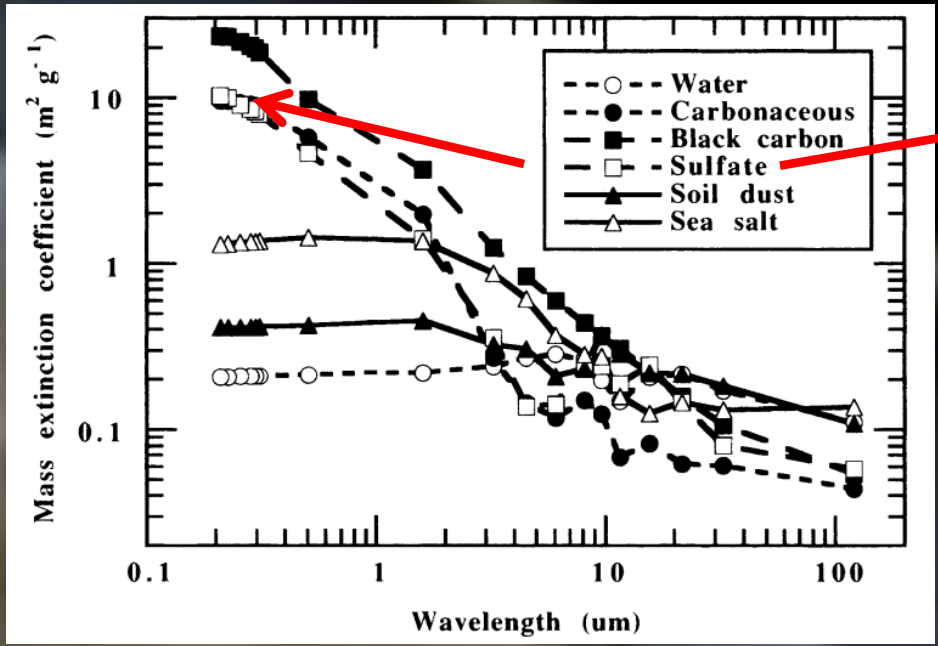
3D microphysical modeling of stratospheric sulfate geoengineering

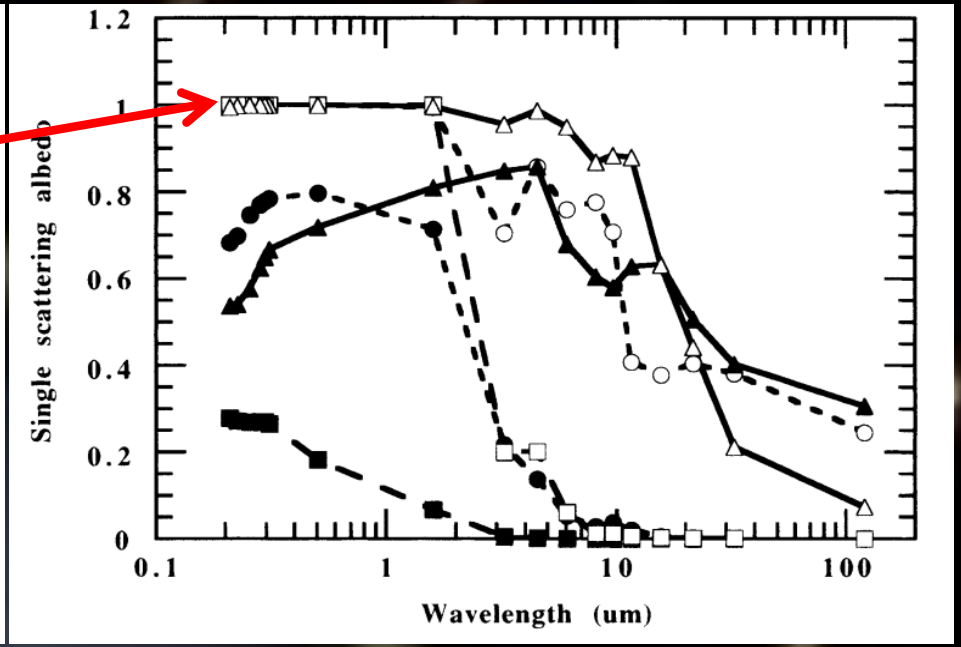
Jason M. English

Department of Atmospheric and Oceanic Sciences
University of Colorado
November 15, 2011

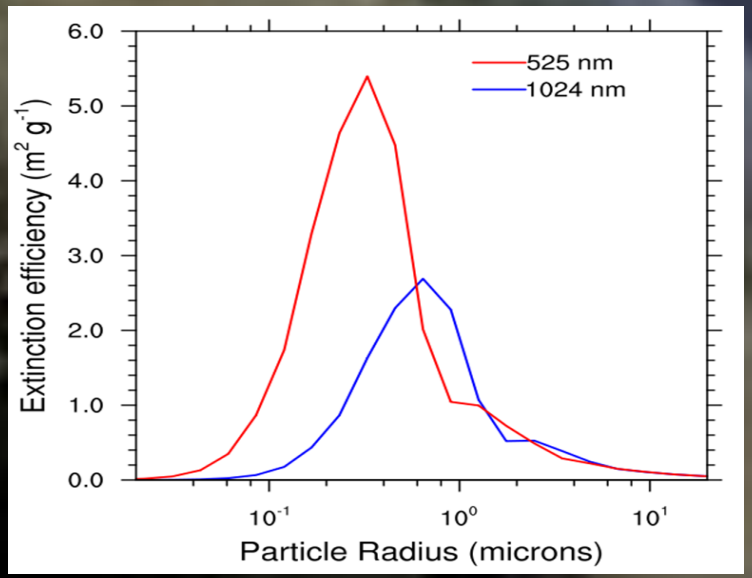
Advisor: Brian Toon
Colleague: Mike Mills

Why choose sulfate aerosols?



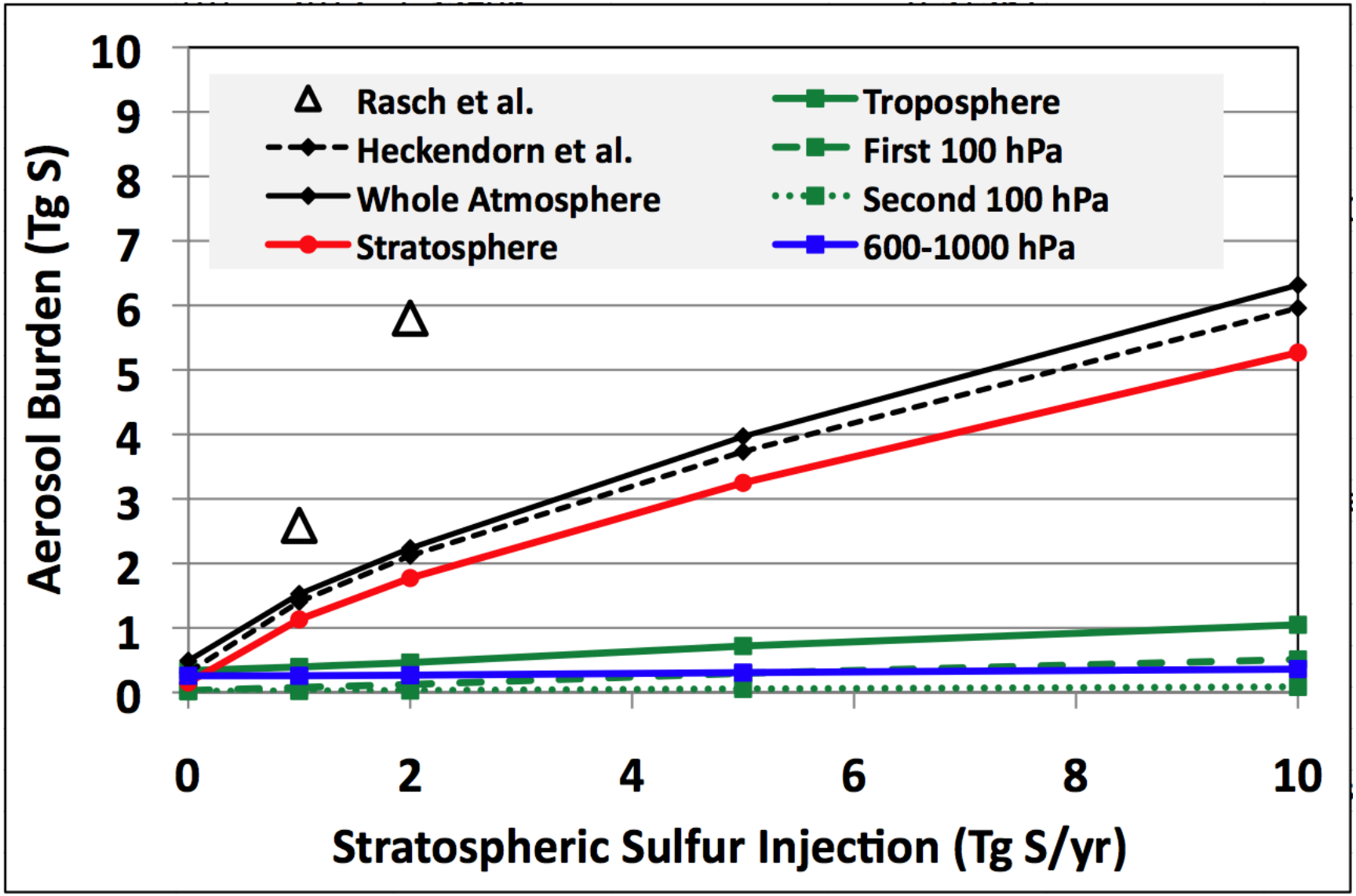


et al.



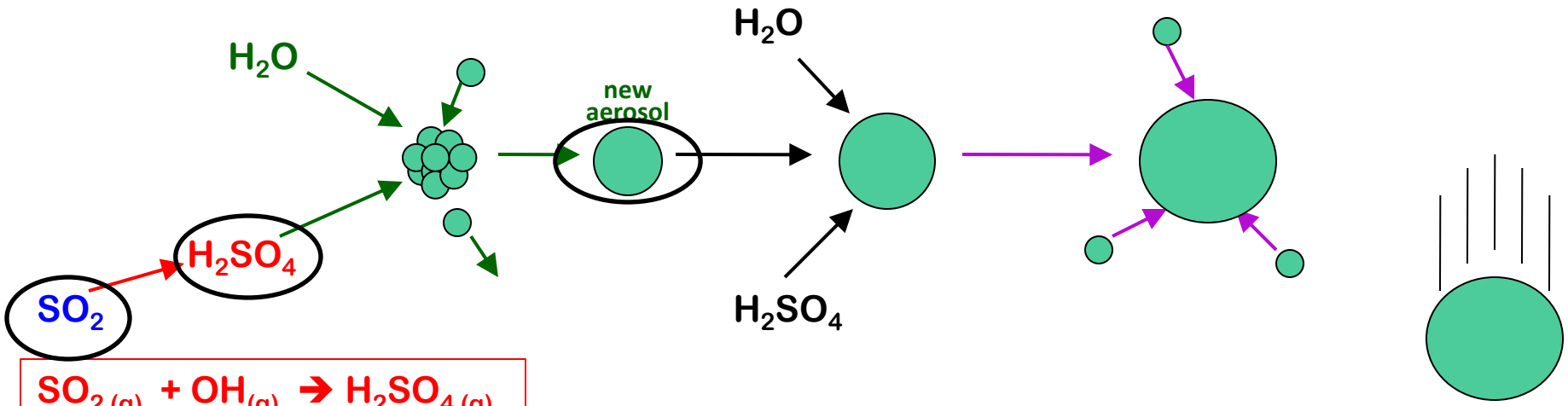
Why is it so important to get particle size right?

Higher SO_2 injections in a narrow region have diminished return



The sulfur cycle

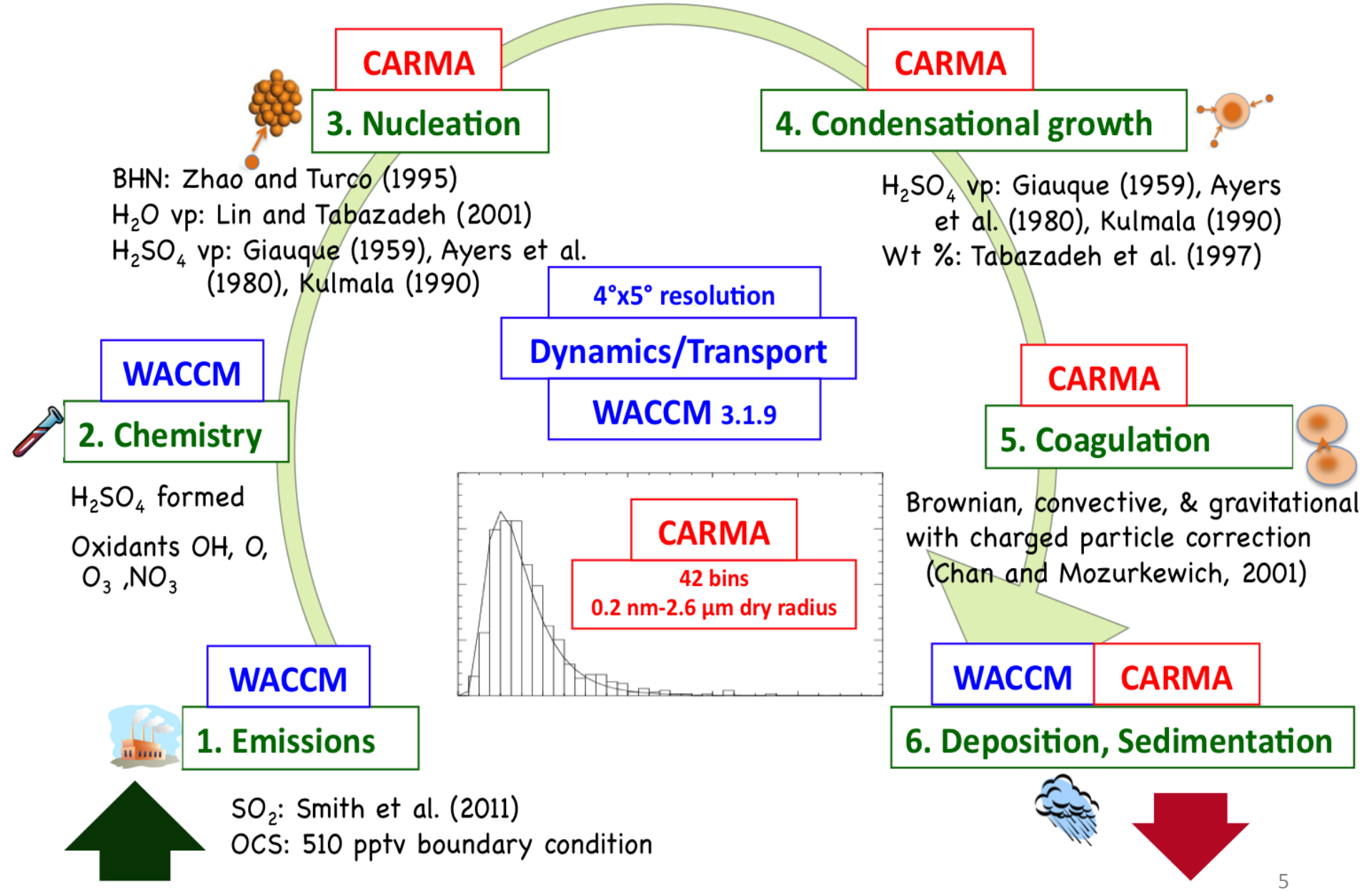
1. emissions	2. chemistry	3. nucleation	4. growth	5. coagulation	6. sedimentation
SO_2 gas injection	Sulfuric acid is made	an aerosol is born	evaporation, condensation	particles collide and combine	particles fall downward



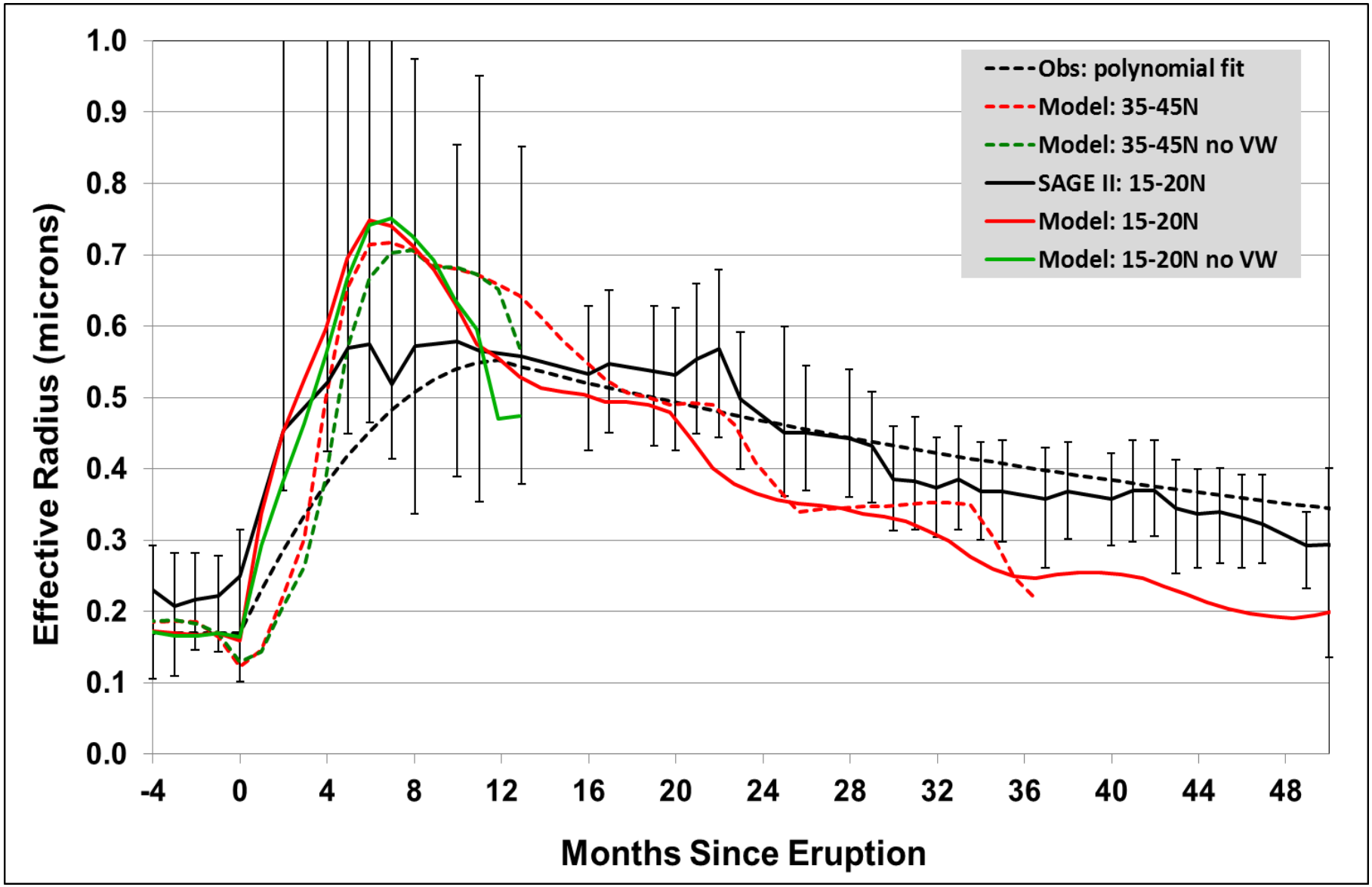
$SO_{2\,(g)} + OH_{(g)} \rightarrow H_2SO_{4\,(g)}$

Nucleation mode	Aitken mode	Accumulation mode
<1 – 20 nm	20 - 80 nm	0.1 - 2 μm

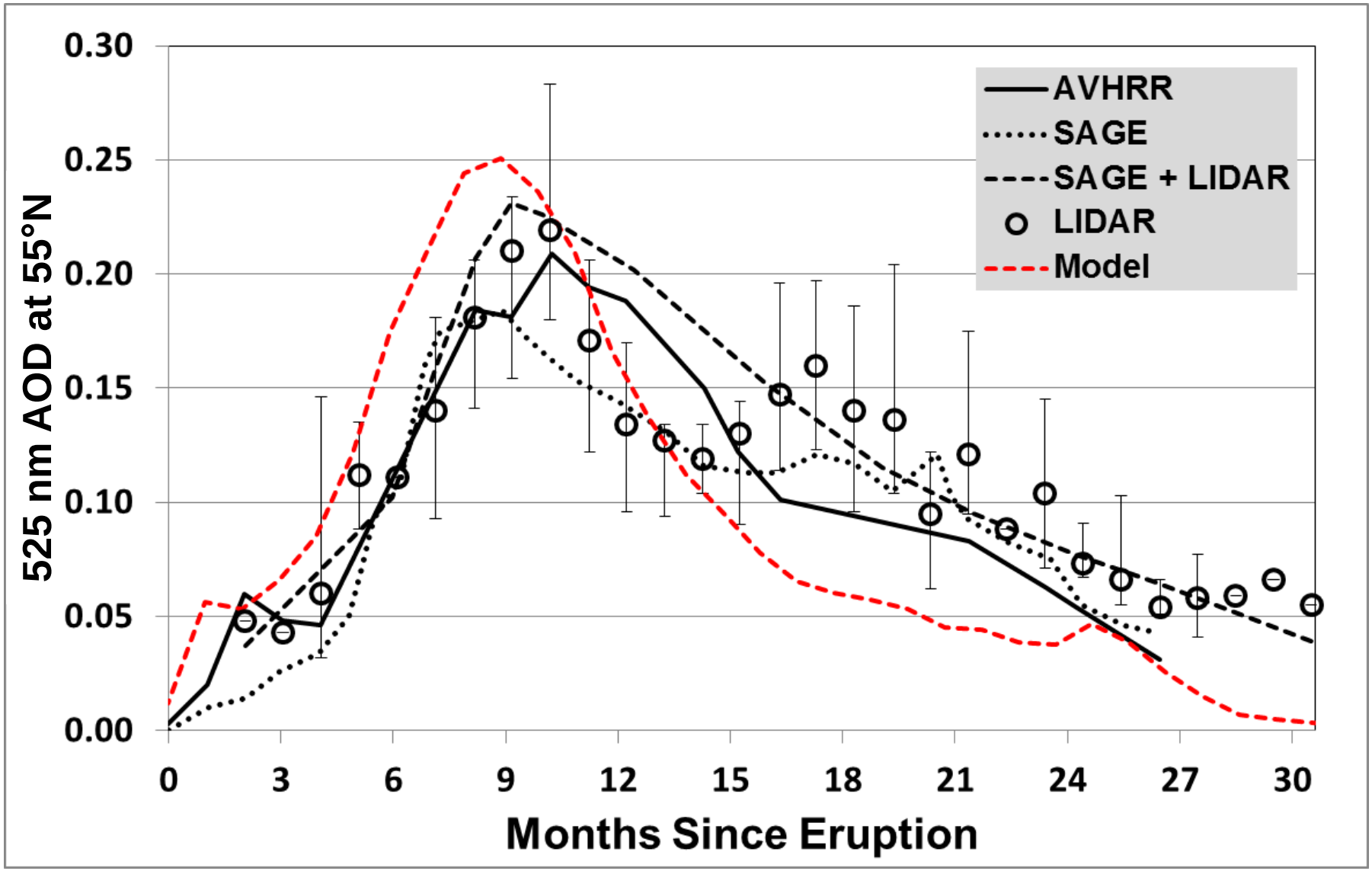
WACCM/CARMA model



R_{eff} more than triples 6 months after eruption



AOD increases 100x 9 mos. after eruption



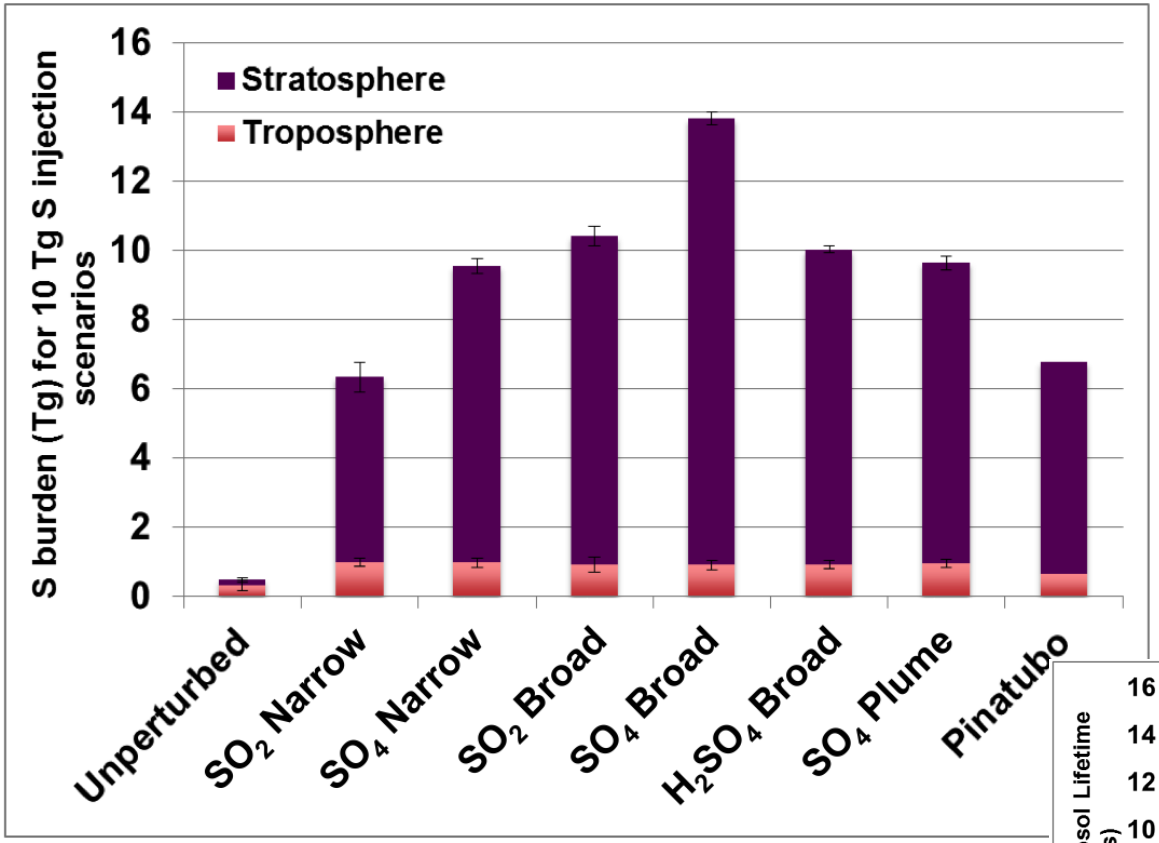
Geoengineering (10 Simulations)

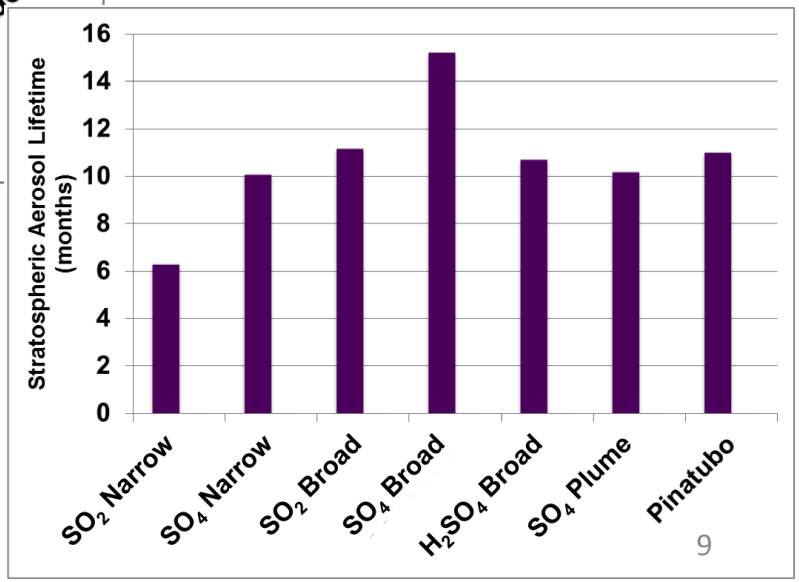
1) Varying SO_2 injection rates
   - 1, 2, 5, 10 Tg S yr^{-1} (Pinatubo = 10 Tg S)
   - All in narrow region (4°S-4°N, 19-20 km, all longitudes)

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 SO_2, at 10 Tg S yr^{-1}

3) Injection species
   - SO_2 gas
   - H_2SO_4 gas
   - SO_4 (sulfate particles, lognormal, width 1.5, peak 100 nm)
   - All at 10 Tg S yr^{-1}

Burden increased by broad injection, SO_4 particles

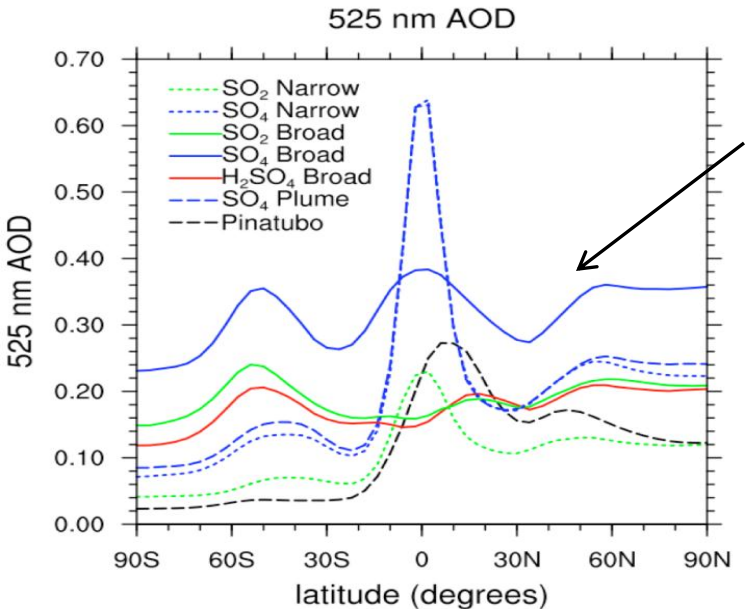




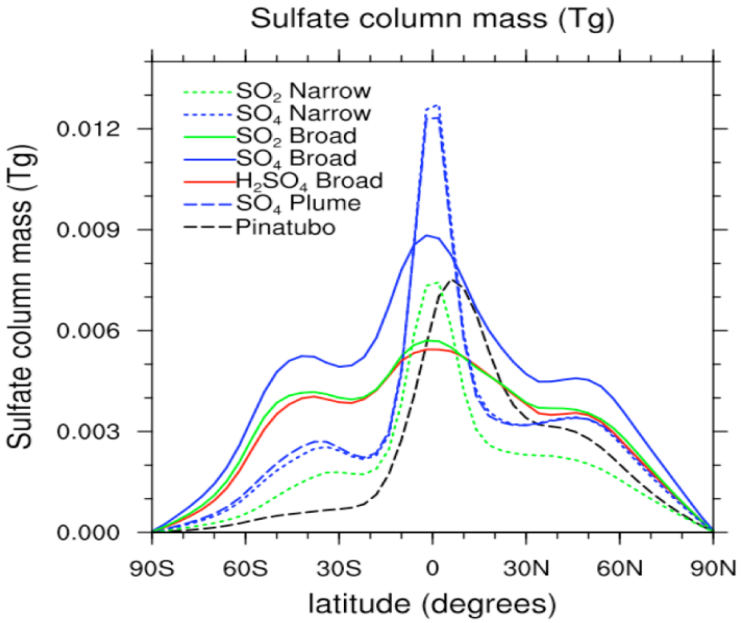
↑Lifetime ↑Burden

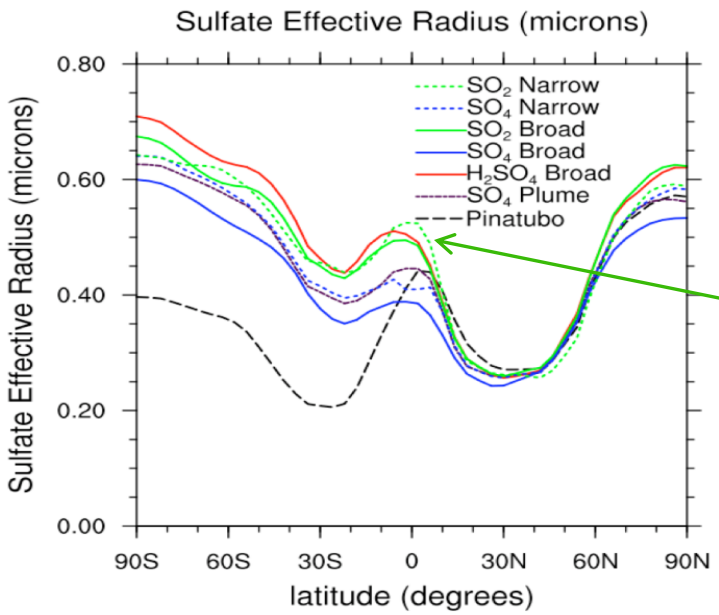
Most schemes have lifetime <1 yr

AOD increased by broad injection, SO_4 particles



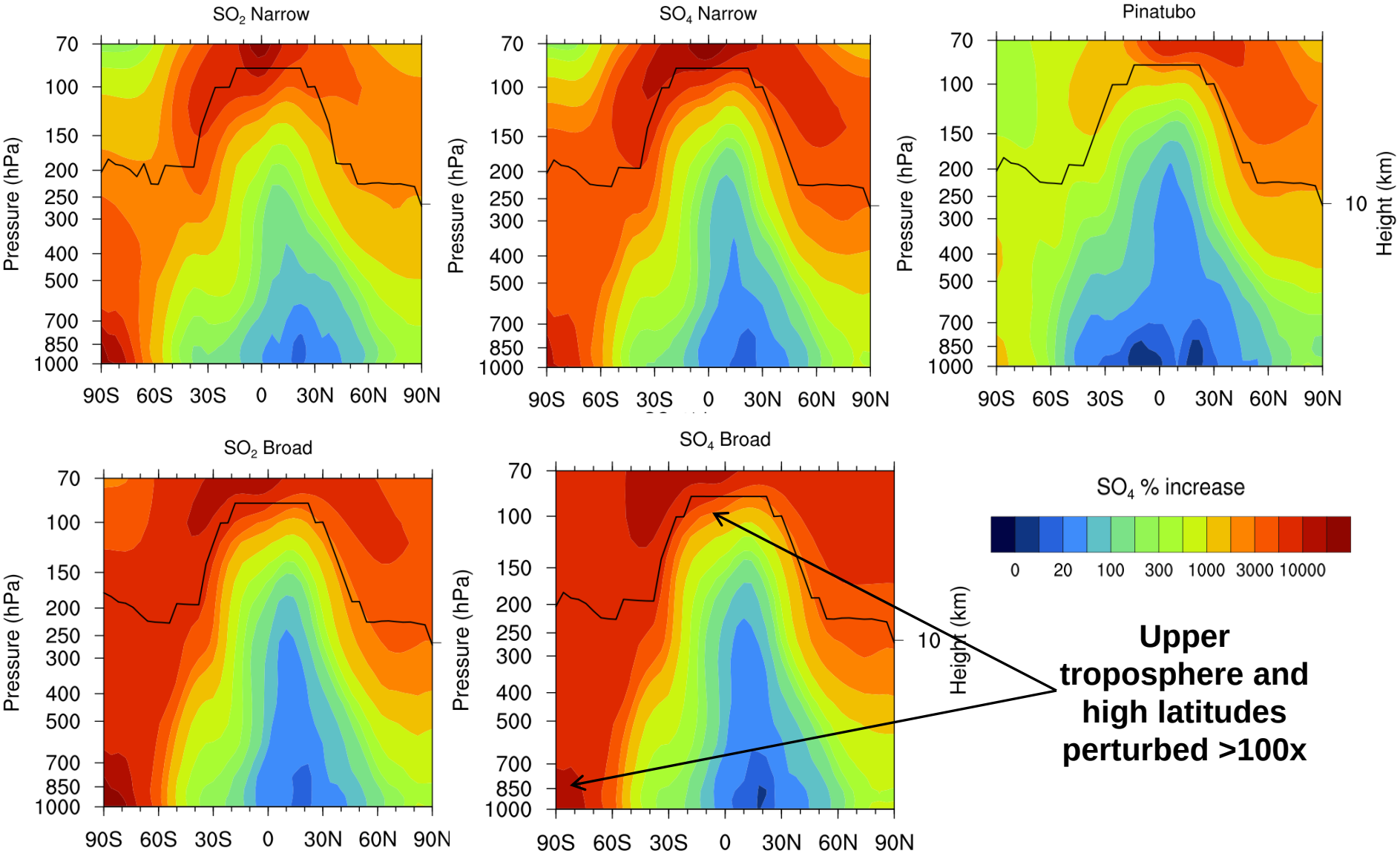
Broad injection distributes AOD; Narrow is high at equator; regional climate changes?



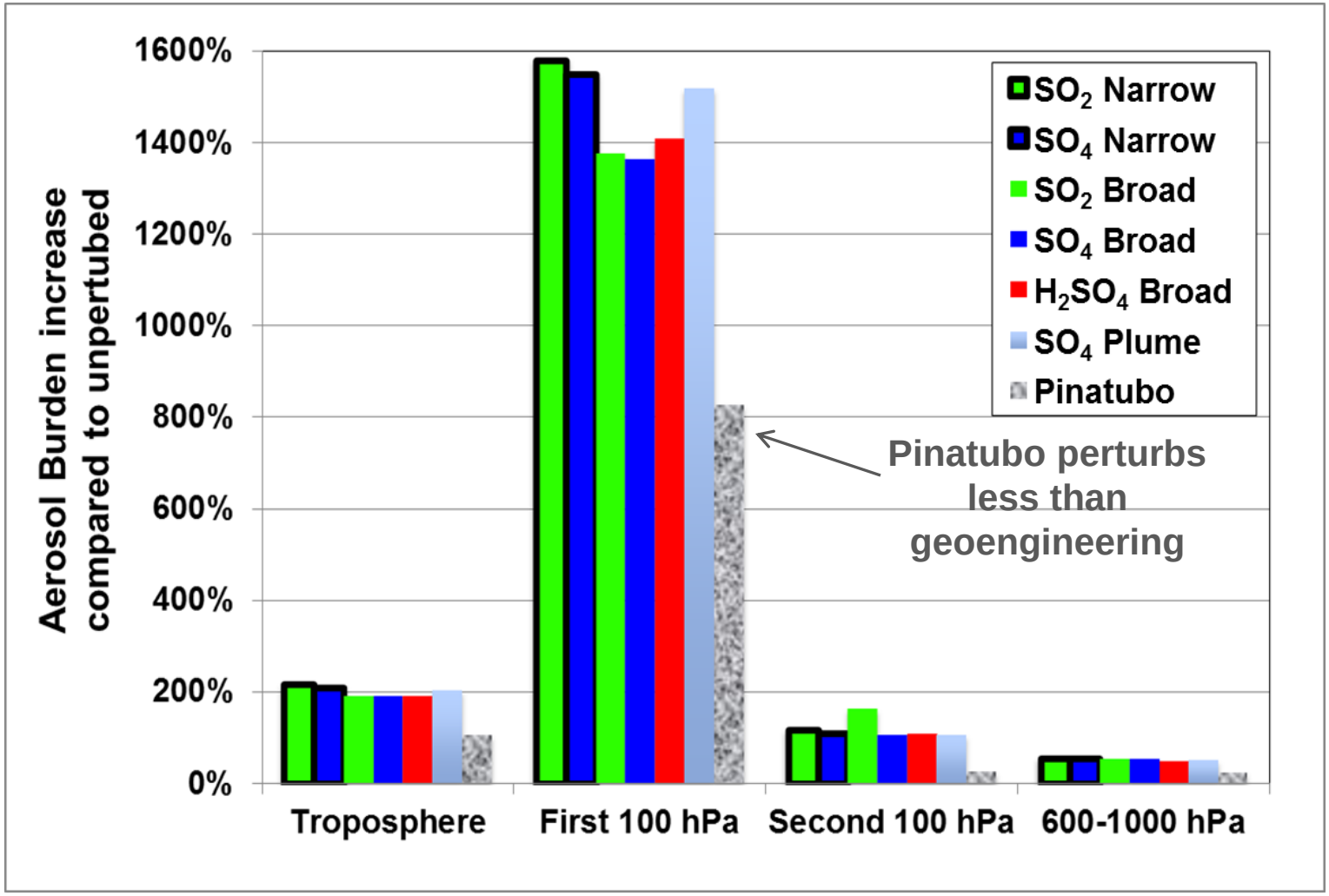


R_{eff} higher at equator for narrow schemes

All geoengineering increases tropospheric burdens

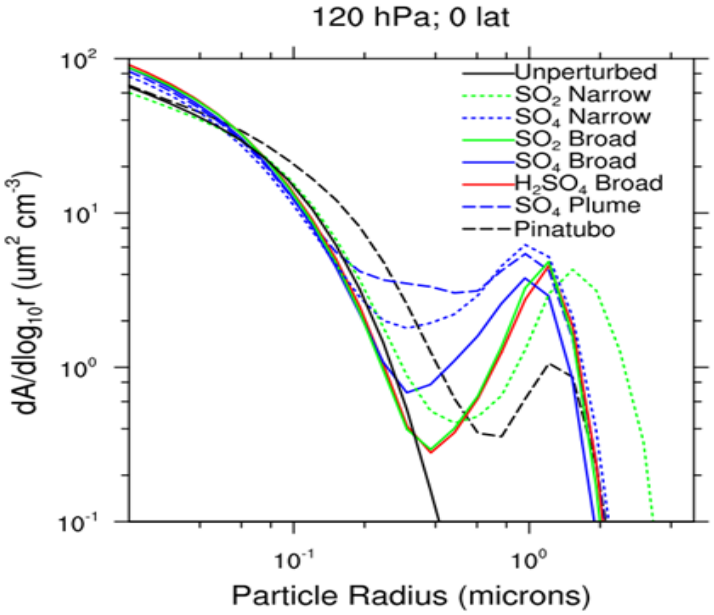


Tropospheric burden increases 200%; mostly in the 100 hPa region closest to tropopause

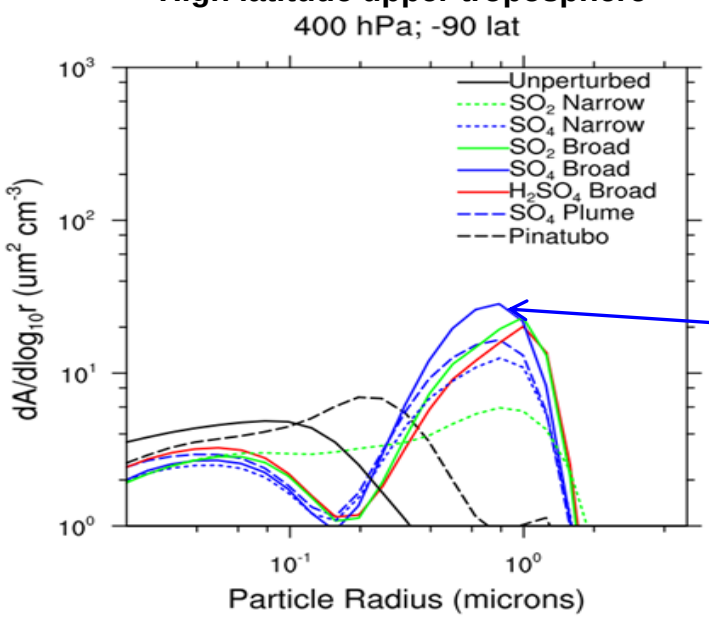


Possible impacts on clouds/chemistry

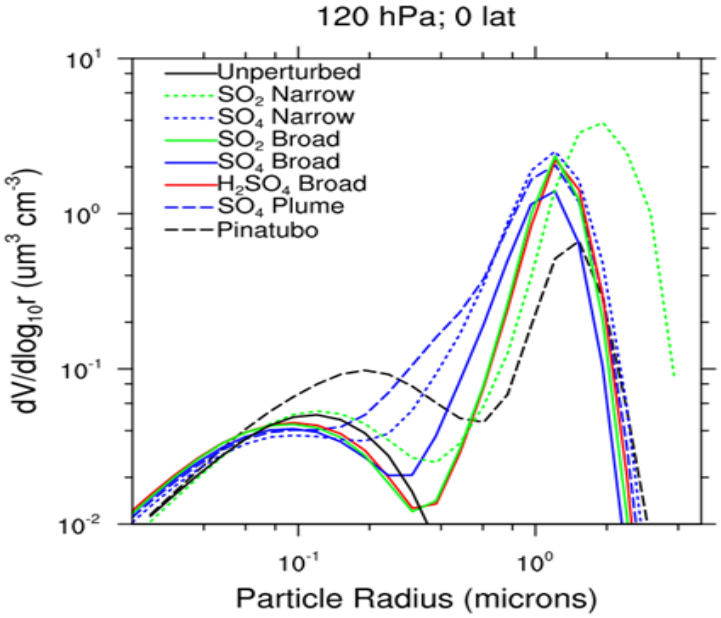
Tropical upper troposphere

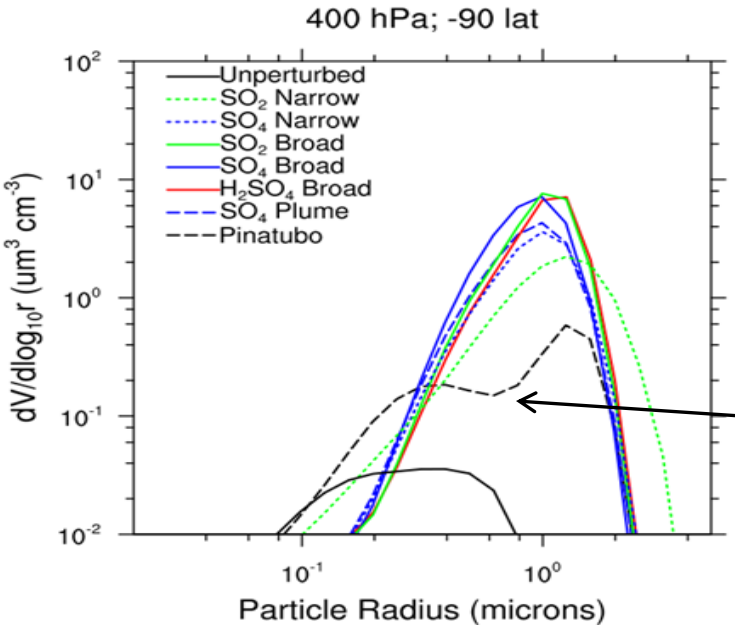


High latitude upper troposphere



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





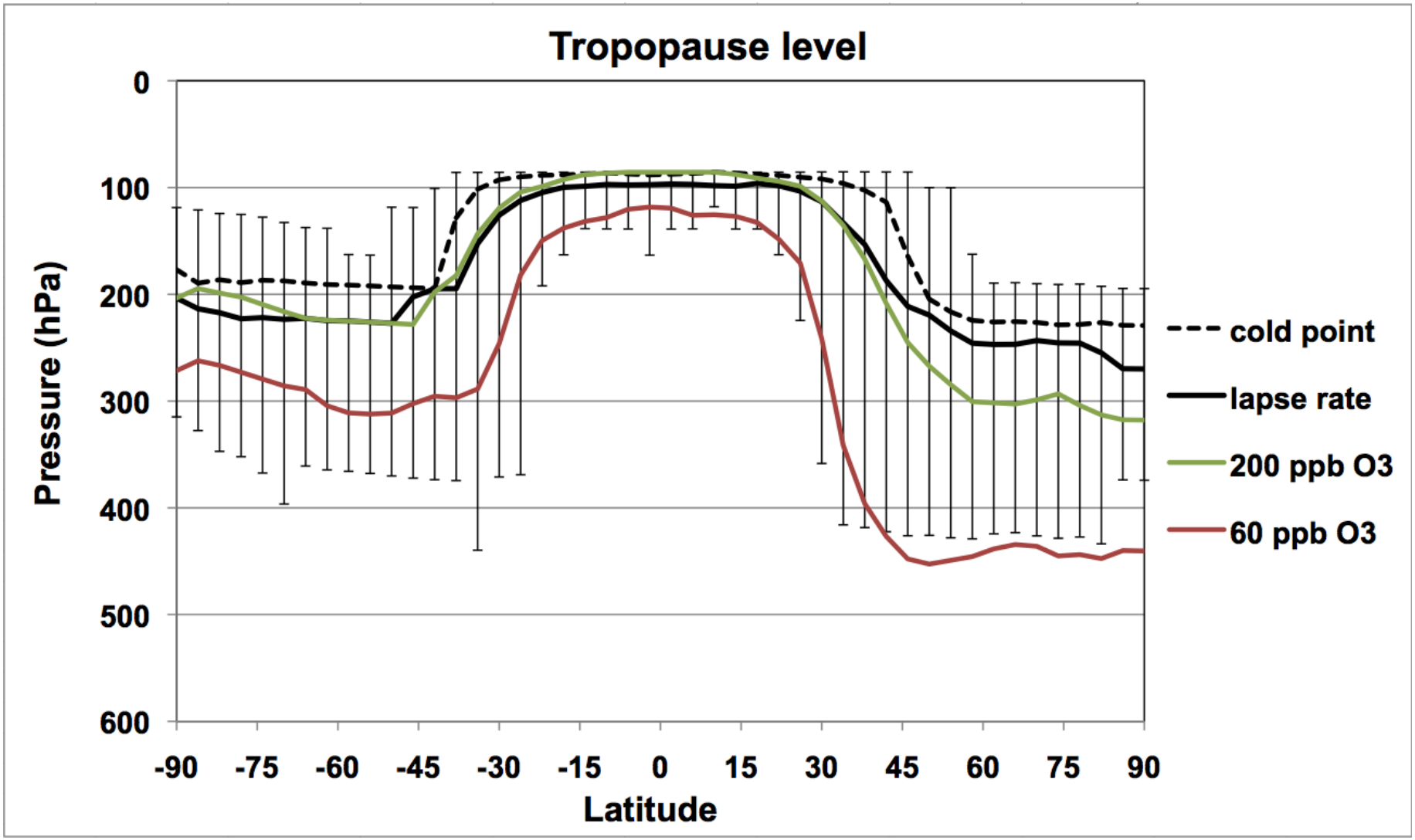
Pinatubo perturbs less than geoengineering

Summary

- Increasing SO_2 injection rates in a narrow region has limited efficacy
- AOD and burdens can be improved by:
  - Broadening the injection zone
  - Injecting particles instead of SO_2
  - Injecting H_2SO_4 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

This work is under review in JGR [English et al., 2011]

Identifying tropopause



Geoengineering increases tropospheric burdens