Surprising particle growth after large volcanic eruptions

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Thanks to collaborators
Brian Toon and Michael Mills
Accurate representation of stratospheric aerosol is critical

- **Bulk aerosol model:** predict mass, prescribes size.
- **Modal aerosol model** (prescribed lognormal)
- **Sectional aerosol model (CARMA)**

- Extinction efficiency (m²/g)
- Sedimentation at 100 hPa (mm/s)
- SA per unit mass
The 1991 eruption of Mt. Pinatubo

Data from Ansmann et al., 1996
The Toba super-eruption 74,000 years ago

- Largest eruption in past 200 million years
- Up to 100x larger than Pinatubo
- Disagreement re: climate impact
  - May have caused a bottleneck in human evolution (Ambrose, 1998)
  - 10K cooling; 20-yr impact (Robock et al. 2009)
  - 3.5K cooling; 10-yr impact (Timmreck et al. 2010).
1. Emissions

- SO₂ (prescribed UT source)
- OCS (510 pptv boundary condition)

2. Chemistry

- H₂SO₄ formed
- Oxidants OH, O, O₃, NO₃

3. Nucleation

- Nuc: Zhao and Turco 1995
- H₂O vp: Lin & Tabazadeh 2001
- H₂SO₄ vp: Giauque/Ayers/Kulmala

4. Condensational growth

- H₂SO₄ vp: Giauque/Ayers/Kulmala
- Wt %: Tabazadeh 1997

5. Coagulation

- Brownian, convective, gravitational, and van der Waals forces

6. Deposition, Sedimentation

- English et al., 2011, ACP
Three eruptions simulated

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Pinatubo</td>
<td>10 Tg S</td>
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<tr>
<td>Pinatubo x 10</td>
<td>100 Tg S</td>
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<tr>
<td>Toba</td>
<td>1000 Tg S</td>
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• 10-year simulations

• SO$_2$ gas injected continuously over 48 hours on June 14-15 of first year
Pinatubo: Model captures peak but declines too quickly

- Model is mostly within error bars but declines too quickly (need aerosol heating, QBO)
- Including van der Waals forces increases effective radius and reduces AOD

Data from Ansmann et al., 1996

Data from Russell et al., 1996

50 to 55 °N; 1-300 hPa
AOD is limited in larger eruptions, esp. when van der Waals forces are included (100x emissions = 20x AOD). Why?
Larger Eruptions have larger particles, limited burdens
Van der Waals forces increases $R_{eff}$
Mode peak size and widths evolve

20-200 hPa; Equator

Mode peak (μm) [solid lines]

50-990 hPa; 80-90°S

Mode peak (μm) [solid lines]

Comparing Toba Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>( R_{\text{eff}} )</th>
<th>Mode width</th>
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<tbody>
<tr>
<td>Robock et al., 2009 (Bulk)</td>
<td>(~0.6 , \mu m ; (0.45 , \text{dry}))</td>
<td>1.25</td>
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<tr>
<td>Timmreck et al., 2010 (Modal)</td>
<td>(0.8 - 1.1 , \mu m)</td>
<td>1.2</td>
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<tr>
<td>English et al., 2013 (Sectional)</td>
<td>(1.1 - 2.2 , \mu m)</td>
<td>1.2 - 2.1</td>
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Summary/Next Steps

• Large eruptions have self-limiting radiative effects due to increased particle size*
  - Toba (100x Pinatubo) has only 50x burden; 20x AOD; 5-yr AOD
  - Particle size grows to 2.0 μm! (Van der Waals increases size by 25%)
  - Mode widths vary from 1.2 to 2.1; modal models don’t allow this to evolve (larger widths mean shorter lifetime)

• Accurate representation of stratospheric aerosol processes is critically important to constrain:
  - Devastation from super-eruptions
  - Effects of small/moderate volcanoes on recent temperature trends
  - Geoengineering schemes

• Two paths for stratospheric aerosol model development
  - WACCM5/CARMA for most accurate representation
  - WACCM5 & CAM5 with modified MAM (Mike Mills, Ryan Neely, Simone Tilmes)