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Stratospheric Aerosol Injection Emulation for Controller Design

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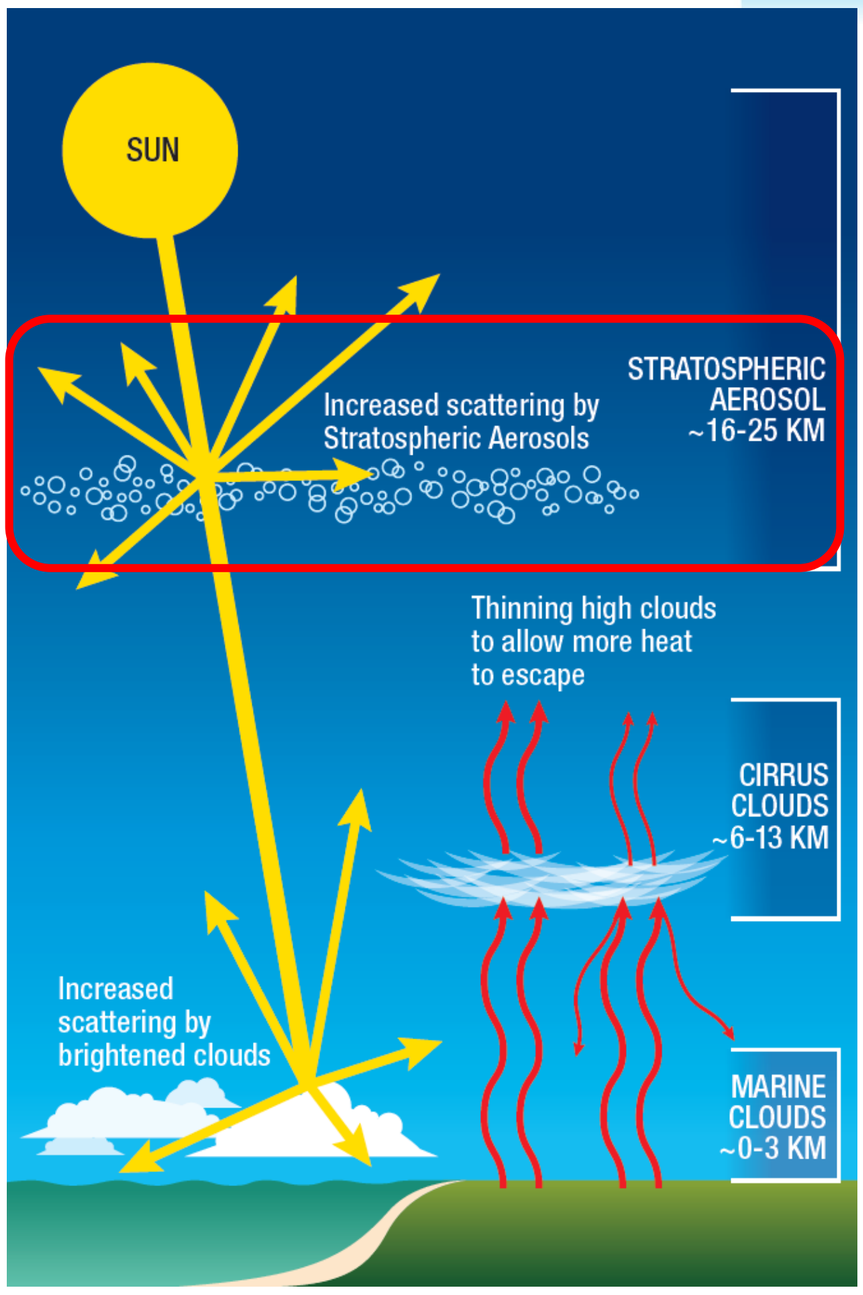
Context:

- **Greenhouse gas emissions raise global surface temperatures** by trapping outgoing infrared radiation.
- **Stratospheric Aerosol Injection** (SAI) **cools surface temperatures** by lofting droplets into the middle atmosphere and scattering incoming sunlight.
- SAI studies often use a **feedback controller** to correctly set the amount and location of injection for a desired climate.
- Earth System Models (ESMs) are often tedious or expensive to run, so coupling with a **simpler model** is desired for rapid or experimental controller design.
- **Emulation of ESMs** (e.g. the DOE model E3SM *[1]*) will allow for deeper exploration and understanding of SAI capabilities.

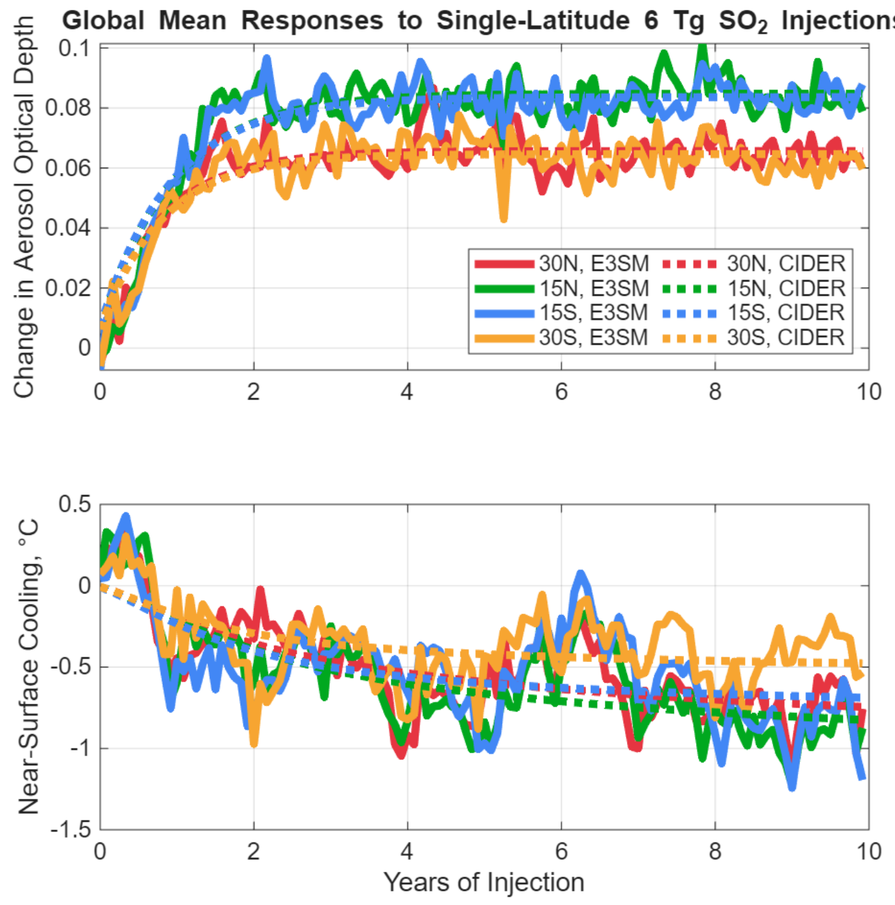


(National Academy of Sciences, 2021)

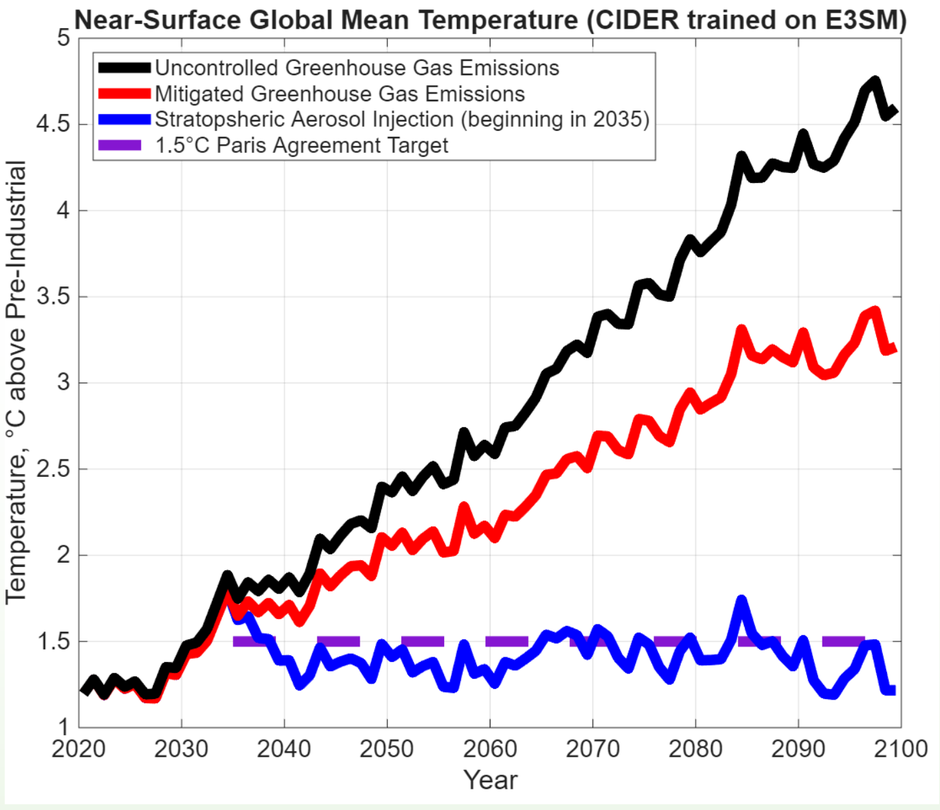
Results:

- **Climate Intervention Dynamical EmulatoR** (CIDER) *[2]* **trained to mimic E3SM** at a fraction of the computational cost.

E3SM Cost per Simulated Year	CIDER Cost per Simulated Year
1.2 million core hours	11 core seconds



- SAI feedback controller *[3] [4] [5]* coupled with CIDER can **maintain global mean temperature target**, even in the presence of rising greenhouse gas concentrations.
- **Matching E3SM simulation in progress!**



Conclusions:

- **E3SM-trained CIDER can be used for SAI controller testing and design.**
- **The current state-of-the-art control algorithm seems to be able to control the climate in E3SM via SAI.**

References:

[1] Jean-Christophe Golaz, Wuyin Lin, Xue Zheng, et al. The Energy Exascale Earth System Model version 3. Part II: Overview of the coupled system. *ESS Open Archive.* https://doi.org/10.22541/essoar.175097464.44666291/v1 June 26, 2025.

[2] Farley, J., MacMartin, D. G., Visioni, D., Kravitz, B., Bednarz, E., Duffey, A., and Henry, M.: A Climate Intervention Dynamical Emulator (CIDER) for Scenario Space Exploration, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-1830, 2025.

[3] Kravitz, B., MacMartin, D. G., Mills, M. J., Richter, J. H., Tilmes, S., Lamarque, J.-F., Tribbia, J. J., and Vitt, F.: First simulations of designing stratospheric sulfate aerosol geoengineering to meet multiple simultaneous climate objectives, J. Geophys. Res.-Atmos., 122, 12616–12634, https://doi.org/10.1002/2017JD026874, 2017.

[4] MacMartin, D. G., B. Kravitz, S. Tilmes, J. H. Richter, M. J. Mills, J.-F. Lamarque, J. J. Tribbia, and F. Vitt, 2017: The climate response to stratospheric aerosol geoengineering can be tailored using multiple injection locations. J. Geophys. Res. Atmos., 122, 12 574–12 590, https://doi.org/10.1002/2017JD026868

[5] Richter, J. H., Visioni, D., MacMartin, D. G., Bailey, D. A., Rosenbloom, N., Dobbins, B., Lee, W. R., Tye, M., and Lamarque, J.-F.: Assessing Responses and Impacts of Solar climate intervention on the Earth system with stratospheric aerosol injection (ARISE-SAI): protocol and initial results from the first simulations, Geosci. Model Dev., 15, 8221–8243, https://doi.org/10.5194/gmd-15-8221-2022, 2022.

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