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Impact of Solar and Sulfate Geoengineering on Surface Ozone

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Simulating two SRM scenarios: Sulfate injection and Solar irradiance reduction

- Full tropospheric and stratospheric chemistry version of CESM CAM4-Chem (Community Atmospheric Model version 4 - Chemistry)
- Fully coupled to ocean, land and ice models
- 1 degree resolution in latitude and longitude

G4 specified stratospheric aerosols

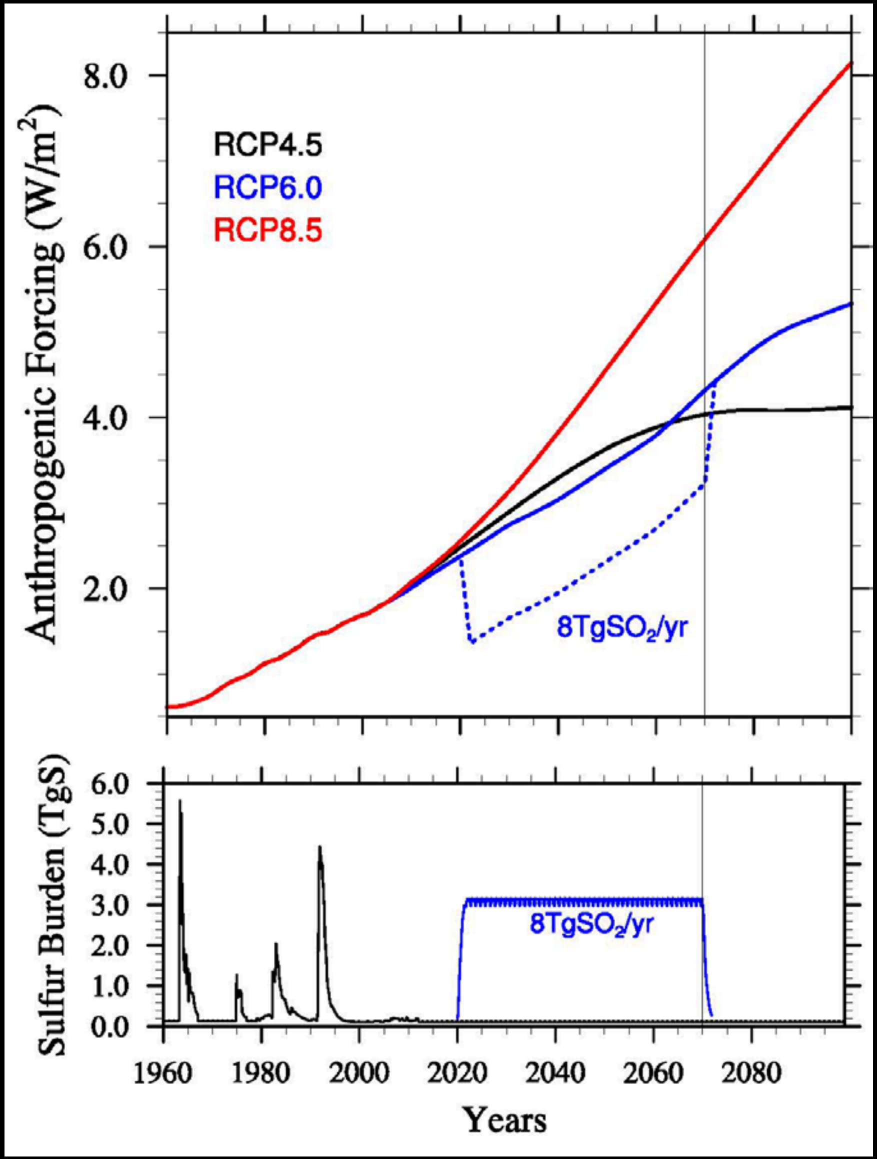
- Three ensemble members of RCP6.0 (2004-2089)
- Three ensemble members of G4SSA (2020-2089)
- Three ensemble members of G4SSA-S (2020-2089)

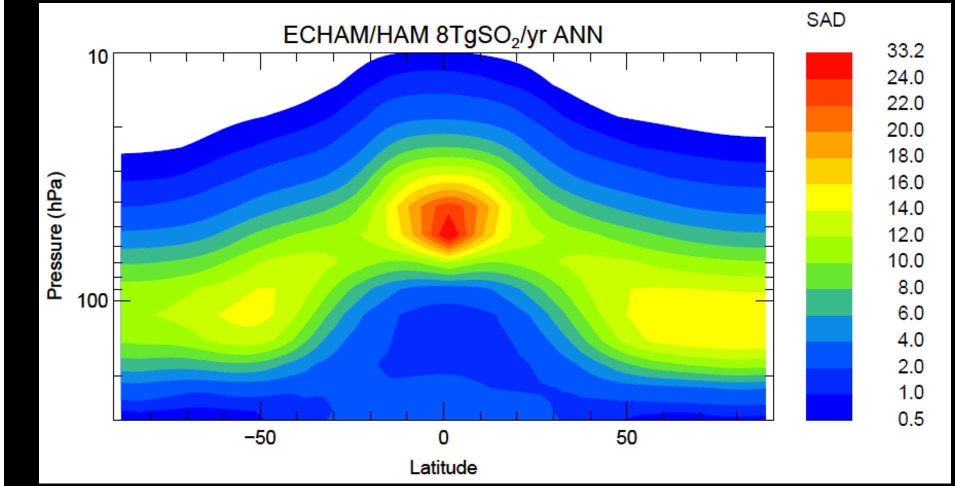
Solar irradiance reduction with the same forcing as in G4SSA at the top of the atmosphere

Tilmes, S., et al. (2015), A new Geoengineering Model Intercomparison Project (GeoMIP) experiment designed for climate and chemistry models, *Geosci. Model Dev.*, 8, 43-49, doi:10.5194/gmd-8-43-2015.

G4SSA Forcing:

Steady-state prescribed aerosol distribution, based on an 8 Tg SO_2 year^{-1} emission scenario using the ECHAM5-HAM model, combined with RCP6.0





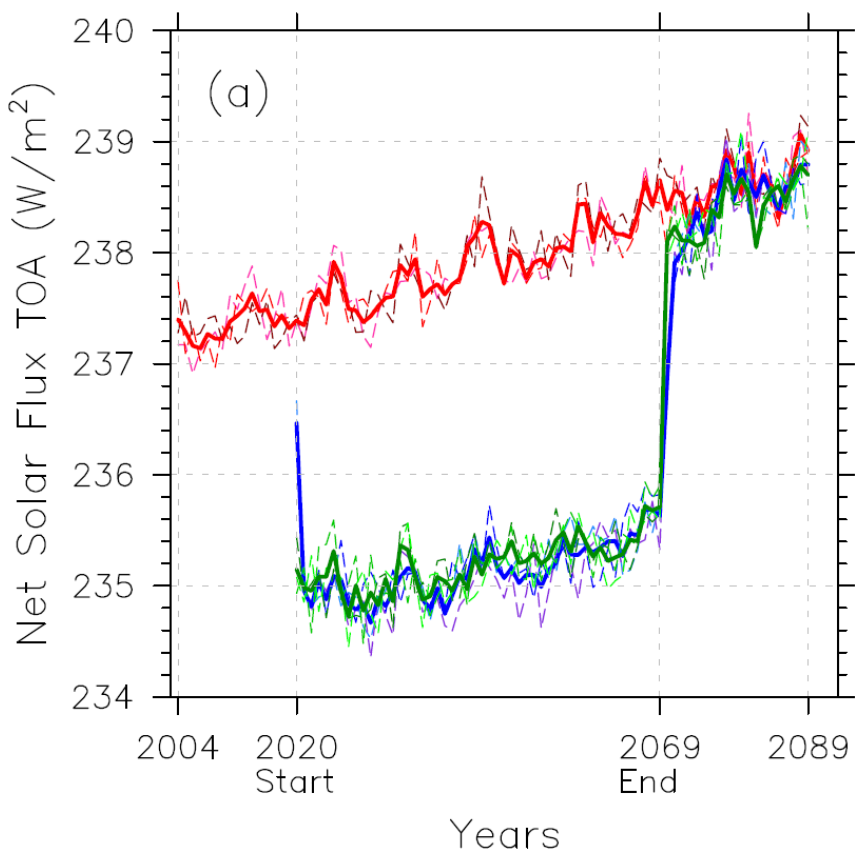
Tilmes, S., et al. (2015), A new Geoengineering Model Intercomparison Project (GeoMIP) experiment designed for climate and chemistry models, *Geosci. Model Dev.*, *8*, 43-49, doi:10.5194/gmd-8-43-2015.

Niemeier, U., et al. (2013), Solar irradiance reduction via climate engineering: Impact of different techniques on the energy balance and the hydrological cycle, *J. Geophys. Res.-Atmos.*, *118*, 11,905–11,917, doi:10.1002/2013JD020445.

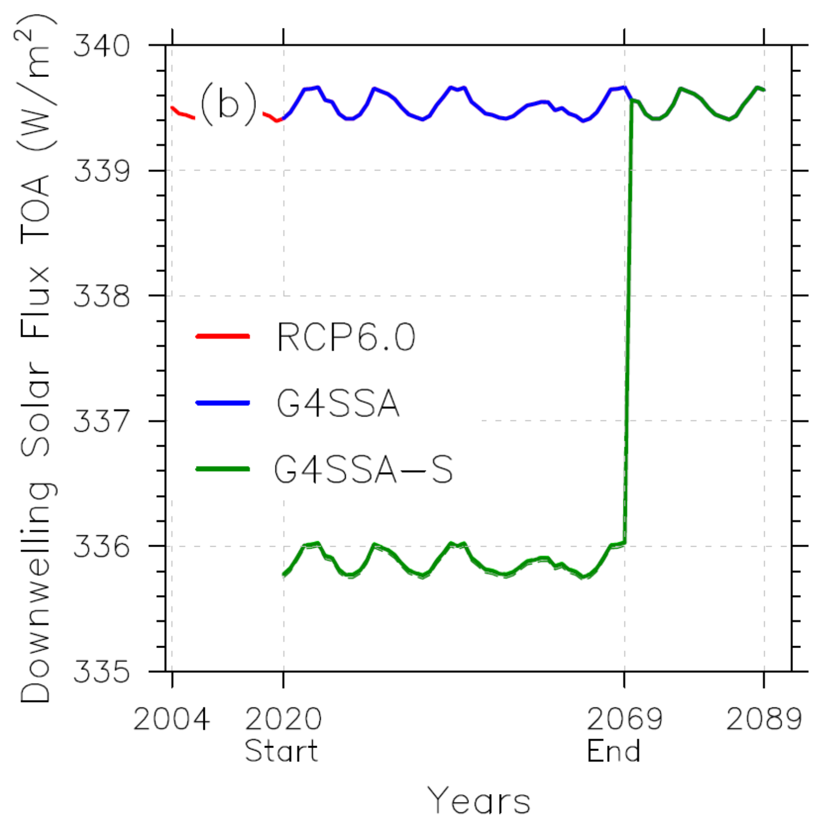
G4SSA-S Forcing:

Keep the net solar radiation at top of atmosphere (TOA) the same as in G4SSA, which is 2.5 W/m^2 less than RCP6.0.

Net Solar Flux (TOA)

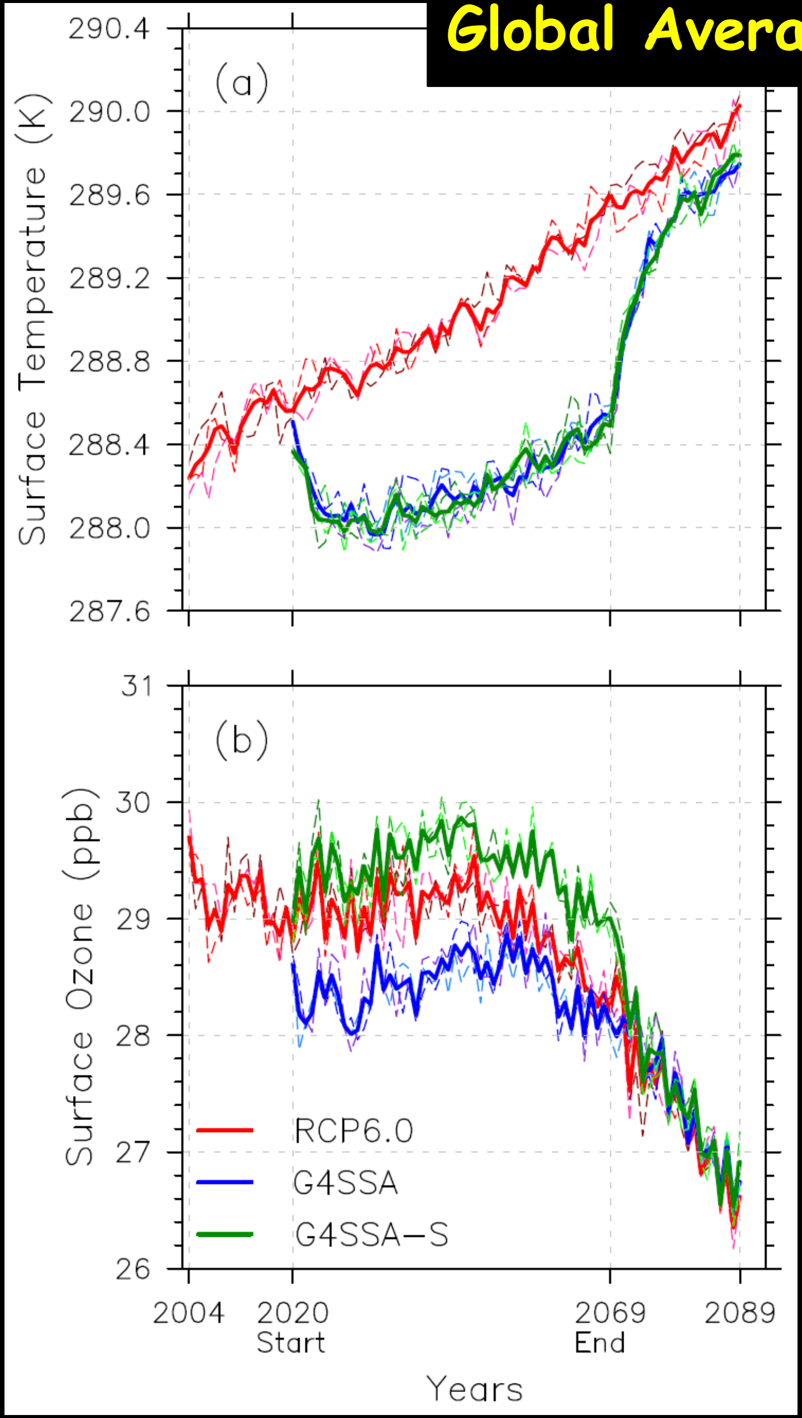


Insolation (TOA)



Total insolation reduction at top of atmosphere is ~1%.

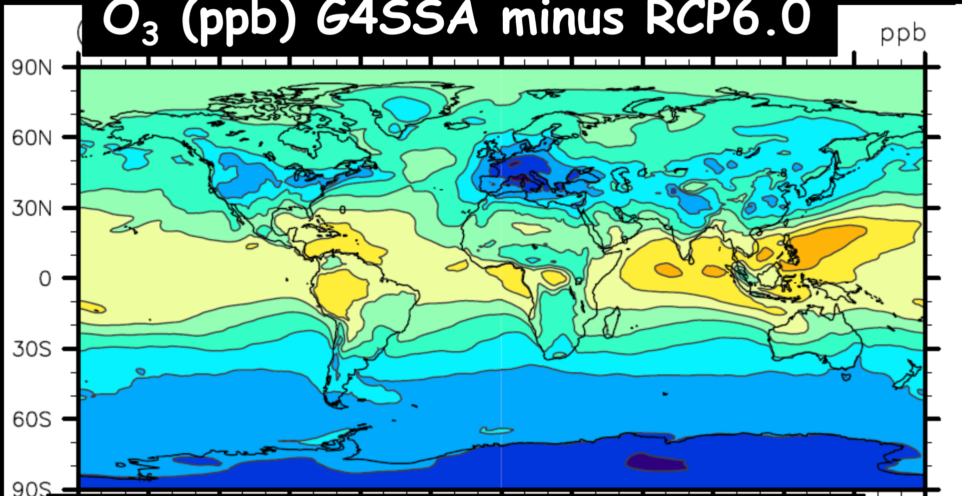
Global Averaged Surface Temperature and Ozone



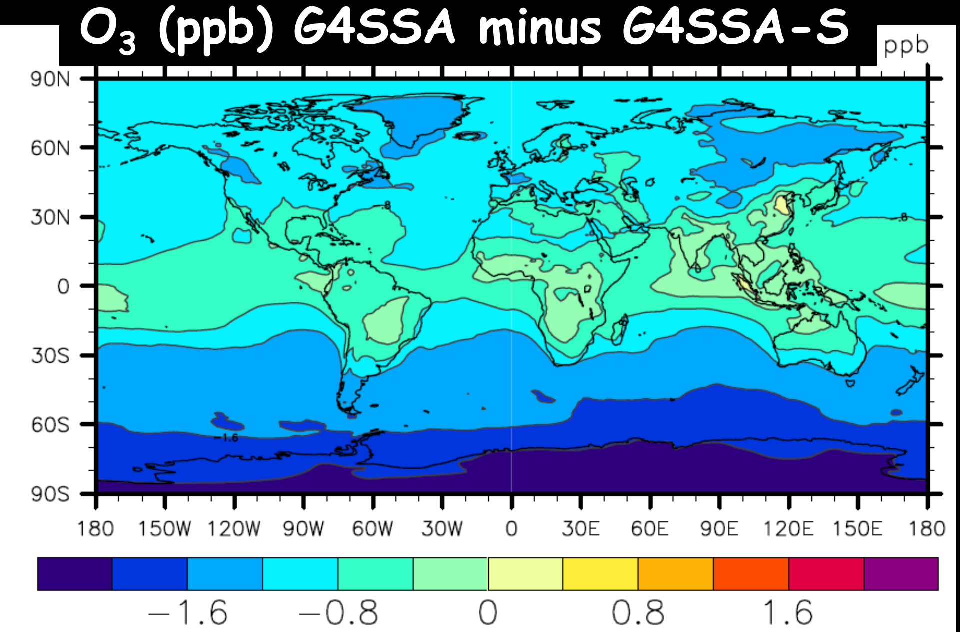
- Compared with RCP6.0, global averaged annual surface temperature reductions of G4SSA and G4SSA-S are very similar (~0.8 K).

- G4SSA shows less surface O_3 when compared with RCP6.0 as a global average, while G4SSA-S shows an opposite change – surface O_3 concentration increases relative to RCP6.0.

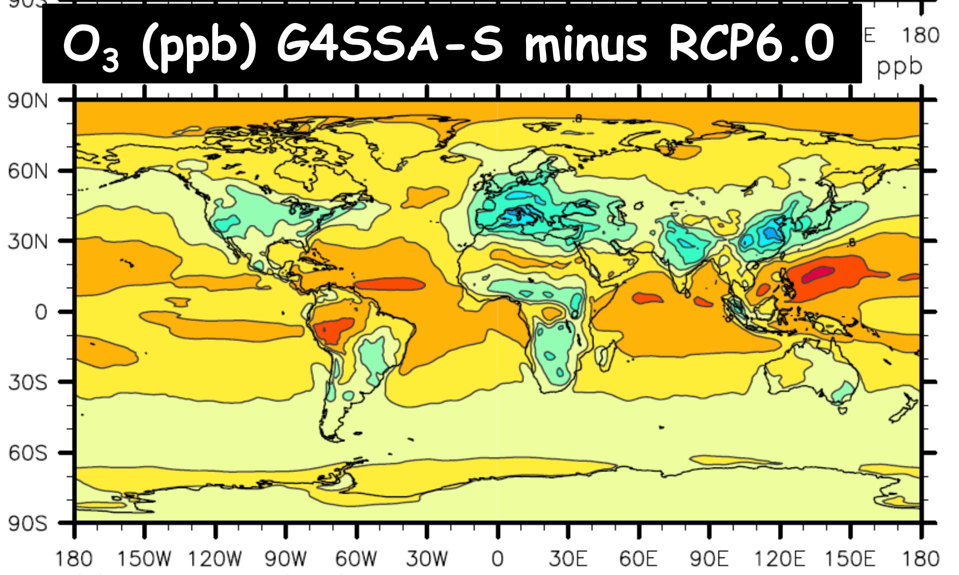
Surface Ozone Concentration Difference (ppb)
(average of three ensembles, average of 2030-2069)



O_3 (ppb) G4SSA minus RCP6.0



O_3 (ppb) G4SSA minus G4SSA-S

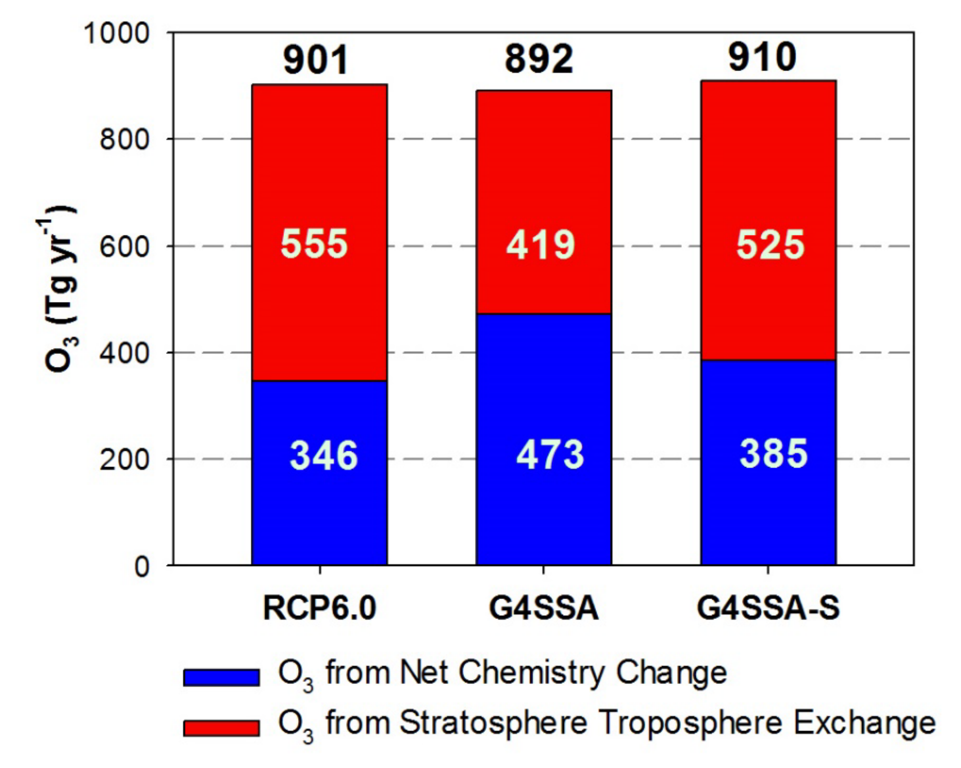


O_3 (ppb) G4SSA-S minus RCP6.0

Changes in regional surface ozone concentrations are controlled by ozone exchange from the stratosphere, photo-chemical changes in the troposphere (production and loss rates), and deposition rates

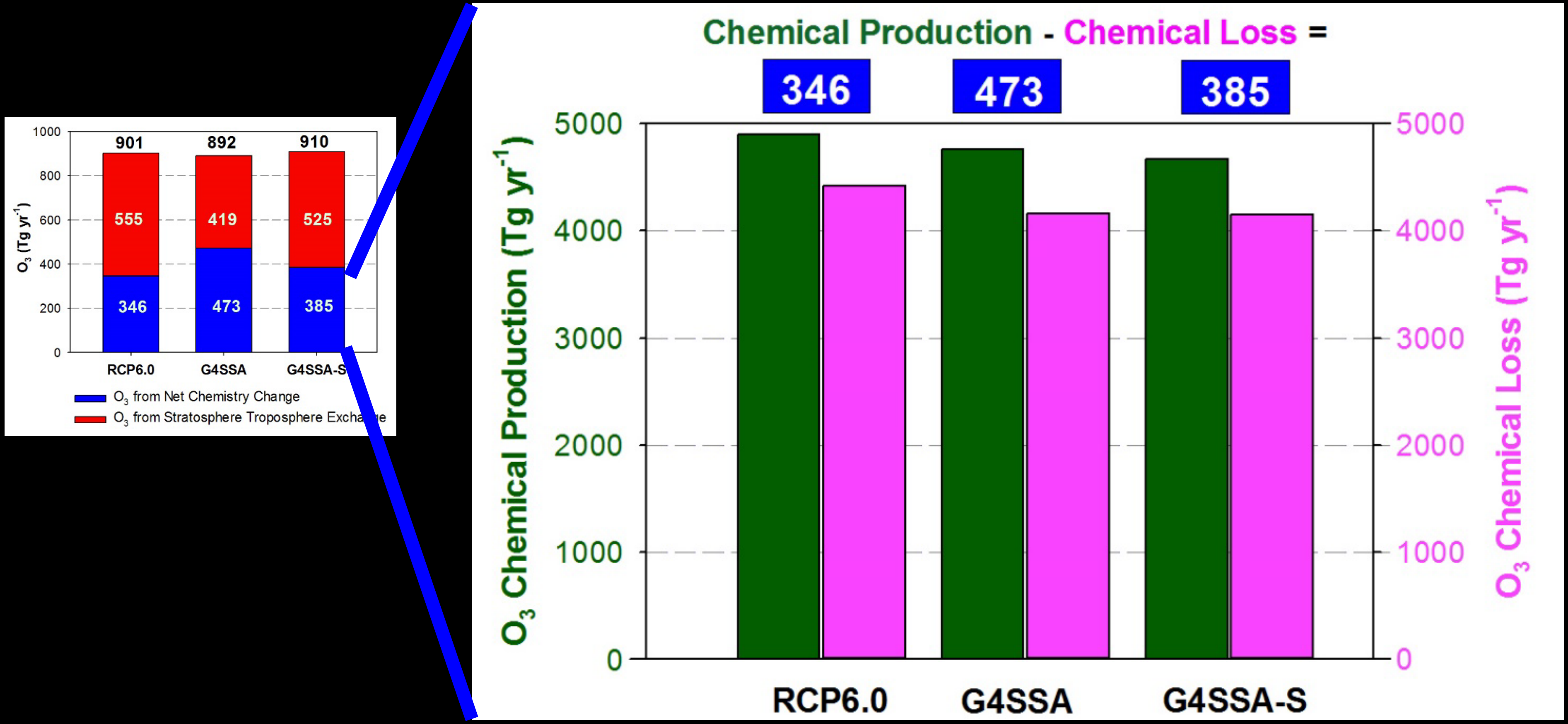
Tropospheric O_3 Flux = O_3 from Net Chemistry Change + O_3 from the STE

Net Chemistry Change = Chemistry Production – Chemistry Loss



- Compared with RCP6.0, tropospheric O_3 decreases in G4SSA and increase in G4SSA-S, which is consistent with the changes on surface ozone;
- Both G4SSA and G4SSA-S show increase of net chemical change and reduction of ozone from the stratosphere related to RCP6.0;
- Changes in G4SSA are stronger than changes in G4SSA-S.

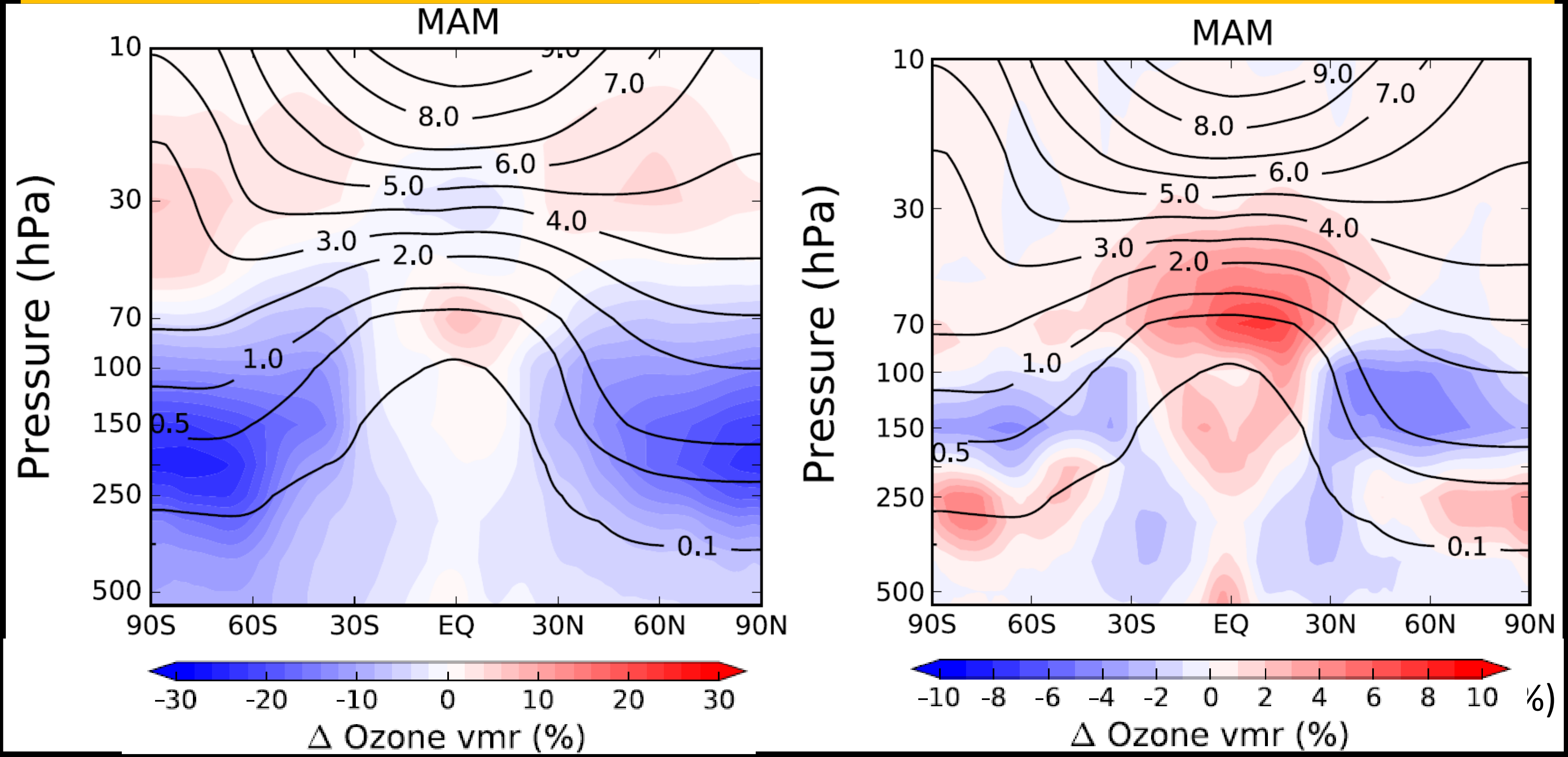
Tropospheric O_3 Net Chemistry Change = O_3 Chemistry Production – O_3 Chemistry Loss



- G4SSA has stronger increase of ozone net chemical change than G4SSA-S;
- Reduction of ozone chemical loss in both G4SSA and G4SSA-S is due to less water vapor in the troposphere;
- Less reduction of ozone chemical production in G4SSA related to G4SSA-S is caused by more Ultra Violet radiation in the troposphere under G4SSA.

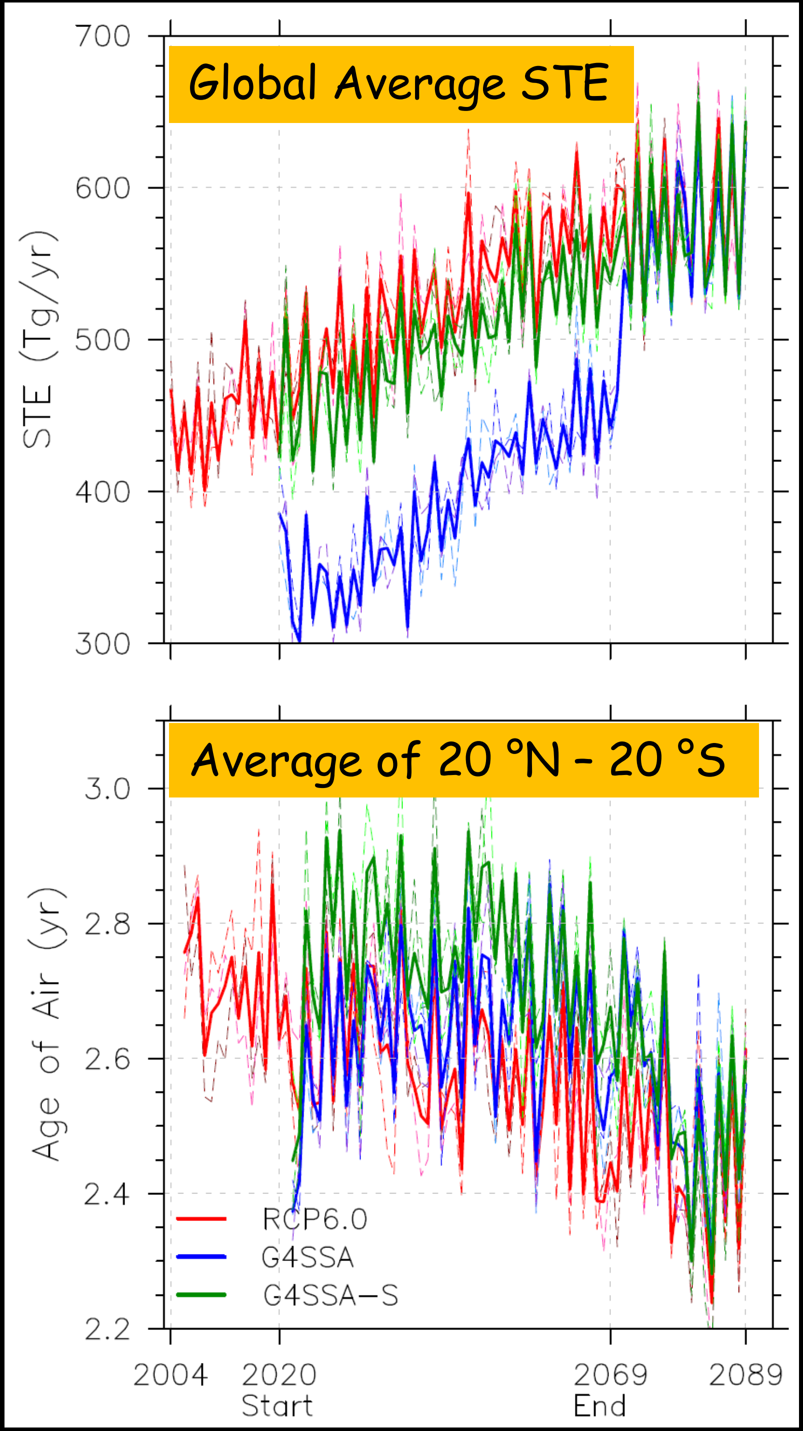
Stratospheric ozone depletion under G4SSA

O_3 (%) G4SSA minus RCP6.0 (MAM) **O_3 (%) G4SSA-S minus RCP6.0 (MAM)**



Zonal mean O_3 concentration change (%) in MAM (average of 2030-2069, average of three ensembles)

Ozone from the Stratosphere Troposphere Exchange (STE)



- Strong reduction of O_3 – STE in G4SSA is mainly due to stratospheric ozone depletion;
- Mild reduction of O_3 – STE in G4SSA-S is due to the slow down of the Brewer-Dobson Circulation, which is supported by the Age of Air.

Age of Air (at 10 mb) calculation is based on a point on a zonal mean map (1°N, 139 mb)

Conclusions:

- Surface ozone concentration is a balance between ozone transported from the stratosphere and net chemical change in the troposphere.

- With stratospheric sulfate injection, stratospheric ozone depletion is the main cause of surface ozone reduction.

- When we decrease insolation, the increase of ozone net chemical change is the major cause of increased surface ozone concentration.