

Solar Radiation Management: A Climate Tool with Geopolitical Implications

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► Key Takeaways

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| <ul style="list-style-type: none">■ Solar radiation management (SRM) could help cushion a climate overshoot, buying time to scale up mitigation and carbon dioxide removal (CDR).■ Weak governance and low awareness may precipitate climate dominance by major powers, particularly at the expense of the Global South and marginalized communities. | <ul style="list-style-type: none">■ Stratospheric aerosol injection (SAI) in particular could be rapidly deployed at scale despite high risks, with the Arctic region as a likely testing ground.■ France and the European Union should adopt a clear stance on SRM, establishing common institutions and regulations. |
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Introduction

The Paris Agreement (2015) aims to keep global warming below 2 °C, preferably 1.5 °C, above pre-industrial levels. Mitigation (reducing greenhouse gas emissions) remains the core tool for reaching net carbon neutrality¹ by mid-century. However, a temperature overshoot is anticipated.² The United Nations Environment Programme (UNEP) forecasts that the 1.5 °C threshold will be exceeded in the coming years, with warming potentially peaking between 2.2 °C and 3.6 °C this century.³ Against this backdrop, three trends characterize the climate policy debate.

First, while initially viewed as distracting from mitigation, adaptation measures—such as building seawalls, selecting heat-resistant crops, or greening urban areas—are now fully integrated into the policy toolbox. Second, carbon dioxide removal (CDR) has emerged as a contentious complement to mitigation and adaptation.⁴ Since 2007, the Intergovernmental Panel on Climate Change (IPCC) has included CDR methods in most scenarios that meet the 2 °C target. Forestry, bioenergy with carbon capture and storage (BECCS), or direct air capture and storage (DACs) could hasten carbon neutrality by compensating for residual emissions from hard-to-abate sectors like cement production and aviation. This could lead to negative emissions (where sequestered CO₂ exceeds emitted CO₂), causing atmospheric concentrations to decline. Third, solar radiation management (SRM)—techniques that aim to stimulate Earth's albedo, reflect part of solar radiation and induce artificial cooling—are garnering significant attention.

This *Memo* is devoted to SRM, specifically stratospheric aerosol injection (SAI), which seeks to mimic the cooling effect of particles released during volcanic eruptions. Since Nobel laureate Paul Crutzen warned in 2006 that SAI should be investigated if mitigation falls short,⁵ SAI has dominated SRM discussions. This prominence stems from a lack of major technological hurdles, modest projected costs, and the promise of rapid cooling with immediate benefits against heatwaves, droughts, hurricanes, and coral bleaching. Yet SAI also carries potentially deleterious side effects, including acid rain, ozone layer depletion, hydrological disruption, and the risk of termination shock.⁶

SRM and hybrid policies

SRM techniques aim at enhancing Earth's albedo at various altitudes: at ground level (urban surface brightening, crop brightening), in the troposphere (marine cloud brightening, cirrus cloud thinning), in the stratosphere (SAI), and in space (orbital mirrors) to cool local,

1. Net carbon neutrality means that residual emissions are compensated for by carbon dioxide removal (CDR).

2. See the Intergovernmental Panel on Climate Change (IPCC), available at: <https://apps.ipcc.ch>.

3. *Limiting Overshoot*, Nairobi: United Nations Environment Programme, 2026.

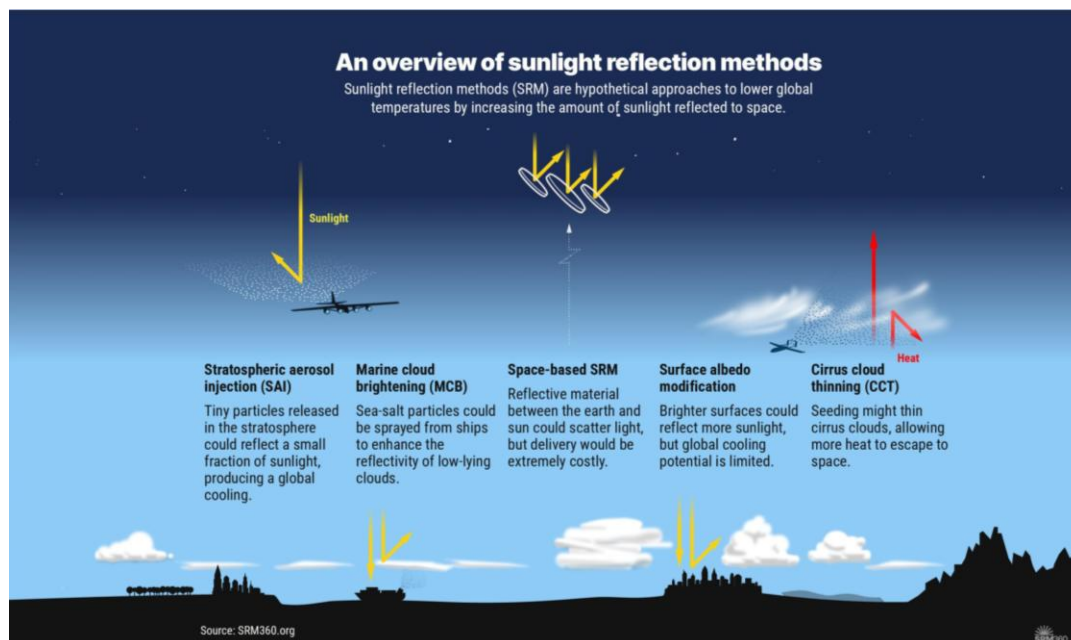
4. See The State of Carbon Dioxide Removal's reports, available at: www.stateofcdr.org.

5. P. J. Crutzen, "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma", *Climatic Change*, Vol. 77, No. 3, 2006, pp. 211–219.

6. *One Atmosphere*, Nairobi: United Nations Environment Programme, 2023.

regional, or global temperatures. Since CO₂ emissions and concentrations remain unaffected, SRM cannot be considered a definitive solution to climate change.

Graphic 1: SRM Techniques



Source: "An Overview of Sunlight Reflection Methods", SRM360, 2024, available at: <https://srm360.org>.

Three methods offer near-term potential, while a fourth (space SRM) could deliver significant cooling, but not until late in the century.

- **Urban Surface Brightening (USB):** Already implemented in cities such as New York, Los Angeles or Athens, cooling from this intervention remains localized.
- **Marine Cloud Brightening (MCB):** MCB involves spraying seawater droplets from vessels to feed low-lying, highly reflective clouds, cooling the ocean below. Led by Southern Cross University, an outdoor experiment is currently underway in Australia (Reef Restoration and Adaptation Project, RRAP) to protect the Great Barrier Reef. MCB deployment and effects are primarily local, though it could moderate El Niño phenomena.⁷
- **Stratospheric Aerosol Injection (SAI):** The method is designed to disperse tiny particles (e.g., sulfates or silica) into the stratosphere using aircraft, balloons or drones. It is currently the most accessible technology with potential global consequences. Cooling would be rapid (a few months), but short-lived (1–2 years) and unevenly distributed across the globe. Furthermore, variables beyond temperature, such as precipitation, sea currents, and photosynthesis, may be negatively impacted.

7. C. Xing et al., "Subtropical Marine Cloud Brightening Suppresses the El Niño–Southern Oscillation", *Earth's Future*, No. 13, 2025.

SRM must be conceptualized as part of a portfolio

SRM effects will depend on specific deployment parameters. For SAI, this includes aerosol type and quantity, injection altitude, latitude and season, alongside greenhouse gas concentrations and other climate instruments (mitigation, adaptation, and CDR). Thus, SRM must be conceptualized as part of a portfolio (hybrid policy) in which mitigation, adaptation and CDR interact. SRM could reinforce other dimensions (e.g., adaptation or ocean carbon sinks) and buy time to ramp up interventions like mitigation or carbon capture. It could also help shave off temperature peaks and moderate a possible temperature overshoot.⁸

However, SRM presents a design problem.⁹ The question is not merely what consequences to expect from its deployment, but how to achieve desirable outcomes while minimizing the negative impacts. SRM must be evaluated within comprehensive climate strategies based on intended goals, such as protecting coastal areas against sea-level rise, or reducing thermal stress on populations and ecosystems. Mission-driven research projects—as opposed to purely curiosity-driven science—could help tackle concrete questions relevant to decision-makers.¹⁰ The roadmap released by the non-profit organization Reflective in September 2026 is an attempt to structure SAI research in this direction.¹¹ Yet, for this focused approach to be efficient and just, robust strategies, proper regulation, and public involvement are imperative.

A risky technology in an adversarial context

No serious researcher advocates substituting SRM for mitigation, primarily because SRM cannot solve climate change and carries significant risks and uncertainties.¹² Global SRM (SAI and space geoengineering) will most likely slow the hydrologic cycle, making the Earth drier and potentially disrupting the monsoon. Furthermore, a global catastrophe could result from a termination shock, a sudden thermal surge caused by abruptly halting SRM deployment. In such a scenario, warming could reach up to 20 times the present rate, estimated at 0.2 °C per decade, jeopardizing adaptation.

The topic fuels controversies between two distinct camps. The first camp judges the menace as overblown, at least for SAI, due to its technology's accessibility.¹³ SAI costs will probably be modest enough¹⁴ for the deployment apparatus (airbases, planes, supply chain for the sulfur, etc.) to be duplicated. Thus, if a geoengineer is incapacitated, another

8. L. Boselius et al., “Peak Shaving with Solar Radiation Modification Would Shorten Global Temperature Overshoot”, *Oxford Open Climate Change*, Vol. 5, No. 1, 2025.

9. B. Kravitz et al., “Geoengineering as a Design Problem”, *Earth System Dynamics*, No. 7, 2016, pp. 469–497.

10. D. G. MacMartin and B. Kravitz, “Mission-driven Research for Stratospheric Aerosol Geoengineering”, *Proceedings of the National Academies of Sciences of the USA*, Vol. 116, No. 4, 2019, pp. 1089–1094.

11. More details on: <https://roadmap.reflective.org>.

12. According to Frank Knight's definition, unlike risk, uncertainty involves adverse events whose existence, likelihood, or consequences cannot be calculated or quantified.

13. A. Parker and P. J. Irvine, “The Risk of Termination Shock from Solar Geoengineering”, *Earth's Future*, No. 6, 2018, pp. 456–467.

14. W. Smith, “The Cost of Stratospheric Aerosol Injection through 2100”, *Environmental Research Letters*, Vol. 15, No. 11, 2020.

could step in. The second camp objects that those safeguards rely on too rosy a view of international relations¹⁵ that downplays the adversarial nature of world politics. Moreover, they argue that redundancy mechanisms would not be reliable enough in the event of a global catastrophe, like a major economic crisis or political collapse. In short, a proper weighing of worst-case scenarios should compel policymakers to rule out SRM technologies prone to termination shock (mainly SAI and space SRM).

International relations are indeed becoming more confrontational, jeopardizing the very kind of principled cooperation that could facilitate coordinating SRM research and deployment. Even if computer models suggest SRM benefits could be somewhat evenly distributed, inequalities between regions and populations will be inevitable, and nations will act on diverging climate interests. Russia, for example, has little incentive to prevent an ice-free Arctic Ocean during summer.

For SRM to be efficient and just, it must not be monopolized by a single nation or a coalition controlling the entire chain running from modeling to deployment. However, large-scale SRM challenges cooperation among states and private actors (such as new space companies). Ideally, all stakeholders should agree on a coherent strategy. Yet, the accessibility of unilateral deployment of SAI (and MCB to a lesser extent) weakens the impetus to collaborate, especially between actors with misaligned climate objectives.

In this respect, SAI presents a different puzzle from mitigation or CDR. For the latter, efficiency is crippled by free riding, where actors offload the burden of CO₂ abatement or capture onto others, leading to an under-provision of the public good (mitigation or CO₂ extraction). In contrast, SAI is characterized by free driving.¹⁶ Due to its low costs, lack of technological barriers, and fragmented regulation, a single entity or a small coalition, endowed with sufficient resources, could unilaterally deploy the technology, deeply destabilizing international relations. The geoengineer could be blamed for adverse climate events (even if imputation is difficult),¹⁷ and a dissatisfied country might counter-engineer by injecting radiative forcers to cancel the cooling, leading to further climatic and geopolitical chaos.

The geoengineer
could be blamed for
adverse climate
events

Fragmented governance and self-regulation

The prospect of staggering risks, unilateral deployment, and potential global catastrophes underscores why governance must precede deployment. For reasons of legitimacy and efficiency, stakeholders should be involved early in the research process.¹⁸ SRM is not,

15. C. McKinnon, "The Panglossian Politics of the Geoclique", *Critical Review of International Social and Political Philosophy*, Vol. 23, No. 5, 2019, pp. 584–599.

16. G. Wagner and M. L. Weitzman, "Playing God", *Foreign Policy*, October 2012.

17. D. G. MacMartin et al., "Timescale for Detecting the Climate Response to Stratospheric Aerosol Geoengineering", *JGR Atmospheres*, Vol. 124, No. 3, 2019, pp. 1233–1247.

18. S. Jinnah et al., *Building Capacity for Public Engagement on Solar Geoengineering*, Cambridge: Cambridge University Press, 2026.

No major state has established a dedicated governance scheme

however, directly regulated or governed, as no dedicated international treaty or organization is in place. Nevertheless, certain legal instruments could apply tangentially, such as the Environmental Modification Convention (1977), and international bodies have touched upon the topic, like the Convention on Biological Diversity (decision X/33, 2010). Customary international law offers basic direction (e.g., the duty to prevent transboundary harm). The precautionary principle is regularly invoked, as by the UN Scientific Advisory Board,¹⁹ but divergent interpretations impede univocal guidance. It remains unresolved whether SRM should be categorically prohibited due to its risks or if research should be permitted to develop technologies that might prevent severe climate harm.²⁰ Finally, the United Nations (UN) remains cautious on the topic. For instance, Switzerland's two resolution proposals—to scientifically assess geoengineering and its governance (UNEA-4, 2019) and to establish a UN expert group (UNEA-6, 2024)—were both withdrawn. The UNEP omitted SRM entirely from its most recent report on the ongoing overshoot trajectory.²¹ In short, the UN does not appear to be the appropriate forum for governing SRM.

At the national level, no major state has established a dedicated governance scheme, partly due to a reluctance to open the “climate manipulation” Pandora's box. Consequently, research is primarily self-governed, while deployment faces mounting demands for prohibition.

“De facto” research governance

SRM research has undergone multiple scientific assessments by bodies like the United States National Research Council and the United Kingdom Royal Society,²² creating “de facto governance”.²³ Researchers have self-regulated through codes of conduct such as the Oxford Principles (2009) and the American Geophysical Union's Ethical Framework Principles for Climate Intervention Research (2024). While initially confined to researchers in the Global North, projects like Co-Create are expanding those initiatives to other stakeholder groups. Nonetheless, concerns persist regarding opaque self-regulation and insufficient public participation, particularly from the Global South.

Governance is also exercised through financial channels, as funders dictate project scope and can enforce stage-gate processes with funds released conditionally upon intermediate evaluations. The fact that philanthropic sources (38.17% of total SRM funding for the period 2007–2025 [\$267.19 million]) outpace public ones (32.75%)

19. “Brief of the Scientific Advisory Board on: Solar Radiation Management”, UN Scientific Advisory Board, May 28, 2025.

20. *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance*, Washington, D.C.: The National Academies Press, 2021, p. 103.

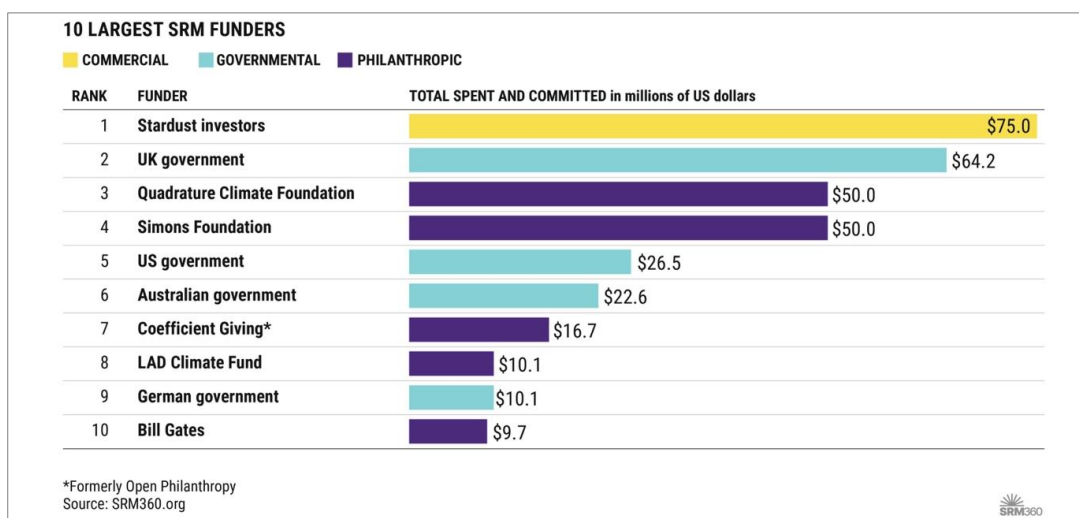
21. *Limiting Overshoot*, UNEP, op. cit.

22. S. Jinnah and Z. Dove, “Solar Radiation Management: A History of the Governance and Political Milestones”, *Environmental Science: Atmospheres*, Vol. 5, No. 6, 2025, pp. 656–673.

23. A. Gupta and I. Möller, “De Facto Governance: How Authoritative Assessments Construct Climate Engineering as an Object of Governance”, *Environmental Politics*, Vol. 28, No. 3, 2019, pp. 480–501.

underscores the growing influence of private actors. This trend is accentuated by the widening gap between philanthropic and public commitments until 2030, alongside the emergence of commercial capital.²⁴ Non-governmental actors now dominate global funding. For-profit SAI company Stardust Solutions tops all funders with \$75 million raised in venture capital. Meanwhile, the United Kingdom (UK) leads public sources, via ARIA, surpassing the United States (US), whose future commitment remains unclear.²⁵

Graphic 2: Largest SRM Funders



Source: "Philanthropies and Stardust's Investors Outspend Most Nations on SRM", SRM360, 2026, available at: <https://srm360.org>.

Fragmented governance, self-regulation, and private funding severely impair democratic oversight and accountability, a shortcoming that is exacerbated by low public familiarity with SRM, which renders mission-driven research problematic. While such a research model may strengthen the efficient allocation of research resources, it raises legitimacy and ethical concerns over how and by whom missions should be selected.

Deployment moratoria and bans

Moratoria are temporary prohibitions that are regularly updated (e.g., commercial whaling). Such proposals usually target deployment, while computer, lab and indoor research remain unaffected. The Group of Chief Scientific Advisors to the European Commission²⁶ and the Climate Overshoot Commission²⁷ support such a position. Bans are permanent prohibitions intended to apply to deployment that often extend to outdoor, large-scale experiments. Examples include the 2021 call for an International Non-use Agreement on Solar Geoengineering, the 2025 African Ministerial Conference on the

24. "Philanthropies and Stardust's Investors Outspend Most Nations on SRM", SRM360, 2026, available at: <https://srm360.org>.

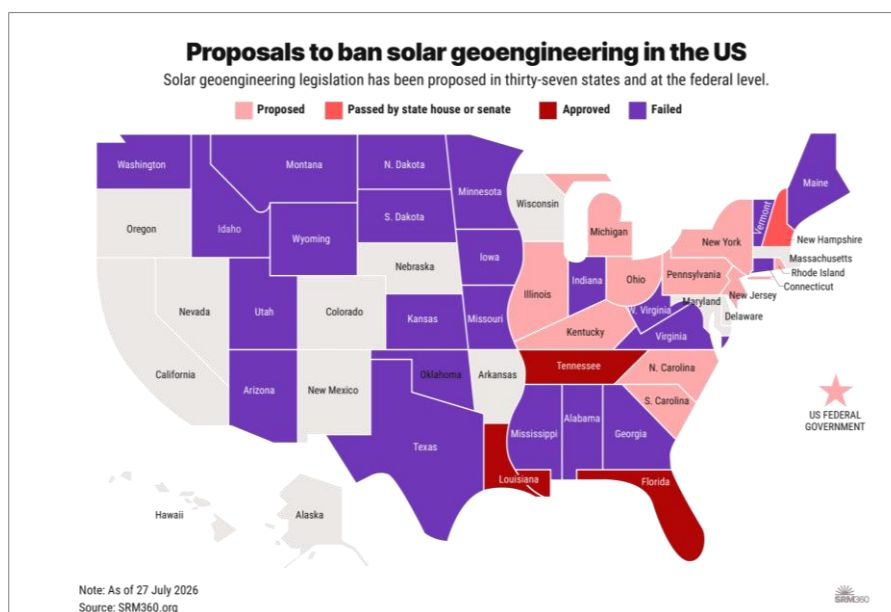
25. "What's New in Solar Geoengineering Funding?", SRM360, September 9, 2026, available at: <https://srm360.org>.

26. Group of Chief Scientific Advisors to the European Commission, *Solar Radiation Modification*, Luxembourg: Publications Office of the European Union, 2024.

27. *Reducing the Risks of Climate Overshoot*, Paris: The Overshoot Commission, 2023.

Environment declaration, and a report by the French Academy of Sciences.²⁸ Several US states have moved in that direction. So far, Florida, Louisiana and Tennessee have enacted bans that cover not only deployment but also outdoor experiments while conflating SRM with weather modification (e.g., cloud seeding). An alternative to an outright ban is to enforce a permit system for SRM research.²⁹

Graphic 3: Proposals to Ban SRM in the US States



Source: "Proposals to Ban Solar Geoengineering in the US", SRM360, 2025, available at: <https://srm360.org>.

Despite those initiatives, national governments' apathy may hasten the chaotic development of research driven by actors with little concern for responsible research. Even if rogue deployments never materialize, unregulated SRM research risks a slippery slope toward deployment, or capture by specific interests. Deficient international governance leaves SRM highly vulnerable to geopolitical tensions too. In a contested global landscape, SRM starts being viewed through an adversarial lens, which is criticized by many researchers. In the US, some voices advocate framing SRM as a strategic security issue and a matter of "weather sovereignty"³⁰ to counter China's expanding weather modification capabilities. In 2024, China more than doubled its SRM research spending to over USD 5 million under its Earth System and Global Change program,³¹ though still far behind US and UK commitments.

28. *Géo-ingénierie climatique: État des lieux scientifique, enjeux et perspectives*, Paris: Académie des sciences, 2025, p. 14.

29. T. Hester and C. Segall, "The Case Against Blanket Bans: A State Permitting Model for Solar Radiation Management", Environment, Energy & Natural Resources Center, University of Houston Law Center, 2026.

30. G. D. Banks, "The National Security Case for U.S. Leadership in SRM Technology", American Council for Capital Formation, 2026; "Protecting American Weather Sovereignty Strategies for a Safe and Secure Atmosphere for America", Rainer Center Project and Silver Lining, 2026.

31. R. Bowen, "PRC Intends to Boost Role in Solar Radiation Modification", American Council for Capital Formation, 2026.

A vehicle for dominance?

SRM could potentially be instrumentalized by major nations, socioeconomic groups (the wealthy, technocrats, scientists) or specific industrial sectors (oil companies, artificial intelligence, the defense industry, Silicon Valley).

Scientific capture

This occurs when researchers monopolize the debate and technologies for their advantage, or the advantage of the countries that host their research. The primary concern is that Global North scientists will dominate the field.³² Currently, institutions in the US (e.g., universities such as Chicago and Harvard for SAI; Washington and UC San Diego for MCB), the UK (University of Cambridge's Centre for Climate Repair), and Australia (Southern Cross University), and, to a lesser extent, Germany and the European Union (EU) lead SRM research. In the US, however, the second Trump administration remains timid due to the importance of conspiracy theories such as “chemtrails” within the MAGA movement. China may become a contender due to its extensive weather modification program and recent funding efforts, though its official stance on SRM remains subdued. For the foreseeable future, a small group of nations will likely continue to define research agendas, determining computational modeling frameworks, research priorities, and potentially aligning research strategies with national interests.³³ Organizations like the Degrees Initiative and the Alliance for Just Deliberation on Solar Geoengineering are attempting to attenuate these asymmetries by supporting Global South research and the participation of marginalized communities.

Private capture

SRM could fall under the control of businesses mostly located in the Global North. Startups like Make Sunsets and Stardust Solutions have already entered the field. While still timid on the question, fossil fuel interests might champion SRM as a technofix to delay decarbonization. The risk is amplified by a dynamic, financially potent, and politically invasive tech sector pushing technofixes, sometimes in the service of antidemocratic ideas. Figures like Elon Musk have already speculated about space geoengineering. Robust public funding and research oversight are essential to prevent such private capture.

Political dominance

SRM (geo)politics is a field in the making. The conversation is expanding beyond scientific circles focused on fending off the worst outcomes of climate change through a risk-to-risk approach³⁴ into defense and security spheres. Direct militarisation remains hypothetical.

32. J. C. Stephens et al., “The Dangers of Mainstreaming Solar Geoengineering: A Critique of the National Academies Report”, *Environmental Politics*, Vol. 32, No. 1, 2023, pp. 157-166.

33. D. P. McLaren, “Whose Climate and Whose Ethics? Conceptions of justice in Solar Geoengineering Modeling”, *Energy Research & Social Science*, Vol. 44, 2018, pp. 209-221.

34. T. Felgenhauer et al., “Practical Paths to Risk-Risk Analysis of Solar Radiation Modification”, *Oxford Open Climate Change*, Vol. 5, No. 1, 2025.

No SRM technology can guarantee precise enough impacts on a given adversary with no spillover beyond targeted regions. Although militaries have more potent instruments, SRM may become part of the power toolbox. Arctic SAI illustrates how SRM could intersect with existing geopolitical dynamics.

The Arctic as a testing ground

While traditional SAI models consist of tropical injections from which aerosols could diffuse worldwide (Brewer-Dobson circulation), new scenarios advocate for High-Latitude Low-Altitude SAI (HiLLA-SAI), principally in the Arctic.³⁵ Injected particles would remain confined to the Poles, which are vulnerable to warming and essential for climate stability, helping preserve or reconstitute the cryosphere. HiLLA-SAI could be more finely tuned and less globally intrusive than tropical dispersion. Because the stratosphere sits at a lower altitude at the poles, retrofitted commercial jets could be used instead of novel high-altitude aircraft, substantially cutting costs. However, aerosols would fall more rapidly than in higher-altitude injections. Finally, with those regions

being sparsely (Arctic) or not at all (Antarctica) populated, public acceptance of modest outdoor experiments may be easier to manage.

If initiated, SRM will
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HiLLA-SAI may put existing multilateral cooperation, such as the Arctic Council, to the test. If initiated, SRM will accelerate SRM's evolution into a contentious geopolitical object, entangled in a web of national interests and dynamics that go beyond "simple" climate stabilization.³⁶ If

governance is not already in force by then, the prospect of efficient and just SRM will remain elusive. On the other hand, Arctic SAI, even on a small scale, may offer a testing ground for international cooperation, research oversight, geoengineering literacy, and stakeholders' involvement. The Arctic could become the place where early regulation emerges, benefiting from existing structures of coordination among states, autonomous regions (e.g., Quebec, Greenland), and Indigenous organizations (Saami Council, Inuit Circumpolar Council).

However, the window is closing rapidly. As the EU and France struggle to formulate a cohesive position, a vacuum is left for other actors and international competitors to advance SRM technologies aligned with their own agendas.

35. A. Duffey et al., "The Global Climate Response to High-Latitude Low-Altitude Stratospheric Aerosol Injection (HiLLA-SAI)", *Earth System Dynamics*, No. 17, 2026, pp. 353–385.

36. N. Kornbech et al., "Securing the 'Great White Shield'? Climate Change, Arctic Security and the Geopolitics of Solar Geoengineering", *Cooperation and Conflict*, Vol. 60, No. 2, 2025, pp. 286–307.

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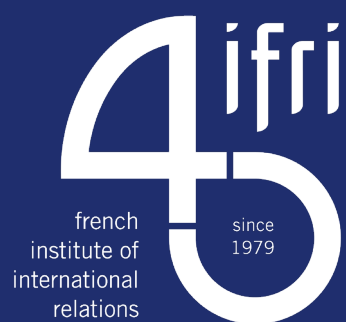
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