SAND2022-8100C

PACI: Performance Assessment for Climate Intervention

PRESENTER: **Lauren Wheeler**

Team: Lauren Wheeler[1], Todd Zeitler[1], Sarah Brunell[1], Carianne Martiez[1], Kevin Potter[1], Benjamin Wagman[1], Erika Roesler[1], Lyndsay Shand[1], Jessica Lien[1]

[1]*Sandia National Laboratories*

PROJECT MOTIVATION & GOALS

- *"Currently, there are no international agreements imposing any legally binding obligations that are specific to SRM."*
  -Reynolds, 2022: *Solar Radiation Modification: Governance gaps and challenges*)
  - There is a need for an assessment process to understand the impacts of climate intervention strategies against potential future regulations and to support policy decisions
- Develop and test a framework for assessing climate intervention scenarios with a focus on Stratospheric Aerosol Injection (SAI)
  - **End goal:** Assessment of **regional** responses, across multiple variables, to a particular set of SAI strategies which incudes a theoretical ranking (global and regional) of those outcomes

Which tools and proposed frameworks are we using to define or guide our analyses?

1. Leverage existing model archives (GLENS; Tilmes et al., 2018)
2. Adapting an existing assessment framework: Performance Assessment methodology
3. Focusing on Risk-Risk Assessments (e.g., Harrison et al., 2021)
4. Identifying key climate risk parameters using IPCC Matrix of Climate Risks and Sectors of Impacts (IPCC, 2022)
5. Literature reviews of SAI and the events which could impact deployment and need consideration
6. ***Question to Community: What else?***

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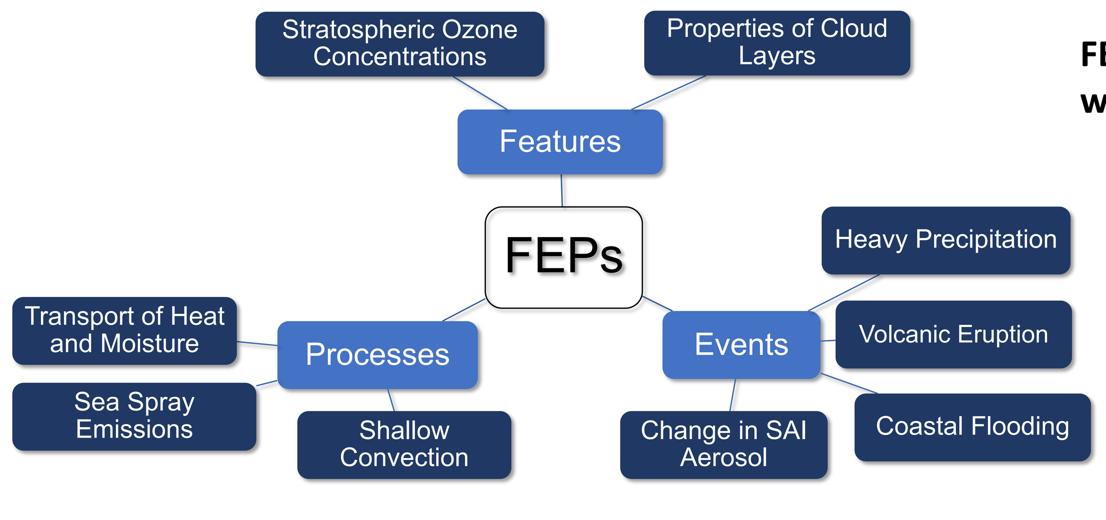
Tailoring Performance Assessment to Climate Intervention

- **The Performance Assessment (PA) methodology (Meacham et al., 2011) can be applied to Climate Intervention to address three primary questions:**
  - **Q1: What processes and events that might affect the Earth system could occur in the atmosphere through 2100?**
    - Requires an analysis of Features, Events, and Processes (FEPs) that considers the current implementation of an Earth System Model.
  - **Q2: How likely are the various processes and events that might affect the Earth system to occur in the atmosphere through 2100?**
    - Considers parameterization of models (ESMs), including uncertainty in current data (epistemic) and future events (aleatoric).
    - May also include model uncertainty in implementation of SAI.
  - **Q3: What are the consequences of the various processes and events that might affect the atmosphere in the Earth system through 2100?**
    - Considers an output measure (e.g., mean surface temperature change) relative to a pre-defined performance metric (e.g., regulation)
- In addition, accounting for uncertainty in the parameters of the models using the PA leads to a further question:
  - **Q4: How much confidence should be placed in answers to the first three questions?**
    - The confidence in the results of PA is based in part on the strength of the original research done to inform the ESM, as well as experimental results used to develop and confirm parameters and models.
    - Numerically, confidence can take into account the range of inputs considered and number of independent calculations of system performance.
- These questions give rise to a methodology for quantifying the probability distribution of possible temperature response over the next 100 years, and for characterizing the uncertainty in that distribution due to imperfect knowledge about the parameters contained in the models used to predict temperature changes. There is currently no regulatory requirement for this type of probabilistic methodology for climate intervention, but the current work seeks to investigate the potential for applying a PA methodology to Climate Intervention methods such as SAI.

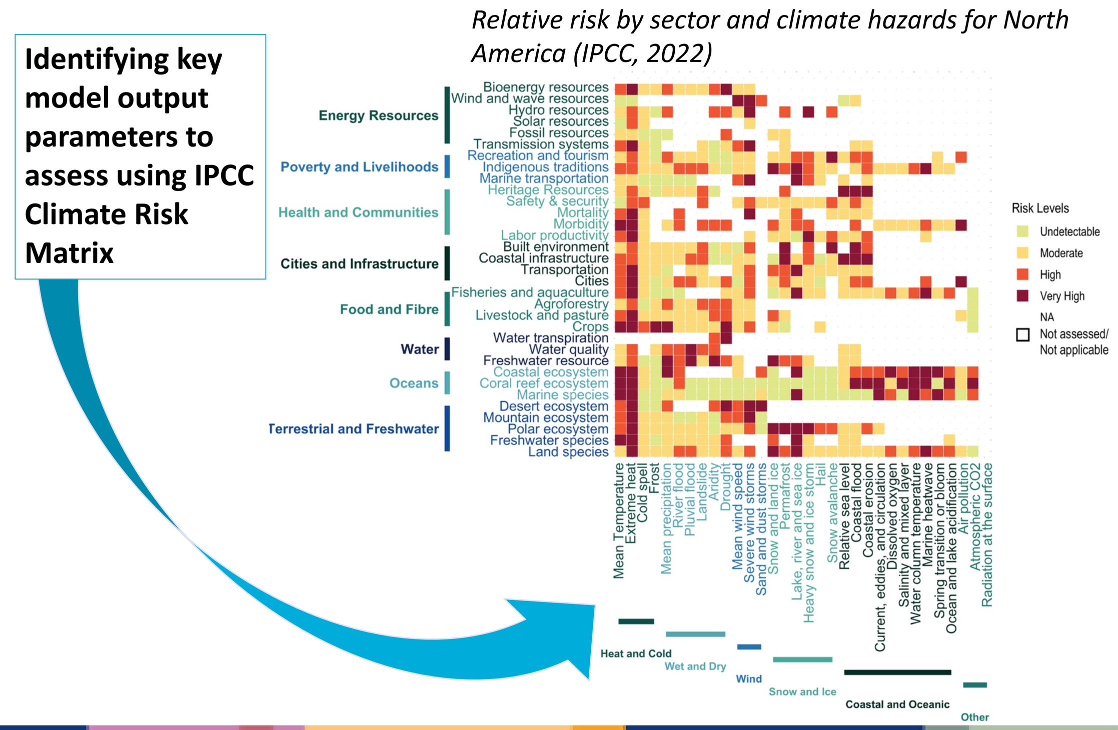
The assessment space of impacts across the Earth system is large. Our approach is to identify assessment targets based on current ESM outputs and leverage existing metrics for climate change risk assessments and analyses of SAI simulations.



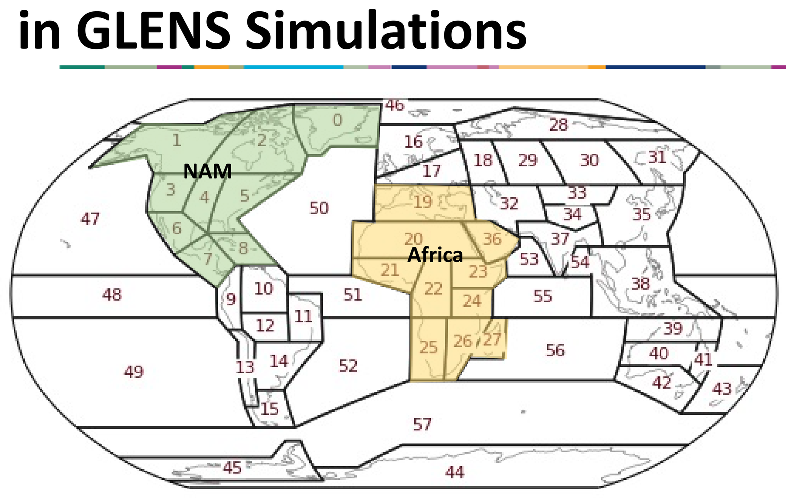
FEPs informs what scenarios need to be assessed or what's "screened in" to the assessment.

Events that would Disrupt a SAI Deployment and may have Downstream Risks Requiring Further Assessment	
Events	**Description**
Interference by competing SAI programs	Financial requirements may be substantial, but possibility exists (Smith, 2020). Radiative efficacy declines as deployed mass increases beyond some value (Smith, 2020). Covert deployment (rogue actor attempting to geoengineer the world) may be unlikely (Smith and Henley, 2021).
Uncertainty in warming scenarios	Assumptions about Representative Concentration Pathway (RCP) (e.g., 4.5, 6.0, 8.5) as deployment modeling is performed to estimated capability of SAI (Smith, 2020).
Change in aerosol candidates	Due to negative environmental impacts and negative health impacts, an aerosol other than sulfates may be necessary.
Interruption of deployment	Deployment would need to be continuous or cooling effect would cease (Smith and Henly, 2021).
	Anthropogenic Interruption - Supply chain disruptions or slow/stalled technologic development mid-deployment. Interference by competing SAI programs or heterogeneous preferences on the climate outcomes. A failure to converge far prior to the onset of deployment on such consensus targets could compromise the legitimacy of such a program or render deployment impossible (Smith and Henly, 2021).
	Natural Interruption - Interference from large volcanic eruption (e.g., Mount Pinatubo eruption).

Relative risk by sector and climate hazards for North America (IPCC, 2022)

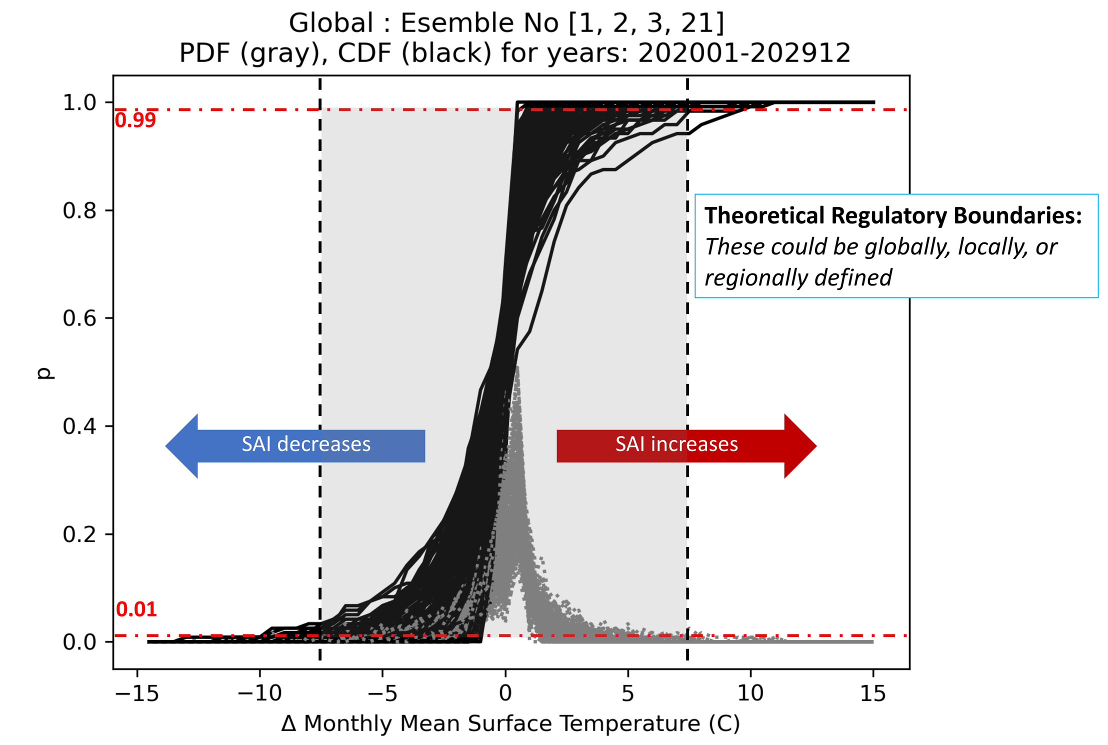


Assessing Global and Regional Responses to SAI in GLENS Simulations

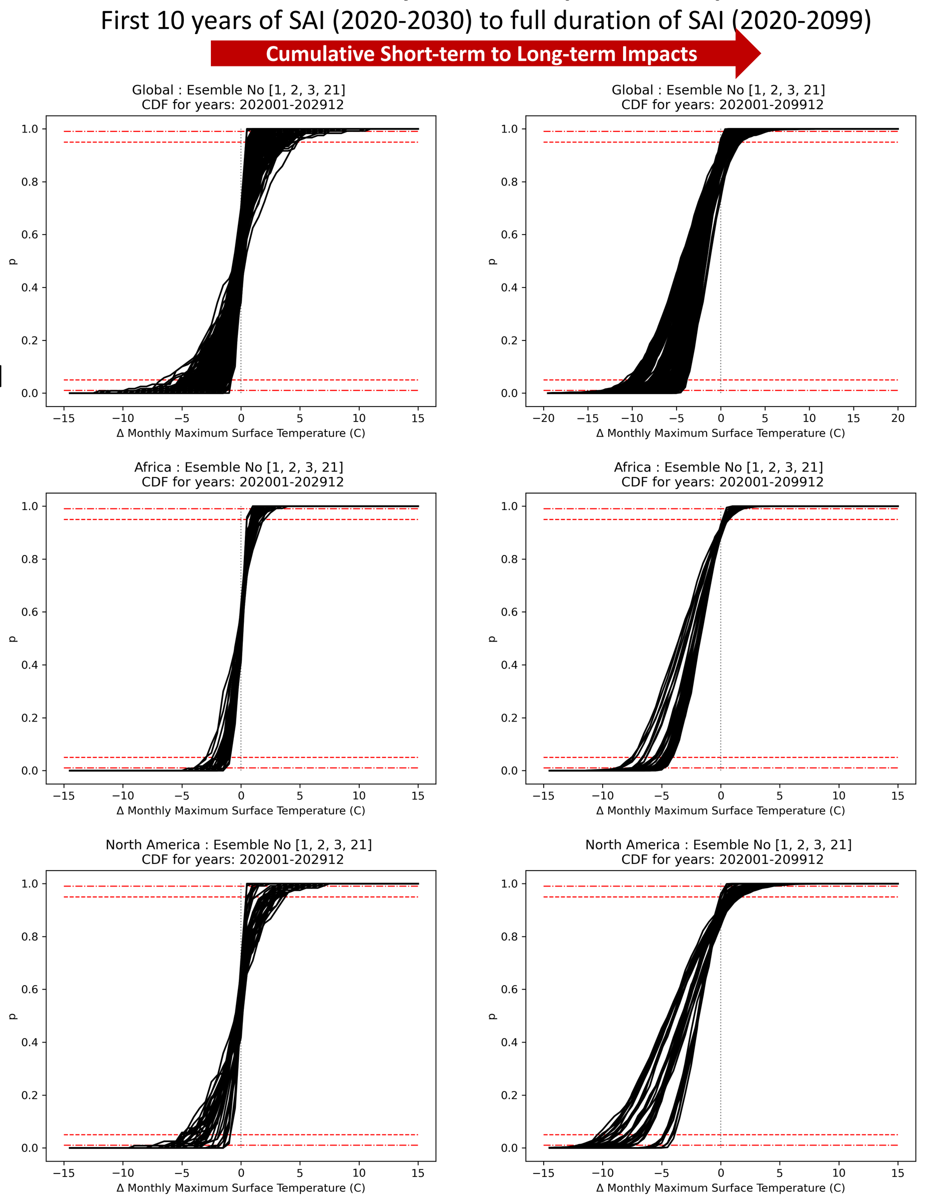


(Iturbide et al. 2022; https://github.com/IPCC-WG1/Atlas)

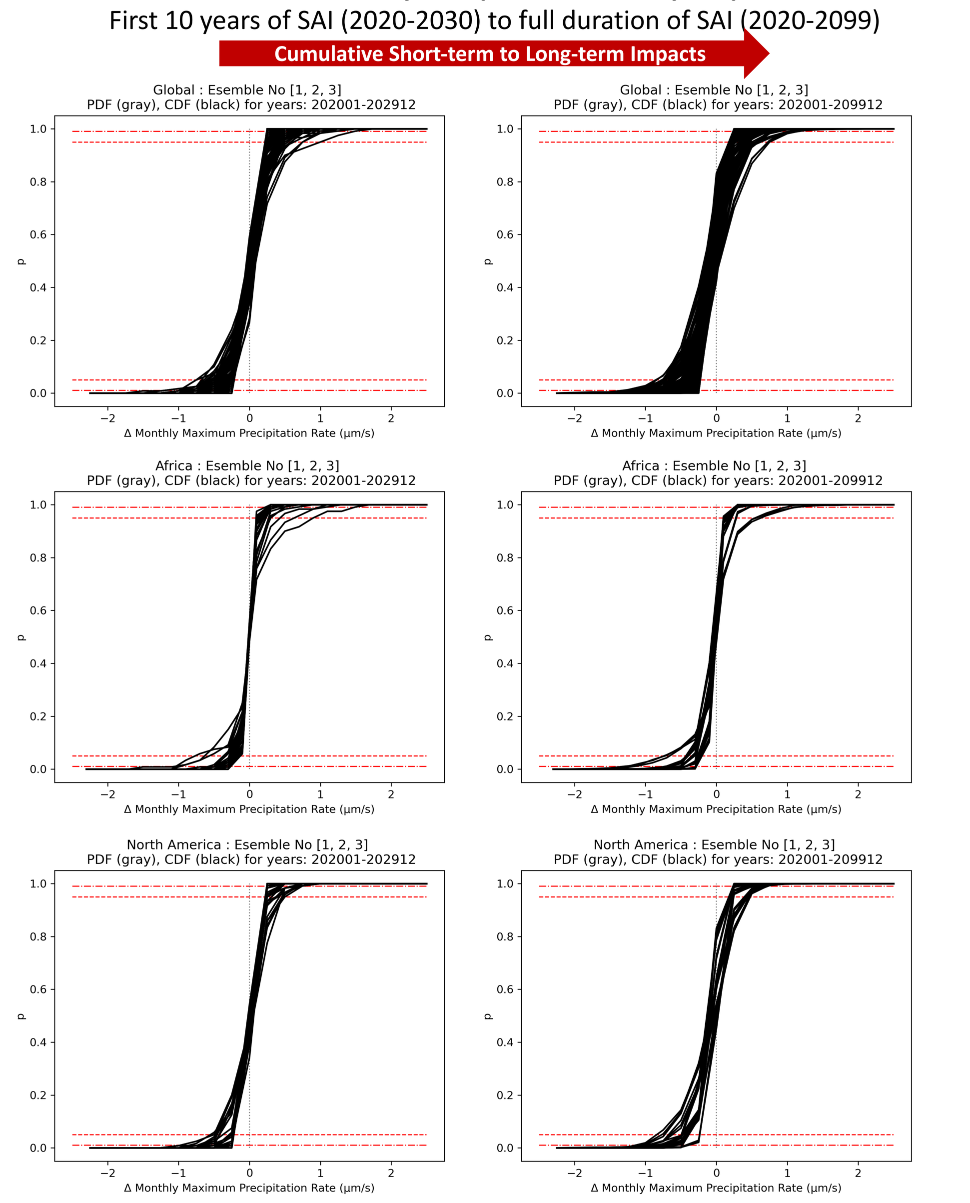
Figure description:
- Values on x-axis are the difference between control and feedback simulations
  - **Δ = Feedback – Control**
- Each line is the monthly ensemble average for the land surface in that region



Maximum Monthly Surface Temperature Response
First 10 years of SAI (2020-2030) to full duration of SAI (2020-2099)



Maximum Monthly Precipitation Intensity Response
First 10 years of SAI (2020-2030) to full duration of SAI (2020-2099)



NEXT STEPS:
- Build out the assessment by incorporating more climate model output variables
- Incorporate uncertainty from model selection and emissions scenarios (e.g., add in ARISE-SAI and GeoMIP simulations)
- Develop a method to weight responses to regional or local models of population

Developing Fully Connected Neural Network Surrogate Model Trained on GLENS Simulations to Predict Climate Response

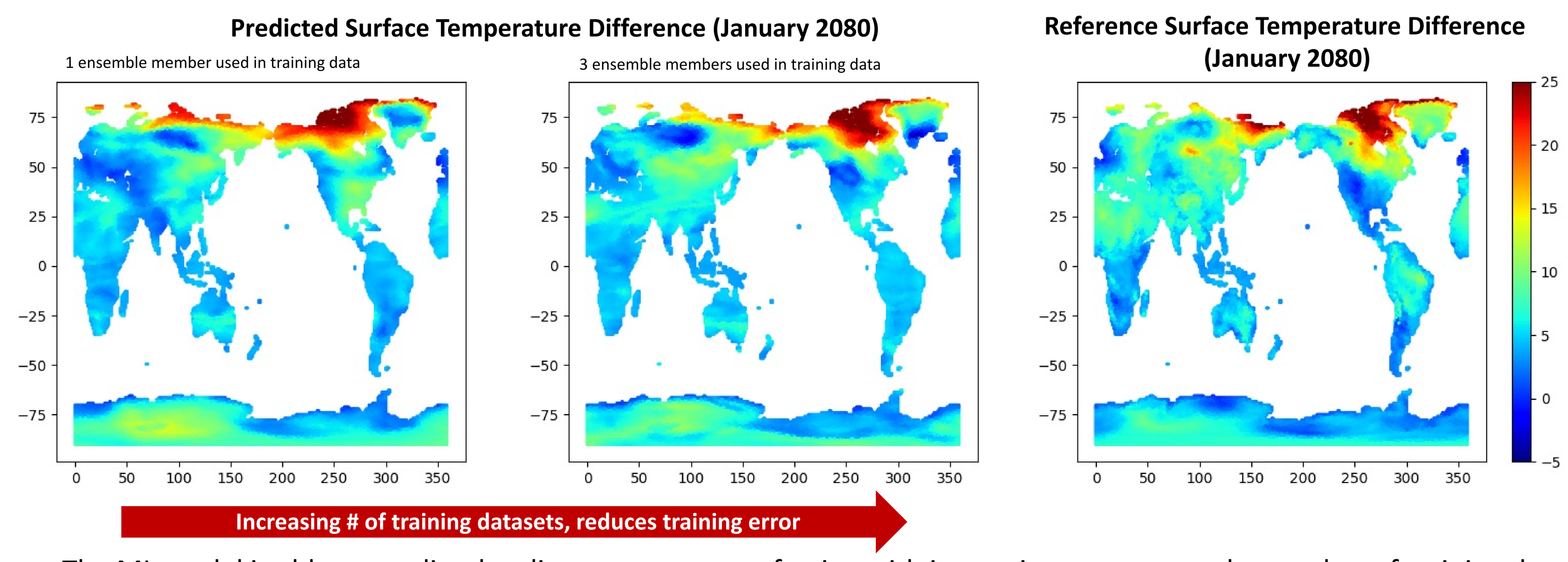
Inputs: year, month, latitude, longitude, stratospheric AOD

Output: Difference in surface temperature (over land) between the control and feedback runs

Training set: ~20-60 million points from GLENS (ensemble no 001, 002, 003)

Test set: Data withheld from GLENS (ensemble no 021)

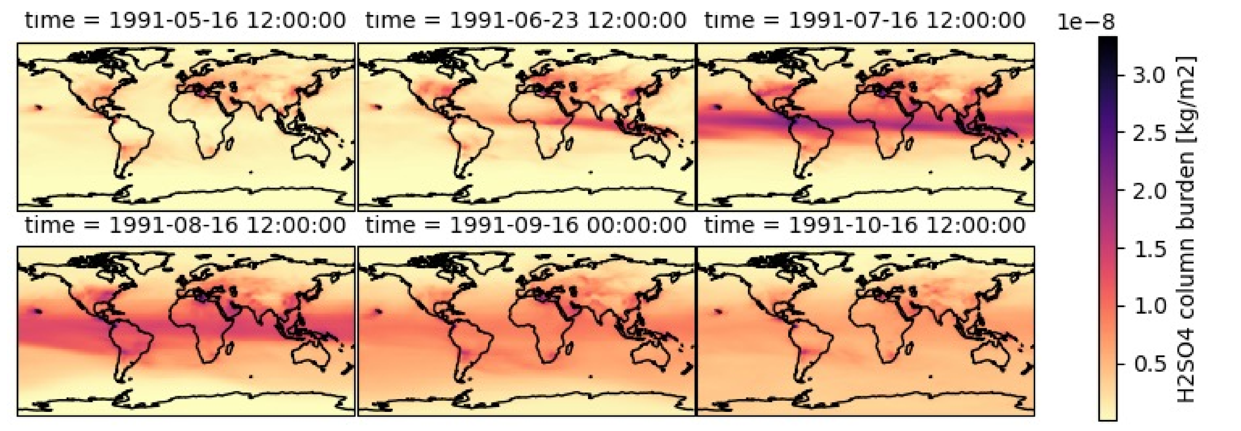
Number of training runs	Test run mean absolute error	Train run mean absolute error
1	3.041	0.5843
2	2.672	0.8907
3	2.608	1.056



- The ML model is able to predict the climate response to forcing with increasing accuracy as the number of training datasets increases
  - Enables the development of a library of ESM simulations to train models for optimizing SAI strategies that meet potential future regulations at lower cost than running an ESM for every possible scenario

NEXT STEPS:
- Increase the number of input ensemble members from both GLENS and other simulation archives (e.g., GeoMIP and ARISE-SAI)
- Include more climate response variables
- Develop a graph convolutional network
- Evaluate autoregressive model over inference distribution

Designing Simulations to Address Uncertainty in the SAI Scenario based on FEPs analysis



H_2SO_4 mass per m^2 in the E3SMv2 experimental "SO_2" prognostic volcanic aerosol simulation. This figure shows the H_2SO_4 (which is forming from oxidation of SO_2) and spreading globally (Wagman et al., 2021).

IN PROGRESS:
- Apply the GLENS SAI injection scenario in E3SMv2
  - **Increases uncertainty assessment by adding uncertainty due to the model selection (E3SM versus WACCM) into the PA**
    - **Will also introduce random volcanic eruptions to build out uncertainty due to random events**
  - Answers a couple of questions:
    - How does a strategy designed for a state-of-the-art stratospheric model (WACCM) impact a model designed and tuned for the troposphere?
    - Does the strategy achieve the temperature target goals from GLENS?
      - Demonstrate broader applicability of strategies designed in more complex models to other less complex GCMs and ESMs

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