AEROCOM Intercomparison

Aerosol Effects on Cirrus Clouds (IND-ICE)

• CAM5
  - Xiaohong Liu, K. Zhang, Y. Wang (U. Wyoming & PNNL)
• CAM5-Michigan
  - C. Zhou, J. Penner (U. of Michigan)
• ECHAM6-HAM2
  - D. Neubauer, U. Lohmann (ETH, Zurich)
• GEOS-5
  - D. Barahona (NASA GSFC)
Aerosols strongly impact the Earth’s energy budget through modifying the properties of clouds.

Aerosol effect on cirrus clouds ($T < -37 \, ^\circ C$) is less quantified.
## Global Mean Black Carbon Radiative Forcing from 1750 to 2005

Bond et al. (2013)

### Global climate forcing of black carbon and co-emitted species in the industrial era (1750 - 2005)

<table>
<thead>
<tr>
<th>Climate forcing terms</th>
<th>Estimate (Uncertainty range)</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BC direct effects</strong></td>
<td></td>
<td></td>
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<tr>
<td>Atmosphere absorption &amp; scattering</td>
<td>0.71 (0.08, 1.27)</td>
<td>Med</td>
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<tr>
<td><strong>BC cloud indirect effects</strong></td>
<td></td>
<td></td>
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<tr>
<td>Combined liquid cloud (semi-direct, albedo, and lifetime)</td>
<td>-0.2 (-0.61, 0.1)</td>
<td>Low</td>
</tr>
<tr>
<td>BC in cloud droplets</td>
<td>0.2 (-0.1, 0.9)</td>
<td>Very low</td>
</tr>
<tr>
<td>Mixed-phase cloud</td>
<td>0.18 (0, 0.36)</td>
<td>Very low</td>
</tr>
<tr>
<td>Ice cloud</td>
<td>0.0 (-0.4, 0.4)</td>
<td>Very low</td>
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<tr>
<td><strong>BC snow and sea ice effects</strong></td>
<td></td>
<td></td>
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<tr>
<td>BC snowpack effective forcing</td>
<td>0.10 (0.014, 0.30)</td>
<td>Med</td>
</tr>
<tr>
<td>BC sea ice effective forcing</td>
<td>0.030 (0.012, 0.06)</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Total climate forcing</strong></td>
<td></td>
<td></td>
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<tr>
<td>BC only</td>
<td>1.1 (0.17, 2.1)</td>
<td>-----</td>
</tr>
<tr>
<td>BC + co-emitted species</td>
<td>-0.06 (-1.45, 1.29)</td>
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</tbody>
</table>

- **LOSU**: Low, Very low
Global climate models have started to include the treatment of ice nucleation linked to aerosols

- Homogeneous nucleation on sulfate aerosol
- Heterogeneous nucleation on dust and/or black carbon (BC)
- Competition between homogeneous vs. heterogeneous

The goal of this AeroCom intercomparison (IND3-ICE) is to more systematically assess the impact of aerosols on cirrus clouds and to estimate associated anthropogenic aerosol forcing.
Ice Nucleation in Cirrus 101

Multiple mechanisms for ice formation can be active.

Ice Crystal Population

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")
AEROCOM Intercomparison (IND3-ICE)

- GCM simulations with configuration:
  - Prescribed SST
  - Nudged with reanalysis data (wind)
  - IPCC AR5 emissions

- Three sets of simulations (PD & PI)
  - **CTL**: Homogeneous and heterogeneous combined
    - Reference model
  - **FIX**: Fixed ice nucleation in cirrus clouds (Gettelman et al. 2012)
    - Fixed ice nucleation for T<-37°C using a constant ice number of 383.6 /L, based on Cooper (1986) for T= -37°C
  - **HOM**: Homogeneous nucleation only
    - No heterogeneous ice nucleation in cirrus clouds when T<-37°C
Ice Water Content

IWP = 17.3 g/m² (CAM5), 18.9 (CAM5-Michigan), 10.2 g/m² (ECHAM6), 26.9 (GEOS5)
ICENUM = 0.96 /m² (CAM5), 3.2 (CAM5-Michigan), 14.5 /m² (ECHAM6), 3.3x10⁴ (GEOS5)
Ice Number vs. Krämer Data

CTL & HOM

CAM5

A) T v. Ice Concentration, (300-80hPa, -60 to 75lat)

ECHAM6

A) T v. Ice Concentration, (300-80hPa, -60 to 75lat)

CAM5-Michigan

A) T v. Ice Concentration, (300-80hPa, -60 to 75lat)

GEOS5

A) T v. Ice Concentration, (300-80hPa, -60 to 75lat)
Ice Number Change (PD-PI)
TOA Net Flux Change (PD-PI)

Δnet (SW+LW) = -1.4 (CAM5), -1.35 (CAM5-M), -1.0 (ECHAM6), -1.4 W/m² (GEOS5)
ΔLW = 0.67 (CAM5), 0.74 (CAM5-M), 0.86 (ECHAM6), 0.57 W/m² (GEOS5)
TOA Net LW Flux Change (PD-PI)

**FIX**

**CAM5**

- a) CAM5
- 0.159 W m²

**CAM5-Michigan**

- b) CAM5M
- 0.123 W m²

**ECHAM6**

- c) ECHAM
- 0.280 W m²

**GEOS5**

- d) GEOS5
- 0.052 W m²
TOA Net LW Flux Change (PD-PI)

\[ \text{CTL} - \text{FIX} = \text{AIE-cirrus} \]

\[ \Delta \text{LW (cirrus)} = 0.51 \text{ (CAM5)}, 0.62 \text{ (CAM5-M)}, 0.58 \text{ (ECHAM)}, 0.52 \text{ W/m}^2 \text{ (GEOS5)} \]
TOA Net Flux Change (PD-PI)

CTL – FIX = AIE-cirrus

\[ \Delta \text{SW+LW (cirrus)} = 0.20 \text{ (CAM5)}, \ 0.13 \text{ (CAM5-M)}, \ 0.32 \text{ (ECHAM)}, \ 0.14 \text{ W/m}^2 \text{ (GEOS5)} \]
Ice Number Change (CTL – HOM)

CAM5

ECHAM6

CAM5-Michigan

GEOS5
Ice Water Content Change (CTL – HOM)

CAM5

ECHAM6

GEOS5

CAM5-Michigan
ΔLW (cirrus thinning) = -0.28 (CAM5), -0.88 (CAM5-M), -0.87 (ECHAM), 0.19 W/m² (GEOS5)
ΔSW+LW (cirrus thinning) = -0.1 (CAM5), -0.44 (CAM5-M), -0.52 (ECHAM), 0.42 W/m² (GEOS5)
Summary

- The global mean IWC differ by a factor of 2, and the difference in ice number concentration is larger (by ~ one order of magnitude) between CAM5, CAM5-Mich, ECHAM6 and GEOS5;

- Anthropogenic aerosol increases ice number concentration in cirrus clouds in most of global regions from pre-industrial to present-day time, with a longwave forcing of 0.5-0.6 W/m2, and net forcing of 0.1-0.3 W/m2 between CAM5, CAM5-Mich, ECHAM6 and GEOS5 (regional differences are larger)

- Cirrus thinning experiment (CTL – HOM) reduces ice number concentration in cirrus clouds in most of global regions, with a net flux change of -0.1 (CAM5), -0.4 (CAM5-Mich), -0.5 (ECHAM6), and +0.4 W/m2 (GEOS5).
Future Plan

- Compare high frequency model output (3 hourly) with observation data;
- Write the results for publications.
Relative Contribution of Ni from HOM and HET, HET/(HOM+HET)

CTL

CAM5

ECHAM6

GEOS5

CAM5-Michigan