Geoengineering Stratospheric Aerosols: Lessons from Volcanic and PyroCb Injections

M. Dubey, J. Reisner, G. D'Angelo, X. Sun, and P. Chylek (Los Alamos National Laboratory)

Background/Objectives. Stratospheric aerosol injection (SAI) that increases the reflection of incident sunlight cooling the earth has been touted as a means to offset global warming by greenhouse gases (GHGs). The accelerating pace of GHG rise and climate impacts (heat waves, sea ice loss, sea level rise, drought, deluges, storms, forest dieback and wildfires) has reinvigorated the exploration of SAI to cool the planet. SAI is an independent anthropogenic force that does not offset the infrared absorption by human GHGs and the net effect on regional climate, hydrology and ecosystems remains unknown and confounds risk-benefit analysis. It also opens national security challenges as nations could implement SAI unilaterally. Global climate models and recently proposed process field experiments (e.g., Harvard's SCOPEX) are the primary tools being used to assess SAI. We introduce a wholistic analysis of the forcing, cooling and drying patterns observed after natural volcanic sulfate and megafire smoke injections into the stratosphere to evaluate SAI. Our approach includes observations and modeling that are more robust and should be acceptable to the public. Early publications offer promising approach for scientists to learn from nature and evaluate SAI.

Approach/Activities. Sulfate, soot and calcium carbonate with distinct optical and microphysical properties have been proposed for SAI. El. Chicon (1982) and Pinatubo (1992) volcanoes lofted large amounts of sulfur dioxide that oxidized to sulfate in the tropical stratosphere and cooled the surface providing historic data useful to evaluate climate models. Furthermore, large stratospheric mass injections of smoke by Pyrocumulonimbi (PyroCb) in British Columbia (BC2017) and Australia (AUS2020) provide data on smoke lifetime, burden and impacts.

We compare observed hemispherical mean surface temperature (HadCRUT4.6.0.0) and the ensemble means of the CMIP5 climate models' reconstructions (40 models, over 100 simulations) using regression analysis with observed forcing. We find that volcanic aerosol regression coefficients of the CMIP5 simulations are significantly larger than the volcanic aerosol coefficients of the observed temperature. The largest overestimate is in the winter season of each hemisphere (Chylek GRL 2020). We dig deeper into the post volcanic climate record to show that low latitude cooling is followed by wintertime warming at high latitudes and use it to evaluate individual model performance. Models are able to simulate these patterns after Mt Pinatubo's eruption but there is a delayed response of surface temperatures after the El Chicon eruption. We rank the models by their skill and recommend such criteria be used for SAI assessments. The climate response of aerosol injection is complex and regional, and it needs to be much better understood before it is considered for climate intervention.

We perform global GEOS-5, E3SM CESM simulations of BC2017 and AUS2020 smoke injection and match observations that imply a smoke lifetime of 5 months, using a 1-2% soot content (D'Angelo JGR 2022). We find that larger amounts of soot increase its lifetime by enhancing self-lofting in the stratosphere. Dark aerosols like soot or hematite have longer residence times than white calcium carbonate that have been proposed and test on small scale in the field. AUS20 simulations show discernable transient cooling effect that was detected.

Results/Lessons Learned. Our approach and publications are providing valuable risk-benefit analysis using natural SMI mimics over a range of aerosol types and loadings. We will expand our analysis to include regional climate responses of temperature and rain, forest fertilization by diffuse radiation, stratospheric ozone loss, global circulation changes, visibility and surface deposition.

1. Chylek, P., Folland, C., Klett, J. D., & Dubey, M. (2020). CMIP5 Climate Models Overestimate Cooling by Volcanic Aerosols, Geophys. Res. Lett., 47, e2020GL087047
2. D’Angelo, G., Guimond, S., Reisner, J., Peterson, D. A., & Dubey, M. (2022). Contrasting stratospheric smoke mass and lifetime from 2017 Canadian and 2019/2020 Australian megafires: Global simulations and satellite observations. Journal of Geophysical Research: Atmospheres, 127, e2021JD036249