ISSUES NOTE[1]

UN environment programme

Solar Radiation Modification

No substitute for real climate action

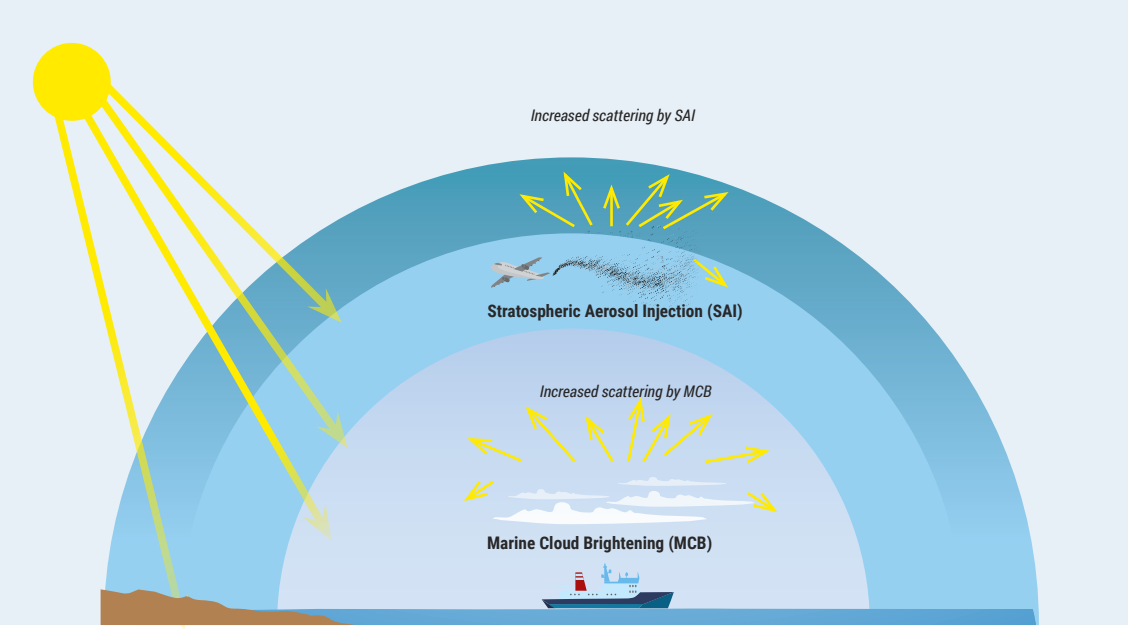
Solar Radiation Modification remains speculative, with huge uncertainty, risks and potential impacts, and is not a replacement for urgent reduction of greenhouse gases.

Executive Summary

Solar Radiation Modification (SRM) technologies—such as Stratospheric Aerosol Injection (SAI) and Marine Cloud Brightening (MCB) are speculative concepts that aim to temporarily lower global temperatures by reflecting solar radiation back into space (Figure 1). These approaches do not reduce greenhouse gas concentrations—the root cause of climate change—nor do they address its impacts. These technologies also represent different levels of readiness and have been subject to a great deal of political and scientific controversy. Sometimes cast as an emergency tool, SRM remains poorly understood and fraught with uncertainties and risks, and is no substitute for mitigation or stronger adaptation. For now, SRM is largely confined to models, simulations and theory. The unintended consequences include disruptions to climate patterns, biodiversity and the ozone layer, with regional hydrological impacts modelled as being uneven.

1 This Issues Note provides a review of the latest literature on specific topics that are of relevance to UNEP's mandate. It also presents a set of agreed approaches and recommendations regarding UNEP's communication of the subject matter. It is meant to ensure consistency in messaging across the organization on this topic.

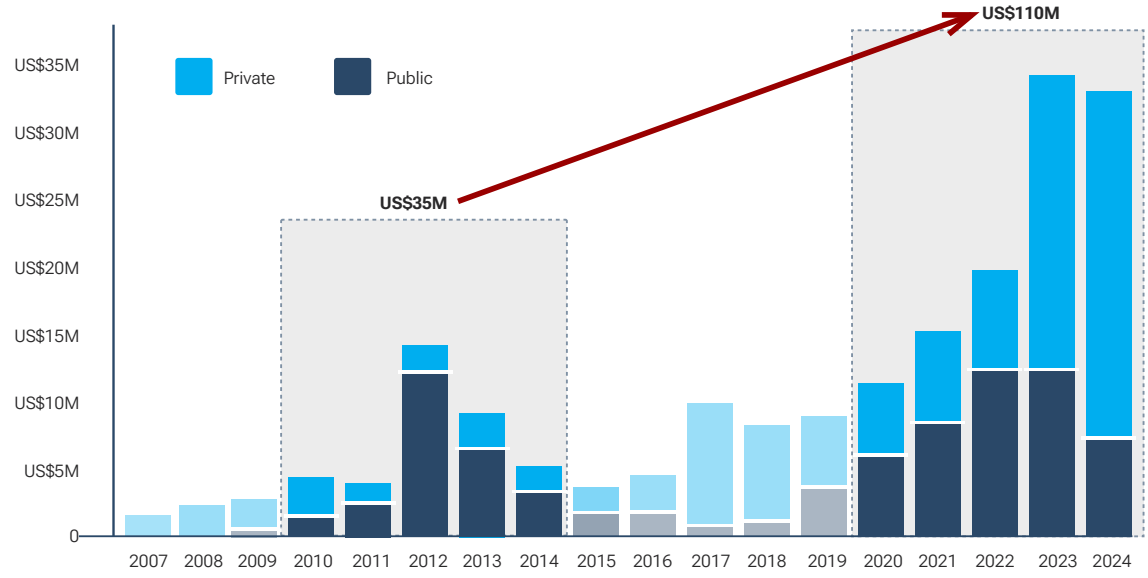
Figure 1: Overview of Solar Radiation Modification Mechanisms



Source: Developed by UNEP

1. **Climate models suggest SRM could temporarily reduce global temperatures, but may also introduce substantial risks,** including regional climatic imbalances, ecological perturbations and uncertain impacts.
2. **Modelling studies suggest that SRM could trigger uneven and potentially destabilising side effects:** weaker monsoons in South and East Asia, reduced intensity and frequency of extreme rainfall and alteration of the snowpack and glaciers, with knock-on effects for water availability and agricultural productivity (Wang et al. 2024). These risks are most acute where livelihoods are highly climate-sensitive.
3. **Stratospheric Aerosol Injection (SAI) may further alter stratospheric temperatures, circulation patterns and ozone dynamics**, reinforcing concerns about poorly understood—and potentially harmful—impacts (Lee et al. 2023).
4. **SRM technologies, and SAI in particular, present serious potential risks**—disrupted rainfall and monsoon patterns (Zhao et al. 2022), harm to biodiversity and ecosystems (Futerman et al. 2025) and the so-called "termination shock" if deployment were abruptly halted (Trisos et al. 2018).
5. **Serious ecological impacts could occur with deployment of SRM.** Emerging reviews highlight that biodiversity and ecosystem services may face severe risks under SRM, even if temperature targets are met (Zarnetske et al. 2021; Futerman et al. 2025). Potential impacts include reduced primary productivity, shifts in species ranges, disruptions to ocean chemistry and abrupt termination effects. Risks may be especially acute for fragile systems such as coral reefs, Arctic tundra and dryland biomes (Wells et al. 2024). Communities already facing high climate exposure could also face disproportionate harm from SRM side effects (Fu et al. 2025; Stephens 2025).
6. **Without rigorous, region-specific analysis, SRM may amplify existing global inequities and undermine the principles of climate justice**, particularly in Southeast Asia, Latin America and Africa (Fu et al. 2025). Such disparities risk fuelling geopolitical tension and distrust—or even conflict—if unilateral deployment benefits some countries at others' expense (Baur et al. 2023; Huynh and McNeill 2024).
7. **Scientific interest in SRM is rising across public, private and philanthropic sectors.** Funding has surged from roughly US$35 million in 2010–2014 to over US$110 million in 2020–2024 (Figure 2),

Figure 2: Growing Public and Private Investment in Solar Radiation Modification



Source: Adapted from SRM360.org

including US$31 million in 2024 alone. Public and philanthropic contributions are growing, including US$75 million from the United Kingdom's Advanced Research and Invention Agency (ARIA) and over US$100 million from private donors, with annual support expected to reach US$40–55 million—nearly half from private sources (Buck et al. 2025).

8. **Yet, SRM research remains largely limited to modelling and conceptual studies, with very limited empirical work, concentrated in a handful of countries** and provides only insight into potential impacts and consequences of these technologies should they be deployed.

9. **Some researchers warn that discussion and research on SRM could weaken political will to cut emissions** or even incentivise greater fossil fuel energy consumption—the moral hazard effect (McLaren 2025). At the same time, the regional impacts and distributional effects remain highly uncertain, with low-income countries likely to bear a disproportionate share of the risks (Low et al. 2024; Fu et al. 2025).

10. **A key concern is that heightened attention could dilute the urgency of mitigation and adaptation by creating false expectations or diverting scientific and political resources toward speculative approaches**—particularly when framed as a "plan-C"[1] in the context of climate emergency.

11. **Others argue that limited and transparent exploration is a prudent form of climate risk management rather than a moral hazard, especially as global temperatures approach or exceed 1.5°C.** Understanding SRM's potential risks, limits and governance requirements, they contend, is essential to avoid ill-informed or unilateral interventions (National Academies of Sciences, Engineering, and Medicine 2021; Keith 2021; Parson and Keith 2024). The science of SRM itself still faces major limitations, with significant gaps in our understanding of core physical processes. Models struggle to capture fine-scale climatic effects, long-term socio-economic outcomes and complex feedbacks within the climate system. Key uncertainties persist in areas such as aerosol characteristics and behaviour, atmospheric chemistry and dynamics, aerosol-cloud interactions, ecosystem responses, human health and socio-political consequences (Haywood et al. 2025).

12. **Translating global SRM model results into meaningful regional assessments remains highly challenging.**

1 https://degreesglobalforum.org/sessions/documentary-screening-plan-c-for-civilization/

13. **While some contend that research is necessary to understand and clarify risks, others caution that even preliminary exploration may generate momentum towards deployment** (Oomen 2024). These debates unfold amid stark asymmetries: over 98 per cent of SRM funding is concentrated in institutions based in high-income countries, with less than 2 per cent reaching low- and middle-income countries[2]. The growing involvement of private equity further raises concerns that commercial incentives may skew research priorities away from broader societal needs and the interests of climate-vulnerable communities.

14. **Such disparities risk marginalising the voices of those most exposed to climate harm, raising fundamental questions of fairness and legitimacy** (Jinnah and Dove 2025). Intergenerational equity and human rights concerns, increasingly emphasised by United Nations bodies (e.g. United Nations Human Rights Council 2023), reinforce the case for governance frameworks anchored in precaution, transparency and justice.

15. **There are no agreed multilateral norms or institutions to govern SRM research or experimentation** (The Royal Society 2023). Research spans basic science, modelling, small-scale field experiments and emerging commercial interest—each demanding tailored oversight. Even micro-scale outdoor experiments can prove contentious, blurring the line with deployment and risk normalising SRM (Jinnah and Dove 2025). Effective governance must be grounded in legal, scientific and ethical principles: the precautionary approach, human rights obligations and commitments to equity, transparency and environmental stewardship.

Issues to be monitored as research continues

- **SRM deployment remains an uncertain, high-risk, and politically sensitive area of endeavour.** While it attracts attention in the context of a potential emergency response to temporarily exceeding global temperature targets, the scientific, ecological, and ethical uncertainties far outweigh any speculative benefits at present.
- **SRM research needs to be monitored**, and any field experiments should be carefully reviewed for purpose, scale and potential impact.
- **Any SRM-related activity must be approached as a limited scientific inquiry, subject to rigorous, transparent and globally coordinated oversight.** Limited observations and small-scale field studies may refine models, but must be carefully designed, transparently governed and rooted in a precautionary approach. Public and media discourse should clearly distinguish exploratory research from deployment to avoid eroding trust or normalising unproven technology.
- **Equitable participation requires reciprocal capacity-sharing, co-development of knowledge and recognition of diverse perspectives, including Indigenous knowledge.** Ensuring gender balance and inclusivity is vital, as women and men bring diverse knowledge and approaches to climate resilience. Long-term investment in local research institutions in climate-vulnerable regions is essential.
- **Ethical principles—intergenerational fairness, procedural justice and human rights protections—must guide SRM discussions from the outset.** Research should integrate social sciences, embed co-design processes and prioritize meaningful engagement with vulnerable and marginalised communities, including women and girls who face disproportionate impacts from climate change.

2 https://srm360.org/article/srm-funding-overview/

References

Baur, S., Nauels, A., Nicholls, Z., Sanderson, B.M., and Schleussner, C.-F. (2023). The deployment length of solar radiation modification: An interplay of mitigation, net-negative emissions and climate uncertainty. Earth System Dynamics, 14, 367–381. https://doi.org/10.5194/esd-14-367-2023

Buck, H.J., Shah, P., Yang, J.Z. and Arpan, L. (2025). Public concerns about solar geoengineering research in the United States. *Communications Earth & Environment*, 6. https://doi.org/10.1038/s43247-025-02595-5

Fu, W., Yue, X., Tian, C., Xu, R. and Guo, Y. (2025). Unequal socioeconomic exposure to drought extremes induced by stratospheric aerosol geoengineering. *EGUsphere,* 1–26. https://doi.org/10.5194/acp-25-13103-2025

Futerman, G., Adhikari, M., Duffey, A., Fan, Y., Gurevitch, J., Irvine, P. et al. (2025). The interaction of solar radiation modification with Earth system tipping elements. *Earth System Dynamics*, 16, 939–978. https://doi.org/10.5194/esd-16-939-2025

Haywood, J.M., Boucher, O., Lennard, C., Storelvmo, T., Tilmes, S. and Visioni, D. (2025). World Climate Research Programme lighthouse activity: An assessment of major research gaps in solar radiation modification research. *Frontiers in Climate*, 7, 1507479. https://doi.org/10.3389/fclim.2025.1507479

Huynh, H.N. and McNeill, V.F. (2024). The potential environmental and climate impacts of stratospheric aerosol injection: A review. *Environmental Science: Atmospheres*, 4(2), 114–143. https://doi.org/10.1039/D3EA00134B

Jinnah, S. and Dove, Z. (2025). Solar radiation management: A history of the governance and political milestones. *Environmental Science*: Atmospheres, 5(6), 656–673. https://doi.org/10.1039/D5EA00008D

Keith, D.W. (2021). Toward constructive disagreement about geoengineering. *Science*, 374(6569), pp.812-815. https://www.science.org/doi/10.1126/science.abj1587

Lee, W. R., Visioni, D., Bednarz, E. M., MacMartin, D. G., Kravitz, B., & Tilmes, S.(2023). Quantifying the Efficiency of Stratospheric Aerosol Geoengineering at Different Altitudes. *Geophysical Research Letters*, 50(14), Article e2023GL104417. https://doi.org/10.1029/2023GL104417

Low, S., Fritz, L., Baum, S.M. and Sovacool, B.K. (2024). Public perceptions on solar geoengineering from focus groups in 22 countries. *Communications Earth & Environment*, 5(1), 352. https://www.nature.com/articles/s43247-024-01518-0

McLaren, D.P. (2025). Reconstructing risk–risk analysis to support effective governance of high-risk climate interventions. *European Journal of Risk Regulation,* First View, 1–17. https://doi.org/10.1017/err.2025.10019

National Academies of Sciences, Engineering, and Medicine. (2021). *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance* [Consensus Study Report]. National Academies Press. https://doi.org/10.17226/25762

Oomen, J. (2024). Producing the inevitability of solar radiation modification in climate politics. *Ethics & International Affairs*, 38(3), 287–301. https://doi.org/10.1017/S0892679424000273

Parson, E. A., and Keith, D. W. (2024). Solar Geoengineering: History, Methods, Governance, Prospects. *Annual Review of Environment and Resources*, 49, 337–366. https://doi.org/10.1146/annurev-environ-112321-081911

Stephens, J.C. (2025). Climate justice and the dangers of solar geoengineering. In M. Beech (Ed.), *Geoengineering and Climate Change: Methods, Risks, and Governance*. John Wiley & Sons. https://doi.org/10.1002/9781394204847.ch4

The Royal Society. (2023). *Governing Solar Radiation Modification: Advancing Responsible Research*. https://royalsociety.org/srmgi-report

Trisos, C.H., Amatulli, G., Gurevitch, J., Robock, A., Xia, L. and Zambri, B. (2018). Potentially dangerous consequences for biodiversity of solar geoengineering implementation and termination. *Nature Ecology & Evolution*, 2(3), 475–482. https://doi.org/10.1038/s41559-017-0431-0

Wang, O., Liang, J., Gu, Y., Haywood, J.M., Chen, Y., Fang, C. et al. (2024). Projected future changes in extreme precipitation over China under stratospheric aerosol intervention in the UKESM1 climate model. *Atmospheric Chemistry and Physics*, 24(21), 12355–12373. https://doi.org/10.5194/acp-24-12355-2024

Wells, A.F., Henry, M., Bednarz, E.M., MacMartin, D.G., Jones, A., Dalvi, M. et al. (2024). Identifying climate impacts from different stratospheric aerosol injection strategies in UKESM1. *Earth's Future*, 12(3), e2023EF004358. https://doi.org/10.1029/2023EF004358

Zarnetske, P.L., Gurevitch, J., Franklin, J., Groffman, P.M., Harrison, C.S., Hellmann, J.J. et al. (2021). Potential ecological impacts of climate intervention by reflecting sunlight to cool Earth. *Proceedings of the National Academy of Sciences of the United States of America*, 118(15), e1921854118. https://doi.org/10.1073/pnas.1921854118

Zhao, M.. and Cao, L. (2022). Regional response of land hydrology and carbon uptake to different amounts of solar radiation modification. *Earth's Future*, 10(6), e2022EF003288. https://doi org/10.1029/2022EF003288

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