

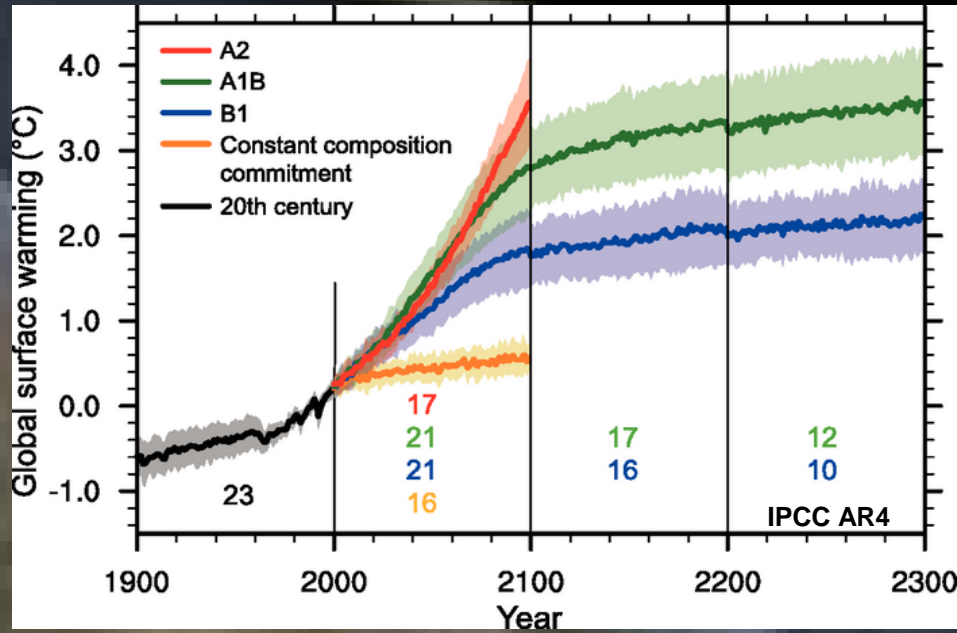
Stratospheric sulfate geoengineering using WACCM/CARMA: Particle size & tropospheric burdens

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Why study geoengineering?

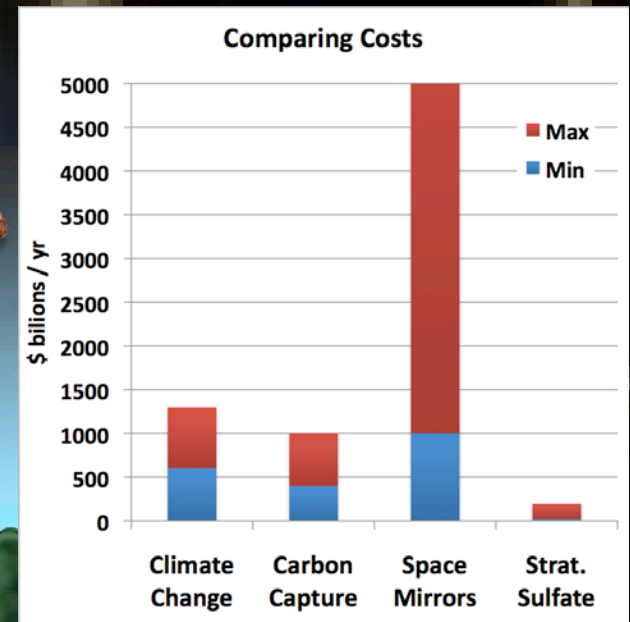
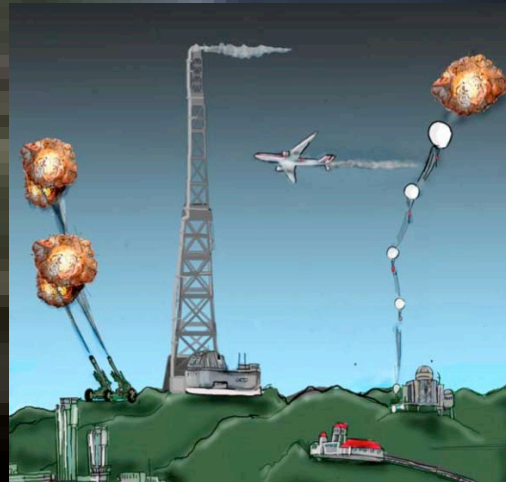


Sea level rise
 Biodiversity loss
 Extreme weather
 Crop yields
 Disease
 Etc.

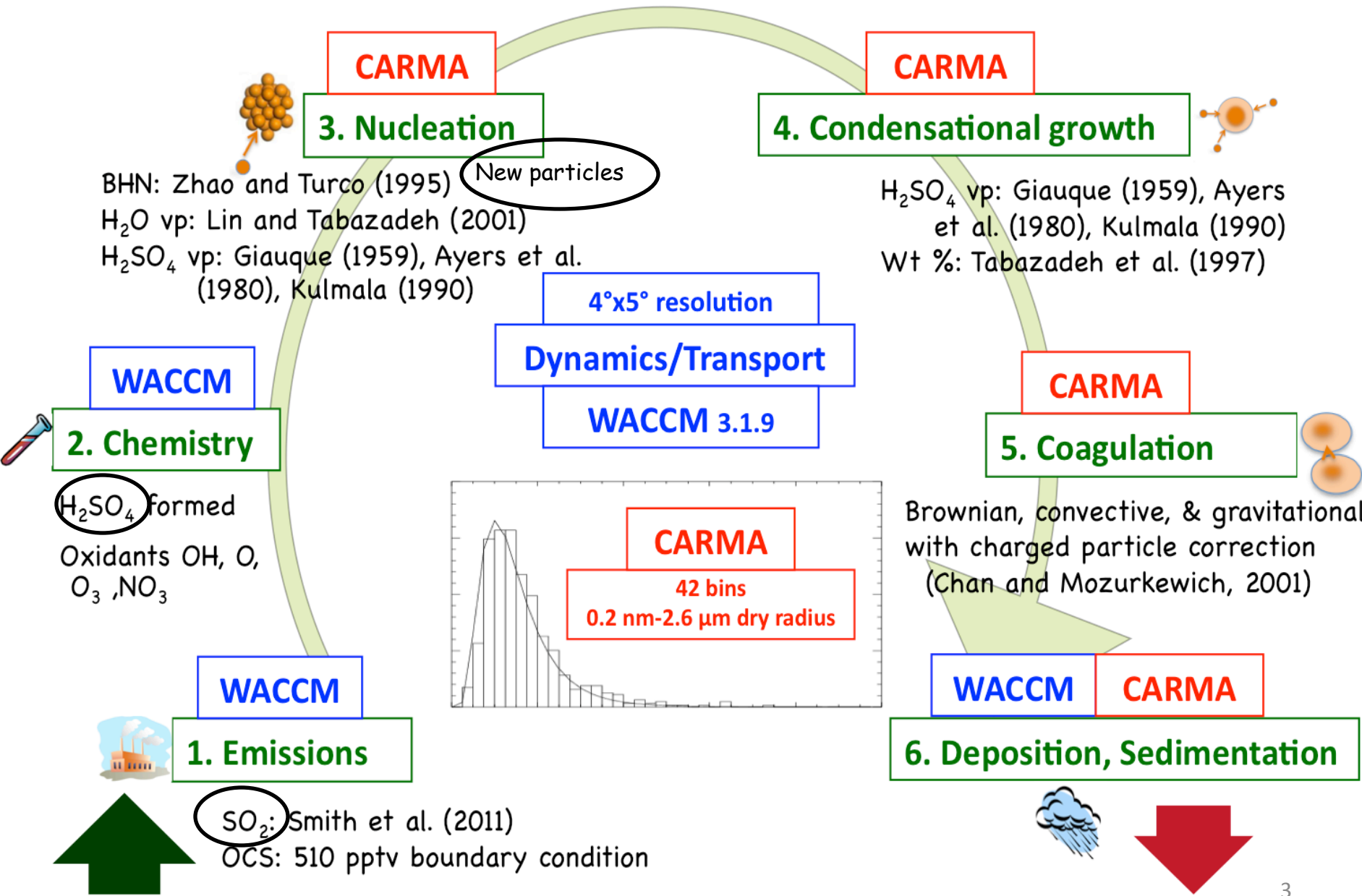
Cost 1 - 2% of global GDP yr⁻¹
 (\$0.6 - 1.3 trillion)
[Stern report]

Stratospheric sulfur
 geoengineering:

\$1 to \$200 billion yr⁻¹

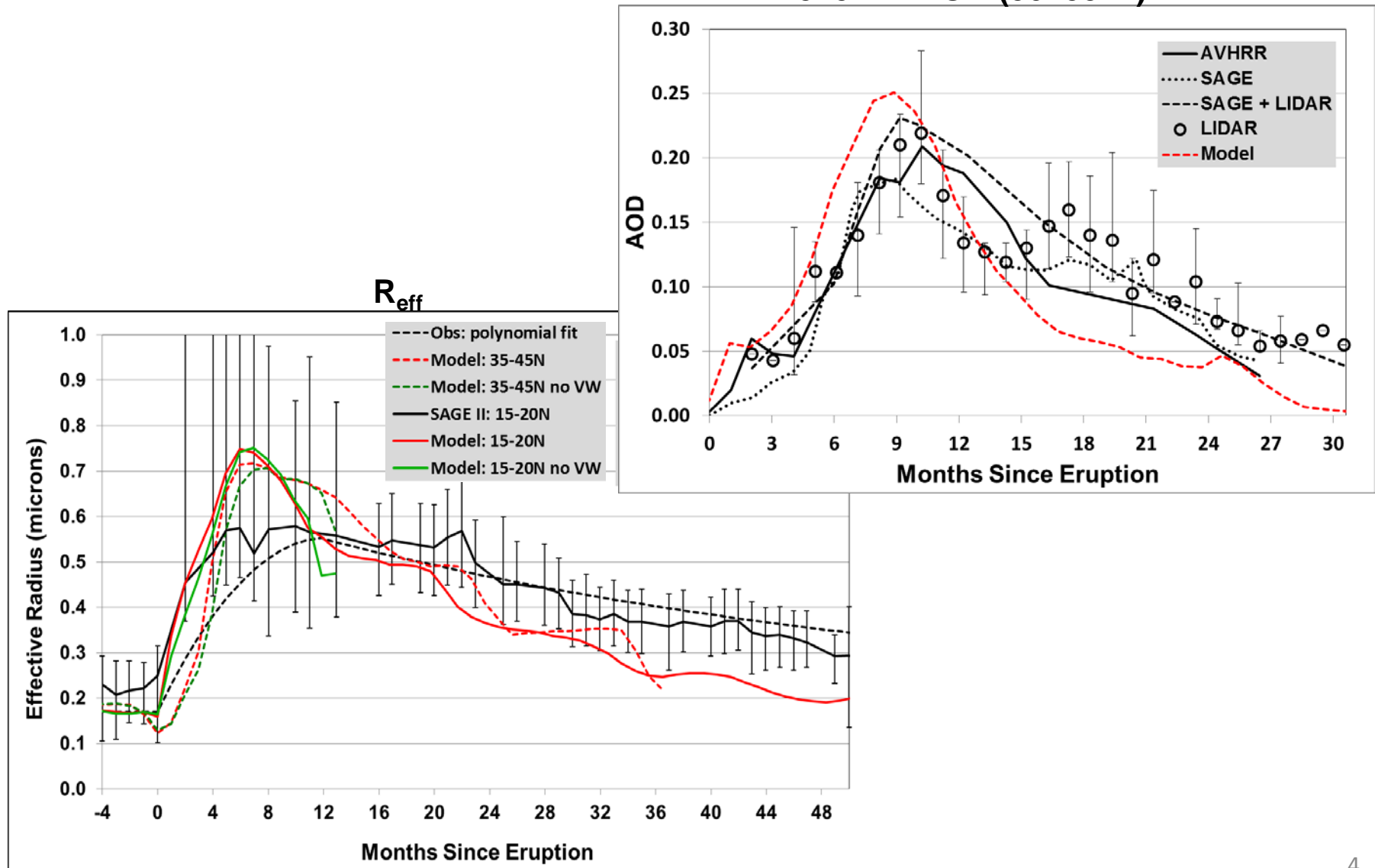


WACCM/CARMA model



Mt Pinatubo eruption: R_{eff} increases 3x; AOD 100x WACCM/CARMA within error bars of data

525 nm AOD (50–55°N)



Geoengineering (10 Simulations)

1) Varying SO₂ injection rates

- 1, 2, 5, 10 Tg S yr⁻¹ (Pinatubo = 10 Tg S)
- All in narrow region (4°S-4°N, 19-20 km, all longitudes)

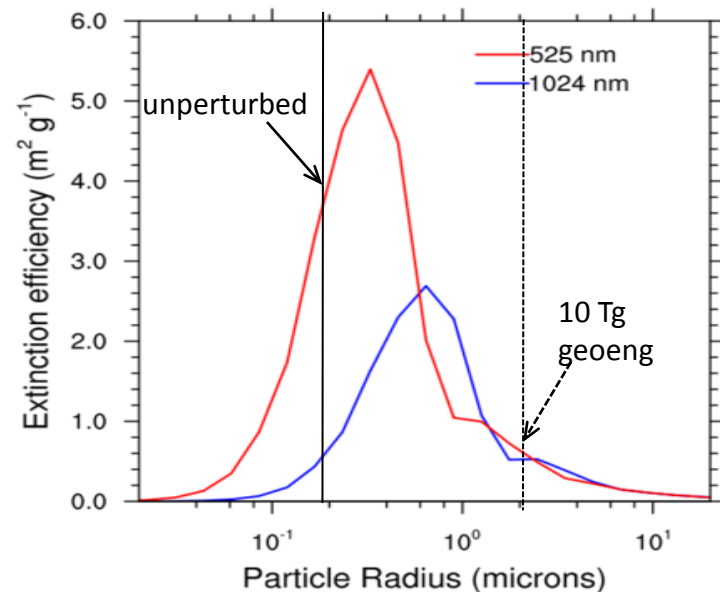
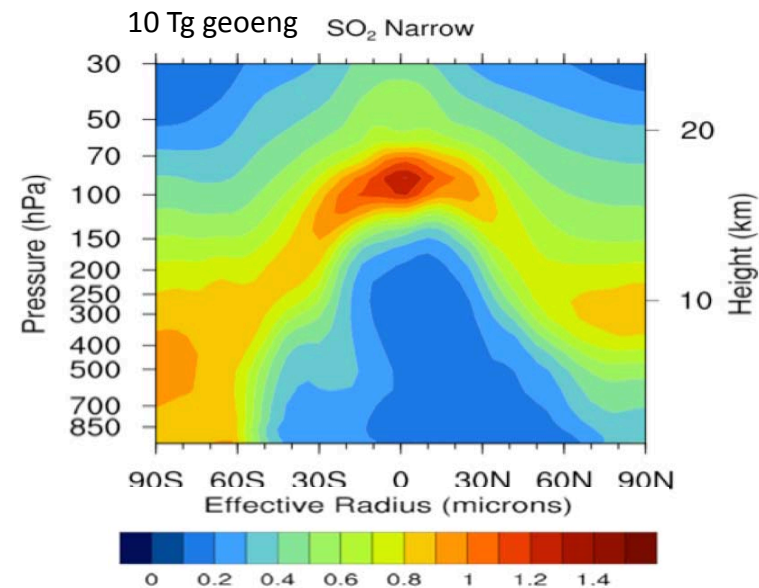
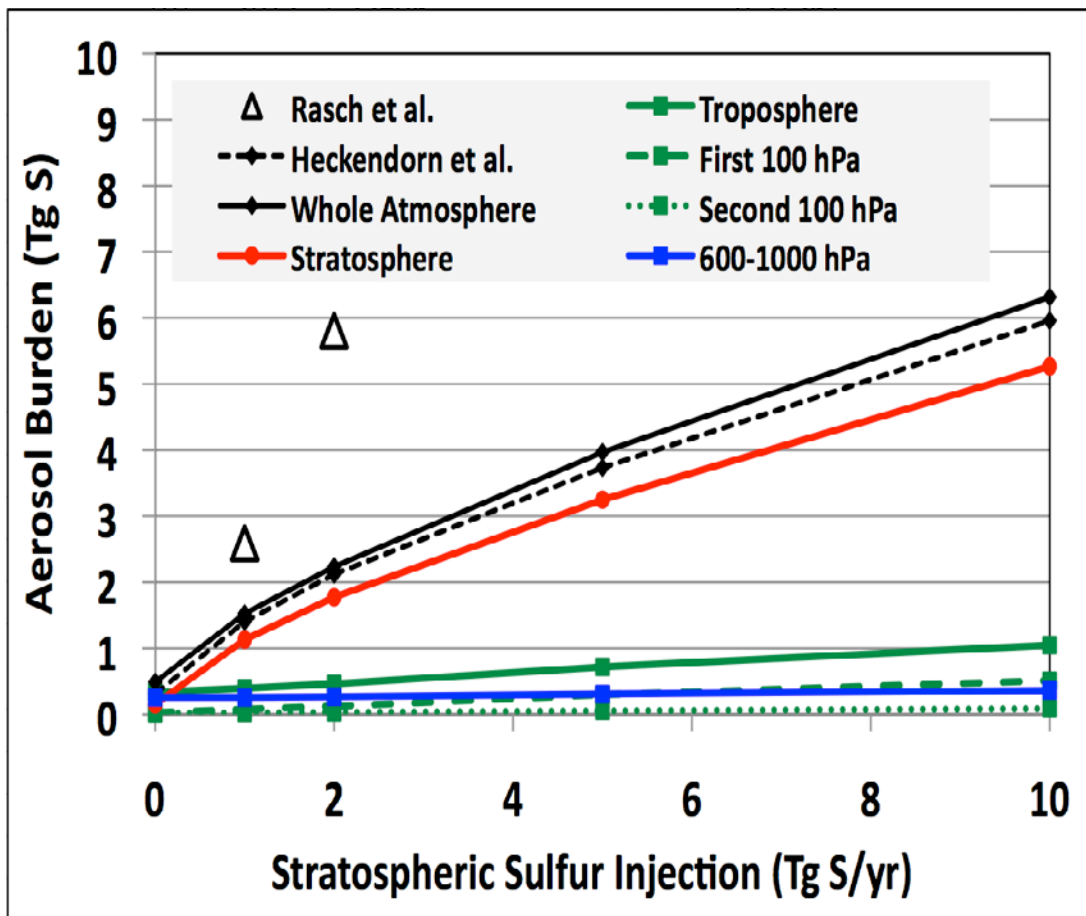
2) Injection zone size

- Narrow (4°S-4°N, 19-20 km, all longitudes)
- Plume (4°S-4°N, 19-20 km, 135°-145°E)
- Broad (32°S-32°N, 20-25 km, all longitudes)
- All SO₂, at 10 Tg S yr⁻¹

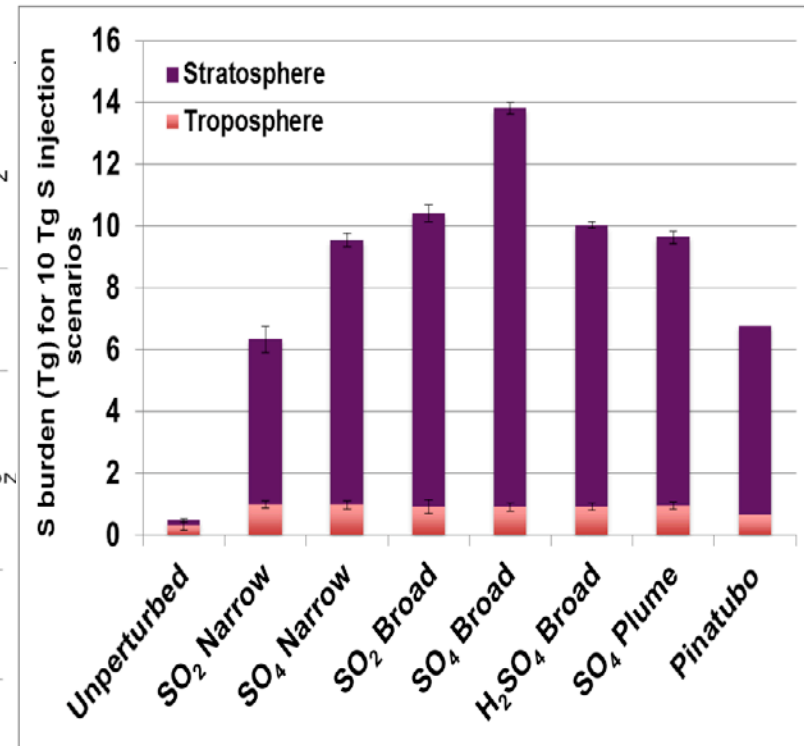
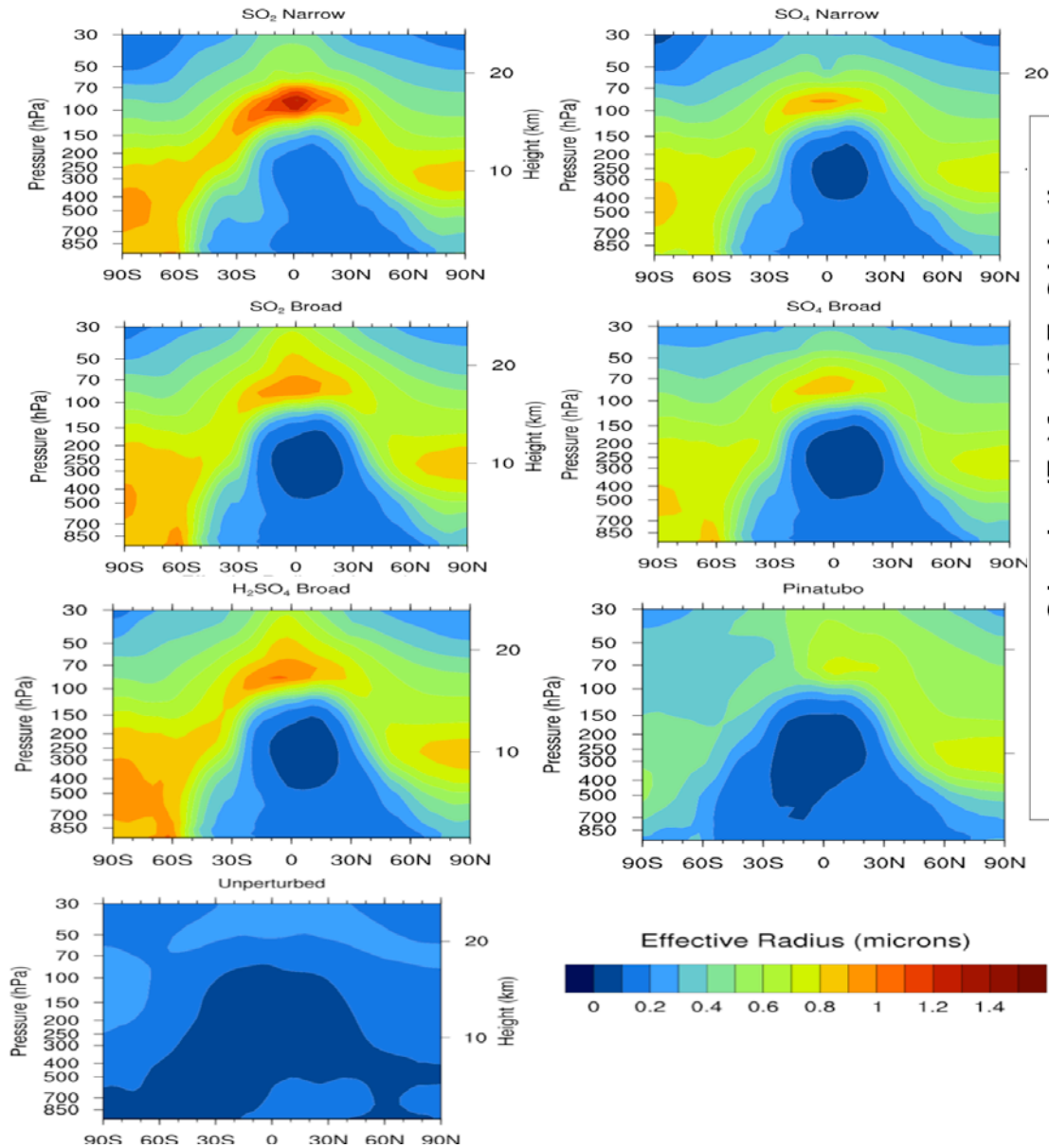
3) Injection species

- SO₂ gas
- H₂SO₄ gas
- SO₄ (sulfate particles, lognormal, width 1.5, peak 100 nm)
- All at 10 Tg S yr⁻¹

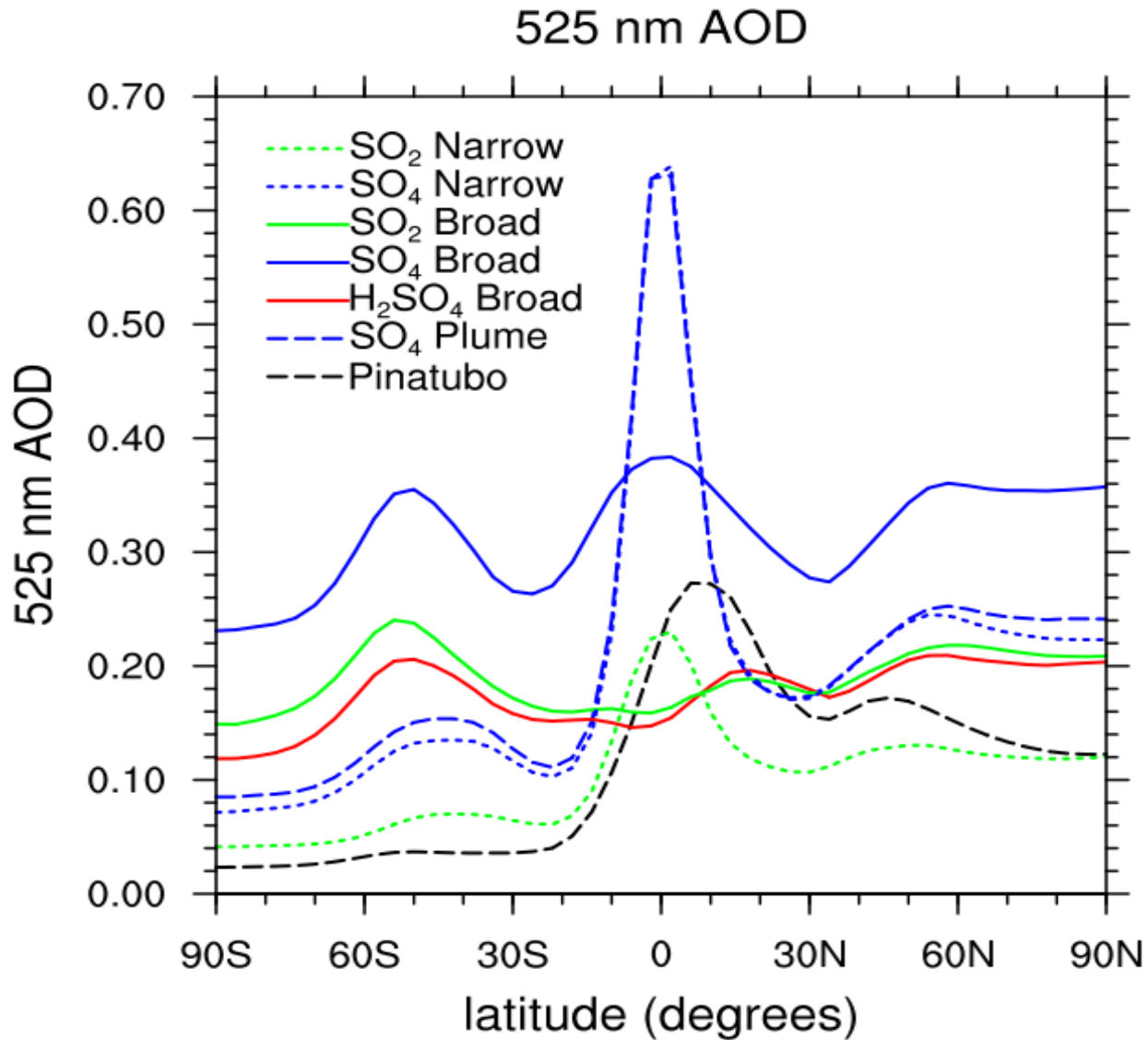
Higher SO₂ injections in a narrow region have diminished return due to larger particles



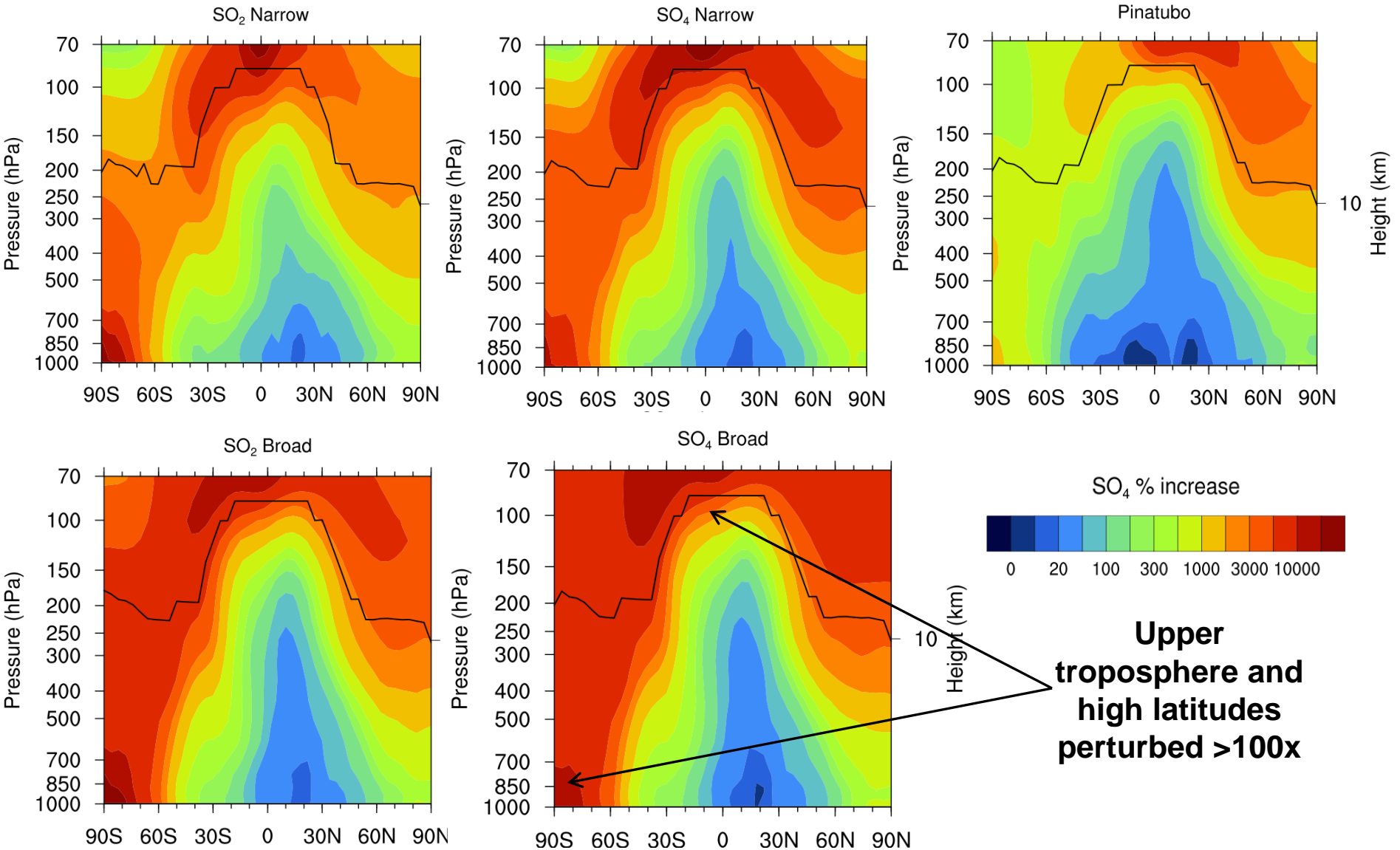
Particle size (and burdens) may be controlled by broader injection or particles instead of gases



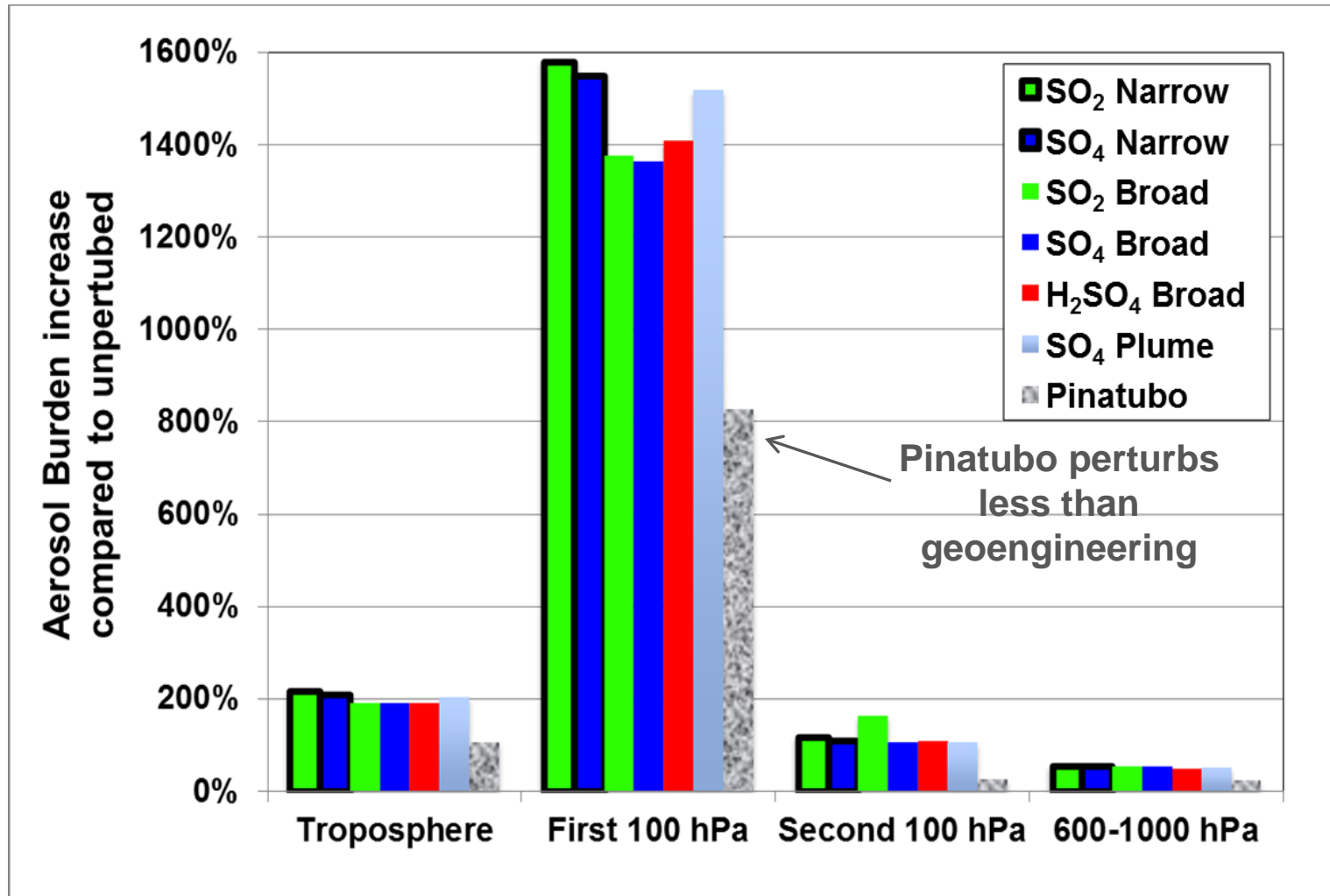
Different injection zones induce regional radiative forcings



All geoengineering increases tropospheric burdens

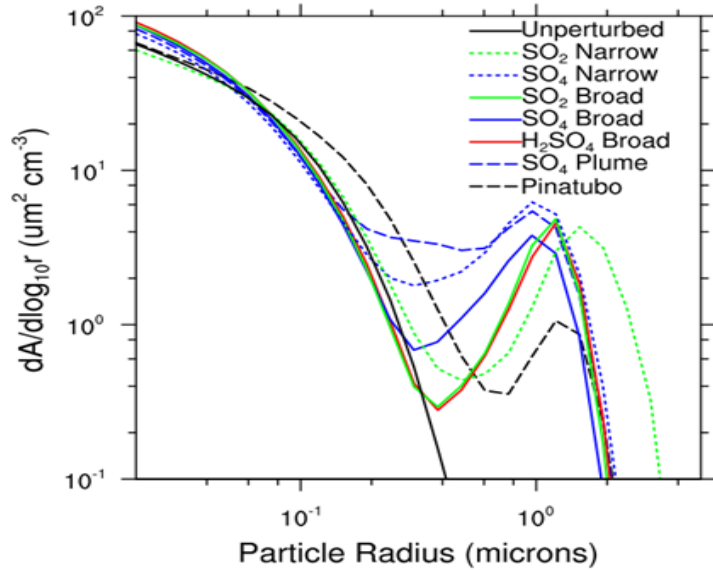


Tropospheric burden increases 200%; mostly in the 100 hPa region closest to tropopause

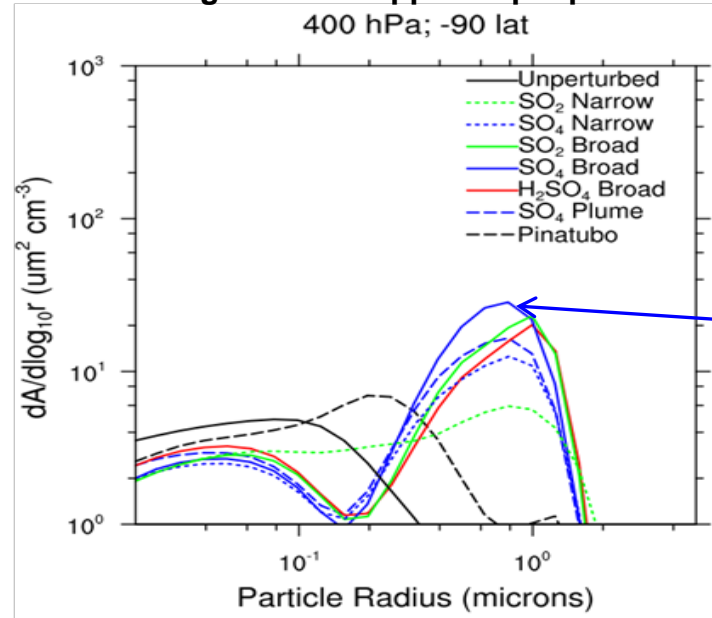


Possible impacts on clouds/chemistry

Tropical upper troposphere
120 hPa; 0 lat

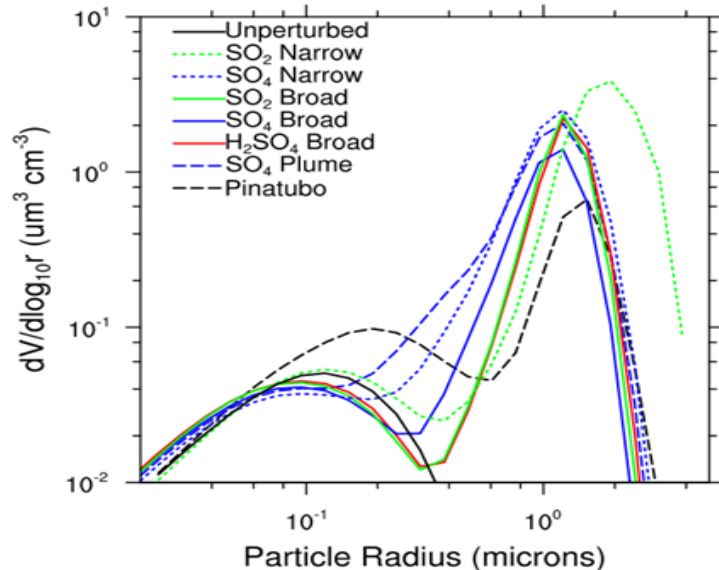


High latitude upper troposphere
400 hPa; -90 lat

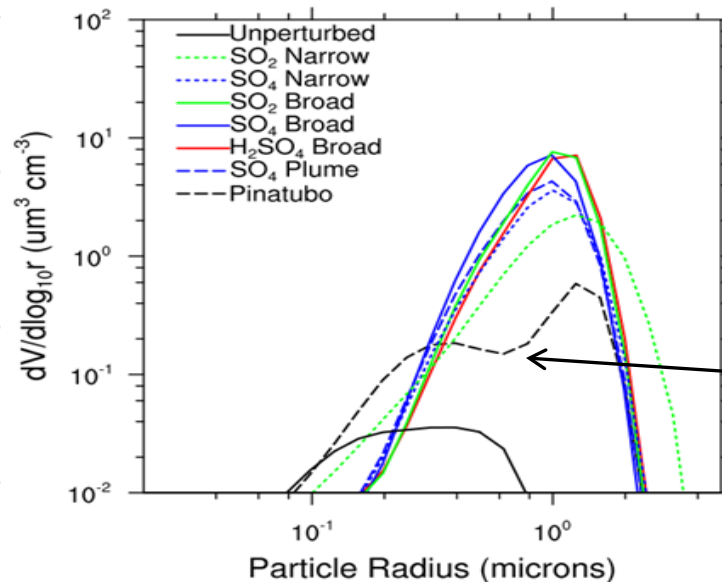


**Broad injections
(solid lines)
perturb high
latitudes more
than narrow
(dotted lines)**

120 hPa; 0 lat



400 hPa; -90 lat



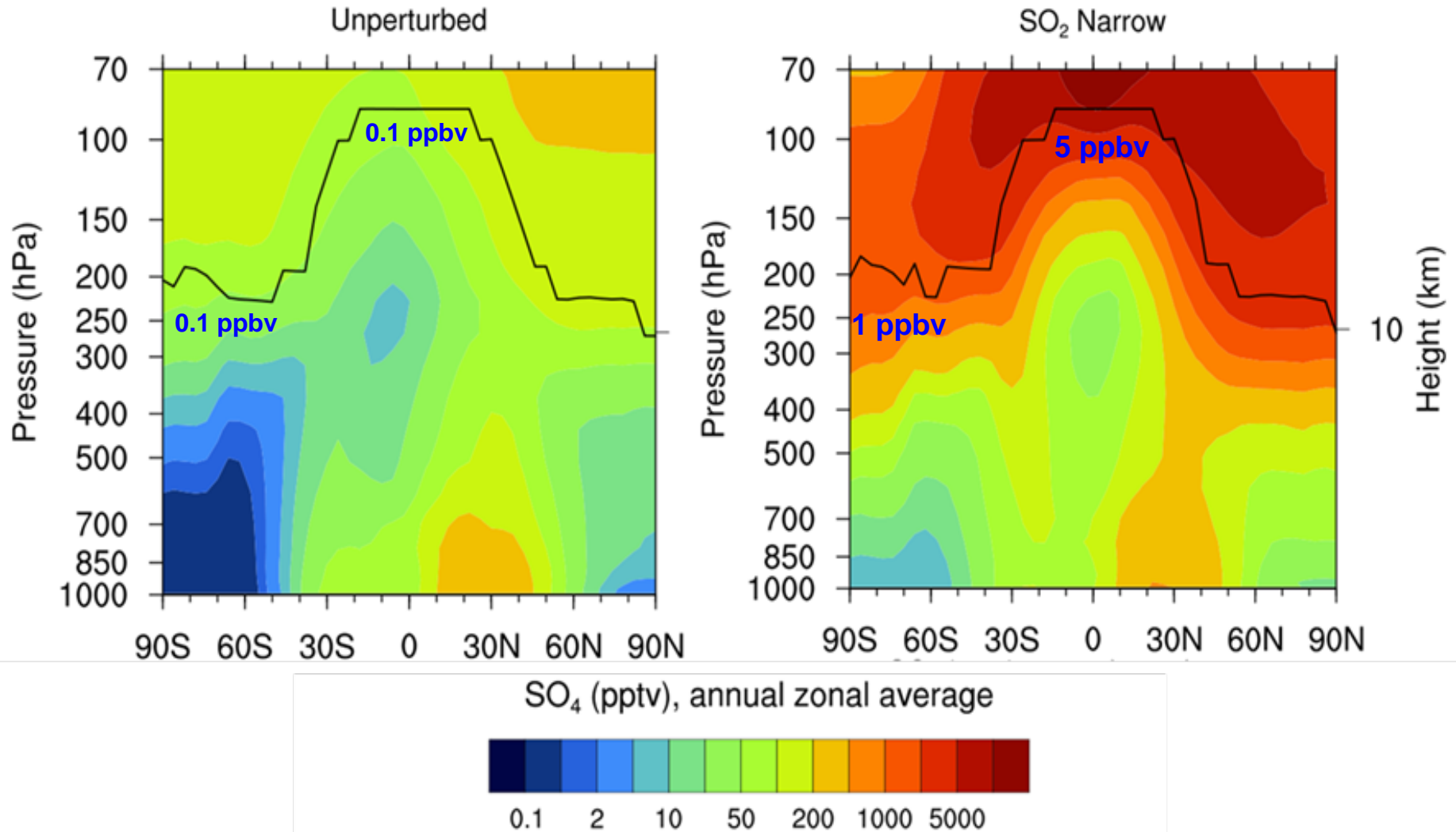
**Pinatubo
perturbs less
than
geoengineering**

Summary

- Increasing SO₂ injection rates in a narrow region has limited efficacy due to larger particle sizes
- AOD and burdens can be improved by:
 - Broadening the injection zone
 - Injecting particles instead of SO₂
 - Injecting H₂SO₄ gas might have benefit based on a plume model (Pierce et al., 2010) but it is based on many assumptions and we found no benefit in our model
- Tropospheric burdens are increased with all schemes, esp. high latitudes and upper troposphere, possibly impacting clouds or chemistry
- Geoeng still has other known issues: ozone destruction, ocean acidification, hydrological cycle changes

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Geoengineering increases tropospheric burdens



Identifying tropopause

