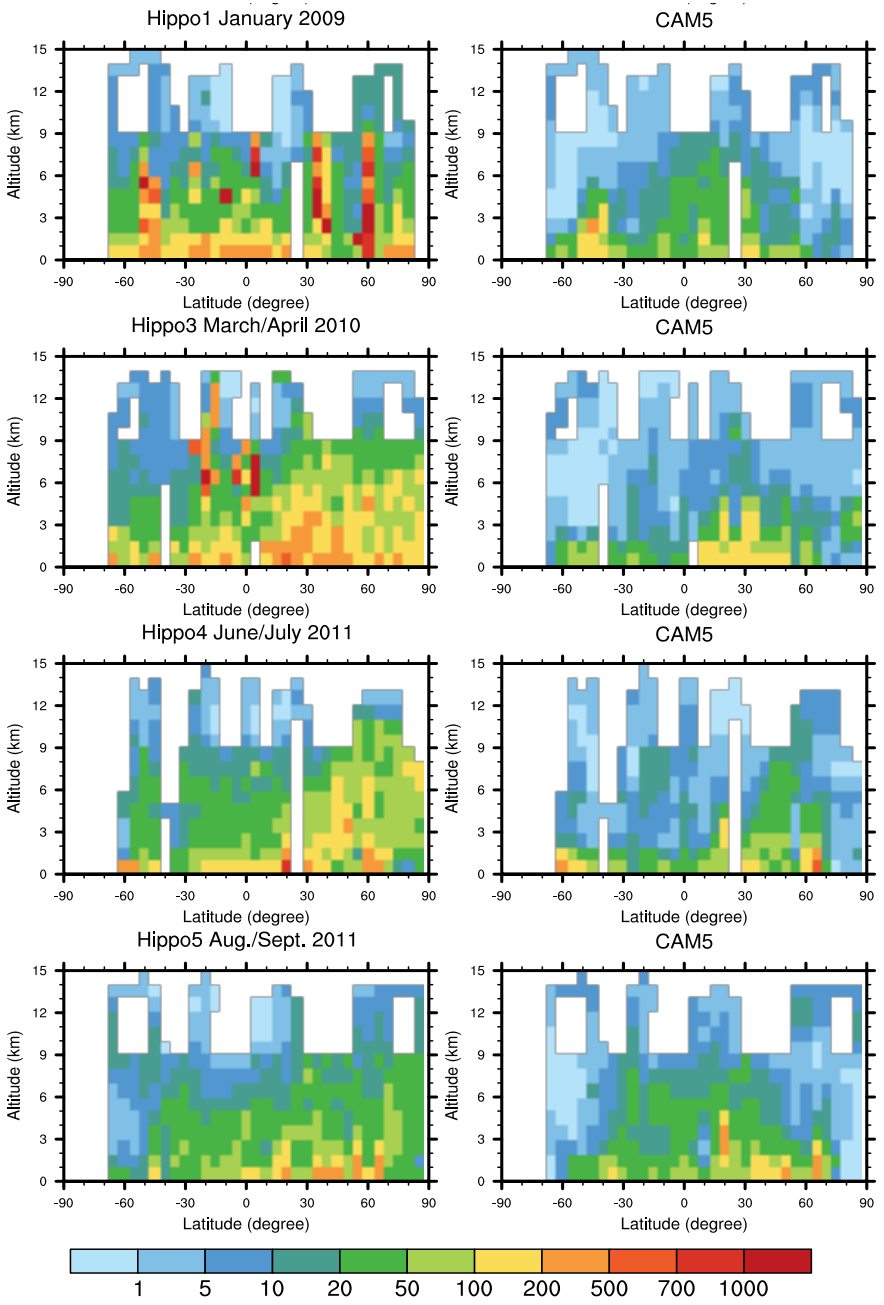
BC: HIPPO vs CAM5

Latitude and altitude cross section of observed and simulated BC concentrations (ng/kg)



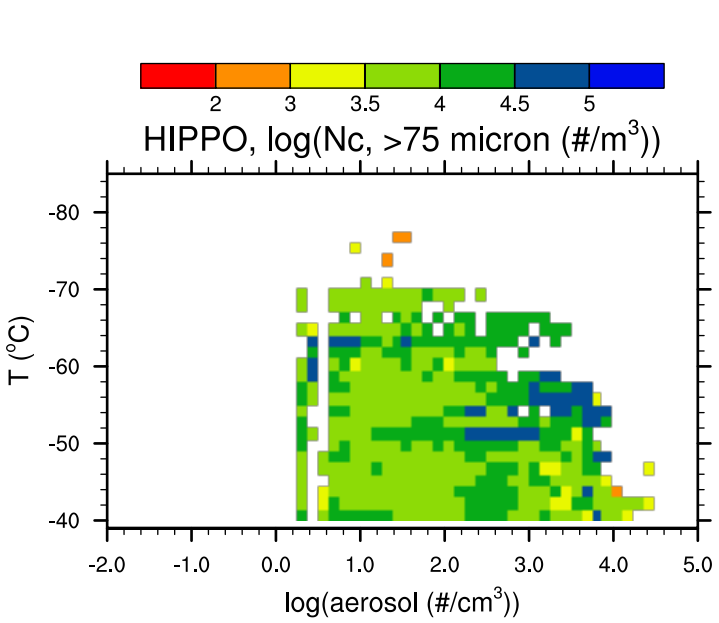
Aerosol number (0.1-1 um): HIPPO vs CAM5

Latitude and altitude cross section of observed and simulated aerosol number concentrations (#/cm^3)



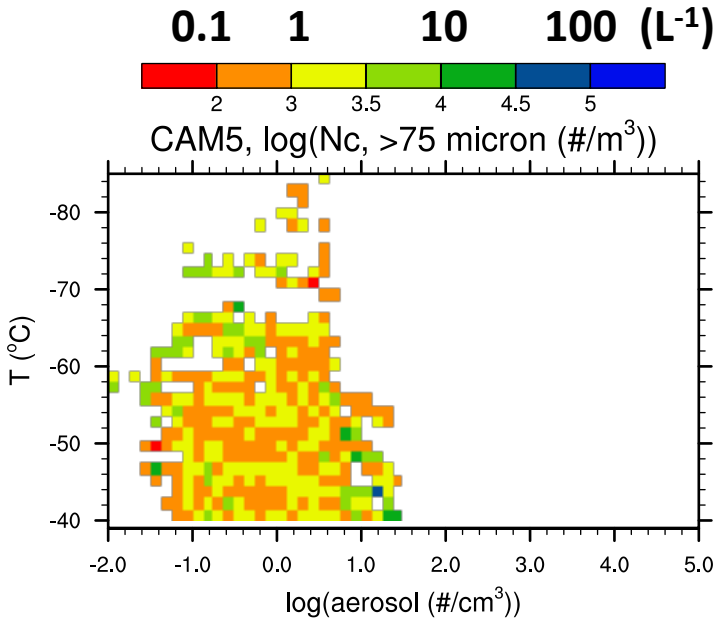
Distributions of ice crystal concentration (Nc) in relation to aerosol number (0.1-1 um) & temperature

HIPPO
D>75 um

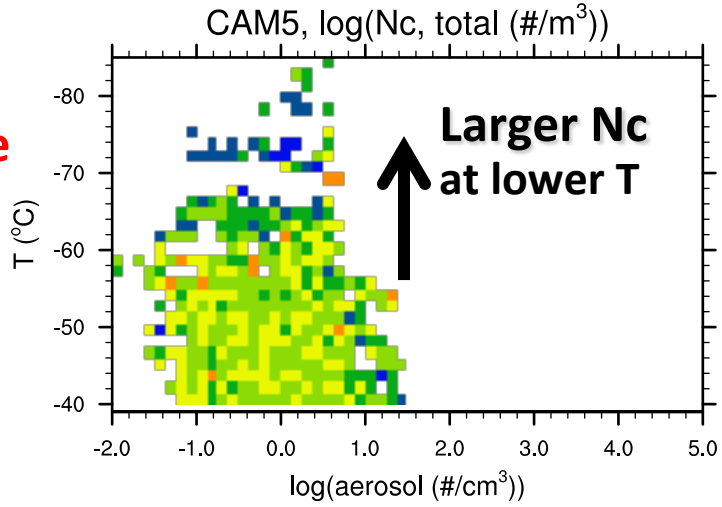


0.1 1 10 100 (L^{-1})

CAM5
D>75 um

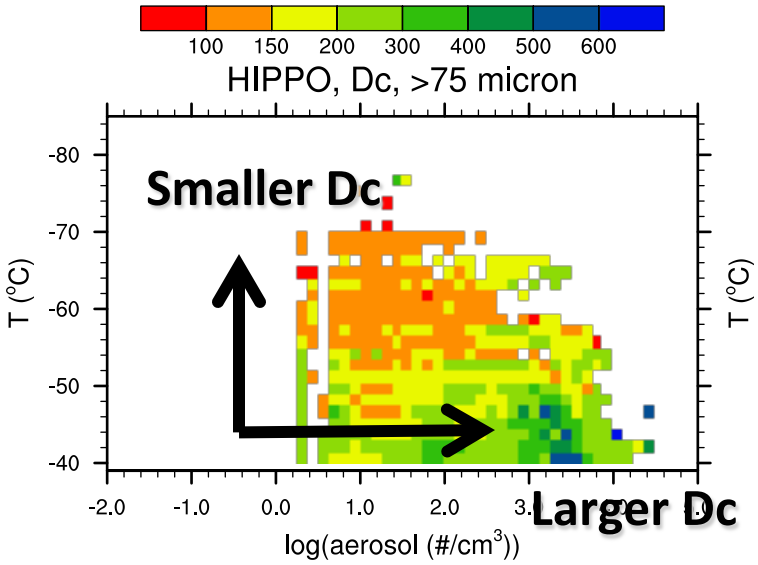


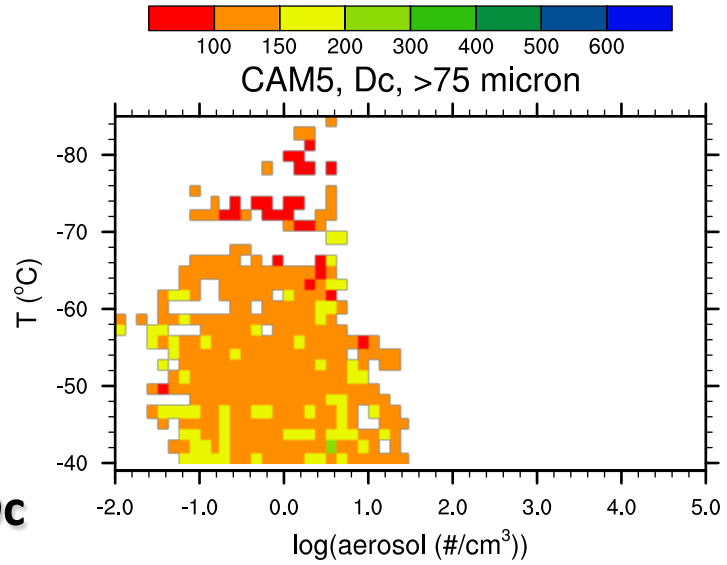
CAM5
All ice size



Distributions of number-weighted mean diameter (Dc) in relation to aerosol number (0.1-1 um) & temperature

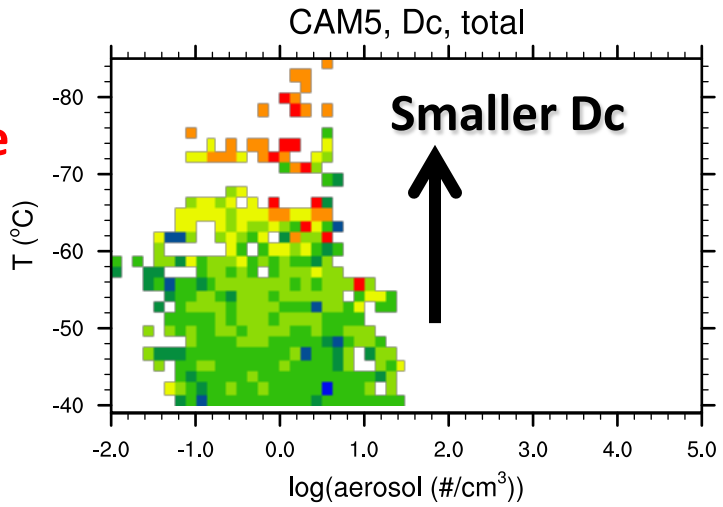
HIPPO
D>75 um





CAM5
D>75 um

CAM5
All ice size



Summary

- Direct comparison of CAM5.4 simulated clouds against HIPPO observations is conducted by collocating model output with aircraft flight tracks.
- CAM5.4 can capture most of observed cloud occurrences. However, the model overproduces / misses cloud occurrences. This is mainly due to the RH bias attributed mostly to the bias of water vapor, not in T.
- CAM5.4 underestimates N_i by a factor of 2 to 5, and produces smaller ice particle sizes than observations (for ice crystals larger than 75 um).
- Aerosol effects on cirrus clouds can not be clearly identified from HIPPO observed Nc and Dc.