### CESM Whole Atmosphere Working Group Session

**Tuesday, 18 June 2013**

**The Village – Aspen / Blue Spruce Room – Breckenridge, Colorado**

*Webcast Instructions and Information: http://www.cesm.ucar.edu/events/webcasts/*

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker and Topic</th>
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</thead>
<tbody>
<tr>
<td>8:50 a.m.</td>
<td>Mike Mills – Emissions-based volcanic aerosol development</td>
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<tr>
<td>9:15 a.m.</td>
<td>Yunqian Zhu – Polar stratospheric clouds modeling using SD-WACCM / CARMA mode</td>
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<td>9:40 a.m.</td>
<td>Doug Kinnison (given by Dan Marsh) – Status and results from CCMI WACCM simulations</td>
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<td>10:05 a.m.</td>
<td>Nick Pedatella – Data assimilation in the Whole Atmosphere Community Climate Model</td>
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<td>10:30 a.m.</td>
<td><em>Break</em></td>
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<td>11:00 a.m.</td>
<td>Dan Marsh – Meteoric metal chemistry in WACCM</td>
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<td>11:25 a.m.</td>
<td>Hanli Liu – Ionosphere variability due to lower atmosphere driving</td>
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<td>11:45 a.m.</td>
<td>Discussion</td>
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<td>12:00 p.m.</td>
<td>Adjourn</td>
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</table>
Emissions-based volcanic aerosol development

Mike Mills
WACCM Liaison

With help from Dick Easter, Steve Ghan, Ryan Neely, Jean-François Lamarque, Andrew Conley, Jason English, and Xiaohong Liu
Happy Birthday to our favorite (Dan) Marshian!
No scientifically supported WACCM compsets in 1.2.0 yet
Prescribed volcanic aerosol in WACCM4 and CAM

CCSM4 optical depth based on prescribed volcanic aerosol mass

Improved optical depth based on prescribed volcanic aerosol mass and radius

Courtesy J-F Lamarque
SW forcing at the surface

Obs AOD

Stratospheric 525 nm AOD

Months Since Eruption

AOD Difference between Pinatubo and No Pinatubo

AOD

WACCM
CAM
CCSM4

Old
New

Month (Jan 1991)

Temperature Difference at 50hpa

ΔT at 50hPa

WACCM
CAM
CCSM4

Old
New

Obs

Time (h)
Modeling geoengineering schemes and unobserved (including historic and paleo) volcanoes requires an emissions-based volcanic aerosol scheme.
• CARMA microphysics
  • sectional (bin) model with detailed aerosol microphysics
  • incorporated in CESM
  • stratospheric sulfate model exists
  • Showstopper for CAM4/WACCM4: radiative code (CAM-RT) is only compatible with aerosols of fixed size.
    • For the shortwave, there are flags in the code for different wavelengths that trigger absorption calculations for water vapor, CO2, and CO2/H2O overlap. The optics for each aerosol in each of these bands has to be computed using complex formula using an original radiation code, not readily accessible.
    • Additionally, computation of the longwave effects requires an offline computation to optimize the heating rates compared to a reference line-by-line computation.
  • CAM5/WACCM5 has an entirely new radiation code (RRTMG) that is more flexible to connect outside models. However, coupling CARMA sulfates to radiation in CAM5/WACCM5 will require significant development work to avoid competing for sulfur sources with the existing modal aerosol module (MAM) in CAM5, which treats sulfates as an internal mixture with many other aerosol types.
• Use MAM for stratospheric sulfates?
Gas-phase species: H$_2$SO$_4$, SO$_2$, DMS, SOA (gas)

“Sulfate is partially neutralized by ammonium in the form of NH$_4$HSO$_4$, so ammonium is effectively prescribed and NH$_3$ is not simulated. We note that in MAM-3 we predict the mass mixing ratio of sulfate aerosol in the form of NH$_4$HSO$_4$ while in MAM-7 it is in the form of SO$_4$.”

- CAM5 scientific description

![Modal Aerosols in MAM-3](image)

<table>
<thead>
<tr>
<th>Mode</th>
<th>σ$_g$</th>
<th>Size range (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAM3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aitken</td>
<td>1.6</td>
<td>0.015–0.053</td>
</tr>
<tr>
<td>Accumulation</td>
<td>1.8</td>
<td>0.058–0.27</td>
</tr>
<tr>
<td>Coarse</td>
<td>1.8</td>
<td>0.80–3.65</td>
</tr>
</tbody>
</table>

Table 1.

<table>
<thead>
<tr>
<th>Mode</th>
<th>a1 acc</th>
<th>a2 Aitken</th>
<th>a3 coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO$_4$</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>POM</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOA</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dust</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>salt</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>number</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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### Stratospheric Aerosols in MAM-3

#### Predicted Species for Interstitial and Cloud-Borne Component

<table>
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<tr>
<th>Mode</th>
<th>a1 accum</th>
<th>a2 Aitken</th>
<th>a3 coarse</th>
</tr>
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<tbody>
<tr>
<td>SO4</td>
<td>✔️</td>
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<td>✔️</td>
</tr>
<tr>
<td>POM</td>
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<td></td>
<td></td>
</tr>
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<td>✔️</td>
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**Gas-phase species:** H$_2$SO$_4$, SO$_2$, DMS, SOA (gas)

**Added:** OCS, S, SO, SO$_3$, HSO$_3$

**Added evaporation from accumulation to Aitken**

**Need to add growth and evaporation between accumulation and coarse**

**Will this require adding POM, SOA, BC to the coarse mode?**

**Mind the gap!**

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**Table: Mode Distribution**

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Liu et al., 2012
eruption (month 21 in Figure 11c) and about 7 months after the Toba eruption (month 13 in Figure 11d). In both regions, the particles at the large end of the accumulation mode disappear more quickly than those at the small end of the accumulation mode due to the faster sedimentation of the largest particles. The details of this evolving aerosol size distribution can have significant impacts on radiative forcing, as aerosol mass extinction efficiency is strongly related to particle radius. Aerosol mass extinction efficiency for 525 nm radiation peaks at about 0.4 μm radius and for 1024 nm radiation peaks at about 0.8 μm radius. When particles are larger than the radius of maximum mass extinction, their radiative forcing is less efficient. Hence, large eruptions, with their large particles, can be self-limiting.

The evolving size distributions predicted by our sectional model are complex and would be difficult to accurately prescribe in bulk aerosol or modal models. To assist with comparison to modal models, we calculate accumulation mode peak size and width from our sectional model by finding the mode width that most closely resembles our size distributions, assuming a lognormal shape. Mode width is found by finding the mode width of a lognormal distribution with the smallest difference from our sectional model. Difference is calculated by summing fractional errors at each bin on the large half of the distribution (from the mode peak to the largest bin) and finding the mode width with the smallest error. Calculations begin with the first month containing an accumulation mode in that region, which ranged from zero to three months after the eruption. These calculations have been completed for the three simulated eruptions over time. In the tropical stratosphere (Figure 12a), the mode peak size is predicted to reach 0.69 μm after Pinatubo, 1.3 μm after Pinatubo/C2, and 1.7 μm after Toba, afterwards decreasing within a few months to about 0.5 μm as the particles are transported to higher latitudes via the Brewer–Dobson circulation. In the high-latitude troposphere and stratosphere (Figure 12b), there is a longer time lag to reach mode peak size (12 months after the Pinatubo eruption, 6 months after the Pinatubo/C2 eruption, and 4 months after Toba), but the peak size is larger except for Pinatubo (2.0 μm for Toba, 1.5 μm for Pinatubo/C2, and 0.32 μm for Pinatubo). Due to a relatively longer aerosol lifetime in the troposphere and stratosphere, the rate of decline is slower in the high latitudes, with mode peak size still declining after 5 years for the eruptions larger than Pinatubo. Mode widths are generally more stable with time than $R_{eff}$, but vary significantly with eruption size. In the tropical stratosphere, the Pinatubo mode width is about 1.2 and Pinatubo/C2 is about 1.3. Mode width is about 1.3 for the first 6 months after the simulated Toba eruption, then jumps to 1.6 as the accumulation mode broadens and the mode

Figure 11. Evolving monthly average accumulation mode size distribution for Pinatubo (top row) and Toba (bottom row) every 2 months for 35 months. The eruption occurred in month 6. The regions analyzed were chosen to include the majority of the volcanic cloud for both eruptions.
Figure 5. Annual zonal average of sulfate aerosol number, surface area, and volume size distribution for each SO$_2$ injection scenario at the equator and 39, 55, and 90 hPa.

From the optimum mass scattering radius near 150 nm. Our results reinforce the original conclusion postulated by Pinto et al. (1989) as well as recent microphysical simulations (Heckendorn et al., 2009; Niemeier et al., 2010; Hommel and Graf, 2011) that there may be an upper limit to the radiative forcing that can be obtained with sulfate aerosols.

4.2 Injection region

We now compare the efficacy of injection region for various 10 Tg S injection scenarios. Injecting SO$_2$ into a broader latitude and slightly higher altitude region (32°N–32°S and 19.9–24.6 km) produces about a 60% higher mass burden than the equivalent SO$_2$ injection in a narrow region (10.1 Tg versus 6.3 Tg) (Fig. 6). Injecting a lognormal distribution of SO$_2$ particles in a broad region produces about 40% higher mass burden than the equivalent injection of SO$_2$ particles in a narrow region (13.8 Tg versus 9.6 Tg). Likewise, stratospheric aerosol lifetime increases for broad injections by about 80% for SO$_2$ injection and 50% for SO$_2$ particle injection relative to injections in narrow latitudinal bands (Fig. 6). While part of the increase in burden is due to the slightly higher injection altitude, burden is improved for two other reasons as well: First, particle growth by H$_2$SO$_4$ condensation is reduced because H$_2$SO$_4$ vapor is more dilute, and second, coagulation is reduced because aerosol concentration is also more dilute. The benefit of a larger injection region is less for SO$_2$ particle injection because this scenario is generally influenced by concentration of aerosol...
Pinatubo eruption, June 15, 1991: 20 Tg SO$_2$, 16-20 km

SO$_2$ accumulation mode

SO$_4$ nucleation mode

SO$_4$ accumulation mode

Pinatubo eruption, June 15, 1991: 20 Tg SO$_2$, 16-20 km
Sulfate (molec/cm³) at 12.5°N

Based on observations

dgnumh_i = 400 nm

dgnumh_i = 1 µm

dgnumh_i = 10 µm

[Graphs showing sulfate distribution at different particle sizes and time periods]
Based on observations

H2SO4_mass [molecules/cm3air], 15 Oct 1991 00:00

Sulfate (molec/cm³), October 1991

H2SO4_mass [molecules/cm3air], 15 Oct 1991 00:00

Based on observations

H2SO4_mass [molecules/cm3air], 15 Oct 1991 00:00
Tropical temperature anomalies

- **30 hPa**
  - Obs
  - dgnumhi: 400 nm (default)
  - 1 µm
  - 10 µm

- **50 hPa**

- **70 hPa**

- **100 hPa**
Surface temperature anomalies

1013.25 hPa

Temperature anomaly (K)

Year


-0.60 -0.30 0.00 0.30 0.60

dgnumhi:
400 nm (default)
1 µm
10 µm

Community Earth System Model

Whole Atmosphere Community Climate Model

NCAR
Questions

• Can MAM3 be adapted for exchange between the accumulation and coarse modes?
• Can the gap between the accumulation and coarse modes be filled?
• Will these changes result in significant disruption of tropospheric aerosols?
• Will MAM3 with these adaptations represent volcanic aerosol evolution and radiative anomalies reasonably?
• Would this be better done with CARMA?
• What will be the role for emissions-based volcanic aerosols in climate models?