Workshop Report: Identifying and leveraging empirical datasets for Solar Radiation Modification Impact Research

EDF-sponsored Workshop in Washington, DC, February 5-6, 2025.
Attended by 22 scientists across the fields of agriculture, hydrology, wildfire, solar radiation modification, and stratospheric chemistry

Brief Workshop Summary

Workshop Background and Motivation

Solar radiation modification (SRM) methods are intended to lower global temperatures by reducing incoming radiation to the earth surface. Global climate models are improving in their ability to predict global temperature changes, but humanity will need to know more than global average temperature. While SRM may be a viable method for reducing average temperatures, it will cause other impacts via changes to precipitation amounts and patterns, extreme temperatures, direct vs. diffuse light ratios, deposition of injected material, and other mechanisms. These may also drive significant impacts on agriculture, ecosystems, health, and other critical systems for humans and non-human nature, interacting with the direct temperature reductions. Decisions on SRM should be driven by science that estimates both the potential benefits of reducing negative climate change impacts and its potential to create harmful or unforeseen impacts. We need more knowledge about the impacts of SRM to inform such decisions.

To date, researchers have mostly studied potential SRM impacts using global climate models. It is difficult to calibrate and validate SRM models, given the lack of empirical data of SRM injections and the basic challenge of simulating future climate change. A distinct but complementary approach leverages observations of useful *analogs* for SRM (e.g., volcanic eruptions, wildfire smoke, natural fluctuations in light quantity and quality) to examine impacts directly. Observational datasets that capture potential impacts of a natural analog might also provide a way to add empirical context to some model results. We investigated the potential for analogs in this phase of our work.

EDF convened researchers with expertise in three socially-critical areas—agriculture, water supplies, and ecosystems/wildfires—together with SRM researchers to identify reasonably historical SRM proxies or analogs. The group explored the available empirical and historical data which might inform further SRM impact research. This brief report summarizes the themes discussed but is not meant to be comprehensive of all possible avenues for exploring empirical data to enable SRM impact research.

Participants were prompted by a series of questions:

1. What are the key drivers of change in the sectors of interest (e.g. agricultural crop yields, water supply data, and fire). How might climate change, with or without future SRM, influence these factors?

2. What historical events or phenomena might function as analogs to SRM? What are their strengths, limitations and weaknesses with respect to simulating SRM?
3. Can we detect the influence of those SRM analogs on the metrics of interest? What are unknowns that cannot be studied through analogs (an example may be changes that take decades to emerge, a limitation associated with the limited timespan of potential analog processes)?

The workshop began with a presentation on the effects of two large volcanic eruptions (a potentially valuable proxy for SRM) on crop yield (following Proctor et al. 2018). That work found that while cooler air temperatures after volcanic events were associated with greater yield across crops, the reduction in light from the same events reduced yields, with the two competing effects resulting in minimal change overall in crop yields. While volcanoes are not a perfect analog for how SRM would ultimately be deployed, they do provide insights into the impacts of increasing stratospheric aerosols on systems of interest without having to run a planetary-scale experiment.

The workshop was then organized into four breakout sessions:
1: What variables drive impacts, and how might they be affected by SRM activities?
2: What historical analogs might be useful in studying the impacts of SRM?
3: Is attribution of impacts to SRM analogs possible?
4: Key research priorities

Summary of Discussion

Several themes emerged as well as some overarching discussion of how research might be organized in the future to better understand the impacts of SRM on systems and sectors of interest and to understand the potential for empirical data to inform understanding. Again, these themes are illustrative of the discussion but not meant to represent a complete exploration of all possibilities for using empirical data to better understand SRM impacts.

A. Agricultural impacts of SRM emerged as an area that merits—and is amenable to—empirical research. Participants identified and discussed a set of linked questions that could be pursued to conduct systematic research. The questions that emerged were:
    - What variables are most important to estimate agricultural yield and at what scale?
    - Which of these variables are most affected by SRM?
    - At what scale are these variables most reliably measured?
    - Do our models reliably replicate those variables at the scale necessary for evaluating impact on agriculture? How do they handle climate change scenarios alone?
    - How do different deployment scenarios affect the estimation of SRM impacts on agriculture?
    - What crops (including commodity crops, animal feed, high value crops and staples grown for subsistence farming) still need to be investigated to understand the full impact of SRM on agriculture?

B. Stratospheric aerosol injection is expected to change the ratio of direct to diffuse sunlight, but this is a phenomenon that is understudied. Participants discussed the effect of increased diffuse light in agricultural and snowmelt-dominated water systems; they felt that light response curves for plants were not well known at the levels at which SRM will act. Properties such as light intensity, spectral distribution, degree of scattering, and UV red shift were brought up as important to investigate both in terms of the plant/ecosystem response and in terms of SRM deployment. Many SRM simulations in the past were run in models with simplistic reductions of the solar constant (sometimes known as "solar dimming") rather than in models that can simulate the effects of aerosols on the range of light properties that would affect plant growth. Difficulties in using empirical data to investigate questions about the effect of light properties on crops and ecosystems include the challenges of signal to noise and the length of observational records. Some possible avenues for future research that participants discussed included conducting shading experiments to mimic the expected impacts of SRM at long term agricultural or ecosystem research sites and using existing datasets with possible analogs for SRM such as volcanoes (even smaller ones) or even comparing light effects at different latitudinal gradients. Some of the questions raised by participants included:

- What properties are more sensitive to direct vs. diffuse radiation ratios?
- How might SRM affect plant productivity?
- In the context of SRM, how is plant productivity affected by diffuse vs. direct light? Will a red shift trigger etiolation or other undesirable responses in plants?
- How do state variables change in various SRM scenarios?
- How have different crops around the world responded to changes in diffuse vs. direct light?
- How important is duration of the proxy occurrence for a given perturbation?

C. What are the limits to historical analogs? Another discussion theme involved identifying limits and opportunities of empirical data sets as analogs to study SRM impacts and gain more systematic knowledge about not only SRM but also climate change impacts. The questions raised included:

- How can we use existing data sets, big data, and even AI to explore analogs to learn about implications of SRM on systems of interest?
- What patterns can be detected, how can we better understand the connection of inputs and outputs? Are there lags? How do we best use statistical learning?
- What analogs best mimic SRM?
- Why and how (if at all) do short-term perturbations like volcanic eruptions, wildfire smoke, contrails, changes in ship tracks due to changes in shipping fuel, etc. provide useful information for understanding SRM? In other words, what is the best way to use natural experiments and what are their limitations? What is detectable with natural experiments?
- How can we be ready for the next big volcanic eruption? What variables can be monitored sufficiently and in what locations to present a record of opportunity that can then be analyzed when a volcano erupts? What is the potential of

smaller, more frequent eruptions or areas of the world with more continuous volcanic activity to serve as analogs?

D. Finally, there were some questions of interest raised about SRM itself and some outstanding questions about detecting impacts against a larger earth system backdrop. For example:
   - What changes and impacts caused by climate change are not reversible with SRM? Where does hysteresis exist in the earth system? Can analogs inform that?
   - How do the impacts of cooling via aerosols in a greenhouse gas-warmed world differ from conditions that would have been present at lower greenhouse gas concentrations (e.g. present day)?
   - How does SRM change interannual variability? Does the standard deviation of annual temperatures go up or down over time?
   - What targets for impact research matter most to people? For example, is it possible to design SRM to “Save the Amazon,” “Save coral reefs” or to hit agricultural productivity targets? How well can we estimate possible societal goals for SRM and what would be needed to improve?
   - Can you use impact targets as design criteria to help decide SRM strategies?
   - Can we design and test a strategy for robust impact research that is replicable and could be then be used and adapted in anticipation of future decision maker questions about impacts?