Potential ecological impacts of climate intervention by solar radiation management

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Climate Intervention: Knowledge Gaps in Ecological Impacts

Climate intervention is a set of proposed activities designed to intentionally modify global climate to reduce anthropogenic global warming; one approach, solar radiation management (SRM), aims to deliberately reduce or stabilize the temperatures by reflecting incoming solar radiation to increase Earth's albedo. The most well studied approach to SRM is stratospheric aerosol intervention (SAI). **While a great deal of work has been done on climate projections for SAI, almost nothing is known about its predicted ecological impacts (Figure 1).** Ecologists have not addressed the real possibility that climate intervention could take place, and awareness of the extent of work on SRM modeling is limited within this community. Climate scientists may not be fully aware of the potential impacts that anthropogenic climate change and SRM strategies may have on ecological systems (Zarnetske, Gurevitch et al. in review).

Anthropogenic climate change has enormous consequences for humans and nature. If we could use SAI to stabilize temperatures while also working to minimize GHG emissions,

- *Should we do it? Or are the risks and uncertainties too great, **relative to ongoing anthropogenic climate change?***
- *Do the risks and consequences of climate intervention for humans and ecological systems outweigh the possible benefits?*
- *Or are the risks and consequences of anthropogenic climate change so great that we cannot ignore potential reductions of those risks using SAI?*
- *What ecological systems and regions would be most helped, and which ones would face greater risks?*
- *Should biodiversity and ecosystem outcomes be goals of SAI? How do the impacts and risks of different SAI scenarios compare?*

The answers to these critical questions are necessary to inform future decisions about potential implementation.

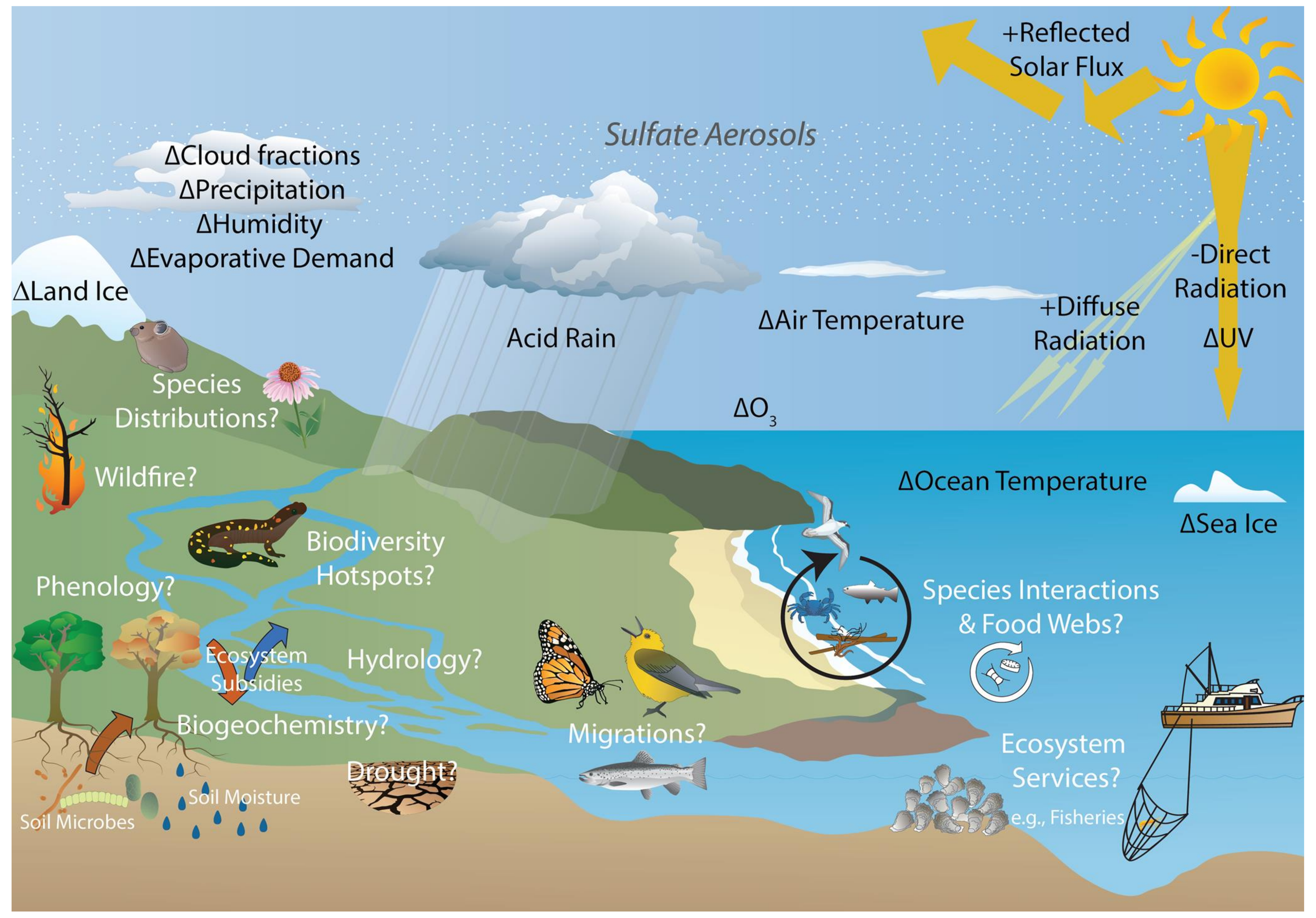

Figure 1. The effects of Solar Radiation Management (SRM) with stratospheric aerosol intervention (SAI) on ecological systems are largely unknown. Some effects on climate are known for certain SAI scenarios (indicated with + for increases, – for decreases, Δ for change). Biotic and abiotic responses vary with region and SAI scenario. SAI would reflect more ultraviolet (UV) radiation to space, reducing surface UV. SAI could also destroy some stratospheric ozone, increasing surface UV (see Fig. 2A), depending on the scenario. Ozone would be reduced at high latitudes. For potential changes in ocean pH and temperature see Figure 3. *Images courtesy of Integr.& Appl. Net., U Maryland Ctr Env Sci.*

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Stratospheric Aerosol Intervention (SAI) Scenarios

SAI is inspired by the way that volcanic eruptions cool the global climate, and involves injecting gaseous precursors of reflective sulfate aerosols into the stratosphere. Different SAI scenarios have been modeled by climate scientists, and involve different assumptions about GHG emissions, and the amount, duration, timing and location of SAI into the atmosphere (Tilmes et al. 2020; Figure 2).

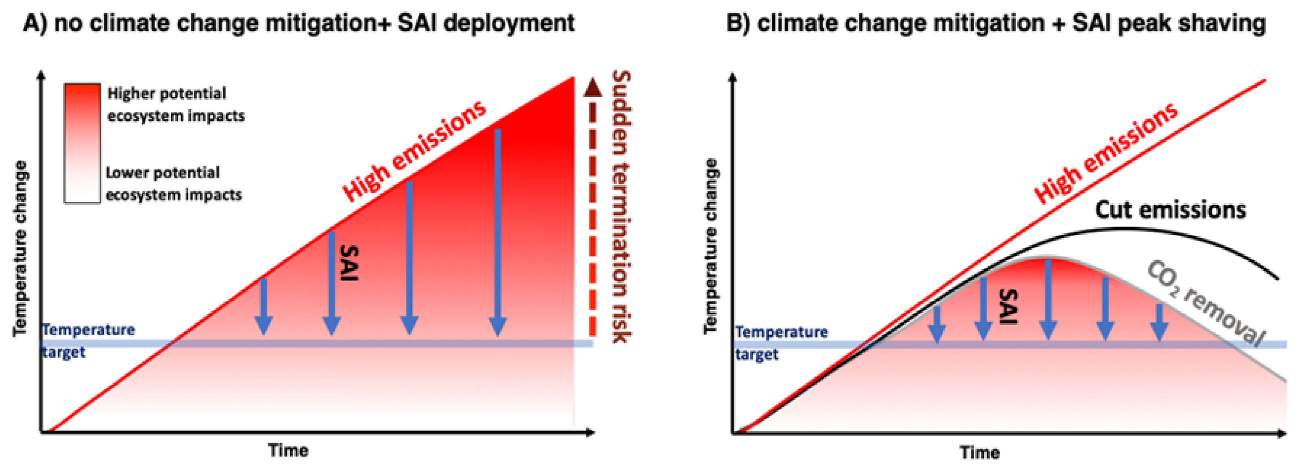

Figure 2. Potential temperature change over time for two different stratospheric aerosol intervention (SAI) scenarios. (A) With no emissions reduction and SAI deployment, increasing amounts of SAI are deployed to reduce temperature (blue arrows) to a specific temperature target (blue line), with increased risk for sudden SAI termination risk (red arrow). (B) With climate change mitigation and SAI "peak shaving", global warming is reduced by emission reduction (black line) and CO_2 removal (grey line), then further reduced by SAI (blue arrows). The red shaded areas below the two curves indicate the potential overall risk for ecological systems from increased temperature and SAI deployment. While the "peak shaving" scenario poses fewer risks, it will be difficult to achieve, and also, this scenario may be inadequate to reduce Arctic permafrost thaw and consequences for biodiversity, as well as feedbacks to the climate system from methane release.

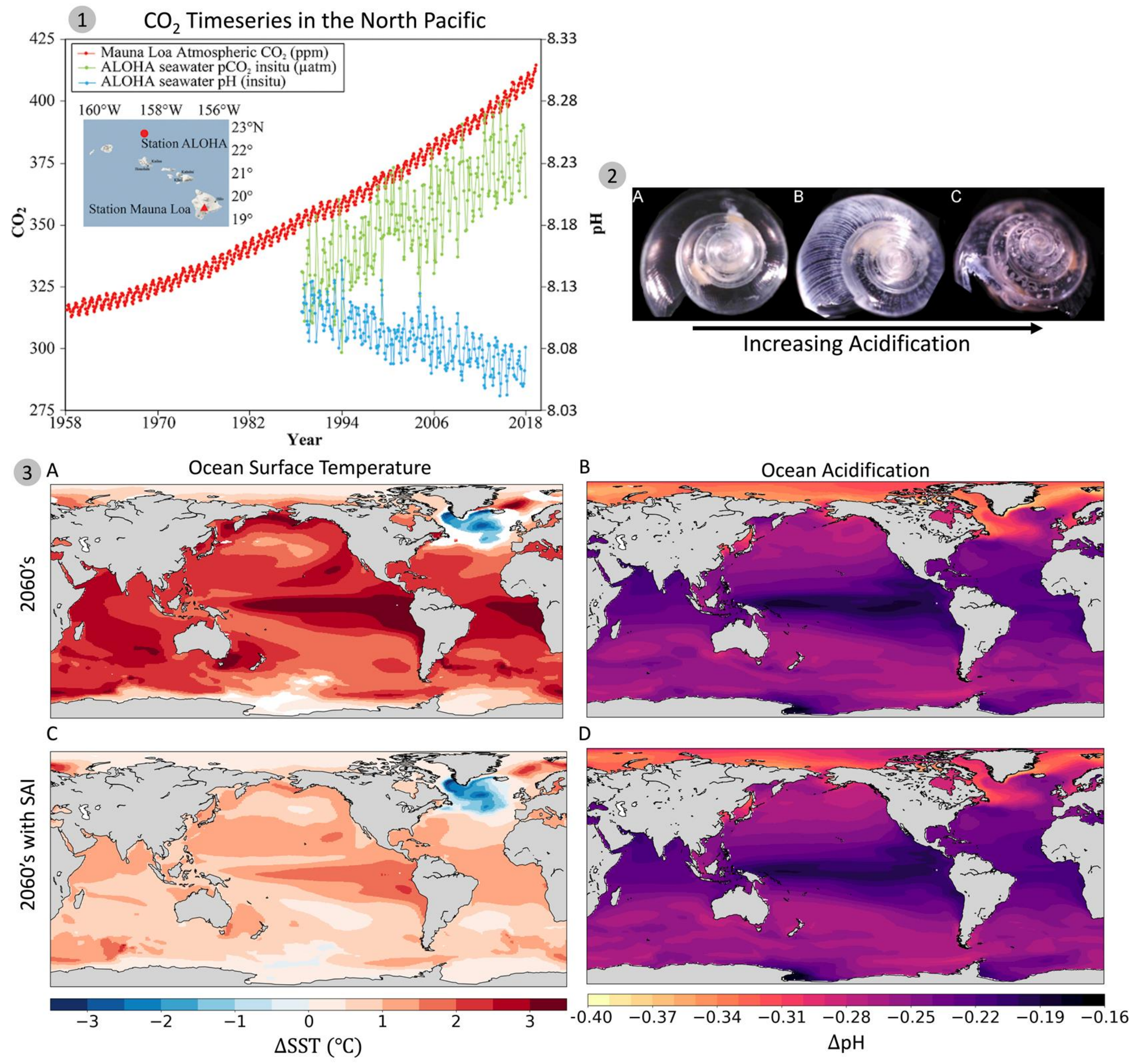

Figure 3. SAI alone would not reduce ocean acidification, which strongly impacts marine ecosystems. 1) Historical time series of CO_2 and ocean acidification at station ALOHA. Anthropogenic carbon emissions (red line) have been absorbed by the ocean (green line), reducing pH and harming calcifying marine organisms at the base of the marine food web (blue line). 2) Shells of calcifying marine plankton (pteropods) are damaged by ocean acidification. 3) Stratospheric aerosol intervention applied to a "peak shaving" future climate scenario as in Fig. 2B reduces sea surface temperature anomalies (ΔSST; A,C) but would not ameliorate ocean acidification (ΔpH; B,D). Scenario shown is SSP5-3.4-OS (Tilmes et al. 2020).

Potential Ecological Risks and Consequences of SAI

SAI would not simply turn back the clock to the climate at some previous time. It could change many climate variables beyond temperature that are important for ecological systems.

Potential effects of SAI include:

- Increase ratio of diffuse to direct radiation
- UV radiation: UV radiation: + or - depending on latitude/CFC conc./injection strategy
- Dissociation of temperature from atmospheric CO_2 concentration
- Precipitation: geographic distribution, intensities and seasonality changes
- Changes to surface ozone
- Regional perturbations to climate including seasonal and diurnal cycles of temperature, precipitation, humidity, and snow and ice cover
- Small decreases in land NPP due to cooling (if CO_2 remains high)

GHGs and SAI affect climate differently and affect hydrologic and biogeochemical processes differently. GHGs cause global warming by absorbing energy in the atmosphere, but SAI would reduce the amount of solar energy that enters Earth's system. This would have marked ecological consequences, because regional, seasonal, and diurnal climate responses will not be the same as with no forcings, even if global average temperature does not change.

Potential risks of SAI include:

- Acid precipitation
- "Moral hazard" of reduced incentives to limit GHG emissions
- Catastrophic sudden termination with very rapid temperature rise
- Decreased transpiration with cool temperatures and high CO_2 leading to increased streamflow
- No mitigation of ocean acidification (Figure 3)
- Complex changes to biogeography of tropic forests due to changes in water supply and seasonality, temperature, VPD, diffuse:direct light ratio
- Changes to monsoonal and other rainfall patterns resulting in unknown + and - effects on biodiversity hotspots

Potential of SAI to amelioration anthropogenic climate change may include:

- Decreased average and extreme high temperatures globally
- Reduced incidence of extreme precipitation events
- Some amelioration of warming effects in Arctic, depending on scenario
- Slowing advances of tropical and subtropical pests and pathogens to temperate regions (?)
- Slowing/alteration of climate velocities and changes to species, community and biome distributions

Ecologists should be more aware of SRM research, and climate scientists of ecological work

Collaboration between ecologists and climate scientists can help to:

- Identify a common set of SAI research goals
- Elucidate potential ecological risks and opportunities of SAI
- Develop possible climate intervention strategies that meet ecological goals, and
- Improve awareness of potential SAI effects (+ and -) and risks

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