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 microphysical 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°).

- 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

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Wsubi upper limiter</th>
<th>Preexisting ice</th>
<th>Ice nucleation</th>
<th>Dcs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>yes</td>
<td>no</td>
<td>Hom/Het</td>
<td>150 μm</td>
</tr>
<tr>
<td>PRE-ICE</td>
<td>no</td>
<td>yes</td>
<td>Hom/Het</td>
<td>150 μm</td>
</tr>
<tr>
<td>HET</td>
<td>yes</td>
<td>no</td>
<td>HET</td>
<td>150 μm</td>
</tr>
<tr>
<td>DCS</td>
<td>yes</td>
<td>no</td>
<td>Hom/Het</td>
<td>250 μm</td>
</tr>
</tbody>
</table>

- **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 σw**

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 (σw) at different spatial scales.

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Validation of modeled IWC, Ni, Di with observations

Model captures the observed increase in 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.

**Cloud occurrences during the flight on April 29, 2010**

**Comparison of Ni along flight**

Green shaded (T≤−40°C): Ni (obs) ~100 -1000 L⁻¹, homogeneous Ni (mod) ~ 10 L⁻¹, heterogeneous model significantly underestimates Ni.

**Comparison of modeled Ni with observation during a case study**

- 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 Ni and environmental variables (T, w-variance).
- CAM5.3+ underestimates IWC and Ni by a factor of 2 to 5, although produces much better ice particle sizes compared to observations.
- Model low bias in Ni is often due to the RH bias attributed mostly to the bias of water vapor, not in T.

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Summary