A Response to:
Five Solar Geoengineering Tropes That Have Outstayed Their Welcome

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IN A NEW PIECE[1] in the journal Earth Futures, Jesse Reynolds, Andy Parker and Peter Irvine take on what they characterize as "Five solar geoengineering tropes that have outstayed their welcome."[2] While I think it's salutary to engage in an ongoing colloquy about the risks and benefits of solar radiation management (SRM) approaches, it will be my contention in this Comment that the article doesn't wholly dispel many of the concerns outlined in the piece. Additionally, I believe it raises some additional issues that are ripe for debate as we continue to scrutinize the emerging field of climate geoengineering.

In this Comment, I will address the authors' take on three of these alleged "tropes."

Claim 1 - Once started, SRM cannot be stopped

The authors initially address the assertion of some critics that SRM technologies would have to be deployed for a protracted period (perhaps for centuries[3]) to avoid the threat of the so-called "termination" or "rebound effect." The termination effect refers to the potential for a huge multi-decadal pulse of warming should the use of an SRM scheme be terminated abruptly in the future due to technological failure or a decision by future policymakers.[4] This would be a consequence of the buildup of carbon dioxide that had accrued in the atmosphere in the interim, with its suppressed warming effect, as well as the temporary suppression of climate-carbon feedbacks.[5] As the authors note, "[n]umerous 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."[6]

In response, the authors first argue that termination shock risks could likely be obviated by deploying SRM at a reduced scale, "exerting a low degree of cooling," or gradually ramping up deployment and subsequently ramping down.[7] Many other proponents have also recently suggested that SRM technologies might be used for "peak temperature shaving," perhaps seeking only to keep temperatures in stasis, rather than seeking to radically reduce temperatures.[8]

However, I find this argument problematic for several reasons. First of all, it suggests that, using David Victor's phrase, that one country or group of countries, or an international regime, would have "hands on

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[1] Jesse Reynolds, Andy Parker & Peter Irvine, *Five Solar Geoengineering Tropes that Have Outstayed their Welcome,* EARTH'S FUTURE (2016), http://onlinelibrary.wiley.com/doi/10.1002/2016EF000416/epdf.
[2] *Id.* at 1.
[3] Scott Barrett, *Solar Geoengineering's Brave New World: Thoughts on the Governance of an Unprecedented Technology,* 8(2) REV. ENVTL. & ECON. & POL'Y 294, 297 (2014); Katharine L. Ricke, M. Granger Morgan & Myles R. Allen, *Regional Climate Response to Solar-Radiation Management,* 3 NATURE GEOSCI. 537, 538 (2010).
[4] William C.G. Burns, *Climate Geoengineering: Solar Radiation Management and its Implications for Intergenerational Equity*, 4 STANFORD J. L. SCI. POL'Y 37, 47 (2008), https://journals.law.stanford.edu/sites/default/files/stanford-journal-law-science-policy-sjlsp/print/2011/05/burns_final.pdf.
[5] H. Damon Matthews & Ken Caldeira, *Transient Climate-Carbon* 104(2) PROC. NAT'L ACAD. SCI. 9951 (2007).
[6] Reynolds, Parker & Irvine, *supra* note **Error! Bookmark not defined.**, at 3.
[7] *Id.*
[8] Andrew Lockley, *Licence to Chill: Building a Legitimate Authorisation Process for Commercial SRM Operations,* 18(1) Envtl. L. Rev. 25, 37 (2016); Joshua Horton, *The Emergency Framing of Solar Geoengineering: Time for a Different Approach,* 2(2) THE ANTHROPOCENE REV. 147, 150 (2016).

the thermostat,"[9] and could thus ensure that an SRM technology would be deployed at a limited scale. In reality, this may not be the case. Many proponents of SRM technologies tout the fact they could be deployed unilaterally, or by a small consortium of States. As Michaelson concludes, this "minimizes the impact of the tragedy of the commons by not requiring international behavior modification."[10] However, the corollary of this argument is that it's by no means clear that the "thermostat" would thus be set to only effectuate peak shaving of temperatures. Should the SRM genie be let out the bottle, one or more States might decide that it was in their best interest to effectuate greater reductions in temperatures than what the authors of this article might deem "optimal" (such as, low-lying developing States).[11] Or States might try to offset the impacts of deployment of SRM options by other States by "counter-climate engineering."[12] Even one of the most full-throated supporters of climate geoengineering, David Keith, acknowledges this threat, concluding that a single State might unilaterally deploy a geoengineering option to pursue what it perceives as its self-interest, with little regard for the interests of the rest of the world.[13]

Second, development of a limited-scale SRM option would require sufficient understanding of climatic processes and feedback mechanisms, as well as stratospheric chemistry and aerosol microphysics.[14] However, as one of the authors of this article (Irvine), has observed in another recent study, in the context of sulfur dioxide injection proposals, "simulations to date of the consequences of [solar aerosol injection] have been made with models with a number of significant shortcomings resulting in significant uncertainty in some aspects of the response."[15] Perhaps most pertinently, Irvine et al. further notes that models employed in GeoMIP (Geoengineering Model Intercomparison Project) experiments "are producing very different aerosol clouds for the same deployment of SAI, which will of course affect the climate outcomes … the global cooling effect of the same release of SO_2 is very different in the various models."[16] Thus, I believe that one would be hard-pressed to argue that we currently could confidently "tailor" SRM deployment to meet desired objectives, nor is there compelling evidence that we will have sufficient knowledge of critical parameters in the future to do so.

Finally, the authors argue that SRM options "could be phased out without any temperature rises at all if it coincided with the large scale use of carbon dioxide removal techniques."[17] However, several issues would be raised by this proposition. First, coupling

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[9] David G. Victor, *On the Regulation of Geoengineering,* 24(2) OXFORD REV. ECON. POL'Y 322, 331 (2008).
[10] J. Michaelson, *Geoengineering: A Climate Change Manhattan Project,* 17(1) STANFORD ENVTL. L. 74, 76 (1998).
[11] Mark G. Lawrence, *The Geoengineering Dilemma: To Speak or Not to Speak,* 77 CLIMATIC CHANGE 245, 246 (2006).
[12] Lee Lane, *Plan B: Climate Engineering to Cope with Global Warming,*12(3) MILKEN INST. 45, 51 (2010), http://assets1b.milkeninstitute.org/assets/Publication/MIReview/PDF/44-53MR47.pdf. *See also* Michael Zűrn & Stefan Schäfer, *The Paradox of Climate Engineering,* 4(3) GLOBAL POL'Y 1, 5 (2013);
[13] David Keith, *Learning to Manage Sunlight: Research Needs for Solar Radiation Management,* Testimony before the Energy and Environment Subcommittee of the US House of Representatives Committee on Science and Technology, 4 Feb. 2010, at 5, http://archives.democrats.science.house.gov/Media/file/Commdocs/hearings/2010/Energy/4feb/Keith_Testimony.pdf . *See also* Martin L. Weitzman, *The Geoengineered Planet* in IN ONE HUNDRED YEARS (I. Huerta-Palacios, ed. 2013).
[14] Peter J. Irvine, et al., *An Overview of the Earth System Science of Solar Geoengineering,* 7 WIREs CLIMATE CHANGE 815, 824 (2016).
[15] *Id.*
[16] *Id.*
[17] Reynolds, Parker & Irvine, *supra* note **Error! Bookmark not defined.**, at 4.

and coordinating the deployment of SRM options with CDR options, in addition to mitigation and adaptation climate responses, would present a tremendous challenge for the climate governance community. It is far from clear that the world community would be up to this tremendous escalation in governance complexity. Second, carbon dioxide removal options remain largely speculative at this point, with only a few pilot plants in

operation,[18] and major concerns exist as to whether such options will ever be economically viable, especially with tepid carbon price signals.[19] Finally, carbon dioxide removal options may pose serious risks that could severely limit their deployment or seriously undermine the desirability of coupling their use with SRM approaches. For example, consider the implications of large-scale deployment of Bioenergy with Carbon Capture and Storage (BECCS), the only so-called negative emissions technology considered by the Intergovernment Panel on Climate Change in its Fifth Assessment Reports.[20] Even if deployed at modest scales, could result in appropriation of more than 20% of net primary productivity.[21] This could result in substantial spikes in food prices for some of the world's most vulnerable populations, imperiling food security.[22] Moreover, BECCS deployment could put severe strains on water resources[23] and pose "massive" changes in species abundance and richness.[24]

Claim 2 - SRM is a right-wing project

The second argument advanced by the article's authors is that the SRM research agenda is not impelled by "actors allied with carbon-intensive industry, the military, and climate denialism."[25] I concur that this argument lacks support. However, it does highlight the importance of carefully scrutinizing the motivations and interests of actors in the climate geoengineering community to ensure objectivity.

As Jane Long, former Director at Large for the Lawrence Livermore Laboratory, has observed, "We will need to protect ourselves from vested interests [and] be sure that choices are not influenced by parties who might make significant amounts of money

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[18] A. Neil Craik & William C.G. Burns, *Climate Engineering Under the Paris Agreement: A Legal and Policy Primer,* Centre for International Governance Innovation, Special Report (2016), at 3, https://www.cigionline.org/sites/default/files/documents/GeoEngineering%20Primer%20-%20Special%20Report.pdf; *Negative Emissions Tested at World's First Major BECCS Facility,* CarbonBrief, May 31, 2016, https://www.carbonbrief.org/analysis-negative-emissions-tested-worlds-first-major-beccs-facility.

[19] Massimo Tavoni & Robert Socolow, *Modeling Meets Science and Technology: An Introduction to a Special Issue on Negative Emissions,* 118 CLIMATIC CHANGE 1, 4 (2013); Elmar Kriegler, et al., *Is Atmospheric Carbon Dioxide Removal a Game Changer for Climate Change Mitigation Options?,* 118 CLIMATIC CHANGE 45, 47 (2013); American Physics Society, *Direct Air Capture of CO_2 With Chemicals,* at i, https://www.aps.org/policy/reports/assessments/upload/dac2011.pdf.

[20] Dominic Woolf, Johannes Lehmann & David R. Lee, *Optimal Bioenergy Power Generation for Climate Change Mitigation with or Without Carbon Sequestration,* NATURE COMMUNICATIONS, Oct. 21, 2016, DOI: 10.1038/ncomms13160, at 2.

[21] Pete Smith et al, *Biophysical and Economic Limits to Negative CO2 Emissions*, 6 NATURE CLIMATE CHANGE 42, 46 (2016).

[22] Scott Barrett, *Solar Geoengineering's Brave New World: Thoughts on the Governance of an Unprecedented Technology*, 8(2) REV. ENVTL. ECON. 249, 254 (2014); UN Office of the High Commissioner, Mandate of the Special Rapporteur on the Right to Food, *Note on the Impacts of the EU Biofuels Policy on the Right to Food*, 23 Apr. 2013, www.srfood.org/images/stories/pdf/otherdocuments/20130423_biofuelsstatement_en.pdf.

[23] Markus Bonsch et al, *Trade-offs Between Land and Water Requirements for Large-Scale Bioenergy Production*, 8 GCB BIOENERGY 11, 12 (2014).

[24] Markus Bonsch et al, *supra* note 23, at 12. *See also* Phil Williamson, *Scrutinize CO2 Removal Methods*, 530 NATURE 153, 154 (2016).

[25] Reynolds, Parker & Irvine, *supra* note **Error! Bookmark not defined.**, at 4.

through a choice to modify climate, especially using proprietary intellectual property."[26] In this context, there is a serious question as to whether some of the most prominent climate geoengineering researchers may face a conflict of interest in terms of their research and commercial pursuits. Several prominent climate geoengineering scientists are involved in commercial enterprises seeking to develop and market geoengineering technologies.[27] Indeed, we've already seen this potential conflict of interest manifested in the context of SRM field research. One of the rationale for shelving a planned experiment to inject water into the atmosphere, as part of the Stratospheric Particle Injection for Climate Engineering (SPICE) project, was the discovery that two of the scientists involved in the experiment had failed to reveal that they had submitted patents for similar technologies.[28] Given the momentousness of any decision to deploy SRM technologies, every effort should be made to both ensure transparency in all aspects of research, as well as to assiduously avoid potential conflicts of interest.

Claim 3 – Modelling studies indicate that SRM would disrupt monsoon precipitation

The fourth issue addressed in the article is the potential for SRM to lead to serious regional precipitation anomalies, focusing onthe conclusion of a number of studies that deployment of some SRM technologies might alter hydrological cycles and, *inter alia,* disrupt Asian and African summer monsoons.[29] In response, the authors initially contend that these potentially serious impacts could be ameliorated by limiting the scale of deployment to offset only half of the warming associated with rising greenhouse gas emissions. I believe that my reservations about limited-scale SRM deployment, outlined above, would be equally apposite here.

The second argument advanced by the authors is that SRM would reduce evaporation, and enhance plant water use efficiency, thereby more than offsetting any potential reduction in water availability associated with decreases in precipitation.[30] However, at least in the context of sulfur aerosol injection, there is empirical evidence that casts doubt on these conclusions. A study by Trenberth & Dai[31] of the impacts of the eruption of Mt. Pinatubo in 1991, which resulted in the spewing of massive amounts of sulfur dioxide into the stratosphere, should give us cause to question the authors' insouciance. This event is pertinent to assessments of sulfur aerosol injection geoengineering options. This is because the amount of sulfur dioxide that would need to be injected into the stratosphere to compensate for projected warming in the second half of this century could be commensurate, or somewhat higher, than the emissions from the eruption of Mt. Pinatubo.[32] Trenberth & Dai found that sulfur

[26] John Vidal, Bill Gates Backs Climate Scientists Lobbying for Large-Scale Geoengineering, The Guardian, Feb. 6, 2012, https://www.theguardian.com/environment/2012/feb/06/bill-gates-climate-scientists-geoengineering.
[27] Carbon Engineering, http://carbonengineering.com/; Intellectual Ventures Laboratory, http://www.intellectualventureslab.com/?page_id=258.
[28] Daniel Cressey, *Geoengineering Experiment Cancelled Amid Patent Row,* Nature News, May 5, 2012, http://www.nature.com/news/geoengineering-experiment-cancelled-amid-patent-row-1.10645; Erin Hale, Geoengineering Experiment Cancelled Due to Perceived Conflict of Interest, The Guardian, May 16, 2012, https://www.theguardian.com/environment/2012/may/16/geoengineering-experiment-cancelled.
[29] Reynolds, Parker & Irvine, *supra* note **Error! Bookmark not defined.**, at 6.
[30] *Id.*
[31] Kevin E. Trenberth & Aiguo Dai, *Effects of Mount Pinatubo Volcanic Eruption on the Hydrological Cycle as an Analog of Geoengineering,* 34 GEOPHYS. RES. LETTERS, L15702 (2007).
[32] A.V. Elisee, I.I. Mokhov and A.A. Karpenko, *Global Warming Mitigating by Means of Controlled Aerosol Emissions into the Stratosphere: Global and Regional Peculiarities of Temperature*

dioxide injection into the stratosphere associated with the eruption of Mt. Pinatubo ultimately resulted in substantial reductions in both precipitation and river discharge. Indeed these reductions were much larger than variations for all other years in the more than half century of data examined in the study, including during strong El Nino events.[33]

Similarly, Hegerl & Solomon found that Mt. Pinatubo resulted in substantial declines in global stream flow and increases in the incidence of drought.[34] Perhaps Reynolds, et al. would contend that the offsetting factors they cite would prove dominant in the longer term. However, I would suggest that additional support should be proffered for this proposition given the potentially dire ramifications of altering precipitation patterns.

SRM remains a highly contested climate policy option; I would not so easily dispatch some of the concerns addressed by Reynolds, et al. in their piece.

Response as Estimated in IA RAS CM Simulations, 22(4) ATMOS. & OCEANIC OPTICS 388, 390 (2009).

[33] Trenberth & Dai, *supra* note 31, at 3.

[34] Gabriele C. Hegerl & Susan Solomon, *Risks of Climate Engineering,* 325 SCI. 955, 955 (2009).