Geoengineering efficacy of sulfur injections in the upper troposphere versus the lower stratosphere

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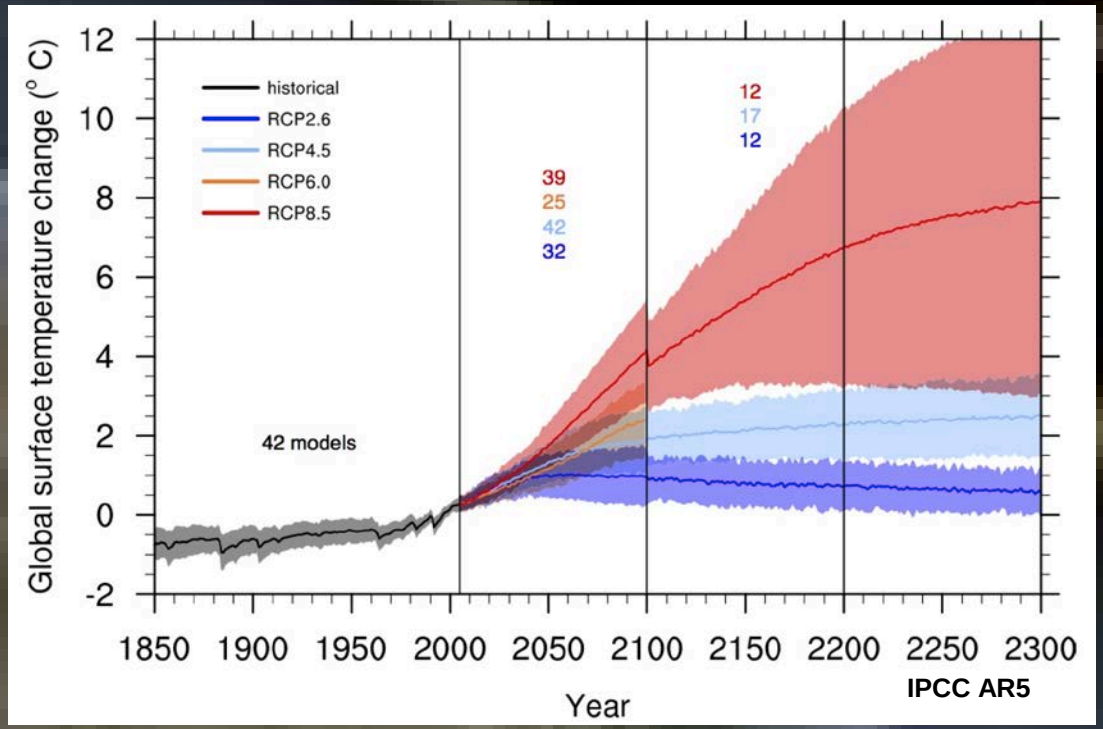
Why should we study geoengineering?



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

Plan A: Do Nothing.
Cost 1 - 2% of global GDP yr^{-1} ($0.6 - 1.3 trillion)
[Stern report]

Plan B: Reduce GHG emissions

- Expensive, politically unfavorable, hasn't happened yet
- Some climate change inevitable (ocean heat and CO_2 storage)

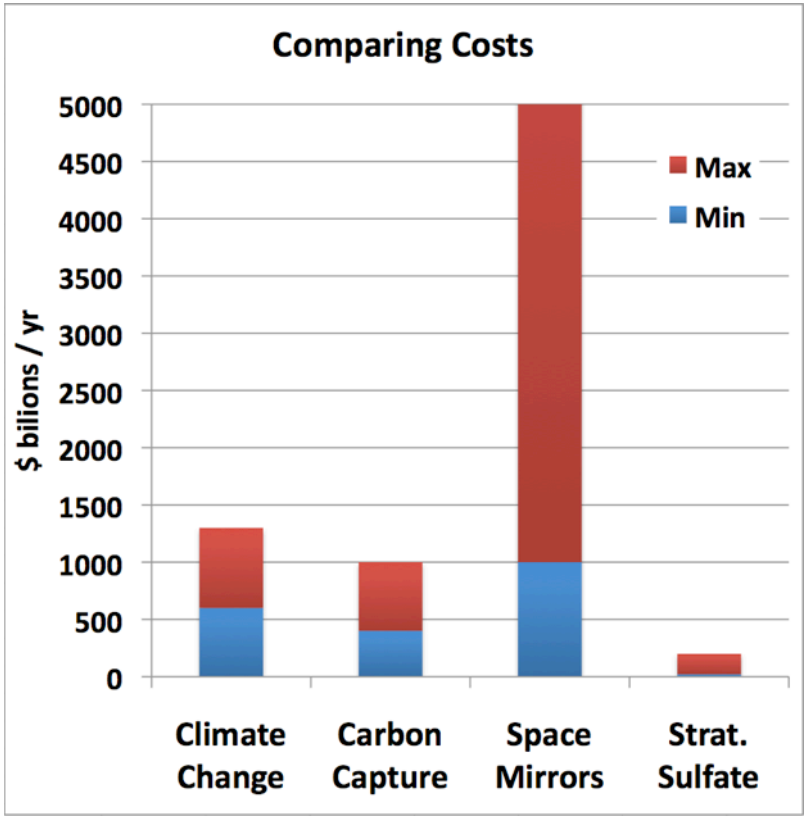
Plan C: Implement geoengineering (Carbon capture, SRM, etc)

- Many consequences/unknowns
- BUT we have risks with doing nothing, also!

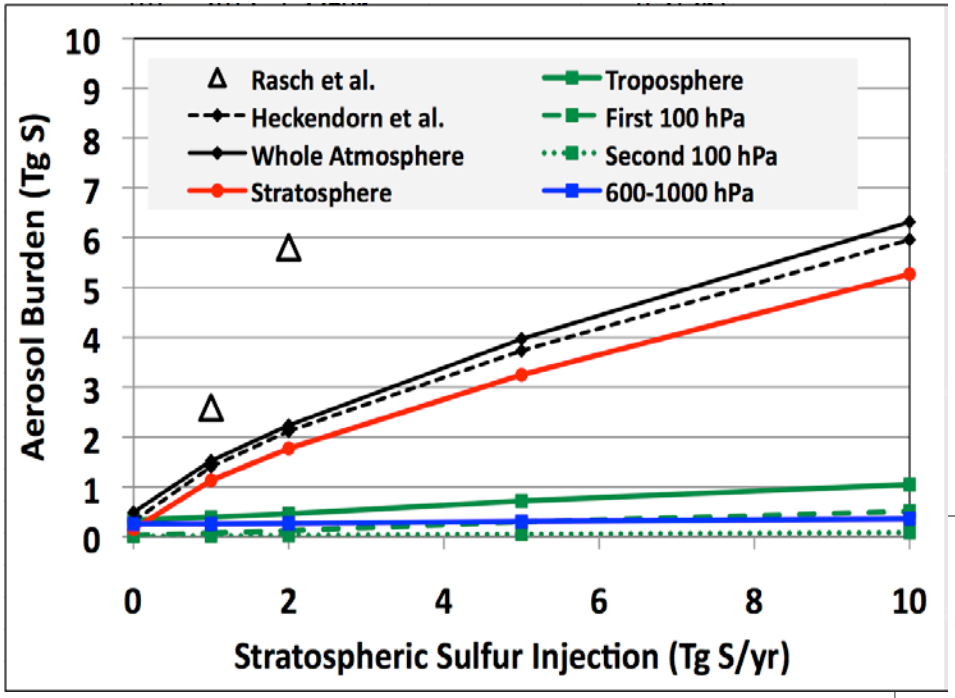
Leading SRM idea: stratospheric sulfur geoengineering

Drawing by Brian West. Robock et al., 2009

- Why the stratosphere?
  - Longer aerosol lifetime
- Inject ~5 to 20 Tg SO_2/yr
- Balloons, tall pipes, aircraft, artillery
- Cost: <$2 to 200 billion/yr
- This may be economical…



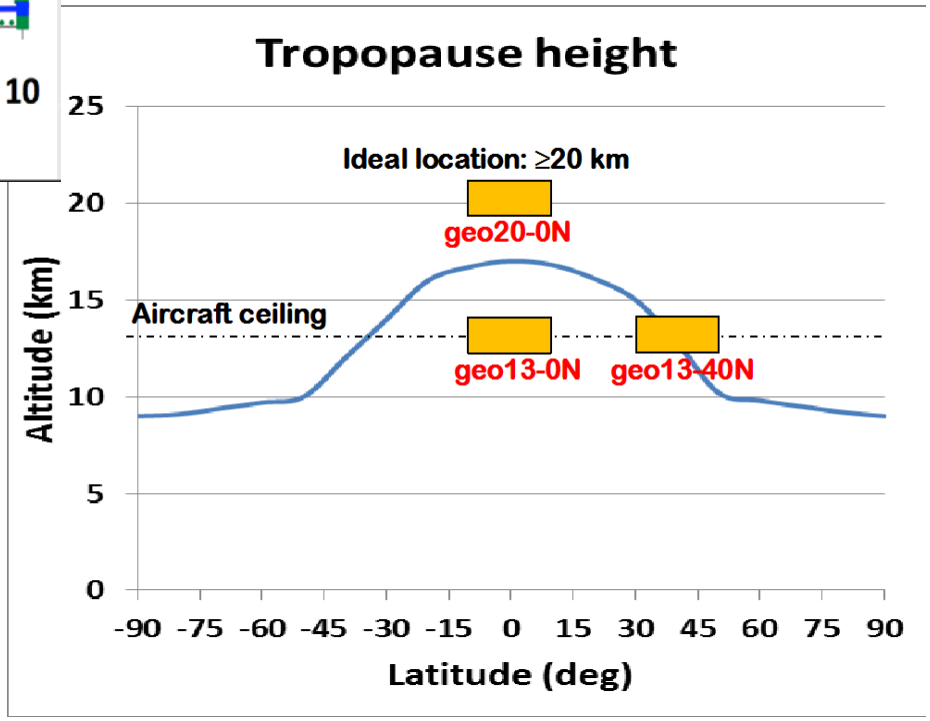
Microphysical simulations with sectional aerosol models predict limited efficacy in the stratosphere due to aerosol growth



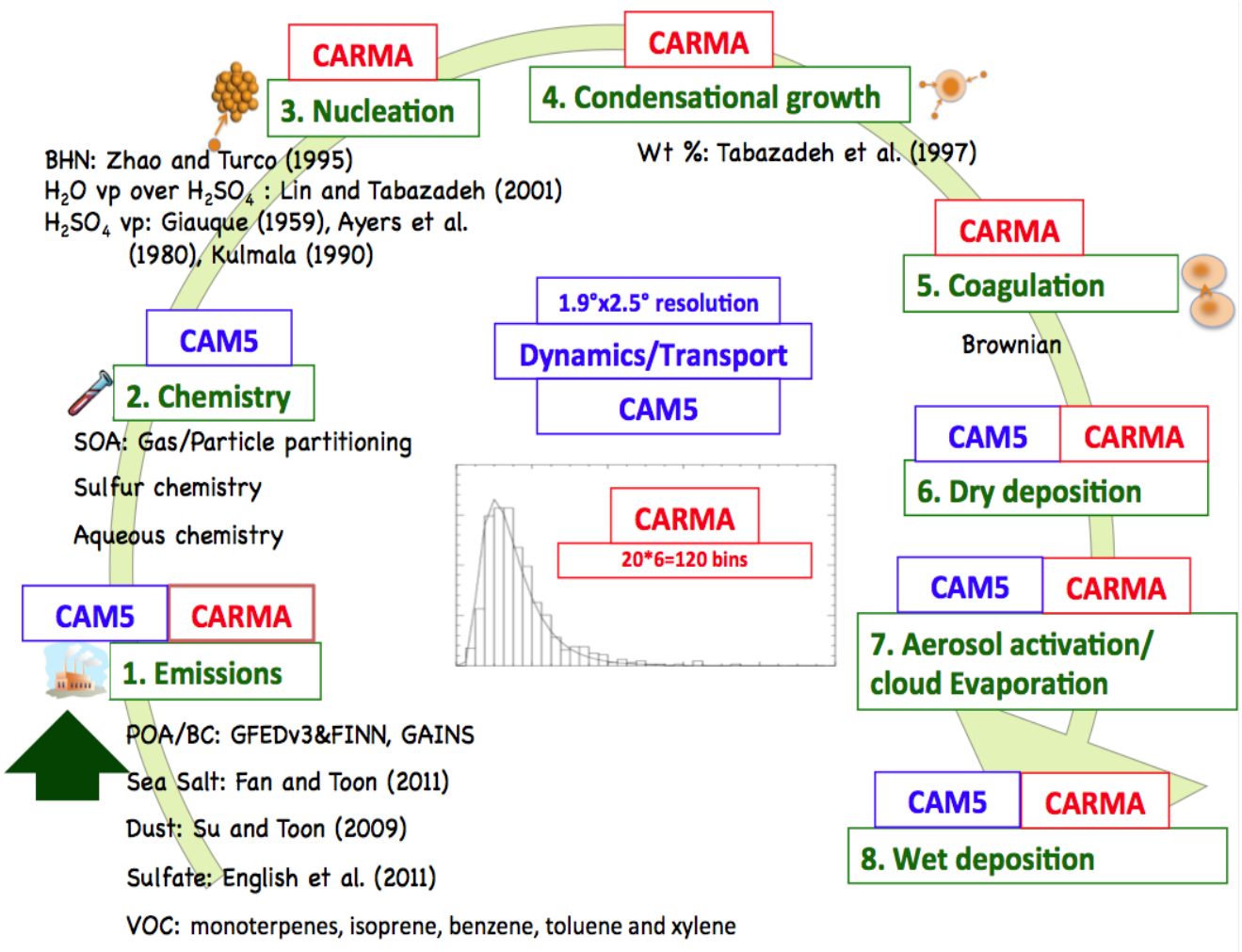
English et al. 2012

SO_2 injections at 20 km altitude, equator, WACCM3/CARMA

However, most aircraft cannot reach the tropical stratosphere How effective is geoengineering at 13 km altitude?



The 56-level CAM5/CARMA model is well-suited for study



CAM5: Global climate model with 56-vertical levels, two-moment cloud microphysics, RRTMG radiation

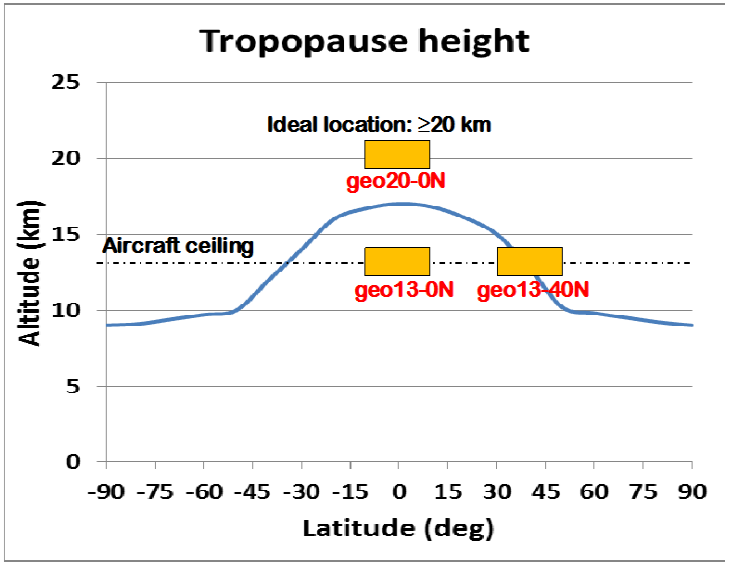
CARMA: 5 aerosol types (Sulfate, sea salt, dust, black carbon, organic carbon), pure sulfate & internally mixed, sectional size representation (20 bins each) (Toon et al. 1988)

Coupling: CARMA aerosols are fully interactive with chemistry, radiation, and liquid clouds

Future work: couple CARMA aerosols to ice clouds and stratospheric heterogeneous chemistry

Experiments: SO_2 injections (10 Tg S yr^{-1}) at 3 different locations

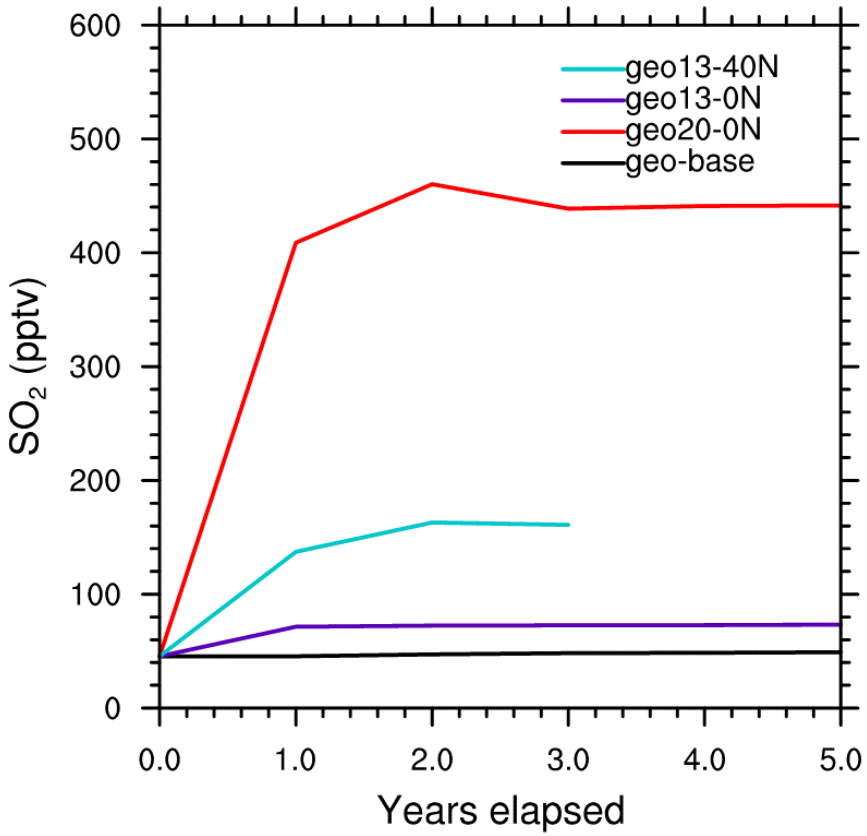
Name	Description
geo-base	CAM5/CARMA base model run
geo20-0N	20 km altitude, 2°S-2°N, all longitudes (Heckendorn et al. 2009, English et al., 2012)
geo13-0N	13 km altitude, 2°S-2°N, all longitudes
geo13-45N	13 km altitude, 42°S-47°N, all longitudes

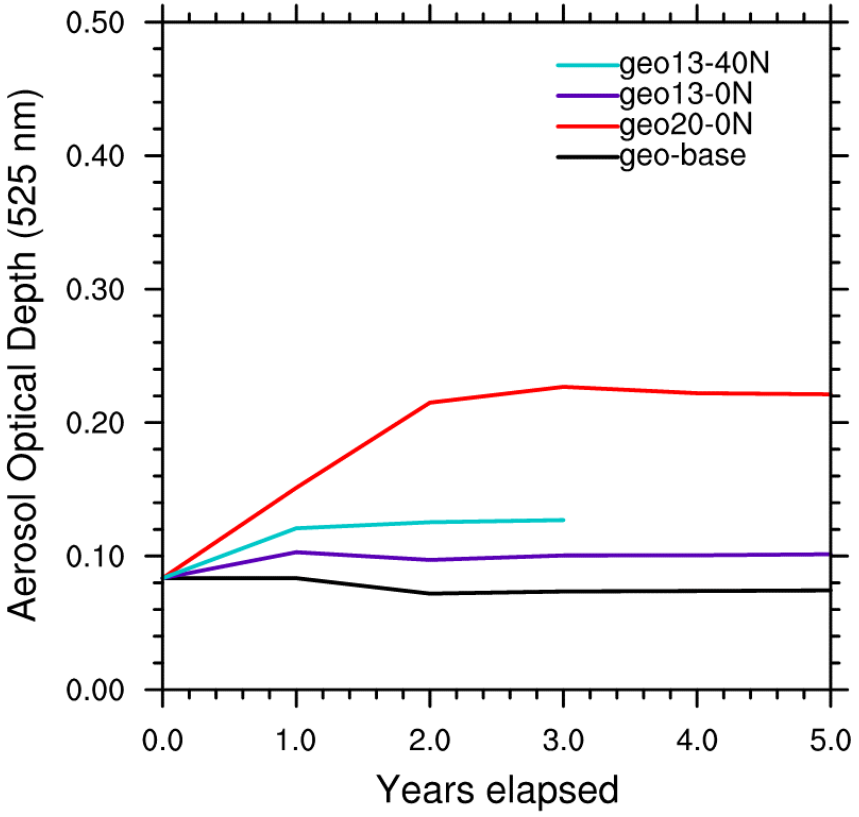


Specifications for all four experiments:

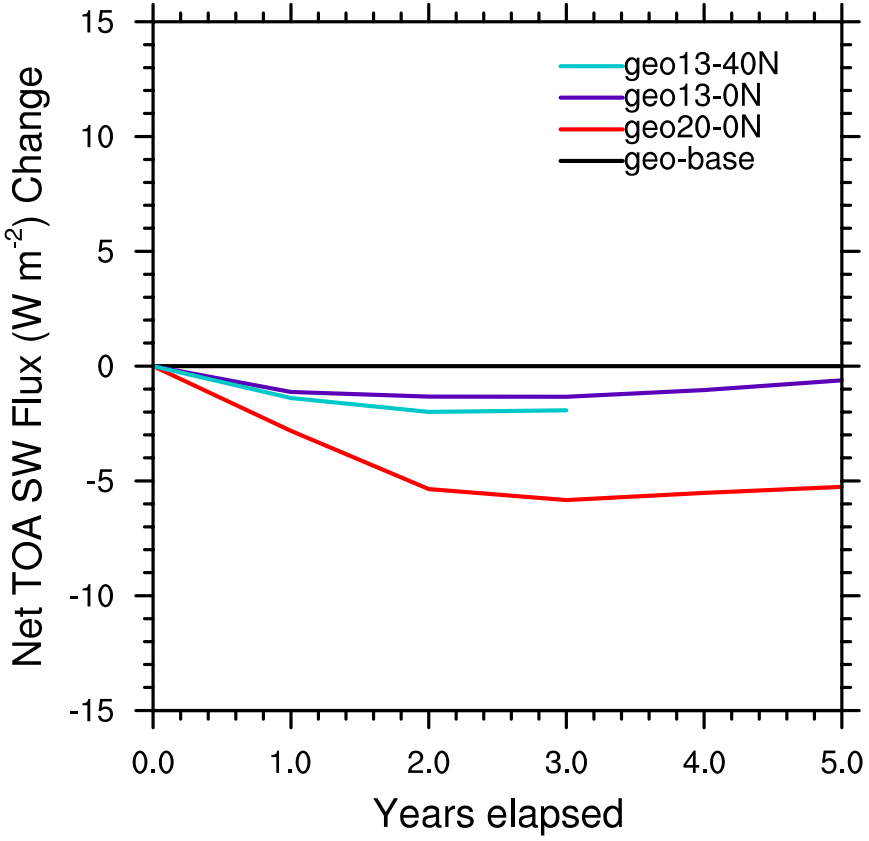
- 1.9°x 2.5°, 56 vertical levels
- 5-year AMIP simulations with FC5 compset (year 2000 emissions of CO_2 and aerosols, prescribed SSTs and sea ice extent)

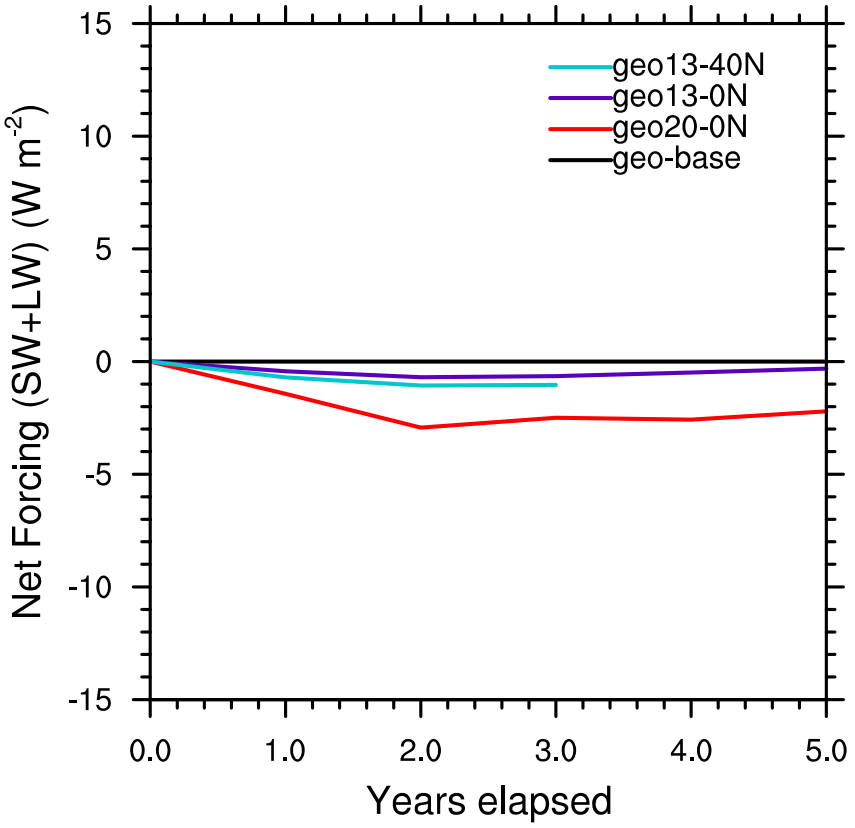
20 km injections have 2-year ramp-up; 13 km injections 1 yr



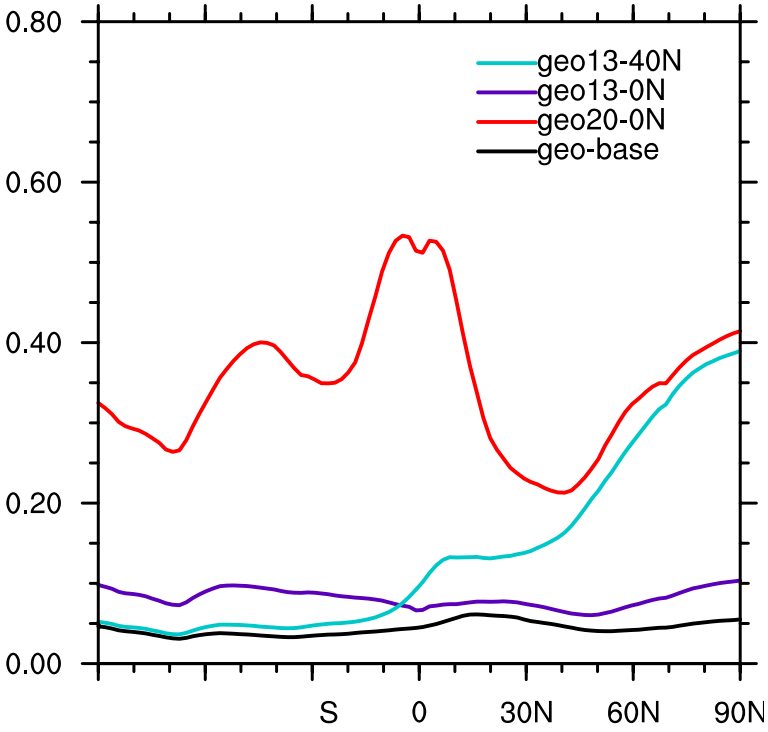


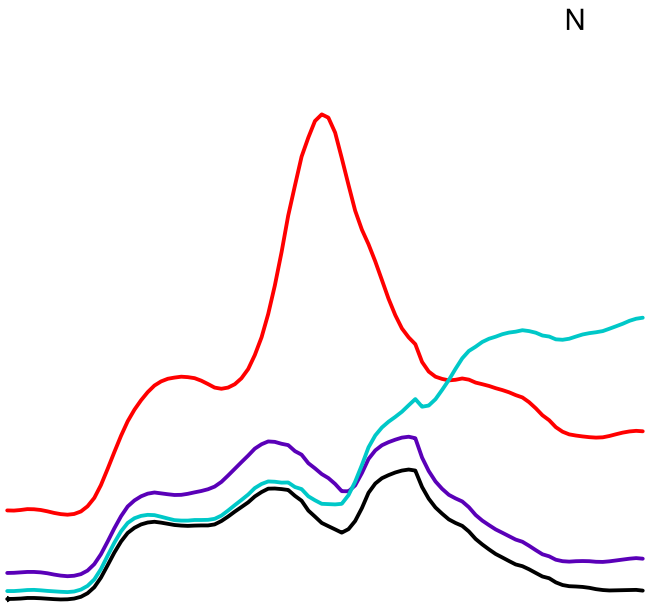
20km injections are about 3x more effective, but 13km injections may be able to offset 1-2 Wm^{-2}



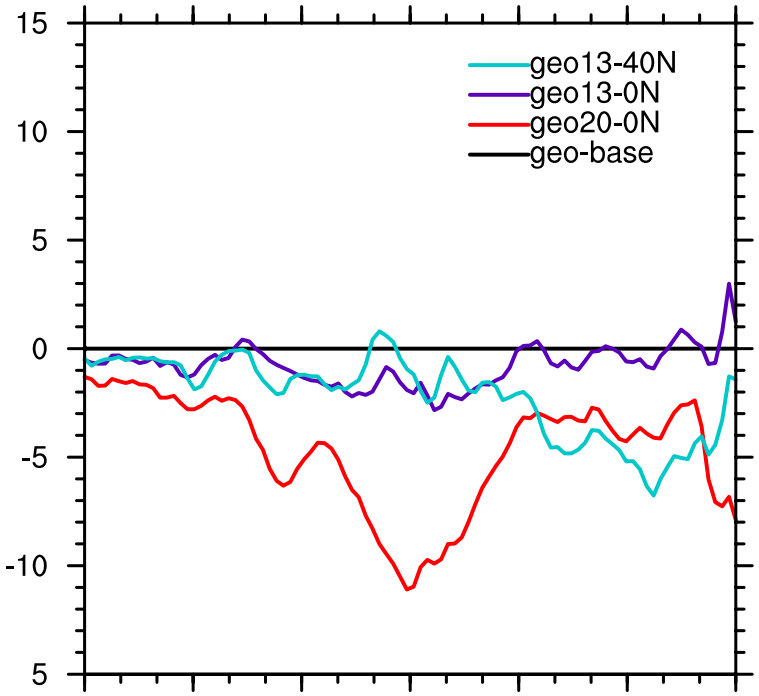


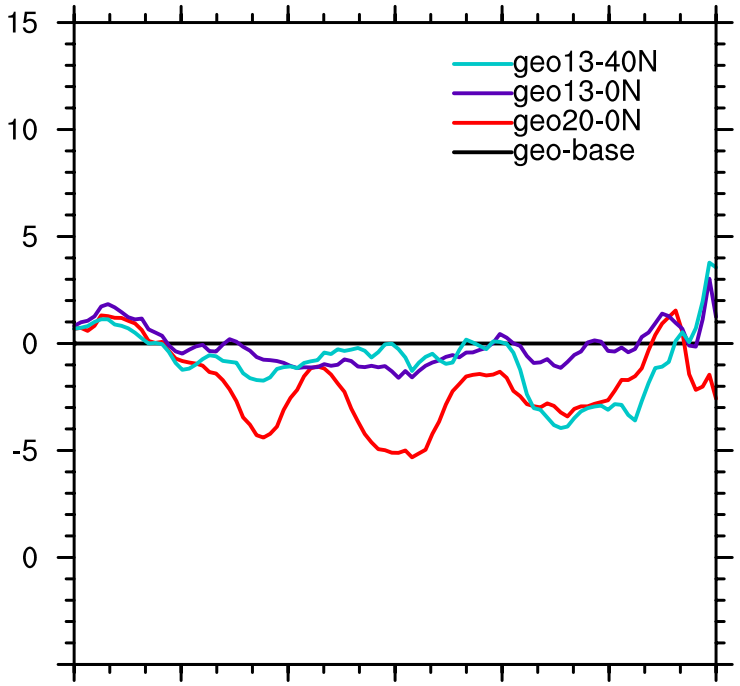
Zonal asymmetries in Radiative Forcing with all 3 approaches



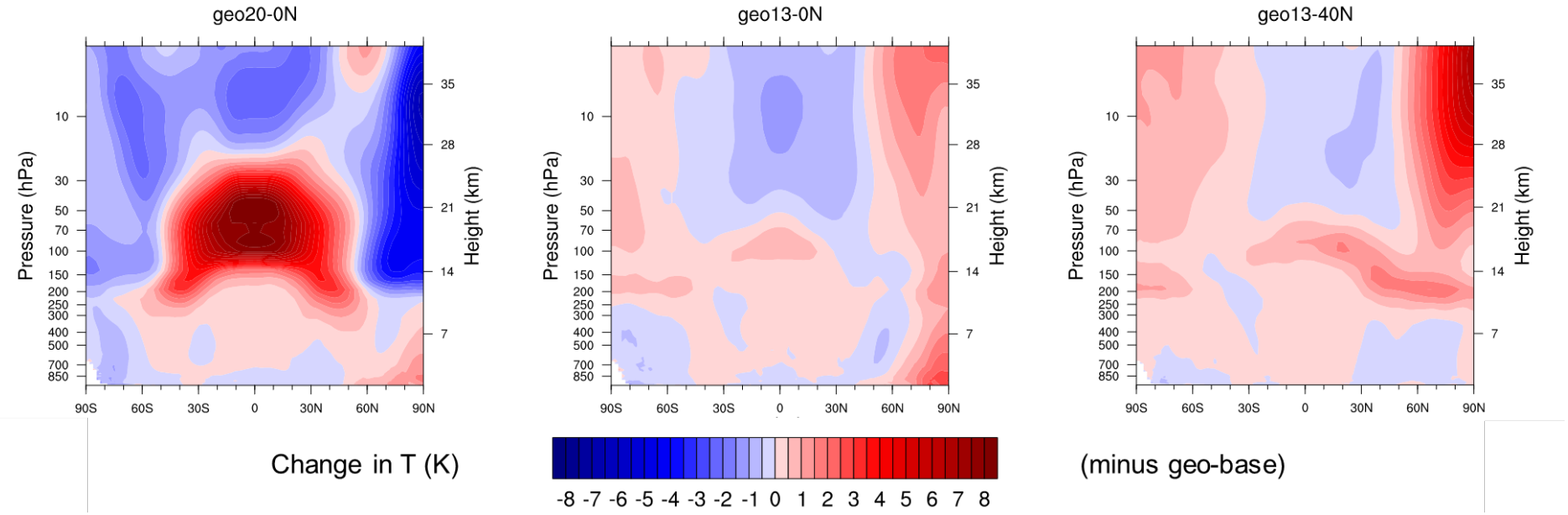


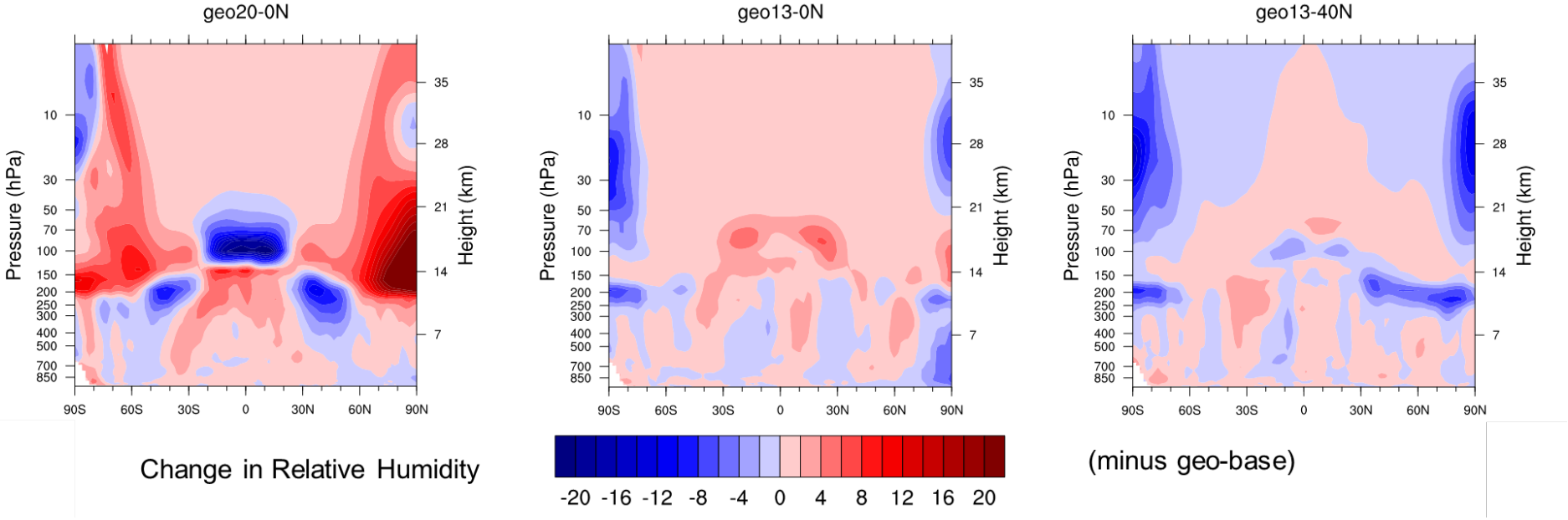
SW forcing stronger than net SW+LW



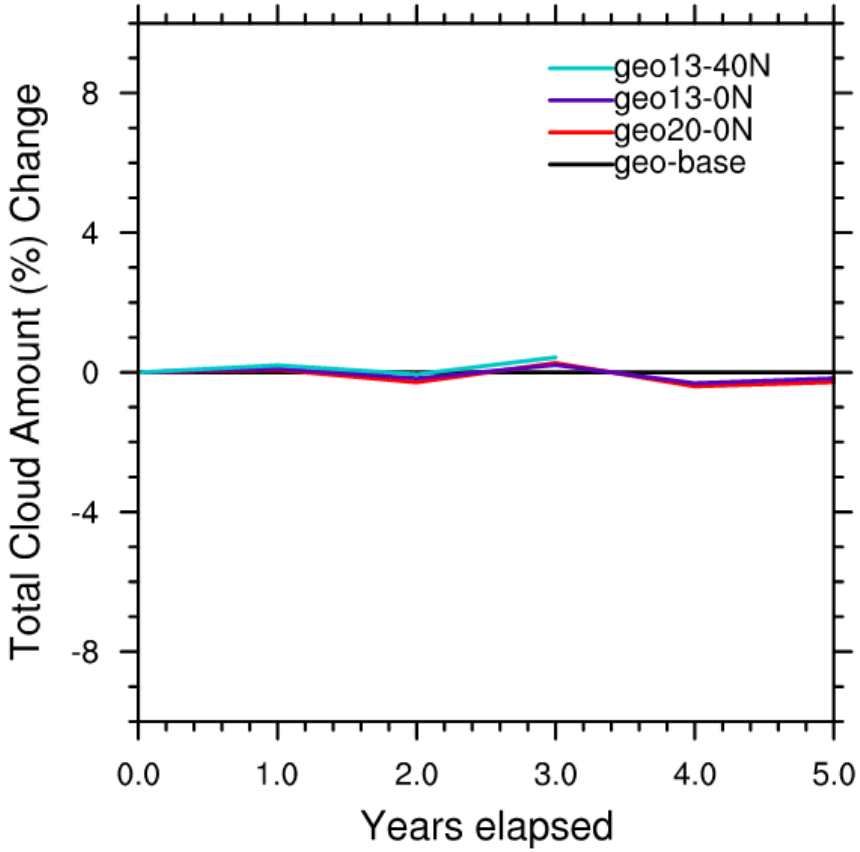


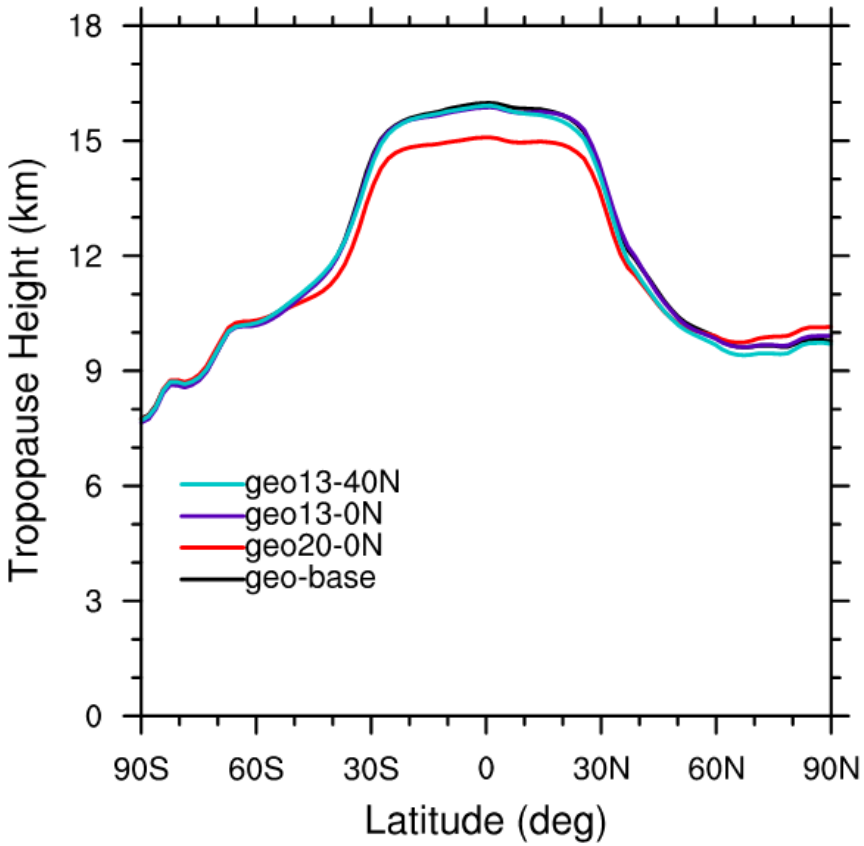
Strong UTLS T/RH perturbations with 20 km injections



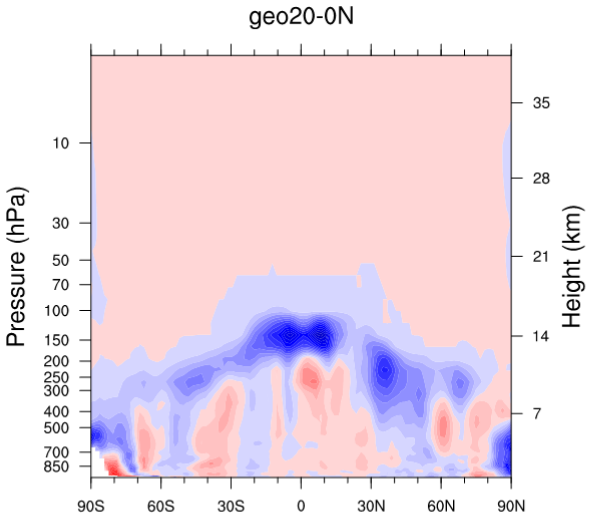


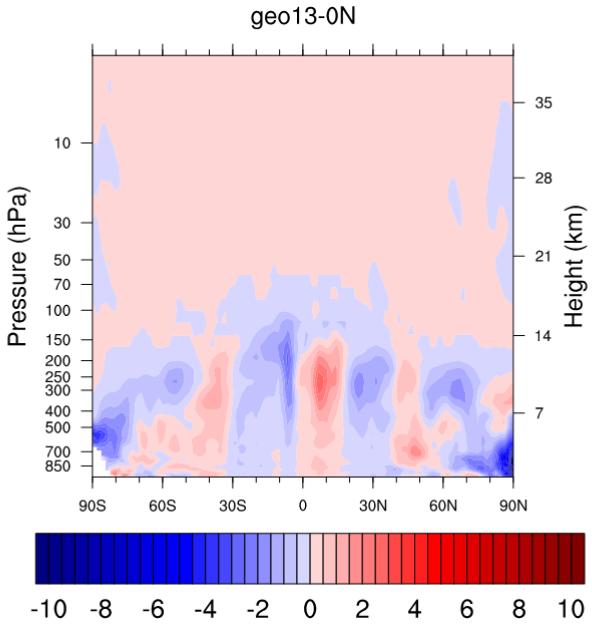
Global cloud amount unchanged, 20 km injection lowers tropopause

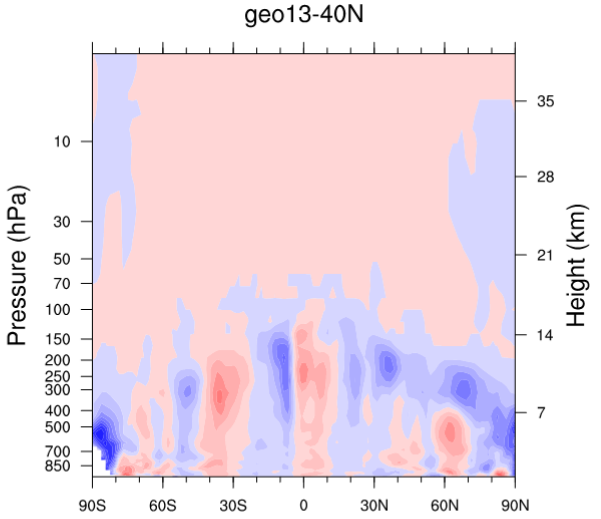




20 km injections have less high cloud / lower cloud tops; OLR impact?

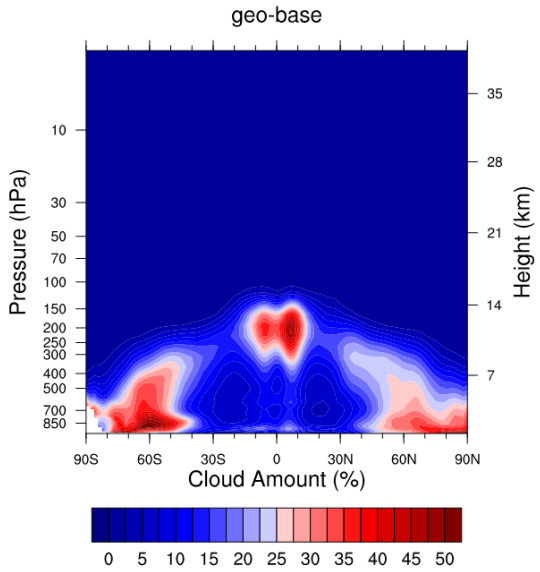






Change in Cloud Amount

(minus geo-base)



Summary

- 20 km injections are about 3x as effective as 13km injections
- However, 13 km injections:
  - may offset 1-2 Wm^{-2}
  - are more attainable by aircraft
  - may reduce stratospheric perturbations/ozone loss
  - may minimize effects to clouds and tropopause height

Next Steps

- Quantify ozone loss for each injection (activate CARMA het chem)
- Compare “lifting costs” of injections at 13 km versus 20 km?
- Hemispheric summer injections?