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

Jason English
Laboratory for Atmospheric and Space Physics, and
Department of Atmospheric and Oceanic Sciences
University of Colorado at Boulder
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Advisor: Brian Toon
Colleagues: Mike Mills, Simone Tilmes
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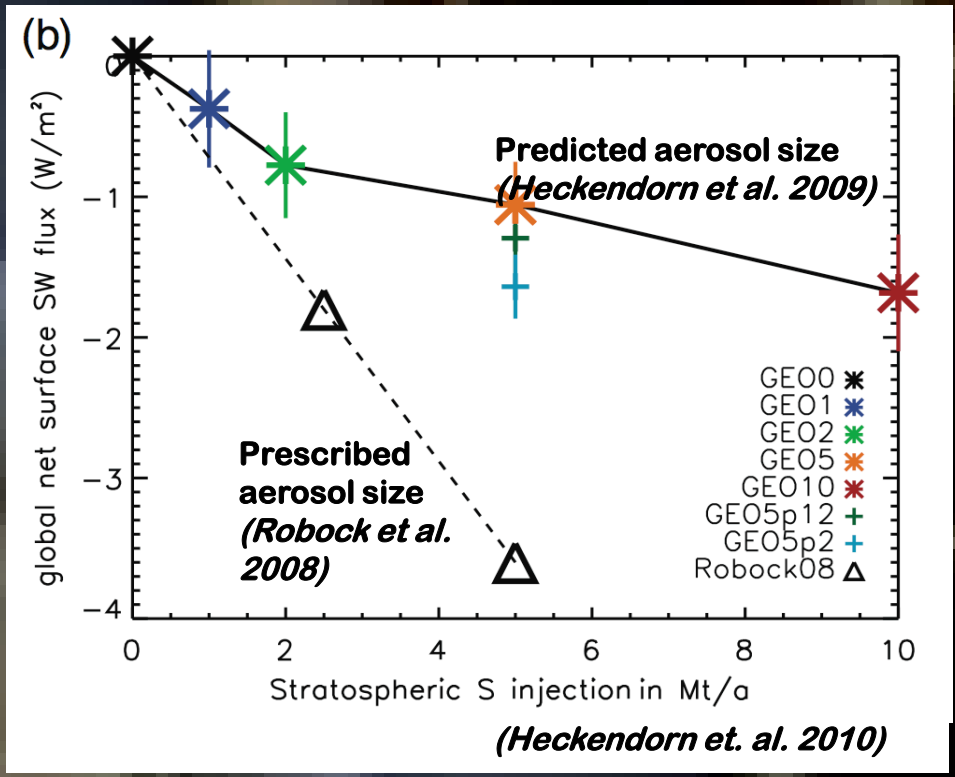
Motivation

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

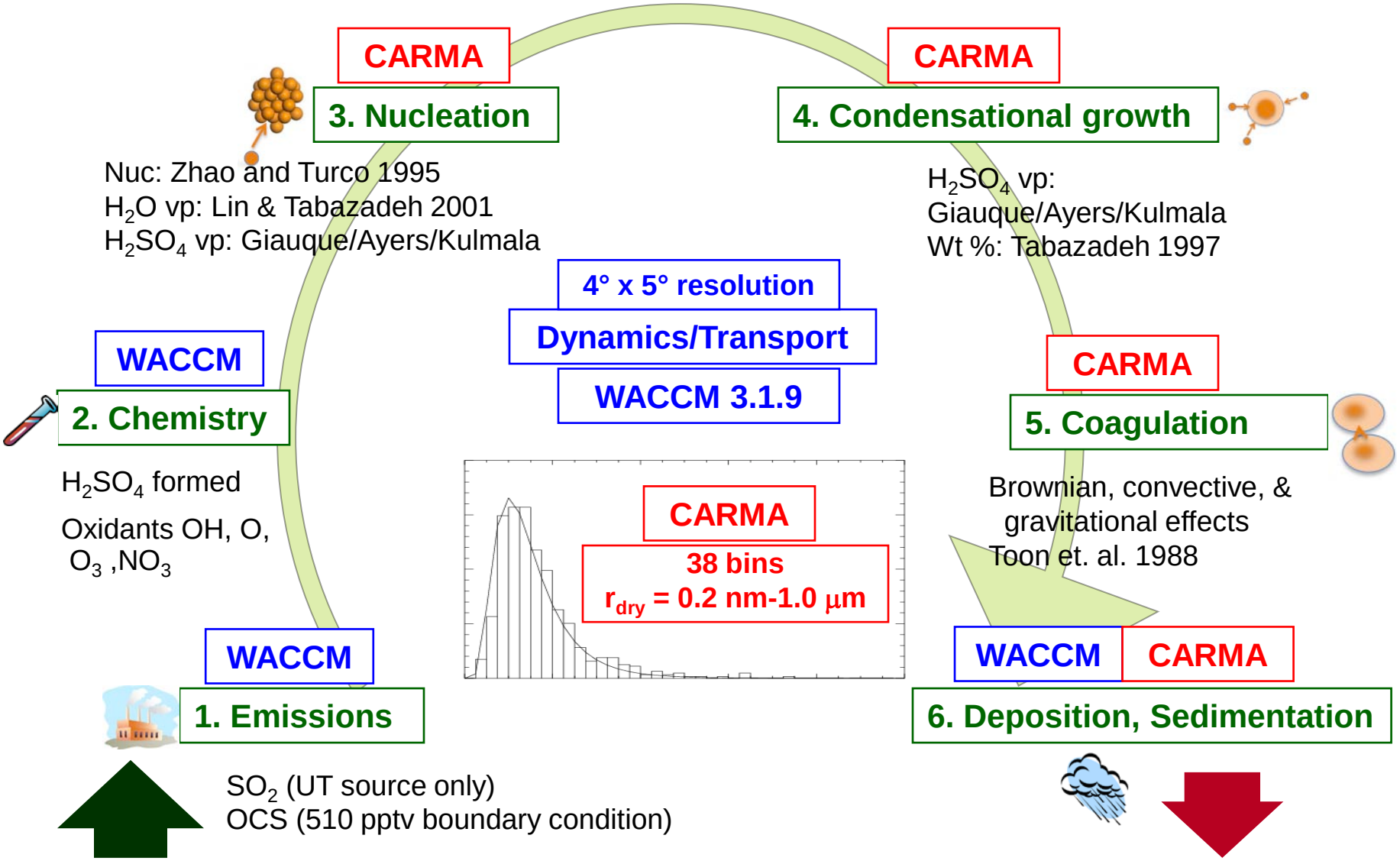
Volcanic eruptions demonstrate temporary reduced SW flux; ozone loss; hydrological cycle changes *(Trenberth and Dai 2007)*

Simulations of continuous injection suggest large uncertainty in temperature efficacy



(Heckendorn et. al. 2010)

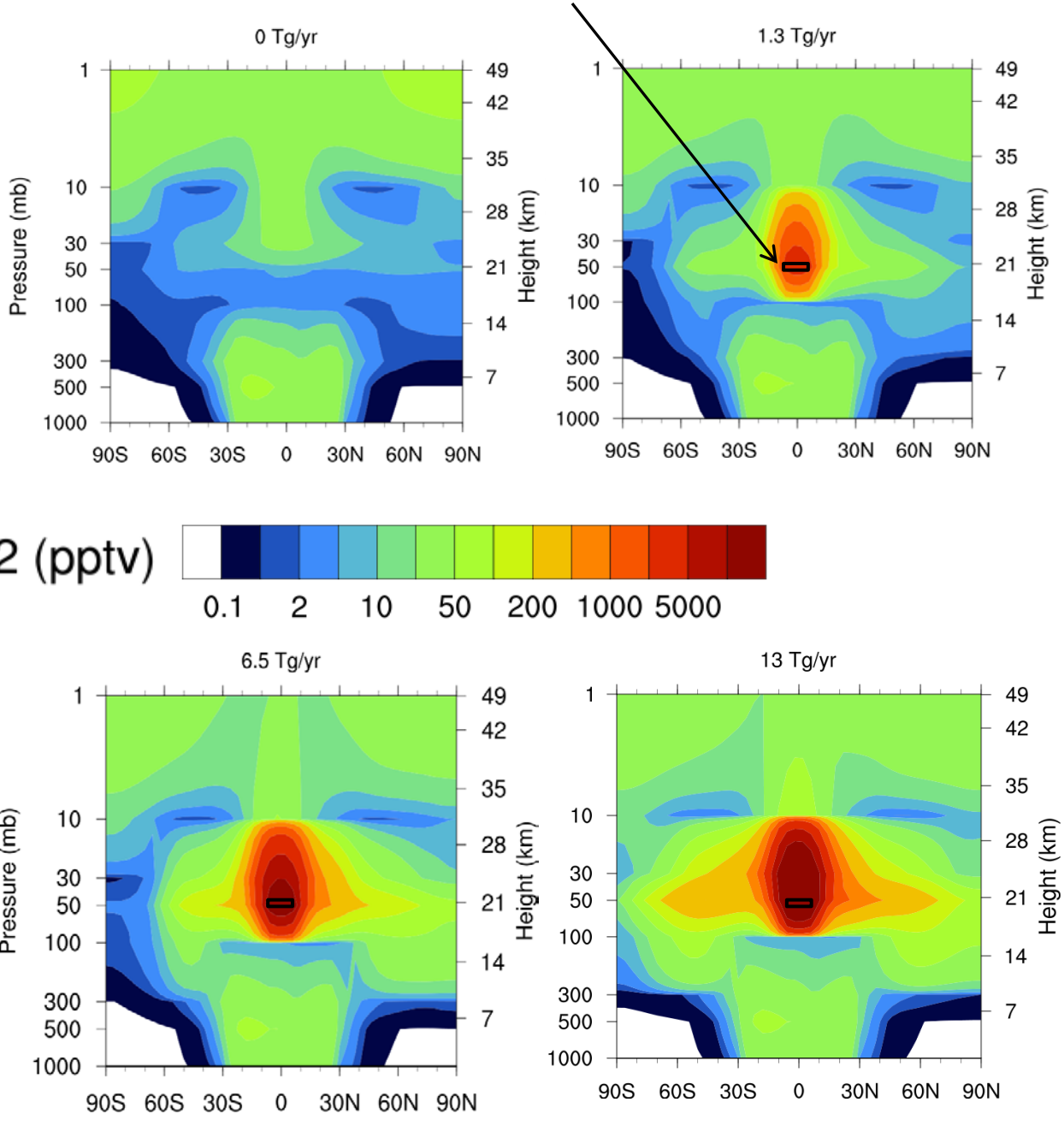
WACCM/CARMA Coupled Model



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

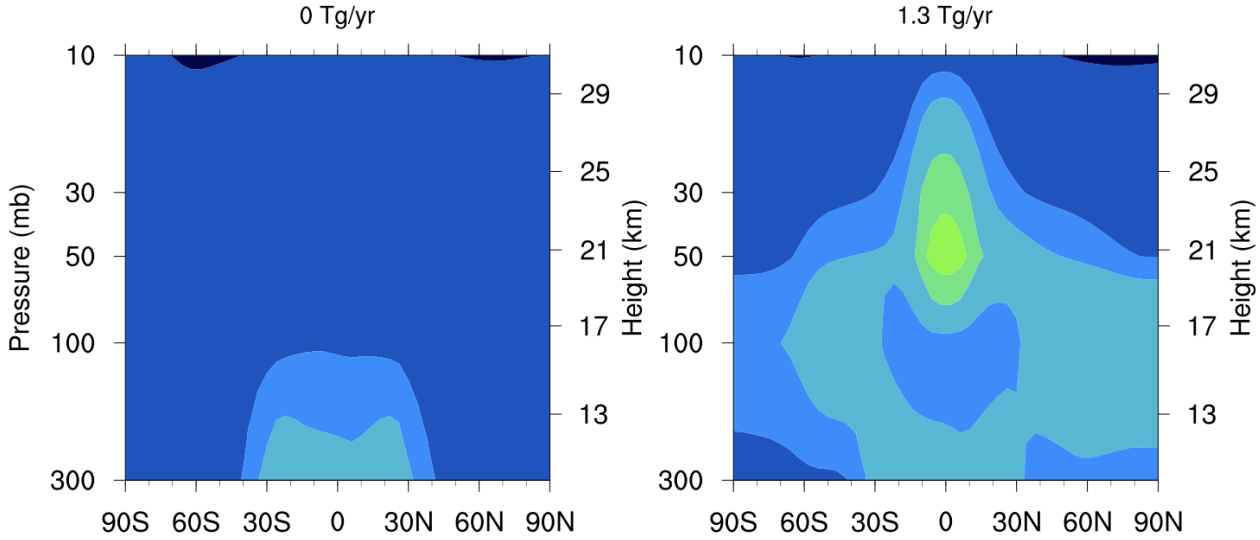
Five SO_2 injection schemes (50 mb, 8N-8S, all longitudes)

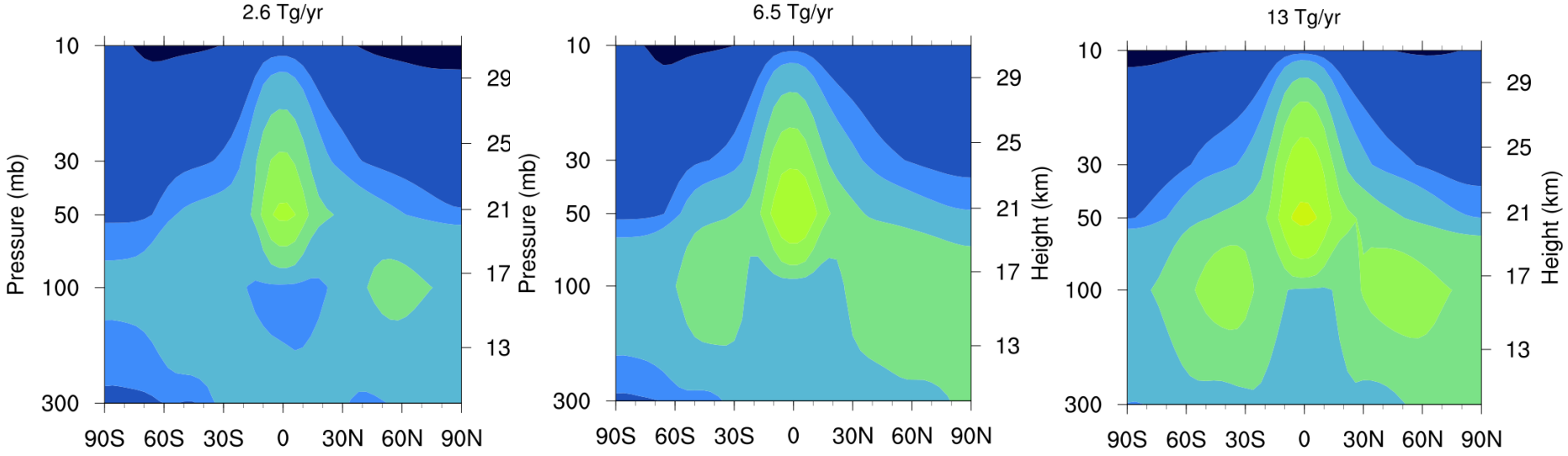
1) 0 Tg (baseline)
2) 1.3 Tg S / yr
3) 2.6 Tg S / yr
4) 6.5 Tg S / yr
5) 13 Tg S / yr



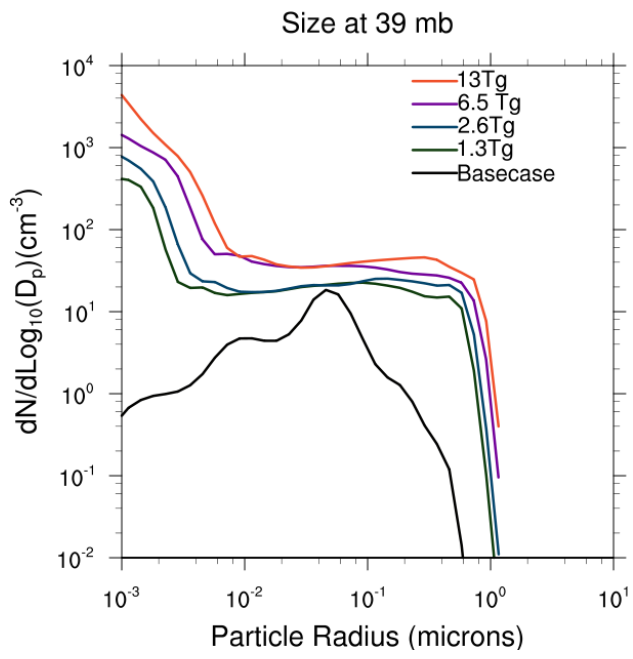
Surface area increases up to 100x

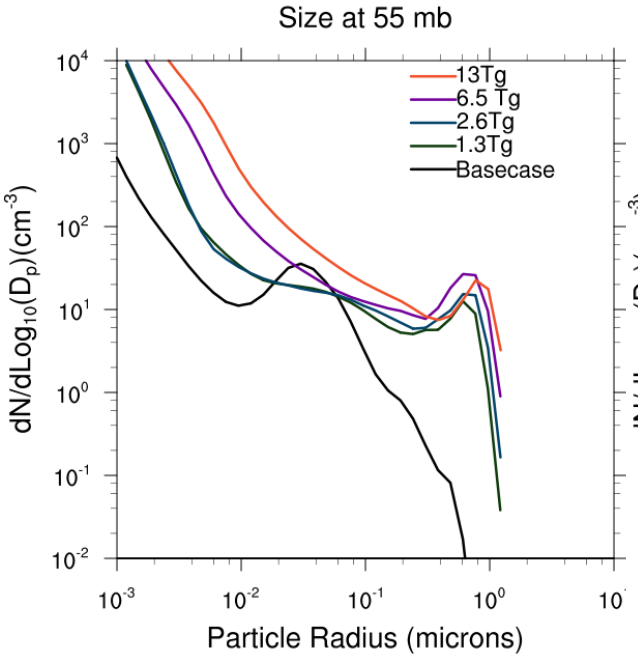
1) 0 Tg (baseline)
2) 1.3 Tg S / yr
3) 2.6 Tg S / yr
4) 6.5 Tg S / yr
5) 13 Tg S / yr

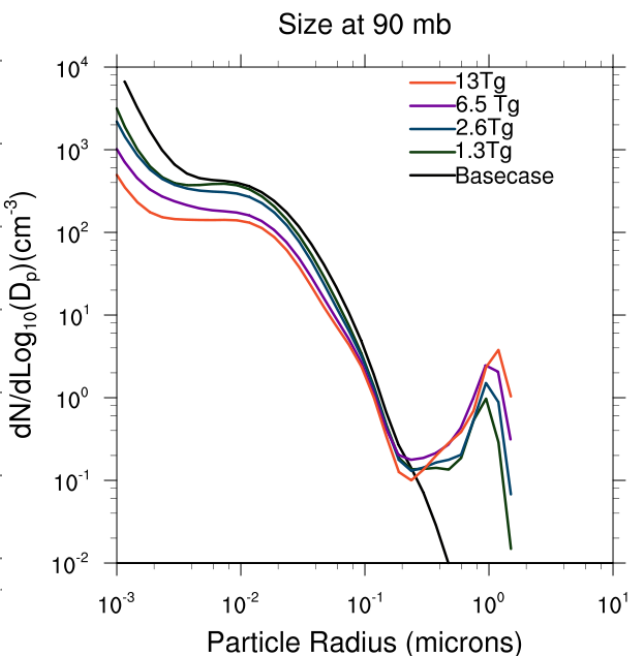


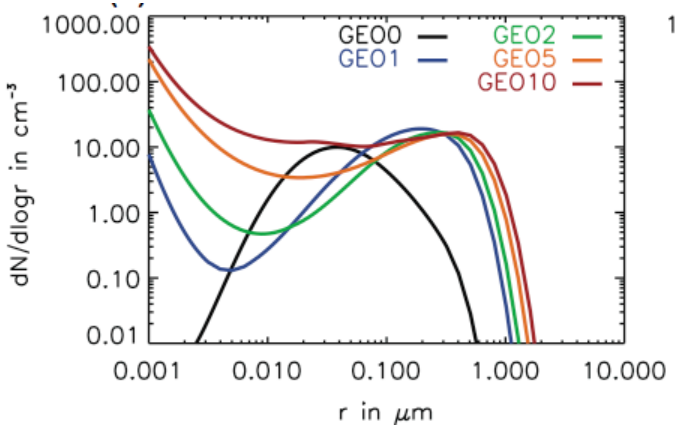


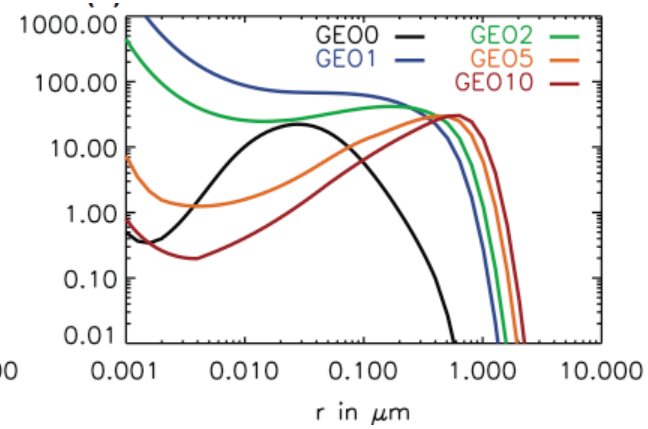
Geoeng. Particles are ~4x larger than Pinatubo

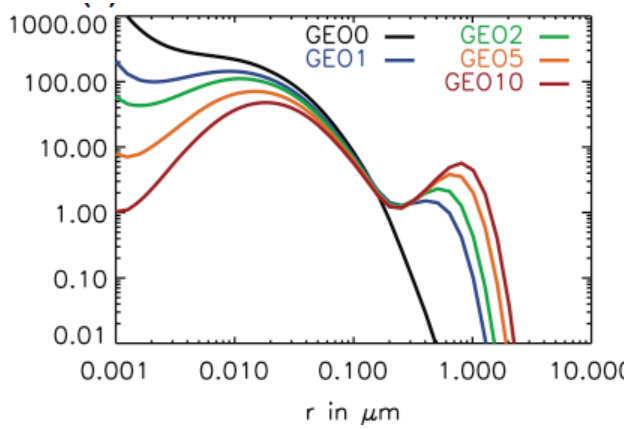






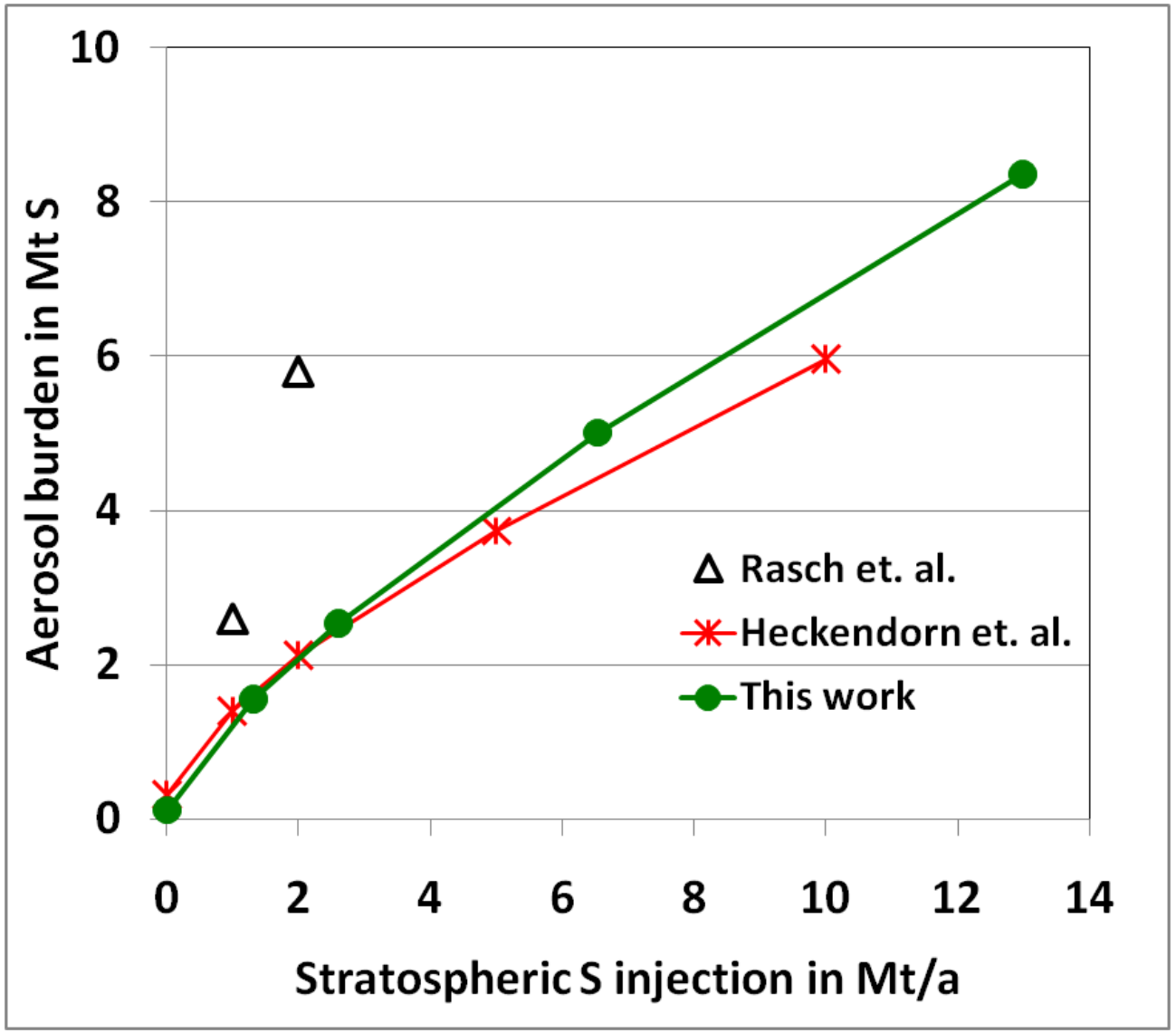


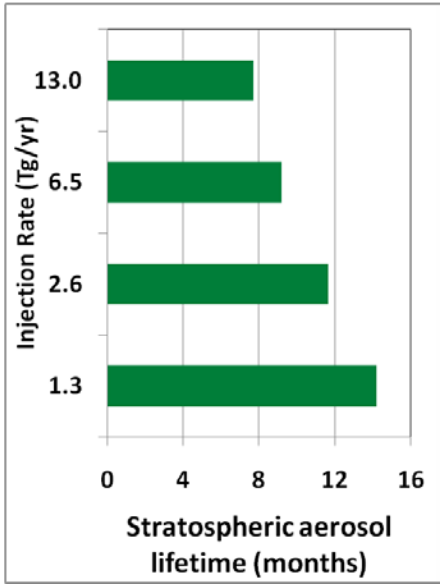


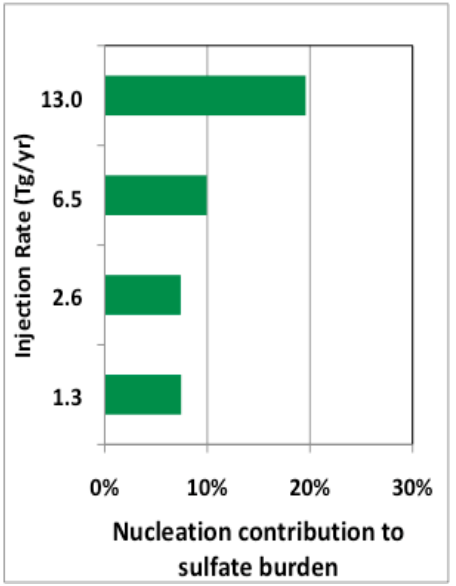


Heckendorn et. al. 2009

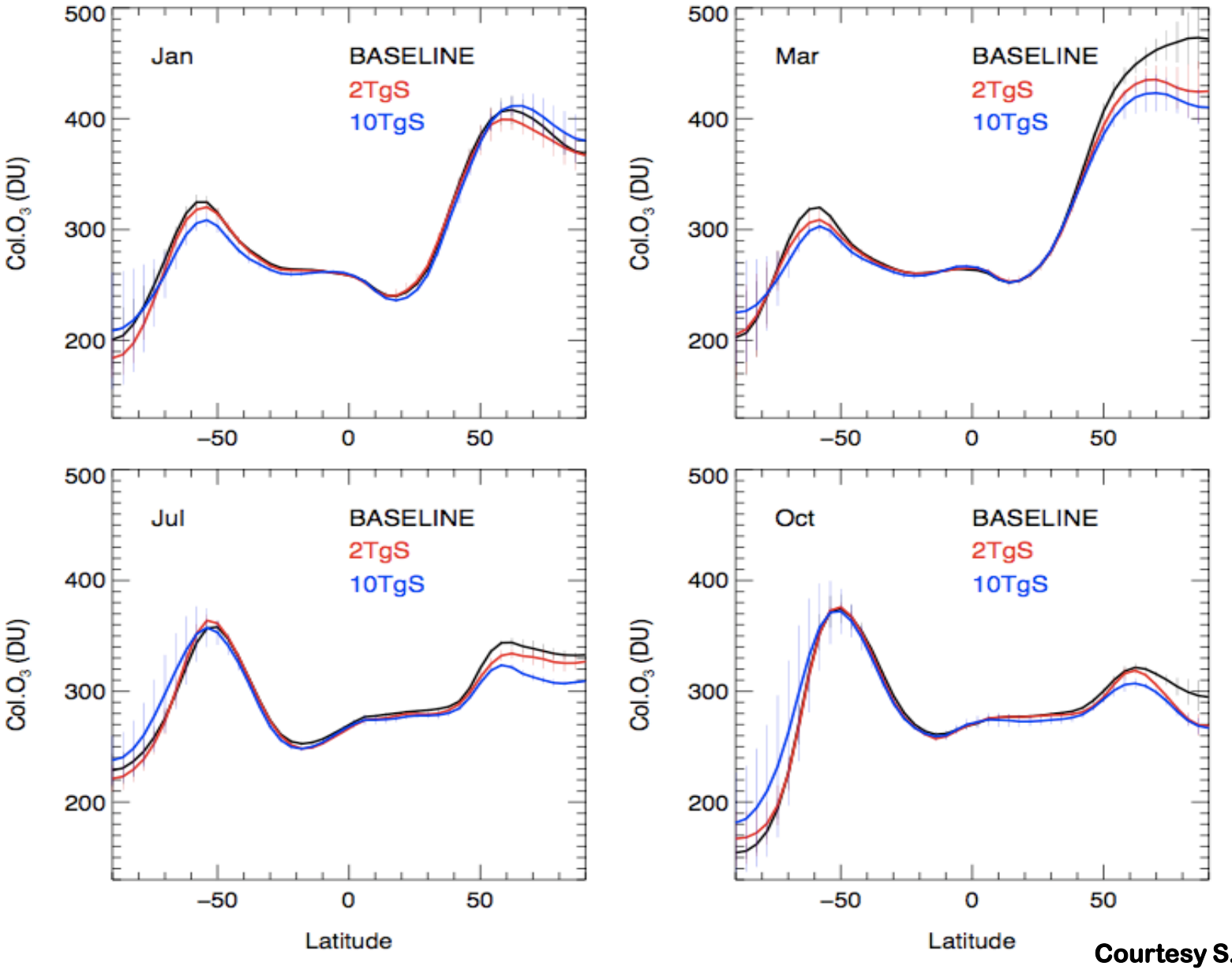
Microphysical simulations predict lower burden (shorter lifetime) than simulations with prescribed size distributions







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



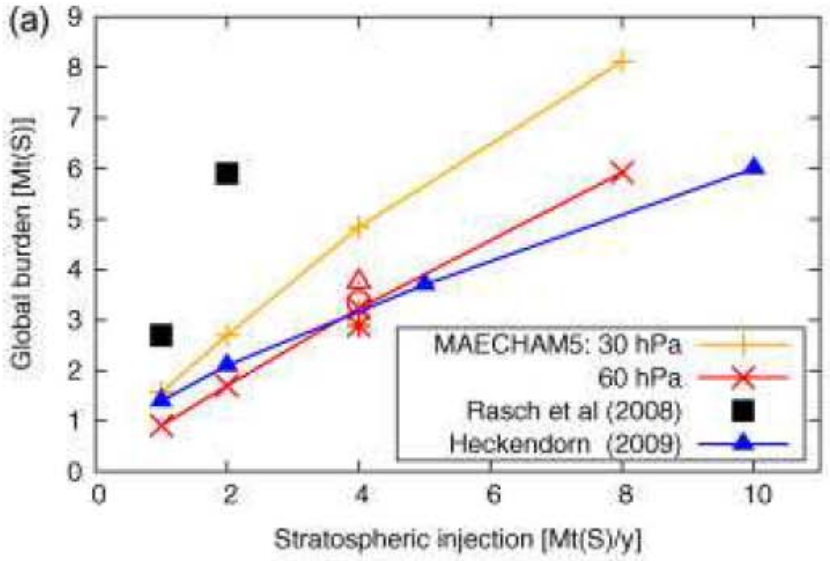
Courtesy S. Tilmes

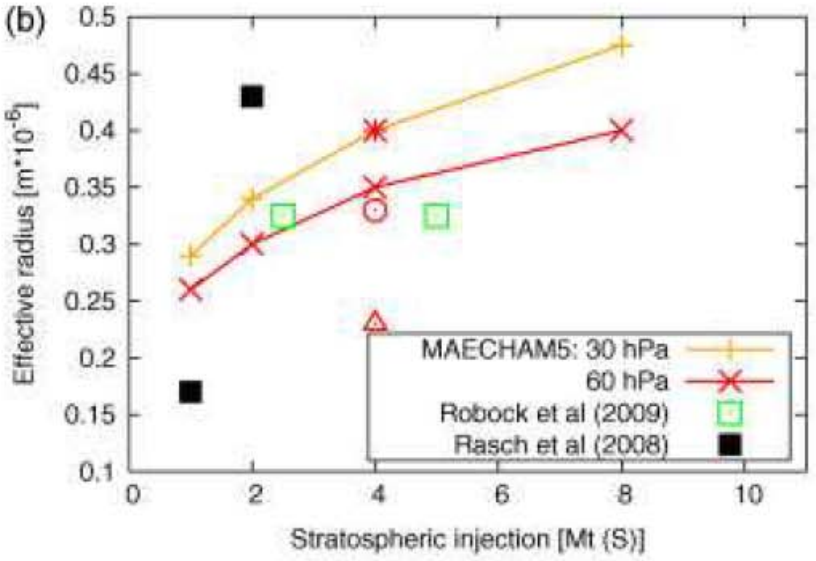
These WACCM-CARMA simulations suggest:

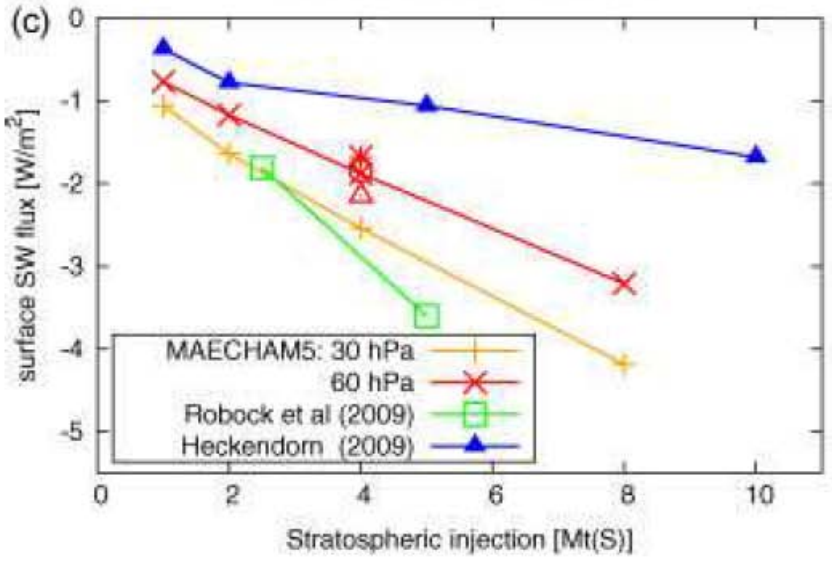
- Stratospheric sulfur injection aerosols peak at 1 μm*, ~4 times larger than Pinatubo
- These large sizes fall out of the stratosphere much faster than previously assumed, esp. at higher injection rates*
- Geoeng. simulations predict some ozone loss, but high variability due to coarse resolution
- Stratospheric sulfur injection geo-engineering may have a limited efficacy (~2 W m^{-2} ?)*

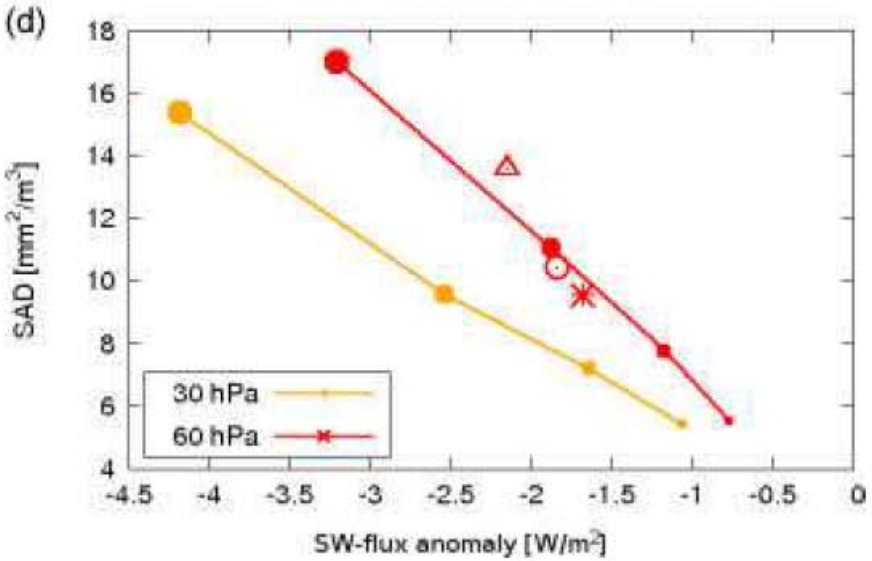
*in agreement with *Heckendorn et. al*

Higher injection altitude → 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 compreensive model available for stratospheric study:
  - 3D
  - 66 vertical levels
  - Full chemistry
  - Sectional (not modal)
  - Full microphysics

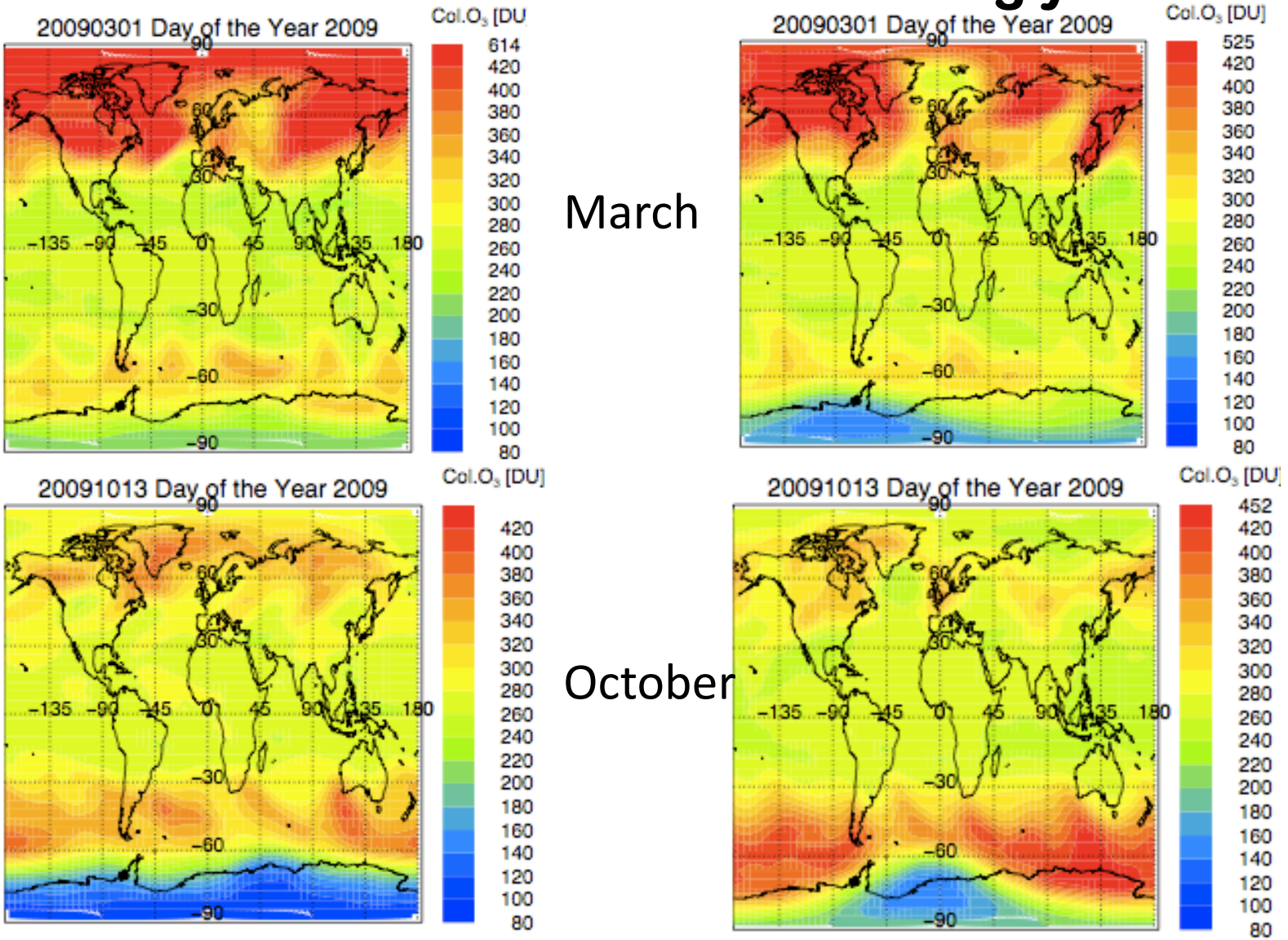
13 Tg perturbation has smaller polar vortex (1-yr comparison)

Baseline

13 Tg/yr

March

October



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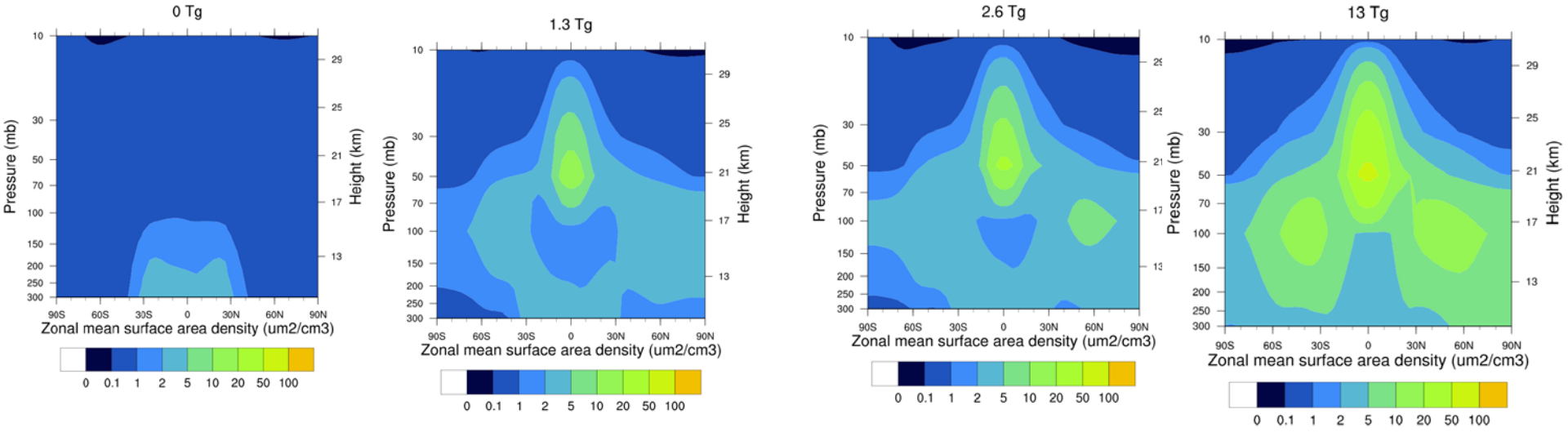
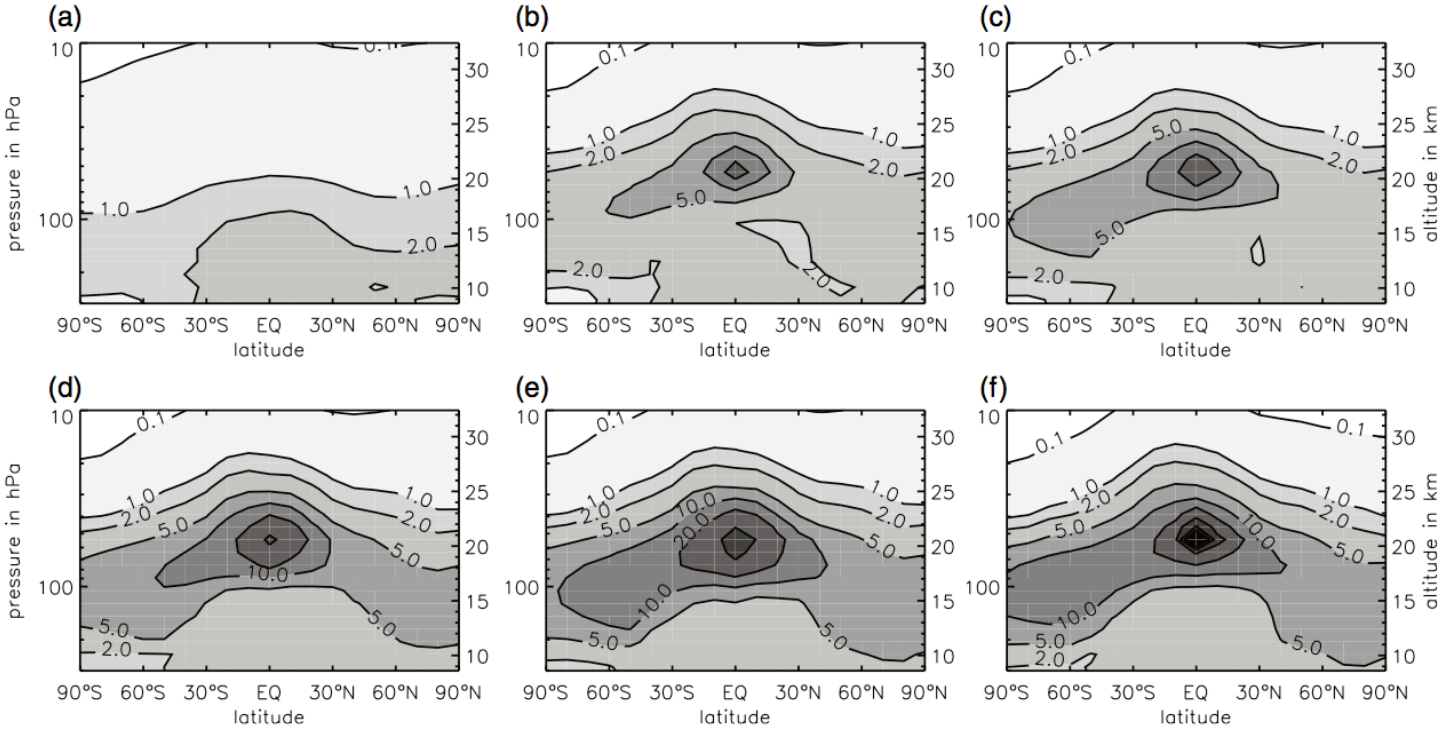

0 Tg
1.3 Tg
2.6 Tg
13 Tg
Pressure (mb)
Height (km)
Zonal mean surface area density (um2/cm3)
0 0.1 1 2 5 10 20 50 100


(a)
(b)
(c)
(d)
(e)
(f)
pressure in hPa
altitude in km
latitude
90°S 60°S 30°S EQ 30°N 60°N 90°N

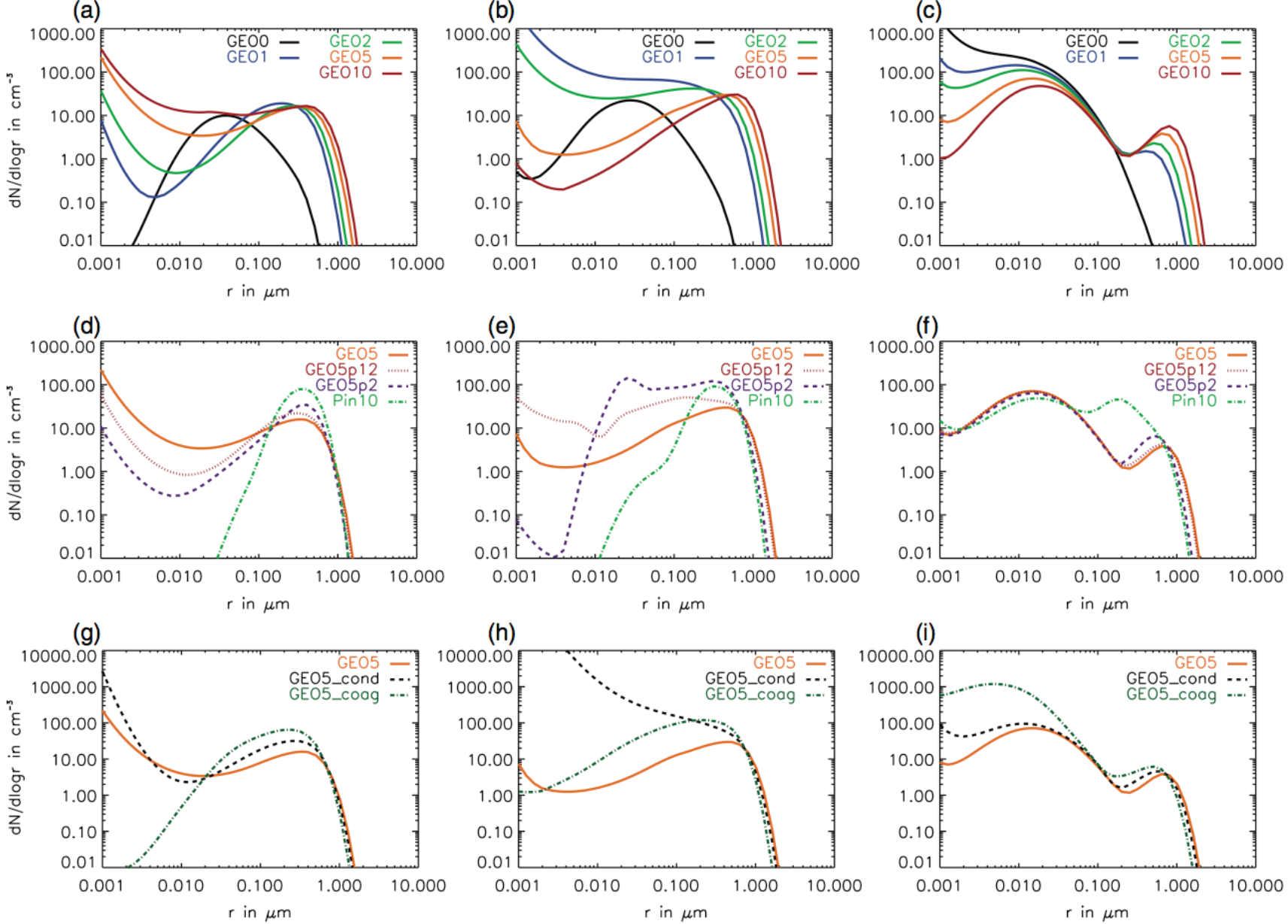


Figure 5. Annual mean differential number density $dN/d\log r$ in cm^{-3} at the equator at 39 hPa (first column), 55 hPa (second column) and 90 hPa (third column). (a)–(c) Continuous S injection into the lower stratosphere of 0, 1, 2, 5 and 10 Mt/a (GEO0–GEO10). (d)–(f) Continuous and pulsed emission 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.