

Using WACCM/CARMA to study a stratospheric sulfur injection geo-engineering scheme

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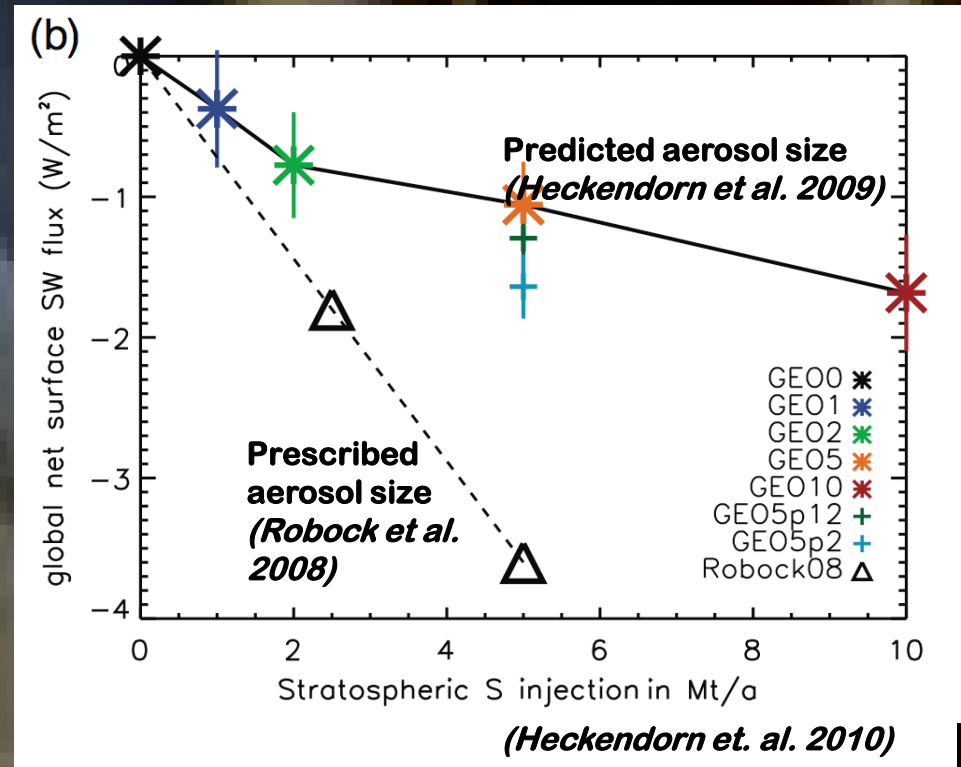
Motivation

In the future we may need to choose between the risks and consequences of climate change vs climate geo-engineering

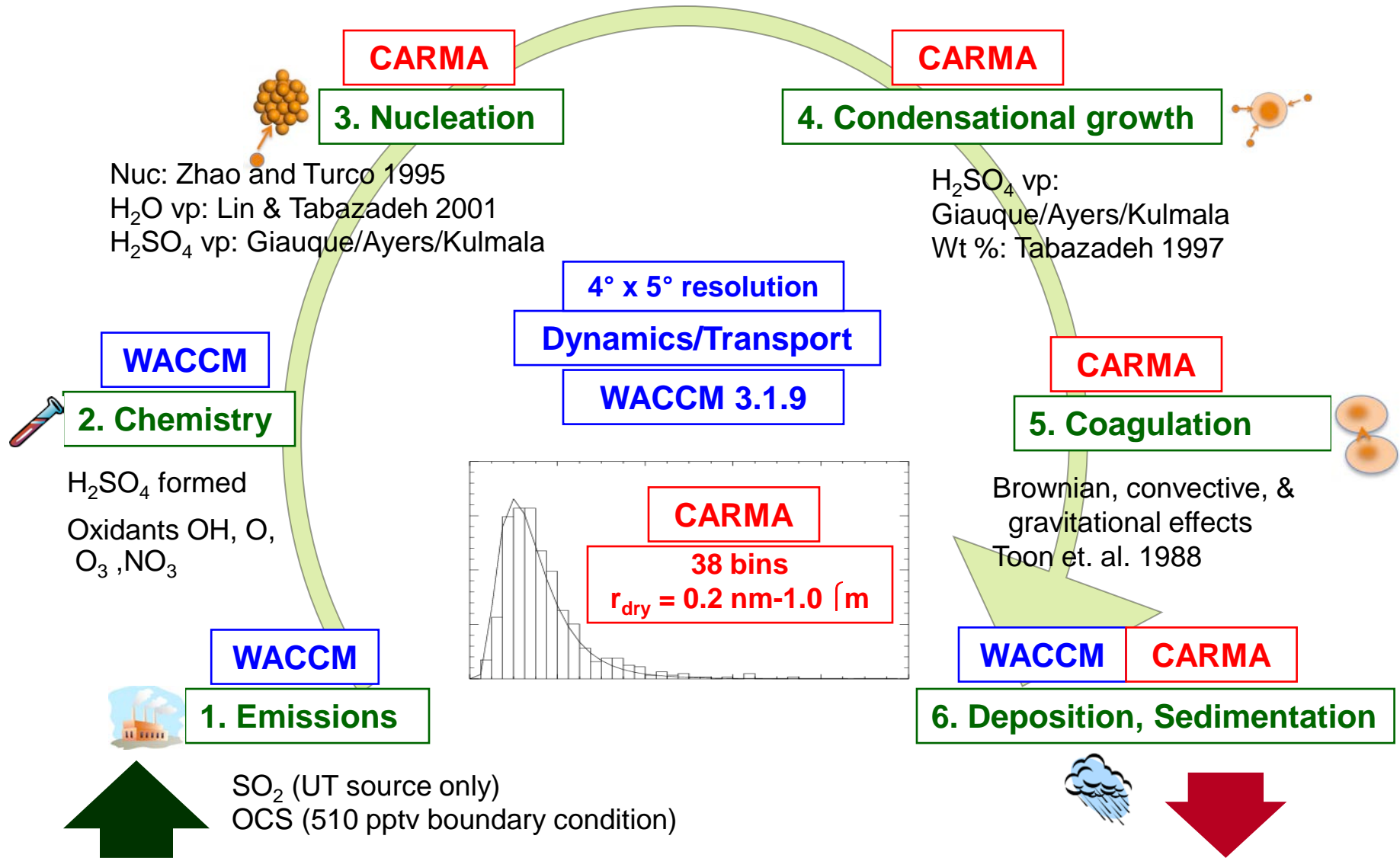
The stratospheric sulfur injection idea

Volcanic eruptions demonstrate temporary reduced SW flux; ozone loss; hydrological cycle changes (Trenberth and Dai 2007)

Simulations of continuous injection suggest large uncertainty in temperature efficacy



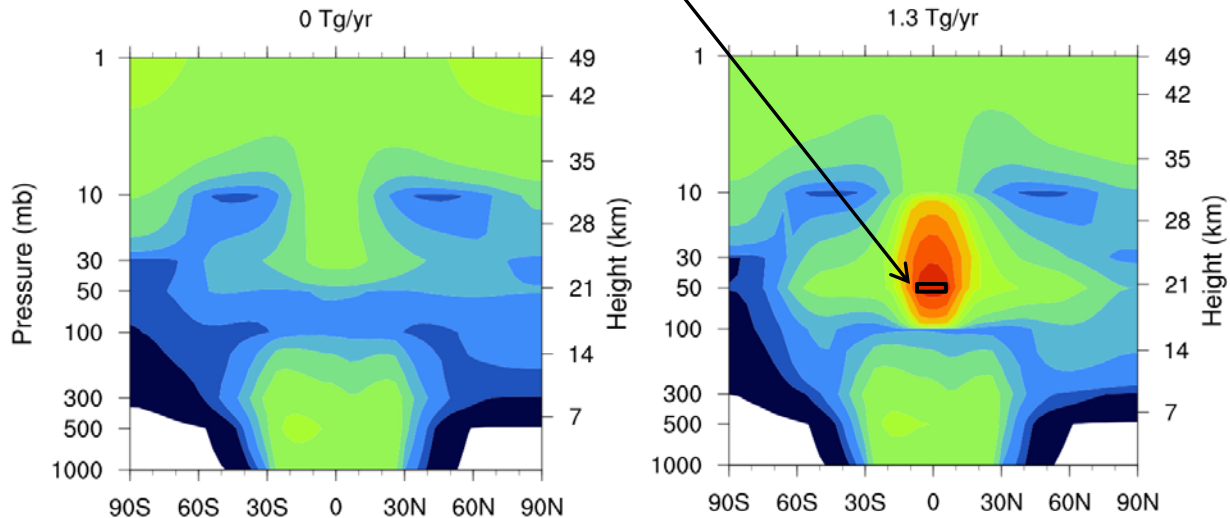
WACCM/CARMA Coupled Model



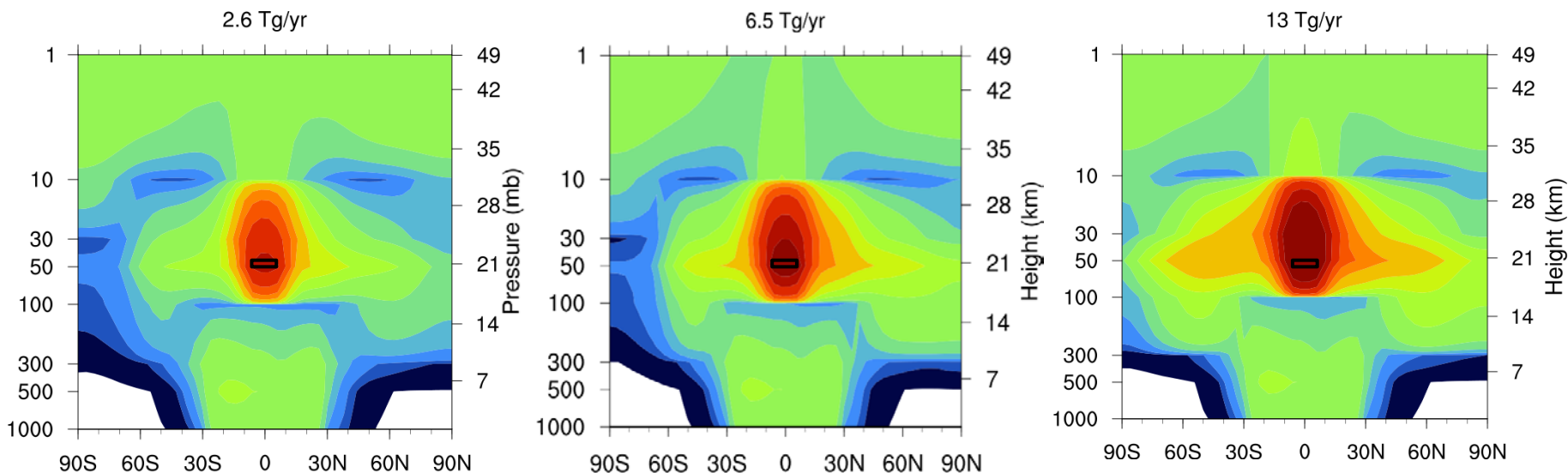
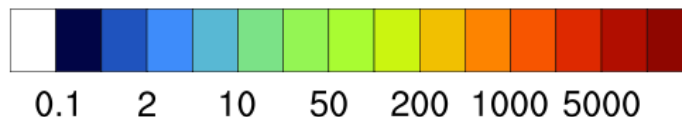
Aerosol radiative effects not coupled, but het chem is
5 year simulations; 5th year analyzed

Five SO₂ injection schemes (50 mb, 8N-8S, all longitudes)

- 1) 0 Tg (baseline)
- 2) 1.3 Tg S / yr
- 3) 2.6 Tg S / yr
- 4) 6.5 Tg S / yr
- 5) 13 Tg S / yr

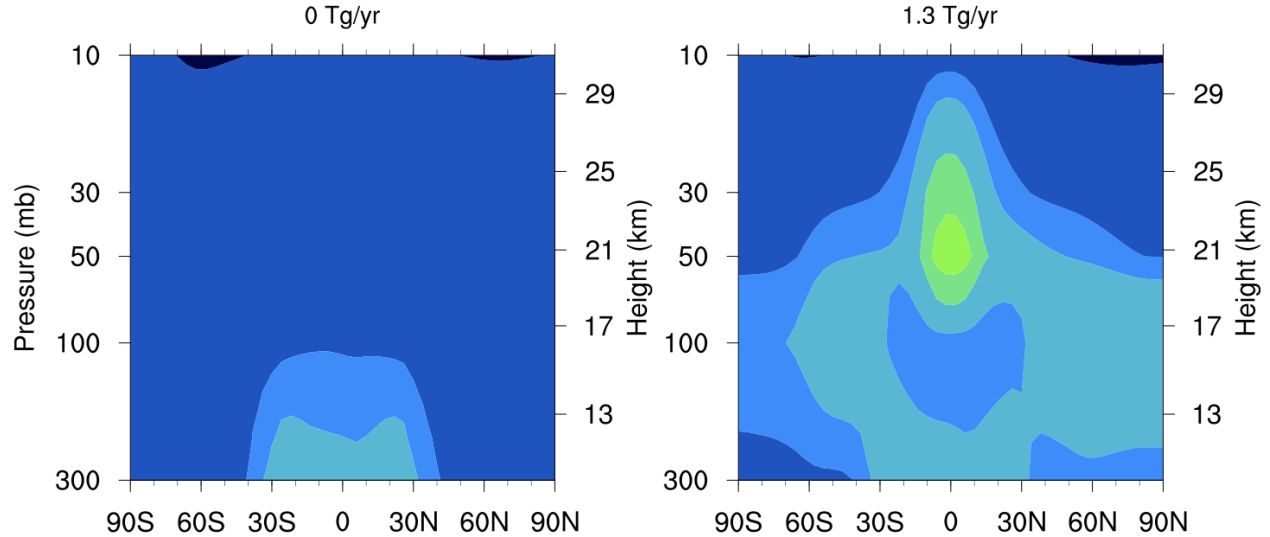


SO₂ (pptv)

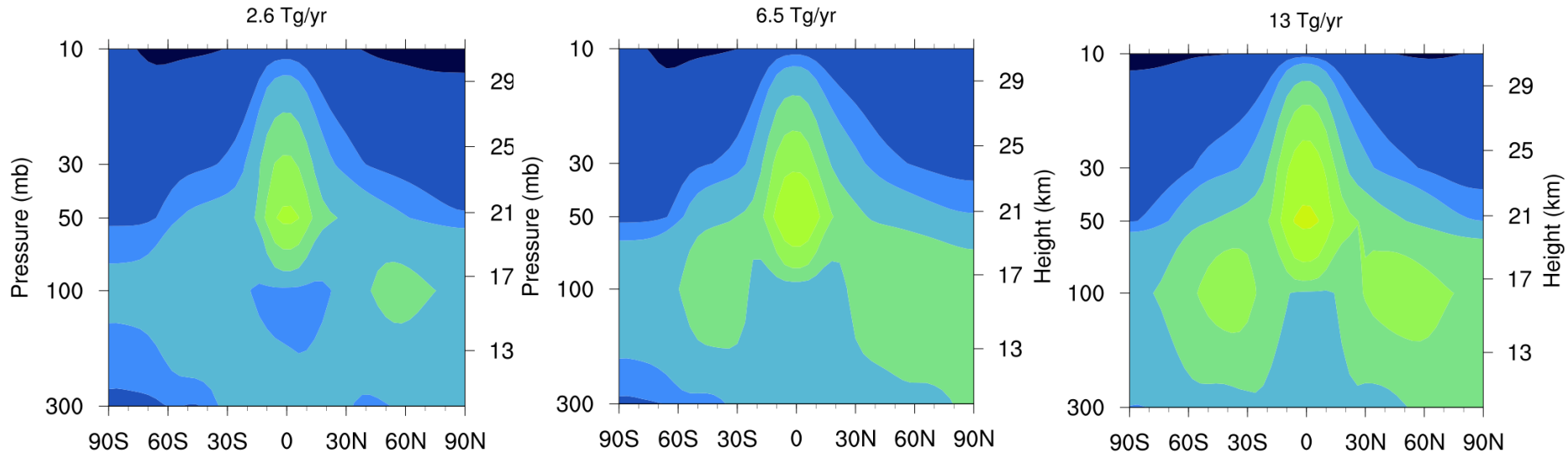
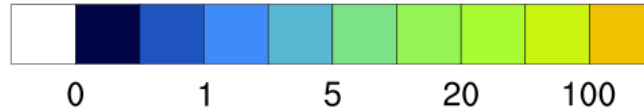


Surface area increases up to 100x

- 1) 0 Tg (baseline)
- 2) 1.3 Tg S / yr
- 3) 2.6 Tg S / yr
- 4) 6.5 Tg S / yr
- 5) 13 Tg S / yr

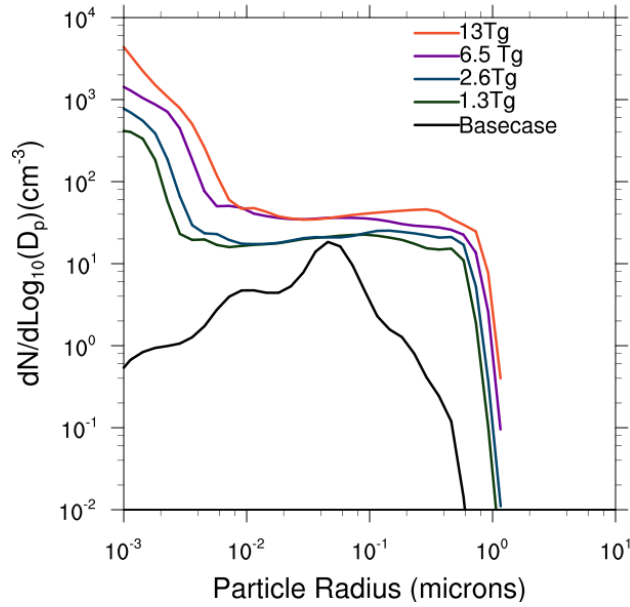


Zonal mean surface
area density ($\mu\text{m}^2 \text{cm}^{-3}$)

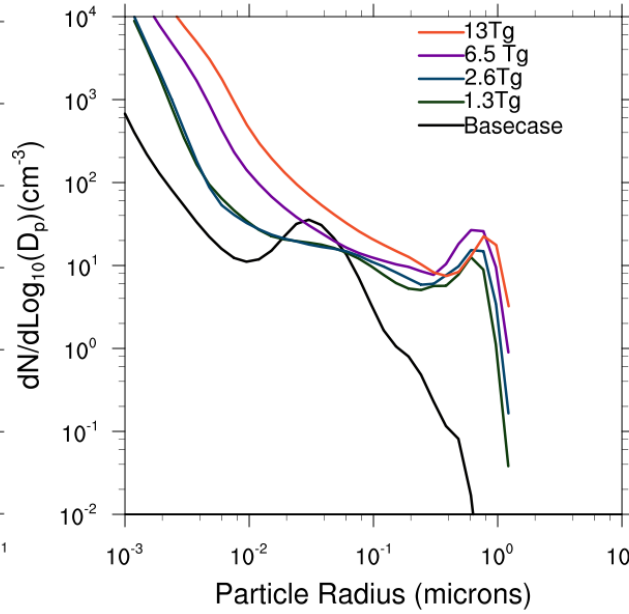


Geoeng. Particles are ~4x larger than Pinatubo

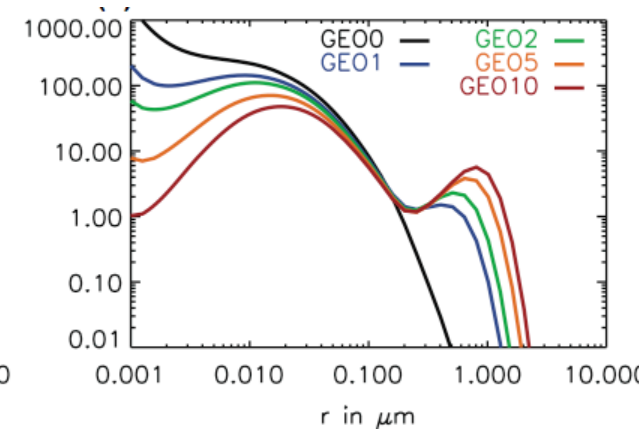
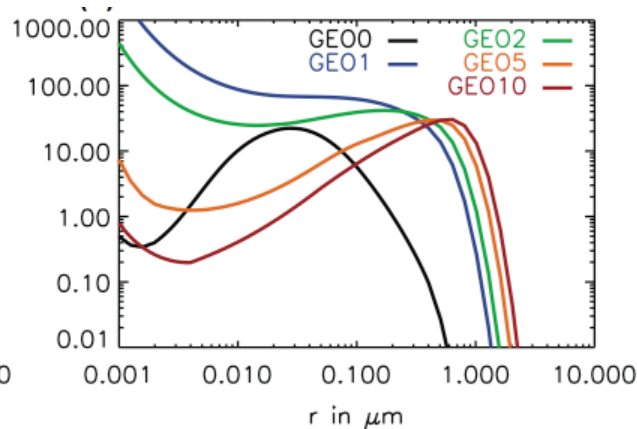
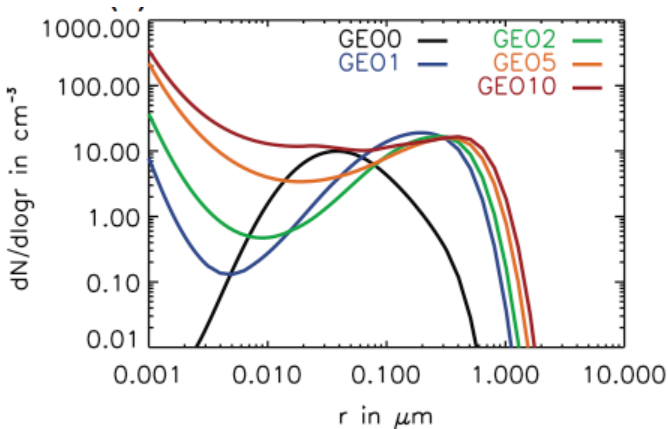
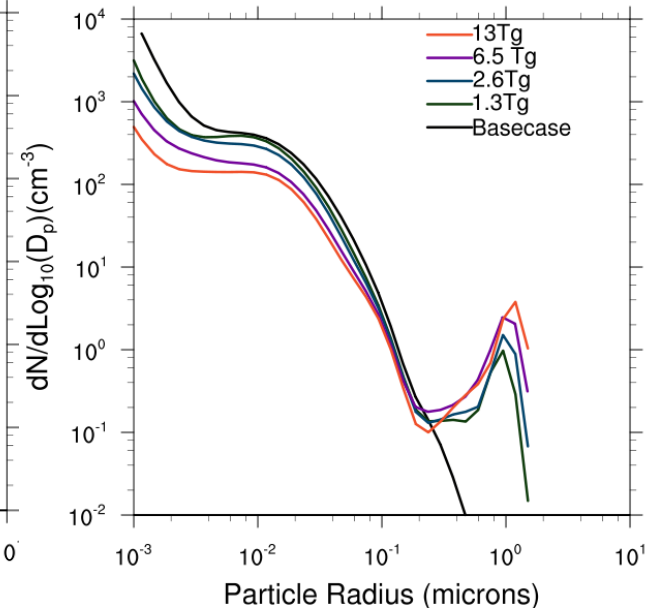
Size at 39 mb



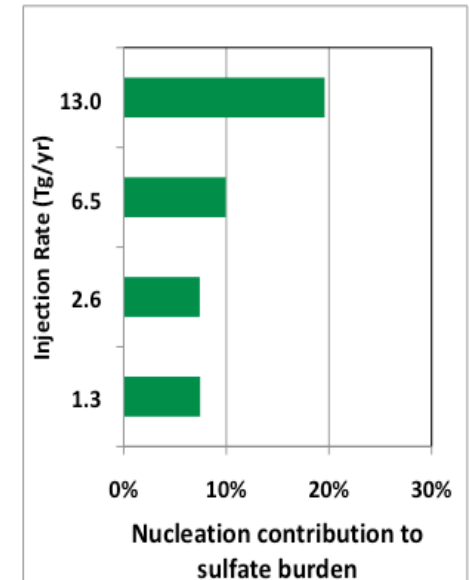
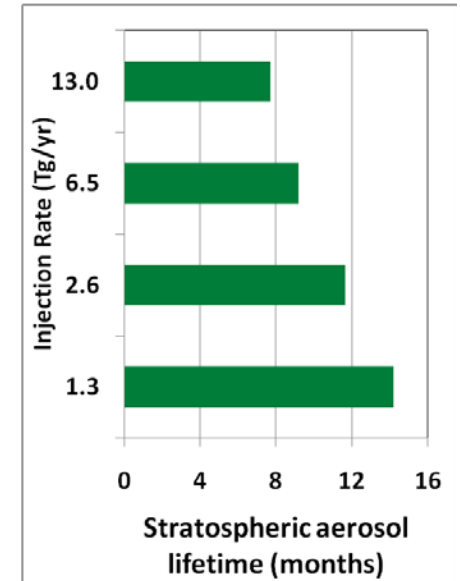
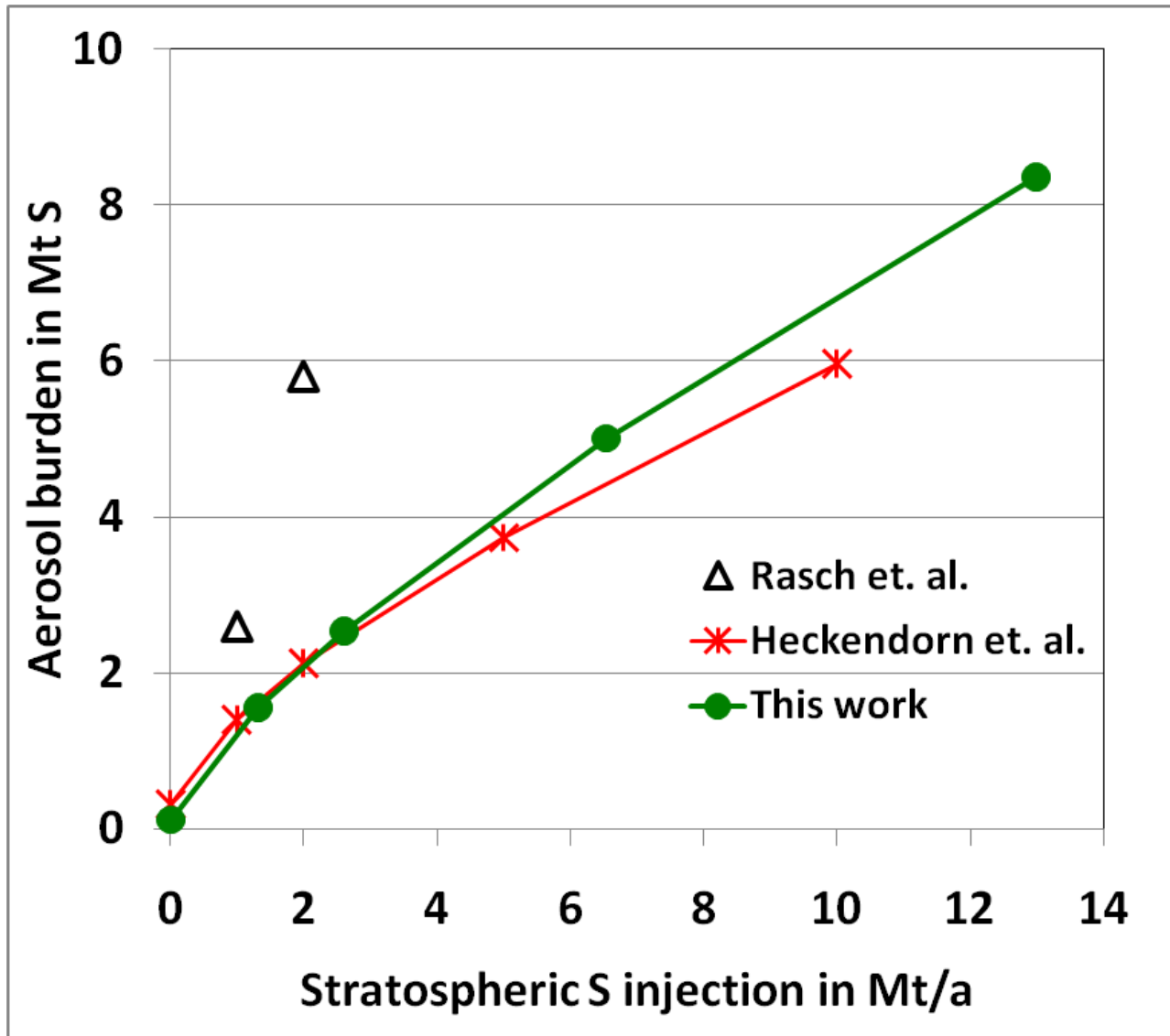
Size at 55 mb



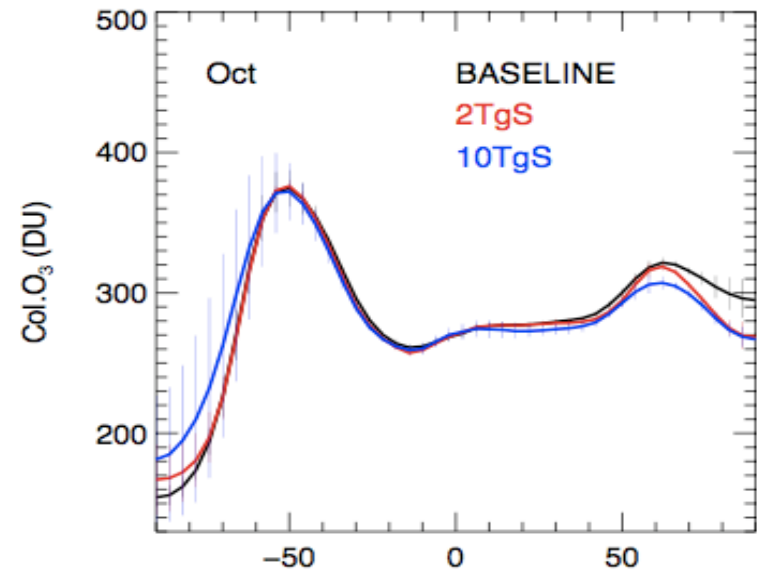
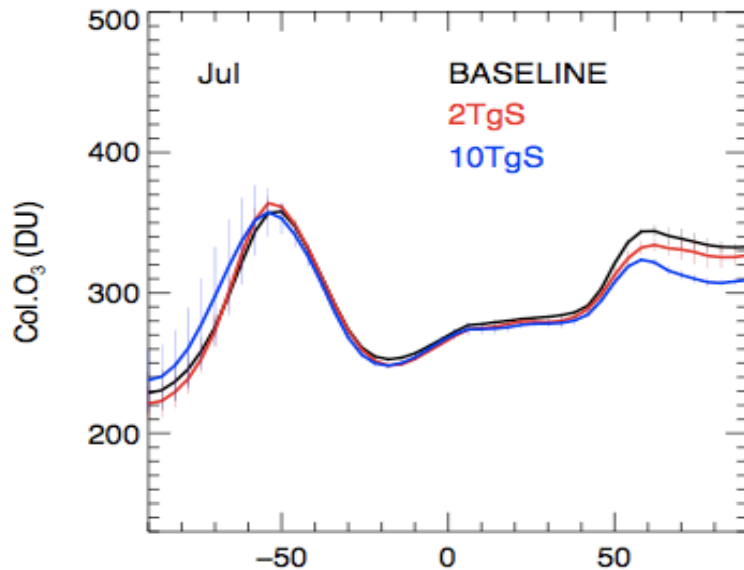
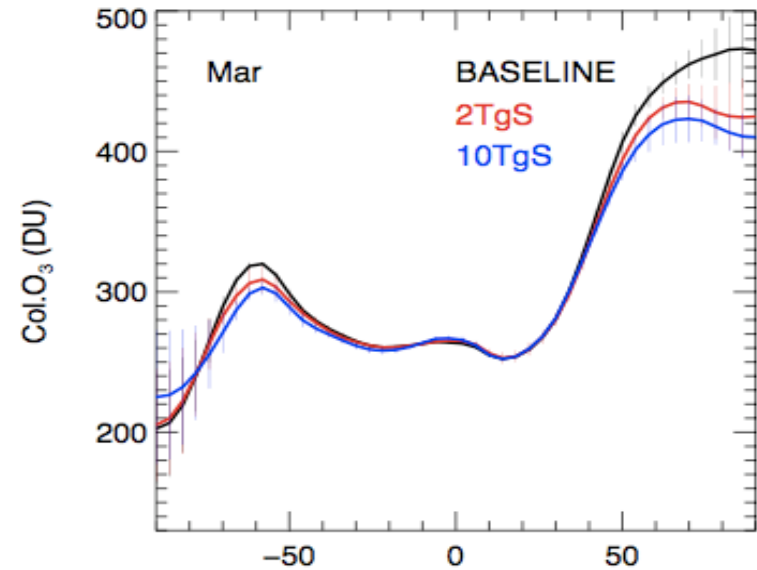
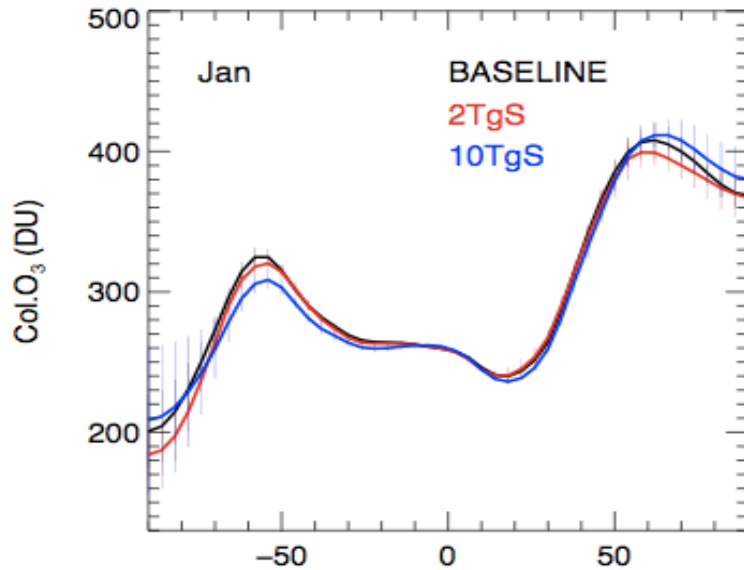
Size at 90 mb



Microphysical simulations predict lower burden (shorter lifetime) than simulations with prescribed size distributions



Geoeng. may decrease ozone in some locations, but large inter-annual variability at high latitudes (4-yrs)



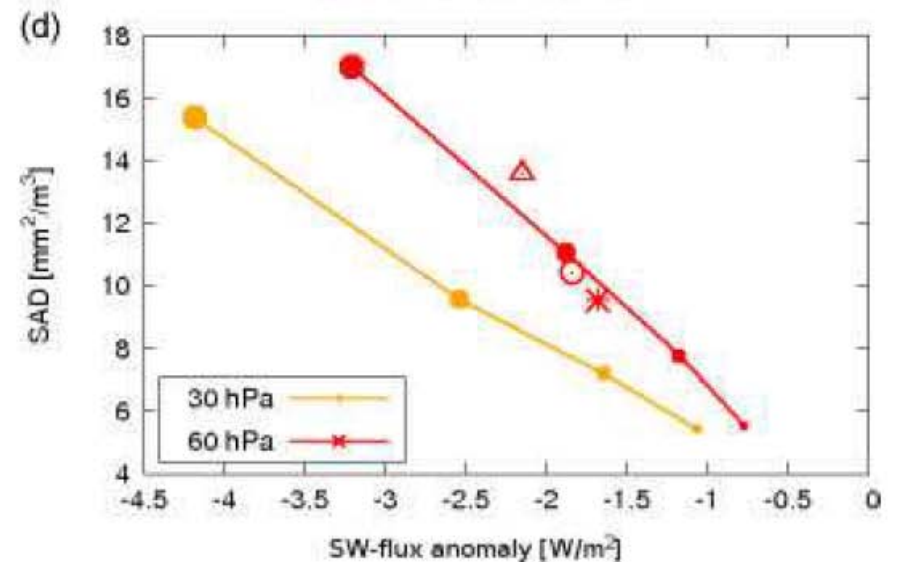
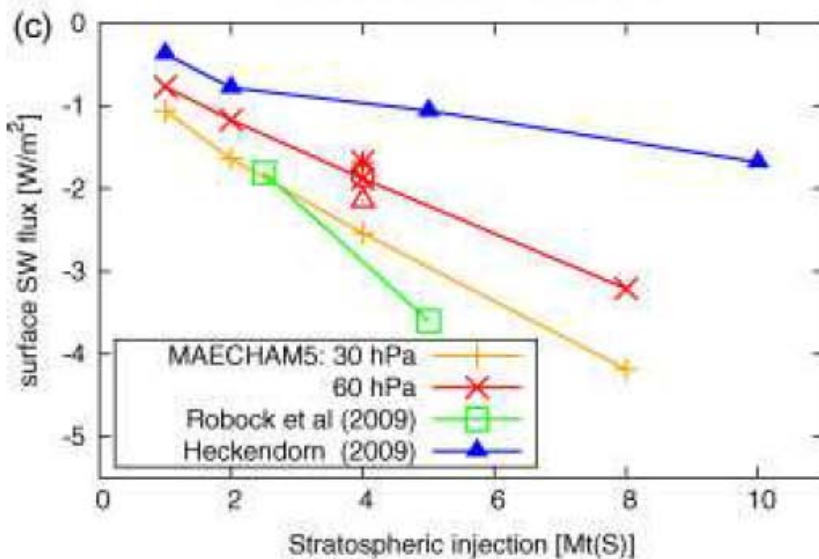
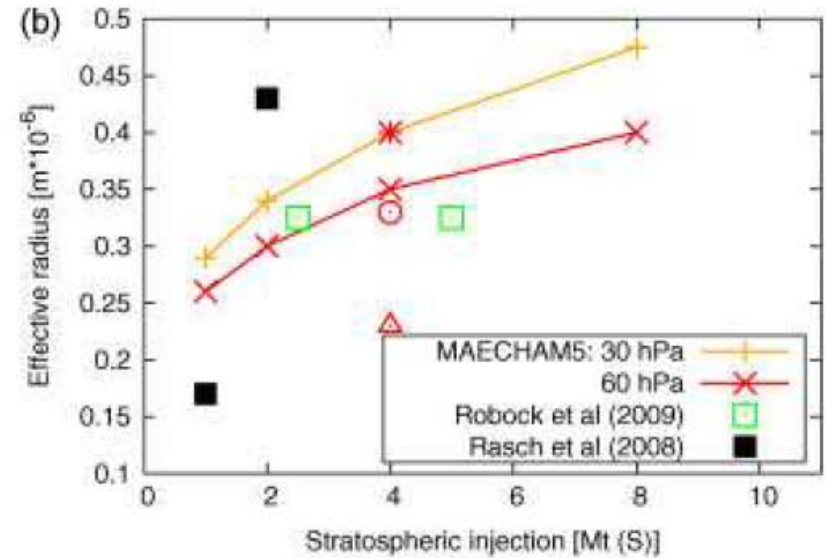
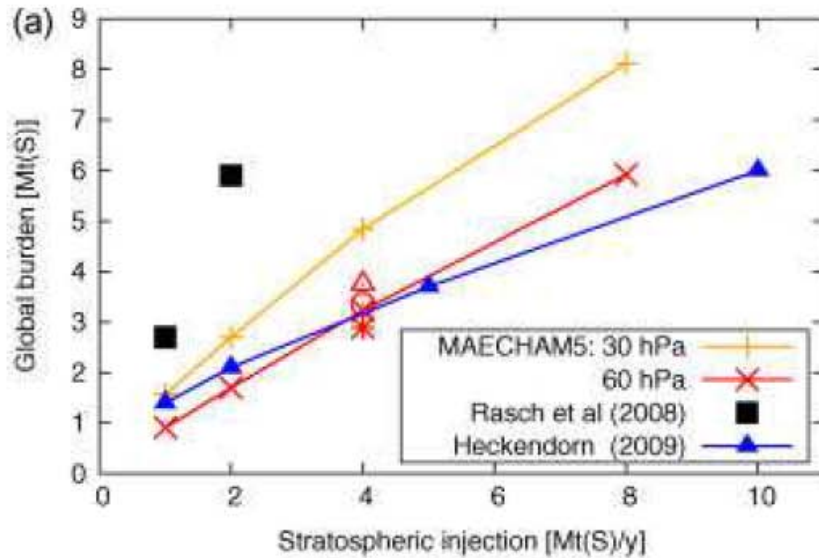
These WACCM-CARMA simulations suggest:

- Stratospheric sulfur injection aerosols peak at $1 \mu\text{m}^*$, ~4 times larger than Pinatubo
- These large sizes fall out of the stratosphere much faster than previously assumed, esp. at higher injection rates*
- Geoeng. simulations predict some further ozone loss, but need more years of comparisons
- Stratospheric sulfur injection geo-engineering may have a limited efficacy ($\sim 2 \text{ W m}^{-2} ?$)*

*in agreement with *Heckendorn et. al*

Higher injection lead to increased efficacy

3d sim finds increased SW effect (Niemeier et al., 2010)



Next Steps

- Calculate RF using WACCM/CARMA
- Study Polar Injections also
- WACCM/CARMA remains the most comprehensive model available for stratospheric study:
 - 3D
 - 66 vertical levels
 - Full chemistry
 - Sectional (not modal)
 - Full microphysics

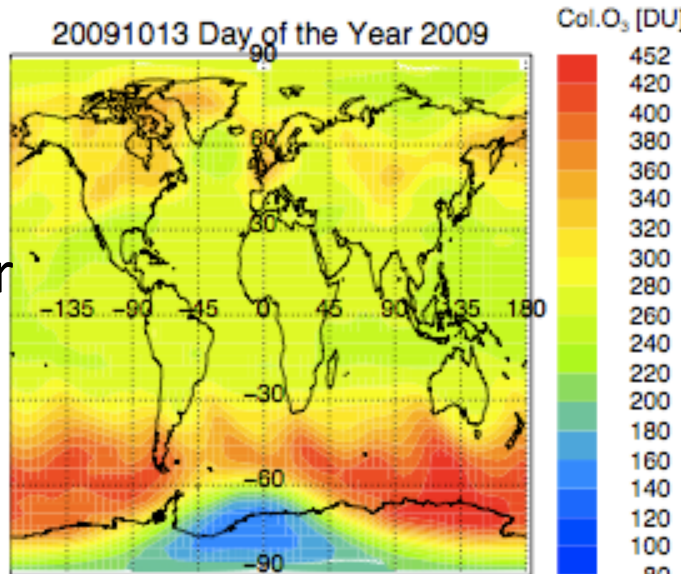
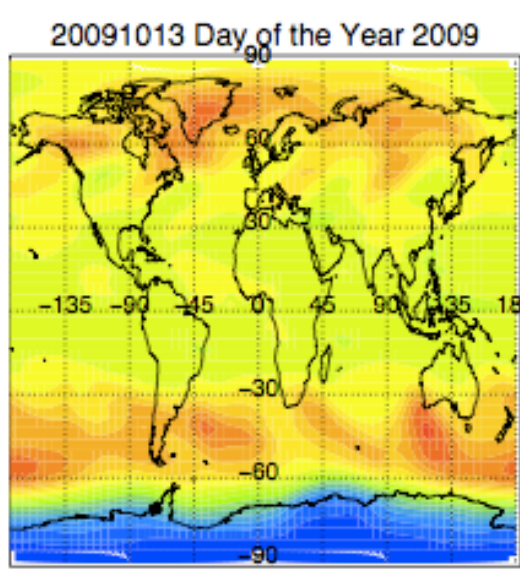
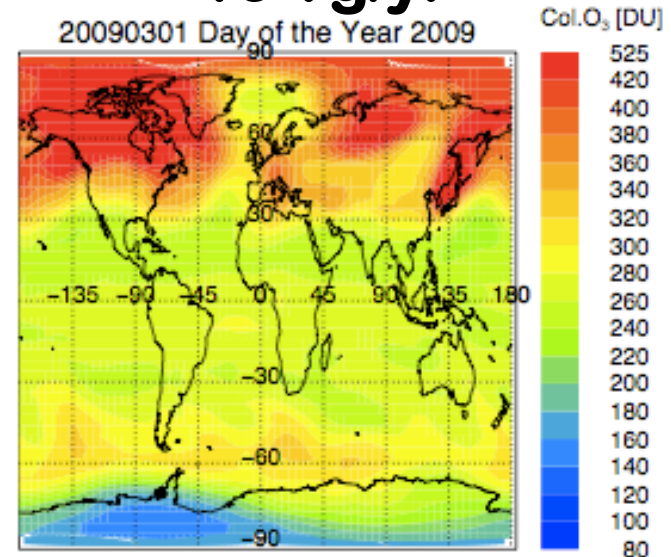
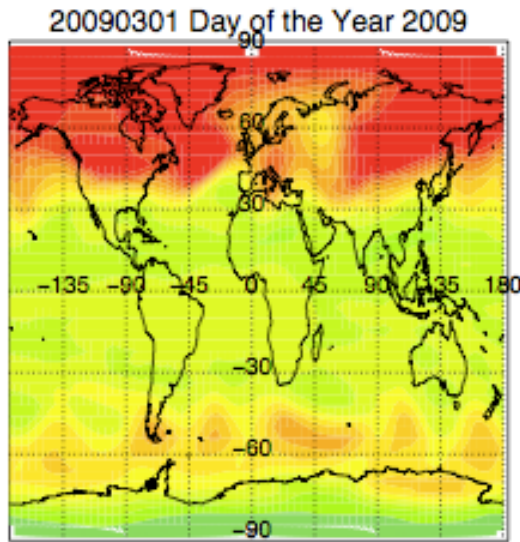
13 Tg perturbation has smaller polar vortex (1-yr comparison)

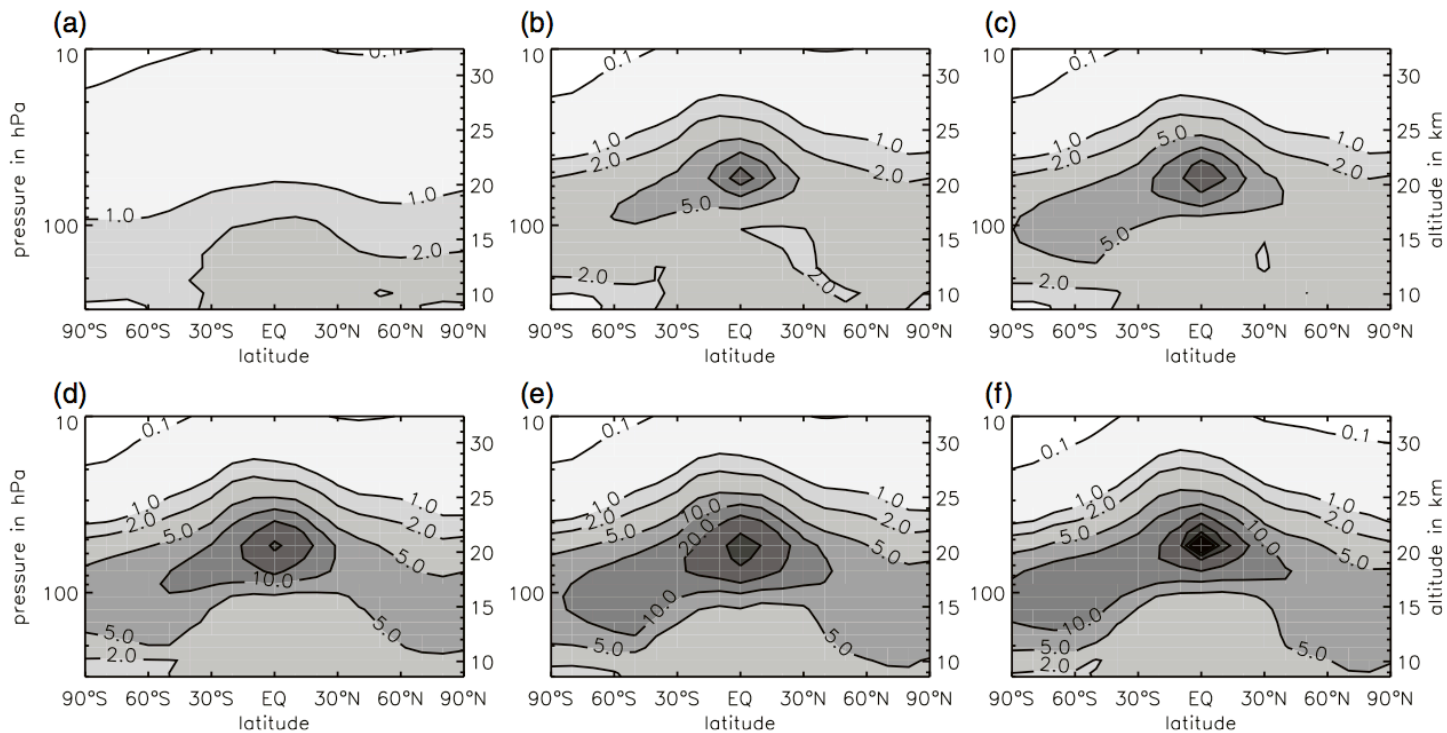
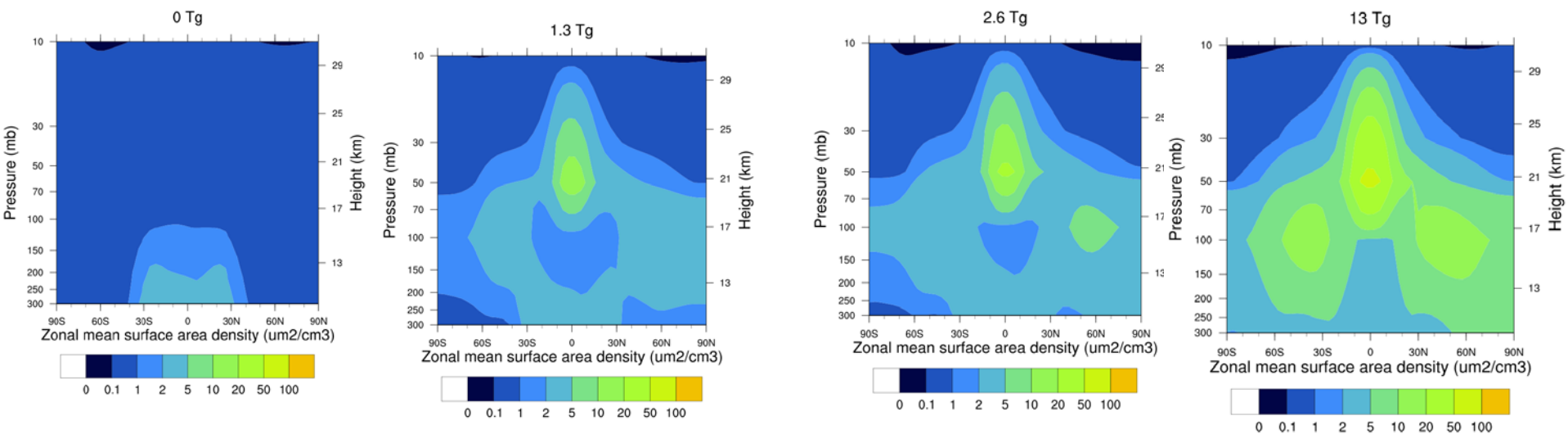
Baseline

13 Tg/yr

March

October





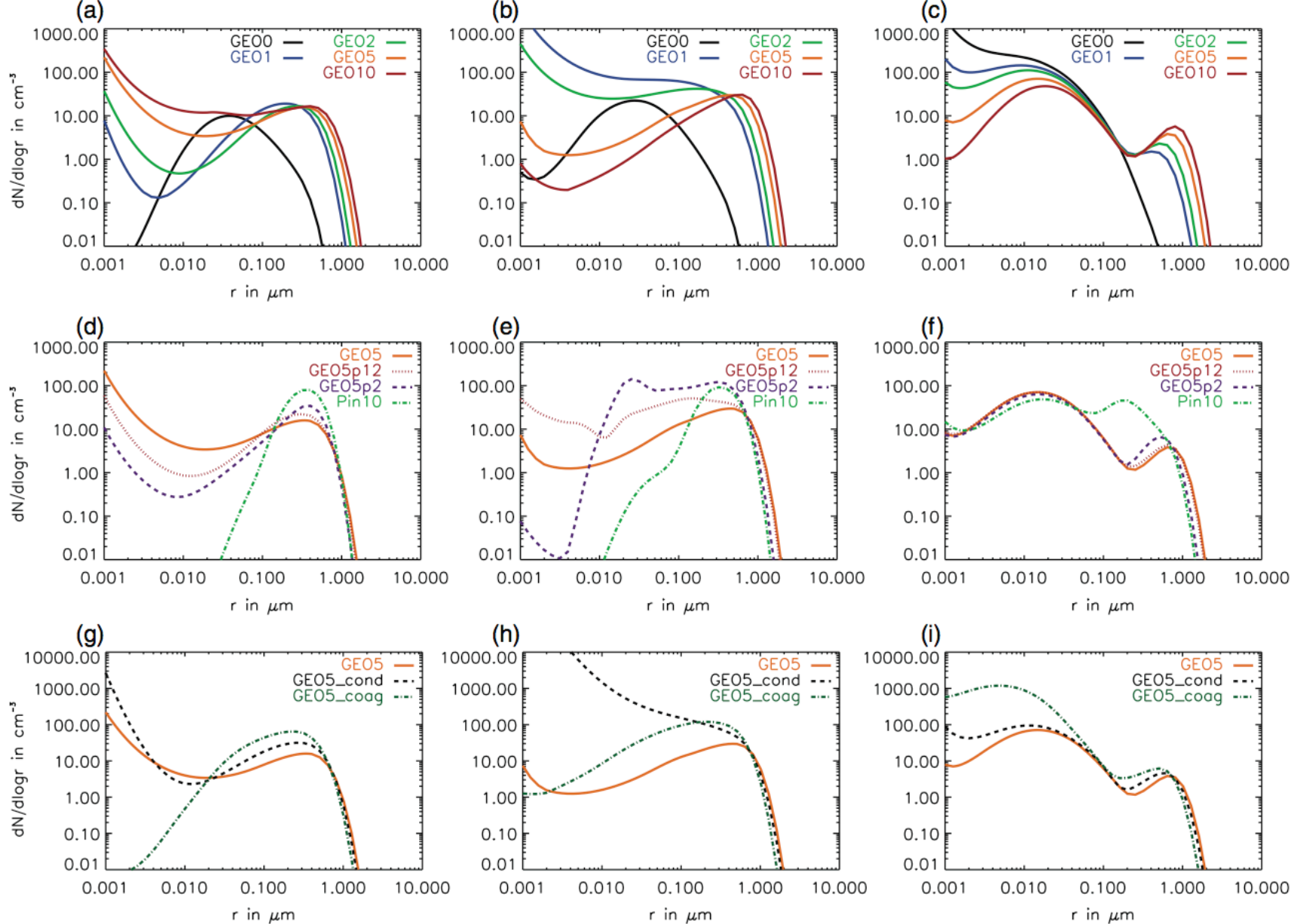


Figure 5. Annual mean differential number density $dN/d \log r$ in cm^{-3} at the equator at 39 hPa (first column), 55 hPa (second column) and 90 hPa (third column). (a)–(c) Continuous S injection into the lower stratosphere of 0, 1, 2, 5 and 10 Mt/a (GEO0–GEO10). (d)–(f) Continuous and pulsed emission of 5 Mt/a S emissions (GEO5, GEO5p12, GEO5p2) and annual mean aerosol size distribution for PIN10 from June 1991 to May 1992. (g)–(i) GEO5, GEO5_cond with reduced condensation rates and GEO5_coag with reduced coagulation rates.