Microphysical simulations of large volcanic eruptions: Pinatubo and Toba

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Thanks to collaborators
Brian Toon and Michael Mills
The 1991 eruption of Mt. Pinatubo

- 1992: Temperature dropped 0.5°C; coolest year in the past 25 years
- We also saw ozone loss, hydrological changes

20 Tg SO$_2$ (10 Tg S) into stratosphere

Surface Temperature Record

- Monthly Average
- Annual Average
- Five Year Average


Pinatubo Volcano

El Nino / La Nina
The Toba super-eruption 74,000 years ago

- Largest eruption in past 20 million years
- Up to 100x larger than Pinatubo
- Global T dropped 3-5°C
- Cooling lasted 2-20 years
- May have caused a bottleneck in human evolution
The importance of getting aerosol size right

- Mass extinction (m²/g)
- Sedimentation at 100 hPa (mm/s)
- SA per unit mass
WACCM/CARMA model

1. Emissions
   - SO₂: Smith et al. (2011)
   - OCS: 510 pptv boundary condition

2. Chemistry
   - H₂SO₄ formed
   - Oxidants OH, O, O₃, NO₃

3. Nucleation
   - BHN: Zhao and Turco (1995)
   - H₂O vp: Lin and Tabazadeh (2001)
   - H₂SO₄ vp: Giauque et al. (1960), Ayers et al. (1980), Kulmala (1990)

4. Condensational growth
   - H₂SO₄ vp: Giauque et al. (1960), Ayers et al. (1980), Kulmala (1990)
   - Wt %: Tabazadeh et al. (1997)

4°x5° resolution

Dynamics/Transport

WACCM 3.1.9

5. Coagulation
   - Brownian, convective, & gravitational with van der Waals correction (Chan and Mozurkewich, 2001)

6. Deposition, Sedimentation

WACCM/CARMA is coupled 3-d advectively, but not radiatively

CARMA

CARMA

CARMA

CARMA

CARMA
Experimental Design

<table>
<thead>
<tr>
<th>Three eruptions simulated</th>
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</thead>
<tbody>
<tr>
<td><strong>Pinatubo</strong></td>
</tr>
<tr>
<td><strong>Pinatubo x 10</strong></td>
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<tr>
<td><strong>Toba</strong></td>
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- Simulations with and without van der Waals forces (no VW)
- 10-year simulations
- SO$_2$ gas injected continuously over 48 hours on June 14-15 of first year

**Simulated SO$_2$ cloud**
2°S – 14°N
95 – 115°E
Pinatubo: Model captures peak but declines too quickly

- Model is mostly within error bars but declines too quickly (no aerosol heating, no QBO)
- Including van der Waals forces increases effective radius and reduces AOD
Pinatubo: Model overpredicts AOD in NH; underpredicts SH

- Hemispheric transport could be improved by QBO
- Cerro Hudson eruption may contribute to SH
Larger Eruptions have larger particles, limited burdens

### Comparing Toba Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Reff (µm)</th>
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<tbody>
<tr>
<td><em>Robock et al., 2009</em> (Bulk)</td>
<td>~0.6 µm (0.45 dry)</td>
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<tr>
<td><em>Timmreck et al., 2010</em> (Modal)</td>
<td>0.8 – 1.1 µm</td>
</tr>
<tr>
<td><em>English et al., 2013</em> (Sectional)</td>
<td>1.1 – 2.2 µm</td>
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AOD is limited further in larger eruptions

[Graph showing the 525 nm AOD over months since eruption for different eruptions, including Toba, Pinatubo, and Pinatubo no VW.]
Effective radius peaks in high latitudes and below 150 hPa.
Extinctions peak in lower stratosphere and poles

AOD (525 nm)

Extinction (10^3 km⁻¹)

Latitude (deg)

Pressure (hPa)

Months since Jan of eruption year

Pinatubo

Pin x10

Toba
Accumulation modes perturbed in tropics and at poles

Pinatubo

Toba

20-200 hPa; Equator

50-990 hPa; 80-90°S
Mode peaks and widths vary

Comparing Toba Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Mode width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robock et al., 2009 (Bulk)</td>
<td>1.25</td>
</tr>
<tr>
<td>Timmreck et al., 2010 (Modal)</td>
<td>1.2</td>
</tr>
<tr>
<td>English et al., 2013 (Sectional)</td>
<td>1.2 - 2.1</td>
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Summary

• Our Pinatubo simulations capture the observed peaks in the NH but decline too quickly and are too low in the SH
  ➢ Need to add QBO, aerosol heating, Cerro Hudson to the model

• Large eruptions have self-limiting radiative effects due to increased particle size
  ➢ Toba (100x Pinatubo) has only 50x burden; 20x AOD; 5-yr AOD and $2.0\ \mu m\ \text{reff}$

• Accumulation mode peak and widths evolve in a complex manner; 2-moment modal models may not be accurate
  ➢ Mode widths vary from 1.2 to 2.1
  ➢ High latitude mode peak varies from 2 um to 0.5 um over 4 years