Impacts of Heterogeneous Ice Nuclei on Cirrus Clouds and Climate in NCAR CAM5

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Homogeneous ice nucleation is relatively well understood, while there are still large unknowns on heterogeneous ice nuclei (IN) (properties and number concentrations).

The goal of this study is to investigate the IN effects on cirrus clouds and climate using CAM5 with two ice nucleation parameterizations.
Multiple mechanisms for ice formation can be active.

Homogeneous Freezing
Mainly depends on $RH_i$ and $T$

Heterogeneous Freezing
(Immersion, deposition, …)
Also depends on the material and surface area

Wet aerosol particles
+ Insoluble Material ("Ice Nuclei")
Conceptual Model of Ice Formation in Cirrus

- Liquid droplets + Insoluble material
- Homogeneous freezing of droplets
- Crystal growth, fresh IN continue to freeze and deplete vapor
- Heterogeneous IN freezing begin forming ice
- Expansion cooling and ice supersaturation development
- Soluble and insoluble aerosol initial distribution
2-moment stratiform microphysics

- Prognostic ‘cloud mass’ and ‘cloud droplet number’ (Γ-function size distributions)
- Diagnostic ‘precipitation mass’ and ‘precipitation droplet number’

Ice-phase cloud microphysics

- Ice crystal nucleation link to aerosols (Liu and Penner, 2005)
- Allow ice supersaturation (Liu et al., 2007)
Parameterizations of Ice Nucleation in CAM5

- *Liu and Penner (2005)*: consider the competition between homogeneous (HOM) and heterogeneous immersion nucleation (HET) (hereafter **LP**). HET based on classical nucleation theory (CNT).

- *Barahona and Nenes (2008a,b; 2009)*: develop a framework that can use different IN nucleation spectra (CNT, CFDC measured IN) for HET, and consider the competition of HOM and HET (hereafter **BN**).
## CAM5 Simulations

<table>
<thead>
<tr>
<th>Case Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>LP2005, combined nucleation</td>
</tr>
<tr>
<td>LP-hom</td>
<td>LP2005, pure hom. nucleation</td>
</tr>
<tr>
<td>LP-het</td>
<td>LP2005, pure het. nucleation</td>
</tr>
<tr>
<td>BN</td>
<td>BN2009, combined nucleation</td>
</tr>
<tr>
<td>BN-hom</td>
<td>BN2009, pure hom. nucleation</td>
</tr>
<tr>
<td>BN-het</td>
<td>BN2009, pure het. nucleation</td>
</tr>
</tbody>
</table>
Comparison between LP and BN scheme

LP-hom

BN-hom
Comparison between LP and BN scheme

BN-het based on Phillips et al. (2008)
Comparison between LP and BN scheme

BN-het based on Phillips et al. (2008)
Comparison between LP and BN scheme

Relative contribution of Ni from homogeneous and heterogeneous nucleation in the combined case (LP and BN)
Ni vs. T

LP and BN in comparison with Kramer et al. (2009)
LP and BN in comparison with SpartiCus data (cirrus clouds measurement over SGP site, Jan.-June 2010)
LP and BN in comparison with MOZAIC and AIRS
Climate Impacts

Difference of LP-hom and LP
Climate Impacts

Cloud

Qv

Difference of LP-hom and LP

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### Global Annual Means

<table>
<thead>
<tr>
<th></th>
<th>SWCF</th>
<th>LWCF</th>
<th>CLDHGH</th>
<th>CLDTOT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LP</strong></td>
<td>-53.0</td>
<td>29.5</td>
<td>42.5</td>
<td>65.4</td>
</tr>
<tr>
<td><strong>LP_HOM</strong></td>
<td>-55.0</td>
<td>31.9</td>
<td>42.6</td>
<td>65.6</td>
</tr>
<tr>
<td><strong>LP_HET</strong></td>
<td>-46.3</td>
<td>22.6</td>
<td>38.8</td>
<td>62.1</td>
</tr>
<tr>
<td><strong>BN</strong></td>
<td>-52.9</td>
<td>28.8</td>
<td>41.1</td>
<td>64.5</td>
</tr>
<tr>
<td><strong>BN_HOM</strong></td>
<td>-52.9</td>
<td>29.1</td>
<td>41.6</td>
<td>64.7</td>
</tr>
<tr>
<td><strong>BN_HET</strong></td>
<td>-43.8</td>
<td>18.6</td>
<td>37.5</td>
<td>61.0</td>
</tr>
</tbody>
</table>

\[ \Delta (CF) = -0.4 \text{ W/m}^2 \text{ (LP)}, -0.3 \text{ W/m}^2 \text{ (BN)} \]
Summary

- Heterogeneous IN effects are investigated using CAM5 with two ice nucleation parameterizations.
- Ice nucleation may be dominated by homogeneous nucleation in the midlatitudes cirrus (200<T<230 K), however, in SGP site it overestimates PDF(Ni).
- IN has a net cloud forcing change of 0.3-0.4 W/m².