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

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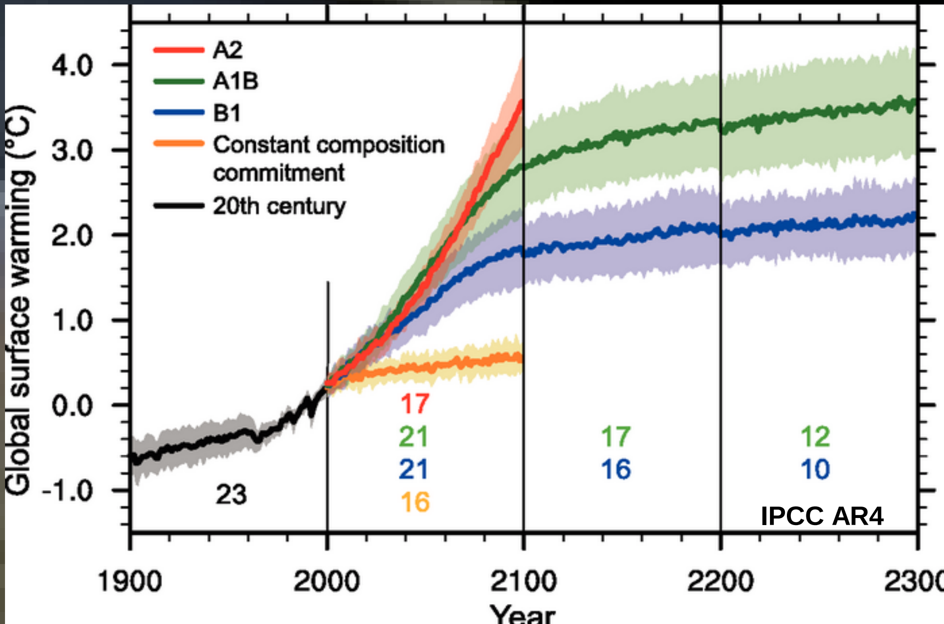
Why study geoengineering?

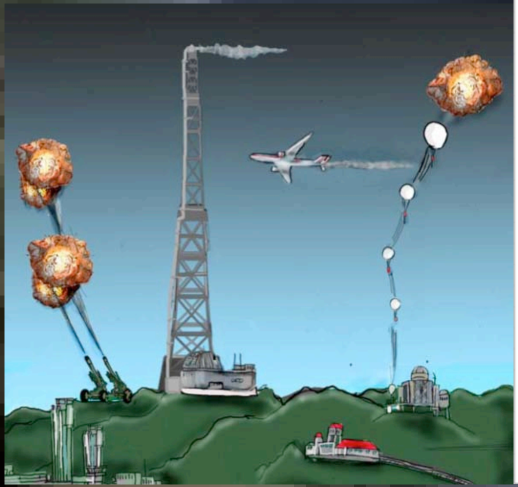


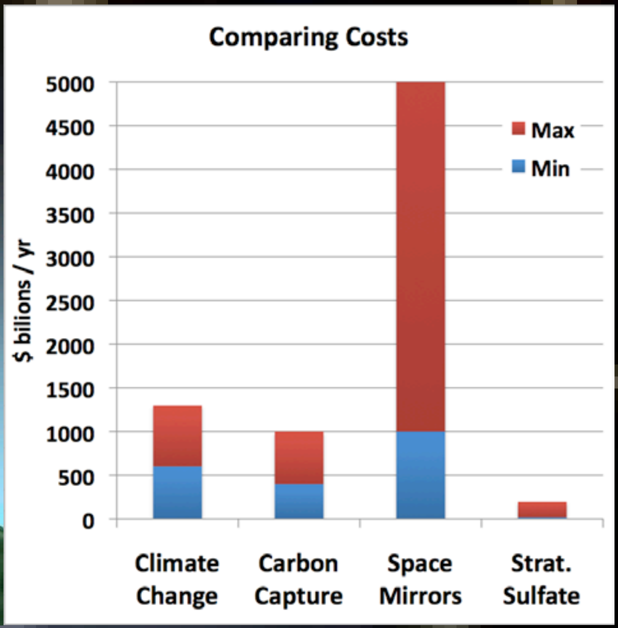
Sea level rise
Biodiversity loss
Extreme weather
Crop yields
Disease
Etc.

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

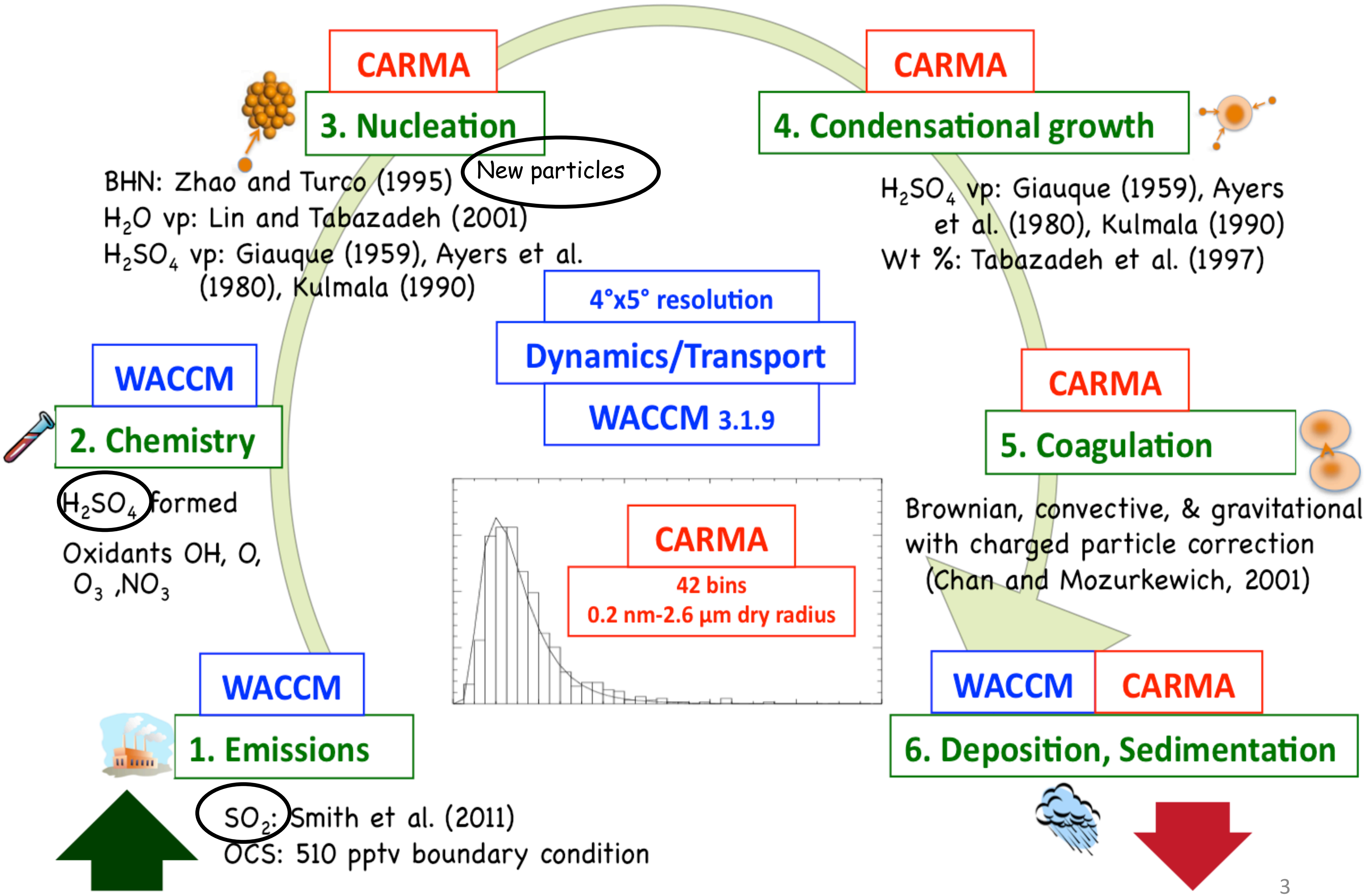
Stratospheric sulfur geoengineering:

\$1 to \$200 billion yr^{-1}





WACCM/CARMA model



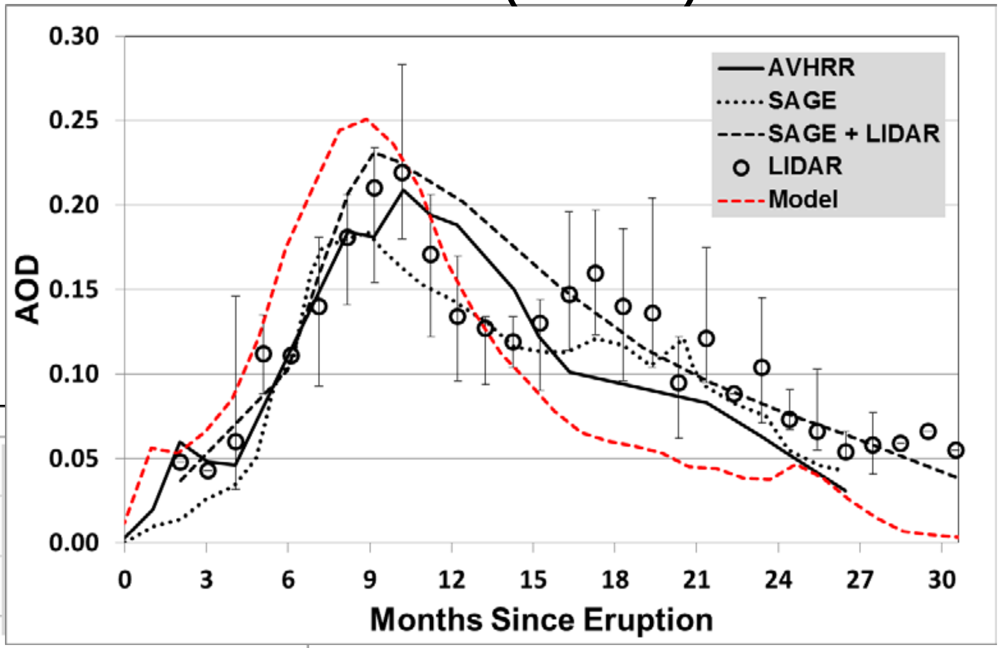
MOZART3 chemistry plus sulfur:

Binary Reactions			
	Reaction	Rate ($cm^3\ s^{-1}$)	Source
R1	$OCS + O \rightarrow SO + CO$	$2.1 \times 10^{-11} exp(-2200/T)$	Sander et al. (2006)
R2	$OCS + OH \rightarrow SO_2 + \{C\} + H$	$1.1 \times 10^{-13} exp(-1200/T)$	Cheng and Lee (1986)
R3	$S + OH \rightarrow SO + H$	6.6×10^{-11}	Jourdain et al. (1978)
R4	$S + O_2 \rightarrow SO + O$	2.3×10^{-12}	Davis et al. (1972)
R5	$S + O_3 \rightarrow SO + O_2$	1.2×10^{-11}	Clyne and Townsend (1975)
R6	$SO + OH \rightarrow SO_2 + H$	$2.70 \times 10^{-11} exp(335/T)$	Blitz et al. (2000)
R7	$SO + O_2 \rightarrow SO_2 + O$	$1.25 \times 10^{-13} exp(-2190/T)$	Sander et al. (2006)
R8	$SO + O_3 \rightarrow SO_2 + O_2$	$3.4 \times 10^{-12} exp(-1100/T)$	Sander et al. (2006)
R9	$SO + NO_2 \rightarrow SO_2 + NO$	1.4×10^{-11}	Brunning and Stief (1986a)
R10	$SO + CLO \rightarrow SO_2 + CL$	2.8×10^{-11}	Brunning and Stief (1986a)
R11	$SO + BRO \rightarrow SO_2 + BR$	5.7×10^{-11}	Brunning and Stief (1986b)
R12	$SO + OCLO \rightarrow SO_2 + CLO$	1.9×10^{-12}	Clyne and MacRobert (1981)
R13	$HSO_3 + O_2 \rightarrow SO_3 + HO_2$	$1.3 \times 10^{-12} exp(-330/T)$	Sander et al. (2006)
R14	$SO_3 + H_2O \rightarrow H_2SO_4$	$2.26 \times 10^{-23} \times T \times exp(6544/T)$	Lovejoy (1996)
Ternary Reactions			
	Reaction	Rate	Source
T1	$SO_2 + OH + M \rightarrow HSO_3 + M$	$k\_o = 3.0 \times 10^{-31} (T/300)^{4.3}$ $k\_infinity$: 1.6×10^{-12}	Blitz et al. (2003)
Photolytic Reactions			
	Reaction		Source
J1	$H_2SO_4 + h\nu \rightarrow SO_3 + H_2O$		Vaida et al. (2003)
J2	$SO_2 + h\nu \rightarrow SO + O$		Okabe (1978); Yung and DeMore (1982)
J3	$SO_3 + h\nu \rightarrow SO_2 + O$		Burkholder and McKeen (1997)
J4	$OCS + h\nu \rightarrow S + CO$		Molina et al. (1981)
J5	$SO + h\nu \rightarrow S + O$		Yung and Demore (1982)

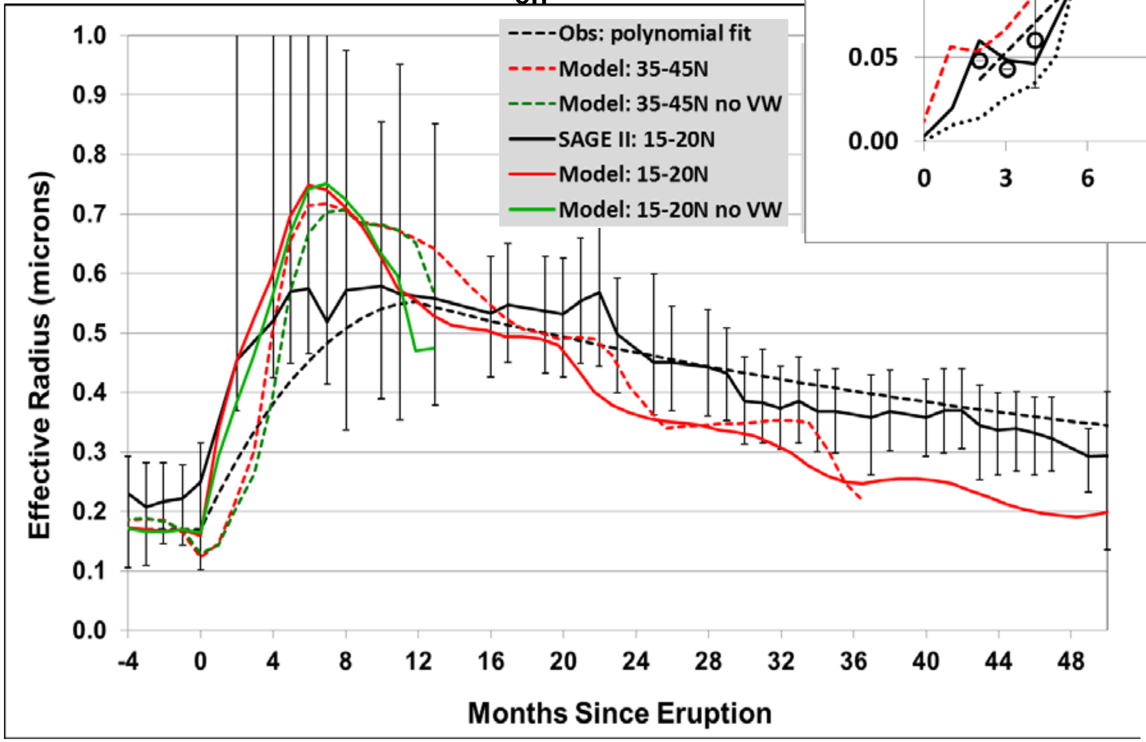
English, J. M., O. B. Toon, M. J. Mills, and F. Yu (2011), Microphysical simulations of new particle formation in the upper troposphere and lower stratosphere, Atmos. Chem. Phys., 11, 9303-9322, doi:10.5194/acp-11-9303-2011.

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

525 nm AOD (50–55°N)



R_{eff}



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)

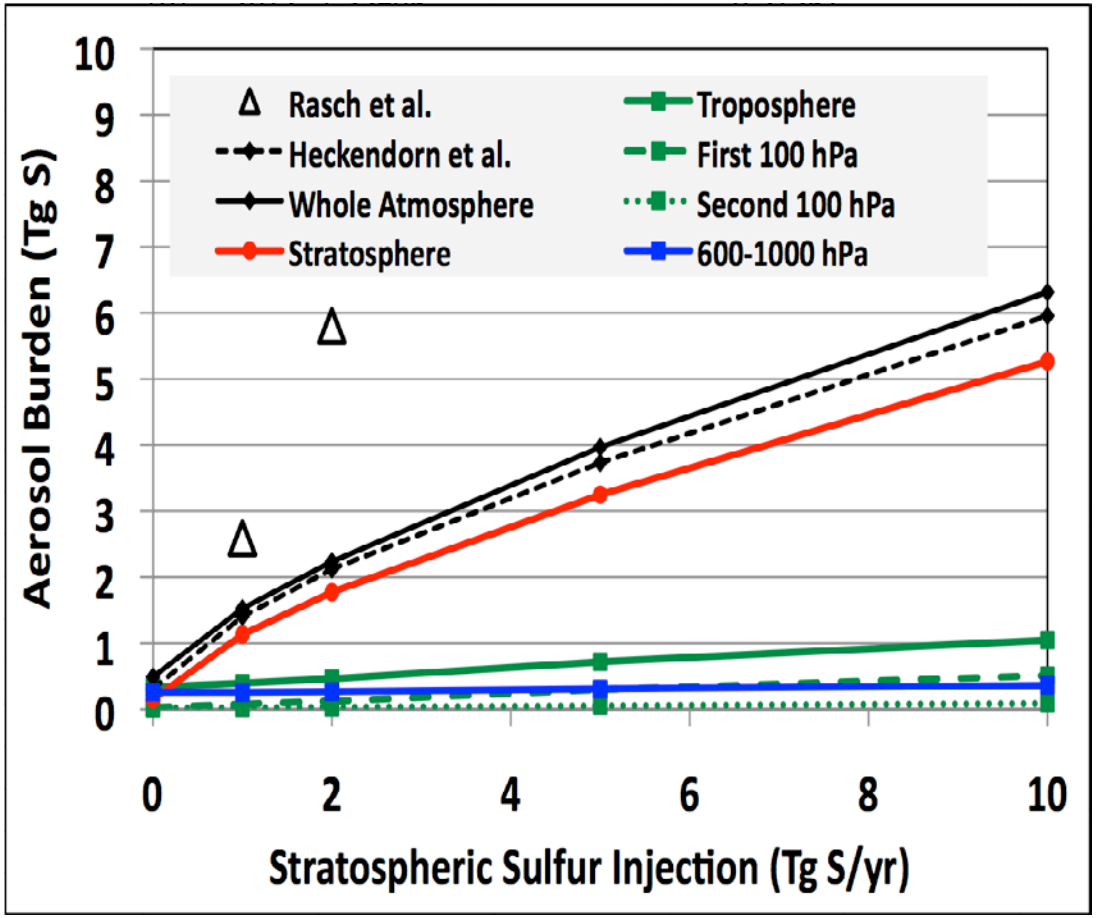
2) Injection zone size

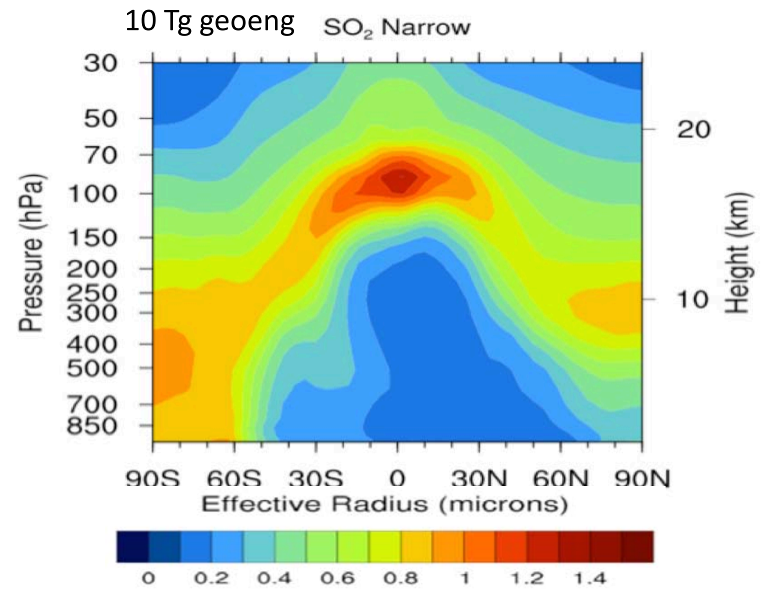
- Narrow (4°S-4°N, 19-20 km, all longitudes)
- Plume (4°S-4°N, 19-20 km, 135°-145°E)
- Broad (32°S-32°N, 20-25 km, all longitudes)
- All SO_2, at 10 Tg S yr^{-1}

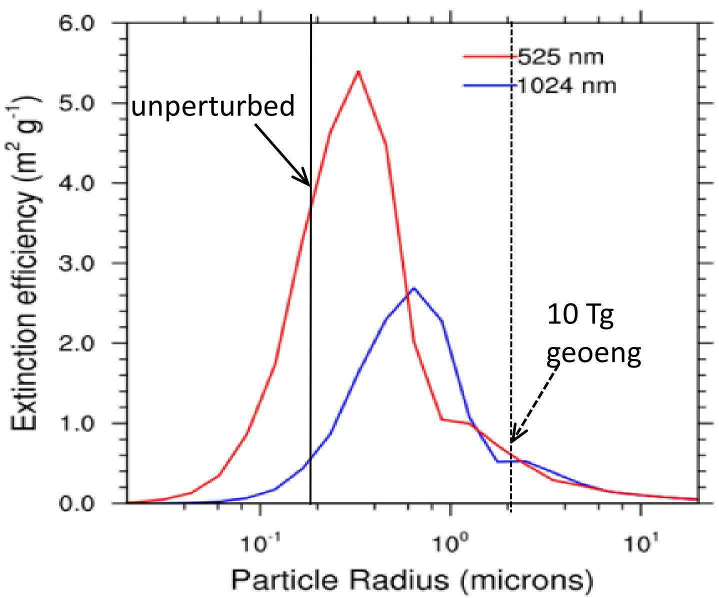
3) Injection species

- 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}

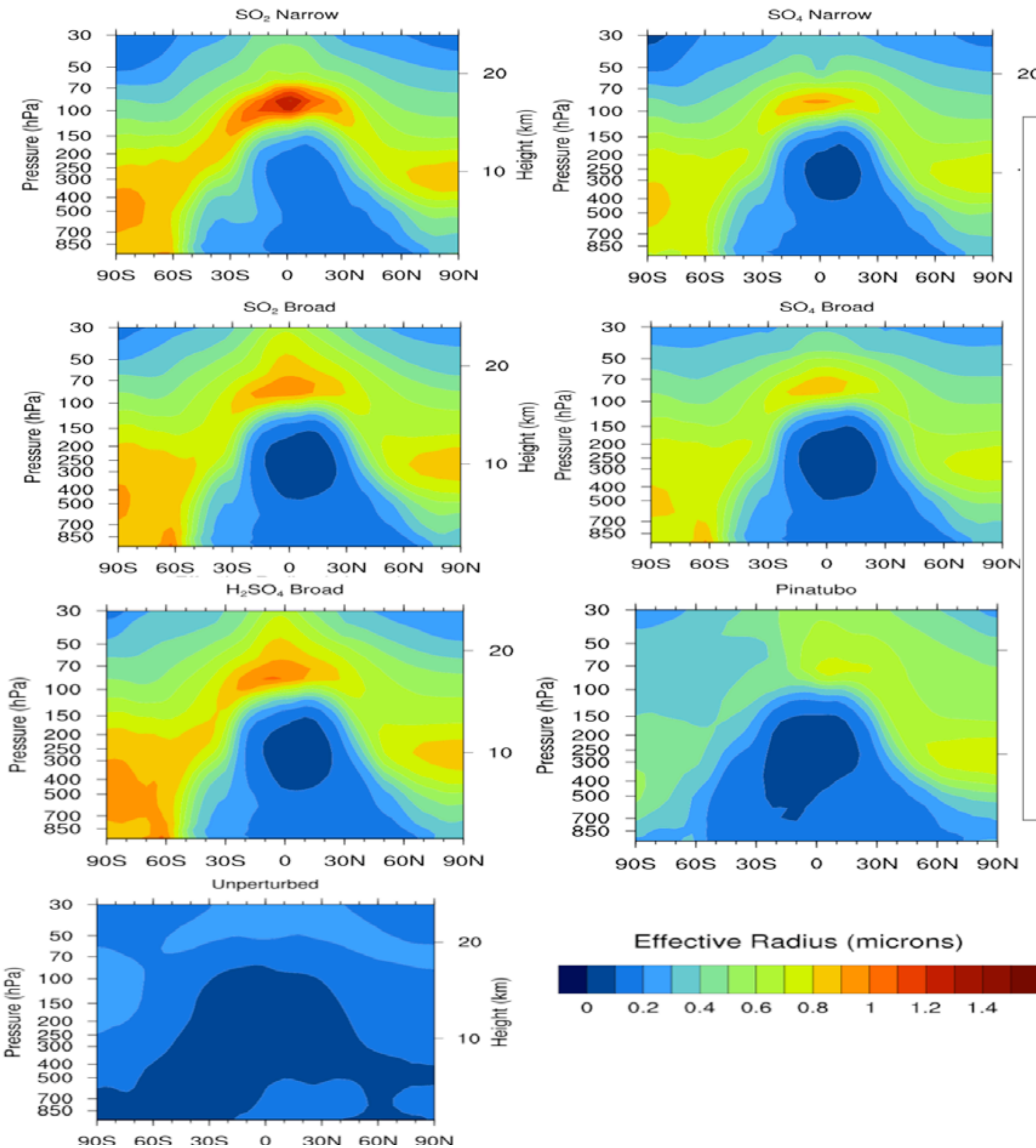
Higher SO_2 injections in a narrow region have diminished return due to larger particles

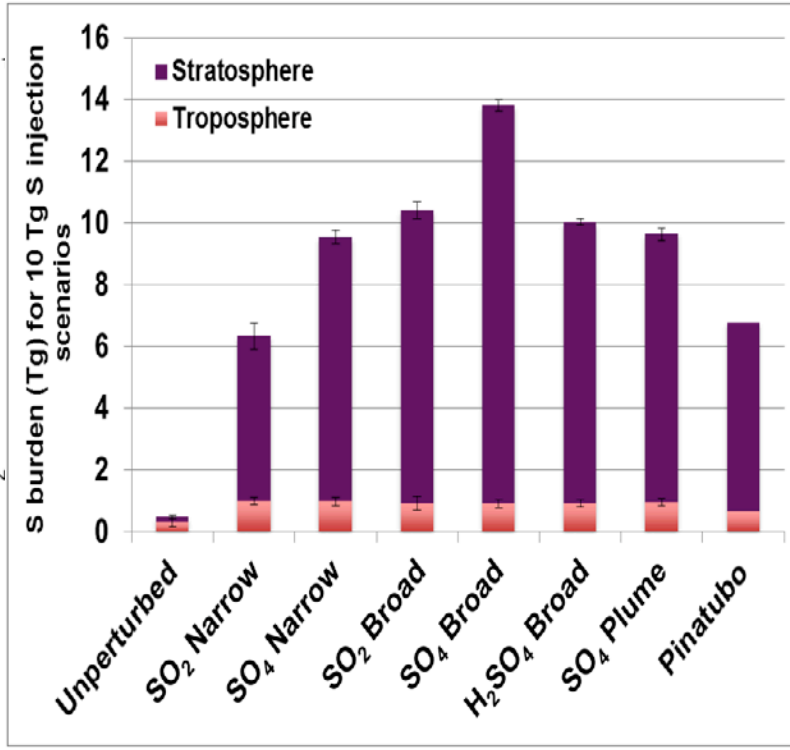




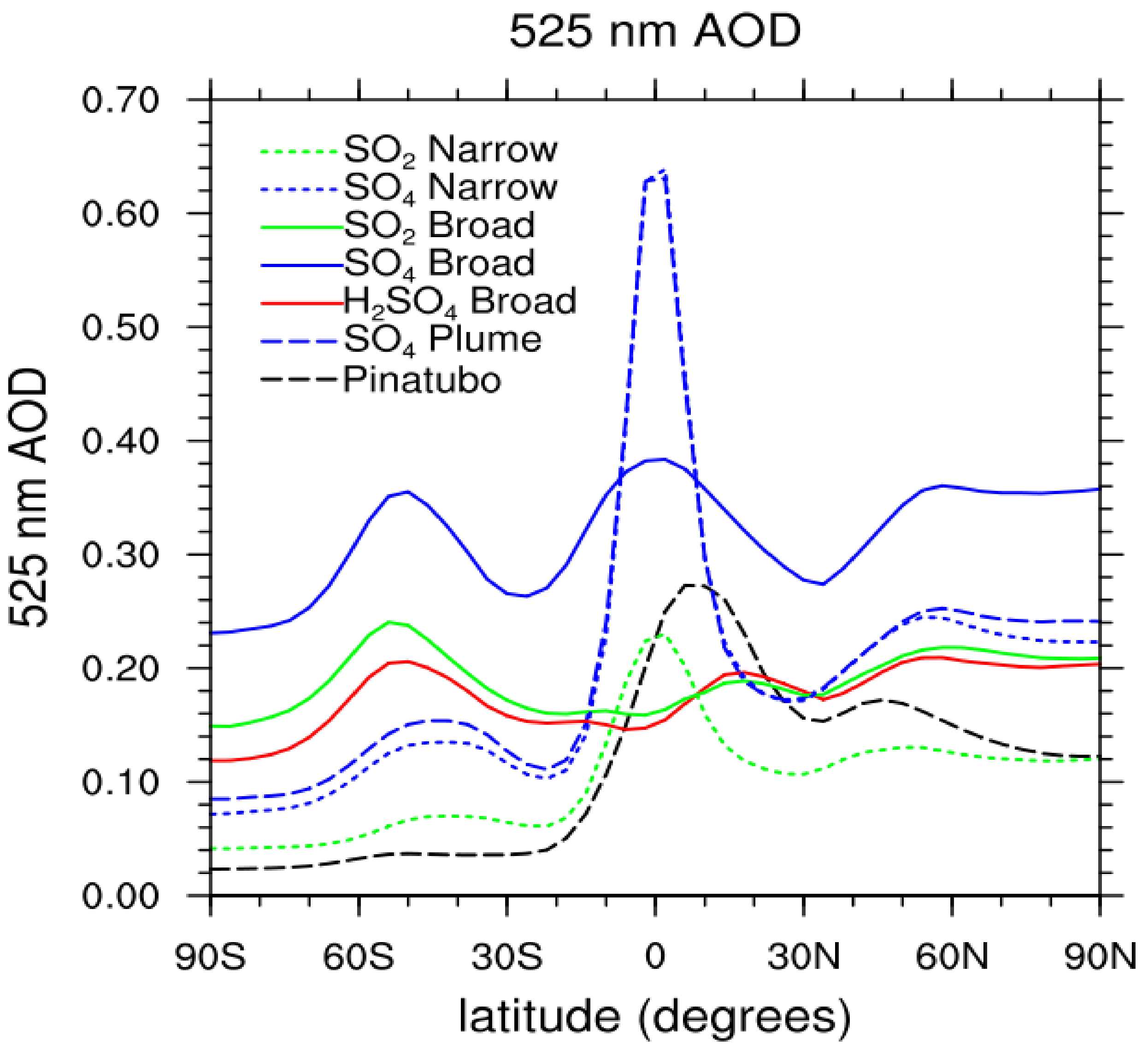


Particle size (and burdens) may be controlled by broader injection or particles instead of gases

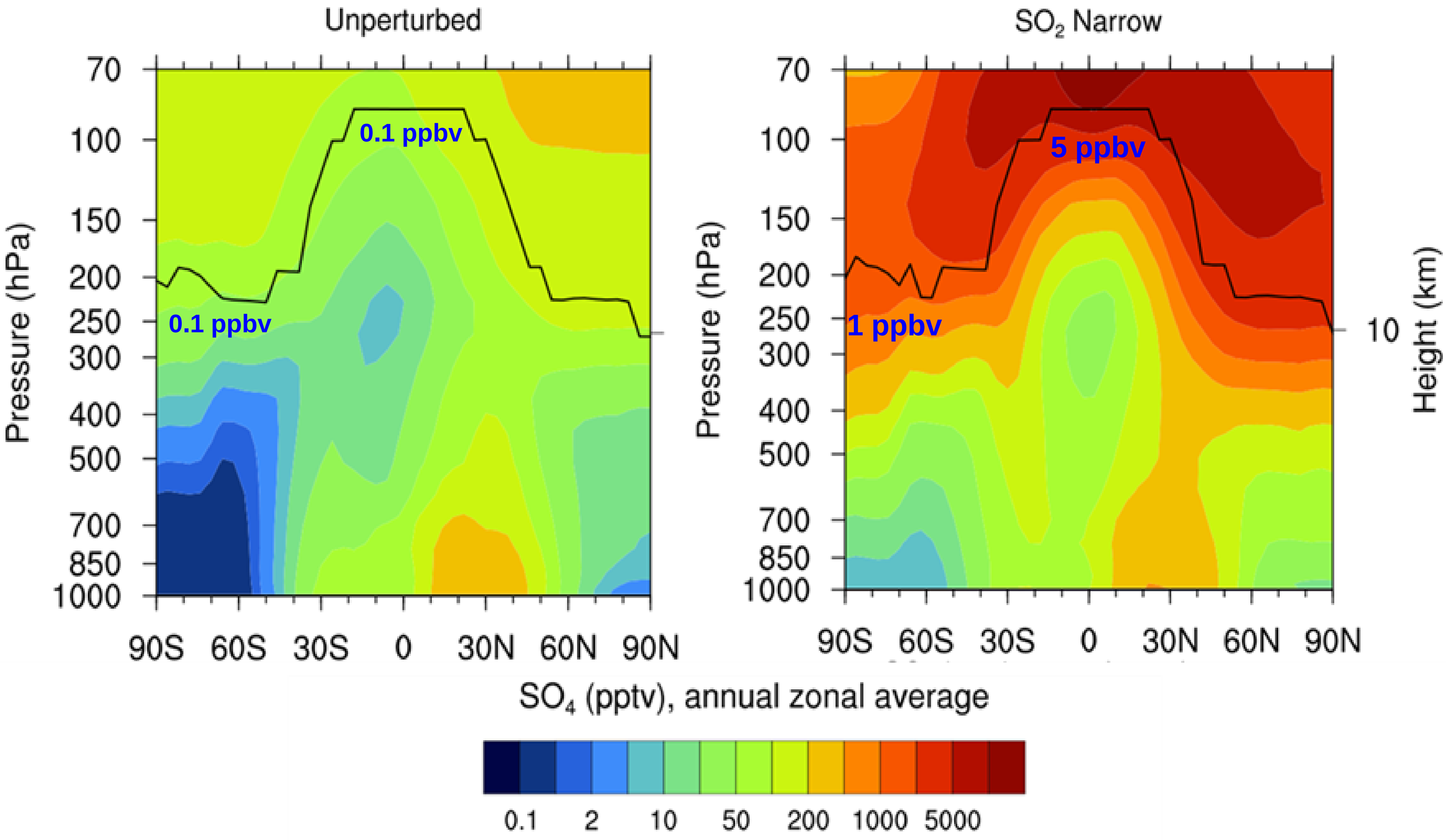




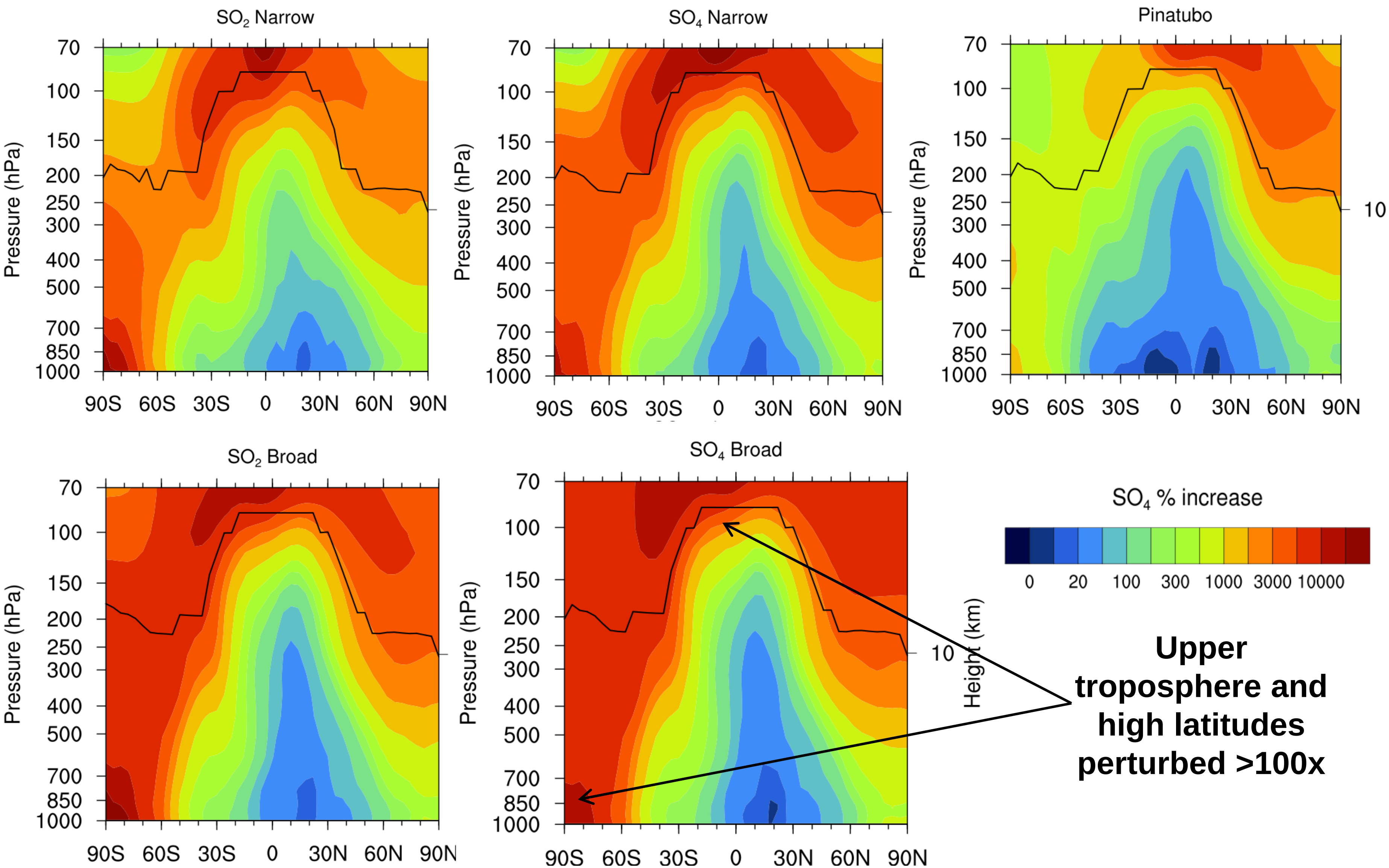
Different injection zones induce regional radiative forcings



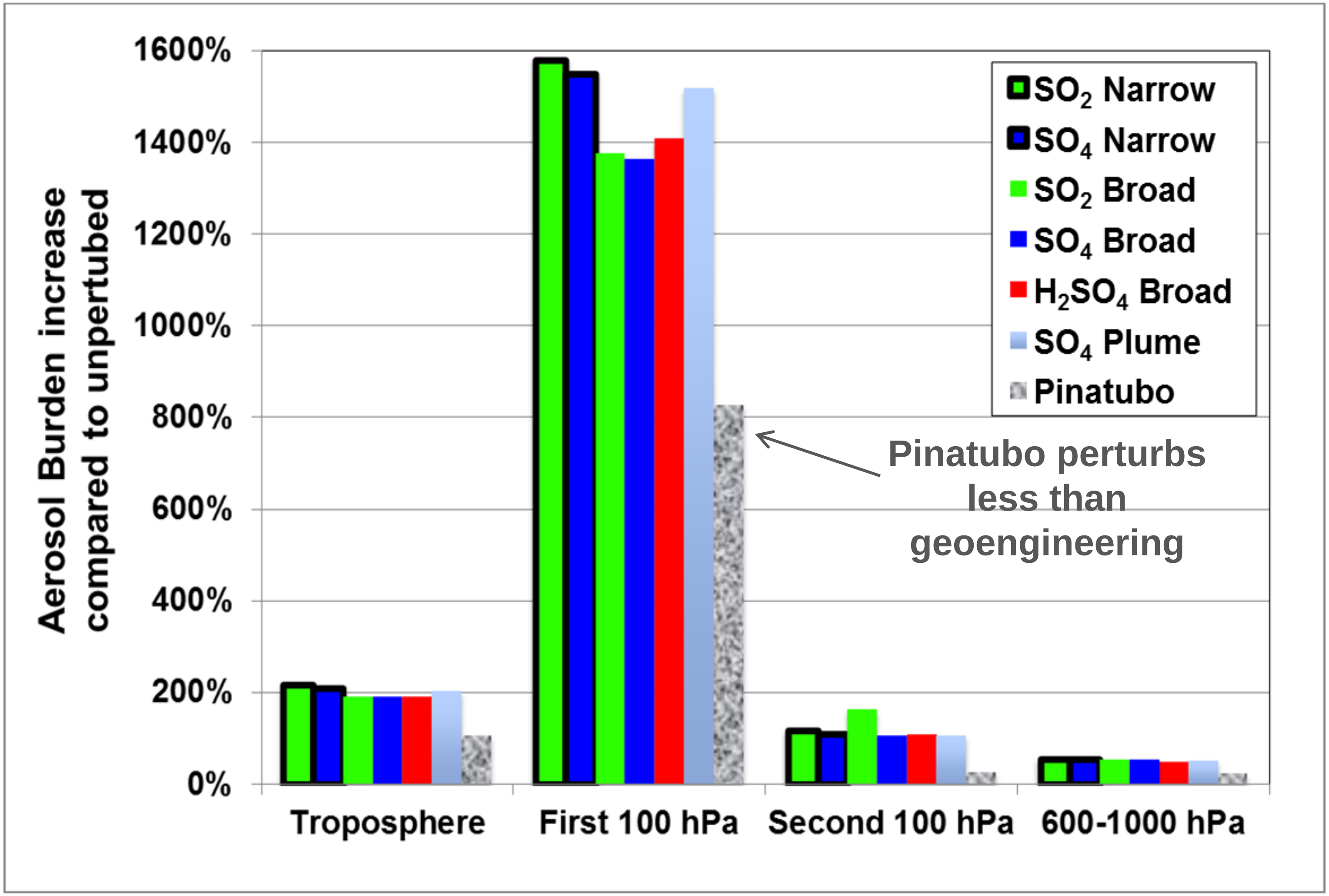
Geoengineering increases tropospheric burdens



All geoengineering increases tropospheric burdens



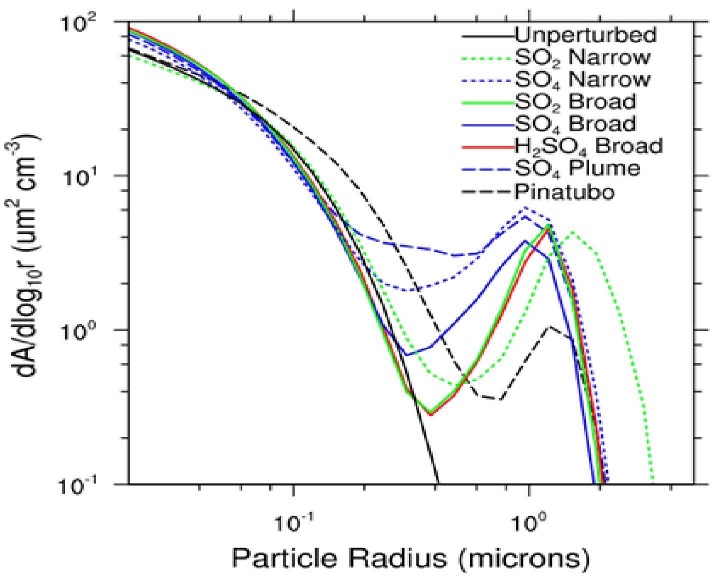
Tropospheric burden increases 200%; mostly in the 100 hPa region closest to tropopause



Possible impacts on clouds/chemistry

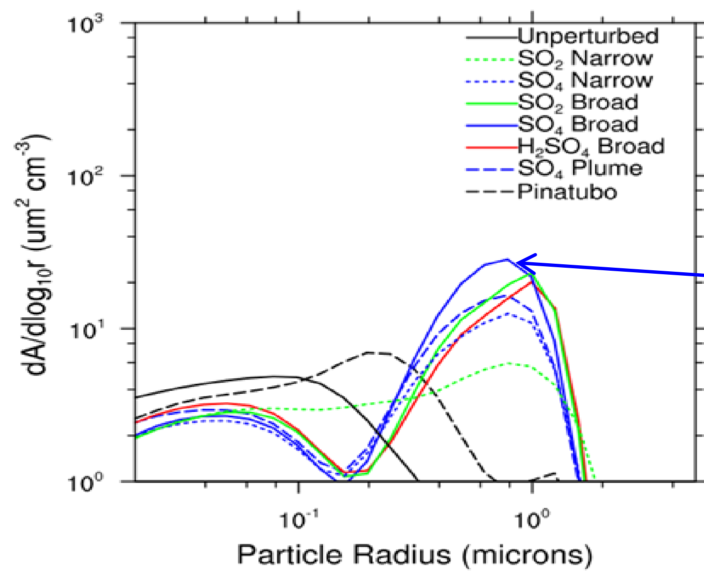
Tropical upper troposphere

120 hPa; 0 lat



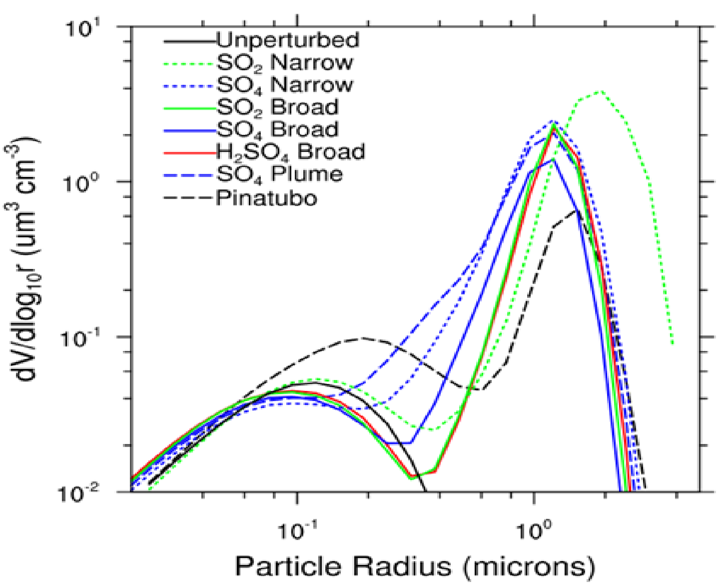
High latitude upper troposphere

400 hPa; -90 lat

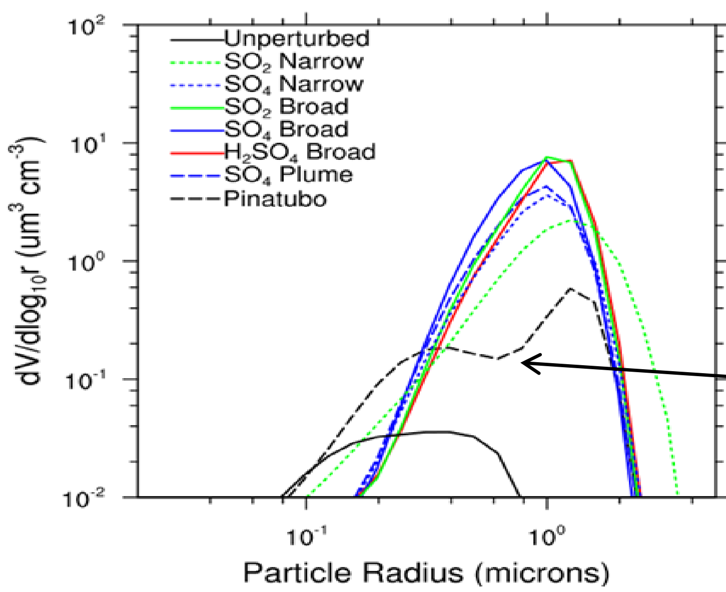


Broad injections (solid lines) perturb high latitudes more than narrow (dotted lines)

120 hPa; 0 lat



400 hPa; -90 lat



Pinatubo perturbs less than geoengineering

Summary

- Increasing SO_2 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 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

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Identifying tropopause