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RESEARCH ARTICLE

Scientific models versus power politics: How security expertise reframes solar geoengineering

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Abstract
Persistently rising atmospheric greenhouse gas concentrations challenge dominant Liberal hopes that science and multilateralism might deliver rational, global climate outcomes. Emerging Realist climate approaches that take geopolitics and national interests more seriously have yet to explore Morgenthau's concern that 'scientism' – exaggerated faith in scientific rationality to solve political problems – would lead to disastrous underestimations of power and irrationality. Recently, Realists have mooted 'solar geoengineering' designs as a 'lesser evil' option to deliberately cool the Earth independently of emissions reductions. However, assessments of solar geoengineering prospects barely factor in Realist concerns, focusing instead on idealised scientific modelling of bio-physical effects and Liberal governance scenarios. To explore how geoengineering techno-science would be 'translated' into security assessments, geopolitical logics were elicited through interviews and group discussions with (mainly Arctic-oriented) national security professionals. Security experts reframe solar geoengineering in three significant ways: (a) from a climate 'global public good' to a source of geopolitical leverage and disruption; (b) from a risk-reduction tool to a potential source of distrust and escalation; and (c) from a knowledge-deficit problem solvable by more research, to a potential disinformation vector. This expands Realist scholarship on climate change and identifies serious risks to ongoing scientific and commercial pursuit of such technologies.

Keywords: classical realism; climate geopolitics; disinformation; dual use; geoengineering; solar radiation modification (SRM)

> Two moods determine the attitude of our civilization to the social world: confidence in the power of reason, as represented by modern science, to solve the social problems of our age and despair at the ever-renewed failure of scientific reason to solve them.
>
> Hans J. Morgenthau (1946)[1]

Introduction
The world faces a deep and widening gap between scientifically informed and globally agreed temperature targets, and continued emissions driving up atmospheric greenhouse gas concentrations. While for Liberal Institutionalists this might still be resolved with redesigned international

[1]Hans Joachim Morgenthau, *Scientific Man vs. Power Politics* (Chicago, Il: University of Chicago Press, 1946), p. 9.

institutions[2] (despite underlying economic and geopolitical drivers),[3] others have recently turned to Realism for inspiration. Some see the structure of the international system as an explanation of policy failure[4] or search for ways forward on climate change more attuned to the primacy of nationalism in world politics.[5] Others aim to marry a realist starting point with a progressive redistributive climate stance.[6] Classical Realism has also been mobilised in search of climate strategies based on an collective notion of long-term 'national interest' expanded to include the global climate and future generations.[7]

While a welcome diversification, such recourses to Realism have focused more on power politics than on questioning rationalist-scientific underpinnings of current climate governance. In *Scientific Man vs. Power Politics*, Hans Morgenthau, while by no means dismissing science, bemoaned what he saw as 'scientism': the illusion that 'the social world is susceptible to rational control conceived after the model of the natural sciences'.[8] Writing against the horrors of the Second World War, the Holocaust, and the advent of nuclear weapons, Morgenthau argued that the embrace of a bald scientific rationality had led to technocratic depoliticisation of world politics.[9] This hampered moral restraint and self-reflection[10] and catastrophically failed to account for power politics. Despite Morgenthau's efforts, rationalism largely triumphed in post–Second World War US social science (and inflected his own mid-career work, as well as his neo-realist heirs).[11]

Little surprise, then, that scientistic framings and technological fixes continue to be primary responses to complex political issues today, not least climate change.[12] A striking example may be found in debates about solar geoengineering or 'solar radiation modification' (SRM) techniques. The stated rationale of SRM is to mask some effects of excess emissions by deliberately reflecting a portion of incoming sunlight, though this leaves root causes and other harms from greenhouse gasses like ocean acidification untreated. As a policy originally based on 'the grossly disappointing international political response' to limiting emissions,[13] SRM is increasingly seen as a possible option, partly because it could ostensibly be done quickly and by a single actor (or small coalition), bypassing the impasse of global climate politics.[14] Yet would solar geoengineering evade stubborn international dynamics around climate change, or encounter and engender new ones?

Proposed solar geoengineering techniques include stratospheric aerosol injection (the distribution of reflective particles in the high atmosphere), marine cloud brightening (artificially enhancing the numbers of cloud condensation nuclei in oceanic stratus clouds, making their upper surfaces

[2] Robert O. Keohane and David G. Victor, 'Cooperation and discord in global climate policy', *Nature Climate Change*, 6:6 (2016), pp. 570–5.

[3] Isak Stoddard, Kevin Anderson, Stuart Capstick et al., 'Three decades of climate mitigation: Why haven't we bent the global emissions curve?', *Annual Review of Environment and Resources*, 46 (2021), pp. 653–89.

[4] Jean-Daniel Collomb, 'The limitations of U.S. climate leadership: A Realist perspective', in Michael Stricof and Isabelle Vagnoux (eds), *U.S. Leadership in a World of Uncertainties* (Cham: Springer, 2022), pp. 155–72.

[5] Anatol Lieven, *Climate Change and the Nation State: The Case for Nationalism in a Warming World* (New York: Oxford University Press, 2020).

[6] Nick Bisley et al., 'For a progressive realism: Australian foreign policy in the 21st century', *Australian Journal of International Affairs*, 76:2 (2022), pp. 138–60.

[7] Jonathan Symons, 'Realist climate ethics: Promoting climate ambition within the Classical Realist tradition', *Review of International Studies*, 45:1 (2019), pp. 141–60.

[8] Morgenthau, *Scientific Man vs. Power Politics*, p. 10.

[9] Hartmut Behr, 'Scientific Man vs. Power Politics: A pamphlet and its author between two academic cultures', *Ethics & International Affairs*, 30:1 (2016), pp. 33–8.

[10] William E. Scheuerman, 'Was Morgenthau a Realist? Revisiting Scientific Man vs. Power Politics', *Constellations*, 14:4 (2007), pp. 506–30.

[11] Sean Molloy, 'Truth, power, theory: Hans Morgenthau's formulation of realism', *Diplomacy & Statecraft*, 15:1 (2004), pp. 1–34.

[12] Gwendolyn Blue, 'Scientism: A problem at the heart of formal public engagement with climate change', *ACME: An International Journal for Critical Geographies*, 17:2 (2018), pp. 544–60.

[13] Paul J. Crutzen, 'Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma?', *Climatic Change*, 77:3 (2006), pp. 211–19 (p. 211).

[14] David G. Victor, 'On the regulation of geoengineering', *Oxford Review of Economic Policy*, 24:2 (2008), pp. 322–36.

more reflective), surface albedo modification (techniques to reflect more sunlight from the Earth's surface, such as preserving or restoring ice sheets and glaciers), and, even more speculatively, space-based sunshades (deflecting sunlight with mirrors before it even reaches the Earth). In all cases, scientists and engineers are investigating whether geoengineering could work as a cooling measure, and with what probable environmental risks and benefits.[15]

While such scientific ideas figure increasingly in policy settings such as the IPCC (Intergovernmental Panel on Climate Change)[16] and, recently, the United States government,[17] they remain primarily rooted in a knowledge base of climate modelling and physical analogues (notably volcanic eruptions). Idealised scenarios of controlled deployment of SRM[18] presuppose (typically unspecified) international governance based on scientific reasoning and (often implicit) liberal and rationalist understandings of the international system. Uncertainties and risks are seen to be due to a lack of accurate scientific information or faulty institutions,[19] and ethics rarely go beyond a utilitarian assessment of the balance of risks and benefits.[20] This makes for remarkable optimism in some quarters. In one version, 'this single technology could increase the productivity of ecosystems across the planet and stop global warming; it could increase crop yields, particularly those in the hottest and poorest parts of the world. It is hyperbolic but not inaccurate to call it a cheap tool that could green the world.'[21]

Such pronouncements on what SRM 'could' do rely on discounting a host of less rational and predictable dimensions of the world. As Morgenthau highlighted, scientific man (*sic*) – in this case, scientific models – can be a dangerously misleading guide to what really animates states and 'men' and can even be a poor guide to reason itself.[22] For Morgenthau, 'when we speak of "the pure reason of the natural scientist", we cannot mean a reason divorced from the irrational forces determining human behaviour'.[23] But Realism was until recently 'largely absent from discussions of solar engineering',[24] scholars deeming SRM likely 'unsuitable for use as a standard tool of foreign policy'[25] due to its unfocused and unforeseeable physical effects. But what might the limits of scientific mastery and political rationality imply for the feasibility and desirability of solar geoengineering? Save a brief theoretical exploration of solar geoengineering as a conceivable (but improbable) 'lesser evil' measure,[26] this question has not been addressed from a Classical Realist starting point – a consequential lacuna since 'many foreign policy decision-makers identify Realism as their primary theoretical reference-point'.[27]

[15]Peter J. Irvine, Ben Kravitz, Mark G. Lawrence, and Helene Muri, 'An overview of the Earth system science of solar geoengineering', *WIREs Climate Change*, 7:6 (2016), pp. 815–33.

[16]V. Masson-Delmotte, Panmao Zhai, Anna Pirani et al. (eds), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2021).

[17]The White House Office of Science and Technology Policy, 'Congressionally Mandated Research Plan and an Initial Research Governance Framework Related to Solar Radiation Modification', Office of Science Technology and Policy, Washington, DC, 2023.

[18]David W. Keith and Douglas G. MacMartin, 'A temporary, moderate and responsive scenario for solar geoengineering', *Nature Climate Change*, 5:3 (2015), pp. 201–6.

[19]Joseph E. Aldy, Tyler Felgenhauer, William A. Pizer et al., 'Social science research to inform solar geoengineering', *Science*, 374:6569 (2021), pp. 815–18.

[20]Nicholas Harrison, Janos Pasztor, and Kai-Uwe Barani, 'A risk–risk assessment framework for solar radiation modification', International Risk Governance Center, 2021.

[21]David Keith, *A Case for Climate Engineering* (Cambridge, MA: MIT Press, 2013), p. 13.

[22]On gendered notions of mastery and control, see Holly Jean Buck, Andrea R. Gammon, and Christopher J. Preston, 'Gender and geoengineering', *Hypatia*, 29:3 (2014), pp. 651–69.

[23]Morgenthau, *Scientific Man vs. Power Politics*, p. 134.

[24]Joshua B. Horton and Jesse L. Reynolds, 'The international politics of climate engineering: A review and prospectus for International Relations', *International Studies Review*, 18:3 (2016), pp. 438–61 (p. 450).

[25]Ibid., p. 448.

[26]Symons, 'Realist climate ethics'.

[27]Symons, 'Realist climate ethics', p. 141.

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Rather than adopting a theoretical 'Realist' position ourselves,[28] we elicit and explore empirically how solar geoengineering science is being 'translated'[29] in national security settings. Notwithstanding the limitations of national security discourse on climate change – largely overlooking how militaries themselves contribute to climate change[30] and often exaggerating the effects of climate impacts on migration and wars[31] – we open up non-ideal explorations of SRM by asking what SRM would look like to those whose expertise is not climate science but statecraft and security, and whose institutional position is not an international (scientific) body but a nation-state. We draw on 8 workshops with national security experts and analyse interview responses from 19 further security professionals to gauge how the meaning of solar geoengineering would change if security practitioners – rather than climate scientists – defined its purpose and concepts. This aims to explore a key dimension of a Classical Realist ethos in particular, namely its critique of scientism and its '[counselling] against hubris and worr[y] over misperception of state intentions',[32] offering an empirically grounded analysis of the potential power politics of solar geoengineering.

The following section reviews existing knowledge on solar geoengineering, emphasising the knowledge gap on security implications, especially as considered from theoretical perspectives outside liberal institutionalism. Next we introduce the study's methodology drawing on the 'translations of security' framework,[33] followed by a section which outlines the interpretations and expectations of geoengineering among our security actor informants. Subsequently, we discuss key themes that emerged and consider their implications for governance and scientific research of SRM. We argue it is hubristic to presume that SRM would be directed according to optimised global welfare or justice goals as typically presumed in the climate modelling that has dominated knowledge production of solar geoengineering so far. Any attempted development or SRM intervention is highly unlikely to be exempt from particularistic interests, securitised logics, and geopolitical contingencies.

A 'lesser evil'?

Climate ethicists have previously questioned whether SRM should be considered a 'lesser evil' in relation to ethical maxims,[34] but drawing on Morgenthau, Jonathan Symons asks specifically whether SRM could be considered a 'lesser evil' for dealing with climate change, given the difficulties of getting a world of self-interested powers to coordinate rapid global mitigation of emissions.[35] In answering, Symons echoes Morgenthau's deep scepticism about the ability of scientific method and rationalist approaches to solve existential challenges. Though SRM might theoretically be able to provide some respite from the worst impacts of global warming, the uncertainties and potential hubris of SRM make it unpalatable for Classical Realists.[36]

Meanwhile, a Liberal Institutionalist imaginary currently pervades scientific research on SRM, which presents it as an environmental tool that would be deployed to reduce global warming harms, albeit with potential unwanted side effects. Environmental assessments and modelling of

[28]Even the idea that Morgenthau himself is 'a Realist' is contested, e.g. Scheuerman, 'Was Morgenthau a Realist'.

[29]Trine Villumsen Berling, Ulrik Pram Gad, Karen Lund Petersen, and Ole Wæver, *Translations of Security: A Framework for the Study of Unwanted Futures* (London: Routledge, 2021).

[30]Neta C. Crawford, *The Pentagon, Climate Change, and War: Charting the Rise and Fall of US Military Emissions* (Cambridge, MA: MIT Press, 2022).

[31]Neel Ahuja, *Planetary Specters: Race, Migration, and Climate Change in the Twenty-First Century* (Chapel Hill: University of North Carolina Press, 2021).

[32]Symons, 'Realist climate ethics', p. 158.

[33]Berling, Gad, Petersen, and Wæver, *Translations of Security*.

[34]Stephen Gardiner, 'Is "arming the future" with geoengineering really the lesser evil? Some doubts about the ethics of intentionally manipulating the climate system', in *Climate Ethics: Essential Readings* (Oxford: Oxford University Press, 2010).

[35]Symons, 'Realist climate ethics'.

[36]Symons, 'Realist climate ethics'.

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SRM techniques focus on probable bio-physical impacts on overall or regional climates.[37] SRM modelling experiments bracket out geopolitical and governance challenges, with many studies presuming, for simplicity, a single global planner[38] or a 'God' position positing 'a single global program that pursues the interests of the entire planet'.[39] Economistic optimisation frameworks allow SRM to substitute for some adaptation and mitigation,[40] entertaining the idea that rational calculi concerning climate risks and benefits might guide optimal policy. Visual representations of geoengineering reinforce and provide 'visual proofing' for this planetary management view[41] typical of Earth system science.[42] While researchers often emphasise uncertainties and risks to solar geoengineering, separating technical feasibility from political and practical parameters allows model results to condition and construct SRM as 'feasible', shaping the idea of what it could and should be used for.[43] Studies specifying ideal political conditions have concluded that it could be warranted – if used with humility, precaution, and in the service of the global poor and to protect vulnerable ecosystems, for example,[44] or if the threat of climate change becomes big enough, and it is used in pursuit of a 'just' cause.[45]

But how and under what conditions might it be used in a non-ideal, fragmented, and increasingly multipolar world? This is more the domain of International Relations (IR) than Earth system science. When security dynamics have featured in the literature, rationalist assumptions about state behaviour focus attention on possible disagreement over temperature preferences – 'the thermostat'.[46] Motivations to research or deploy SRM are assumed to depend on states' preferences often imputed from modelled future climates (or the likely economic costs of predicted changes in temperature or precipitation).[47] This makes coordination seem relatively manageable, or even for some, 'likely' to deliver a 'global efficient level' of SRM,[48] with the most serious concern being

[37] Mark G. Lawrence, Stefan Schäfer, Helene Muri et al., 'Evaluating climate geoengineering proposals in the context of the Paris Agreement temperature goals', *Nature Communications*, 9:1 (2018), p. 3734; National Academies of Sciences, Engineering, and Medicine, *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance* (Washington, DC: National Academies Press, 2021).

[38] Peter Irvine, Ben Kravitz, Mark G. Lawrence et al., 'Halving warming with idealized solar geoengineering moderates key climate hazards', *Nature Climate Change*, 9:4 (2019), pp. 295–9; Keith and MacMartin, 'A temporary, moderate and responsive scenario for solar geoengineering'; Douglas G. MacMartin, Peter J. Irvine, Ben Kravitz, and Joshua B. Horton, 'Technical characteristics of a solar geoengineering deployment and implications for governance', *Climate Policy*, 19:10 (2019), pp. 1325–39.

[39] Wake Smith, *Pandora's Toolbox: The Hopes and Hazards of Climate Intervention* (Cambridge: Cambridge University Press, 2022), p. 279.

[40] Mariia Belaia, Juan B. Moreno-Cruz, and David W. Keith, 'Optimal climate policy in 3D: Mitigation, carbon removal, and solar geoengineering', *Climate Change Economics*, 12:3 (2021), p. 2150008.

[41] Ann-Kathrin Benner and Delf Rothe, 'World in the making: On the global visual politics of climate engineering', *Review of International Studies* 50:1 (2024), pp. 79-106.

[42] Eva Lövbrand, Silke Beck, Jason Chilvers et al., 'Who speaks for the future of Earth? How critical social science can extend the conversation on the Anthropocene', *Global Environmental Change*, 32 (2015), pp. 211–18.

[43] Duncan McLaren and Olaf Corry, 'The politics and governance of research into solar geoengineering', *WIREs Climate Change*, 12:3 (2021), p. e707.

[44] Matt McDonald, 'Geoengineering, climate change and ecological security', *Environmental Politics* 32:4 (2022), pp. 565-85.

[45] Rita Floyd, 'Solar geoengineering: The view from just war/securitization theories', *Journal of Global Security Studies*, 8:2 (2023), p. ogad012.

[46] Peter Irvine and David Keith, 'The US can't go it alone on solar geoengineering', *Environmental Affairs* (April, 2021) pp. 38–44 available at: {https://policyexchange.org.uk/wp-content/uploads/2022/10/Environmental-Affairs-the-Geopolitcs-of-Climate-Change.pdf}; Andy Parker and David Keith, 'What's the right temperature for the Earth?', *The Washington Post* (2015); Janos Pasztor, 'The need for governance of climate geoengineering', *Ethics & International Affairs*, 31:4 (2017), pp. 419–30.

[47] Muhammet A. Bas and Aseem Mahajan, 'Contesting the climate: Security implications of geoengineering', *Climatic Change*, 162 (2020), pp. 1985–2002; Ian D. Lloyd and Michael Oppenheimer, 'On the design of an international governance framework for geoengineering', *Global Environmental Politics*, 14:2 (2014), pp. 45–63; Katharine L. Ricke, Juan B. Moreno-Cruz, and Ken Caldeira, 'Strategic incentives for climate geoengineering coalitions to exclude broad participation', *Environmental Research Letters*, 8:1 (2013), p. 014021.

[48] Wilfried Rickels et al., 'Turning the global thermostat: Who, when, and how much?', Kiel Working Paper (2018).

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a 'free-driver' effect that could otherwise lead to 'over-provision' of SRM to the lowest preferred temperature.[49] Concern about weaponisation of SRM has been dismissed as 'either false or grossly overstated', partly because of SRM's geophysical 'imprecision'.[50] Richer accounts do exist, which consider more complex state motivations,[51] coalition-building difficulties, domestic political struggles, and probable complex dynamics around scientific advice[52] and clashing worldviews,[53] and whether solar geoengineering would be incompatible with democratic practices.[54] With materialist assumptions, SRM sooner resembles a tool of empire[55] than a climate solution.

While most SRM research proponents reproduce Liberal assumptions, not all studies based on Liberal Institutionalist frames are favourable towards SRM. Some associated with 'Earth System Governance' research argue SRM is not amenable to 'effective and democratic controls' through international institutions.[56] They acknowledge 'serious concerns … about militarization and security'[57] but focus mainly on injustices arising from lack of effective institutional control from majority world countries.

There remains, therefore, a serious gap in understanding how security experts and military professionals – whose thinking tends to be closer to the Realist tradition – might treat climate geoengineering. One study identifies differing stakes various states have in or against Arctic geoengineering, recommending more research of 'frames that various state and non-state actors use to understand geoengineering'.[58] Another identifies concerns regarding possible securitisation of solar geoengineering as a negotiating tool, a military capacity, a target in conflict, or a cause of conflict.[59] Another speculates that 'tying solar geoengineering decision-making directly to state interests, combined with the technology's unforeseeable consequences, creates a risk of interstate conflict that could include potential environmental catastrophe'.[60] The importance of such concerns only rises in the context of proliferating 'climate emergency' framings and an (increasingly) competitive and fractious international security environment.

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[49] Anna Lou Abatayo, Valentina Bosetti, Marco Casari, Riccardo Ghidoni, and Massimo Tavoni, 'Solar geoengineering may lead to excessive cooling and high strategic uncertainty', *Proceedings of the National Academy of Sciences*, 117:24 (2020), pp. 13393–8; Martin L. Weitzman, 'A voting architecture for the governance of free-driver externalities, with application to geoengineering', *The Scandinavian Journal of Economics*, 117:4 (2015), pp. 1049–68.

[50] Joshua Horton and David Keith, 'Can solar geoengineering be used as a weapon?', (29 April 2021) available at: {https://www.cfr.org/blog/can-solar-geoengineering-be-used-weapon}; see also Wake Smith and Claire Henly, 'Updated and outdated reservations about research into stratospheric aerosol injection', *Climatic Change*, 164:3 (2021) pp.1-15. .

[51] Elizabeth L. Chalecki and Lisa L. Ferrari, 'A new security framework for geoengineering', *Strategic Studies Quarterly*, 12:2 (2018), pp. 82–106.

[52] Rose Cairns, 'Climates of suspicion: "Chemtrail" conspiracy narratives and the international politics of geoengineering', *The Geographical Journal*, 182:1 (2016), pp. 70–84; Zachary Dove, Joshua Horton, and Katharine Ricke, 'The middle powers roar: Exploring a minilateral solar geoengineering deployment scenario', *Futures*, 132 (2021), p. 102816; Felix Schenuit, Jonathan Gilligan, and Anjali Viswamohanan, 'A scenario of solar geoengineering governance: Vulnerable states demand, and act', *Futures*, 132 (2021), p. 102809.

[53] Duncan McLaren and Olaf Corry, 'Clash of geofutures and the remaking of planetary order: Faultlines underlying conflicts over geoengineering governance', *Global Policy*, 12 (2021), pp. 20–33.

[54] Bronislaw Szerszynski, Matthew Kearnes, Phil Macnaghten, Richard Owen, and Jack Stilgoe, 'Why solar radiation management geoengineering and democracy won't mix', *Environment and Planning A: Economy and Space*, 45:12 (2013), pp. 2809–16.

[55] Kevin Surprise, 'Stratospheric imperialism: Liberalism, (eco)modernization, and ideologies of solar geoengineering research', *Environment and Planning E: Nature and Space*, 3:1 (2020), pp. 141–63.

[56] Frank Biermann, Jeroen Oomen, et al., 'Solar geoengineering: The case for an international non-use agreement', *WIREs Climate Change*, 13:3 (2022), pp. 1-8 (p. 4).

[57] Biermann et al., 'Solar geoengineering', p. 3.

[58] Joseph Versen, Zaruhi Mnatsakanyan, and Johannes Urpelainen, 'Concerns of climate intervention: Understanding geoengineering security concerns in the Arctic and beyond', *Climatic Change*, 171:3 (2022), pp. 000–000 (p. 26).

[59] Benjamin K. Sovacool, Chad Baum, and Sean Low, 'The next climate war? Statecraft, security, and weaponization in the geopolitics of a low-carbon future', *Energy Strategy Reviews*, 45 (2023), p. 101031.

[60] William Morrissey, 'Avoiding atmospheric anarchy: Geoengineering as a source of interstate tension', *Environment and Security* 2:2 (2024): 291-315.

Physically, SRM, and in particular stratospheric aerosol injection, is anticipated to allow rapid-impact, high-leverage interventions in trans-boundary physical and political systems. Even localised SRM – such as cloud brightening conducted in particular marine regions with appropriate conditions – would be expected to have physical and political effects that spread widely,[61] meaning that SRM would almost certainly have effects beyond the borders of any single state, unlikely to be uniform in impact.[62] While climate models now offer predictions of average effects at the scale of large global regions, localised shifts in climate patterns and weather events and the interactions between such shifts and social vulnerabilities would appear practically impossible to predict or even attribute.[63] While none of these characteristics suggest SRM will be directly weaponised, they do indicate multiple ways in which it might translate into national security concerns. Moreover, SRM could (also) acquire a military rationale or security dimension in delivery.[64] Prospective techniques involve domains of activity and expertise – such as placing aerosols in the stratosphere, building structures in near-Earth orbit, or deploying vessels in international waters – in which military roles can be anticipated in providing (and/or protecting) critical infrastructures for deployment.[65]

While these conditions provide grounds for scrutiny from a security angle, this paper goes further by directly examining how security professionals with different national and disciplinary backgrounds initially interpret SRM. We adopt a *translations of security* approach, asking 'what happens to conventional understandings of security, risk, uncertainties and dangers when practiced within and across new spaces of professions, disciplines, organizations, cultures, and scales'.[66] Our specific question is how techno-scientific knowledge about SRM is 'translated' at the interface of climate science and (national) security, which we operationalise through a methodological focus on the Arctic context. Using evidence from interviews and workshops with security experts, we examine how techno-scientific knowledge about SRM is made relevant in international security settings, revealing frames that security experts apply. While these would not be the sole framings states would rely on, security professionals and their institutions (militaries, ministries of defence, and defence industries) would (and may already) be significant stakeholders. The security experts we engaged harboured diverse security mindsets (including liberal ideas about democracy and order) but were focused on competition and adversarial security logics and held less optimistic views on global agreements and institutional solutions than the typically Liberal Institutionalist governance literature.

Investigating security translations of geoengineering

To begin to anticipate the diverse ways in which SRM might be translated and reframed by security communities, in the next section we report interpretations and responses to SRM prospects elicited in 19 semi-structured interviews with security experts from the USA, Denmark, Canada, the UK, and Russia – plus NATO officials originally from Denmark and the Netherlands – comprising

[61] John Latham, Philip Rasch, Chih-Chieh Chen et al., 'Global temperature stabilization via controlled albedo enhancement of low-level maritime clouds', *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 366:1882 (2008), pp. 3969–87. While an ongoing marine cloud brightening trial over the Great Barrier Reef has received little political attention thus far, it is small-scale, oriented to local cooling effects to prevent coral bleaching. By contrast, a proposed equipment test for stratospheric aerosol injection (without forcing effect) was put on hold due to controversy and global opposition from Indigenous and environmental organisations, see Aaron M. Cooper, 'FPIC and geoengineering in the future of Scandinavia', in *Arctic Justice* (Bristol: Bristol University Press, 2023), pp. 139–53.

[62] Here, we exclude forms of local albedo modification such as covering glaciers with reflective blankets. These can have local benefits but do not have significant climatic leverage.

[63] Thilo Wiertz, 'Visions of climate control: Solar radiation management in climate simulations', *Science, Technology, & Human Values*, 41:3 (2016), pp. 438–60.

[64] Achim Maas and Jürgen Scheffran, 'Climate conflicts 2.0? Climate engineering as a challenge for international peace and security', *Sicherheit und Frieden (S + F) / Security and Peace*, 30:4 (2012), pp. 193–200.

[65] Paul Nightingale and Rose Cairns, 'The security implications of geoengineering: Blame, imposed agreement and the security of critical infrastructure', Climate Geoengineering Governance Working Paper Series, 18 (2014).

[66] Berling et al., *Translations of Security*, p. 12.

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individuals with interests or experience in climate security from military, political, think-tank, and academic settings, ranging from serving military strategic advisors through retired officers to academic specialists in national or international security.[67] Our interviews were designed to explore 'meetings between ... different terminologies, conceptualizations, and practices'.[68] In particular, we investigated how security professionals versed in climate security initially make sense of intentional climate interventions. As linguists recognise, 'translations' involve choices and generate new meanings and ambiguities, passed on in subsequent communications.[69] Our subsequent discussion of the interview findings also draws on notes taken during participation in eight national and international workshops discussing prospective stratospheric aerosol injection with security professionals and officials, which took place in the USA, Netherlands, Belgium, the UK, and online (organised from the UK, Denmark/Pakistan, UK/France, and Canada).

In a 'translations of security' approach, 'security' is produced in so-called translation zones: 'meetings between [different] conceptualizations of unwanted futures and programmes for their management'.[70] 'Climate security' as a field already involves a set of competing discourses and practices articulating 'security' and 'climate' together in different ways.[71] Solar geoengineering science adds a new element to translation zones of security, potentially changing the security landscape, despite 'deeply entrenched assumptions about the relationship between security and threats – i.e., security from violence – [which] shape the ways that national security institutions interpret – or "securitize" – environmental threats'.[72] Different groups have very different abilities to affect and successfully securitise 'unwanted futures'. Unsurprisingly, 'national security' discourse dominates over broader notions like human or ecological security when it comes to what 'climate security' actually means to our interlocutors.[73]

Two further clarifications are merited. Geoengineering and security meet each other here, not for the first time, but as already-related concepts. Climate modelling has origins in Cold War military planning, and geoengineering research is preceded by a long lineage of militarised ambitions of weather modification and ecosystem modification.[74] Although links remain,[75] as attested by the recent announcement of a commercial SRM venture – Stardust Solutions – with funding sources linked to the Israeli military and security industry,[76] *current* academic research on SRM has largely dissociated itself from current military institutions – making the translations perspective relevant nevertheless. Second, we do not suggest the knowledge translation process is one-way. Climate engineering scholars are also 'making sense' of 'security knowledge', such as that introduced by the involvement of the Defence Advanced Research Projects Agency in US geoengineering projects and modelling.[77] But our focus here is on how security actors translate geoengineering science.

Geoengineering has not yet been explored extensively in the security community (in public, at least) and like the general public, many interviewees were largely unfamiliar with the technical details of geoengineering, despite its emergence in security horizon scanning activities.[78] Hence

[67]The interview materials are provided in the supplementary files.

[68]Berling et al., *Translations of Security*, p. 6.

[69]Berling et al., *Translations of Security*, p. 29.

[70]Berling et al., *Translations of Security*, p. 52.

[71]Matt McDonald, 'Discourses of climate security', *Political Geography*, 33 (2013), pp. 42–51.

[72]Nathan Alexander Sears, 'International politics in the age of existential threats', *Journal of Global Security Studies*, 6:3 (2021), p. ogaa027 (p. 15).

[73]McDonald, 'Discourses of climate security'.

[74]Jeremy Baskin, *Geoengineering, the Anthropocene and the End of Nature* (Cham: Springer, 2019), pp. 27–73; James Rodger Fleming, 'Will geoengineering bring security and peace? What does history tell us?', *Sicherheit und Frieden (S + F) / Security and Peace*, 30:4 (2012), pp. 200–4.

[75]Kevin Surprise, 'Geopolitical ecology of solar geoengineering: From a "logic of multilateralism" to logics of militarization', *Journal of Political Ecology*, 27:1 (2020), pp. 213–35 (pp. 217–19).

[76]Andrew Freedman, 'Veteran climate diplomat to advise geoengineering startup', *Axios* (3 May 2024).

[77]Surprise, 'Geopolitical ecology of solar geoengineering'.

[78]US National Intelligence Council, 'Climate change and international responses increasing challenges to US national security through 2040', United States National Intelligence Council, Washington, DC (2021).

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our interviews required the assembly of a 'proxy-translation zone' where 'conceptual [expressions] of how to handle unwanted futures'[79] from security and geoengineering science could be brought together. During the interviews, we first sought to ascertain the concept of security 'native' to the profession and country of the respondent. After this, questioning probed how 'climate change' affected their understanding of 'security'. In the third and main section, interviewees were asked about emerging technologies in general, after which they reflected on SRM upon being presented with a short descriptive text about SRM drawn from the latest National Academy of Sciences (NAS) report.[80] This ensured a shared baseline of technical information. We focused on what respondents thought they would need to know about such a technology to evaluate its security implications, prompting them if needed with a list of general issues such as traceability, controllability, certainty of effect, and public acceptability.[81] In this process, we not only took on a role as intermediaries, transmitting geoengineering knowledge, but also inevitably participated in the security translations of geoengineering. However, informants began from their own understandings of (climate) security, and by being attentive to the different logics and meanings across the scientific and security fields, we sought to identify security implications that matter to the near-term debate and governance of geoengineering research.

Interviewees were recruited through a snowball methodology based on prior contacts on Arctic security. This choice was made because the Arctic is an arena of existing security concern where impacts of climate change are amplified and scientific geoengineering ideas are more frequently imagined as possible.[82] This focus omits important interests and perspectives, such as those from China and the rest of the majority world, but allowed us to explore how SRM might be translated by security actors at a critical international scale. Thus, while the Arctic has its particularities, the findings have general implications for the security politics of geoengineering, as discussed in the section 'Disruption, distrust and disinformation'. The interviewees were military and state security experts and professionals from positions within or close to state security establishments,[83] reflecting where the power to construct 'security' (including 'climate security'[84]) still primarily resides. Although small, and in no sense statistically representative, the sample matched known contemporary 'Northern' climate security discourses. The responses rapidly converged, and while we would not claim complete conceptual saturation,[85] it seems unlikely that our sample misses major security discourses around solar geoengineering in the relevant geographies.

Security professionals' responses

Notions of security and climate security

When asked what 'security' meant in their national context, respondents offered differing notions of a broadening – yet still sovereignty-centred – security, framed as 'defending national sovereignty' (RU1),[86] 'maintaining independence and integrity of the sovereign polity' (DK3) and 'regime survival' (DK2), with maintaining 'low tension' (DK1) or supporting 'peace and cooperation' (US3)

[79] Berling et al., *Translations of Security*, p. 3.

[80] National Academies of Science, Engineering and Medicine, 'Reflecting sunlight'. The presented text is available in the supplementary files.

[81] See interview questions in the supplementary files.

[82] Globalising the Arctic Climate: Geoengineering and the Emerging Global Polity. In Kiel K, Knecht S, editors, Governing Arctic Change : Global Perspectives. London: Palgrave Macmillan. 2017. p. 59-78 https://doi.org/10.1057/978-1-137-50884-3

[83] While there were critical security scholars among our interviewees, for all countries except Russia, the majority of participants came from within the relevant security establishments. The Russian case was complicated by the difficulty of finding representatives after the invasion of Ukraine, so there we rely more on external analysts.

[84] Jan Selby, Gabrielle Daoust, and Clemens Hoffmann, *Divided Environments: An International Political Ecology of Climate Change, Water and Security* (Cambridge: Cambridge University Press, 2022), p. 6.

[85] Benjamin Saunders, Julius Sim, Tom Kingstone, et al., 'Saturation in qualitative research: Exploring its conceptualization and operationalization', *Quality & Quantity*, 52:4 (2018), pp. 1893–907.

[86] Codes refer to distinct interviewees, identified by their nationality and a number only.

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as related international security-oriented goals. These notions were typically interwoven with elements of societal, economic, and human security, such as 'ensure economic and community security' (DK1), 'sustaining economy and livelihoods' (US1), 'protection of what matters to us, including our values' (GB1), 'deliver peace and prosperity' (DK3), 'peace and cooperation' (US3), or 'upholding international order and international law and human rights' (NATO1). In one case, 'human security' themes were explicitly dismissed as merely a rhetorical device concealing core strategic interests (CA1). The distinctive positionality of the states involved was reflected in the detail and tone of responses: for the USA, security goals were expressed in terms of 'maintaining military dominance and geopolitical hegemony' (US2) or ensuring 'the security order is favourable to Western democracies' (US5), which in their view means the USA 'needs to maintain control of the world's oceans and avoid the emergence of hegemonic power in other parts of the world' (US5). For Russia, security was bound up with sustained 'rivalry with the West', and in the Arctic 'simultaneously about military strength and socio-economic development' (DK2), while in less powerful states, goals of maintaining independence or access to critical resources were normal referents for security. For Denmark, continued ties to and sovereignty over Greenland were seen as essential for Arctic security (DK4), and, partly because of challenges to Greenland's territorial integrity and security, the alliance with the USA was almost coterminous with national security (DK5). Such distinctions in security concepts were also reflected in varied justifications reported for interventions beyond state borders, ranging from pragmatic to rules- or value-based rationales, which were later echoed in views expressed regarding possible geoengineering interventions with trans-boundary effects.

In these varied multidimensional expressions, security is already a product of ongoing unequal translations between multiple 'languages' of nationalism, stability, power, law, humanity, democracy, economy, etc. Exploring how climate change adds to this mix, we found it seen as an issue of long-standing concern (US1), of growing material salience (US4), even while still in the process of 'becoming' a 'security issue' (US1), or remaining something of an 'empty signifier', with broad rhetorical and political scope (DK3). In part, this reflects a common belief that the direct impacts of climate will continue to become more visible, and particularly so from the 2030s, when the impacts of different mitigation pathways are anticipated to diverge quite sharply (US3, GB2).[87]

Nevertheless, today climate change is typically understood as one among several emerging *risks* in broadened understandings of national security (US1; NATO1), and as a threat multiplier that increases tensions (DK1, NATO1&2) or exacerbates security challenges through material effects such as permafrost melting and sea-level rise (RU1) and extreme weather events (US1) which will be experienced as serious emergencies (US3). Specific climate-related concerns raised by our interviewees were wide-ranging, from neo-Malthusian themes of increased competition for resources ranging from water to rare earths (GB1), 'mass migration' (US2), 'huge movements of people, like we've never seen before' (GB1), or a 'huge migrant crisis' directly threatening a NATO member's border (NATO1); to 'War on Terror' themes of climate refugee flows enabling spread of terrorism to Europe (NATO1) and of exacerbation of terrorist threats through impacts on livelihoods and stability in regions vulnerable to radicalisation (DK1); to geopolitical concerns in the form of perceived elevated risks of conflict over strategic Arctic sea routes (DK2), climate being a complicating factor in strategic nuclear deterrence in the Northern hemisphere (CA1); and finally, more generally through posing 'challenges to conventional economic models and values' (GB1).

While primarily understanding climate as a risk factor, when prompted, most interviewees could also see some prospect of climate issues as opportunities for cooperation, peace-building, and confidence-building between strategic opponents. For example, 'in the Arctic cooperation on climate might be a route to reducing military instability in the region' (DK3, a sentiment echoed by US3). And as one informant put it, climate may offer an opportunity 'to bring on board key actors who need to realize there is no "winning alone" here, no equivalent of a "great wall" to keep

[87] All but four interviews preceded the severe impacts of the 2023 El Niño summer.

climate change at bay' (GB1). US respondents pointed specifically at opportunities to ease security tensions if effective climate responses reduce fossil demand, thus 'breaking "tethers of fuel" to the Middle East and reconfiguring energy geopolitics' (US1, similarly US2). However, others were more sceptical of such opportunities: 'the Kumbaya version of climate measures is peace-building … I want to believe in that, but …' (US4).

Security translations of geoengineering

Asked about emerging technologies generally, our informants mentioned artificial intelligence, machine learning, quantum computing, autonomous weapons, cyber-warfare tools and bio-weapons, highlighting weaponisation, dual use, and geo-strategic risks. Reasons for concern often involved unpredictable interactions (e.g. with existing nuclear weapons systems) and challenges of effective governance, with the latter especially problematic where it is unclear whether the technology should even be understood as a weapon or could be usable in a recognised domain of warfare. Such ambiguity applied to interventions in the cyber-domain, the electromagnetic spectrum, and also potentially to the climate space.

In translating SRM specifically, the issues raised by our informants fell into several broad categories: militarisation, unilateralism and distrust, non-state responses, and (the difficulty of) governance.

Militarisation

In stark contrast to how they appear in science literature, consideration of SRM technologies evoked imaginaries of weaponisation, with some interviewees explicitly recalling ideas of weather warfare (US2, RU1). Others drew comparisons with weapons systems whose impacts are difficult to constrain spatially, including nuclear, chemical, and biological weapons (GB1, others). But the main sources of worry about militarisation were related to questions of control. Our respondents tended to agree that the predictability of outcomes and the potential uncontrollability of the intervention itself were critical issues influencing the possible security implications of SRM. As one informant argued, invoking 'ideas of weather modification and nuking hurricanes', such proposals would be 'dangerous and geopolitically disruptive because the consequences are unpredictable' (US2). By contrast, for another, such technologies raised fears of a powerful political weapon: 'no question that if you can control weather patterns over another country you can blackmail them' (GB1) or harm their societies or hamper military operations (NATO1) – despite risks of domestic blowback on the geoengineer: 'countries have developed chemical and biological weapons that could have affected themselves' (GB1). Also, the question for the aggressor may be one of relative gains, depending on whether they 'can weather the impacts better than their targets' (CA1).

However, the potential for geoengineering capabilities to be utilised or perceived as a threat or deterrent did not depend on technical controllability alone. These technologies have 'implications for geo-strategic balance' (DK1) and require capabilities to detect deployment (although this was often presumed to be in place with existing surveillance) (RU1). Challenges in attributing climate effects to geoengineering deployments were expected to inject political instability and uncertainty, in particular exacerbating susceptibility to misinformation and propaganda (US1). One informant highlighted the circulation in Russia in 2010 of rumours of US 'hybrid warfare' using 'experimental climate weapons' to cause 'heatwaves and forest fires' (RU1).[88] So, for our security experts, SRM technologies are likely to be securitised whether they are controllable or unpredictable, albeit for

[88]Russian media in March 2023 reported an alleged US plan to develop and deploy SRM as a means to undermine Russian agricultural superiority, available at: {https://ria.ru/20230312/klimat-1856861090.html?utm_source=yxnews&utm_medium=desktop}. The article references a White House website document, which appears to be the congressionally mandated Office of Science and Technology report outlining a possible research plan, which was not actually released until July 2023, available at: {https://www.whitehouse.gov/ostp/news-updates/2023/06/30/congressionally-mandated-report-on-solar-radiation-modification/}.

different reasons in each case. In this light, one interviewee rhetorically demanded: 'give me an example when a cutting-edge technology has not been weaponized … in each case we saw scientific arrogance that "this time will be different"' (CA1).

A related route to potential militarisation was expectation of dual use. Our informants almost universally shared the view that deployment would inevitably raise suspicions of – or actually embody – dual use, particularly if militaries were involved in deployment or supporting infrastructures. This was especially relevant in the already (in their view) securitised zone of the Artic, where deployment of drones for search and rescue is seen as extending surveillance (RU1), and even scientific expeditions consistently raise questions (US3). As one informant told us: 'even if not planning to create weapons, geoengineering research will create capacities for dual use … and a justification for further surveillance' (GB1). Another suggested an analogy with space debris collection technology, presented as 'cleaning up space junk, but with potential dual use as a covert and deniable anti-satellite weapon' (US2). For another, the possibility of space-based geoengineering is tightly bound to the establishment of military pre-eminence in near-Earth orbital space in terms of the resources required (from lunar or asteroid mining), suggesting inevitable military involvement, with enormous geopolitical and security implications: whoever could deploy space-based SRM would be in a position where 'nobody can do anything in space without their consent. And by extension, nobody can do anything of substance on the world's oceans without their consent' (US5).

The ambiguous nature and status of geoengineering as a possible threat – even if not a kinetic weapon – creates uncertainties in its potential effects on international security. One interviewee asked: 'might geoengineering activities trigger NATO article 5 claims to self-defence … would we even know whether it was an act of war?' (US3). Weapon status is not necessarily determined internally but is a result of intersocietal dynamics. Our interviewee continued: 'any government might decide that something is not a domain of warfare, but that works only until an adversary decides otherwise' (US3).

Unilateralism and distrust

The possibility of unilateral deployment is often portrayed as a feature of SRM[89] but has also been doubted on the grounds of presumed rational incentives against going out on a limb.[90] Our respondents translate this question of unilateralism such that it relates not to failed global cooperation to mitigate emissions, but to wider distrust and security dilemmas. Most saw unilateral deployment as plausible, even if highly undesirable, as SRM 'could not deliver general benefits' (US4), and would trigger serious responses, including 'overwhelming demands for counter-geoengineering for deterrence' (GB1), or even consideration of 'how to destroy geoengineering technology' (GB1). 'Diplomatic, and maybe cyber responses' (RU1) were expected and 'concerted efforts to halt unilateral deployment, whatever the global effects; and geopolitically structured responses to regionally limited deployment' (US2). For some, even SRM experiments would raise 'a red flag' if they involved 'putting things in the atmosphere or global commons' (RU1). Because geoengineering 'climate outcomes are probabilistic, not deterministic', one respondent could not 'trust any country that promises "global benefits"' (US2). Even if it were their own country doing it, this informant highlighted that 'other countries would suspect concealed corporate or economic interests', generating distrust and potentially triggering disinformation: 'if I see Russia or China dispersing something into the atmosphere, it would raise real concerns about their rationale and other (secret)

[89]Scott Barrett, 'The incredible economics of geoengineering', *Environmental and Resource Economics*, 39:1 (2008), pp. 45–54; Daniel Heyen, Joshua Horton, and Juan Moreno-Cruz, 'Strategic implications of counter-geoengineering: Clash or cooperation?', *Journal of Environmental Economics and Management*, 95 (2019), pp. 153–77; Weitzman, 'A voting architecture for the governance of free-driver externalities'.

[90]Joshua B. Horton, 'Geoengineering and the myth of unilateralism: Pressures and prospects for international cooperation', in Wil C. G. Burns and Andrew L. Strauss (eds), *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks* (Cambridge: Cambridge University Press, 2013), pp. 168–81.

purposes' (US2). For another interviewee, unless geoengineering can be 'easily explained, visualized and tracked', it will be liable to deliberate misinformation by conventional security opponents, 'a huge challenge … playing into great power competition' (US1).

The positionality of our interviewees was reflected in their expectations of which states might take unilateral action. For Russian informants,[91] the USA was seen as the likely unilateralist, with reference to Cold War trials of weather modification weapons (RU1), while others saw Russia as a more likely source of 'uncontrolled and unconsulted deployment' (DK1). One expected others to be worried if they developed it: 'Let's say the US said we're going to save the globe and do all this, I'm pretty sure China would think it was the worst idea ever. And nobody would trust it was for the benefit of humankind' (NATO1). Development of geoengineering by the West would be seen as 'adding to NATO's encirclement of Russia' (US3). If not deployed in an agreement 'it would be seen as a hostile act' (NATO1). In either case, the expected outcome was a 'research race' to develop capacities, in order to ensure control or threaten retaliation or deterrence.

Expected distributional effects and diverging objectives of SRM were also expected to have geopolitical consequences, including 'contestation over distributional impacts' (DK3), 'collateral damage' (GB1), and 'risks of unintended consequences and side-effects' (US2). Possible implications for extreme events were mooted as (probably) more disruptive of security than incremental changes in sea level or temperature; and one interviewee asked, 'for example, what if geoengineering triggered more typhoons in the South China Sea?' (US3), while another emphasisd it was an 'irreversible' gamble – 'press the button and this is going to be the new world and we don't know where it ends … that will cause a tremendous insecurity in a lot of countries' and would only be contemplated if there was essentially 'nothing to lose' (NATO1).

As a result, respondents thought it critical to understand data, monitoring, verification, attribution, and control/adaptive management prospects for geoengineering (US3, US4, NATO1). These are all topics of research, but also subjects of disagreement among researchers as to the prospects.[92] In most cases, the deployment of geoengineering was to be feared as disrupting or destabilising existing international relations. But some interviewees suggested that 'restoring or refreezing the Arctic would be seen as restoring the security balance' (DK3). Nonetheless, while 'Russia might welcome ice stabilization, [it would] still fear enhanced US or Chinese influence' if those countries were the 'controllers' of the technology and might well issue 'counter-claims for compensation if geoengineering restricted access to resources' (DK3).

The potential for destabilisation was often linked to an expectation that national objectives for climate interventions would diverge, with differing objectives for temperatures, precipitation, and even ice cover (GB1, US3). The 'improbability that temperature preferences will be unanimous' (GB1) means that geoengineering potentially disrupts existing legal governance debates, such as those over 'ice-covered water' [as sovereign territory], raising questions such as 'who owns that iceberg?' (US3). For another respondent, any aim to refreeze the Arctic would probably not be shared by Russia[93] or the Greenland government, but possibly by Denmark and the Indigenous Circumpolar Council of Indigenous representatives, although Inuit tradition emphasises adaptation to climatic shifts and would be sceptical of 'meddling' (DK4).

Expectations of non-state responses

Interviewees' concerns about disinformation around SRM and its effects extended to critical non-state actors. One suggested a risk of 'cascading security problems from unilateral and non-state interventions, including those simply intended to disrupt' (US1), noting that 'extremist' or terrorist groups may effectively recruit on the back of perceptions of geoengineering as colonial

[91] These interviews were conducted before the Russian invasion of Ukraine.

[92] Duncan P. McLaren, 'Whose climate and whose ethics? Conceptions of justice in solar geoengineering modelling', *Energy Research & Social Science*, 44 (2018), pp. 209–21.

[93] Conflicting views on Russian preferences reflected focus on different internal Russian interests (energy access vs northern Russian infrastructure stability, for example).

domination, exploiting weather events and climate impacts with propaganda and misinformation (US1). Strikingly, none raised particular concerns about the 'greenfinger' scenario of a commercial or philanthropic actor taking unilateral action, commonly discussed and disputed in the geoengineering literature[94] and seen in fictional treatments of geoengineering.[95] They worried rather about existing 'extremist' groups: that the technology 'may fall into the hands of non-state actors who want to disrupt or threaten' (GB1) and that, if retained in state hands, geoengineering activities would risk generating unrest, potentially led by subsistence or Indigenous populations who can't deploy counter-geoengineering but might 'disrupt operations even to level of insurrection' (GB1). More widely, there was a fear that involvement in geoengineering might 'undermine trust in security institutions' (DK1). Another interviewee highlighted that Indigenous Arctic populations, currently gaining increased political influence in (most) Arctic states, may have relevant views, with concerns about the footprint of new activities (US3). The vocal opposition to SRM from the Saami people, triggered by the proposal by a Harvard research group to undertake experimentation over their lands, reinforces this view.[96]

On the other hand, some corporate interests were anticipated to support geoengineering. One interviewee specifically warned about the fusion of corporate and state interests in the Russian energy sector (DK2) establishing interests in geoengineering as a means to prolong oil and gas development and exports. A similar warning was issued about the West (NATO1) and the Canadian state, the latter plausibly treating SRM as a means 'to defend economic interests in oil and gas, whilst appearing progressive' and deploying human security rhetoric to help 'over-ride national security reservations' (CA1). Others more generally noted that 'techno-optimism can be an excuse for climate inaction' (GB1, also NATO1) and emphasisd a concern over other environmental harms continuing as a result: 'solar geoengineering implies we get to "party on", and go on destroying biodiversity and creating zoonoses, even if it tackles climate impacts', offering the analogy that 'if I can take a pill at 3.15 that sobers me up, I'll drink until 3 am' (GB1).

Essential but difficult governance

Our informants simultaneously saw a strong *need* for governance of geoengineering, beginning with research governance, yet considered it difficult to develop. For our security experts, analogies with weapons control came readily to mind, as well as considerations of United Nations (UN) institutional settings, ranging from the Security Council to the Framework Convention on Climate Change (UNFCCC). Many found the prospect of effective governance unlikely: 'any tech that really matters has not had a good track record' in this respect (US2). A mini-lateral agreement, extending outwards like the Hague or Geneva conventions, would 'seem the best hope' (US2). One informant suggested that governance requires 'at least cooperation between the US, Russia and China to avoid competition … nuclear weapons and nuclear monitoring regimes are the best analogue' (US1). But a commentator on Russia pointed to difficulties even convening this group: 'US–USSR bilateral arms treaties offer a possible model … [but] Russia might prefer a bilateral deal with the US, as it does on nuclear weapons today, rather than bringing in the Chinese too' (DK3). Others noted that exclusion – especially from a regime governing experimentation – would generate threats of sanctions or diplomatic expulsions, as well as demands for monitoring and access for observers or inspectors, and potentially efforts to develop counter-geoengineering capacities.

Most seemed to see governance as a desirable means to constrain, rather than enable, deployment of geoengineering. One raised bans on chemical and biological weapons as analogues but described them as disappointing because they have not halted development (US2). Another, alluding to an 'arms race', suggested a need to get global leaders to see that 'the geoengineering

[94]E.g. Daniel Bodansky, 'The who, what, and wherefore of geoengineering governance', *Climatic Change*, 121:3 (2013), pp. 539–51; Smith and Henly, 'Updated and outdated reservations about research into stratospheric aerosol injection'.

[95]E.g. Eliot Peper, *Veil* (n.p., 2020); Neal Stephenson, *Termination Shock* (London: HarperCollins, 2021).

[96]Cooper, 'FPIC and geoengineering in the future of Scandinavia'.

competition mustn't start because it can never be won' (GB1). And alongside multiple references to constraints on nuclear proliferation, one cited the Environmental Modification (ENMOD) Convention as a model, though speculated that 'it will take 15 years just to decide what the definition of geoengineering is' (GB1).

Yet the extent of international recognition of climate as an urgent issue was seen to potentially justify experimentation and testing of geoengineering, for some even in a unilateral mode (DK3). For others, this had to be at least bilateral (US3). The latter was more readily conceivable if coordination were to draw on ongoing scientific cooperation (DK3), as this could help avoid suspicions that would otherwise accompany technology trials by Russia or NATO (US3). Such tests – especially if directly involving security actors – might also be seen to (further) undermine the relative independence of scientific activities from security concerns. By contrast, the value of scientific cooperation around nuclear issues, even at the height of the Cold War, was noted approvingly by one (GB1). Experimentation that could be effectively contained within national territories was generally seen as less threatening. One commentator even suggested, not entirely frivolously, that one 'might get away with a lot of "crazy shit" in Greenland, with limited effects on others' (DK3).

Nonetheless, experimentation and even early-stage research were seen to require governance. Research was understood to be potentially inevitable, and in some respects desirable if framed within a model of 'non-proliferation' which implies tight controls. As one interviewee put it: 'it's too late to say "no research" … research is necessary to understand the implications of such technologies', yet 'we need to regulate the research, because it's the research that generates the capacity' (GB1). Others concurred, highlighting that research and experimentation is preferable in 'the international multilateral context' (RU1) and 'should be mandated, financed, regulated and monitored within a legitimate international organization' (DK3) or 'regulated in a collaborative and transparent regime' (US2). Such a global research regulation regime needs to be set up before one country invests heavily and triggers a 'research-race', as it would otherwise become 'impossible to establish' (US2). Another informant similarly saw unilateral research as trigger of security concerns and emphasised the desirability of collaboration even at research stage to prevent future 'deniability' of geoengineering activities or impacts (US3). These informants tended to reproduce an assumption that research could be enabled in a controlled manner with a low risk of 'locking-in' deployment, a view that is typically shared by scientific advocates of geoengineering research but questioned by some governance scholars.[97]

Disruption, distrust, disinformation …

Overall, SRM raises questions – regarding power relations, geopolitics, and military involvement – absent from Earth-system modelling tools and largely excluded from scientific-oriented climate policy debates. In contrast to scientific assessments based on anticipated physical properties and modelled climate impacts, security experts – starting from more Realist assumptions and international dynamics – translate solar geoengineering ideas in ways that suggest significant potential for such technologies to exacerbate distrust and geopolitical tension, especially if advanced unilaterally. Fundamentally, international security practitioners do not operate on the basis of the world as one integrated space or system as climate models do, nor as a system of global governance or rules as Liberal Institutionalists might, but as divided. The rationally intended purposes of scientific tools are not assumed to survive the irrational and complex dynamics of geopolitics.

Security translations of SRM knowledge challenge prevailing science-based articulations of SRM in at least three significant ways. They see it (a) as geopolitically *disruptive* rather than a global public good, (b) as a strategic resource in a world of mutual *distrust* rather than a climate risk management tool, and (c) as a multiplier of *disinformation* risk rather than a knowledge-deficit problem that more scientific studies will solve.

[97]E.g. Catriona McKinnon, 'Sleepwalking into lock-in? Avoiding wrongs to future people in the governance of solar radiation management research', *Environmental Politics*, 28:3 (2019), pp. 441–59.

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First, for security experts SRM is understood as a high-leverage technology, raising concerns about weaponisation irrespective of (im)precisions of the technique. Disruptive potential was identified mostly in terms of the use of SRM as a leverage tool, but also because of likely lopsided and unpredictable impacts and disagreement about aims or ideal climate outcomes. Even if not directly weaponisable, high-leverage technologies are understood by security experts as inherently 'dual use', with potential 'spillover effects' and as vulnerable to being framed by security 'opponents' (whether other states or 'extremist' actors) in misleading or destabilising ways (see below). Insofar as climate modellers do deem the technology predictable and targetable, from a security perspective these very characteristics increase perceived risk regarding strategic leverage.

Related to this, the risk of 'termination shock' (should geoengineering be deployed to mask significant warming and then abruptly halted causing a sudden spike in heating) has been downplayed by climate analysts, partly on the grounds that any deliberate sabotage of an SRM programme would impact negatively on any perpetrator of disruption.[98] However, for some of our respondents termination shock was a particularly worrisome source of geopolitical leverage. States might accept costs or self-harm for sake of deterrence and leverage or consider 'scorched earth' options in conflictual contexts. In this reading, the potential for termination shock becomes a reason to prevent the emergence of geoengineering and this (in their eyes) novel destabilising security risk.

All this makes security actors relatively reluctant to countenance geoengineering, with one interviewee confirming that: 'in wargames, scientists grasp at geoengineering early and consistently before military actors … [who] stay away from geoengineering … until it appears a means of fixing the security problems arising from severe climate impacts' (US1). It was expected that SRM would be tried only at the point when climate change itself became an acute security threat – a case of 'let's flip the coin and nothing to lose' (NATO1). Geoengineering would then be a fully fledged security measure dealing with an emergency (and only incidentally an environmental tool to tackle climate change).[99]

Secondly, in climate science and most policy literature, development of geoengineering capabilities is assumed *a priori* to be as a response to 'climate risk'[100] (this is even part of many definitions of geoengineering),[101] or driven by countries' individual preferences for particular *climatic* conditions (sometimes summarised as 'temperature').[102] Translated into security, however, efficacy in tackling climate risk (or designing optimal local climates) becomes secondary. Rather than being a relatively cheap and easy climate policy option (compared to multilateral coordination of 'expensive' mitigation), security experts evaluated SRM as *strategically potent*. In climate-oriented governance parlance, SRM engenders a 'free-driver' logic because any capable actor could in theory attempt to engineer a preferred climatic state.[103] For security-related actors, drivers of unilateral development (or use) resided much more in distrust towards (and competition with) other countries than climate risks. Our experts predicted that unilateral research and development efforts are highly likely to trigger a research race, with other states than their own (perceived as unfriendly or untrustworthy) considered more likely to be the ones to act first.

While some climate-centred geoengineering literature discounts risks of unilateral deployment due to the benefits of multilateralism,[104] our informants viewed unilateral deployment as possible (although not easy), especially because multilateral governance was perceived as challenging, if not

[98] Andy Parker and Peter J. Irvine, 'The risk of termination shock from solar geoengineering', *Earth's Future*, 6:3 (2018), pp. 456–67.

[99] Chalecki and Ferrari, 'A new security framework for geoengineering'.

[100] Harrison et al., 'A risk–risk assessment framework for solar radiation modification'; Andy Parker, 'Governing solar geoengineering research as it leaves the laboratory', *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 372:2031 (2014), p. 20140173.

[101] John G. Shepherd, *Geoengineering the Climate: Science, Governance and Uncertainty* (London: Royal Society, 2009).

[102] E.g. Abatayo et al., 'Solar geoengineering may lead to excessive cooling and high strategic uncertainty'.

[103] Weitzman, 'A voting architecture for the governance of free-driver externalities'.

[104] John Halstead, 'Stratospheric aerosol injection research and existential risk', *Futures*, 102 (2018), pp. 63–77; Horton, 'Geoengineering and the myth of unilateralism'.

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impossible. Correspondingly, whereas much existing literature presumes governance institutions would be needed to rein in 'rogue' geoengineering, in most of our interviews mutual deterrence was expected to be the dominant form of *de facto* governance. Technologies were understood as difficult to control and coordinate, especially given presumed diverging interests and risks of deliberate disruption and disinformation. Proposed deployment would be met with threats aimed at deterrence rather than institutionalised rules-based governance.

The frequency of unprompted consideration of counter-geoengineering during interviews with security experts was also striking. While considered occasionally by game theorists and geoengineering analysts,[105] it has rarely been studied in climate-modelling scenarios. Security actors' expectations of counter-geoengineering are shaped by the combination of pervasive distrust, and by the weaponisation analogies typically explored, where counter-measures are perhaps more logical.

Thirdly, reliable and trusted information – and therefore more research – is usually considered crucial to SRM as a climate intervention, yet consideration of risks stemming from *dis*information is limited in extant scientific and policy literature.[106] Security interviewees consistently connected uncertainty to the risk of disinformation rather than a lack of sufficient knowledge. Their interpretations of geoengineering knowledge led them to expect further intensification of surveillance and monitoring (especially to try to reduce disinformation risks regarding whether or not geoengineering was being deployed). Drawing parallels from the cyber domain and 'hybrid warfare' doctrines, they suggested disinformation or propaganda about geoengineering could be created and spread by diverse actors, including powers such as the USA, Russia, or China; non-aligned states such as Iran or Bolivia; non-state actors including both corporations and NGOs; and extremist groups such as ISIS or Boko Haram, to aid recruitment or to disrupt public attitudes and trust in state powers. Respondents found it easy to see geoengineering blamed for any adverse weather or climate events, such as droughts, floods, or storms, and conceivably portrayed as atmospheric colonialism, potentially especially disruptive in already climate-vulnerable parts of Asia and Africa. Practical experience so far with the exploitation of the limitations of climate attribution by denialists and opponents of climate action and experience with Covid implies[107] that such fears cannot necessarily be assuaged by more knowledge generated through modelling or even experimentation. Security think-tanks have raised similar concerns.[108]

In contrast, while climate modellers acknowledge problems with attribution, and some worries regarding impacts on international relations, there is a view that such issues, along with controllability and effective modulation, are distinct from modelled global benefits of (well-designed and coordinated) deployment of geoengineering.[109]

While security organisations appear deeply hesitant to embrace these emerging technologies (at least publicly) they do show interest in learning more about them, though with a strong preference for regulated and multilateral forms that might help constrain competition, distrust, and disinformation. Most of our interviewees were reluctant to propose constraints on the content of research agendas but encouraged early governance and coordination of research to enable monitoring and inspection regimes and build up interstate trust.

[105]Heyen et al., 'Strategic implications of counter-geoengineering'; A. Parker, J. B. Horton, and D. W. Keith, 'Stopping solar geoengineering through technical means: A preliminary assessment of counter-geoengineering', *Earth's Future*, 6:8 (2018), pp. 1058–65.

[106]Cairns, 'Climates of suspicion'.

[107]Will Jennings, Gerry Stoker, Viktor Valgarðsson, Daniel Devine, and Jennifer Gaskell, 'How trust, mistrust and distrust shape the governance of the COVID-19 crisis', *Journal of European Public Policy*, 28:8 (2021), pp. 1174–96.

[108]US National Intelligence Council, 'Global Trends 2040: A More Contested World', United States National Intelligence Council, Washington, DC (2021).

[109]MacMartin et al., 'Technical characteristics of a solar geoengineering deployment and implications for governance'.

Global governance?

States are expected to differ over the optimum setting for the 'global thermostat' and, perhaps more importantly, over the appropriate combination of geoengineering and emissions cuts, particularly concerning the level of continued fossil fuel exploitation thus enabled. But we also heard expectations among interviewees of a very clear divergence between the interests of certain states, each wanting to secure a central role in governance for themselves, to the exclusion of broader multilateral representation. Contestation over access to the technology and appropriate observation and monitoring was seen as likely. This could be exacerbated by the possible role of military assets in any delivery of geoengineering, as well as the existing dual-use purposes of Earth-system monitoring programs such as the EU's Copernicus Earth observation programme.[110] While some leading geoengineering modellers have appealed to 'smaller democracies' to take a lead in research and development alongside the USA,[111] intimating an acceptable 'we' of liberal hegemony leading future governance, such a configuration could fuel governance struggles foreseen by security experts. Moreover, if 'security' becomes the primary concern, governance structures cannot be based on the idea that states are motivated primarily by environmental goals. While our respondents were concerned about the security impacts of climate change, the interview evidence suggests greater concern about solar geoengineering having negative, disruptive impacts on geopolitics (at least for the near term) than confidence in it reducing the negative security implications of climate change. Solar geoengineering – it would appear – is seen so far both as exceptional in security terms and less predictable (if not necessarily more severe) than the effect of climate change itself.

While the emergent security framings uncovered here do leave space for the hope that geoengineering research and deployment could be internationally regulated and a space for collaboration, and even peace-building,[112] in part such hope rests upon a possibility that states' shared dependence on the globally interconnected climate system provides a foundation for cooperation. However, as IR scholars have argued, interconnectedness can also be a source of conflict because it involves vulnerabilities and opportunities for power politics.[113] Greater connectivity in other spaces – such as global trade, migration, and the internet – has confounded optimistic Liberal expectations by becoming both a means and source of antagonistic conflict in an 'age of un-peace'.[114] The idea that 'global realism' could emerge in response to common planetary threats like nuclear weapons and climate change[115] has circulated amongst scholars since the emergence of nuclear weapons, though the odds seem to be stacked against. Our interviewees tended to view solar geoengineering instead as *already inherently linked* to wider patterns of competition and saw geoengineering as a potential source of leverage (or blackmail). Efforts to securitise the climate by blaming 'the other' are not new – consider President Trump's claims of climate change as a 'Chinese hoax', or Russian propaganda on 'US climate weapons' noted above. Rather than circumventing the international, geoengineering technologies would be overlaid onto – and may accelerate – existing processes of 'othering' (of other states, of migrants or others) allowing climate instability to be blamed on others' (non-)deployment of such technology.[116]

The more research moves into the physical domain through outdoor experiments and engineering trials, the more likely that prospects of geoengineering as a security tool will gain traction

[110] Delf Rothe, 'Seeing like a satellite: Remote sensing and the ontological politics of environmental security', *Security Dialogue*, 48:4 (2017), pp. 334–53.

[111] Irvine and Keith, 'The US can't go it alone on solar geoengineering'.

[112] Holly Jean Buck, 'Environmental peacebuilding and solar geoengineering', *Frontiers in Climate*, 4 (2022), 869774.

[113] Kenneth N. Waltz, 'The myth of national interdependence', in Ray Maghroori and Bennett Ramberg (eds), *Globalism versus Realism: International Relations' Third Debate* (New York: Routledge, 1982), pp. 81–96.

[114] Mark Leonard, *The Age of Unpeace: How Connectivity Causes Conflict* (London: Bantam Press, 2021).

[115] Rens Van Munster and Casper Sylvest, *Nuclear Realism: Global Political Thought during the Thermonuclear Revolution* (London: Routledge, 2016).

[116] Duncan McLaren and Olaf Corry, '"Our way of life is not up for negotiation!": Climate interventions in the shadow of "societal security"', *Global Studies Quarterly*, 3:3 (2023), p. ksad037.

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in the entangled power–knowledge space of climate science and military planning. Implied optimistic visions of controllable geoengineering for the global good are assumed in climate model studies, but, especially if defined as a 'climate security' measure, our interviews suggested that in the USA, for example, SRM would be viewed in the context of US strategic doctrine (maintaining overall dominance for the USA and its allies). The USA could seek cooperation with other global powers or cultivate client states, treating climate and climate engineering as a peace-building (or co-optation) opportunity, but interviewees' expectations were more that unilateral US investment in research would provoke tensions and a capabilities race with Russia or China.

Conclusion

Realism is increasingly called upon in climate IR to better understand the security challenges involved and the ways the geopolitical impinges on climate policy otherwise conceived in globalist and rationalist terms. Given failing multilateral mitigation policy, high-leverage trans-boundary interventions like SRM could appear tempting from a Realist approach to climate politics. However, Classical Realist notions of precaution and humility in relation to what kinds of rational international cooperation are plausible and ethically palatable, and what conflicts and tragedies are possible, suggest the opposite.[117] Hitherto, security logics around geoengineering have been underexamined and largely speculative, with a tendency to go with scientistic, rationalist presumptions.

Our findings suggest SRM might align poorly with global utilitarian climate purposes, especially once security experts apply frames and concepts from their own area of expertise. Our security experts' responses to solar geoengineering reveal ways that security agencies can be anticipated to initially engage. They may respond differently once more detailed proposals for implementation emerge, and despite the relative power of security agencies, there are other voices that will influence how states will ultimately act. Nonetheless, these concerns suggest, at the very least, plausible pathways to securitisation and militarisation of SRM, regardless of the technical difficulty of direct weaponisation.

Security actors produce a distinctive articulation of 'solar geoengineering' different from those of climate science and climate policy analysts. Questions of control, predictability, and attribution feature in scientific exploration of geoengineering – aiming for greater certainty – but these issues take on different meanings when translated into security contexts. When geoengineering is understood as difficult to target, predict, and attribute, security experts anticipate that its development would exacerbate geopolitical tensions and distrust; if climate science suggests geoengineering would be feasible to control, target, and attribute on the other hand, security concerns about possible weaponisation are raised. In either case, more geoengineering knowledge is less a source of reliable guidance lowering climate risks, and more a source of potential leverage, controversy, and disinformation.

Security translations of scientific SRM knowledge do not leave 'security' unchanged however, e.g. they introduce deliberate intervention and intentionality into the idea of 'climate security'. In security terms, SRM is a potential new geopolitical resource or deterrent, generative of a geoengineering 'arms race' and/or mutual deterrence outcomes. Channelling Morgenthau, it would be hubristic to assume that SRM would be directed according to the carefully optimised schemes of climate modellers in service of multilaterally agreed human security or global justice goals. Any intervention would be influenced by geopolitical factors of urgency and strategic contingency (including potentially continued interests in delaying the ending of fossil fuel exploitation) alongside (secondarily) the perceived security risks of climate change. The most commonly predicted outcomes by security experts are militarised research and (eventually) deployment. If SRM is 'governed', this would happen primarily by mutual deterrence not multilateral governance. Security actors do see pathways (albeit difficult ones) to unilateral use, most likely followed by competing uncoordinated deployment of geoengineering and counter-geoengineering tools.

[117] Symons, 'Realist climate ethics'.

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Such geopolitical thinking that reifies state competition, mutual suspicion, and fears of dual use and weaponisation, presenting these as immutable facts of life grounded in human nature (or an 'anarchic system'), is of course part of the problem. This contributes to inaction on emissions too. Nonetheless, such ideas remain powerful, not least in Northern security establishments.

Security professionals do also point to possible – though narrow – routes to coordinated deployment. One leads from collaborative and transparent (not unilateral) research and experimentation (possibly in arenas like the Arctic), supported by rapid expansion of governance from mini- or bilateral origins to a UN-endorsed treaty, though disagreement so far makes this doubtful.[118] A more likely pathway to deployment – in their eyes – includes an initial stalemate in which unilateral deployment is considered too risky, broken by great powers in a mini-lateral or bilateral deal (with measures to control further proliferation of SRM capabilities) as they come to view climate change as a clear and present *security* problem.

In this respect, SRM might be seen as the 'missing piece' in turning the climate fully into a security problem. This is not so much to suggest that geoengineering unlocks a militarised response to climate, but that militarisation would be a way of unlocking SRM from the likely logjam of multilateral disagreement about it.[119]

Finally, this study remains only a partial exploration of the many possible translations between climate engineering science and security. Subsequent work could usefully consider translations by other security cultures such as that of China (a prominent sceptic of securitisation of climate as an issue) and other actors in the majority world. Human security framings – and potentially ecological or societal security framings – could differentially influence the translations emerging, as could different geoengineering techniques. Improving understandings of these translations and responses is a precondition for thinking about 'governance' of SRM beyond the technocratic language of global climate risk management.

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[118]Duncan McLaren and Olaf Corry, 'The global conversation about solar geoengineering just changed at the UN Environment Assembly. Here's how – Legal Planet', available at: {https://legal-planet.org/2024/03/08/the-global-conversation-about-solar-geoengineering-just-changed/}.

[119]Danielle N. Young, 'Considering stratospheric aerosol injections beyond an environmental frame: The intelligible "emergency" techno-fix and preemptive security', *European Journal of International Security*, 8:2 (2023), pp. 262–80.

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