

Evaluations of The Impacts of Stratospheric Geoengineering on Biogeochemistry Feedbacks



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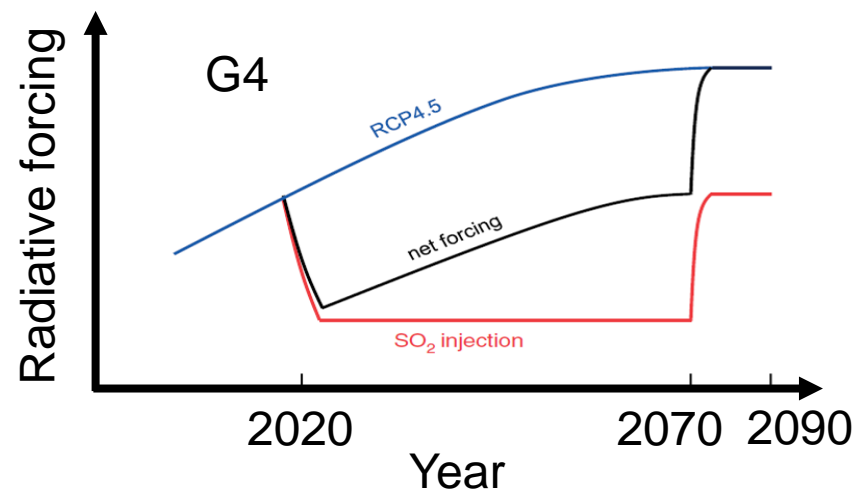
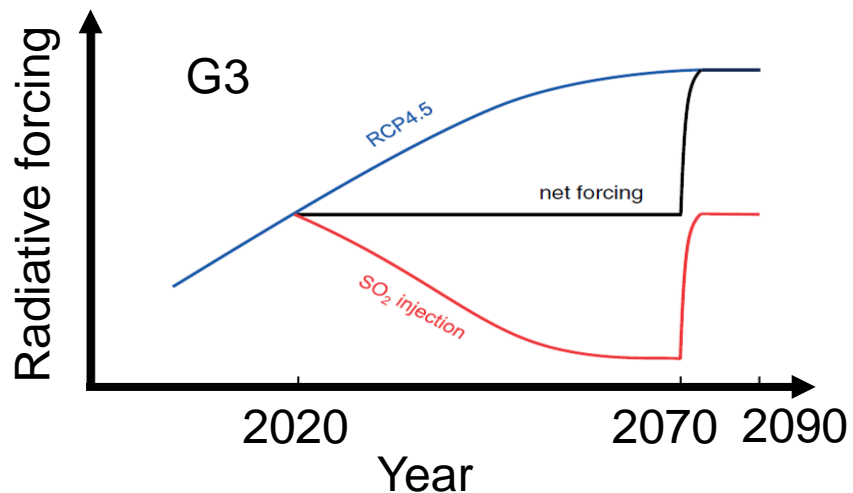
Geoengineering

- ❖ Strategies to mitigate the increasing radiative forcing due to anthropogenic emissions
 - Carbon dioxide removal (CDR)
 - Solar radiation management (SRM)

- ❖ “... artificially enhancing earth's albedo and thereby cooling climate by adding sunlight reflecting aerosol in the stratosphere ... additionally counteract the climate forcing of growing CO₂ emissions.” – *P. J. Crutzen (2006)*

Subset of Geoengineering Model Intercomparison Project (GeoMIP)

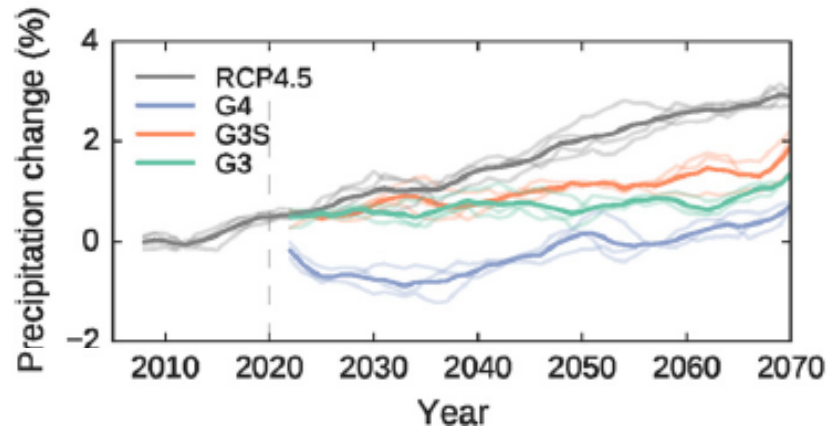
Experiment	Scenario	Synopsis
Baseline	RCP4.5	Future projection forced by RCP4.5
Stratospheric aerosol injections	G3	Keep TOA radiative flux at 2020 levels against RCP4.5 by injecting sulfate aerosols
	G4	Injection of 5 Tg SO ₂ /yr into lower stratosphere during 2020–2069



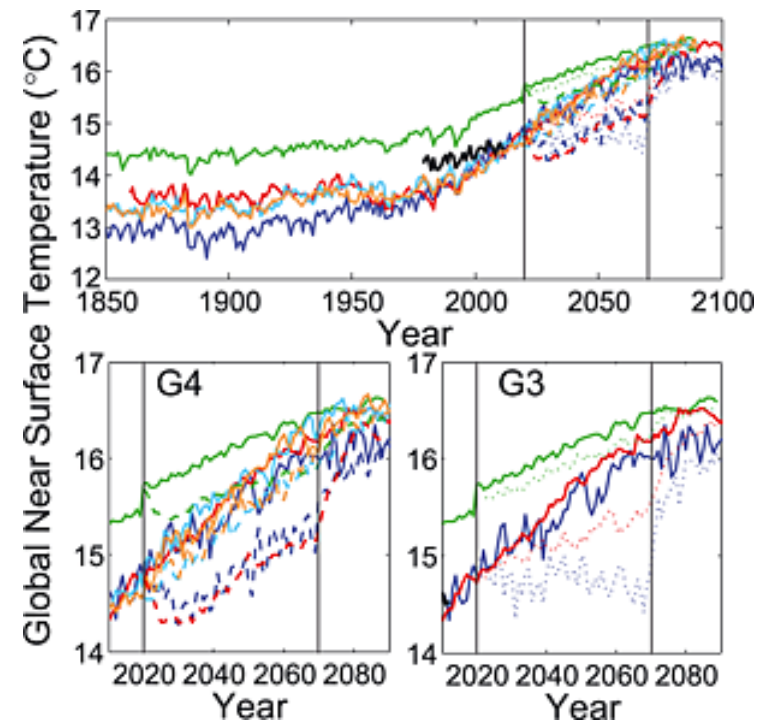
(Kravitz *et al.*, 2011)

Geoengineering Impacts

- ❖ Focused mostly on atmosphere, ocean, and cryosphere
- ❖ Suppressed precipitation due to aerosol indirect effects
- ❖ Reduced rising surface temperature caused by increasing radiative forcing
- ❖ Ocean acidification



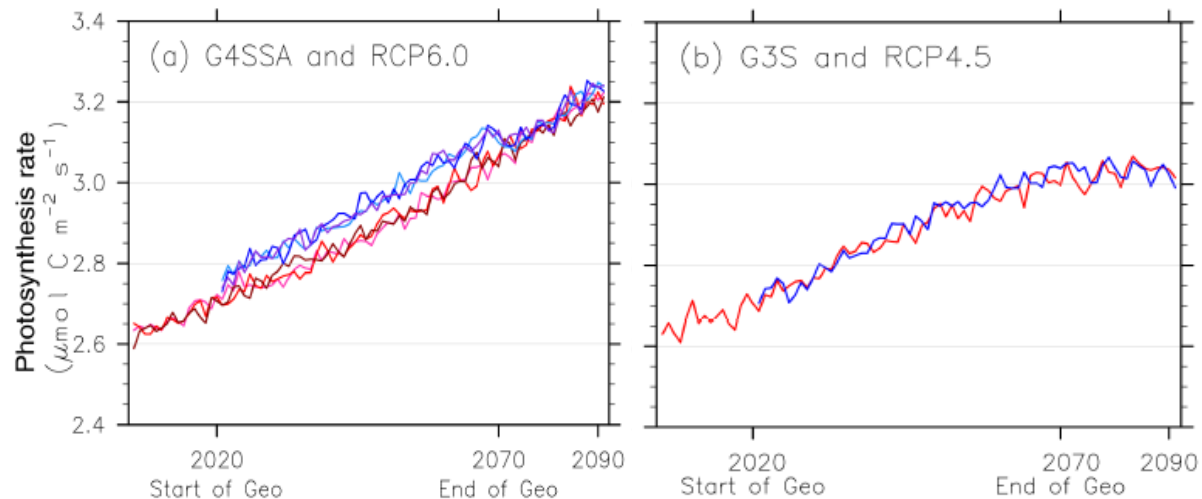
(Ferraro and Griffiths, 2016)



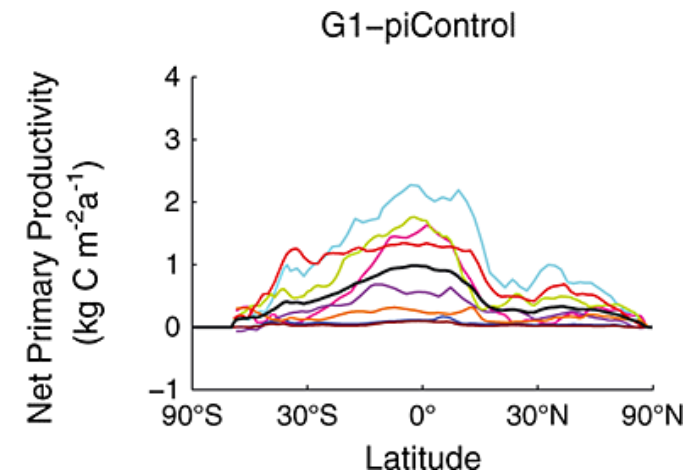
(Berdahl et al., 2014)

Geoengineering Impacts

- ❖ Higher photosynthesis rate as a result of increased diffuse radiation in G4SSA (8Tg/yr aerosols + RCP6.0) scenario
- ❖ Larger net primary productivity (NPP) in G1 (quadrupled CO₂) scenario due to combined effect of CO₂ fertilization and less plant heat stress



(Xia et al., 2016)



(Kravitz et al., 2013)

Science Questions

- ❖ Aerosol ↑, surface temperature ↓, cloudiness ↑, precipitation ↓
- ❖ Responses of the terrestrial ecosystem to geoengineering
 - Does land remain a carbon sink?
 - Does every region undergo the same biogeochemistry (BGC) feedbacks?

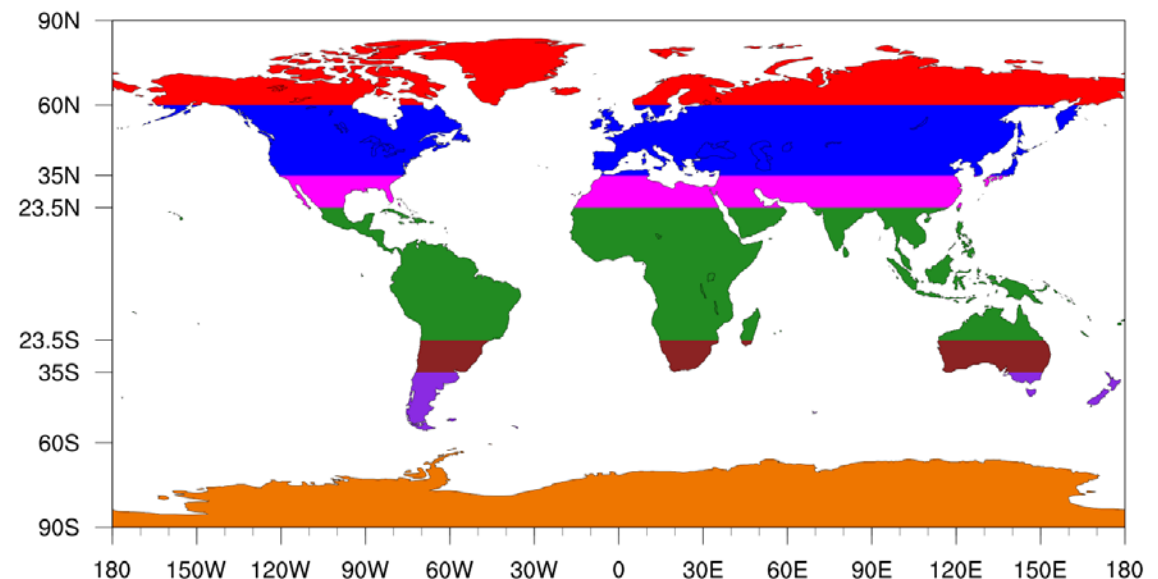
Analytical Methods

- ❖ Monthly model outputs during 2020–2089
 - CMIP5 – RCP4.5: HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM
 - GeoMIP G3: HadGEM2-ES, IPSL-CM5A-LR
 - GeoMIP G4: HadGEM2-ES, MIROC-ESM, GEOSCCM

❖ Regions

Global (GLB)

- NH polar (NHP)
- NH midlatitude (NHM)
- NH subtropics (NHS)
- Tropics (TRP)
- SH subtropics (SHS)
- SH midlatitude (SHM)
- SH polar (SHP)



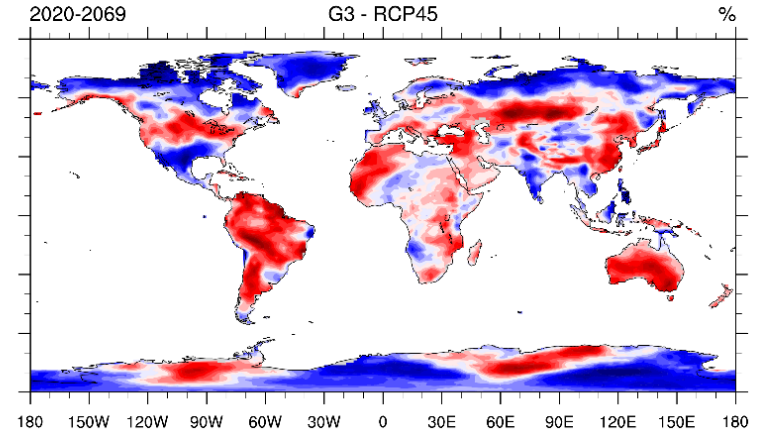
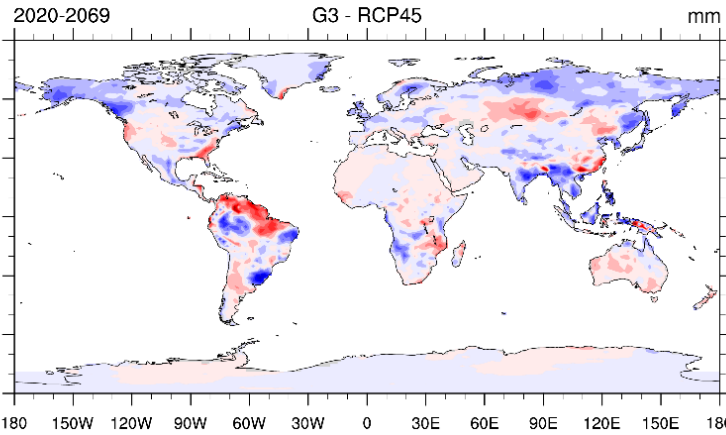
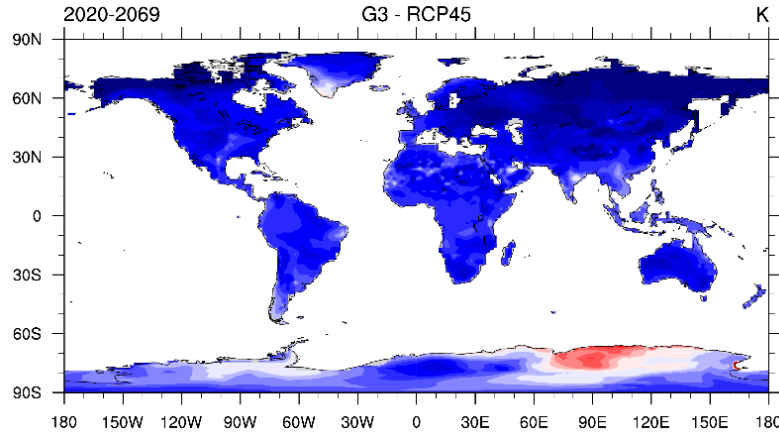
50-year Mean Annual Changes over Land

Surface Temperature

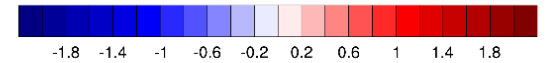
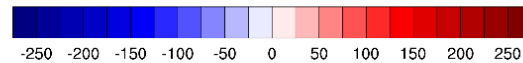
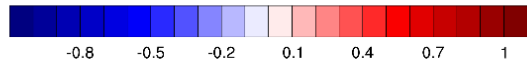
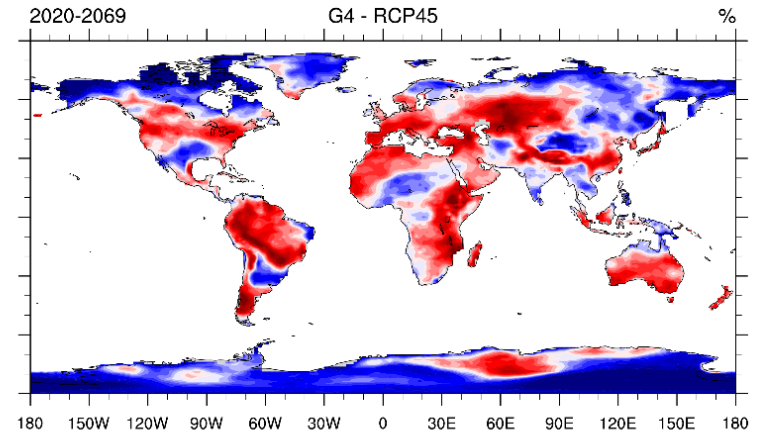
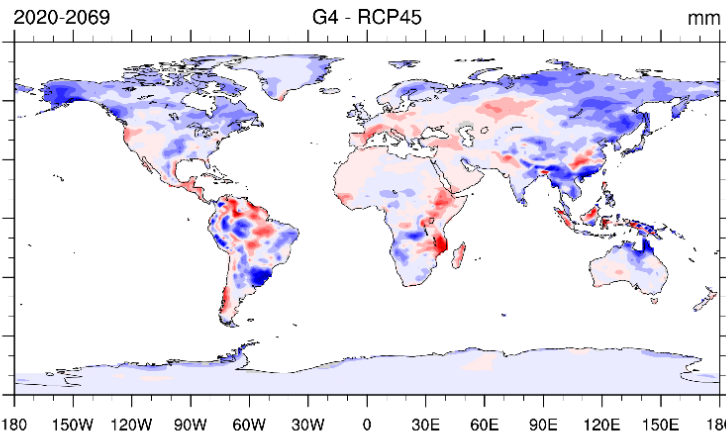
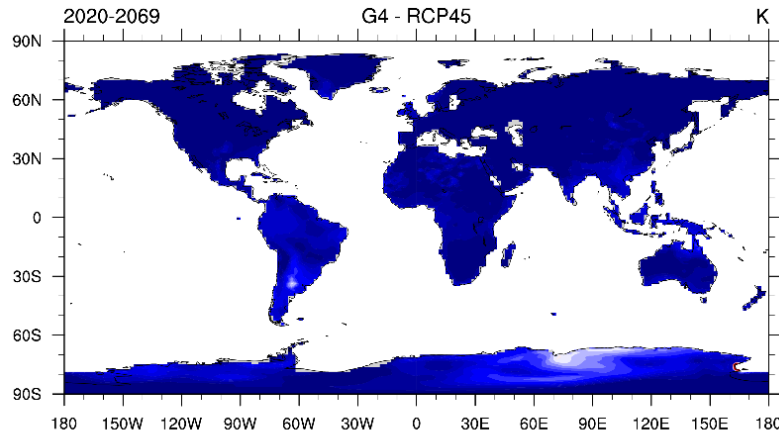
Precipitation

Cloudiness

G3 - RCP45



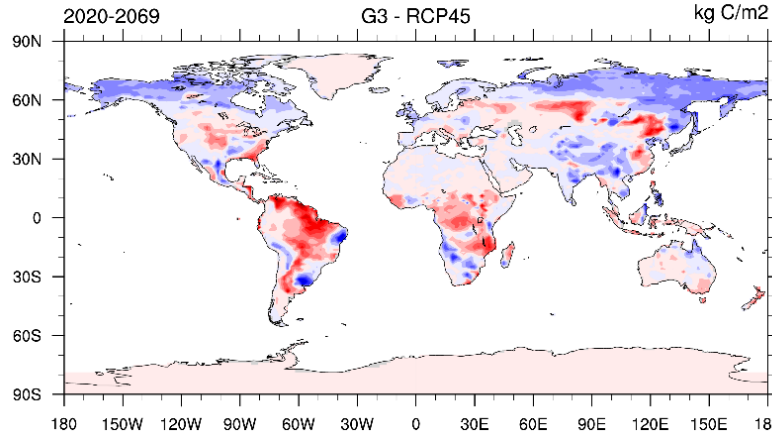
G4 - RCP45



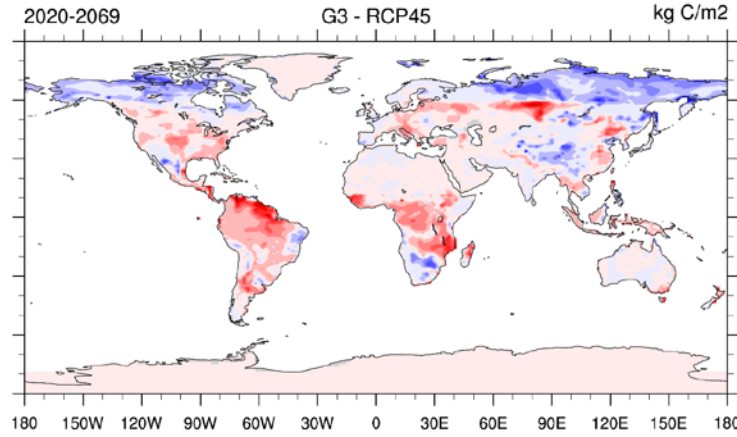
50-year Mean Annual Changes over Land

G3 - RCP45

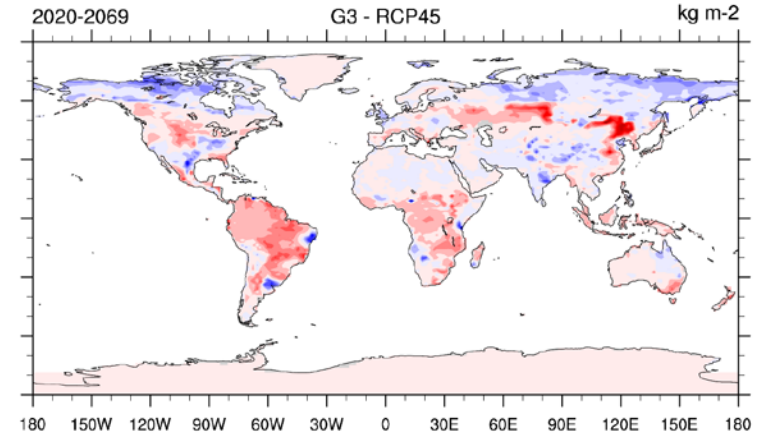
Net Primary Production (NPP)



Net Biosphere Production (NBP)

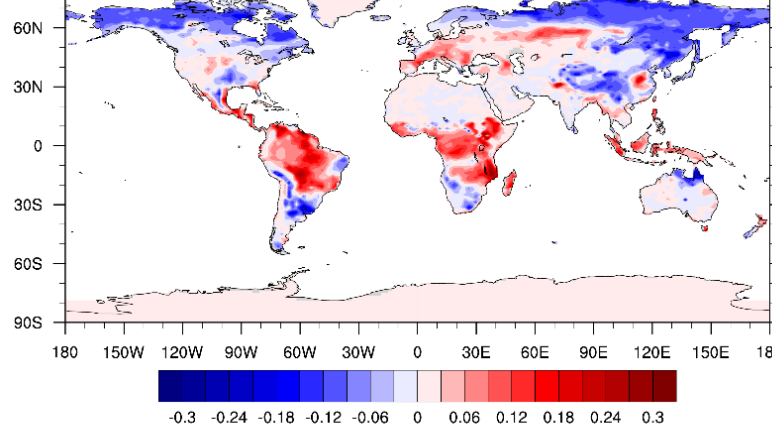


Carbon in Soil

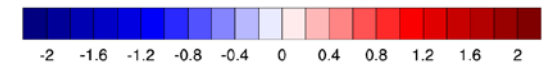
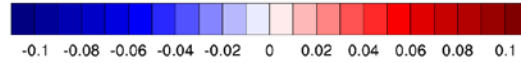
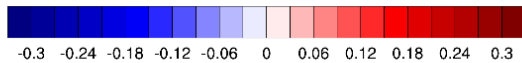
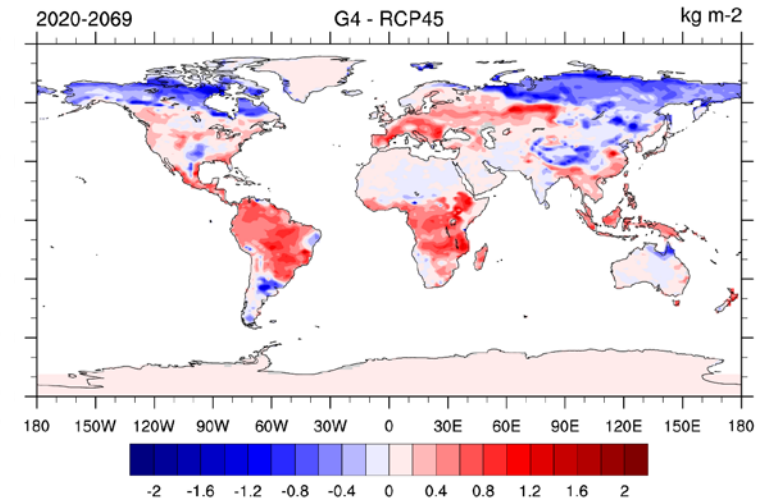
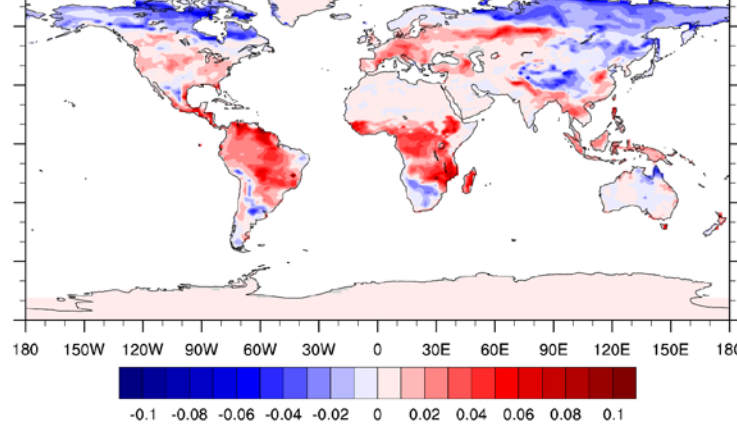


G4 - RCP45

Net Primary Production (NPP)



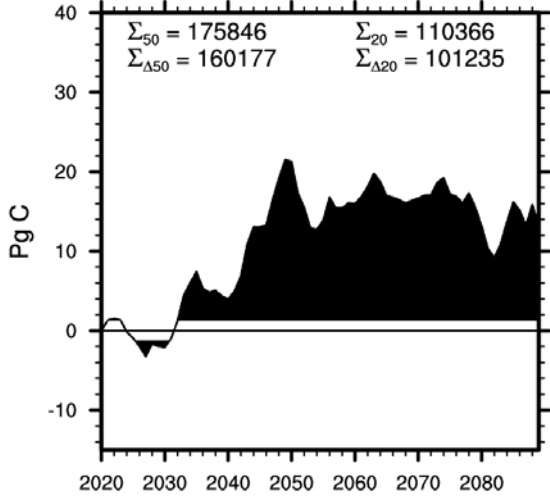
Net Biosphere Production (NBP)



GLB Terrestrial Ecosystem Responses

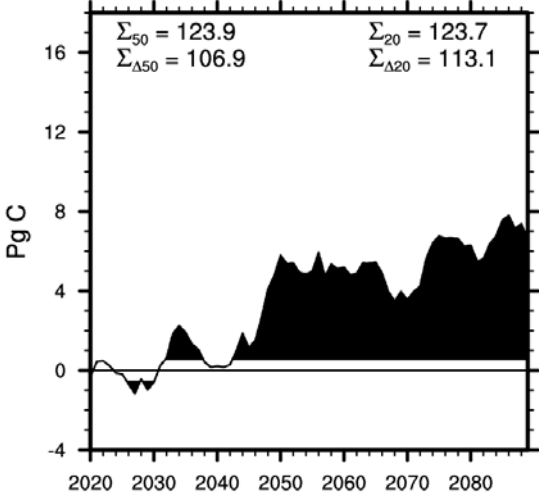
G3 – RCP45

Carbon in Soil



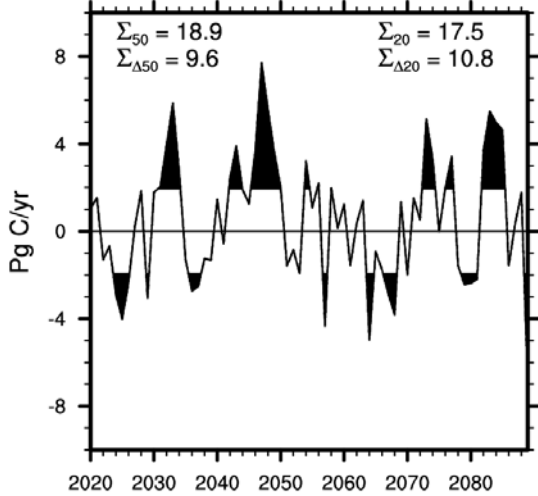
Time
GLB

Carbon in Vegetation



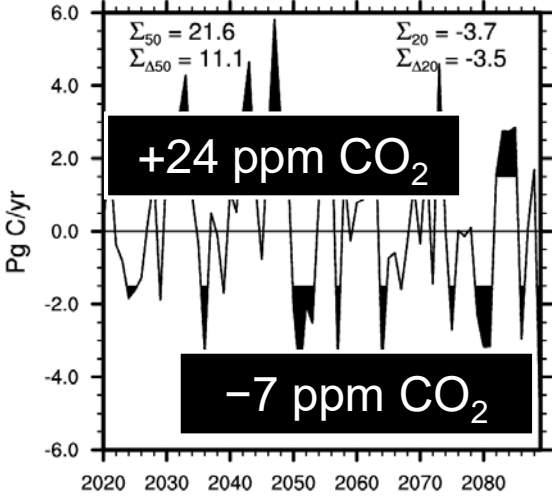
Time
GLB

NPP



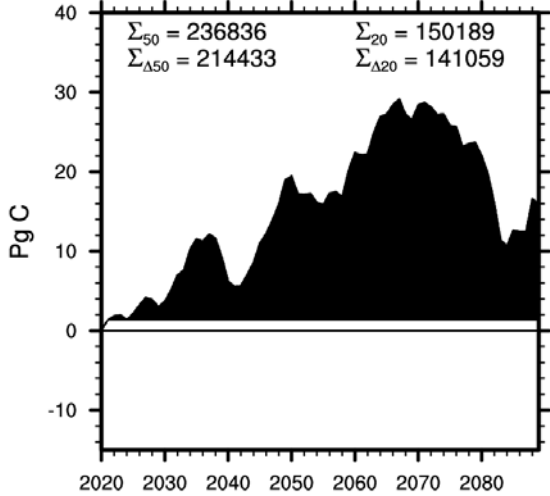
Time
GLB

NBP

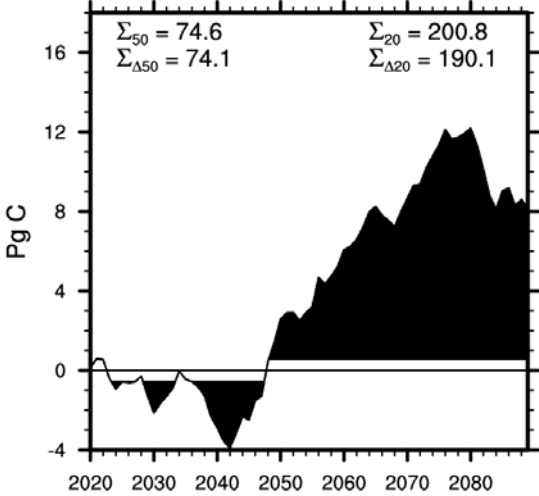


Time
GLB

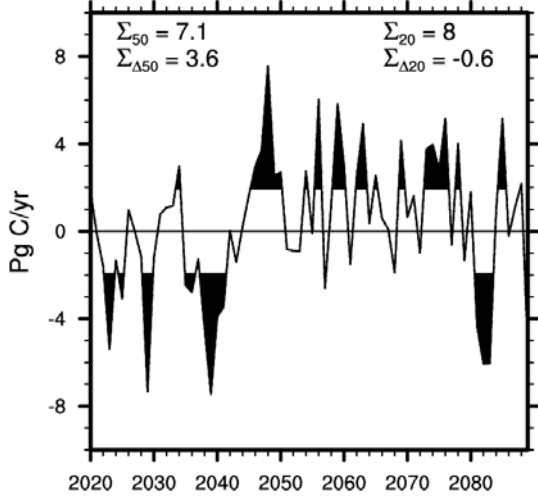
G4 – RCP45



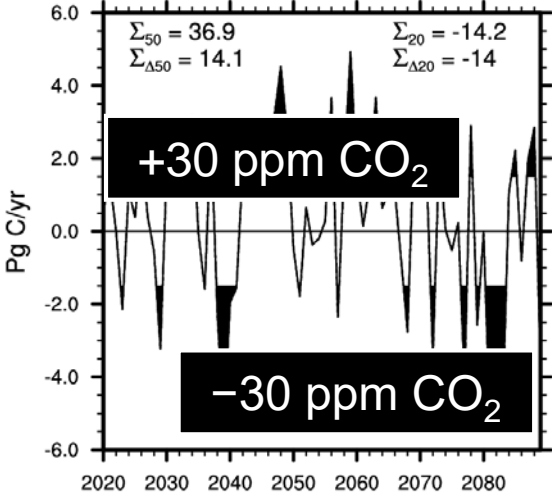
Time



Time



Time

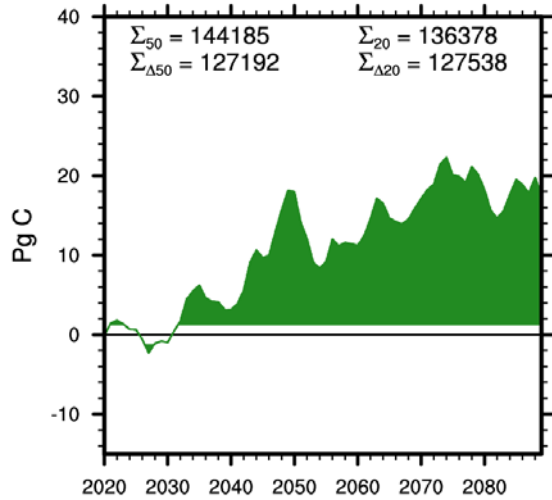


Time

TRP Terrestrial Ecosystem Responses

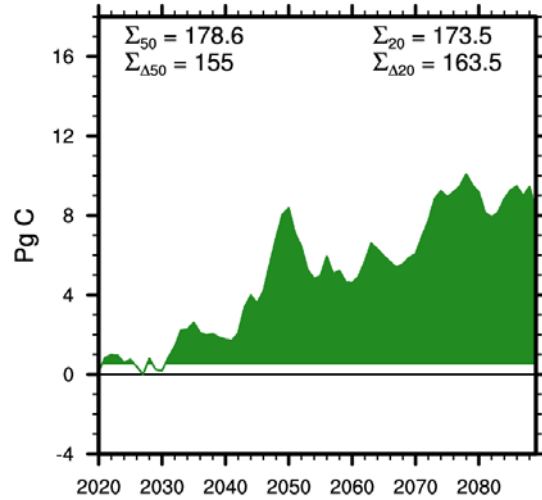
G3 – RCP45

Carbon in Soil



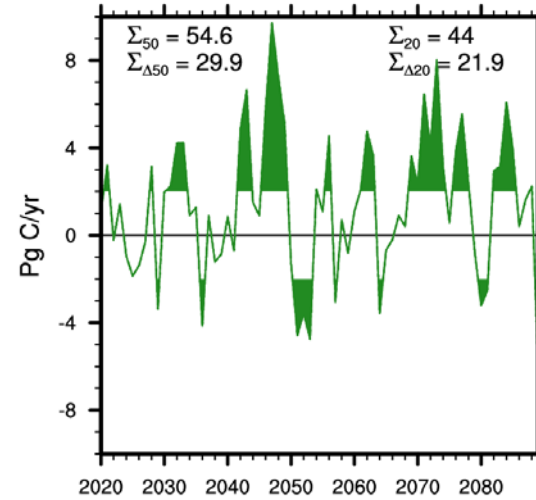
Time
TRP

Carbon in Vegetation



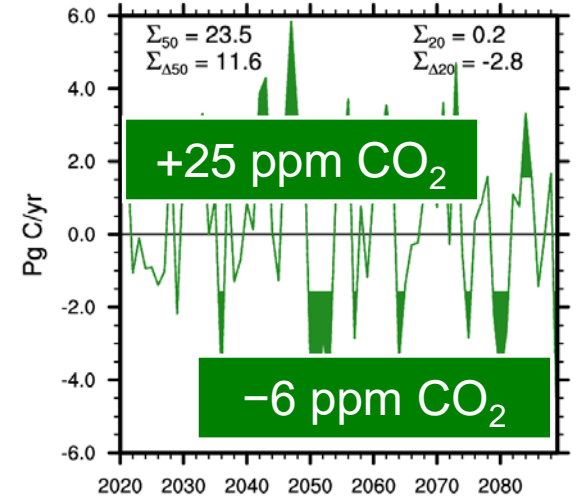
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TRP

NPP



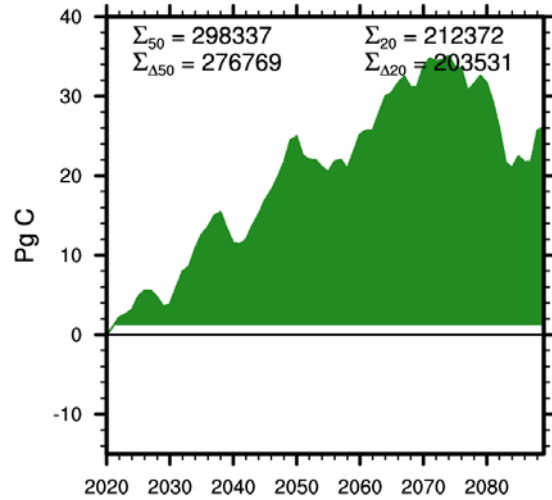
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TRP

NBP

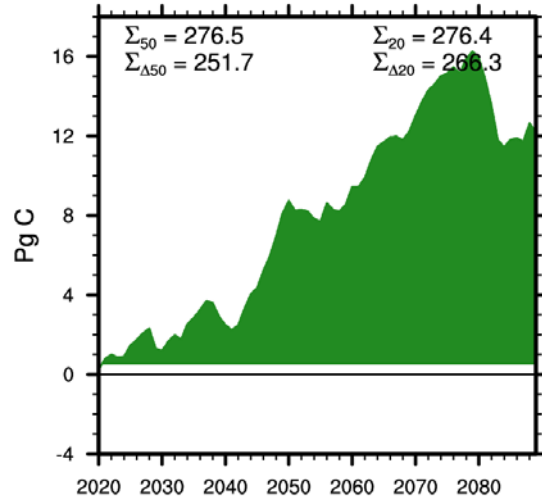


Time
TRP

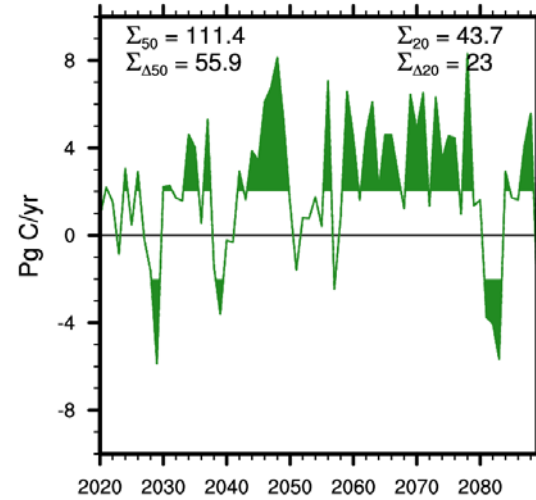
G4 – RCP45



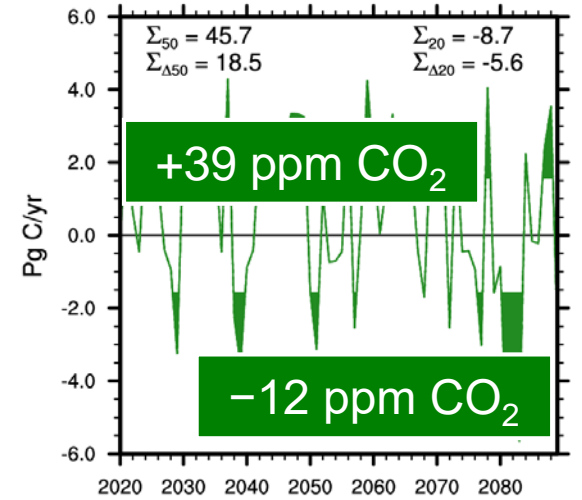
Time



Time



Time

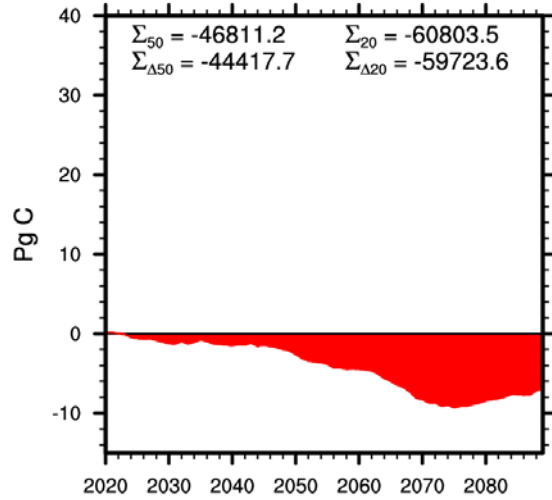


Time

NHP Terrestrial Ecosystem Responses

G3 – RCP45

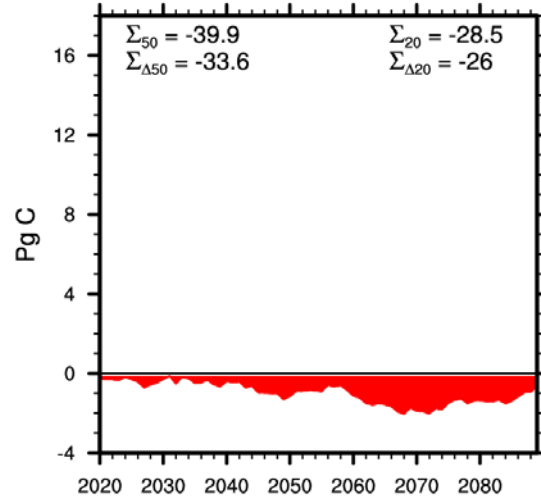
Carbon in Soil



Time

NHP

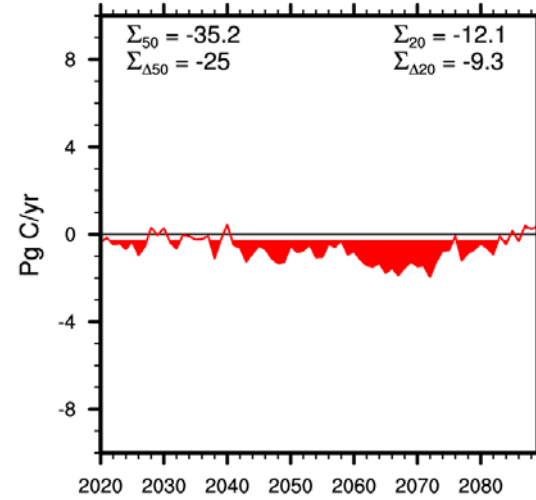
Carbon in Vegetation



Time

NHP

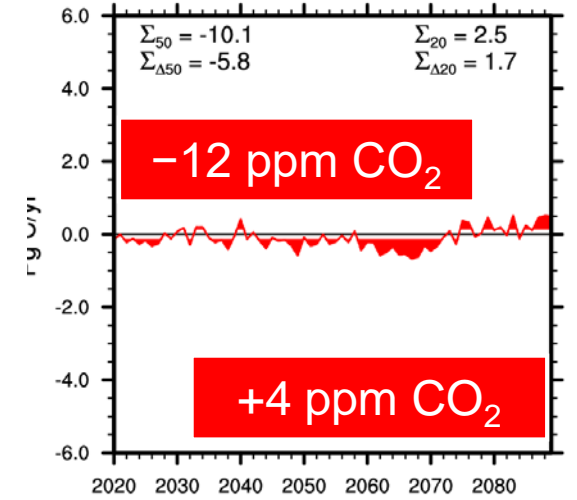
NPP



Time

NHP

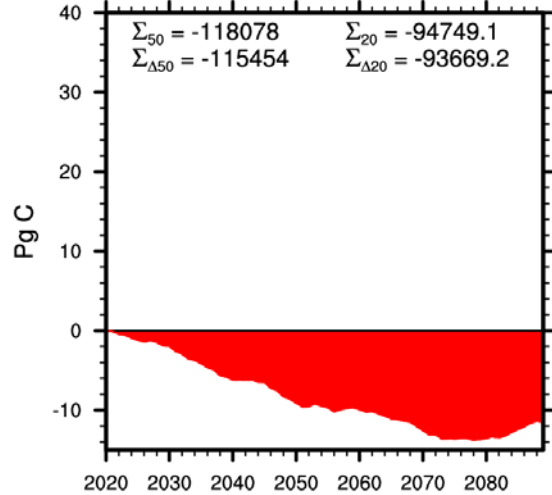
NBP



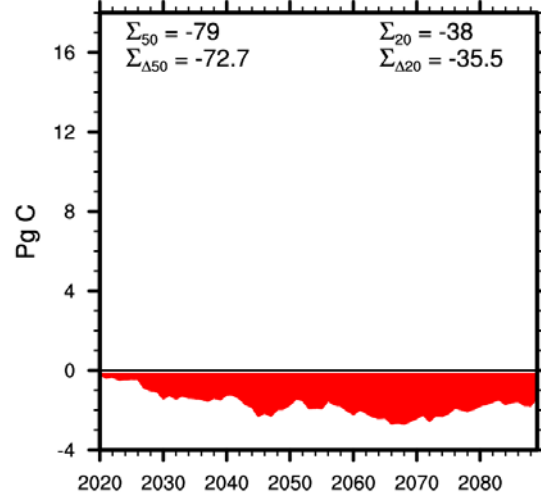
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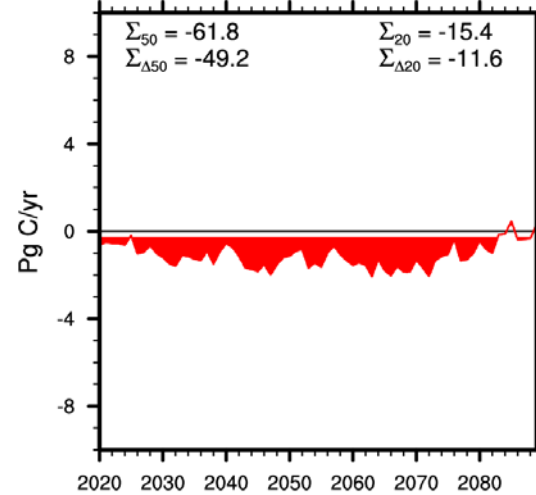
G4 – RCP45



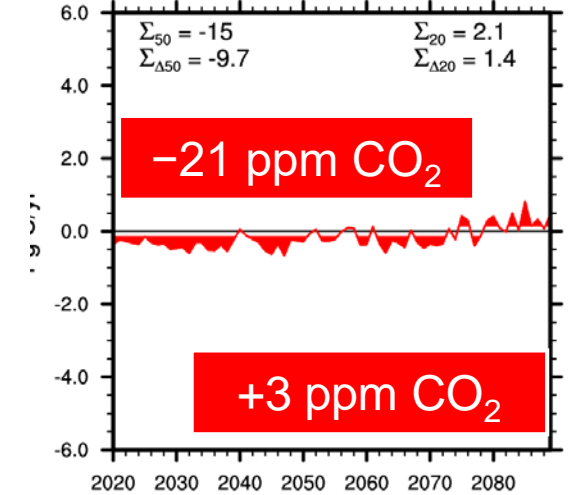
Time



Time



Time



Time

Summary

- ❖ Responses of the terrestrial ecosystem to geoengineering
 - Terrestrial ecosystem **remains a carbon sink** and is able to **store more carbon** in geoengineering G3/G4 scenarios
 - Increased NPP and NBP in **TRP** mainly due to **CO₂ fertilization** and **diffuse radiation** effects
 - Decreased NPP and NBP in **NHP** as a result of **reduced temperature increase**
- ❖ Terrestrial biosphere sequesters +24 (G3) and +30 (G4) ppm CO₂
 - Less aerosol amount required to inject to reach the geoengineering goal
- ❖ Fast BGC feedbacks to bring the earth system back to RCP4.5 condition if geoengineering is stopped

The Next Step...

- ❖ Fully-coupled ESM simulations with terrestrial BGC feedbacks in G4 scenario
- ❖ Extended simulation periods beyond Year 2089

Acknowledgements

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- ❖ University of Tennessee at Knoxville

Thank You