Briefing

Solar Radiation Modification: a dangerous distraction from required emissions reductions

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Solar radiation modification (SRM), where higher amounts of sunlight are reflected back to space through artificially altering either the Earth's surface or the atmosphere, is presented by some as an option that may help to limit global temperature rise.

However, SRM cannot address the root causes of anthropogenic climate change – the continued emissions of greenhouse gases and nor can it address critical issues such as ocean acidification caused by CO_2 emissions.

Some argue that a dedicated international SRM governance framework is required. But our assessment is that there is no such thing as a just and safe governance framework for SRM, and there is a significant risk that continued discussions of SRM governance could lead to a normalisation of SRM as a policy option that is not supported scientifically.

Serious risks from SRM are well established. Investing precious time and resources in this critical decade to explore SRM technologies distracts from the urgent need to step up mitigation efforts to halve emissions by 2030.

SRM is at odds with the ultimate objective of the UNFCCC

- By not addressing greenhouse gas concentrations directly, SRM methods provide no real avenue to achieve the UNFCCC's ultimate objective which is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".
- This, by extension, also holds for the Paris Agreement objectives that have been set out as "enhancing the implementation of the Convention, including its objective".
- In addition, it has to be stressed that global SRM methods themselves constitute "dangerous anthropogenic interference with the climate system".

SRM will introduce additional and potentially catastrophic risks

- The latest assessment of the IPCC is clear that SRM would introduce additional risks, not only in terms of physical impacts but also in terms of governance, international collaboration and peace[1].
- By merely masking global warming, SRM is only effective as long as it is deployed. This leads to the risk of rapid warming and abrupt changes to the hydrological cycle if SRM were to suddenly end, also called the termination shock.
- Sudden SRM termination could lead to the equivalent of 70 years of continued global warming over a span of 20 years[2]. Such fast paced climate change would bring far worse impacts and be impossible to adapt to. This includes the risk of extinction for thousands of species.
- Model studies suggest that global stratospheric aerosol injection deployment would still lead to changes in climate, with warmer and wetter winters over Northern Eurasia and cooler and drier winters over Southern Europe. Especially strong effects can be observed over the Iberian Peninsula where winter precipitation would be reduced even more than under a very high emissions scenario[3].
- All SRM options are projected to lead to changes in the hydrological cycle[1]. This means potential risks such as modifying weather systems, and further endangering ecosystems, biodiversity, agricultural production and human health.
- Changes in regional water cycles as well as changes to the direct sunlight reaching the surface will likely impact crop yields and ecosystem productivity.

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[1] Patt, A. *et al.* International Cooperation. in *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. Shukla, P. R. et al.) (Cambridge University Press, Cambridge, UK and New York, NY, USA, 2022). doi:10.1017/9781009157926.016.

[2] Bhowmick, M., Mishra, S. K., Kravitz, B., Sahany, S. & Salunke, P. Response of the Indian summer monsoon to global warming, solar geoengineering and its termination. *Sci. Rep.* 11, 1–11 (2021).

[3] Jones, A. *et al.* The impact of stratospheric aerosol intervention on the North Atlantic and Quasi-Biennial Oscillations in the Geoengineering Model Intercomparison Project (GeoMIP) G6sulfur experiment. *Atmos. Chem. Phys.* 22, 2999–3016 (2022).

- Stratospheric aerosol injection could further impact human health directly by delaying the recovery of the ozone hole and, in the case of sulfate aerosols, by causing acid rain[1].
- The full suite of additional risks introduced by SRM can only be understood after an implementation at scale. But any such validation of modelling results through large field experiments would already present a form of deployment with potential far-reaching consequences.

No mature SRM technology exists that could be implemented today

- The feasibility of SRM deployment, as well as how the climate and ecosystems will respond, is still largely uncertain – no mature technological solution exists today[4]. For example, one of the most well-known SRM options, stratospheric aerosol injection, is facing severe technological constraints, as dispersing aerosols in sufficiently high altitudes is challenging[5].
- Questions around technical feasibility go hand in hand with large uncertainties on the actual costs. While SRM is often touted as a comparatively low-cost option, this depends on the chosen SRM option and length of deployment. SRM is not a one-off solution but would need to be deployed continuously, leading to unforeseeable, but sustained, financial commitments.
- How our climate responds to SRM has only been assessed through theoretical and modelling studies using oversimplified scenarios[6]. Large uncertainties in SRM-related processes such as aerosol microphysics contribute to a low confidence in understanding the actual climate response[4].
- Uncertainties around SRM technologies means that there is additional risk of substantial residual, or even additional, regional climate change[1].

SRM distracts from the need to rapidly reduce emissions

- By artificially reducing global temperatures, SRM hides the root cause of global warming – ongoing greenhouse gas emissions – and cannot address impacts of high concentrations of greenhouse gases in the atmosphere. For example, as concentrations of CO_2 in the atmosphere would continue to be at high levels, so would ocean acidification, creating severe risks for marine life.
- Speculations on future SRM deployment distract from the more urgent need to reduce emissions and run the risk of competing for resources with mitigation options. Contrary to SRM, the mitigation options required to limit warming in line

[4] Lee, J.-Y. *et al.* Chapter 4. Future Global Climate: Scenario-Based Projections and Near-Term Information. in *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* 553–672 (IPCC, 2021). doi:10.1017/9781009157896.006.553.

[5] Haywood, J. M., Jones, A., Johnson, B. T. & Smith, W. M. F. Assessing the consequences of including aerosol absorption in potential stratospheric aerosol injection climate intervention strategies. *Atmos. Chem. Phys.* 22, 6135–6150 (2022).

[6] Lockley, A. et al. (2022): 18 Politically relevant solar geoengineering scenarios. Socio-Environmental Systems Modelling, vol. 4, 18127, doi:10.18174/sesmo.18127

with 1.5°C are known, available and economically competitive today, at costs of USD100 per tonne of CO_2e or less.

What is solar radiation modification?

SRM aims to counteract warming by increasing the reflection of sunlight from the Earth back to space through altering the surface albedo (the amount of light the surface reflects) and cloud cover in the stratosphere and troposphere. Some of the proposed technologies include the injection of aerosols into the stratosphere or brightening clouds. It is sometimes also referred to as solar radiation management or solar geoengineering[5].

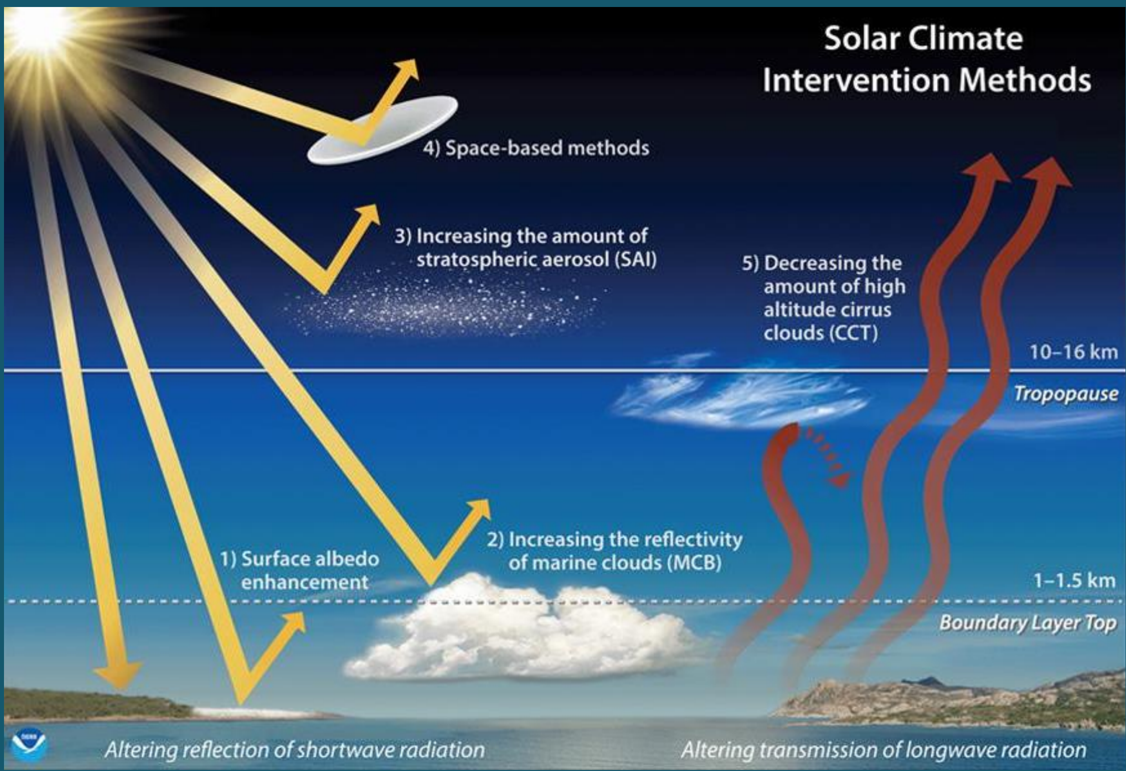

Figure 1: *Proposed SRM methods on the Earth's surface, in the atmosphere, and in space, and their interaction with incoming sunlight (shortwave radiation) and outgoing heat (longwave radiation). Graphic by NOAA/CIRESES*[7]

For descriptions of the main SRM technologies (SAI, MCB and CCT in Figure 1) see Table 1. Other methods to enhance surface albedo are more regional to local in their effect. Due to extremely large logistical and cost demands, hypothetical space-based methods have found little to no regard in recent scientific literature.

[7] Thompson, C.: Climate intervention methods, *NOAA/CIRES*: https://research.noaa.gov/article/ArtMID/587/ArticleID/2756/Simulated-geoengineering-evaluation-cooler-planet-but-with-side-effects.

The ones not responsible but most vulnerable could suffer most – again

- SRM will introduce additional risks for vulnerable regions: their ecosystems, societies and economies, biodiversity, human health, agriculture, and economies as a whole. Regional hazards may result from both locally and globally deployed SRM options. The uneven distribution of impacts will hit communities who are least equipped to handle additional strains, the most[8].
- Just as the effects of global warming are not felt evenly across the globe, neither would be the effects of global cooling. Offsetting global warming through a uniform reduction of incoming radiation is projected to lead to a non-uniform response, with overcooling as well as reduced average rainfall in the tropics and residual warming in the high-latitudes[1].
- For example: the Indian Summer Monsoon brings around 80% of annual rainfall to a region that is home to more than 1 billion people. SRM would lead to ongoing changes in precipitation patterns over the Indian subcontinent. The abrupt termination of SRM would in turn lead to the potential risk of drought and floods, due to large increases in temperature and precipitation[2].

SRM does not address worsening ocean acidification

- Unless CO_2 emissions are substantially reduced in line with 1.5°C pathways, marine ecosystems will continue to be under threat from ocean acidification. Ocean acidification harms calcifying organisms, such as crustaceans or corals, and can cause their dissolution. Ocean acidification leads to decreased growth and survival of marine organisms, especially in early life stages. It also advances erosion and dissolution of coral reef substrate and decreases coral settlement. This will leave communities dependent on coral reefs especially vulnerable, as reef integrity and ecosystem services will be impaired.[9]

A governance framework for SRM that is just and safe for all seems inconceivable

- To ensure global participation, inclusiveness and justice, robust decision-making procedures would have to ensure consensus on places, manner, intensity, and duration of deployment, responsibility, and compensation for any harm that may be caused. Given the uneven spread of effects and risks, reaching global consensus would be highly unlikely.
- Unequal regional participation in the scientific discourse can already be observed. SRM research is predominantly conducted in the global North[1]. This introduces a power dynamic that could be reproduced in any actual SRM deployment, as costs would likely be covered by countries or individuals from the global North who may not be willing to share control[8].

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[8] Biermann, F. *et al.* Solar geoengineering: The case for an international non-use agreement. *WIREs Clim. Chang.* 13, e754 (2022).

[9] Cooley, S. *et al. Oceans and Coastal Ecosystems and their Services*. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (2022). doi:10.1017/9781009325844.005.379.

- Due to pervasive questions about SRM necessity and desirability as well as concerns around ethics and governance, scientists have gone as far as calling for an international non-use agreement[8].
- A just and safe governance framework for SRM deployment would need to be long-term, robust, and global. The likelihood of implementation of such a framework in an equitable way is very low when looking at other current multilateral discourses, such as to solve the climate crisis.
- Unlike global challenges like the climate crisis, SRM deployment is not bound to international cooperation, as it is essentially a technology that can be deployed by any individual actor with the financial, political or military power to do so.
- Any large-scale SRM deployment will lead to transboundary consequences, potentially aggravating existing tensions. It also opens up a door to where political conflict could result in consequences for SRM deployment and impacts, while risking single actors taking over control and misusing these technologies for self-interest or potential hidden agendas[10].

Table 1: Overview of main SRM technologies and their potential impacts based on scientific understanding at the time of publication.

Description	Potential impacts
Stratospheric Aerosol Injection (SAI)	
Injection of particles directly into the stratosphere to deflect sunlight back into space	• Changes in atmospheric circulation (change in precipitation and runoff patterns; disruption of monsoon patterns) • Ozone loss and delay in ozone hole recovery; increased UV radiation • Effects crop yield, land and ocean ecosystem productivity, and could cause acid rain
Marine Cloud Brightening (MCB)	
Enhancing marine cloud reflectiveness by aerial spraying of sea salt into the lower levels of the atmosphere	• Changes in atmospheric circulation (changes in land-sea temperature and precipitation gradient; regional changes in precipitation and runoff) • Uneven distribution if deployed from ships along shipping routes • Changes in land and ocean ecosystem productivity; crop yield • Will leave deposits of sea salt on land
Cirrus Cloud Thinning (CCT)	
Reducing cirrus cloud formation, coverage, and optical thickness by inhibition of nucleation process through the injection of particles at high altitudes	• Imprecise application could lead to warming • Changes to temperature and precipitation patterns • Changes in regional water cycles • Impacts on vegetation; crop yields (altered photosynthesis, carbon uptake)

[10] Tang, A. & Kemp, L. A Fate Worse Than Warming? Stratospheric Aerosol Injection and Global Catastrophic Risk. *Front. Clim.* 3, 1–17 (2021).