Assessment of sulfate aerosols and its uncertainty due to clouds using global models

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(collaborating with Prof. Terry Nakajima et al.)

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Land use and cover changes mainly provide carbonaceous aerosols, and its modeling is very important, but sorry for talking about sulfate aerosol modeling.
Model variability: Sulfate distributions in a global scale

Annual and Zonal Mean Values of sulfate under AeroCom project

(a) Sulfate Radiative Forcing

(b) SO$_4$ burden

(c) Sulfate optical depth

(d) Efficiency: (a)/(c)

[Myhre et al., 2013, Atmos. Chem. Phys.]
Model variability: Sulfate distributions in a regional scale

Surface sulfate in April 2006 over East Asia

MIROC-SPRINTARS (based on Takemura et al., 2005)

RAQM2 (based on Kajino and Kondo, 2011)

RAMS-CMAQ (Hara et al., 2011)

WRF-Chem (Matsui et al., 2011)
What is the model uncertainties?

Difference in the experimental conditions

• Resolution
  – Horizontal: 100–300 km (global) / 20–50 km (regional)
  – Vertical: 20–50 layers

• Emission inventory
  – EDGAR, REAS(Asia), INTEX–B(Asia), … but recent international projects use the common inventory.

Difference in the models

• Host model (dynamic core): At least 20 different modules
  – Basic variables (T, Q, U, V)
  – Horizontal/vertical transports
  – Radiative transfer model
  – Cloud/Precipitation

• Aerosol model: At least 20 different modules
Our approach to investigate the uncertainty

- **Experimental designs:**
  - Same (similar) resolution, emission inventory, & aerosol module, but different host model
  - **MIROC and NICAM**
    - MIROC is a typical general circulation model (GCM) using a spectral method
    - NICAM is also GCM, but can be cloud-resolving GCM using a grid point method
  - Almost same module in physical processes
    - cloud/radiation/turbulence/land surface
  - Nudged by reanalysis (NCEP/FNL) every 6 hr, >2 km height

- **Target:**
  - **Sulfate** (representative secondary aerosols)
  - East Asia (especially China-Korea-Japan)
  - 4 month (January, April, July, October) in 2006
### Experimental conditions in details

<table>
<thead>
<tr>
<th>Host model</th>
<th>Dynamic core</th>
<th>New</th>
<th>Original</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dynamic core</td>
<td>NICAM (Tomita &amp; Satoh, 2004; Satoh et al., 2008, 2014)</td>
<td>MIROC (Emori and Hasumi, 2004; Watanabe et al., 2010)</td>
</tr>
<tr>
<td></td>
<td>Non-hydrostatic icosahedral atmospheric model</td>
<td>General Circulation Model (GCM)</td>
<td></td>
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<tr>
<td>Nudging</td>
<td>Only winds by NCEP–FNL above 2 km height every 6 hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto-conversion</td>
<td></td>
<td>Berry (1967)</td>
<td></td>
</tr>
<tr>
<td>Sulfur chemistry</td>
<td></td>
<td>Gas-phase: SO₂+OH; Aqueous-phase: SO₂+{H₂O₂, O₃}</td>
<td></td>
</tr>
<tr>
<td>Oxidants</td>
<td>Offline-calculated {OH, H₂O₂, O₃} by CHASER (Sudo et al., 2002)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sizes for sulfate</td>
<td></td>
<td>radius=69.5nm, 1-moment bulk</td>
<td></td>
</tr>
<tr>
<td>Experimental designs</td>
<td>Inventory</td>
<td>INTEX-B (Zhang et al., 2009)</td>
<td></td>
</tr>
<tr>
<td>Horizontal res.</td>
<td>g-level 5 (220 km)</td>
<td>T42 (=2.8 deg)~300km</td>
<td></td>
</tr>
<tr>
<td>Vertical res.</td>
<td>40 (10 layers within 2km)</td>
<td>56 (10 layers within 2km)</td>
<td></td>
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</tbody>
</table>
Results: Surface sulfate aerosols

Measurement data: Zhang et al. (2012) over China, EANET over East Asia, Dr. A. Takami at Cape Hedo and Drs. A. Takami & S. Hatakeyama at Fukue

NICAM

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<thead>
<tr>
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<th>APR</th>
<th>JUL</th>
<th>OCT</th>
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<tbody>
<tr>
<td>NICAM (JAN)</td>
<td>NMB = -68%</td>
<td>R = 0.64</td>
<td>NMB = -61%</td>
<td>R = 0.60</td>
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<tr>
<td>NICAM (APR)</td>
<td>NMB = -54%</td>
<td>R = 0.89</td>
<td>NMB = -58%</td>
<td>R = 0.49</td>
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<tr>
<td>NICAM (JUL)</td>
<td>NMB = -61%</td>
<td>R = 0.61</td>
<td>NMB = -54%</td>
<td>R = 0.70</td>
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<tr>
<td>NICAM (OCT)</td>
<td>NMB = -28%</td>
<td>R = 0.77</td>
<td>NMB = -54%</td>
<td>R = 0.75</td>
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MIROC

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Results: Vertical distribution for extinction

Extinction for spherical particles (Sulfate, carbon, and seasalt) \( \propto \) Aerosol mass, optical properties as well as RH

Lidar data: Drs. N. Sugimoto & A. Shimizu
Points:
1) In NICAM, more SO$_2$ are converted into sulfate over the source regions.
2) NICAM-simulated sulfate are more distributed above 2 km heights.
Points:

1) The difference in clouds strongly affects the difference in sulfate.

2) However, the difference in clouds may be inevitable, because models have own suitable tuning parameters in subgrid-scale cloud parameterization.
Large uncertainty in simulating clouds by GCM

Cloud Liquid Water Path \([\text{g/m}^2]\)

[Li et al., 2008, Geophys. Res. Lett.]
Toward a new generation model without cloud parameterization

Until now we showed results with $O(100\text{km})$ grid spacing, but from now we show results with $O(10\text{km})$ grid spacing.
NICAM with 3.5km grid spacing: Cloud resolving model

\[ dx = 3.5\text{km} \]  

[Miura et al., 2007, Science]
Aerosol modeling using NICAM-Chem with $O(10\text{km})$ grids

**NICAM-Chem** (Atmospheric aerosol-chemistry model coupled to NICAM)

**Aerosol-Chemistry module**

Nonhydrostatic ICosahedral Atmospheric Model (NICAM)

- Stretched grid (Regional)
- Uniform grid (Global)

**Scale-up**

**Regionalize**

**Regional calculation**

**Global calculation**

**Validation (East Asia) by Goto et al. (2015)**

- Elemental carbon (Primary particles)
- Sulfate (Secondary particles)

**Aerosol Optical Depth ($dx=14\text{km}$)**

Global distribution of the air pollution with high spatial resolution (up to 3.5km) using supercomputer K

- Using the stretched grid system on NICAM-Chem with 10 km grids, we simulated aerosol and ozone distributions over East Asia and compare them with observation.
- Now, we are simulating NICAM-Chem as a global cloud-resolving model with $<10$ km grids.
Preliminary results by Global-NICAM-Chem with O(10km) grids

**Precipitation [mm/day]**

- NICAM-Chem
- GPCP

**AOD (All species)**

- NICAM-Chem
- MODIS
Summary

1. An inter-comparison study using common aerosol module is conducted: Same model, but different dynamic core: NICAM vs. MIROC (Mainly clouds and possibly transport)

2. A variability in clouds among GCMs can strongly cause important differences in the sulfur distributions.

3. Toward a new generation model: Global simulation with high horizontal resolution with \(O(10\text{km})\) grid spacing (e.g., it can investigate the impacts of biomass burning on regional and global air pollution and climate with high resolution.)

References: