Current Research and Challenges of Stratospheric Climate Intervention

National Center for Atmospheric Research (NCAR)

Simone Tilmes

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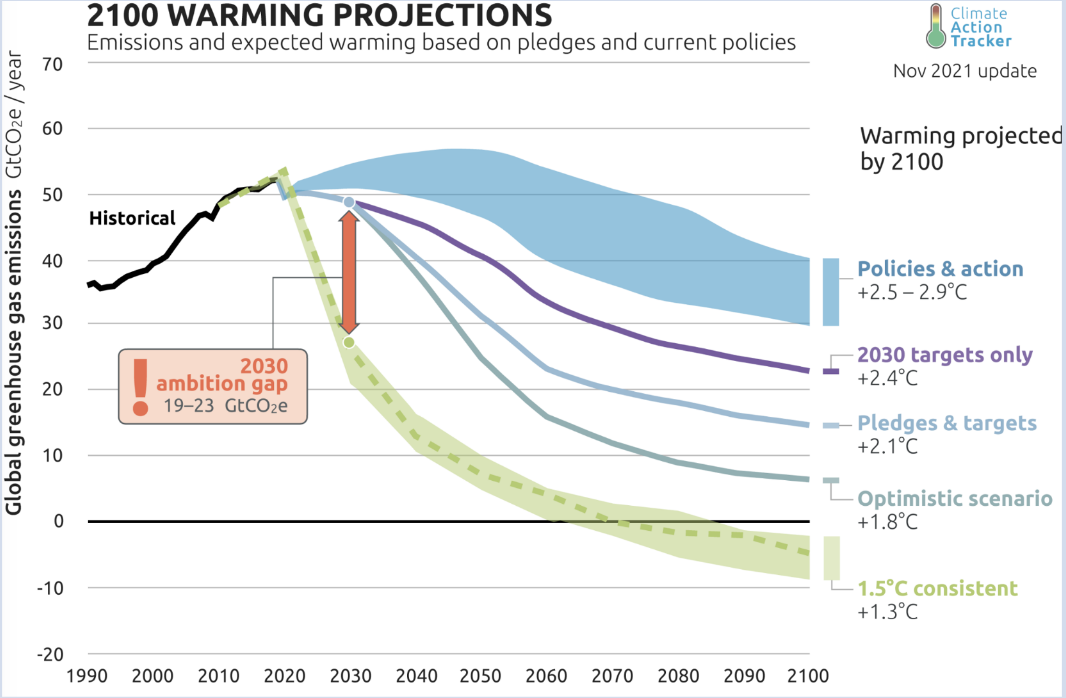
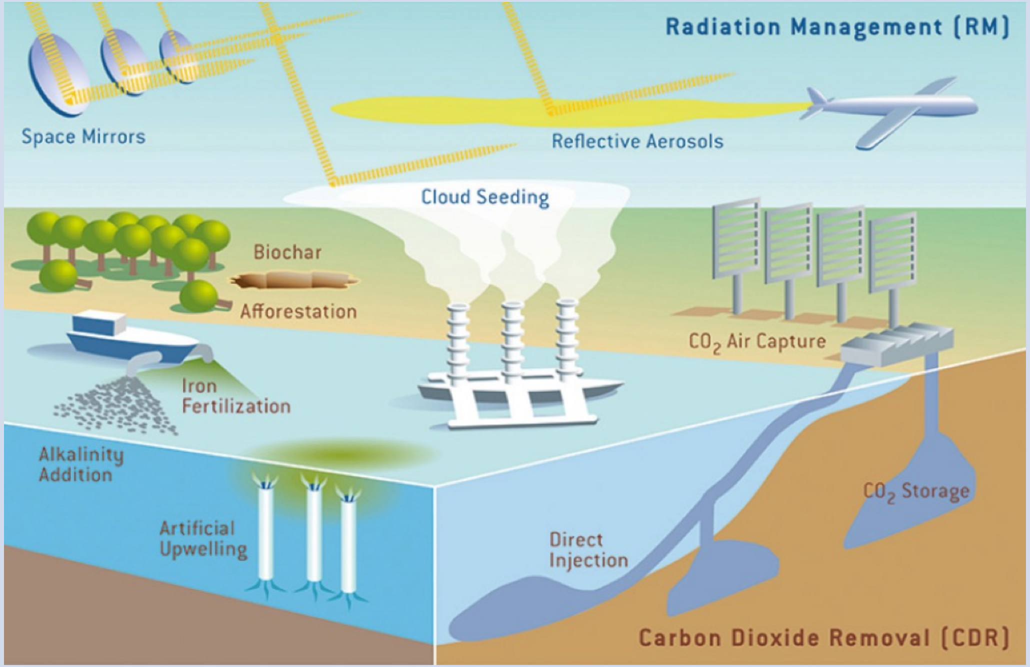
Motivation to Research Climate Intervention Strategies

We are not on the right track to keep global surface temperatures below 1.5C



- Will most likely lead to overshoot of temperature targets
- Increase potential risk of reaching tipping points
- Endanger vulnerable societies and ecosystems
- My hamper attempt to quickly move to alternative energy resources?

Climate Responses to reduce Climate Change and it’s Impacts



Reduce global warming through stabilizations and reduction of atmospheric GHGs

- Mitigation
- Carbon Dioxide Removal

Reduce global warming through artificially changing the reflectivity of the planet

- Global Solar Radiation Modification (SRM)

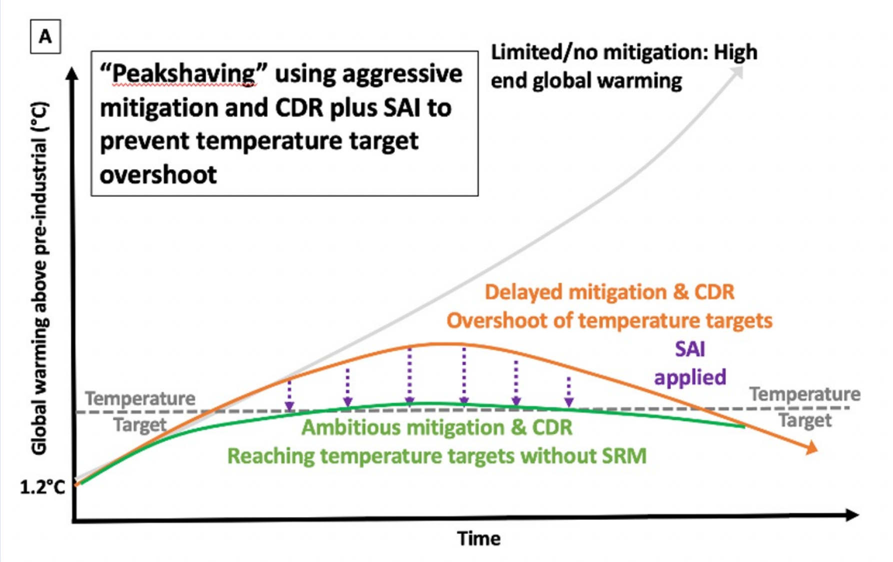
-> including Stratospheric Aerosol Interventions (SAI)

Reduction of impacts and suffering

- Adaptation
- Regional SRM

Two very different Future SAI Scenarios

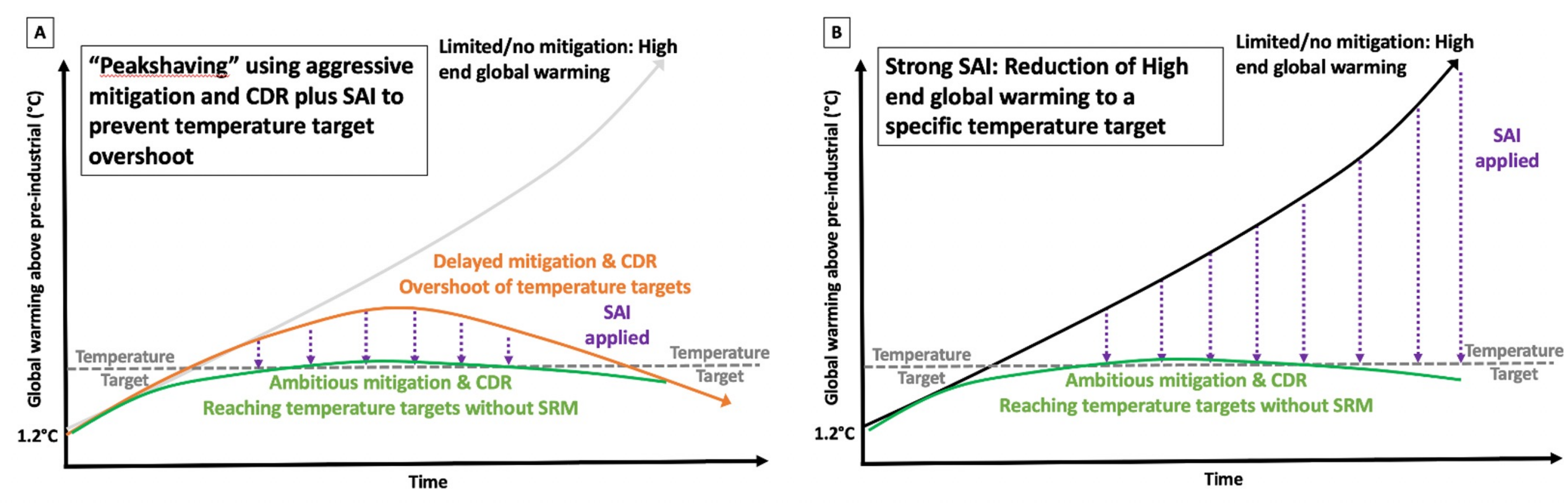
Limited SAI application until atmospheric GHGs are reduced sufficiently using combined climate response strategies.



Two very different Future SAI Scenarios

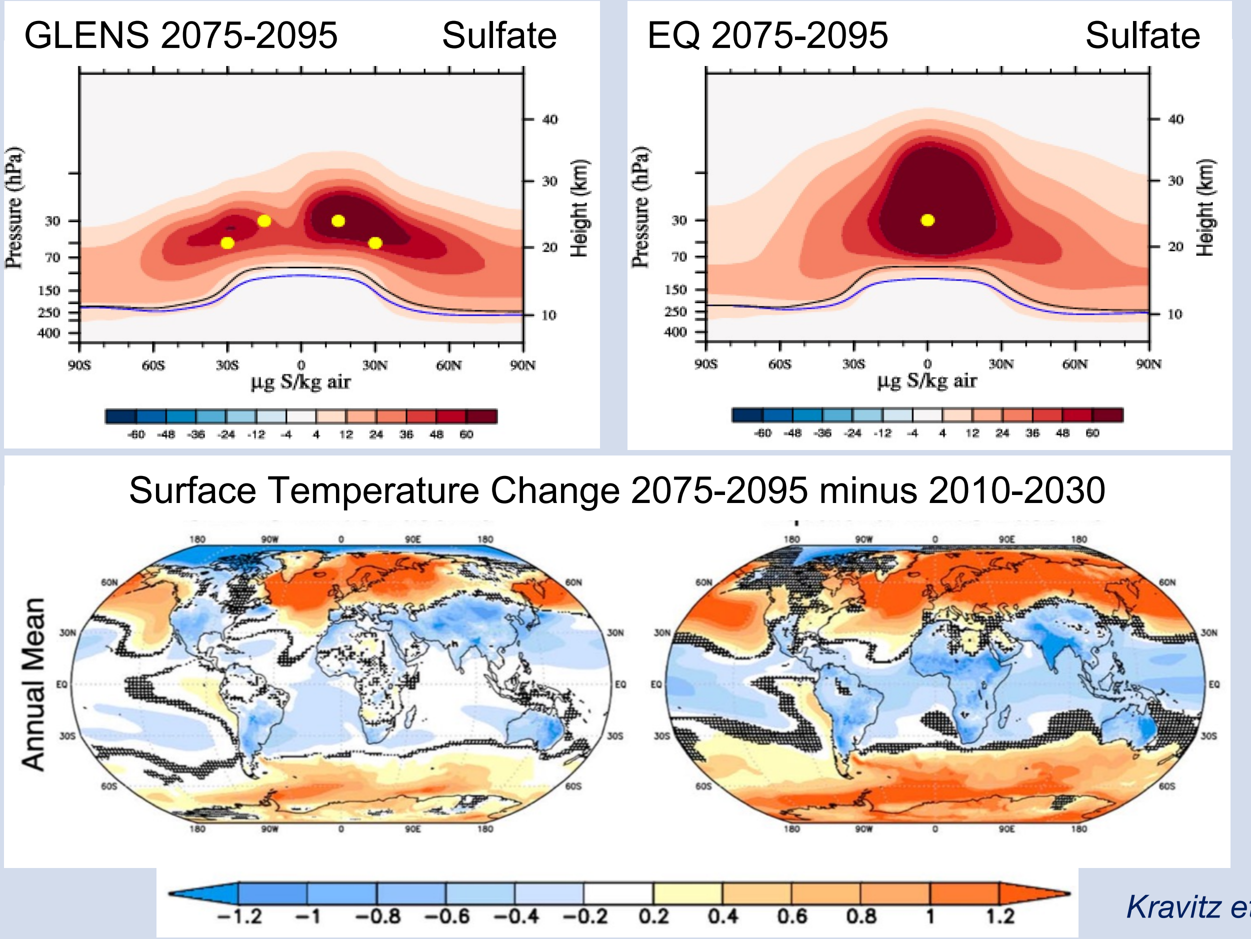
Limited SAI application until atmospheric GHGs are reduced sufficiently using combined climate response strategies.

Continuously increasing SAI application with increasing GHGs. Scenario has been modeled to investigate the impacts of SAI.



Call for risk-to-risk assessments: What are the impacts of different climate response applications compared to a future without them? What are the risks and side effects between the different scenarios? Are there different ethical concerns and risks?

Different Injection Strategies Result in Different Outcomes



Reaching climate targets

- Injections at 4 latitude locations in the stratosphere as done in GLENS (Geoengineering Large Ensemble)
- Feedback control algorithm: modulate annual emissions to reach temperature targets
- Other strategies may include using different aerosols for injections

Kravitz et al., 2021

Current Tools to Simulate the Effects of SAI

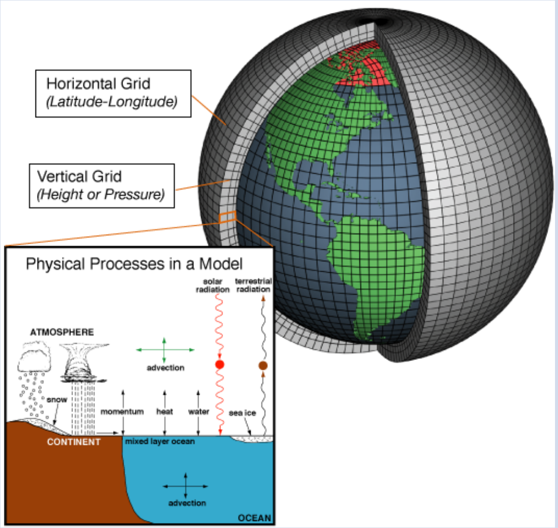
Fully coupled Earth System Model
- Atmosphere, Land, Ocean, Cryosphere

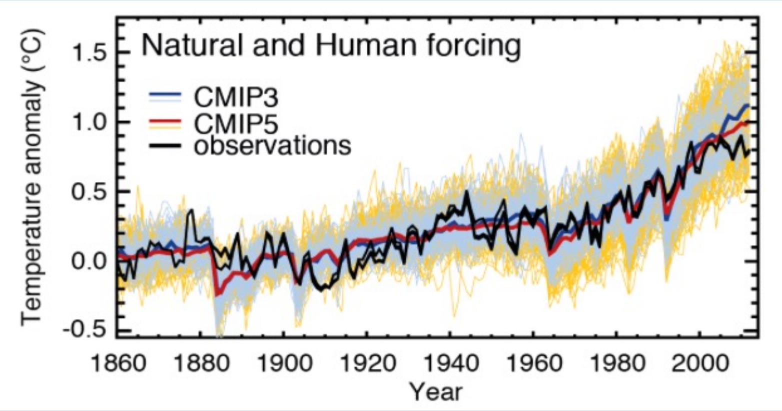
Driven by natural and anthropogenic forcings
- Greenhouse gases
- Emissions of aerosols and gases
- Land-use changes

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, clouds

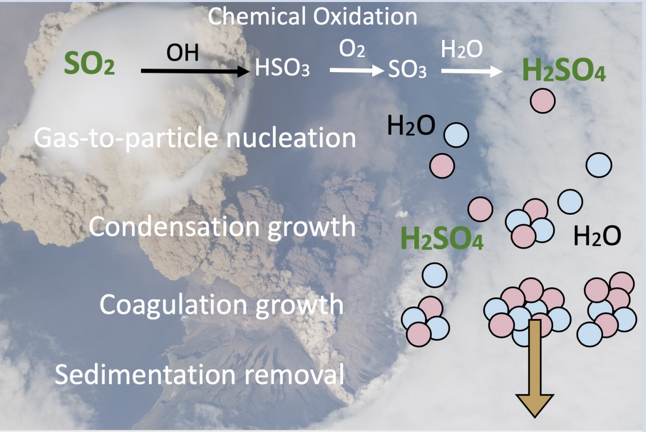
Modelling work: GeoMIP, GLENS, ARISE, etc.





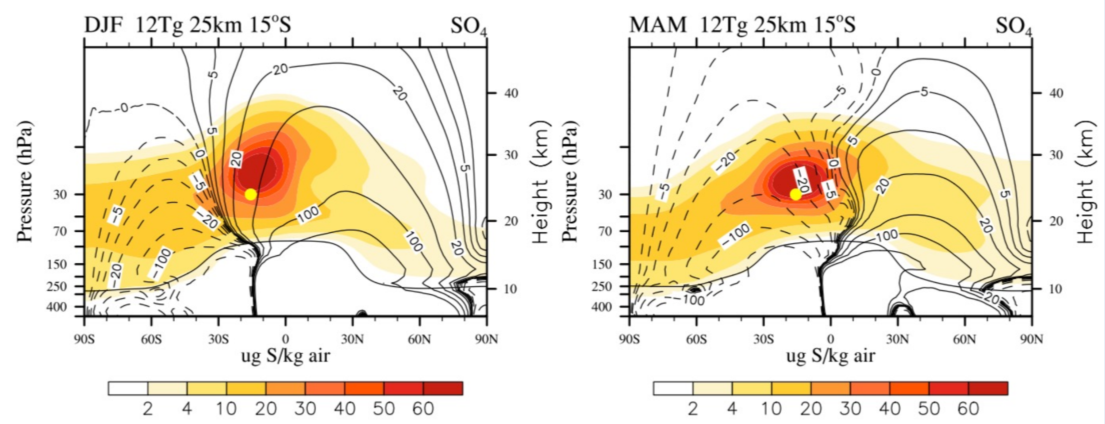
Challenges: Representation of Processes in Models

Aerosol Microphysics



Courtesy: Mike Mills

Large scale transport and chemistry

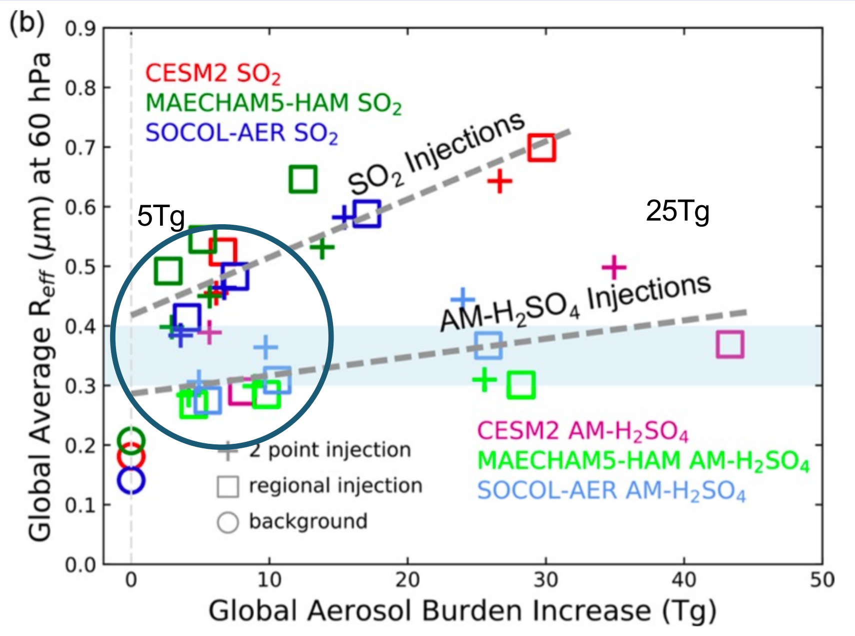


Tilmes et al., 2017

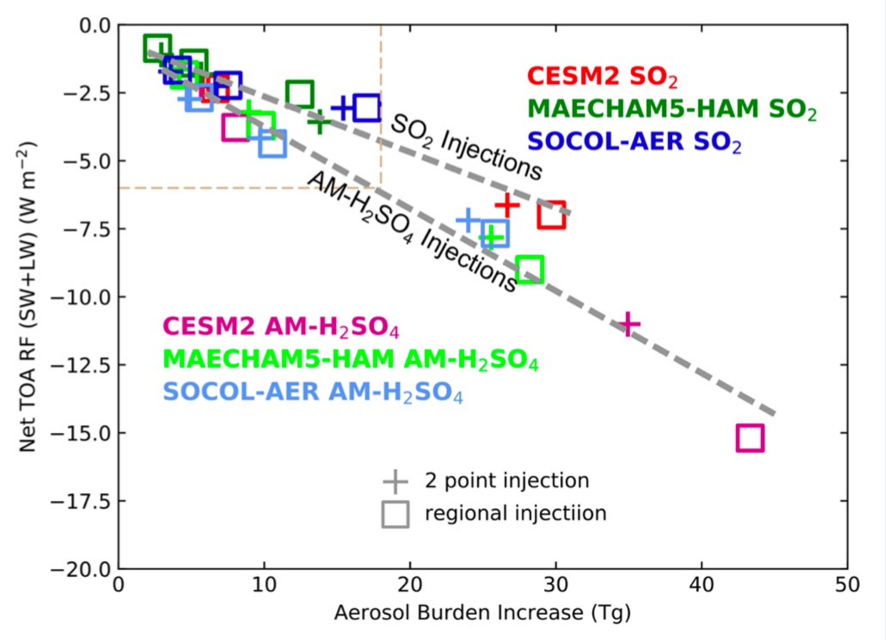
- **Aerosol microphysics** (various different representations from solar dimming to complicated microphysics and sectional aerosol models)
- **Dynamics and transport** of the atmosphere differs between models
- **Chemistry and UV** with impacts on ozone (many models prescribe chemistry)
- **Radiative forcing:** heating of the stratosphere and changes in water vapor
- Fully-coupled **carbon cycle** (land / ocean) (mostly missing)
- Coarse horizontal **model resolution**: Impacts on regional and local scale

Differences in effective Radius and Radiative Forcing

Effective Radius



Top of Atmosphere Net Radiative Forcing

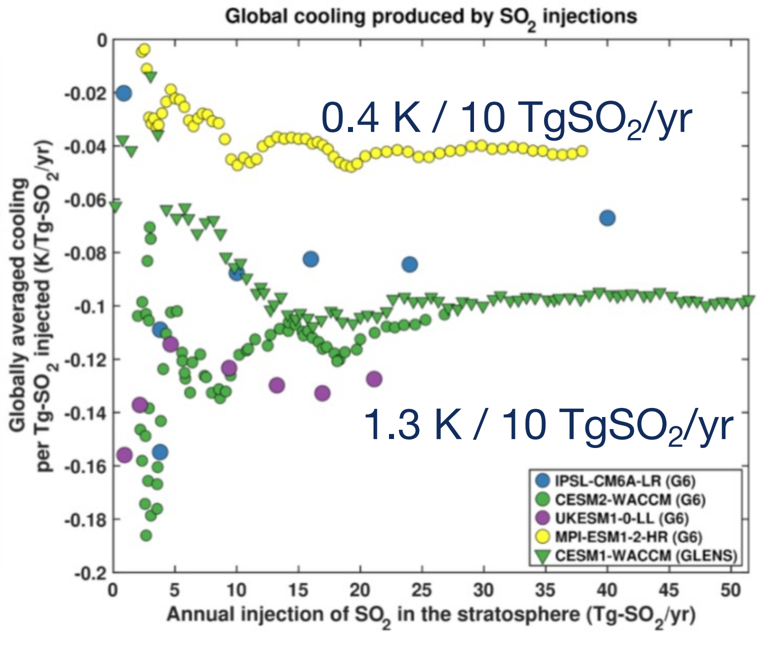


Weisenstein et al., 2022

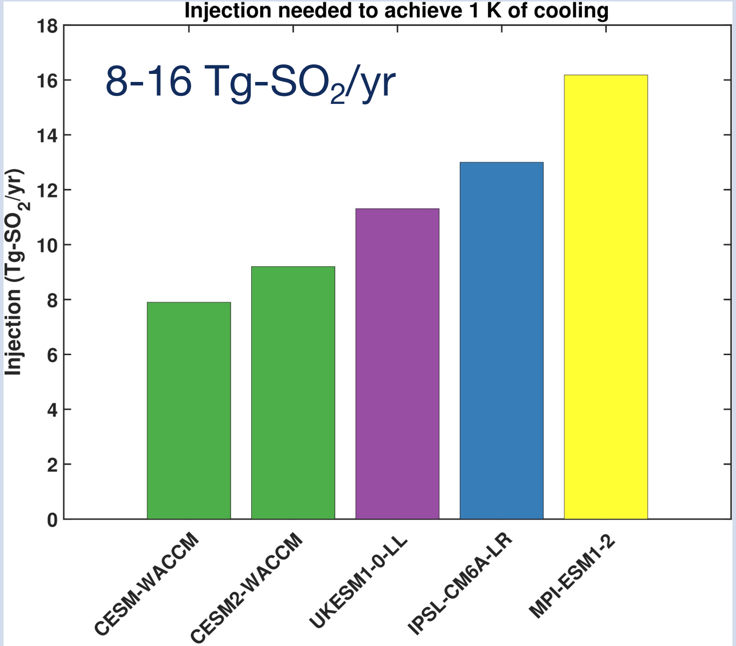
- Large model differences in aerosol burden and radiative forcing
- Sulfur Injections are less efficient than using sulfuric acid aerosol injections
- Particles sizes can be better controlled with sulfuric acid aerosol injections

Range of surface cooling that is achieved in GeoMIP models

Global Cooling per $TgSO_2$/yr



Injections ($Tg-SO_2$/yr) needed for 1K cooling

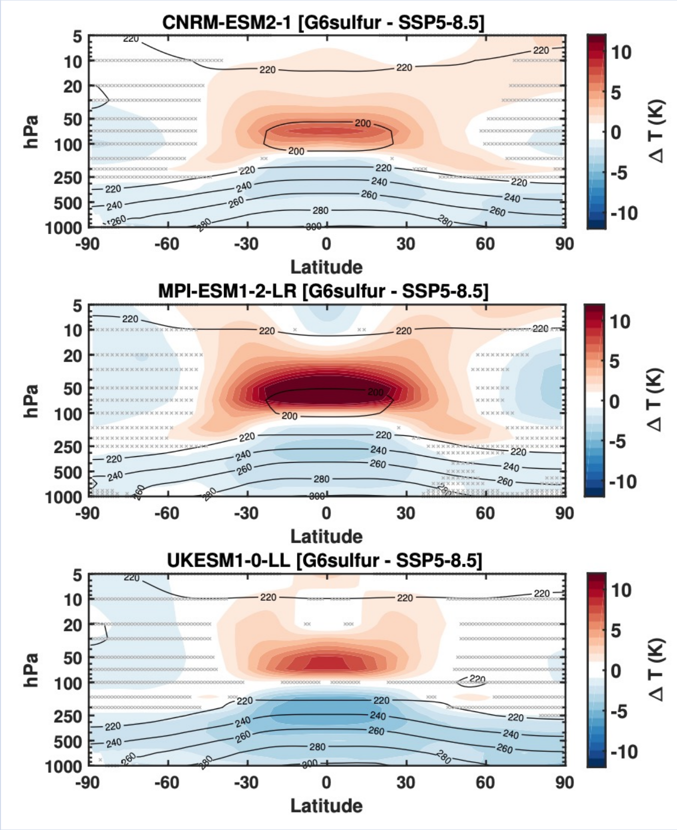


Curtesy: Daniele Visioni and Ulrike Niemeier

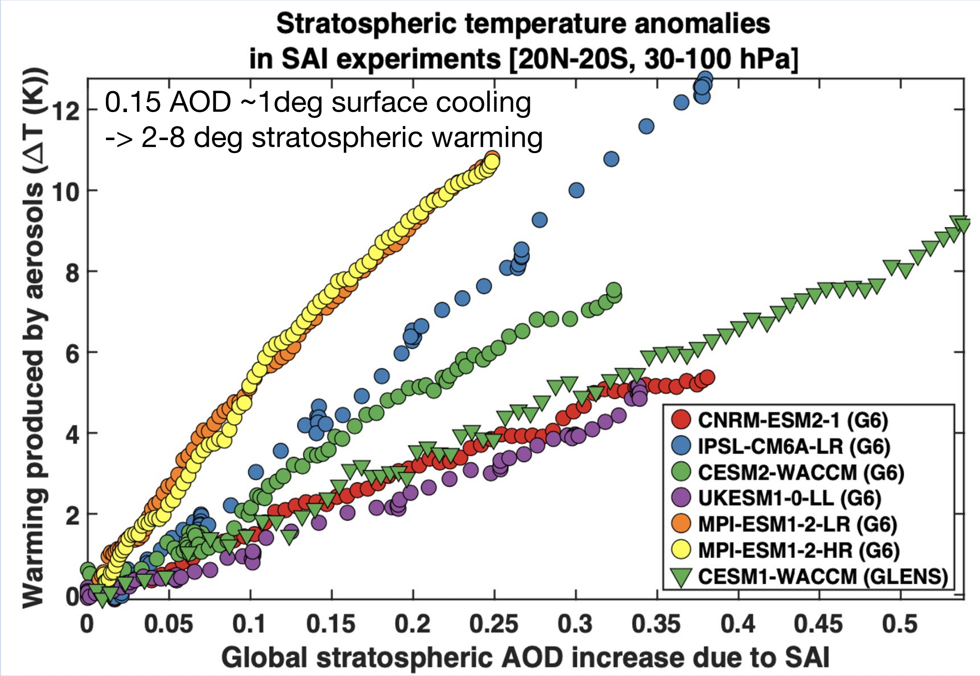
Large uncertainty (factor of 2) in how much sulfur injections are needed for 1 degree of cooling using sulfur injections

Effects of SAI on Stratospheric Temperatures

Tilmes et al., 2022



G6sulfur: Tropical sulfur injections to reduce surface temperatures from SSP5-8.5 to SSP2-4.5 conditions

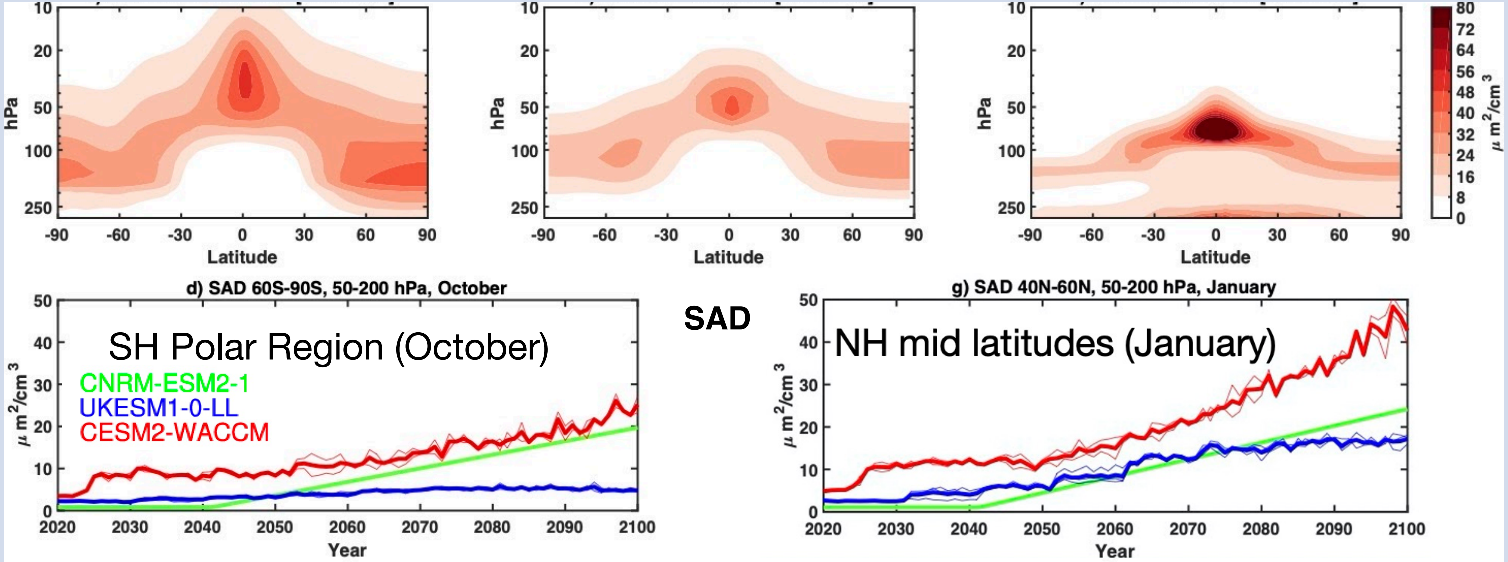


Curtesy: Daniele Visioni

Warming of the Stratosphere has been shown to impact regional rainfall over India.

Differences: Surface Area Density and Ozone

WACCM 2081-2099 | CNRM 2081-2099 | UKESM 2081-2099



Tilmes et al., 2022

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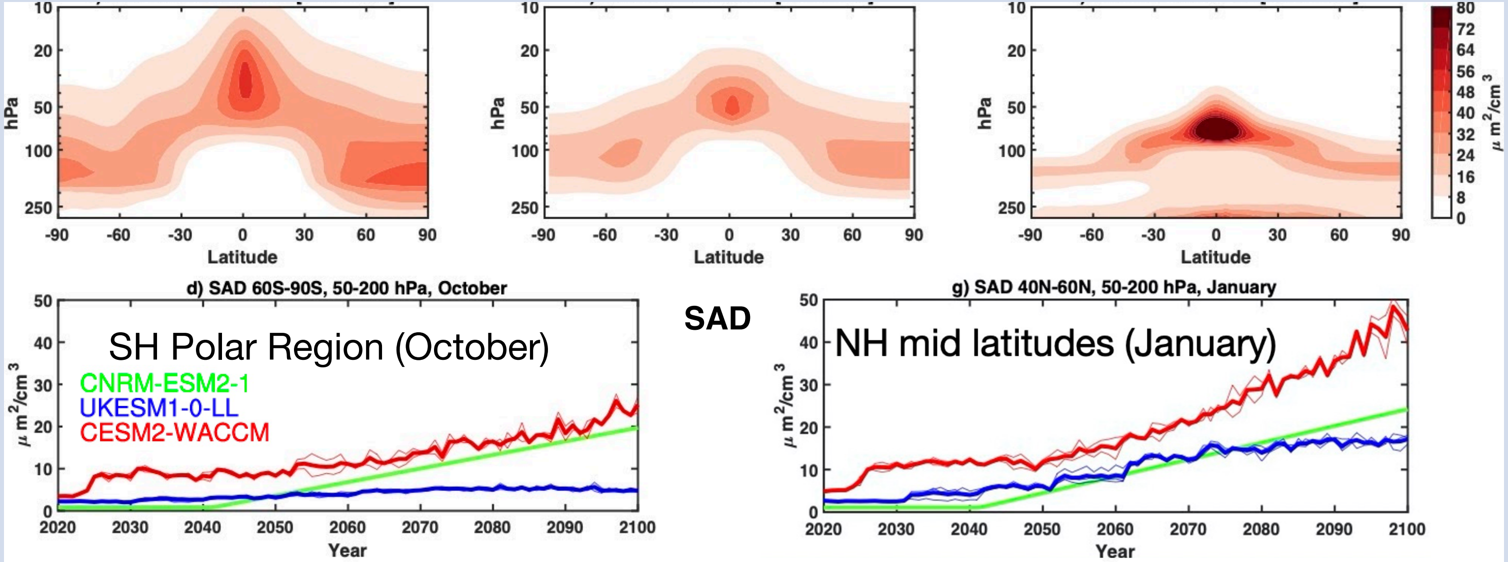
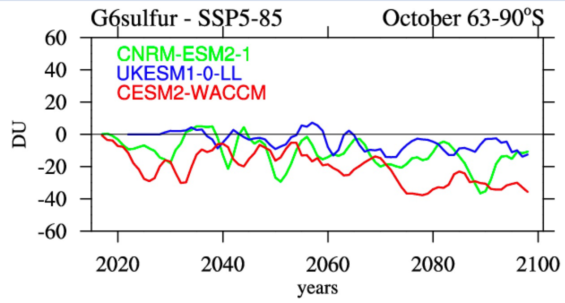
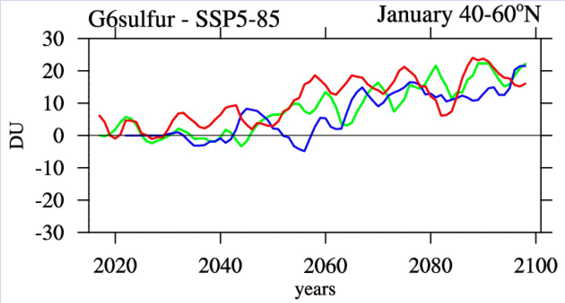


Total Column Ozone Change





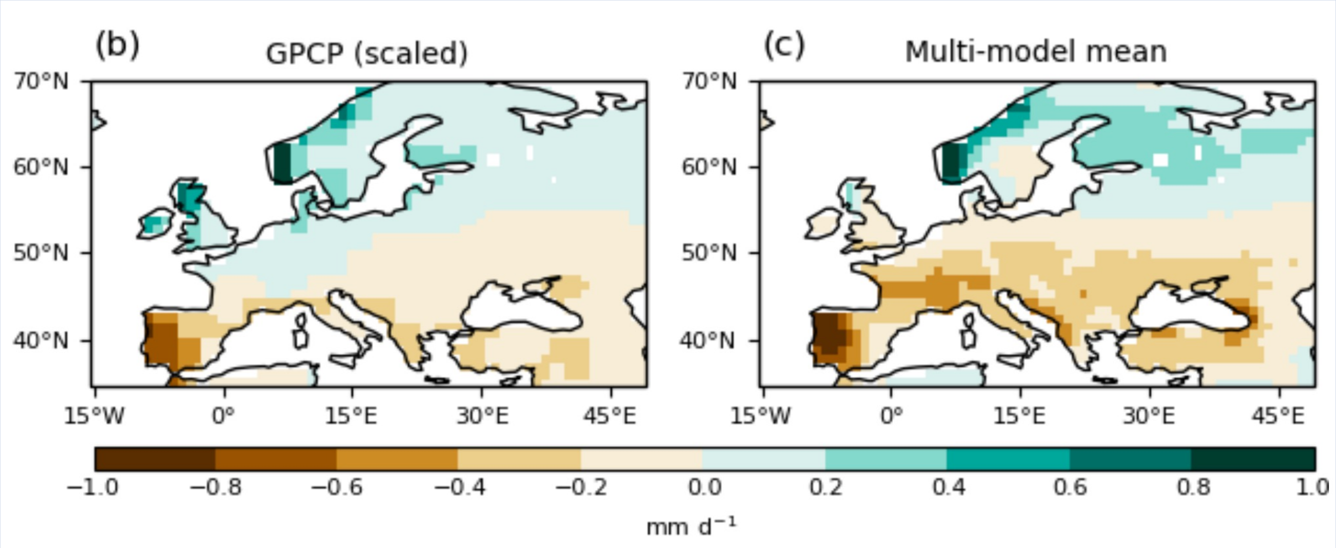
Tilmes et al., 2022

Process Understanding using Models and Observations

Winter (DJF) Rainfall Differences if applying SAI in relation to the North Atlantic Oscillation

Differences in positive and negative North Atlantic Oscillation winters over 1979–2015

Difference with and without SAI based on six different models

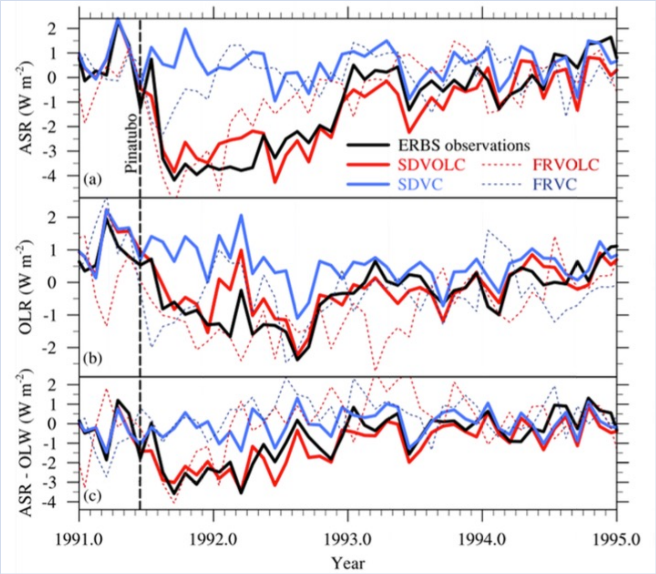


Jones et al., 2022

Stratospheric heating from SAI results in an increase in the Northern Annular Mode and a positive NAO in Winter based on WACCM (Banerjee et al, 2021, Simpson et al., 2019,)

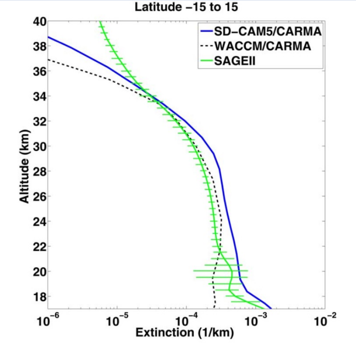
Model Evaluation and Process Understanding

Radiation: changes after Mt Pinatubo



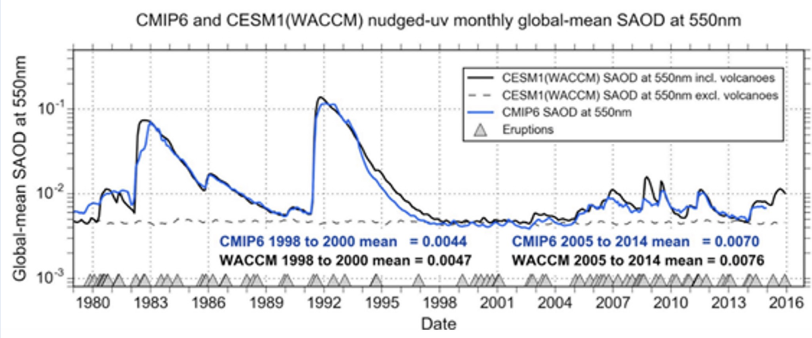
Mills et al., 2016

Aerosol Microphysics, Extinctions

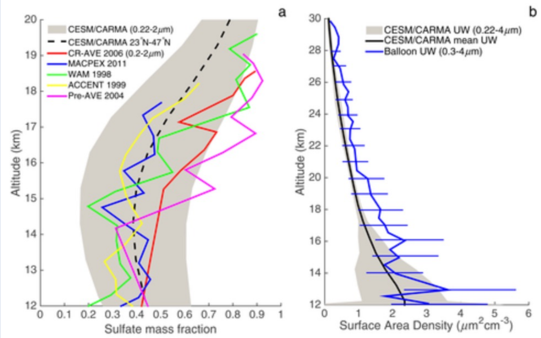


Yu et al., 2015

Aerosol optical depth timeseries



Mass and Surface Area Density using in-situ observations



Yu et al., 2016

Transport and microphysics of an initial volcanic plume from the Sarychev eruption

Haywood et al., 2009

Summary: Stratospheric Climate Interventions

Scientific Key Challenges:

- Reducing uncertainty in the efficiency of SAI (radiative forcing and surface cooling)
- Improving model's complexity: aerosol microphysics, coupling to radiation and chemistry, cloud aerosol interactions, transport (resolution)
- Identifying important processes based on observations and modeling
- Producing realistic future scenarios including an interactive carbon cycle
- Identify climate impacts on regional scale: higher horizontal resolution (downscaling), in comparison to other future scenarios (risk-to-risk assessments)
- Identify best strategies for climate and societal relevant measures

Other Challenges

- Governance of research
- Ethical concerns
- Interdisciplinary exchange and communication between different groups
- Two-way exchange with public and policy makers