Climate Intervention / Geoengineering Research using CESM(WACCM)

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CESM Tutorial, 2021

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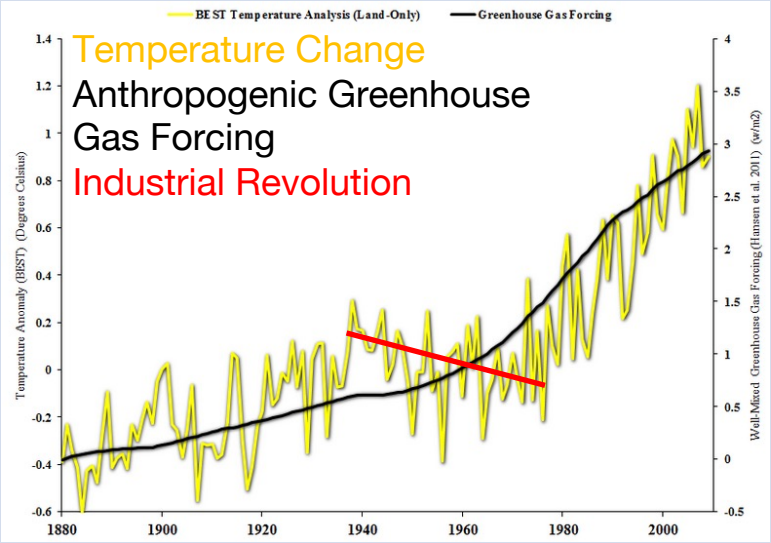
Climate Emergency due to Anthropogenic Impacts



(Un)-intended Climate Intervention:

Increase in greenhouse gas emissions

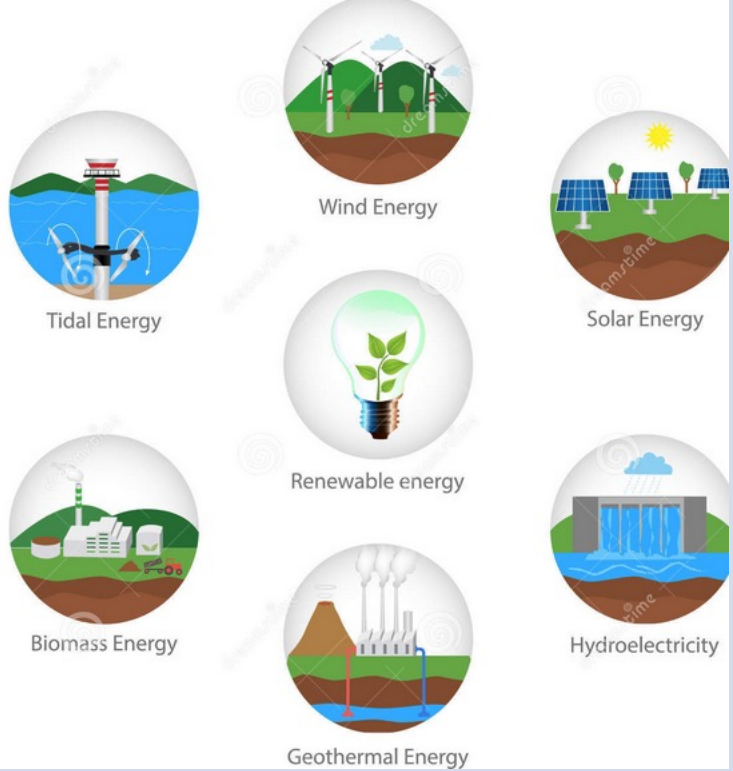
Industrialization: pollution / particles in the atmosphere -> more reflection of sun light

-> Relatively small changes in temperature change the balance of Earth to sustain our way of life.

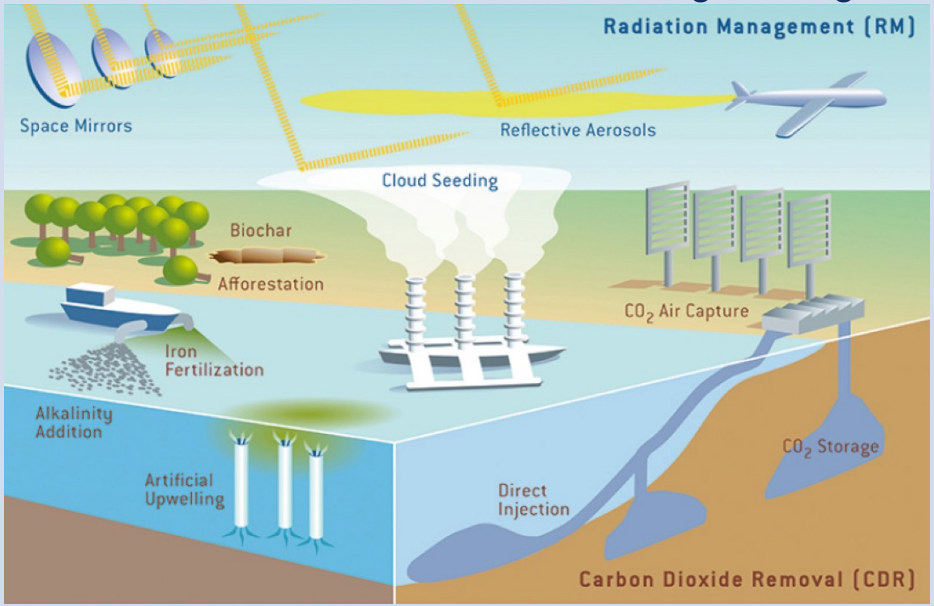
- Unprecedented weather events
- Shifts in rainfall pattern
- Heat waves
- Mass extinctions (plants and animal)

Climate Solutions to Sustain Global Temperatures on Earth

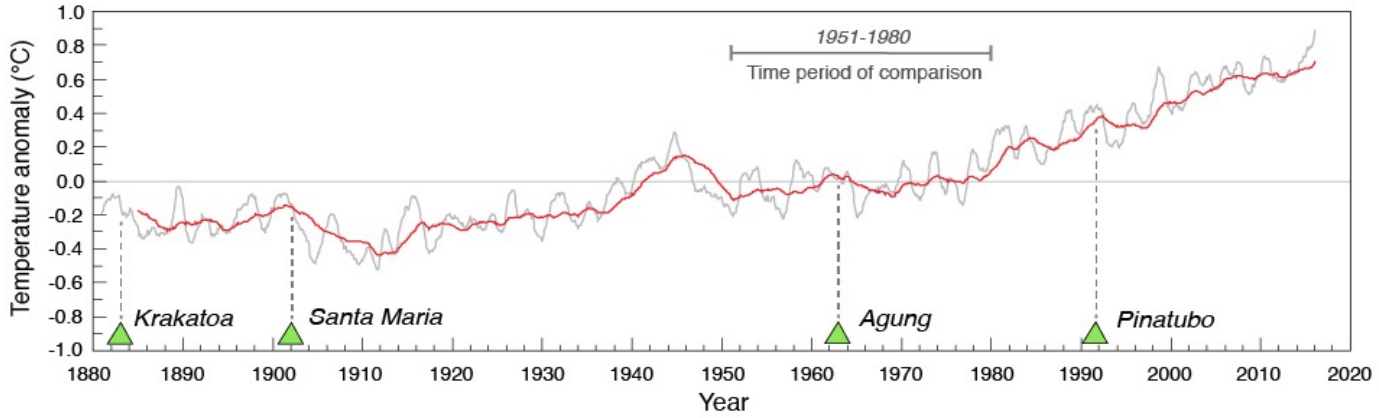
Renewable Energy Production



Climate Interventions / Geoengineering



Solar Radiation Management. Natural Analogues: Volcanoes



Natural analogue of stratospheric aerosols geoengineering but different …

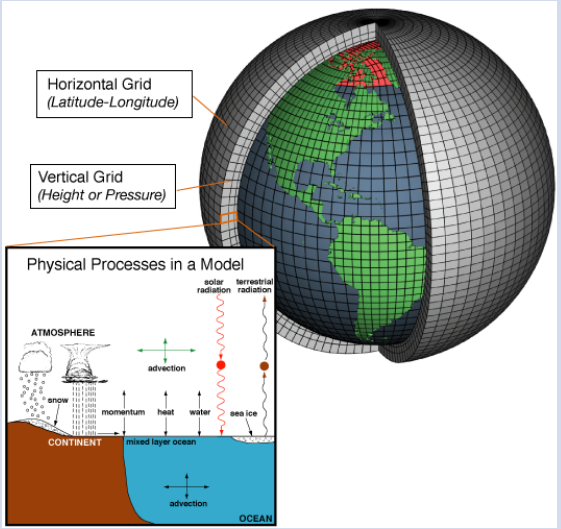
Model Requirements for Stratospheric Aerosol Interventions

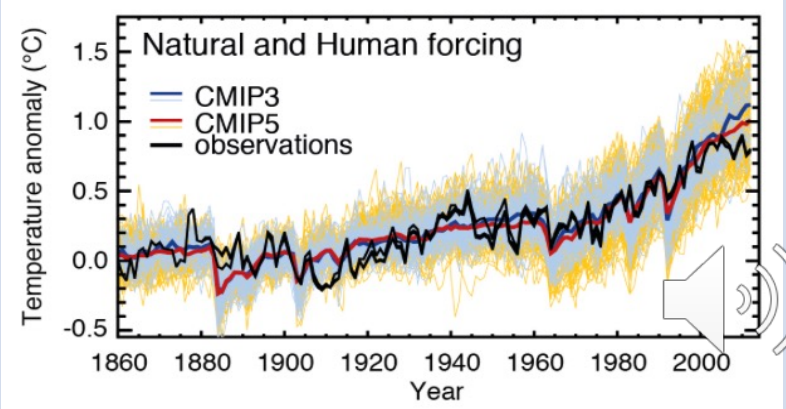
Fully coupled Earth System Model
- Atmosphere, Land, Ocean, Cryosphere

Driven by natural and anthropogenic forcings
- Greenhouse gases
- Emissions of aerosols and gases
- Land-use changes

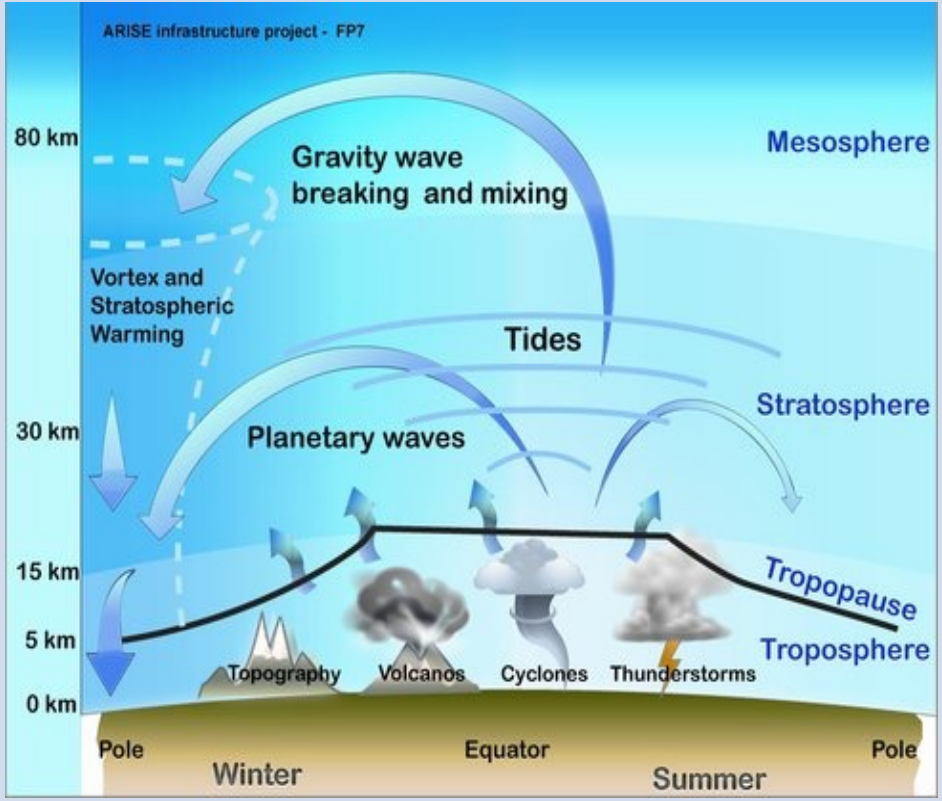
Reproduce present day climate fairly well
- Historical temperature evolution
- Cooling effects of large volcanoes

Well resolved tropospheric and stratospheric processes
- Coupling between aerosol microphysics, chemistry, radiation, dynamics





CESM Whole Atmosphere Community Climate Model (WACCM)

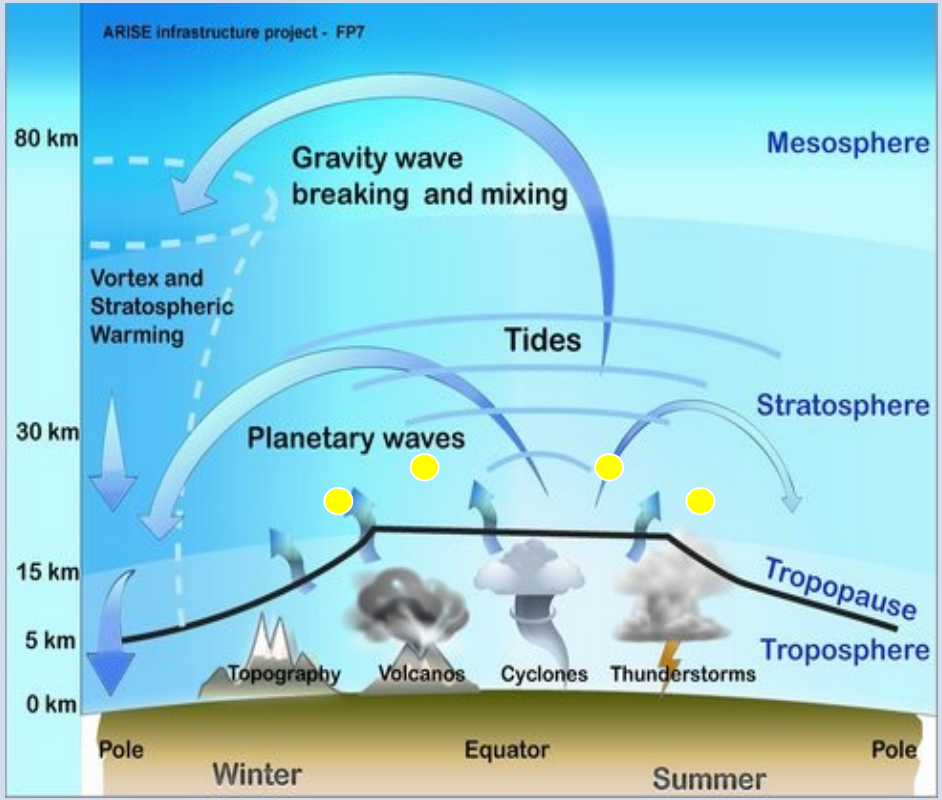


Model Setup

- 0.9x1.25º horizontal resolution
- 140 km lid
- 70 vertical layers
- Interactive Quasi-Biennial Oscillation (QBO)
- Modal aerosol model
- Prognostic volcanoes and aerosol microphysics
- Full stratospheric chemistry
- Coupling to ocean, ice, land

Mills et al., 2016

Stratospheric Aerosol Intervention Simulations using WACCM



Sulfur Injections

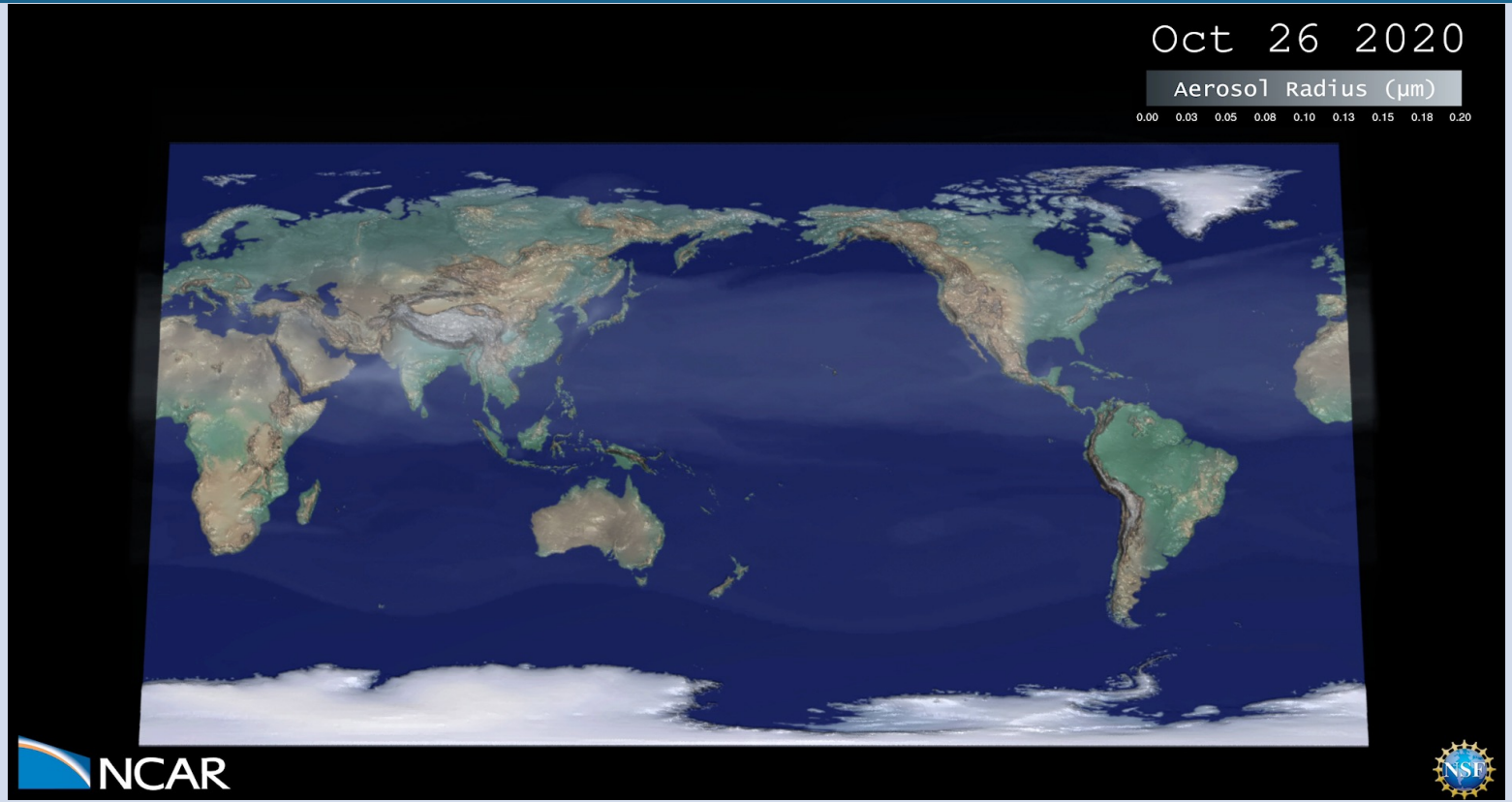
4 different latitudes in the stratosphere:
15N, 15S, 30N, 30S

Feedback-Control Algorithm to reach climate objectives

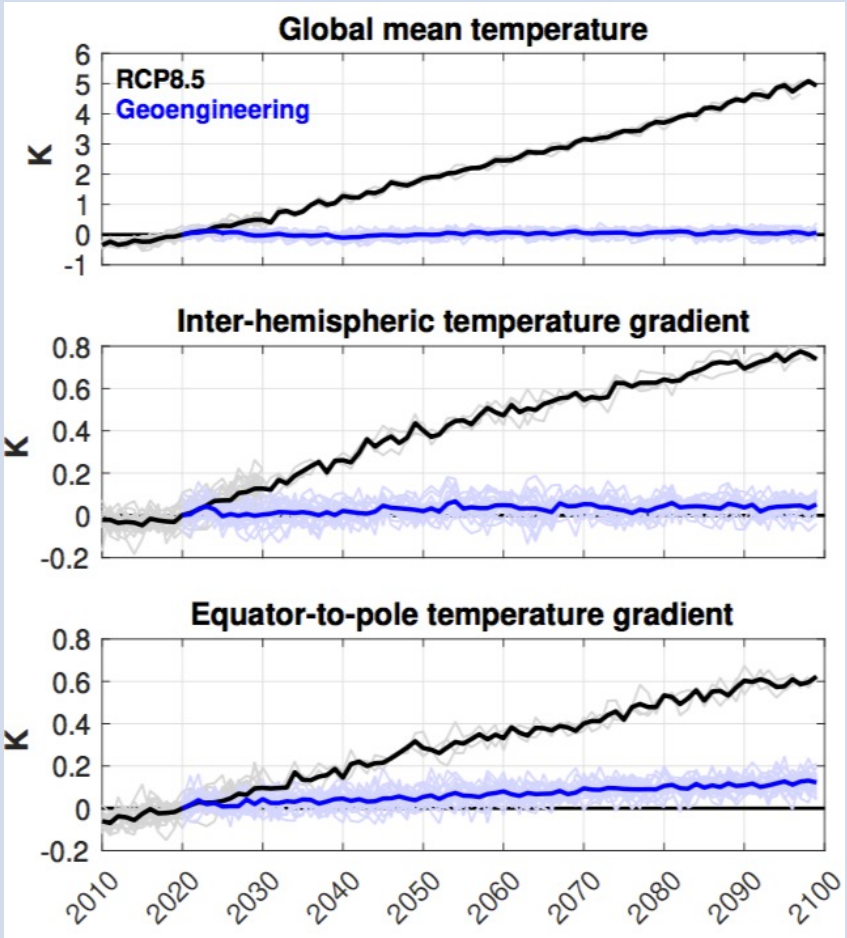
- $\mathbf{T_0}$ = Global mean temperature
- $\mathbf{T_1}$ = Inter-hemispheric temperature gradient
- $\mathbf{T_2}$ = Equator-to-pole temperature gradient

Mills et al., 2017, Tilmes et al., 2017, MacMartin et al, 2017, Richter et al, 2017, Kravitz et al., 2017

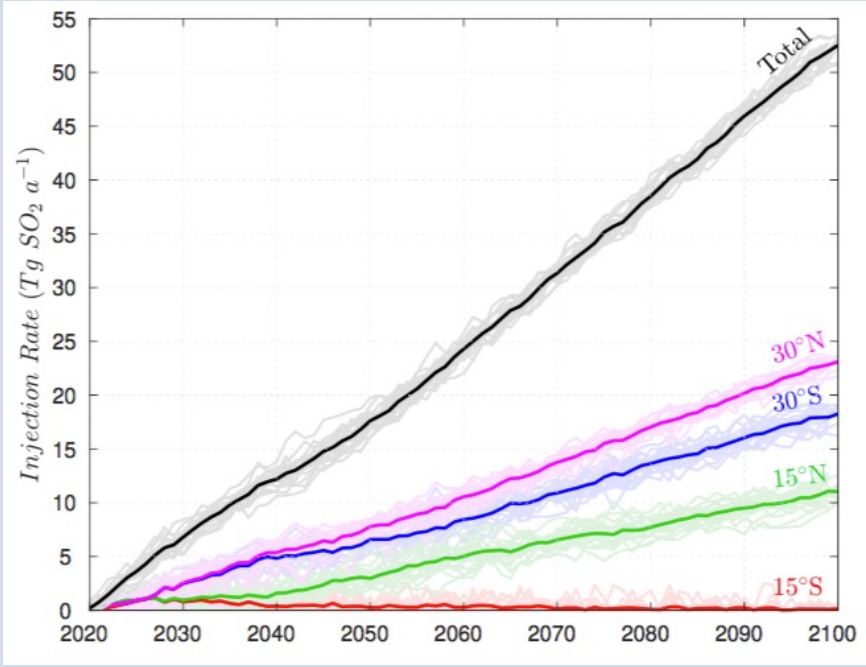
Sulfate aerosols before and during the injection starting Jan 2022



Geoengineering Large Ensemble (GLENS) Project using WACCM



Injection Rate Tg SO_2 per year



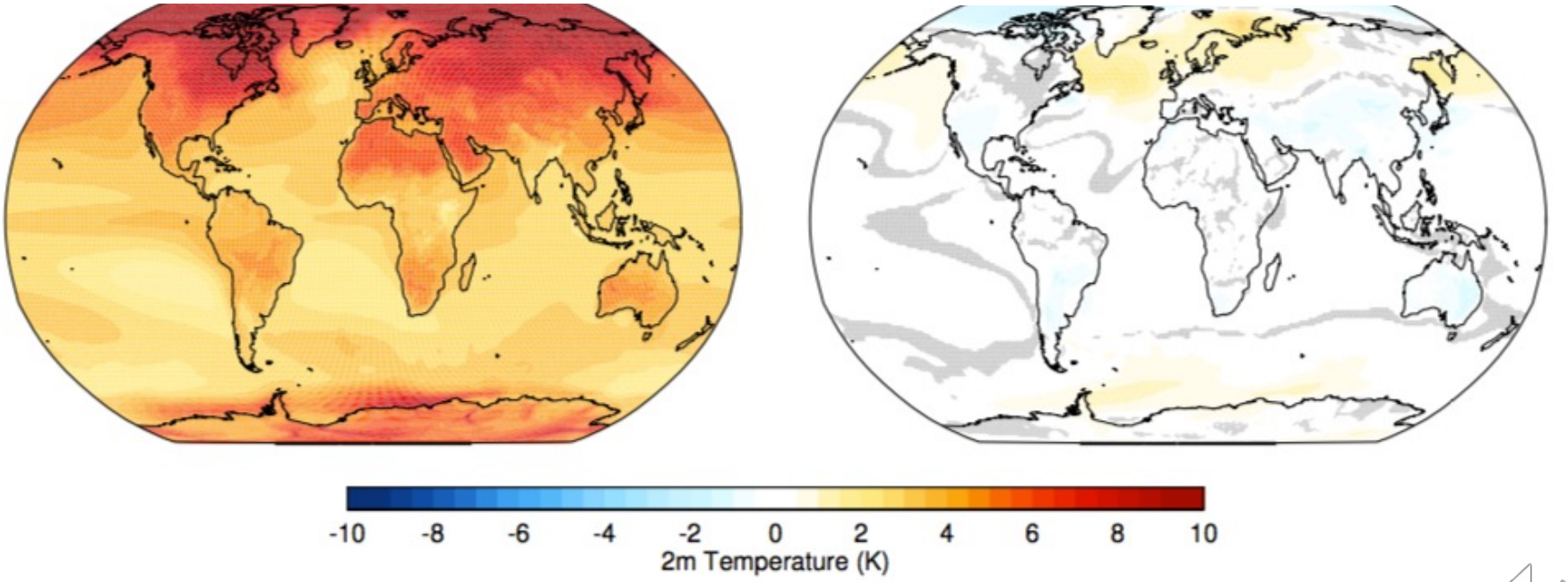
Tilmes et al. 2018 (BAMS)

Geoengineering Large Ensemble (GLENS) Project using WACCM

Surface Air Temperature in 2075-2095 (2020 ref.)

RCP8.5 (2075-2095 minus 2010-2030)

SAI (2075-2095) minus RCP8.5 (2010-2030)



Understand Impacts; Signal to Noise; Processes

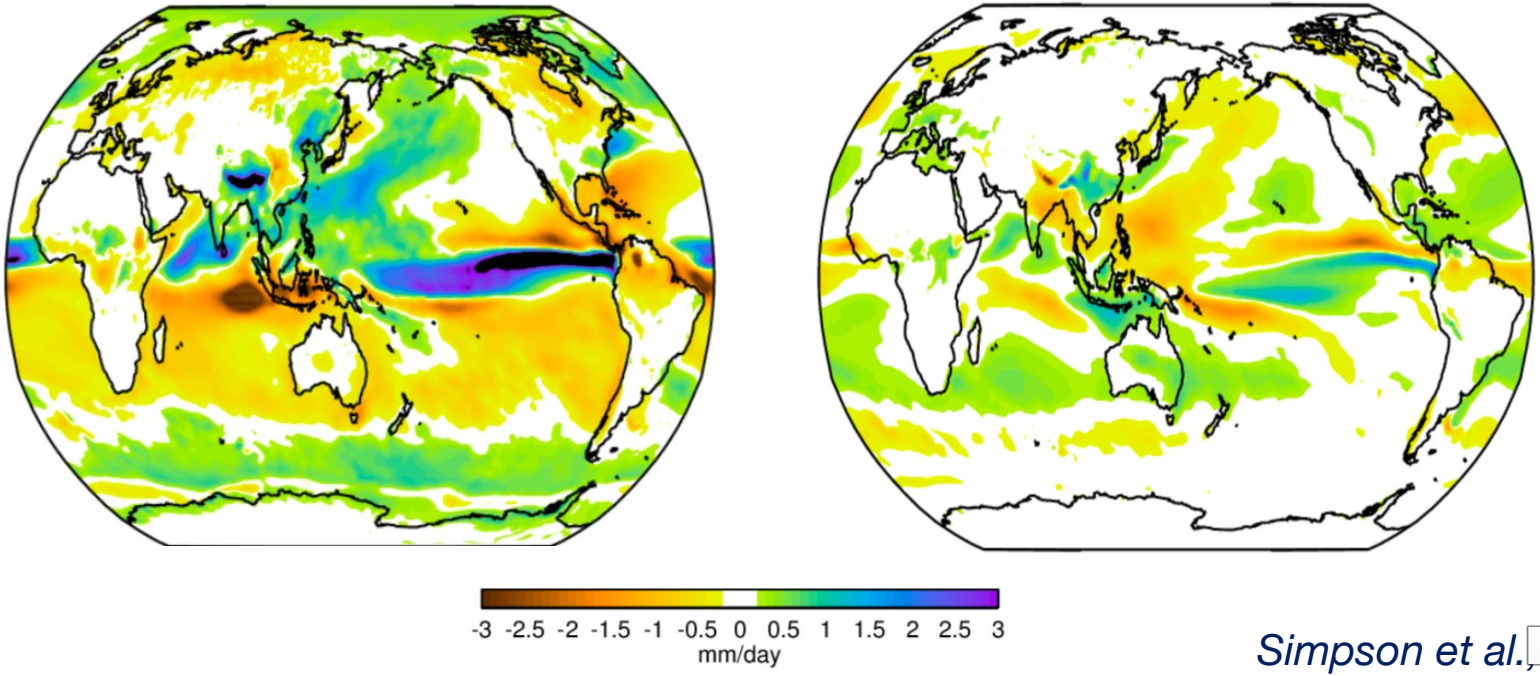
Tilmes et al., BAMS 2018

GLENS: Identifying Regional Climate Change

Precipitation in 2075-2095 (2020 ref.)

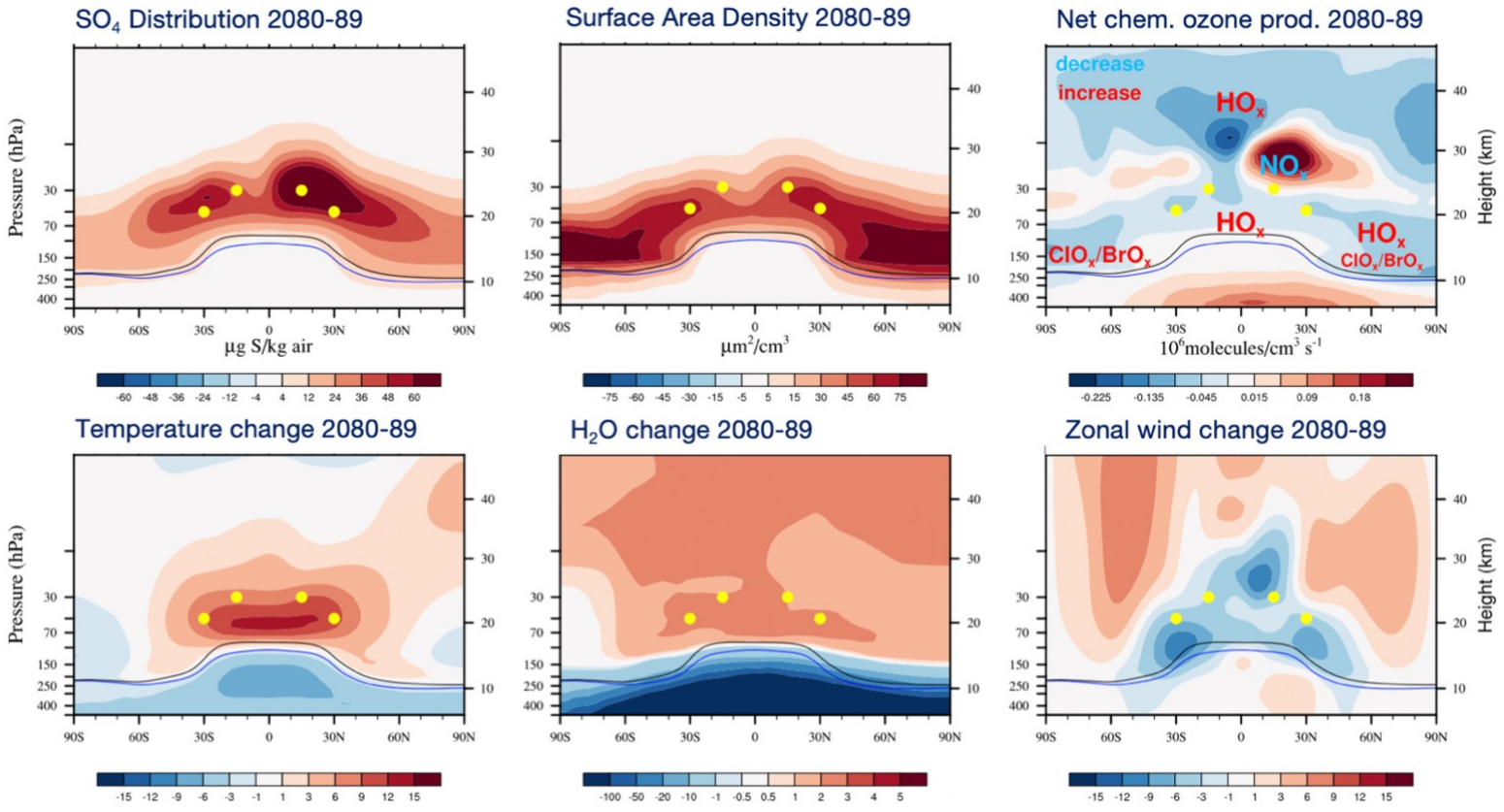
RCP8.5 (2075-2095 minus 2010-2030)

SAI (2075-2095) minus RCP8.5 (2010-2030)



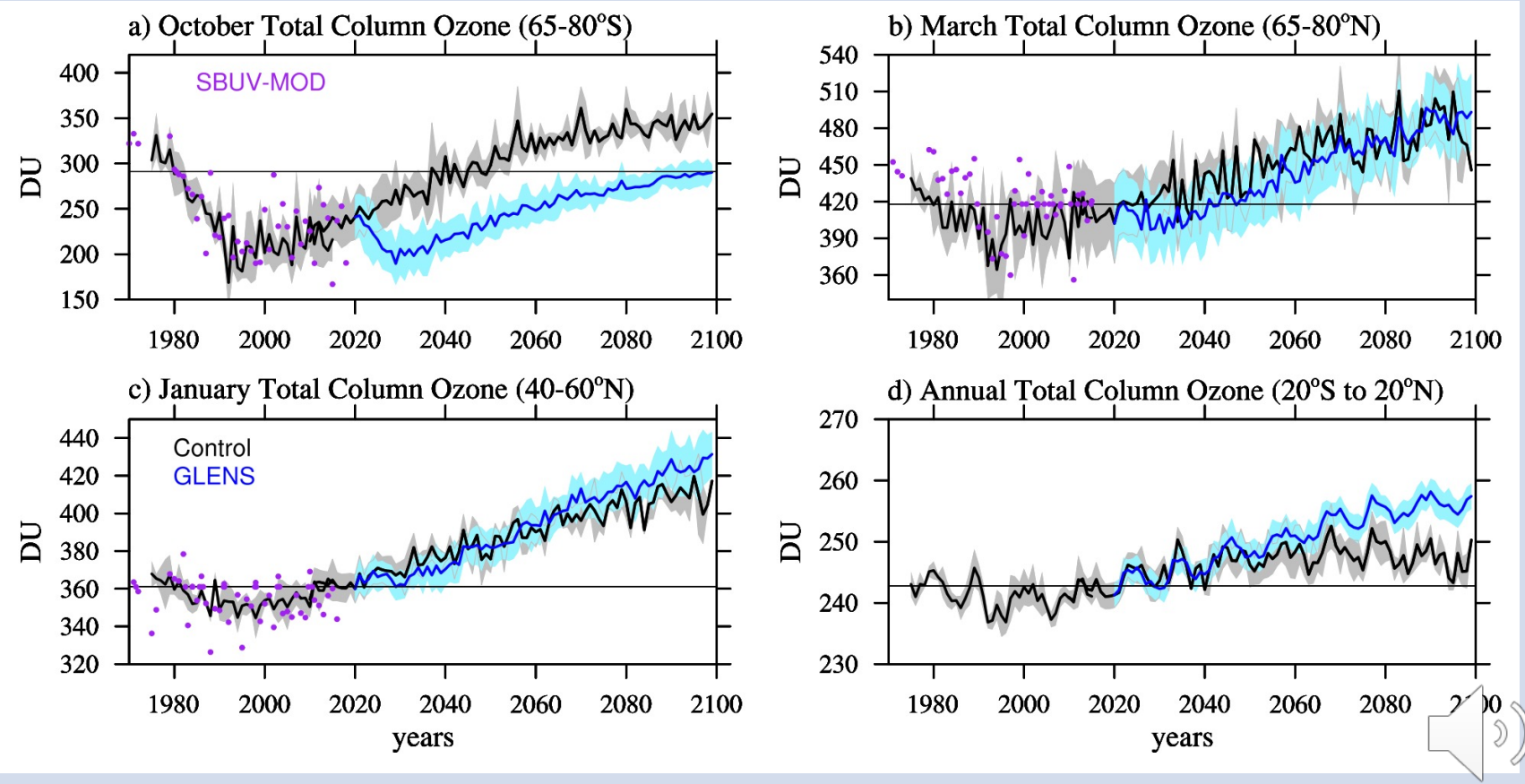
Simpson et al., 2019

GLENS: Impacts on the Stratosphere



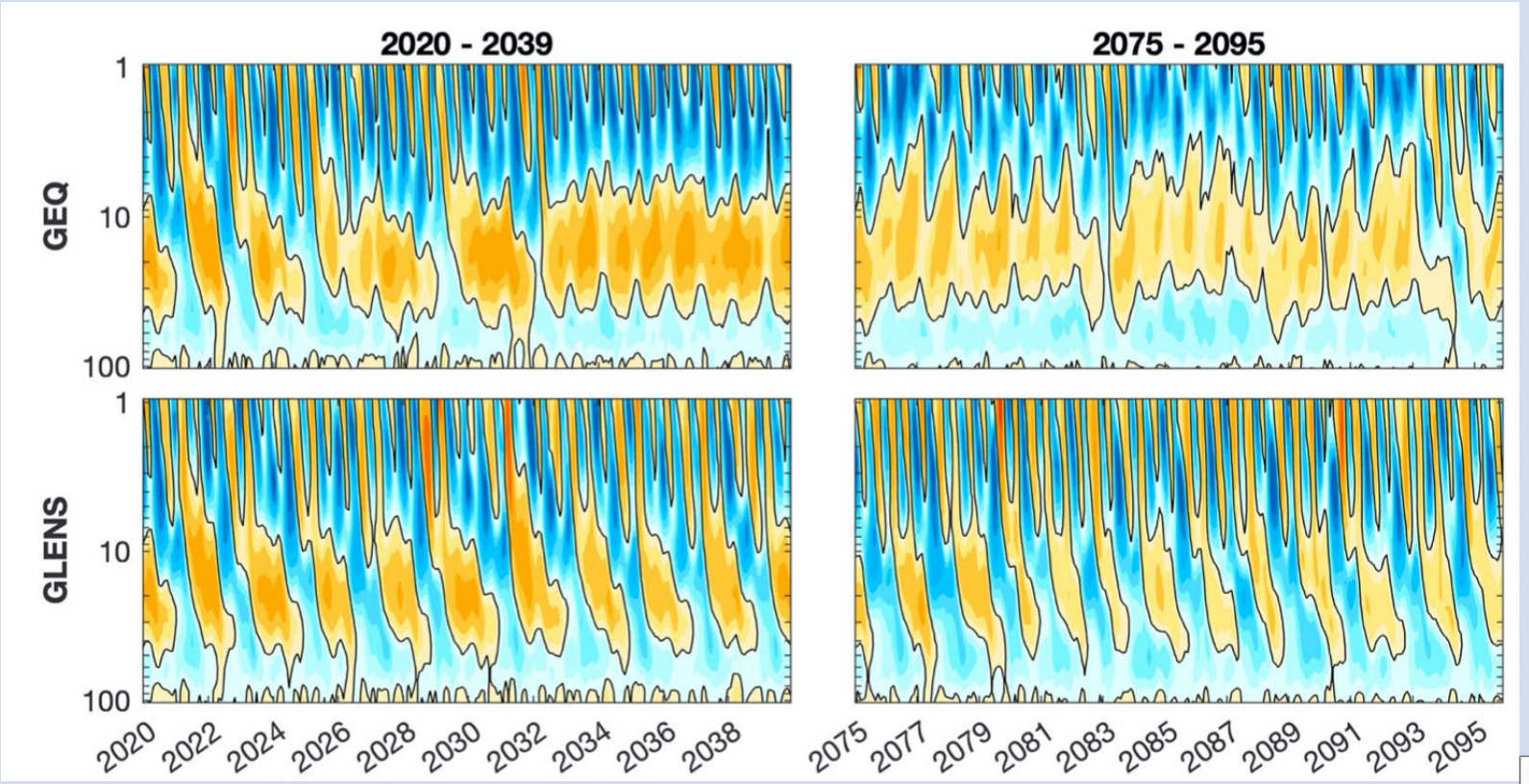
Tilmes et al., 2021, submitted

GLENS: Impacts on Total Column Ozone



Tilmes et al., 2021. submitted

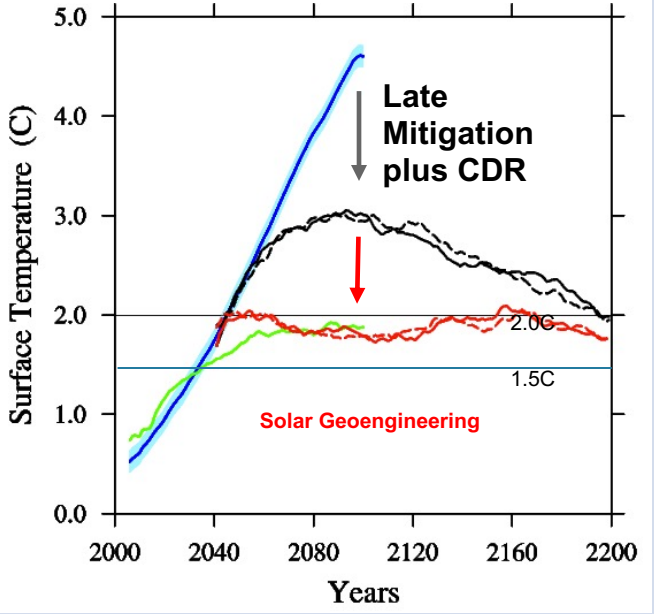
Stratospheric Dynamics: Quasi Biennial Oscillation (QBO)



Kravtiz et al., 2020

Scenarios, Uncertainties, Limitations, and Risks

High Emissions (RCP8.5)
Low emissions scenario (RCP2.6)
Stratospheric Aerosol Intervention



Tilmes et al., 2016, 2020

Need for policy relevant modeling experiments

- Impacts of SAI depend on the scenarios considered and the amount of SAI applied
- New experiments have been performed hat consider a Peak-shaving application

Limitations and Risks

- Technical and physical limitations: deployment, costs, efficiency
- Unknown future pathway
- Termination Effect

Help from the community needed to analyze the different climate intervention scenarios.