Learning to manage sunlight: Research needs for Solar Radiation Management

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Two kinds of geoengineering

Geoengineering describes two distinct concepts. Carbon Dioxide Removal (CDR) describes a set of tools for removing carbon dioxide from the atmosphere, while Solar Radiation Management (SRM) would reduce the Earth's absorption of solar energy, cooling the planet by, for example, adding sulfur aerosols to the upper atmosphere or adding sea salt aerosols to increase the lifetime and reflectivity of low-altitude clouds.

We must make deep cuts in global emissions of carbon dioxide to manage the risks of climate change. While emissions reductions are necessary, they are not necessarily sufficient. Emission cuts alone may be insufficient because even if we could halt all carbon emissions today, the climate risks they pose would persist for millennia—by some measures, the climate impact of carbon emissions persists longer than nuclear waste. Moreover, the climatic response to elevated carbon dioxide concentration is uncertain, so a small risk of catastrophic impacts exists even at today's concentration.

Technologies for decarbonizing the energy system, from solar or nuclear power to the capture of CO_2 from the flue gases of coal-fired power plants, can cut emissions—allowing us to limit our future commitment to warming—but they cannot reduce the climate risk posed by the carbon we have already added to the air, and that risk grows as each ton of emissions drive up the atmospheric carbon burden.

Risk management is at the heart of climate policy: planning our response around our current estimate of the most likely outcome is reckless. We must hope for the best while laying plans to navigate the worst.

SRM and CDR do different things. SRM is cheap and can act quickly to cool the planet, but it introduces novel environmental and security risks and can—at best—only partially mask the environmental impacts of elevated carbon dioxide.

In concert with emissions cuts, CDR technologies can reduce the carbon burden in the atmosphere; one might call it global climate remediation. We need a means to reduce atmospheric CO_2 concentrations in order to manage the long-run risks of climate change. Unless we can remove CO_2 from the air faster than nature does, we will consign the earth to a warmer future for millennia or commit ourselves to the risks of sustained SRM.

But, carbon removal can only make a difference if we capture carbon by the gigaton. The shear scale of the carbon challenge means that CDR will always be relatively slow and expensive.

SRM and CDR each provide a means to manage climate risks; they are, however, wholly distinct with respect to

- the science and technology required to develop, test and deploy them;
- their costs and environmental risks; and,
- the challenges they pose for public policy and governance.

Because these technologies have little in common, I suggest that we will have a better chance to craft sensible policy if we treat them separately.

In the spirit of disclosure, I offer a few comments about my own work. I run Carbon Engineering, a startup company that aims to develop industrial scale technologies for capturing CO_2 from the air. I will be happy to answer questions about these technologies, but I will focus my remarks on SRM because I believe that is where there is the most urgent need for action that links the development of a research program to progress on learning how to manage this potentially dangerous technology.

Because of the serious and legitimate concerns raised by the enormous leverage SRM technologies grant us over the global climate, I think it is crucial that development of these technologies be managed in a way that is as transparent as possible. I therefore do no commercial or proprietary work on SRM.

The primary argument against research on SRM is fear that it will reduce the political will to lower greenhouse gas emissions. I believe that the risks of not doing research outweigh the risks of doing it. Solar-radiation management may be the only response that can fend off unlikely but rapid and high-consequence climate impacts. Further, there are environmental and geopolitical risks posed by the potential of unilateral deployment of SRM, which can best be managed by developing widely-shared knowledge, risk assessment, and norms of governance.

The idea of deliberately manipulating the Earth’s energy balance to offset human-driven climate change strikes many as dangerous hubris. It is a healthy sign that a common first response to geoengineering is revulsion. It suggests we have learned something from past instances of over-eager technological optimism and subsequent failures. But we must also avoid over-interpreting this past experience. Responsible management of climate risks requires sharp emissions cuts and clear-eyed research and assessment of SRM capability. The two are not in opposition. We are currently doing neither; action is urgently needed on both.

An overview of solar radiation management

SRM has three essential characteristics: it is cheap, fast, and imperfect. Long-established estimates show that SRM could offset this century’s global-average temperature rise a few hundred times more cheaply than achieving the same cooling by emission cuts. This is because such a tiny mass is required: a few grams of sulfate particles in the stratosphere can offset the radiative forcing of a ton of atmospheric carbon dioxide. At a few $1000 a ton for aerosol delivery to the stratosphere that adds up to a figure in the order of $10 billion dollars per year to provide a cooling that—however crudely—counteracts the heating from a doubling of atmospheric carbon dioxide.

This low price tag is attractive, but raises the risks of single groups acting alone and of facile cheerleading that promotes exclusive reliance on SRM.

SRM can alter the global climate within months – as shown by the 1991 eruption of Mt. Pinatubo, which cooled the globe about 0.5 C in less than a year. In contrast, because of the carbon cycle's inertia, even a massive program of emission cuts or carbon dioxide removal will take many decades to discernibly slow global warming.

A world cooled by managing sunlight will not be the same as one cooled by lowering emissions. An SRM-cooled world would have less precipitation and less evaporation. Some areas would be more protected from temperature changes than others, creating local winners and losers. SRM could weaken monsoon rains and winds. It would not combat ocean acidification or other carbon dioxide-driven ecosystem changes and would introduce other environmental risks such as delaying the recovery of the ozone hole. Initial studies suggest that known risks are small, but the possibility of unanticipated risks remains a serious underlying concern.

Cheap, fast and imperfect: each of these essential characteristics has profound implications for public policy.

- Because SRM is imperfect, it cannot replace emissions cuts. If we let emissions grow and rely solely on SRM to limit warming, these problems will eventually grow to pose risks comparable to the risks of uncontrolled emissions.
- Because SRM is cheap, even a small county could act alone, a fact that poses hard and novel challenges for international security.
- Finally, because SRM appears to be the only fast-acting method of slowing global warming it may be a powerful tool to manage the risks of unexpectedly dangerous climate outcomes.

Towards Solar Radiation Management research plan

The capacity to implement SRM cannot simply be assumed. It must be developed, tested, and assessed. Research to date has largely consisted of a handful of climate model studies, using very simple parameterizations of aerosol microphysics. More complex models of aerosol physics need to be developed and linked to global climate models. Field tests will be needed, such as experiments generating and tracking stratospheric aerosols to block sunlight and dispersing sea-salt aerosols to brighten marine clouds. Decades of upper atmosphere research has produced a mass of relevant science. But, except for a recent ill-conceived Russian test, there have been no field tests of SRM.

There has been no dedicated government research funding available for SRM anywhere in the world; though, a few programs for have begun in Europe in the past few months.

The environmental hazards of SRM cannot be assessed without knowing the specific techniques that might be used, and it is impossible to identify and develop techniques without field testing. Such tests can be small: tonnes not megatonnes.

It is widely assumed, for example, that a suitable distribution of stratospheric sulfate aerosols can be produced by releasing SO_2 in the stratosphere, but new simulations of aerosol micro-physics suggest the resultant aerosol size distribution would be skewed to large particles that are relatively ineffective. Several aerosol compositions and delivery methods may offer a way around this problem, but choosing between them and assessing their environmental impacts will require small-scale in-situ testing.

To provide a specific example related to my own work, NASA's ER-2 high-altitude research plane might be used to release a ton of sulfuric acid vapor along a 10 km plume in the stratosphere, and fly through the plume to assess the formation of aerosol and its sun scattering ability and its impact on ozone chemistry. Such tests take a few years to plan and cost a few million dollars.

An international research budget growing from roughly $10 million to $1 billion annually over this decade would likely be sufficient to build the capability to deploy SRM and greatly improve understanding of its risks.

It is important to start slowly. Research programs can fail if they get too much money too quickly. Given the limited scientific community now knowledgeable about SRM, a very rapid buildup of research funding might result in a lot of ill-conceived projects being funded and, given the inherently controversial nature of the technology, the result might be a backlash that effectively ends systematic research.

The US will need an interagency research program, because no single agency has the right combination of abilities to manage the whole program. For example, NSF's processes for transparent peer-review and investigator driven funding will be important in effectively supporting the diversity of critical analysis that is necessary on such an inherently controversial topic. But NSF is perhaps less suited to manage the larger mission oriented programs that link technology development and science.

NASA has some institutional history and abilities that may be particularly relevant to stratospheric SRM. The high-speed research program, for example, linked scientific efforts to understand the impacts a supersonic transport fleet on the ozone layer with technology development aimed to minimize those impacts. The management and research assets used in this program could serve as the foundation of a program to develop and test technologies for delivering stratospheric aerosols. But NASA is less suited to fostering diverse early-stage science.

DOE's Office of Science has a record managing large programs and DOE has a relevant track record with its Atmospheric Radiation Measurement (ARM) program. But SRM is not at its core an energy problem and there will be difficulties fitting it into the DOE structure.

Finally, the inherently controversial nature of SRM research makes it particularly important that it not be entrusted exclusively to either its proponents or its adversaries. The development of an interagency program may help to foster the necessary diversity. Indeed, there may be value in a "blue team/red team" approach, as sometimes used for military preparedness planning. One team is charged to make an approach as effective and low-risk as possible, while the other works to identify all the ways it can fail. Anticipating the conditions of urgency, even panic, that might attend a future decision to deploy SRM, such an adversarial approach may increase the quality and utility of information available in time to aid future decision-makers.

Concluding thoughts

Although risk of climate emergencies may motivate SRM research, it would be reckless to conduct the first large-scale SRM tests in an emergency. Instead, experiments should expand gradually to scales big enough to produce barely detectable climate effects and reveal unexpected problems, yet small enough to limit resultant risks. Our ability to detect the climatic response to SRM grows with the test's duration, so starting sooner makes the scale of experiment needed to give detectable results by any future date—say by 2030—smaller. A later start delays when results are known, or requires a bigger intervention in order to detect the response.

Beyond research, building responsibly toward future SRM capability also requires surmounting problems of international governance that are hard, and novel. These are quite unlike the problems of emissions mitigation, where the main governance challenge is motivating contributions to a costly shared goal. For SRM, the main problem will be establishing legitimate collective control over an activity that some might seek to do unilaterally. Such a unilateral challenge could arise in many forms and from many quarters. At one extreme, a state might simply decide that avoiding climate-change impacts on its people takes precedence over environmental concerns of SRM and begin injecting sulfur into the stratosphere, with no prior risk assessment or international consultation. If this were a small state, it could be quickly stopped by great-power intervention. If it were a major state, that might not be possible.

Alternatively a nation might grow frustrated at the pace of international cooperation and establish a national program of gradually expanding research and field tests. This might be linked to a distinguished international advisory board, including leading scientists and retired politicians of global stature. It is plausible that, after exhausting other avenues to limit climate risks, such a nation might decide to begin a gradual, well-monitored program of SRM deployment, even absent any international agreement on its regulation. In this case, one nation—which need not be a large and rich industrialized country —

would effectively seize the initiative on global climate, making it extremely difficult for other powers to restrain it.

No existing treaty or institution is well suited to SRM governance. Given current uncertainties immediate negotiation of a treaty is probably not advisable. Hasty pursuit of international regulation would risk locking in commitments that might soon be seen as wrong-headed, such as a total ban on research or testing, or burdensome vetting of even innocuous research projects.

A better approach would be to build international cooperation and norms from the bottom up, as knowledge and experience develop—as has occurred in cases as diverse as the development of technical standards for communications technology to the landmine treaty which emerged bottom-up from action by NGOs. A first step might be a transparent, loosely-coordinated international program supporting research and risk assessments by multiple independent teams. Simultaneously, informal consultations on risk assessment, acceptability, regulation, and governance could engage broad groups of experts and stakeholders such as former government officials and NGO leaders. Iterative links between emerging governance and ongoing scientific and technical research would be the core of this bottom-up approach.

Opinions about SRM are changing rapidly. Only a few years ago, many scientists opposed open discussion of the topic. Many now support model-based research, but discussion of field testing of the sort we advocate here is contentious and will likely grow more so. The main argument against SRM research is that it would undermine already-inadequate resolve to cut emissions. I am keenly aware of this 'moral hazard'—indeed I introduced the term into the geoengineering literature—but I am skeptical that suppressing SRM research would in fact raise commitment to mitigation. Indeed, with the possibility of SRM now widely recognized, failing to subject it to serious research and risk assessment may well pose the greater threat to mitigation efforts, by allowing implicit reliance on SRM without critical scrutiny of its actual requirements, limitations, and risks. If SRM proves to be unworkable or poses unacceptable risks, the sooner we know the less moral hazard it poses; if it is effective, we gain a useful additional tool to limit climate damages.