Climate Intervention / Geoengineering Research using CESM(WACCM)

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CESM Tutorial, 2022



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

 Increases potential risk of reaching tipping points

 Endangers vulnerable societies and ecosystems

• May hamper attempts to quickly move to alternative energy resources?

Climate Responses to reduce Climate Change and it's Impacts



First suggestion to use climate interventions (stratospheric aerosols) to cool the climate: Budyko 1974!

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)

Reduction of impacts and suffering

- Adaptation
- Regional SRM

Solar Radiation Modification Methods



Eastham et al., 2021

- Whitening of the Earths Surface / increasing the reflectivity of ocean / ice
- Marine Cloud Brightening
- Stratospheric Aerosol Intervention / Injection
- Sun shield Solar Dimming
- (Cirrus Cloud Thinning -> reduced warming effects of high clouds)

Solar Radiation Management. Natural Analogues: Volcanoes





Natural analogue of stratospheric aerosols geoengineering but different ...

Marine Cloud Brightening: Natural Analogues: Ship Tracks

Observed Ship Tracks





Theory: Twomey Effect More Cloud Condensation Nuclei from aerosols (sulfates, sea-salt) increase reflectivity of clouds

Limitations

- Limited to Areas of Marine Clouds
- Increasing aerosols does not always lead to brighter clouds -> need proper particle size and meteorological conditions

CESM Whole Atmosphere Community Climate Model (WACCM)



Model Setup WACCM5.5 and WACCM6

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

Mills et al., 2016, Gettelman et al., 2019

Using WACCM to Develop SAI Strategies



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

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 (2020 conditions)
- Other strategies (injection altitude, material, timing) could change climate outcomes, and can affect ozone differently

Sulfate aerosols before and during the injection starting Jan 2022



Using Models to Develop SAI Strategies



Surface Temperature Change 2075-2095 minus 2010-2030



Reaching climate targets

 Injections outside the tropics can change the distribution of aerosols to improve climate impacts

Stratospheric Dynamics: Quasi Biennial Oscillation (QBO)



Kravtiz et al., 2020

Geoengineering Large Ensemble (GLENS) Project using WACCM

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



20 Ensemble Members to Understand Impacts; Signal to Noise; Processes

Tilmes et al., BAMS 2018

GLENS: Identifying Regional Climate Change

JJA: Precipitation – Evaporation 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: Identifying Regional Climate Change

JJA: Precipitation – Evaporation in 2075-2095 (2020 ref.)

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



Impacts of SAI increase with the application amount

Impacts of SAI depend on the specifics of the Scenario



Effects of SAI on Total Column Ozone: SH Polar Latitudes



- Abrupt deepening of ozone hole in the first 10 years of the onset of SAI
- Continued reduction of TCO for the strong SAI scenario
- The Antarctic Ozone hole recovery is delayed the longest using a strong SAI scenario (by 25-50 years)
- TCO is not reaching historical lows



Tilmes et al., 2020

New Sets of available SAI WACCM Simulations:

Recently produced ARISE-SAI: Assessing Responses and Impacts of Solar climate intervention on the Earth system with stratospheric aerosol injection

ARISE-SAI-1.5 (Richter et al, 2022)

- CESM2(WACCM)
- SSP2-4.5 scenario
- Start in 2035
- Target: 2020 2039 mean
- SO₂ injection at ~ 21 km altitude
- 10-member ensemble

Peekshaving (Tilmes et al, 2020)

- CESM2(WACCM)
- SSP5-8.5, SSP5-3.4-OS
- Start in 2020 (2034)
- Target: 2020 / 2034 mean
- SO₂ injection at 23-25 km altitude
- 3-member ensemble

GLENS (Tilmes et al, 2018)

- CESM1(WACCM)
- RCP8.5 scenario
- Start in 2020
- Target: 2010 2030 mean
- SO₂ injection at 23 25 km altitude
- 20-member ensemble

ARISE: https://www.cesm.ucar.edu/projects/community-projects/ARISE-SAI/ Overshoot: https://www.earthsystemgrid.org/dataset/ucar.cgd.ccsm4.geomip.ssp5.html GLENS: https://www.cesm.ucar.edu/projects/community-projects/GLENS/

Different model version: Different Results

WACCM5.5

vs WACCM6

- Need for different injection location
- Differences in regional temperature response and rainfall pattern

Contact Yaga Richter for more information **jrichter@ucar.edu**



Marine Cloud Brightening Simulations with CESM

ARISE-MCB

Four seeding schemes: 2.5%, 5%, 7.5%, 12.5% of the ocean surface: increase of cloud droplet number to 375/cm³

Contact Jack Chen for more information cchen@ucar.edu









Community Climate Intervention Strategies Project

Steering Committee: Simone Tilmes (ACOM), Peter Lawrence (CGD), Brian Medeiros (CGD), Roy Rasmussen (RAL), Wojciech Grabowski (MMM), Andreas Prein (MMM), Britt Stephens (EOL), Andrea Smith (COMET), Tim Barnes (UCAR SciEd), Monica Morrison (Indiana University), Doug MacMartin (Cornell University), Dale Rothman (George Mason University), Karen Rosenlof (NOAA), Greeshma Gadikota (Cornell University), Gyami Shrestha (U.S. Carbon Cycle Science Program at USGCRP), Anton Simon (Brad College)



03/01/2021

Community Exchange Forum now open

Webinar Series 2020 and 2021

May 26: NAS Report: Governance & Social Aspects

June 23: Scenario Planning

July 28: Ecological and/or Regional Impacts

August 25: Implementation and Engineering: CDR

September 22: Implementation and Engineering: SRM

October 27: Communication, Education and Outreach

November 17: Project Lightning Talks and Networking Session

https://www.ccis.ucar.edu/