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Key Points:
- Some claims about SRM persist in academic and popular literature despite evidence and strong arguments to the contrary
- This paper describes and refutes five common claims regarding costs, risks, and politics of SRM that are unsupported by the evidence
- Repeating unsupported claims do a disservice to the debate when there is a need for evidence-based, even-handed scrutiny of SRM

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Five solar geoengineering tropes that have outstayed their welcome

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Abstract In the last decade, solar geoengineering (solar radiation management, or SRM) has received increasing consideration as a potential means to reduce risks of anthropogenic climate change. Some ideas regarding SRM that have been proposed have receded after being appropriately scrutinized, while others have strengthened through testing and critique. This process has improved the understanding of SRM's potential and limitations. However, several claims are frequently made in the academic and popular SRM discourses and, despite evidence to the contrary, pose the risk of hardening into accepted facts. Here, in order to foster a more productive and honest debate, we identify, describe, and refute five of the most problematic claims that are unsupported by existing evidence, unlikely to occur, or greatly exaggerated. These are: (A) once started, SRM cannot be stopped; (B) SRM is a right-wing project; (C) SRM would cost only a few billion dollars per year; (D) modeling studies indicate that SRM would disrupt monsoon precipitation; and (E) there is an international prohibition on outdoors research. SRM is a controversial proposed set of technologies that could prove to be very helpful or very harmful, and it warrants vigorous and informed public debate. By highlighting and debunking some persistent but unsupported claims, this paper hopes to bring rigor to such discussions.

1. Introduction

During the last decade, solar geoengineering (or solar radiation management, henceforth simply "SRM") has come under increasing consideration as the risks of anthropogenic climate change—especially to the world's most vulnerable people and ecosystems—have become clearer and more severe. Paul Crutzen's recommendation to research SRM because meaningful emission mitigation looks "like a pious wish" [*Crutzen*, 2006, p. 217] initiated a wave of academic and societal interest in the means to deliberately alter the planet's climate.

As the years have passed since Crutzen's seminal paper, his pessimistic analysis has increasingly looked prescient and prudent. Global greenhouse (GHG) emissions have risen by around 20% since 2006 [*Global Carbon Project*, 2015], and SRM research in the natural and social sciences has moved forward at an accelerating rate. High-profile reports from the Royal Society [*Shepherd et al*., 2009] and the U.S. National Academies [*McNutt et al*., 2015], international conferences at Asilomar in 2010 and in Berlin in 2014, a concerted international modeling effort [*Kravitz et al*., 2015], and the launch of an initiative to bring developing country voices into the discussions (the Solar Radiation Management Governance Initiative) all represent significant milestones on the road to a better understanding of SRM.

Looking back on the last decade's developments underlines the value of the entangled processes of research, reflection, and discussion. Some of the contentious topics that arose following Crutzen's essay, such as how best to govern field experiments and how countries could come to agreement over the deployment of SRM, continue to engage researchers and inspire debate, and will likely do so for some time.

Other ideas that were at one stage quite prominent have fallen away as increased scholarly attention highlighted their shortcomings. For example, it took little more than back-of-the-envelope calculations to remove space mirrors and white roofs from the list of serious proposals for increasing the Earth's albedo [*Shepherd et al*., 2009, pp. 25, 32–34]. On the carbon removal side of geoengineering, ocean fertilization is now much less prominent than it was a decade ago. Despite protests from vocal

activist groups, field tests were allowed to proceed and generally revealed many of the problems of the technique.

Some beliefs around potential SRM use that were once canonical have also retreated in the glare of sustained scrutiny. While it once was common to hear the claim that SRM should be thought of as a reactive response to be deployed at the onset of a global climate emergency, this idea has been challenged on numerous grounds and is losing favor [*Sillmann et al*., 2015]. Similarly, the suggestion that SRM could realistically be deployed by a rich individual, a private corporation, or a small country is also falling from grace as analyses indicate that nonstate or so-called "rogue" action appear to be quite unlikely [*Parson*, 2014, pp. 94–103].

The fact that these ideas were put forth, scrutinized, and ultimately reconsidered is a source of encouragement for those of us involved in the SRM discourse. At the same time, other claims continue to be repeated despite contrary evidence, to a point at which some of them risk hardening into apparent facts. As a result, it can sometimes be difficult to distinguish legitimate claims from those that have a weak evidence base. Here, we identify, describe and refute five of the most prominent claims that are variously unsupported by existing evidence, unlikely to occur, or simply inaccurate in order to foster a more productive and honest debate. We selected those that are asserted frequently, that are incorrect in some fundamental way, and that can be described and refuted in a few hundred words. There are others that would require substantially more space. For each, we point to one or two examples in the academic or popular literature, although many citations are possible. While it is a topic that deserves attention, we do not try to explain why these claims arose and persist.

2. Claim A: Once Started, SRM Cannot Be Stopped

In her most recent bestseller, influential anticapitalist activist Naomi Klein wrote "once you start spraying material into the stratosphere to block the sun, it would basically be impossible to stop because if you did, all the warming that you had artificially suppressed by putting up that virtual sunshade would hit the planet's surface in one single tidal wave of heat" [*Klein*, 2014, p. 260]. Klein is not alone in this belief; she merely repeats an assertion that is common in both popular commentary and academic analysis of SRM [e.g., *Brovkin et al*., 2009; *Goes et al*., 2011].

The assertion stems from the fact that SRM would not reduce atmospheric GHG concentrations; it would only mask their warming effect by blocking some sunlight. Therefore, if SRM were to stop suddenly, temperatures would begin to rebound rapidly toward the levels they would have reached without it. Numerous studies have found that this effect—sometimes dubbed "termination shock"—could be extremely damaging for humans and ecosystems as there would be less time to adapt to the new temperatures [*Matthews and Caldeira*, 2007]. While the threat of termination shock is a genuine concern, it has led some commentators to claim that if SRM were ever started, it could not be stopped or that it would need to be maintained for thousands of years. Yet this claim is demonstrably incorrect as there are three ways in which SRM could be started and then stopped without incurring termination shock.

First, if SRM were only exerting a low degree of cooling, then it could be switched off suddenly without risking termination shock. *Kosugi* [2013] demonstrated that if the SRM cooling remained below a certain threshold, it would be hard even to detect the effects of terminating deployment against the natural variations in temperature.

Second, even a high degree of SRM cooling could be stopped without inducing termination shock if it were slowly ramped down over decades. *Keith and MacMartin* [2015] modeled a scenario in which SRM cooling is ramped up and then slowly ramped back down again. This resulted in a slower overall rise in global temperatures (relative to a no-SRM scenario), which stands in contrast to the rapid rise in temperatures associated with a sudden cessation of a large-scale deployment of SRM.

Third, SRM deployment of any scale could be phased out without any temperature rises at all if it coincided with the large-scale use of carbon dioxide (CO_2) removal techniques [*Shepherd et al*., 2009]. If CO_2 levels were brought down by CO_2 removal techniques, then the amount of SRM cooling needed to keep temperatures steady would decline, and if CO_2 levels were brought down sufficiently, SRM cooling would no longer be needed.

Therefore, the claim that "Once you start SRM it can't be stopped" is simply not true. To be accurate, it should read "Once you start SRM and it is exerting a fairly high degree of cooling, it cannot be stopped suddenly, but could be phased out over a long period." While accurate, that is less compelling a claim.

3. Claim B: SRM Is a Right-Wing Project

Some observers claim that SRM is a project of conservative political forces and has been driven by actors allied with carbon-intensive industry, the military, and climate denialism. Activist and philosopher Clive Hamilton claimed in the *New York Times*, "If there is such a thing as a right-wing technology, geoengineering is it." [*Hamilton*, 2015; see also *Steffen*, 2009; *Klein*, 2014]. This is a simple narrative that aligns well with the common perception that the climate change debate is binary and polarized. In this view, some groups and people recognize the threat of climate change and advocate for aggressive reductions of GHG emissions, while various interests aligned with the fossil fuel industry and antiregulation ideologues seek to undermine such efforts. Many of the concerned groups and people believe that SRM would undermine political support for emissions cuts, in turn extending the fossil fuel era. Concluding that advocacy of SRM research originates from climate deniers and oil executives is perhaps understandable but untrue.

Confirming this narrative requires cherry-picking anecdotal evidence from infrequent contributions by fringe conservative actors, such as one statement by former Speaker of the House Newt Gingrich [*Gingrich*, 2008] and single opinion columns from a staff member of the Hudson Institute [*Furchtgott-Roth*, 2008]. Yet one could similarly cherry-pick evidence in order to tell a story in which SRM is the project of environmental groups and the likes of the Dalai Lama [*Dizikes*, 2012] and Amartya Sen [*SRM Science* 2015, 2015], while conservative groups dismiss it, and climate denialists deride it as a "batshit crazy," "smoke and mirrors" [*Watts*, 2011], and a "bad idea" [*Knappenberger*, 2014].

An examination of the people who have actually moved SRM from the margin toward more serious consideration reveals three common characteristics. First, they have mostly spent their careers working on understanding and preventing climate change and are highly concerned about its projected negative impacts. Second, they desire emissions cuts but are pessimistic regarding the likelihood that these will actually be sufficient to prevent dangerous climate change. For example, Crutzen wrote in his influential article, "By far the preferred way to resolve the policy makers' dilemma is to lower the emissions of the greenhouse gases. However, so far, attempts in that direction have been grossly unsuccessful" [*Crutzen*, 2006, pp. 211–212]. Since then, all major reports from leading scientific bodies, such as the UK Royal Society and the U.S. National Academies, have made their leading recommendation or conclusion an emphasis on the primacy of emissions mitigation [*Shepherd et al*., 2009, p. ix; *McNutt et al*., 2015, p. 3]. Likewise, David Keith, the author of *A Case for Climate Engineering* [*Keith*, 2013b], supports fossil fuel divestment [*Keith*, 2013a]. Ken *Caldeira* [2012] has repeatedly said that "the only ethical path is to stop using the atmosphere as a waste dump for greenhouse gas pollution." And several large American environmental groups have cautiously supported SRM research and helped moved its serious consideration forward [*Environmental Defense Fund*, 2015; *Frumhoff*, 2015; *Natural Resources Defense Council*, 2015]. Third, advocates for SRM research are typically unenthusiastic about its potential development and deployment [*Anshelm and Hansson*, 2014]. For example, Caldeira said, "Only fools find joy in the prospect of climate engineering" [*Caldeira*, 2008].

Although a handful of actors on the political right have indeed voiced support for SRM, others have made clear their opposition. A similar picture is found on the left. Claims that it is a project of the right wing or the climate change denial movement are consistent with wider climate change narratives but are not supported by the evidence.

4. Claim C: SRM Would Cost a Few Billion Dollars Per Year

It has become a common practice to describe SRM as "cheap" [*Copenhagen Consensus Center*, undated] based on studies that—very usefully—explored the direct deployment costs of stratospheric aerosol injection. These found that getting enough sulfates up to the stratosphere to curb global warming would require only a few billion U.S. dollars per year, orders of magnitude less than the costs of aggressive GHG emissions cuts [*Moriyama et al*., 2016]. Commentary on the "incredible economics of geoengineering" [*Barrett*, 2008] subsequently ran with the idea. Some speculated that private corporations or individuals might implement SRM [*Victor*, 2008], while Newt Gingrich welcomed the projected low cost

[*Gingrich*, 2008], but the claim that SRM would only cost a few billion dollars per year does not stand up well to scrutiny.

The total costs of the SRM system would ultimately be much higher than those for the simple delivery because there would be many other items added to the bill before the final reckoning. For example, a large-scale observation and modeling effort would be needed if the deployer wanted to monitor the impacts of their climate intervention. Furthermore, high-level security would be necessary to protect the deployment infrastructure, and excess deployment capacity would be desirable "insurance" against the possibility of faulty or destroyed delivery equipment. In addition, even if SRM were to reduce net harms from climate change around the world, some areas might still experience negative environmental effects. Funds might be needed to compensate countries who claim—rightly or wrongly—that they have been harmed. Finally, it has been observed how the final costs of large public projects often balloon beyond original estimates [*MacKerron*, 2014]. The final bill for SRM deployment, therefore, seems likely to be *substantially* higher than the few billions dollars projected for delivering aerosols to the atmosphere.

5. Claim D: Modeling Studies Indicate That SRM Would Disrupt Monsoon Precipitation

In a pioneering modeling study, *Robock et al*. [2008, p. 1] concluded, " … if there were a way to continuously inject SO2 into the lower stratosphere, it would produce global cooling." However, they went on to warn that "Both tropical and Arctic SO_2 injection would disrupt the Asian and African summer monsoons, reducing precipitation to the food supply for billions of people." Although the hydrological response to SRM is a legitimate source of concern, activist and media interpretations of such results are often misleading and have had a large impact on the broader public debate. Two crucial considerations are often missing from many analyses.

First, the degree of cooling from SRM and the magnitude of the associated reduction in monsoon precipitation would be a choice. Global warming is projected to increase global mean precipitation and the average precipitation in most monsoon regions, including in Asia and Africa [*Tilmes et al*., 2013]. Studies have consistently found that SRM deployed to offset all the warming from elevated GHG concentrations would result in a net reduction in global mean and monsoon precipitation compared to a low GHG baseline that would be roughly equal to, but opposite in, sign to the increase in precipitation that is projected under global warming. However, the level of cooling would be a choice, and if SRM were deployed to offset around half of the warming from rising GHG concentrations, then models consistently indicate that there would be no net change in global mean precipitation and little change in monsoon precipitation compared to a low GHG baseline [*Irvine et al*., 2010; *Ricke et al*., 2010; *Tilmes et al*., 2013]. In other words, the net reduction in monsoon precipitation is not an inevitable result of SRM deployment; it only occurs in scenarios where SRM is deployed at very large scale.

Second, reports on the effects of SRM often cite its impacts on precipitation, but that only tells half of the story. The quote above reflects an (seemingly reasonable) assumption that less rainfall would reduce water availability for people, plants, and animals. However, along with reducing precipitation, SRM would reduce evaporation, and to understand the effect on water availability, both changes in precipitation and evaporation must be considered. Furthermore, at elevated CO_2 concentrations, plants will use water more efficiently and grow faster if other constraints allow [*Franks et al*., 2013]. Taking these factors together, climate model studies of SRM deployment in which many regions show a reduction in rainfall also show an *increase* in river flow as reductions in evaporation and transpiration more than offset the changes in rainfall [*Kravitz et al*., 2013; *Glienke et al*., 2015].

As climate change risks are the reason for considering SRM, the benefits and risks of deploying it can only be sensibly evaluated against those of not deploying it. At this early stage, we have far too little evidence to conclude how SRM might affect a range of climate risks, such as on water availability. However, contrary to many media reports, modeling studies have consistently indicated that SRM could significantly reduce the disruptions to temperature and precipitation but that it cannot eliminate these changes [*Boucher et al*., 2013].

6. Claim E: There Is an International Prohibition on Outdoors Research

Some writers assert that outdoor SRM activities would violate international law. Most often, they claim that it is subject to a legally binding international moratorium [*Friends of the Earth*, 2015], sometimes going so far as to refer to a "ban" [*Tollefson*, 2010]. This generally refers to a decision taken by the Conference of Parties to the Convention on Biological Diversity (CBD) [*Secretariat of the Convention on Biological Diversity*, 2010]. However, an assertion of a binding international moratorium or ban on outdoor SRM research is inaccurate on several counts.

First, CBD decision X/33, as well as the its 2012 decision XI/20, are hortatory, not binding. The former merely "invites Parties … to consider" not allowing SRM activities that would (significantly, adversely) affect biodiversity until three criteria are met: (1) an adequate scientific basis, (2) consideration of risks, and (3) scientific justification. Furthermore, the decision also indicates that it applies only in the absence of adequate regulation. That is, under certain circumstances, outdoor geoengineering activities—even those that would affect biodiversity—would be consistent with the decision.

Second, the assertion of a moratorium on outdoor research misreads the text of the CBD decision. One of the authors of this essay, Andy Parker, was present for all 14 h of geoengineering side negotiations at the 2010 Conference of Parties. It was clear that the delegates were not agreeing on a moratorium on outdoor research as evidenced by X/33's references to two specific articles of the CBD. Article 14 was invoked to clarify that, where geoengineering activities do not have *significant adverse* impacts on biodiversity, they are covered neither by Convention nor the decision. Article 3 was noted to remind parties that they must notify and consult with potentially affected states in the event that their planned activities may have transboundary impacts.

Third, assertions of a research moratorium at the CBD ignore that the decision *explicitly states* that small-scale research may proceed, providing that environmental impact assessments are conducted.

Finally, such conferences of parties do not have the power to create binding international law. That is limited to treaties and the recurring customary behavior of states.

Ultimately, the statement is a moderate and welcome expression of caution from the parties to the CBD. Indeed, the CBD institutions acknowledge it as such, calling it a "non-binding normative framework" in a report [*Secretariat of the Convention on Biological Diversity*, 2012, p. 106].

7. Conclusion

In the decade since Crutzen's seminal paper, research, discussion, and critical reflection on SRM have flourished. This process has been fruitful. In some cases, it has generated promising new ideas for how SRM might be developed, delivered, or governed. In other cases, equally desirably, it has exposed the problems with ideas that were once frequently accepted. Winnowing out the weaker ideas has been crucial for improving the quality of debate while increasing the chances that the thorny issue of SRM can be handled prudently—whether ultimately it is implemented or rejected.

This process is, of course, imperfect, and there are still inaccurate notions about SRM that have obstinately outstayed their welcome, even though they are unsupported by the evidence or even demonstrably untrue. This paper identifies, describes, and refutes five common but problematic claims that linger in SRM analysis. Due to space limitations, it did not consider how and why the claims arose and persist. However, research into this—and into why the most persistent and inaccurate claims seem to predominantly support arguments against SRM—would be both fruitful and welcome.

There are many strong arguments for the expansion of SRM research and development and many legitimate concerns about its implications. The debate around SRM must be well informed, and scrutiny should be fair. Wherever the claims listed here appear in commentary, they undermine debate by misinforming it. Discussion and reflection need to distinguish legitimate concerns from those that are fundamentally incorrect. At this stage, it remains unclear whether SRM will prove to be a useful tool in the fight against climate change. Regardless, the sooner that such SRM myths are dispelled, the sooner that the discourse can move on to consideration of SRM's genuine potential benefits and risks.

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