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Geoengineering Wars and Atmospheric Governance

Craig Martin & Scott Moore*

The increasingly harsh and unevenly distributed heat-related harms caused by climate change, together with frustration over the collective inability to respond to the crisis, are likely to make unilateral geoengineering efforts increasingly attractive. Stratospheric aerosol injection ("SAI") is a form of solar radiation modification that is effective, technically feasible, and within the financial means of many states and even non-state actors. Yet, there are virtually no global governance structures in place to specifically regulate such activity, and existing international law would provide only weak constraints on unilateral SAI efforts. These features create incentives for unilateral action in what is known as a "free driver" problem: few constraints on a unilateral action that has low direct cost combined with immediate direct individual benefit despite widely distributed risks and indirect costs.

There would be significant collateral environmental and climatic harms associated with SAI. That, coupled with the high risk of unilateral action, is reason enough for both caution and stronger governance. But another risk posed by any unilateral SAI effort—one that is underappreciated and under-theorized—is that of armed conflict. We explore how and why states would likely perceive the potential risks associated with unilateral SAI effort as constituting a threat to national security, and in the absence of adequate legal and institutional mechanisms to constrain such unilateral action, might well contemplate the use of force to defend against the perceived threat. The Article explores and explains how and why the jus ad bellum regime is unlikely to prevent states from engaging in unauthorized use of force against unilateral SAI actors.

In sum, there are strong incentives for unilateral SAI deployment, there is little in the way of global governance to constrain it, states will view it as a threat to national security, and the jus ad bellum regime is in turn unlikely to constrain any

* Craig Martin is Professor of Law and Co-Director of the International and Comparative Law Center, Washburn University School of Law; Scott Moore is Practice Professor of Political Science and Director of China Programs and Strategic Initiatives, University of Pennsylvania. We would like to thank Jutta Brunée, Bill Burke-White, Jimmy May, Mark Nevitt, and Freddy Sourgens for their feedback, comments, and other input at various stages of the development of this project as well as Molly Morgan for her invaluable research assistance, and Andrew Doan and Zach Green for their help with the final editing process. We are also grateful to the *Harvard International Law Journal* editorial team for all their great work, patience, and flexibility in the editorial process. We are, of course, responsible for any errors.

use of force in response—which creates a distinct risk that unilateral SAI deployment could result in armed conflict.

We argue that this underappreciated risk, combined with the growing pressure and incentive for unilateral action, provides further grounds for the urgent development of more robust governance for SAI—specifically, apart from other forms of geoengineering. We argue that a traditional multilateral treaty structure with an accompanying institutional apparatus is required, and we provide some preliminary ideas on the objects and purposes of such a governance structure. We explain that either the United Nations Framework Convention on Climate Change *("UNFCCC") or the* Montreal Protocol *would provide an ideal forum within which to commence the work of developing such a governance structure.*

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Introduction

The early 2020s, which were marked by record high temperatures as well as wildfires and extreme weather events all over the world, may well be remembered as the time when the climate change crisis finally burst into the public consciousness as a clear and present danger rather than a distant problem for future generations. Aside from the deaths, injuries, and destruction caused by extreme weather events, extreme heat itself caused not only social disruption and economic loss on every continent but also a considerable number of deaths across the world.[1] It was the extreme heat more than anything that seemed to sear the issue into the public discourse.[2] The causes and consequences of climate change are complex and seemed obscure to much of the public, but suddenly everyone could feel the heat and understand the implications. Indeed, it will only get hotter, even under the most optimistic scenarios for reducing greenhouse gas ("GHG") emissions. The international community has committed to keeping the global average temperature increase to less than 2° Celsius (relative to pre-industrial levels) and to making best

1. Full data for the summer of 2023 is not yet available, but a study of heat-related mortality rates in Europe in the summer of 2022 determined that over sixty-one thousand people died from heat-related causes. Joan Ballestar et al., *Heat-Related Mortality in Europe During the Summer of 2022*, 29 Nature Med. 1857 (2023).

2. *See, e.g.*, Timothy Hyde and Dolores Albarracin, *Record-Breaking Heat Days Disproportionately Influence Heat Perceptions*, 13 Sci. Reps. 1 (2023); Matthew Ballew et al., *Americans Are Becoming More Worried About Extreme Heat*, Yale Program on Climate Change Commc'n (July 27, 2023), https://climatecommunication.yale.edu/publications/worry-about-extreme-heat/ [https://perma.cc/S6JM-6J3U].

efforts to limit the increase to 1.5°. But the Intergovernmental Panel on Climate Change ("IPCC") determined in its most recent report that the world is on track for an "overshoot," with an increase in average global temperature of between 2° and 4° Celsius above pre-industrial levels by 2100. Indeed, under high-emissions pathways, average global temperatures could rise as high as 5.7° Celsius. The planet is already at 1.3° Celsius above pre-industrial levels, and global temperature increases will likely exceed 1.5° by 2040.[3] How shall states, particularly the more vulnerable nations, respond to intolerable temperature increases?

The speed, intensity, and scale of these changes are making various forms of geoengineering look increasingly attractive. Already the focus of popular science fiction,[4] the idea of employing different forms of solar radiation modification ("SRM") to moderate impending temperature increases, even if only as an interim measure while we make the necessary energy transition and reduce GHG emissions, is an issue that is attracting serious attention and investment. Among the various forms of SRM currently under investigation,[5] stratospheric aerosol injection ("SAI") has emerged as a particularly effective and inexpensive method. Political and policy institutions ranging from the White House to the United Nations Environment Program ("UNEP") and the IPCC have included SRM as a possible interim policy response to climate change.[6] At least two corporate

3. Intergovernmental Panel on Climate Change [IPCC], *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, at 35–115 (Hoesung Lee et al. eds., 2023) [hereinafter IPCC, *AR-6*]. *See* discussion *infra* Part I.A. As this article was being finalized, it was reported that the world had experienced a 1.5° Celsius increase for a full twelve-month period for the first time. Mark Poynting, *World's First Year-Long Breach of Key 1.5C Warming Limit*, The BBC (Feb. 8, 2024), https://www.bbc.com/news/science-environment-68110310 [https://perma.cc/CM8P-P4FJ].

4. Kim Stanley Robinson, The Ministry for the Future (2020), opens with a horrifyingly graphic account of a heat wave in India that kills millions of people, in response to which the Indian government commences a prolonged unilateral program of injecting sulfate-based aerosols into the stratosphere to block solar radiation (SAI), in the face of objections from the international community; *see also* Neal Stephenson, Termination Shock (2021), which similarly centers on a unilateral SAI program, and *Extrapolations* (Apple TV+ 2023).

5. *See The Harvard Solar Geoengineering Research Program*, The Salata Inst. for Climate & Sustainability at Harv. Univ., https://geoengineering.environment.harvard.edu/geoengineering [https://perma.cc/7N8U-EMQ6] (last visited Sept. 11, 2023).

6. *See* The White House, Congressionally Mandated Research Plan and an Initial Research Governance Framework Related to Solar Radiation

ventures have already begun to develop a business model based on SRM, and investments in such enterprises are expected to surge.[7] SRM proponents argue that it is now clear that we are not likely to cut GHG emissions sufficiently by mid-century, or even by 2075, to keep increases in temperature below 2° or even 3° Celsius by the end of the century. They argue, therefore, that the harm caused by that level of warming makes temperature-reducing geoengineering necessary—at least until the world can begin to finally reduce GHG concentrations in the atmosphere.[8]

These arguments are part of a larger debate over whether and to what extent various forms of geoengineering are necessary in responding to climate change. The term "geoengineering" is used in different ways and has a range of definitions of varying scope, broadly meaning any "deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change."[9] The term is thus inclusive of some forms of carbon dioxide ("CO_2") removal and carbon capture and sequestration

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MODIFICATION (2023), https://www.whitehouse.gov/wp-content/uploads/2023/06/Congressionally-Mandated-Report-on-Solar-Radiation-Modification.pdf [https://perma.cc/H7AU-9H7G] [hereinafter WHITE HOUSE SRM REPORT]; U.N. Env't Programme [UNEP], *One Atmosphere: An Independent Expert Review on Solar Radiation Modification Research and Deployment* (2023), https://wedocs.unep.org/bitstream/handle/20.500.11822/41903/one_atmosphere.pdf [https://perma.cc/Y9DE-S5WF] [hereinafter UNEP, *One Atmosphere*]; IPCC, *AR-6*, *supra* note 3.

7. The case of Make Sunsets was first described in James Temple, *A Startup Says it's Begun Releasing Particles into the Atmosphere, in an Effort to Tweak the Climate*, MIT TECH. REV. (Dec. 24, 2022), https://www.technologyreview.com/2022/12/24/1066041/a-startup-says-its-begun-releasing-particles-into-the-atmosphere-in-an-effort-to-tweak-the-climate/ [https://perma.cc/Y67J-M9HX]. On an Israeli-American venture called Stardust, see Julia Simon, *Startups Want to Cool Earth by Reflecting Sunlight. There are Few Rules and Big Risks*, NPR (Apr. 21, 2024), https://www.npr.org/2024/04/21/1244357506/earth-day-solar-geoengineering-climate-make-sunsets-stardust [https://perma.cc/R7WB-9WHX]. On expected investment, see Corbin Hiar, *Solar Geoengineering Looks to Silicon Valley for New Wave of Funding*, SCI. AM., (Feb. 15, 2024), https://www.scientificamerican.com/article/solar-geoengineering-looks-to-silicon-valley-for-new-wave-of-funding/ [https://perma.cc/M634-N8LN].

8. *See e.g.*, Eric Niiler, *Scientists Resort to Once-Unthinkable Solutions to Cool the Planet*, WALL ST. J. (Feb. 14, 2024), https://www.wsj.com/science/environment/geoengineering-projects-cool-planet-weather-f0619bf7?mod=trending_now_news_5 [https://perma.cc/4J6U-F8NV]; *see also* discussion *infra* Part I.A.

9. Alan Robock, *Benefits and Risks of Stratospheric Solar Radiation Management for Climate Intervention*, 50 THE BRIDGE 59, 59–60 (2020), http://climate.envsci.rutgers.edu/pdf/RobockBridge.pdf [https://perma.cc/E8MV-3CJZ].

technologies.[10] There is an important distinction, however, between technologies that are aimed at reducing GHG emissions, thus addressing the root cause of climate change, and those such as SRM that are aimed at merely abating the increase in temperature, which may be viewed as addressing the secondary cause or even the symptom of the primary problem.[11]

There are a range of different proposed SRM methods, but in this Article, we focus on the particular form of atmospheric SRM that is receiving the most attention, namely SAI. Volcanic eruptions have demonstrated that the injection of sulfur dioxide into the stratosphere creates aerosols that reflect solar radiation, which in turn causes significant decreases in global temperatures. As we explore below, the development of a program for persistently injecting the stratosphere with sulfur dioxide or similar aerosols is technically feasible for many countries, and compared to the cost of other responses to climate change, an SAI program would be orders of magnitude cheaper. In short, SAI is a feasible, cheap, and effective method of reducing average global temperatures.

It would also be dangerous. An SAI program would have predictable direct negative effects on the climate system, regional weather patterns, the environment, and biodiversity, as well as collateral impacts on food security and socio-political stability.[12] In addition, there is the significant risk of unforeseen and non-linear negative consequences. Thus, there is significant debate over how to weigh the competing risks—the range of likely harms caused by increasing heat as we overshoot our temperature objective if we do not employ some form of SRM on the one hand, and, on the other, the significant climate, environmental, and even geopolitical risks associated with employing SAI.

Notwithstanding the considerable risks, many of the international institutions that have addressed the issue of SAI have noted the paucity

10. Haomiao Du, An International Legal Framework for Geoengineering: Managing the Risks of an Emerging Technology 7–14 (2018); *see also* Thomas G. Weiss, *Governance, Good Governance and Global Governance: Conceptual and Actual Challenges*, 21 Third World Q. 795 (2000).

11. *See* David Humphreys, *Smoke and Mirrors: Some Reflections on the Science and Politics of Geoengineering*, 20 J. Env't. & Dev. 99 (2011); *see also* Jesse L. Reynolds, *Climate Engineering and International Law*, *in* Climate Change Law, Elgar Encyclopedia of Environmental Law 178 (Daniel Farber & Marjan Peeters eds., vol. 1, 2016).

12. *See* IPCC, *AR-6*, *supra* note 3; UNEP, *One Atmosphere*, *supra* note 6; *see also* discussion *infra* Part I.C.

of global governance structures to coordinate collective action or regulate the research, development, and possible deployment of any SAI program.[13] As we explore below, there are several treaties, including those that comprise the international climate law regime, as well as related principles of customary international law, which might collectively operate to deter unauthorized or unilateral efforts to engage in SAI. But this web of law would likely exercise only a weak constraint on such activity.[14] The combination of increasingly dangerous temperatures, the availability of SAI as a cheap and easy method for temporarily moderating temperatures, its wide range of externalities, and the absence of a robust governance structure to regulate it gives rise to what economists refer to as a "free-driver" problem. Whereas collective action problems are often characterized by inaction arising from free-rider problems, they may also have free-driver problems, in which the individual action of any one party incurs low direct costs, provides immediate direct benefits, and spreads the majority of costs and harms widely among the rest of the community, all of which create great pressure for unilateral action.[15] The free-driver features of SAI, combined with the very weak constraints on independent action, creates a significant risk of unilateral implementation of an SAI program by one or several states, or even by commercial non-state actors.

This risk of unilateral SAI action has been raised not only by scholars and experts in the field but also by a number of important state and international institutional entities.[16] Many of these have noted that, quite apart

13. *See, e.g.*, UNEP, *One Atmosphere*, *supra* note 6, at 11; White House SRM Report, *supra* note 6, at 7, 38.

14. *See infra* Part II.

15. Gernot Wagner & Martin L. Weitzman, Climate Shock: The Economic Consequences of a Hotter Planet 38 (3d prtg. 2016); *see* discussion *infra* Part I.C.

16. *See, e.g.*, Off. of the Dir. of Nat'l Intel., Nat'l Intel. Council, National Intelligence Estimate: Climate Change and International Responses Increasing Challenges to U.S. National Security Through 2040 (2021), https://www.dni.gov/files/ODNI/documents/assessments/NIE_Climate_Change_and_National_Security.pdf [https://perma.cc/AJ8Q-X9EC] [hereinafter National Intelligence Estimate]; *see also* Sec'y of State's Int'l Sec. Advisory Bd., Report on New Security Challenges 30–33 (2024) https://www.state.gov/wp-content/uploads/2024/03/ISAB-Report-on-New-Security-Challenges_Final.pdf [https://perma.cc/6FAQ-K92T] [hereinafter Secretary of State Report on Security Challenges]; IPCC, *Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the IPCC Sixth Assessment Report*, at 2473–78 (Hans-Otto Pörtner et al. eds., 2022); UNEP, *One Atmosphere*, *supra* note 6, at 19.

from the direct and indirect harms flowing from the implementation of the program itself, there is an additional geopolitical risk. That is, there is a risk of political instability and even armed conflict arising from efforts to prevent or terminate unilateral SAI deployment.[17] But while asserted in passing, this distinct risk has not been explored, developed, or explained in any meaningful way in the literature examining the pros and cons of SAI, or the reasons behind why stronger governance is required. Part of our purpose here is to address this apparent lacuna.

In this Article, we examine how and why a unilateral SAI deployment could be perceived as a threat to national security—and to international peace—by possibly triggering a use of force in response to that threat. We examine how the international law regime designed to prevent such a use of force would offer only weak constraints. We do not claim that unilateral SAI deployment would inevitably provoke such a use of force—but we do argue that, given the incentives and the operation of the relevant legal regimes, it is not only plausible, but a significant yet under-appreciated risk. Furthermore, that risk should be factored into discussions regarding the relative merits of SAI, and the need for stronger governance.

To elaborate on this point briefly here, the consequences of climate change itself have already been identified by state institutions as posing threats to national security.[18] Similarly, the state interdiction of natural resources such as water have long been a source of conflict and even considered a *casus belli*.[19] Unilateral action affecting the climate system, weather patterns, and the environment is analogous to these forms of threat. What is more, the potential manipulation of climate and weather

17. National Intelligence Estimate, *supra* note 16, at 11; UNEP, *One Atmosphere*, *supra* note 6, at 19; White House SRM Report, *supra* note 6, at 7, 38.

18. *See, e.g.*, National Intelligence Estimate, *supra* note 16; U.S. Dep't of Def., Report on Effects of a Changing Climate to the Department of Defense (2019) [hereinafter DoD Climate Change 2019 Report]; Nat'l Intelligence Council, Implications for US National Security of Anticipated Climate Change (2016) [hereinafter NIC, Implications for US National Security]; U.K. Ministry of Def., Global Strategic Trends: The Future Starts Today (6th ed. 2018) [hereinafter UK MOD Global Strategic Trends].

19. On water as a source of conflict, see, for example, Peter Gleick & Morgan Shimabuku, *Water-Related Conflicts: Definitions, Data, and Trends from the Water Conflict Chronology*, 18 Env't. Rsch. Letters 1 (2023), https://iopscience.iop.org/article/10.1088/1748-9326/acbb8f/pdf [https://perma.cc/WLX2-GZSC].

has also been identified as a potential threat to national security.[20] There is thus a risk that states will use force to prevent unilateral SAI deployments, either with U.N. Security Council authorization or unilaterally, thereby triggering armed conflict. We explain how and why the jus ad bellum legal regime that would govern and potentially constrain the use of force in response to such threats would likely fail to prevent armed conflict in response to the SAI program. There are other recent examples of efforts to relax the jus ad bellum for purposes of dealing with the "new" threats posed by nuclear proliferation, transnational terrorism, humanitarian crises, and cyber-operations, and we argue that states would either invoke some expanded doctrine of self-defense, or a sui generis exception to the prohibition on the use of force, or indeed ignore the regime entirely, in order to address the SAI threat to their national security.[21] This risk of armed conflict as a distinct and additional harm associated with unilateral SAI efforts is not sufficiently accounted for in the debates over the dangers of exploring and developing SAI capabilities.

In our view, this combination of risks and likely harms creates an urgent need for a global governance framework. But much of the debate over governance has tended to focus more broadly on a governance structure for all forms of geoengineering, or at best, for all forms of SRM. As a result, many calls for greater governance of geoengineering more generally (such as direct carbon capture, or even marine cloud whitening, for instance), are more focused on actually facilitating the reasonable development and deployment of programs rather than creating greater restraint and control over them.[22] But few other forms of geoengineering involve the levels and kinds of risk that are collectively created by the potential

20. United States Department of Defense Science Board, Climate Change and Global Security 23 (2024) ("Since weather extremes may alter the defense posture of both Allies and potential adversaries, weather manipulation could be weaponized. The threat of state-sponsored large-scale weather manipulation using geoengineering techniques warrants an Allied ability to detect such actions."). See also discussion of the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), *infra* Part II.A.2.

21. One of us has written on this risk previously. *See* Craig Martin, *Atmospheric Intervention: Climate Change and the* Jus ad Bellum *Regime*, 45 Colum. J. Env't. L. 331 (2020) [hereinafter Martin, *Atmospheric Intervention*].

22. *See generally* Climate Engineering and the Law: Regulation and Liability for Solar Radiation Management and Carbon Dioxide Removal (Michael B. Gerrard & Tracy Hester eds., 2018); Geoengineering our Climate? Ethics, Politics, and Governance (Jason Blackstock & Sean Law eds., 2018).

development of SAI. In a nutshell, these are not only the risks of widespread climatic and environmental harm in the event of deployment, but the likelihood of unilateral action flowing from the "free-driver" features of the unique characteristics of the problem, and the lack of sufficient governance structures in the international climate change law regime to prevent it. That in turn creates the underappreciated risk of states using force to prevent or terminate unilateral SAI deployment, which is made more plausible by the weakness of yet a second international law governance structure, the jus ad bellum regime. And all of this—the focus on symptoms rather than causes, creating significant climatic and environmental harms, and ultimately causing armed conflict—would undermine the coordination of efforts to deal with climate change itself. While we recognize that there are competing risks at play here, with the serious risks of not doing something to moderate temperatures, the underappreciated risk of armed conflict created by the potential for unilateral SAI tips the balance in favor of constraint.

In our view, it is precisely this particular and significant collection of risks associated with possible SAI deployment, including the underappreciated risk of armed conflict flowing from unilateral deployment, that requires a treaty-based global governance structure specifically for the purpose of regulating the development and deployment of SAI alone. This would be a specific SAI-focused governance regime, separate and apart from other geoengineering governance initiatives, with a primary object and purpose of constraining any attempts to act unilaterally on SAI. This is not to say that SAI as a possible interim measure should be prematurely rejected, but its risks necessitate prudent governance, and unilateral action should be prohibited. We explore below some of the core elements that such a structure should have, and we explain why and how such a governance structure could be expeditiously developed within and under the rubric of either the *Montreal Protocol on the Protection of the Ozone Layer* (*"Montreal Protocol"*), or the *United Nations Framework Convention on Climate Change* ("UNFCCC"). Such a framework, centered on a multilateral treaty that could be negotiated within the institutional settings of either of these treaty regimes, would fall within the scope of the objects and purposes of both of these treaty regimes, and it would enjoy the legitimacy and other features deemed essential for modern global governance regimes.

Part I is about the attractions and risks of SAI, in which we explain how SAI is one of the most technically and financially feasible means of

moderating rising temperatures, and why this will create pressure for states to deploy it and risks that states will do so unilaterally. We also explain the significant risks of harm associated with the deployment of SAI. Part II is about the current global governance of SAI, in which we examine how and why the current international law and governance structures fail to directly address the potential risks of SAI and are thus unlikely to constrain any unilateral deployment of SAI. Part III is all about the additional and underappreciated risk that unilateral SAI will lead to armed conflict. In this Part, we explore how a unilateral SAI deployment will be viewed by other states as a threat to national security, and to international peace and security, by creating the real risk that states would use force to prevent such unilateral deployment. It further examines how and why yet a second international law regime, the jus ad bellum regime, would likely fail to constrain such armed responses to unilateral SAI deployment. Part IV is about developing a stronger governance framework specifically designed to regulate SAI and constrain unilateral SAI deployment, in which we make suggestions regarding the substance of a governance model and under what frameworks it could be developed. A strong governance framework designed specifically to deal with SAI would serve to moderate all of these risks.

I. The Attractions and Risks of SAI

We begin our analysis by looking more closely at the environmental and climate risks posed by SAI, and the reasons why there is a significant probability that either states or non-state actors may unilaterally engage in SAI notwithstanding such risks. To place this into context, however, we first briefly explain the essence of the problem that SAI is thought to address and why it is seen as such an attractive response.

A. The Climate Change Problem and the Appeal of SAI

Most readers are no doubt quite familiar with the basic contours of the causes and implications of the climate change crisis.[23] But there are some aspects of the problem that are helpful to review for purposes of understanding the pressure to engage in SAI or other forms of SRM. The basic problem is that increasing GHG concentrations in the atmosphere are producing an increase in average global temperatures, which in turn will

23. For a summary of the science, *see* IPCC, *AR-6*, *supra* note 3, at 35–115.

result in significant impacts on climate systems and biodiversity.[24] The international community committed itself to stabilizing GHG concentrations in the atmosphere to "safe levels" in the 1992 UNFCCC.[25] What precisely is a safe level of concentration remains a matter of debate,[26] but the international community has since focused on framing climate policy targets in terms of temperature increase. In the Cancun Agreement of 2010, the parties to the UNFCCC set a temperature ceiling of no more than 2° Celsius above pre-industrial levels, and then, in the *Paris Agreement of 2015*, the parties agreed to strengthen this goal to "well below" 2° Celsius and to pursue "efforts to limit the temperature increase to 1.5° Celsius above pre-industrial levels."[27] This relationship between GHG concentrations and the increase in global average temperature is important to understanding both the appeal and the downsides of certain forms of geoengineering.

It is the concentrations of GHGs in the atmosphere that give rise to the so-called "greenhouse effect" that causes increased average global temperatures. The pre-industrial (mid 18th Century) concentration of CO_2 was approximately 280 parts per million ("ppm").[28] At the time of writing, these concentrations had increased to over 422 ppm.[29] But CO_2 is only one of the four main GHGs. Methane, nitrous oxide, and the fluorocarbons that comprise the other major GHGs have a far more potent greenhouse gas effect than CO_2, though they are present in smaller concentrations

24. Clive Thompson, *How 19th Century Scientists Predicted Global Warming*, JSTOR Daily (Dec. 17, 2019), https://daily.jstor.org/how-19th-century-scientists-predicted-global-warming/ [https://perma.cc/X5NL-59ZE]; *see also* IPCC, *AR-6*, *supra* note 3 (describing current understanding of predictions); Andreas Meyer et al., *Risks to Biodiversity from Temperature Overshoot Pathways*, 377 Phil. Trans. R. Soc. B 103, 103–04 (2022) (discussing impact of emissions and temperature on biodiversity).

25. United Nations Framework Convention on Climate Change, art. 2, May 9, 1992, 1771 U.N.T.S. 107 [hereinafter UNFCCC].

26. Daniel Bodansky, Jutta Brunnée & Lavanya Rajamani, International Climate Change Law 126 (2017).

27. Paris Agreement to the United Nations Framework Convention on Climate Change, art. 2(a), Dec. 12, 2015, T.I.A.S. No. 16-1104 [hereinafter Paris Agreement].

28. The IPCC now uses the mid-18th century as the benchmark for "pre-industrial" period, though there remains debate on what the best benchmark is, and previously the later date of 1850 was used. *See, e.g.*, Rosamund Pearce, *Guest Post: The Challenge of Defining the 'Pre-Industrial' Era*, Carbon Brief (Jan. 25, 2017), https://www.carbonbrief.org/challenge-defining-pre-industrial-era/ [https://perma.cc/M5EC-M9HW].

29. *Trends in Atmospheric Carbon Dioxide,* NOAA Global Monitoring Laboratory, https://gml.noaa.gov/ccgg/trends/monthly.html [https://perma.cc/TBR2-3AQD].

and persist for much shorter periods.[30] The concentrations of all GHGs, expressed in carbon dioxide equivalent ("CO_2e") terms, exceeded 500 ppm in the summer of 2020.[31] The key point here, however, is that while so much of policy-making focuses on reducing or offsetting annual GHG *emissions*, it is ultimately the *concentrations* of these gases in the atmosphere that are at the heart of temperature rise.

"Climate sensitivity" is a term used to describe the range of likely temperature increases that will result from a doubling of the pre-industrial concentration of CO_2e.[32] The IPCC, in its report in 2022, projected that we are on track to reach CO_2e concentrations that range anywhere between 600 to over 800 ppm before the end of this century—that is, more than doubling the pre-industrial concentration; and stated with considerable confidence that the *likely* range for climate sensitivity is 2.5° to 4° Celsius, and a *very likely* range of 2° to 5° Celsius.[33] These predictions are dependent on various likely emission-reduction and carbon removal scenarios on the one hand, and on the other hand, the possible triggering of certain tipping points and negative feedback loops that could result in non-linear increases in GHG concentrations (such as the release of large methane deposits from thawing permafrost).[34] Global average

30. The four main greenhouse gases are carbon dioxide, methane (which has a global warming potential ("GWP") of twenty-seven to thirty times that of CO_2 over one hundred years, and persists for about twelve years), nitrous oxide (which has a GWP of 273 times that of CO_2 over one hundred years, and persists for 109 years), and a collection of synthetic fluorinated gases such as hydrochlorofluorocarbons ("HCFCs") and hydrofluorocarbons ("HFCs") (which have GWPs that range in the thousands times more than CO_2 over one hundred years, and persist anywhere from a few weeks to over a thousand years). CO_2 can last far longer than two hundred years, but it is absorbed in many ways within the carbon cycle and has no precise "lifespan." *See* U.S. EPA, UNDERSTANDING GLOBAL WARMING POTENTIALS (2024), https://www.epa.gov/ghgemissions/understanding-global-warming-potentials [https://perma.cc/66L3-FWLZ].

31. J.H. Butler and S.A. Montzka, *The NOAA Annual Greenhouse Gas Index (AGGI),* CO_2. EARTH (2015), https://www.co2.earth/annual-ghg-index-aggi [https://perma.cc/2WHU-MLTW].

32. IPCC, *AR-6*, *supra* note 3, at 122.

33. *Id.* at 93.

34. *Id.* at 42. *See generally* Org. for Econ. Cooperation and Dev. [OECD], *Climate Tipping Points: Insights for Effective Policy Action* (2022), https://read.oecd.org/10.1787/abc5a69e-en?format=pdf [https://perma.cc/ES3E-4V77] ("[a]ccording to the Intergovernmental Panel on Climate Change (IPCC), a tipping point is 'a critical threshold beyond which a system reorganises, often abruptly and/or irreversibly' and a tipping element is 'a component of the Earth system that is susceptible to a tipping point'"); IPCC, *AR-6*, *supra* note 3, at 106–07.

temperatures have already increased to more than 1.3° Celsius above pre-industrial levels as of the end of 2023.[35]

In short, the preoccupation with GHG emissions is because they continue to contribute to an increasing concentration of GHGs in the atmosphere, which in turn is causing increases in temperature. The crucial point, however, is that even as we reduce GHG emissions, anything above "net-zero" emissions will still contribute to the increase of those concentrations. And what is often misunderstood is that the GHG concentrations in the atmosphere are already so high that future increases in temperature, probably as high as 2° Celsius, are already "baked in"—meaning that even if all GHG emissions were entirely ceased today, we would still see a significant increase in temperature over the next several decades caused by current concentrations.[36] We are thus likely to "overshoot" our temperature and GHG concentration targets before we can begin to bring them both down.

The IPCC and other expert agencies have opined that a temperature increase of even 2.5° Celsius will cause massive harm and disruption to human societies, and a temperature increase of between 4° to 5° Celsius will be catastrophic. What is more, while the IPCC assesses climate sensitivity as being "very likely" within 2° to 5° Celsius, there is a "fat tail" to this probability distribution, meaning that the possibility of a temperature increase of far higher than 5° Celsius—constituting a true existential threat to human civilization—could be as high as ten percent.[37] Thus, while the concentration of GHG emissions in the atmosphere is

35. IPCC, *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty* (Valérie Masson-Delmotte et al. eds., 2022) https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf [https://perma.cc/23BR-BES9]; s*ee also* World Meteorological Org. [WMO], *WMO Global Annual to Decadal Climate Update: Target Years: 2023-2027* (2023), https://library.wmo.int/idurl/4/66224 [https://perma.cc/6TZP-F6DH] [hereinafter *WMO Climate Update*].

36. Chen Zhou et al., *Greater Committed Warming after Accounting for the Pattern Effect*, 11 Nature Climate Change 132–36 (2021); *see also* Associated Press, *Warming already baked in will blow past climate goals, study finds*, NBC News (Jan. 4, 2021), https://www.nbcnews.com/science/environment/warming-already-baked-will-blow-climate-goals-study-finds-rcna216 [https://perma.cc/4ZMQ-JU4Z].

37. Wagner & Weitzman, *supra* note 15, at 48–54.

the root cause of the problem, rising temperature is perceived to be the immediate threat. This leads naturally to the question: What if we could reduce the global average temperature, or at least minimize its increase over time, even if GHG concentrations continued to increase? This is precisely the logic behind many forms of SRM, and particularly SAI, which is far more global in its implications than many other forms of SRM and is relatively both cheap and easy to deploy. We turn next to examine the specific appeal of SAI.

SAI is inspired by the effects that volcanic eruptions—specifically their injection of sulfates and other particulates into the stratosphere—have had on climate in the past. Volcanic eruptions release large amounts of sulfur dioxide, which reacts with other substances in the atmosphere to form tiny droplets known as sulfate aerosols. These aerosols then reflect or block solar radiation.[38] In 1815, the eruption of Mount Tambora in Indonesia resulted in a decrease in temperature in the Northern Hemisphere of between 0.4-0.7° Celsius. This caused the infamous "year without a summer" in Europe in 1816, characterized by crop failures and famine.[39] More recently, the 1991 eruption of Mount Pinatubo in the Philippines, the largest volcanic eruption in the twentieth century, resulted in similar global temperature decreases of approximately 0.5° Celsius over the next year[40] and has been linked to crop failures and food shortages in several parts of the world.[41] It was determined that approximately twenty

38. Carnegie Climate Governance Initiative, Evidence Brief: Stratospheric Aerosol Injection and its Governance (2021), https://www.c2g2.net/wp-content/uploads/SAI-Evidence-Brief.pdf [https://perma.cc/S66T-Q2HG]; Wake Smith & Gernot Wagner, *Stratospheric Aerosol Injection Tactics and Costs in the First 15 Years of Deployment*, 13 Env't Rsch. Letters, no. 12 (2018).

39. J. Luterbacher & C. Pfister, *The Year Without a Summer*, 8 Nature Geoscience 246 (2015); *see also This Day in History: Mount Tambora Explosively Erupts in 1815*, Nat'l Env't Satellite, Data, and Info. Service (Apr. 10, 2020), https://www.nesdis.noaa.gov/news/day-history-mount-tambora-explosively-erupts-1815 [https://perma.cc/AHG4-8VM7].

40. The Royal Soc'y, Geoengineering the Climate: Science, Governance and Uncertainty 29 (2009), https://royalsociety.org/-/media/policy/publications/2009/8693.pdf [https://perma.cc/Z33E-85YD] [hereinafter Royal Society Geoengineering Report].

41. Daisy Dunne, *Solar Geoengineering Could 'Fail to Prevent Damage to Crop Yields'*, Carbon Brief (Aug. 8, 2018), https://www.carbonbrief.org/solar-geoengineering-could-fail-to-prevent-damate-to-crop-yields/ [https://perma.cc/9JVH-VNMP].

megatons of sulfur dioxide were injected into the stratosphere by Pinatubo, and that this was largely responsible for the temperature decrease.[42]

The basic idea of SAI is to utilize these volcanic processes in a controlled manner.[43] Some of the modeling underway suggests that one million tons of sulfur dioxide or similar aerosols would be required to counteract 1° Celsius of global warming per year.[44] There are different proposed methods of implementing the injection, including the use of a fleet of high-altitude aircraft deployed at an altitude of about twenty kilometers (65,000 feet), or the periodic release of modified high-altitude weather balloons carrying a sulfate payload.[45] There are some differences of opinion on how feasible an extensive and ongoing program might be with existing aircraft fleets, but there is fairly widespread agreement that the development of such an airlift capability would be quick and inexpensive.[46]

Indeed, the cost of the entire effort is likely to be cheap relative to the cost of mitigation efforts. The Royal Society recently estimated that the direct cost of a program would be in the order of between three to thirty dollars per kilogram of sulfate, which would translate into an annual cost of only tens of billions of dollars, depending on the precise amount injected per annum.[47] Another detailed analysis and concrete proposal

42. Wagner & Weitzman, *supra* note 15, at 93 (citing Gregg Bluth et al., *Global Tracking of the SO_2 Clouds from the June 1991 Mount Pinatubo Eruption*, 19 Geophysical Rsch. Letters 151, 151–54 (1992), https://so2.gsfc.nasa.gov/pdfs/Bluth_Pinatubo1991_GRL91GL02792.pdf [https://perma.cc/72FF-CKA5]).

43. *See, e.g.*, David Keith et al., *Stratospheric Solar Geoengineering Without Ozone Loss*, 113 Proc. Nat'l Acad. Sci. 14910 (2016), https://www.pnas.org/doi/pdf/10.1073/pnas.1615572113 [https://perma.cc/KX75-GNK7]. It should be noted that other less environmentally harmful reflective aerosols could also be developed and deployed for this purpose.

44. Heather Hansman, *Is This Plan to Combat Climate Change Insane or Insanely Genius?*, Smithsonian Mag. (May 14, 2015), https://www.smithsonianmag.com/innovation/is-this-plan-combat-climate-change-insane-insanely-genius-180955258/ [https://perma.cc/2AA4-PTHJ]. It should also be noted that these estimates are quite preliminary and are dependent on assumptions about a number of important variables; for more on such variables and uncertainty, see Royal Society Geoengineering Report, *supra* note 40, at 130–31.

45. Smith & Wagner, *supra* note 38, at 127–28.

46. *Id.* For a more optimistic view, see Justin McClellan et al., *Cost Analysis of Stratospheric Albedo Modification Delivery Systems*, 7 Env't Rsch. Letters, no. 3 (2012), https://iopscience.iop.org/article/10.1088/1748-9326/7/3/034019/pdf [https://perma.cc/78E9-6U43].

47. Royal Society Geoengineering Report, *supra* note 40, at 32 (citing Jason J. Blackstock et al., Climate Engineering Responses to Climate Emergencies (2009), https://arxiv.org/abs/0907.5140 [https://perma.cc/UTV8-H95F]).

by Smith and Wagner, which assumes four thousand flights in the first year and increasing each year, similarly puts the total operating cost of implementation in the area of $1,400 per ton of sulfur dioxide injected. This amounts to $2.25 billion per year, for a total of $36 billion over the program's first fifteen years.[48] That may not sound cheap, but by comparison the estimated amount of capital investment required to make just the aviation industry carbon neutral by 2050 is in the order of $5 trillion, or almost 140 times more expensive.[49] And relative to current incidental costs inflicted by a temperature increase, the cost of SAI would be modest—one recent study conservatively estimated the economic cost of increased temperatures in the United States alone at $100 billion for 2020. It further suggested that the increased labor-productivity costs resulting from higher temperatures would rise to half a trillion dollars by 2050.[50]

The actual temperature decrease projected for SAI efforts would of course be dependent on not only the volume and frequency of aerosol injections but also the extent of emissions abatement during the period. But the Smith and Wagner study suggests that their proposal would result in a temperature decrease of 0.25° Celsius per decade relative to current IPCC projections in the absence of any SAI program.[51] Over the first fifteen years, this could mean a decrease of approximately 0.375° Celsius—which is a significant amount, given that temperatures have

48. Smith & Wagner, *supra* note 38, at 128–32. For alternative cost estimates, still relatively inexpensive, see, for example, Paul Rouse, *A Review of Climate-Altering Technologies*, *in* International Governance Issues on Climate Engineering: Information for Policymakers 18 (Marie-Valentine Florin ed. 2020); Robock, *supra* note 9, at 62.

49. Lauren Uppink et al., Mission Impossible Partnership, Making Net-Zero Aviation Possible: An Industry-Backed, 1.5°C-Aligned Transition Strategy 52 (2022), https://www.energy-transitions.org/wp-content/uploads/2022/07/Making-Net-Zero-Aviation-possible.pdf [https://perma.cc/ZFF2-DLNX].

50. Adrienne-Arsht Rockefeller Foundation Resilience Center, Extreme Heat: The Economic and Social Consequences for the United States 3 (2021), https://www.atlanticcouncil.org/wp-content/uploads/2021/08/Extreme-Heat-Report-2021.pdf [https://perma.cc/952K-25JQ].

51. Smith & Wagner, *supra* note 38, at 125. The analysis of temperature decrease is based on Representative Concentration Pathway (RCP) 6.0, from IPCC, *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, at 35–112 (Rajendra K. Pachauri et al. eds., 2014).

increased 1.2° in the last 200 years. As the IPCC has emphasized, every tenth of a degree is significant.[52]

The bottom line is that SAI is effective, technically feasible, and relatively inexpensive. The economic costs of reducing carbon emissions and transitioning quickly to carbon-free energy are orders of magnitude larger than the cost of possible SAI programs, while the technology for large-scale carbon removal has not even been developed yet. As a result, SAI stands out as a highly attractive response to the immediate problem of increasing temperatures, even if it does nothing to address the root cause of climate change. But any major SAI deployment is likely to cause significant environmental harm and have its own negative effects on regional climates.

B. The Environmental and Climate Risks of SAI

Regardless of the current excitement around SAI, there is a far longer history of disappointing attempts to modify and control the weather and other atmospheric phenomena.[53] Nonetheless, with temperatures increasing even faster than most models had predicted, there are loud proponents of SAI who argue that SRM is a necessary interim measure, and that even if it may involve certain risks, these are less than the risks associated with *not* engaging in SRM to moderate temperatures in the medium term.[54] It is questionable, however, whether these arguments sufficiently factor in the indirect costs and potential harms that SAI programs are likely to cause. The effects of such externalities range from direct negative environmental and climatic impacts to less obvious influences on climate change policy, and even on political stability and international peace and security.[55]

It should be noted at the outset that SAI, given that it is conducted in the upper atmosphere, cannot be localized or limited to one region. Indeed, to ensure against radical climatic imbalance, it would have to be conducted equally in both the northern and southern hemispheres.

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52. IPCC, *AR-6*, *supra* note 3, at 15, 28.

53. This history is well documented by James Fleming, Fixing the Sky: The Checkered History of Weather and Climate Control (2010).

54. *See, e.g.*, T. M. L. Wigley, *A Combined Mitigation/Geoengineering Approach to Climate Stabilization*, 314 Science 452 (2006); Naomi E. Vaughan & Timothy M. Lenton, *A Review of Climate Geoengineering Proposals*, 109 Climatic Change 745 (2011).

55. UNEP, *One Atmosphere*, *supra* note 6; *see also* Royal Society Geoengineering Report, *supra* note 40.

Thus, it would have a global effect.[56] Beginning with the more direct environmental and climatic impacts, models indicate that an SAI program on the scale necessary to fully counter an approximate doubling of GHG concentrations would interrupt monsoon cycles and cause considerable drying in mid-latitude regions, including the Amazon, sub-Saharan Africa, and South Asia.[57] It is further predicted that SAI is likely to produce warmer winters and cooler summers in the higher latitudes.[58] The potential scale of this impact is suggested by the fact that the year following the 1991 Mt. Pinatubo volcanic eruption, there was fifty percent less rainfall than any previous year.[59] Not only would there be interruption of monsoons and other climatic patterns but there would likely be semi-permanent realignment of patterns—all of which could have severe impacts on agriculture, and thus food security, as well as irreparable harm to sensitive ecosystems and thus biodiversity, in different parts of the world.[60]

The large-scale aerosol injection comprising sulfur dioxide or other sulfates, which is the most commonly suggested and cheapest method of SAI, would also likely lead to depletion of the ozone, possibly by as much as 4.5 percent per year. While the extent of the impact of sulfate-based

56. Douglas MacMartin et al., *The Climate Response to Stratospheric Aerosol Geoengineering can be Tailored Using Multiple Injection Locations*, 122 J. Geophysical Rsch.: Atmospheres 12574 (2017); Jiu Jiang et al., *Different Strategies of Stratospheric Aerosol Injection Would Significantly Affect Climate Extreme Mitigation*, 12 Earth's Future, no. 6, 2024.

57. Similar effects have been shown to be robust across different models and scenarios, including the RCP series commonly used by the IPCC. Other important determinants of hydroclimate and other Earth system impacts of SAI include aerosol type and size. For details on modeled effects of SAI, including mid-latitude drying and hydroclimate effects, see Han N. Huynh & V. Faye McNeill, *The Potential Environmental and Climate Impacts of Stratospheric Aerosol Injection: A Review*, 4 Env't Sci.: Atmospheres 114 (2024).

58. Rouse, *supra* note 48, at 18–47.

59. *See* William C.G. Burns, *Geoengineering the Climate: An Overview of Solar Radiation Management Options*, 46 Tulsa L. Rev. 283, 289 (2010) [hereinafter Burns, *SRM Options*]. For a general scientific overview of the modeled climatic effect of aerosol injection, see also Debra K. Weisenstein et al., *An Interactive Stratospheric Aerosol Model Intercomparison of Solar Geoengineering by Stratospheric Injection of SO_2 or Accumulation-Mode Sulfuric Acid Aerosols*, 22 Atmospheric Chemistry & Physics 2955 (2022).

60. *See generally* Samantha M. Tracy et al., *Stratospheric Aerosol Injection May Impact Global Systems and Human Health Outcomes*, 10 Elementa, no. 1, 2022; K.S. Krishnamohan & Govindasamy Bala, *Sensitivity of Tropical Monsoon Precipitation to the Latitude of Stratospheric Aerosol Injections*, 59 Climate Dynamics 151 (2022).

SAI on ozone depletion is still the subject of some uncertainty,[61] this is obviously a serious risk. It will be recalled that the discovery of a growing hole in the ozone layer, and the recognition of the danger that it posed, is what galvanized international actions leading to the *Montreal Protocol*, which in turn was a role-model for early negotiations on climate change.[62] The ozone layer is now in the process of recovery, and it would be a bitter irony if our response to climate change were to resurrect the threat posed by a failing ozone.

There are other negative impacts of an SAI program employing sulfates as the aerosol. There would be a probable increase in sulfate pollution, a known environmental health hazard already estimated to produce several thousands of premature deaths each year.[63] Moreover, the sulfate from the program washing out of the stratosphere would also further increase the rate of ocean acidification that is already threatening reefs and biodiversity around the world.[64] Climate change is itself already increasingly acidifying the world's oceans, because warmer water absorbs greater levels of CO_2, which in turn increases the pH levels of the water. Many forms of life, both those within reef ecosystems and those that depend on the formation of shells to survive, face an existential threat from increasing acidification.[65] Experts warn of potential cascading effects from this additional acidification that could ripple through marine food chains, further accelerating broader extinctions and irreparable harm to biodiversity.[66]

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61. Burns, *SRM Options*, *supra* note 59, at 291.

62. Montreal Protocol on Substances that Deplete the Ozone Layer, Sept. 16, 1987, 1522 U.N.T.S. 3 [hereinafter Montreal Protocol]; *see also* Elizabeth P. Barratt-Brown, *Building a Monitoring and Compliance Regime under the Montreal Protocol*, 16 YALE J. INT'L L. 519 (1991); Tina Birmpili, *Montreal Protocol at 30: The Governance Structure, the Evolution, and the Kigali Amendment*, 350 COMPTES RENDUS GEOSCIENCE 425 (2018).

63. Burns, *SRM Options*, *supra* note 59, at 290.

64. IPCC, *AR-6*, *supra* note 3, at 11, 15, 37; *see also* Christopher H. Trisos et al., *Potentially Dangerous Consequences for Biodiversity of Solar Geoengineering Implementation and Termination*, 2 NATURE ECOLOGY & EVOLUTION 475 (2018); Alan Robock et al., *Benefits, Risks, and Costs of Stratospheric Geoengineering*, 36 GEOPHYSICAL RSCH. LETTERS L19703 (2009) [hereinafter Robock, *Benefits, Risks, and Costs*]; J.F. Tjiputra et al., *Impact of Idealized Future Stratospheric Aerosol Injection on the Large-Scale Ocean and Land Carbon Cycles*, 121 J. GEOPHYSICAL RSCH.: BIOGEOSCIENCES 2 (2016).

65. *See* IPCC, *AR-6*, *supra* note 3, at 11, 13, 15, 37.

66. Robock, *Benefits, Risks, and Costs*, *supra* note 64. Of course, a non-sulfate-based aerosol would eliminate some of these risks, though they would likely be considerably more expensive.

One of the biggest concerns, however, is that, like an addictive narcotic that temporarily masks pain, SAI could foster complacency regarding the actual causes of climate change, leaving the underlying problem continuing to grow unchecked. This is typically identified as a significant "moral hazard," whereby climate risk will be punted to future generations.[67] Resources, political capital, and effort that could and arguably should be expended on mitigation will instead be diverted to work on developing and implementing SAI programs, which will do nothing to address the underlying problem. In addition, a program that begins to address the immediate symptoms of climate change may reduce the public's sense of urgency, further undermining the political will necessary to implement the transition to a carbon-free economy.[68]

In addition, SAI would likely intensify the unequal distribution of harms caused by climate change. Even now, the consequences of climate change are being felt unevenly, with those least responsible for causing climate change bearing a disproportionate share of its effects.[69] SAI would likely exacerbate this inequity by altering climate patterns in uneven and unpredictable ways, and a unilateral deployment would introduce a new source of friction into an already difficult collective action problem.[70]

Another problem with relying on an SAI program to address temperature is that once begun it would have to be maintained until GHG concentrations were brought down. Indeed, it would have to be sustained at ever increasing levels to counter continued emissions in the medium term. This is because any cessation of the SAI program would result in a catastrophic "termination shock"—the rapid increase in temperature that would result if SAI were discontinued while GHG concentrations remain high.[71] The longer the process is ongoing while GHG emissions

67. Du, *supra* note 10, at 45, 198.

68. Humphreys, *supra* note 11, at 111.

69. *See, e.g.*, Jutta Bruneé, *Climate Change, Global Environmental Justice and International Environmental Law*, *in* Environmental Law and Justice in Context 316 (Jonas Ebbesson & Phoebe Okowa eds., 2009).

70. Jesse L. Reynolds, The Governance of Solar Geoengineering: Managing Climate Change in the Anthropocene 75–76 (2019); *see also* Robock, *Benefits, Risks, and Costs*, *supra* note 64, at L19704.

71. *See* Burns, *SRM Options*, *supra* note 59, at 298. This phenomenon of quite rapid return to "normal" temperatures was demonstrated after the Mount Pinatubo eruption, when global temperatures returned to their prior levels and upward trajectory in just over a year, when the sulfates from the eruption washed out of the stratosphere. *See* Wagner & Weitzman, *supra* note 15, at 93 (citing Bluth, *supra* note 42, at 151–54);

continue to increase, the larger would be the rapid temperature increase upon termination. Thus, once started, there would be a requirement to continue, and the long-term commitment creates technological lock-in and transfers immense risk onto future generations who are not able to consent to such risk.[72] The inequity and unjustness of shifting this kind of climate risk to future generations, commonly referred to as intergenerational equity, was addressed by the Constitutional Court of Germany in the groundbreaking case of *Neubauer v. Germany*, in which the Court held that such shifting of risk was unconstitutional.[73]

A final danger, which is the primary focus of our argument, is that the deployment of SAI poses a significant risk of creating political instability and even armed conflicts. This risk has now been identified quite explicitly by UNEP, the Royal Society Principles on Geoengineering, and the U.S. intelligence community, among others.[74] They have articulated this risk as including the danger of political instability and possible armed conflicts arising because of the collateral consequences of SAI deployment, such as food and water insecurity caused by shifting regional climatic patterns. In addition, however, they have noted the further alarming risk that states could respond with armed force to prevent a unilateral effort to launch an SAI program. While this latter risk has thus been explicitly identified, it has not been sufficiently unpacked, fully examined, and internalized in the debate over the wisdom of an SAI option—and that is the primary purpose of this Article. We turn next to explore the incentives for unilateral action, following which we examine the governance structures that would limit such unilateral action, and

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David Douglass & Robert Knox, *Climate Forcing by the Volcanic Eruption of Mount Pinatubo*, 32 Geophysical Rsch. Letters L05719 (2005), https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2004GL022119 [https://perma.cc/6DH7-SX7U].

72. *See* Rouse, *supra* note 48, at 18–47.

73. BVerfG [Federal Constitutional Court], 1 BvR 2656/18, Mar. 24, 2021 (Ger.), https://climatecasechart.com/wp-content/uploads/non-us-case-documents/2021/20210324_11817_order-1.pdf [https://perma.cc/4MAS-4YTL]. For arguments regarding the implications of SRM for international equity, see *Climate Geoengineering: Solar Radiation Management and its Implications for International Equity*, *in* Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks 201 (Wil C.G. Burns & Andrew L. Strauss eds., 2013) [hereinafter Climate Change Geoengineering].

74. UNEP, *One Atmosphere*, *supra* note 6; National Intelligence Estimate, *supra* note 16, at 11.

then the legal regime that would be relied upon to constrain military action against such unilateral action.

C. The Risk of Unilateral SAI Efforts

The foregoing brief examination of the risks and harms associated with SAI would recommend considerable caution before embarking on even large-scale real-world experimentation, far less full-scale deployment. But added to these risks is the real threat of unilateral SAI programs, whether by states or non-state actors, even in the face of international condemnation—and it is this that makes the need for a strong governance structure all the more urgent. There are several factors that explain why the risk of unilateral action is so high. To begin with, the central features of SAI—being cheap, easy, and with direct benefits on the one hand, but widely dispersed negative externalities on the other—create what economists call a "free-driver" problem. This is the flip side of the better-known concept of a free-rider problem, which is a typical feature of collective action problems such as that created by climate change itself. The response to climate change requires all states to cooperate in a collective, coordinated fashion to reduce GHG emissions, but there are few immediate direct benefits from the marginal contribution of each state. There are thus incentives for individual states to free-ride by doing less than other states, and yet they benefit from the greater efforts and more costly contributions of others. The free-riders benefit from lower climate risk without incurring the costs of reducing emissions themselves.

In contrast, with free-driver problems, the incentives are reversed, such that actors can cheaply and easily act unilaterally to seek an immediate direct benefit, while imposing on others the more widely dispersed effects (both costs and benefits) without securing collective consent or approval.[75] SAI has these features, and thus creates great incentives for individual states—particularly those most vulnerable to the harms caused by increasing temperatures—to take action unilaterally to reduce temperatures in their region, notwithstanding that it will have uneven effects on every other country in the world.[76] This free-driver effect and the pressure it creates for unilateral action distinguishes SAI from most other geoengineering interventions, and informs our argument for an SAI-specific governance approach.

75. Wagner & Weitzman, *supra* note 15, at 36–40.
76. *Id.*

It is not difficult to imagine the increasing pressure for such unilateral action in the short term. In the early 2020s, we are already witnessing unprecedented wildfires causing death, destruction, and breathing problems all over the world, together with surface water temperature levels that genuinely shocked experts.[77] And this is just a harbinger of far worse to come soon. There are regions in some countries that are already experiencing periods with wet-bulb temperatures that are lethal for human beings.[78] At the same time, countries in the Global South, many of which are the most vulnerable to these changes, are becoming increasingly frustrated and exasperated by the failure of the developed countries to both make more headway on reducing GHG emissions and provide the promised financing to fund mitigation and adaptation efforts in response to climate change.[79] This sense of injustice may well provide further impetus for several countries in the Global South to contemplate unilateral action to address increasing temperatures.

The risk of unilateral action is not, of course, limited to states in the Global South. Many commentators have suggested that the United States

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77. *See, e.g.*, *2023 is the Hottest Year on Record, with Global Temperatures Close to the 1.5° Limit*, COPERNICUS (Jan. 9, 2024), https://climate.copernicus.eu/copernicus-2023-hottest-year-record [https://perma.cc/JFL8-H9KZ]; Rebecca Lindsey & Luann Dahlman, *Climate Change: Global Temperature*, CLIMATE.GOV (Jan. 18, 2024), https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature [https://perma.cc/JE8A-ZH7S].

78. Wet-bulb temperature is a temperature measurement that combines air temperature and humidity to indicate how effectively the human body can cool itself—it is the lowest temperature that can be reached by evaporating water into the air at constant pressure. A wet-bulb temperature above 35° Celsius and 95° Fahrenheit is considered potentially fatal for humans. For more, see Alan Buis, *Too Hot to Handle: How Climate Change May Make Some Places Too Hot to Live*, NASA (Mar. 9, 2022), https://climate.nasa.gov/explore/ask-nasa-climate/3151/too-hot-to-handle-how-climate-change-may-make-some-places-too-hot-to-live/ [https://perma.cc/K74N-TYBT]; Steven C. Sherwood & Matthew Huber, *An Adaptability Limit to Climate Change Due to Heat Stress*, 107 PROCEEDINGS NAT'L ACAD. SCIS. 9552 (2010); and Marcel Wedler et al., *More Frequent, Persistent, and Deadly Heat Waves in the 21st Century Over the Eastern Mediterranean*, 870 SCI. TOTAL ENV'T, 161883 (2023).

79. *See, e.g.*, Noah Gordon, *The West's Poor Climate Track Record is Spilling over to Other Policy Areas: The Reputational Costs of Climate Hypocrisy Are Adding Up*, CARNEGIE ENDOWMENT FOR INTERNATIONAL PEACE (May 23, 2022), https://carnegieendowment.org/2022/05/23/west-s-poor-climate-track-record-is-spilling-over-to-other-policy-areas-pub-87174 [https://perma.cc/85BE-2GSQ]; Karishma Vaswani, *The Global South Has Lost Faith in COP28*, BLOOMBERG (Nov. 28, 2023), https://www.bloomberg.com/opinion/articles/2023-11-28/cop28-global-south-has-lost-faith-in-richer-nations-climate-funding [https://perma.cc/42D7-DDE6].

and other advanced industrialized states should take the lead in embarking on SAI efforts, unilaterally if need be.[80] Some have even argued that states that have complied with their other international climate change law obligations under the *Paris Agreement* would have a legal justification for acting unilaterally.[81] What is more, as illustrated by the commercial ventures discussed earlier, there are clearly incentives for corporate entities in the Global North to unilaterally develop SAI programs.[82]

Some academics argue that this risk of unilateral action is exaggerated. Joshua Horton, for example, after noting that a broad spectrum of scientists, policymakers, and other experts have expressed a deep concern regarding such a risk, argues that the threat is more a myth than reality.[83] Horton argues that the risk of unilateral action is low because of the inherent structure of the problem, relying on theories regarding benign and malign problems.[84] A benign problem is one that involves coordination difficulty, in which the overall result depends on the compatibility of individual choices, and there is more than one route to the collective optimum, but individual interests at stake in the various choices are not in conflict with those of the group. A malign problem, in contrast, is the classic collective action problem, in which the incentives of individuals are more directly at odds with the collective interests, the dynamics of which result in "suboptimal outcomes," and make a coordinated resolution very difficult.[85] Horton argues that while climate change is a malign problem, geoengineering is a benign problem governed by a "multilateral logic." It is, so the argument goes, in everyone's interests to cooperate and act multilaterally in pursuing geoengineering.[86] Others echo this argument, suggesting that disagreements over geoengineering are likely not over *whether* to pursue it at all, but *how*, with debate over the details

80. *See* Frédéric Sourgens, *The Dark Sun Network*, 94 Univ. Col. L. Rev. 681 (2023); Frédéric Sourgens, *Geo-Markets*, 38 Va. Env'tl L.J. 58 (2020); *see also* Joshua Horton, *Geoengineering and the Myth of Unilateralism: Pressures and Prospects for International Cooperation*, *in* Climate Change Geoengineering, *supra* note 73, at 168.

81. *See, e.g.*, Sourgens, *The Dark Sun Network*, *supra* note 80, at 723, 727; Sourgens, *Geo-Markets*, *supra* note 80, at 105.

82. *See generally* Temple, *supra* note 7 (describing the case of Make Sunsets).

83. Horton, *supra* note 80, at 56.

84. *Id.* at 63–64; *see* Arild Underdal, *One Question, Two Answers*, *in* Environmental Regime Effectiveness: Confronting Theory With Evidence 3 (Edward Miles et al. eds., 2002).

85. Horton, *supra* note 80, at 63.

86. *Id.* at 64.

of what form it should take and to what extent it should be pursued.[87] Moreover, they argue that the fact that it would be difficult for one country to sustain an SAI program for an extended period is another factor militating against unilateral action.[88]

The problem with these arguments is that they rest on several fundamental unexamined assumptions: first, that states share an interest in engaging in some form of SRM; second, that there is universal acceptance of the need to reduce temperatures as an interim measure; and, finally, that there are thus incentives to cooperate and coordinate. But given the risks, it is not at all clear that there will be any such consensus—and if many states are in fact opposed to SAI, or insist on a far more cautious approach, then interests and incentives will sharply diverge. In that case, the incentives operate very powerfully for the states in favor of SAI to act unilaterally. Indeed, rather than viewing SAI as a separate benign problem, it is more accurate to understand it as one more feature of the malign collective action problem of climate change, which helps to frustrate cooperative and coordinated action. Moreover, while it might be difficult for one or even a few smaller states to sustain an indefinite SAI program, there is a cynical logic to commencing such a program in any event on the reasonable expectation that it would force the hand of the rest of the world—as others would have to continue the program to avoid the shock of termination.

Finally, and most fundamentally, the risk of unilateral SAI action is made that much greater because there are no existing global governance structures in place to effectively deter or constrain it—which we turn to explain in more detail in the next section.

II. Current Governance of SAI

In turning to examine the governance of atmospheric SRM, it is worth noting at the outset that there is considerable literature and differing views on the meaning and scope of the very concept of governance.[89]

87. Scott Barrett, *Solar Geoengineering's Brave New World: Thoughts on the Governance of an Unprecedented Technology*, 8 Rev. Env't Econ. & Pol'y 249, 269 (2014).

88. *Id.* at 261 (even while recognizing the strong incentives for unilateral action that we discuss above).

89. *See, e.g.*, Weiss, *supra* note 10; Klaus Dingwerth & Philipp Pattberg, *Global Governance as a Perspective on World Politics*, 12 Glob. Governance 185 (2006); Tim Rayner et al., *A Sectoral Perspective on Global Climate Governance: Key Findings and*

We explore some of these differing formulations in Part IV, but here, we are primarily focused on the international legal rules, principles, and norms, both substantive and procedural, along with the institutional mechanisms in place to implement and enforce such rules and norms. Together, these governance structures might operate to constrain unilateral action and govern collective decision-making regarding the conduct of geoengineering efforts.[90] As will be explained here, there are legal grounds for suggesting that states would be required to engage in due diligence to assess and minimize the risks associated with any SAI efforts; there are also legal grounds to cooperate and consult with other states that might be harmed; and there are also grounds for holding such states responsible if that harm materialized.

In short, however, the ex ante deterrence and constraint offered by this web of law would be quite weak at best, and there is little in the way of a directly applicable institutional governance structure in place to exercise control over unilateral SAI deployment or to guide collective decision-making in responding to such a deployment. This weakness of the international law and governance structures related to climate change, the environment, and the atmosphere simply increases the risk of unilateral SAI deployment. We have explored in Part I all the incentives and pressures for unilateral action, and here, we explore how the relevant international law and governance structures will exercise little restraint, which is thus an important factor in assessing the overall risk around unilateral deployment.

A. Current Treaty-Based Constraints

No legal regime has been established for the specific purpose of constraining or governing SRM generally or SAI in particular. There are, however, several treaties of more general application that might operate to constrain SAI efforts, as well as general principles and customary international law rules that might similarly limit or deter unilateral SAI programs. While we explore how these might operate to constrain unilateral SAI, we also suggest that none of these, even operating together, provide a sufficiently robust governance structure to adequately reduce the risk of unilateral SAI efforts.

Research Priorities, Earth Sys. Governance, June 2021, at 1; Jan Klabbers, Virtue in Global Governance: Judgment and Discretion (2022).

90. For a short list of definitions of "governance" from various international institutions, see Weiss, *supra* note 10, at 797–98.

1. UNFCCC and Paris Climate Agreement

The UNFCCC[91] and the related *Paris Agreement*[92] are the obvious starting points for assessing treaty constraints on climate geoengineering, as they are the primary multilateral treaties governing state conduct with relation to climate change. Neither includes any direct reference to geoengineering, but certain provisions in each treaty could ground arguments that SAI efforts might be inconsistent with the obligations of state parties.

The ultimate objective of the UNFCCC is to achieve the "stabilization of greenhouse gas concentrations in the atmosphere" and "prevent dangerous anthropogenic interference with the climate system."[93] For purposes of achieving that objective, the treaty provides that the state parties should be guided by certain principles. These include the principles that the parties "should protect the climate system for the benefit of present and future generations . . . on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities" (what we will refer to as the 'protection principle' and the 'CBDR principle' respectively);[94] and the principle that parties "should take precautionary measures to anticipate, prevent[,] or minimize the causes of climate change" (what we will refer to as the 'mitigation principle'). In relation to these, the treaty invokes the 'precautionary principle,' providing that "where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing" the measures to anticipate, prevent, or minimize the causes of climate change and mitigate its adverse effects.[95]

Different forms of geoengineering will vary in their compliance with the objectives and principles of the UNFCCC. Carbon capture and sequestration and carbon removal efforts,[96] for instance, would appear to be entirely consistent with both the treaty objectives and the four

91. UNFCCC, *supra* note 25.
92. Paris Agreement, *supra* note 27.
93. UNFCCC, *supra* note 25, art. 2.
94. *Id.* art. 3(1).
95. *Id.* art. 3(3).
96. It should be noted that "carbon capture and sequestration" refers to the removal (and then storage) of greenhouse gases as they are being emitted, ideally to make such emissions carbon-neutral; "carbon removal" refers to processes that actually remove carbon dioxide or other greenhouse gases from the atmosphere, and thereby reducing the concentrations of such gases in the atmosphere.

principles discussed above. SAI, on the other hand, is more complicated. The primary objective of the UNFCCC is to stabilize GHG concentrations, not to moderate temperature rise, and thus SAI does nothing to achieve that objective. Moreover, as discussed earlier, there is a concern that SAI efforts could weaken the commitment to reduce GHG emissions, and thus be counterproductive to the primary objective of the treaty.[97] In addition, sulfate-based SAI could be characterized as "dangerous anthropogenic interference in the climate system," which the UNFCCC aims to prevent.[98] From this perspective, one could argue that SAI is inimical to the objectives of the UNFCCC.

There is room for debate as to whether SAI programs would be consistent with the principle of protecting the climate system, particularly for future generations, or the principle that states should be adopting precautionary measures to mitigate the *causes* of climate change. Proponents of SAI would argue that it does no permanent harm to the climate system, and that it is entirely consistent with the principle of mitigating the *adverse effects* of climate change, namely increasing global temperatures, particularly in the short term. Moreover, they argue that the precautionary principle supports the argument that uncertainty about the effects should not preclude action. Opponents would respond that there are considerable risks surrounding the effects of SAI, including the potential significant risk of permanent or long-term harm to the climate system itself (and other aspects of the environment), and that in any event the mitigation of the *causes* of climate change is far more important than merely mitigating short term *effects.* They argue that this perspective is far more consistent with the objective of the UNFCCC. Moreover, given the uncertainty surrounding the nature and extent of the potential risks posed by SAI, the precautionary principle should be best understood as militating against deployment, rather than in support of it (we return to these arguments, and certain cross-cutting arguments both relying on the precautionary principle, when we explore the precautionary principle in more detail below).[99] Finally, given the uneven distribution of harm likely to result from SAI, it would be inconsistent with the CBDR

97. *See, e.g.*, Humphreys, *supra* note 11, at 111; Climate Change Geoengineering, *supra* note 73, at 209; Du, *supra* note 10, at 45.

98. UNFCCC, *supra* note 25, art. 2.

99. *See, e.g.*, Du, *supra* note 10, at 201–07; Reynolds, *supra* note 70, at 90–96 (discussing such arguments).

principle to disproportionately injure the most vulnerable and least responsible for climate change.

Turning to the specific commitments in the UNFCCC, few of these would appear to contemplate or be implicated by the prospect of geoengineering. Nonetheless, there are a couple that could be invoked in support of objections to unilateral SAI efforts, if not SAI deployment more generally. Several of the commitments include an obligation to cooperate, including commitments to cooperate: (i) in preparing to adapt;[100] (ii) in ensuring that both mitigation and adaptation cause minimal harm;[101] and (iii) in sharing fully the relevant information related to such responses.[102] These duties of cooperation might be argued to militate against unilateral action, particularly where such action may pose risks to the "economy, public health, and the quality of the environment" of other parties, and when such action is explicitly opposed by some of those other parties to the UNFCCC. This is all the more so when the principle is considered in combination with the operation of related principles of customary international law, such as the more general principle of cooperation and the no-harm principle, to be discussed below. But there are some who argue that geoengineering is entirely outside of the scope of the UNFCCC, precisely because the focus of the UNFCCC is on limiting GHG emissions, and that it explicitly excludes any "action with broader consequences."[103]

The *Paris Agreement* similarly does not directly address geoengineering, and like the UNFCCC, it has provisions that could be invoked by both proponents and opponents of unilateral SAI. The *Paris Agreement* is explicitly aimed at furthering the objectives and principles of the UNFCCC. But it also articulates the aim of "holding the increase in the global average temperature to well below 2° Celsius above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5° Celsius above pre-industrial levels . . . ."[104] In addition, it provides that another aim is that of "increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development . . . ."[105] One could argue, therefore, that because the focus

100. UNFCCC, *supra* note 25, art. 4(1)(e).
101. *Id.* art. 4(1)(f).
102. *Id.* art. 4(1)(h).
103. *See, e.g.*, REYNOLDS, *supra* note 70, at 62 (citing in part UNFCCC, art. 7.2(m)).
104. Paris Agreement, *supra* note 27, art. 2(1)(a).
105. *Id.* art. 2(1)(b).

has shifted to maintaining temperature rather than limiting GHG concentrations in the atmosphere, and because there is an explicit emphasis on adaptation, SAI efforts would be more consistent with these aims.

The counterargument is that the overall structure of the *Paris Agreement*, with its framework of nationally determined contributions ("NDCs"), is still heavily predicated upon prioritizing mitigation of the causes of climate change, and specifically reducing GHG emissions. What is more, the *Paris Agreement* provisions that articulate the aims and guiding principles for adaptation efforts again explicitly emphasize the requirement for cooperation, transparency, and open participation in international adaptation efforts. In addition, they create an obligation to engage in appropriate impact assessments and to consider the likely effect of contemplated adaptation measures on vulnerable ecosystems and populations.[106] It could thus be argued that unilateral SAI efforts, particularly those undertaken in the face of opposition from other parties, would be entirely inconsistent with these obligations.

2. ENMOD

Another treaty that could be implicated by certain unilateral SAI efforts is the *Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques* (the "ENMOD").[107] One of the driving forces behind the establishment of the treaty was concern over the U.S. effort to use weather modification techniques in the Vietnam War.[108] As a result, however, the treaty is quite narrowly focused. The

106. *Id.* arts. 7(5)–(7), (9).

107. Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, May 18, 1977, 1108 U.N.T.S. 151 [hereinafter ENMOD].

108. In addition to the well-known use of defoliants in Vietnam, there was real concern over the U.S. program under Operation Popeye, which was exploring how to alter monsoon patterns over Vietnam. Albert Lin, *International Legal Regimes and Principles Relevant to Geoengineering*, *in* CLIMATE CHANGE GEOENGINEERING, *supra* note 73, at 185; *see also* Lawrence Juda, *Negotiating a Treaty on Environmental Modification Warfare: The Convention on Environmental Warfare and its Impact Upon Arms Control Negotiations*, 32 INT'L ORG. 975 (1978); Tracy Raczek, *Geoengineering: Reining in the Weather Warriors*, CHATHAM HOUSE – INT'L AFFAIRS THINK TANK (Feb. 15, 2022), https://www.chathamhouse.org/2022/02/geoengineering-reining-weather-warriors [https://perma.cc/G9ZV-Y4BV]. For more on the U.S. efforts in Vietnam, see, e.g., Memorandum from the Deputy Under Secretary of State for Political Affairs (Kohler) to Secretary of State Rusk, Weather Modification in North Vietnam and Laos (Project Popeye) (Jan. 13, 1967), *in* 28 FOREIGN RELATIONS OF THE UNITED STATES, 1964–68, LAOS (1998).

parties to the treaty undertake not to "engage in military or any hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage, or injury to any other party."[109] They also undertake to prevent any activity within their jurisdiction that could constitute a violation of this obligation.[110] The prohibition is thus explicitly limited to environmental modification that can be characterized as being for a "military or hostile use," and the language "as the means of destruction, damage, or injury to any other party" also suggests that the provision contemplates only the use of environmental modification for the specific purpose of causing harm to other state parties. Indeed, the treaty was negotiated within the Conference on the Committee for Disarmament, and the preamble of the treaty articulates the wish to contribute to the objective of halting the arms race and "saving mankind from the dangers of using new forms of warfare."[111]

SAI would certainly come within the definition of the term "environmental modification techniques."[112] As discussed earlier, there is a real risk that the persistent large-scale deployment of SAI could cause "widespread long-lasting or severe effects," as those terms are defined in the treaty itself, resulting in "destruction, damage, or injury" to other states.[113] States suffering such harm could plausibly argue that the use of SAI was both an "environmental modification technique" that was "hostile," particularly if it was conducted in the face of specific and widespread objections. But it is still not clear that such action and resulting harm would come within the scope of the ENMOD prohibition, given that the treaty seems to contemplate only such "hostile use" to the extent it is "as a means" of causing the harm, implying that intent is an element of the test—and, even in the most disastrous scenarios, the harm caused by unilateral SAI efforts would be incidental to the purpose of reducing global temperatures. It is not clear that reckless or willful disregard of such collateral harm comes within the ambit of the prohibition. What is more, the treaty explicitly provides that "the provisions of

109. ENMOD, *supra* note 107, at art. I(1).

110. *Id.* art. IV.

111. *Id.* pmbl.

112. *Id.* art. II (defining the term as "any technique for changing—through the deliberate manipulation of natural processes—the dynamics, composition, or structure of the Earth, including its biota, lithosphere, hydrosphere, and atmosphere, or of outer space").

113. *Id.* art. I.

this Convention shall not hinder the use of environmental modification techniques for peaceful purposes and shall be without prejudice to the generally recognized principles and applicable rules of international law concerning such use."[114]

Nonetheless, ENMOD is a treaty already in place, which at the time of writing had seventy-eight state parties (including the United States, the United Kingdom, Russia, India, China, and Pakistan)[115] and thus it could be invoked as a potential legal constraint in any debates surrounding proposed SAI efforts.[116] Even if a unilateral SAI effort by a state party to ENMOD might not constitute a clear violation of the primary obligation, the treaty contains numerous provisions that create obligations to consult and cooperate regarding issues relating to the objectives of the treaty, which include the protection of the environment.[117] The treaty also provides for referral of disputes to the U.N. Security Council. Thus, it is conceivable that ENMOD could be invoked to create a brake on efforts to proceed with a unilateral SAI program.

3. Convention on Biological Diversity

The *Convention on Biological Diversity* (the "CBD")[118] is yet another treaty that could be implicated by unilateral SAI efforts, and it is one

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114. *Id.* art. III(1).

115. *See* U.N. Secretary-General, *Statuses of Treaties, ch. XXVI, 1. Convention on the prohibition of military or any other hostile use of environmental modification techniques*, United Nations Treaty Collection (Nov. 10, 2024, 10:15 AM), https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVI-1&chapter=26&clang=_en [https://perma.cc/XSX9-UP65].

116. Interestingly, the Colombian Supreme Court in 2018 cited ENMOD as being relevant to its consideration of claims that the government's failure to prevent deforestation of the Amazon was a violation of its international legal obligations. *See* Corte Suprema de Justicia [C.S.J.] [Supreme Court], Sala. Civ. abril 5, 2018, Luis Armando Tolosa Villabona, STC4360-2018, *Demanda Generaciones Futuras v. Minambiente* [Future Generations v. Ministry of the Environment and Others] (No. 11001-22-03-000-2018-00319-01) (Colom.), *translated in* Columbia Law School Sabin Center for Climate Change Law, https://climatecasechart.com/non-us-case/future-generation-v-ministry-environment-others/ [https://perma.cc/3JVY-QLN2].

117. The preamble explicitly invokes the Stockholm Declaration on the Human Environment, and "realizes" that "the use of environmental modification techniques for peaceful purposes could improve the interrelationship of man and nature and contribute to the preservation and improvement of the environment for the benefit of present and future generations." ENMOD, *supra* note 107, pmbl.

118. Convention on Biological Diversity, June 5, 1992, 1760 U.N.T.S. 79 [hereinafter CBD].

of the few that includes an explicit discussion of geoengineering risks. It has the benefit of widespread participation, though the United States is one of the few countries in the world that is not a party.[119] The primary objective of the CBD is the conservation of biological diversity,[120] which is recognized as "a common concern of humankind."[121] A core principle of the CBD is that it is the responsibility of each state party to "ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."[122]

The CBD mandates international cooperation for conserving biodiversity beyond national borders and requires states to develop environmental impact assessment procedures for projects potentially affecting biodiversity.[123] Additionally, it obliges states to establish reciprocal arrangements with neighboring countries to mitigate risks to biodiversity in other states or areas outside national jurisdiction.[124] As discussed earlier, sulfate-based SAI could have significant impacts on biodiversity, particularly in marine ecosystems, which could bring it within the scope of the treaty.

The Conferences of the Parties to the CBD ("CBD-COP"), the institutional apparatus of the CBD, is one of the few treaty organizations that has explicitly addressed the issue of geoengineering risks. The CBD-COP issued decisions at several annual meetings that took note of reports from UNEP, among other institutions, on the likely effects that climate-related geoengineering could have on biological diversity. In a decision issued in 2012, the CBD-COP noted that there remain significant gaps in current understanding of how certain forms of geoengineering would impact biodiversity, and called upon parties to work to fill such gaps.[125] In the same decision, it reaffirmed the need to comply with the precautionary principle in any approach to geoengineering, called upon the secretariat to share information regarding the possible impact of geoengineering on

119. *Id.*
120. *Id.* art. 1.
121. *Id.* pmbl.
122. *Id.* art. 3.
123. *Id.* arts. 5, 14.
124. *Id.* art. 14.
125. Conference of the Parties to the Convention on Biological Diversity, *Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Eleventh Meeting*, ¶ 7, 9, 14, U.N. Doc. UNEP/CBD/COP/DEC/XI/20 (Dec. 5, 2012), https://www.cbd.int/doc/decisions/cop-11/cop-11-dec-20-en.pdf [https://perma.cc/9Q9L-ZAJP].

biodiversity with other treaty bodies, and called upon the secretariat to gather and compile information from the IPCC and elsewhere to provide an updated understanding of how geoengineering might impact biodiversity.[126]

At the same time, the CBD-COP noted that while the precautionary principle, customary international law, including the no-harm principle, and obligations to engage in environmental assessments (which we discuss below) would all potentially operate to constrain geoengineering efforts, this forms "an incomplete basis for global regulation."[127] Moreover, it noted both the absence of, and the need for, a sufficient governance structure to regulate geoengineering that might affect biodiversity.[128] In 2010, the CBD-COP issued actual guidance, recommending that governments ensure that no climate-related geoengineering activities that might affect biodiversity be permitted until there had been sufficient scientific study of the potential risks and benefits.[129] The CBD does have a dispute settlement provision that provides for the submission of disputes to either arbitration or the International Court of Justice ("ICJ") in the event the dispute cannot be resolved by negotiation or good offices,[130] but the guidance and decisions noted here do not themselves create binding obligations that would likely trigger the dispute settlement provision.

4. Montreal Protocol

The *Montreal Protocol*, adopted in 1987, is famous as a successful international environmental law regime that exercised considerable influence on the development of the climate change law regime.[131] Negotiated within the rubric of the *Vienna Convention for the Protection of the Ozone Layer* adopted only two years earlier, the *Montreal Protocol* established a regime for phasing out the production and use of a number of chemicals that in

126. *Id.* ¶¶ 8, 15–16.
127. *Id.* ¶ 11.
128. *Id.* ¶¶ 8, 11.
129. Conference of the Parties to the Convention on Biological Diversity, *Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Tenth Meeting*, ¶ 8, U.N. Doc. UNEP/CBD/COP/DEC/X/33 (Oct. 29, 2010), https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-33-en.pdf [https://perma.cc/G8TB-ZT8S]; *see also* Carnegie Climate Governance Initiative, *supra* note 38.
130. CBD, *supra* note 118, art. 27.
131. *See, e.g.*, Benoît Mayer, The International Law on Climate Change 52 (Cambridge University Press 2018); Bodansky et al., *supra* note 26, at 120; *see also* authorities cited *infra* Part IV.B.1.

the mid-1980s were discovered to be responsible for creating a growing hole in the ozone layer. It provided for detailed control measures, including schedules specifying the chemicals subject to control, the timelines for phasing them out, and the quantities that both developed and developing states could produce within those timelines,[132] and it contained financial assistance measures, an obligation to report on compliance, and several enforcement mechanisms, including non-compliance penalties and the imposition of economic sanctions. What is more, the *Montreal Protocol* has a relatively easy amendment procedure, making it responsive to new information and circumstances. Amendments in 1990, 1992, and 1999 added to the list of ozone-depleting substances that would be subject to the constraints. The ozone hole is in the process of "healing" as a result of the operation of the *Montreal Protocol* regime.

Sulfur dioxide and other sulfur-based compounds are not currently among the designated ozone-depleting substances governed by the *Montreal Protocol*.[133] Sulfur dioxide has typically been a pollutant in the lower atmosphere, where it has little effect on ozone. The injection of large quantities of sulfur dioxide or other sulfates into the stratosphere, however, would likely harm the ozone layer, thereby bringing SAI within the scope of the object and purpose of the *Montreal Protocol*. While the treaty would not likely operate as a constraint on such action as currently configured, it could be easily and quickly amended to add stratospheric sulfates to the schedules of ozone-depleting substances. More importantly, as we return to discuss in Part IV, the *Montreal Protocol* could provide one of the optimal institutional frameworks within which to develop a more comprehensive global governance regime to fully regulate SAI efforts.[134]

5. The Helsinki Protocol

Given that the most likely form of SAI involves sulfur dioxide, one might think that treaties that were established specifically to address sulfur dioxide might be implicated. The *Convention on Long-Range Transboundary Air Pollution* ("CLRTAP"),[135] adopted in 1979, was largely

132. Montreal Protocol, *supra* note 62.

133. *Id.* For the full current schedules of the Montreal Protocol, see online version: https://ozone.unep.org/treaties/montreal-protocol/montreal-protocol-substances-deplete-ozone-layer [https://perma.cc/7645-XXVH].

134. *See infra* Part IV.B.1.

135. Convention on Long-Range Transboundary Air Pollution, Nov. 13, 1979, 1302 U.N.T.S. 217 [hereinafter CLRTAP].

inspired by the problem of acid rain and other harms caused by sulfur dioxide pollution. The 1985 *Helsinki Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent* ("*Helsinki Protocol*"),[136] along with subsequent protocols negotiated under the rubric of CLRTAP, created increasingly strict limits on sulfur dioxide emissions. Beginning as a European treaty, it currently has fifty-one state parties, including the United States and Canada.[137] While focused specifically on sulfur dioxide, the regime is aimed at governing ground-level emissions and tropospheric pollution, and none of its provisions would operate to constrain SAI specifically.[138]

B. Current Customary International Law Constraints

There are several principles of customary international law that could potentially constrain or deter unilateral SAI efforts, or are at least relevant to shaping how SAI efforts would be undertaken. We explore the most significant of these here.

1. The No-Harm Principle

The most important principle of customary international law in this context is the "no-harm principle." The origin of the principle is an arbitration decision in a dispute between Canada and the United States over trans-boundary atmospheric pollution caused by a smelting plant in Canada. It established that states have an obligation not to "use or permit the use of its territory in such a manner as to cause injury by fumes in or to the territory of another . . . ."[139] The pollution in question was, ironically,

136. Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on the Reduction of Sulphur Emissions or Their Transboundary Fluxes by at Least 30 Per Cent, July 8, 1985, 1480 U.N.T.S. 215 [hereinafter Helsinki Protocol].

137. U.N. Secretary-General, *Status of Treaties, ch. XXVII, 1.b Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on the Reduction of Sulphur Emissions or Their Transboundary Fluxes by at Least 30 per cent*, United Nations Treaty Collection (Nov. 11, 2024, 10:15 AM), https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-1-b&chapter=27&clang=_en [https://perma.cc/ET6J-TXJN] (showing nineteen Signatories and twenty-five Parties as of time of writing); U.S. Dep't of State, Office of the Legal Adviser, Treaties in Force 42 (2020), https://www.state.gov/wp-content/uploads/2020/08/TIF-2020-Full-website-view.pdf [https://perma.cc/A4KS-QLD8] (reflecting U.S. accession to the CLRTAP).

138. *See generally* Helsinki Protocol, *supra* note 136.

139. Trail Smelter (U.S. v. Can.), 3 R.I.A.A. 1905, 1965 (1941). Shaw notes that the principle can be traced back further still, in the context of international waterways, to

sulfur dioxide. The principle has been broadened and generalized substantially since then and is recognized by the ICJ in a number of important cases. According to the Court:

> It is every state's obligation not to allow knowingly its territory to be used for acts contrary to the rights of other states. A state is thus obliged to use all means at its disposal in order to avoid activities which take place in its territory, or in any area under its jurisdiction, causing significant damage to the environment of another state.[140]

What is more, in the *Threat or Use of Nuclear Weapons* case, the ICJ extended the scope of the obligation to cover any harm to the global commons.[141]

The *United Nations Convention on the Law of the Sea* ("UNCLOS") imposes similar obligations, and given that much of the treaty is now recognized as customary international law, these provisions also help define the contours of the no-harm principle. Its provisions have been interpreted broadly to prohibit pollution of the global commons, including the high seas, the sea bed, and the atmosphere.[142] The no-harm principle as it relates to the environment was also entrenched in important environmental instruments, in particular the *Stockholm Declaration* of 1972 and again in the *Rio Declaration* of 1992, which provided that states have "the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states or of areas beyond the limits of national jurisdiction."[143]

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such cases as the International Commission on the River Oder, P.C.I.J. (ser. A) No. 23 (1929). *See* MALCOLM SHAW, INTERNATIONAL LAW loc. 29684 (6th ed. 2008) (ebook).

140. Pulp Mills on the River Uruguay (Arg. v. Uru.), Judgement, 2010 I.C.J. 14, ¶ 101 (Apr. 20); Certain Activities Carried Out by Nicaragua (Costa Rica v. Nicar.), Judgement, 2015 I.C.J. 665, ¶¶ 101–05, 153 (Dec. 16) (citing Corfu Channel (U.K. v. Alb.), Merits, Judgment 1949 I.C.J. 4, at ¶ 22 (Apr. 9)); Threat or Use of Nuclear Weapons, Advisory Opinion, 1996 I.C.J. 226, ¶ 29 (July 8)).

141. Threat or Use of Nuclear Weapons, 1996 I.C.J. at ¶ 29.

142. United Nations Convention on the Law of the Sea, Dec. 10, 1982, 1833 U.N.T.S. 3 [hereinafter UNCLOS]; on provisions constituting customary international law, *see e.g.*, SHAW, *supra* note 139, at loc. 29713.

143. U.N. Conference on the Human Environment, *Report of the United Nations Conference on the Human Environment*, princ. 21, U.N. Doc. A/CONF.48/14/Rev.1 (June 5–16, 1972) [hereinafter *Stockholm Declaration*]; U.N. Conference on Environment and Development, *Rio Declaration on Environment and Development*, princ. 2, U.N. Doc. A/CONF.151/26 (Vol. I) (Aug. 12, 1992) [hereinafter *Rio Declaration*].

The ICJ's treatment of the no-harm principle suggests that it imposes both substantive and procedural duties. Substantively, the principle has been interpreted as creating an affirmative "prevention of harm" obligation—that is, beyond an obligation to not cause actual harm, it affirmatively requires states to engage in due diligence to ensure that activity within the state's territory or under its jurisdiction is not likely to cause harm beyond its borders.[144] This obligation is not limited to the risk of harm directly to and within the territory of other states, but also includes regions that comprise the global commons.[145] The standard for assessing the adequacy of due diligence will depend on the nature of the specific risks at issue. The International Law Commission ("ILC") *Draft Articles on Prevention of Transboundary Harm from Hazardous Activities* simply require that states take "all appropriate measures to prevent significant transboundary harm,"[146] a formulation that was followed by the ICJ in the *Pulp Mills on the River Uruguay* case.[147] In the environmental context, this due diligence obligation requires the conduct of an ex ante environmental impact assessment in the event that some contemplated activities or projects may cause significant harm.[148]

Finally, the procedural duties under the no-harm principle require states to notify, inform, and consult with other states regarding any risk

144. There is some debate over the best interpretation of this substantive obligation, but this is the more widely accepted view. *See, e.g.,* MAYER, *supra* note 131, at 67–71; PLIPPE SANDS ET AL., PRINCIPLES OF INTERNATIONAL ENVIRONMENTAL LAW 200–10 (3d ed. 2012); Marte Jervan, *The Prohibition of Transboundary Environmental Harm. An Analysis of the Contribution of the International Court of Justice to the Development of the No-Harm Rule*, PLURICOURTS RSCH. PAPER NO. 14–17, Aug. 2014, at 62–64, 98–100; Arg. v. Uru., 2010 I.C.J. 14; Int'l L. Comm'n, *Draft Articles on Prevention of Transboundary Harm from Hazardous Activities, Adopted by the Commission at Its Fifty-Third Session*, U.N. Doc. A/56/10 (2001) [hereinafter ILC, *Articles on Prevention*]. For more on the shift to obligations of conduct, see Jutta Brunée, *Procedure and Substance in International Environmental Law: Confused at a Higher Level?*, 5 EUR. SOC. INT'L L. 1 (2016); Benoît Mayer, *Obligations of Conduct in the International Law on Climate Change: A Defence*, 27 REV. EUR., COMPAR. & INT'L ENV'T. L. 130 (2018) [hereinafter Mayer, *Obligations of Conduct*].

145. *See* Jervan, *supra* note 144, at 53 (significant harm, not serious or substantial, is the established threshold for triggering the obligation); *see also* Int'l L. Comm'n, *Draft Articles on Prevention of Transboundary Harm from Hazardous Activities, with Commentaries*, 2(2) Y.B. INT'L L. COMM'N, U.N. Doc. A/56/10, at 152–53 (2001).

146. ILC, *Articles on Prevention*, *supra* note 144, art. 3.

147. Arg. v. Uru., 2010 I.C.J. at ¶¶ 201–06; Costa Rica v. Nicar., 2015 I.C.J. at ¶¶ 104, 118. *See generally* Jervan, *supra* note 144, at 64–65.

148. Costa Rica v. Nicar., 2015 I.C.J. at ¶¶ 104, 161.

of harm arising from the state's activity, which includes an obligation to provide information arising from the environmental impact assessments prior to engaging in the conduct in question.[149] Thus, the ICJ has held that where an environmental impact assessment confirms that there is a significant risk of transboundary harm, the state planning such activity has a further obligation to notify and to consult in good faith with those states that may be impacted by the activity, with a view to determining measures to prevent or mitigate the risk.[150]

The foregoing suggests that a unilateral SAI effort, which would certainly pose a clear risk of harm to other states and to the global commons, would violate the no-harm principle if such risk materialized. Even in advance of undertaking the SAI effort, under the procedural obligations discussed above, the state would have a due-diligence obligation to undertake environmental impact assessments, and, where such assessments revealed a risk of harm, to consult with states likely to be impacted in an effort to prevent or mitigate such harm. From this perspective, proceeding with a unilateral SAI effort without conducting such an assessment, or proceeding over the objections of other states where any assessment reveals potential risk of harm, would violate the customary international law principle of preventing transboundary harm.

Whether this principle would operate effectively as a constraint on a state contemplating unilateral SRM efforts is open to question. It suffers from several weaknesses. There is little precedent for invoking the principle ex ante in order to enjoin a contemplated activity that poses a risk of harm. But, in light of the due diligence and consultation elements discussed above, it might be possible for opposing states to argue that a violation of the no-harm principle had been committed even before the SAI program was implemented, and to take institutional steps and commence proceedings to enjoin such implementation.[151] But, as with so many of the other constraints here under consideration, there are few significant enforcement mechanisms available. The no-harm principle is typically

149. Brunée, *supra* note 144.

150. Costa Rica v. Nicar., 2015 I.C.J. at ¶¶ 104–07, 168.

151. This would involve a request for provisional measures, but as recent cases reflect, the court is typically reluctant to order provisional measures that would enjoin conduct in a manner that effectively pre-judges that the rights in question are being violated. *See, e.g.*, Application of the Convention on the Prevention and Punishment of the Crime of Genocide in the Gaza Strip (S. Afr. v. Isr.), Provisional Measure, 2024 I.C.J. 192 (Jan. 26).

invoked after harm has been caused, and state responsibility for a violation of the principle is alleged,[152] but even the potential deterrent effect of ex post enforcement is undermined by the fact that the enforcement of claims ex post in this context would be difficult. As discussed earlier, the harm likely to be caused by SAI, some of which would be extremely serious and potentially irreversible, would be both widely dispersed and the result of interactions among complex systems. Given that the ICJ has created a relatively high standard of proof for establishing the direct causation of significant harm under the substantive branch of the no-harm principle,[153] it could be quite difficult to prove that the SAI program of a given state was the direct and proximate cause of, for instance, a shifting monsoon in another region of the globe.

2. *Principles of Cooperation and Precaution*

There are several other principles that operate as part of the overall climate change law framework, and which interact with, or are sometimes considered elements of, the no-harm principle.

a) Cooperation

The principle of cooperation, first articulated by the *Rio* and *Stockholm Declarations* and then codified in the UNFCCC itself, has been further developed in ICJ decisions and ILC draft articles and guidelines. It is now arguably an established principle of customary international law.[154] In the context of climate change, the principle obliges states to cooperate in, among other things, achieving the specific objectives of the UNFCCC.[155] It also obliges them to cooperate in the various aspects of

152. Trail Smelter (U.S. v. Can.), 3 R.I.A.A. 1905 (1941); Arg. v. Uru., 2010 I.C.J. 14; Costa Rica v. Nicar., 2015 I.C.J. 665; Corfu Channel (U.K. v. Alb.), Merits, Judgment, 1949 I.C.J. 4 (Apr. 9); Threat or Use of Nuclear Weapons, Advisory Opinion, 1996 I.C.J. 226 (July 8).

153. Costa Rica v. Nicar., 2015 I.C.J. at ¶¶ 119, 217. For the shift of emphasis to obligations of conduct, see Jervan, *supra* note 144; Brunée, *supra* note 144; and Mayer, *Obligations of Conduct*, *supra* note 144.

154. UNFCCC, *supra* note 25, arts. 3, 4, 7; *Stockholm Declaration*, *supra* note 143, princ. 24; Rio Declaration, *supra* note 143, princ. 27; MAYER, *supra* note 131; Arg. v. Uru., 2010 I.C.J. 14; Gabčíkovo–Nagymaros Project (Hungary v. Slovakia), Judgment, 1997 I.C.J. Rep. 7 (Sept. 25). For ILC treatment of the principle, see *infra* Part II.B.3.

155. MAYER, *supra* note 131, at 75 (citing in part MOX Plant Case (Ir. v. U.K.), Case No. 10, Order of Provisional Measures, 2001 ITLOS Rep. 95, ¶ 82); Land Reclamation by Singapore in and Around the Straits of Johor (Malay. v. Sing.), Case No. 12, Order

preventing trans-boundary harm, as part of the no-harm principle examined above.[156]

b) Precaution

A second important principle is the precautionary principle. While there remains some debate as to whether the precautionary principle is an established principle of customary international law or merely a highly influential soft law norm,[157] it is in any event a central principle of climate change law. It has been articulated in most of the important climate change law instruments and recognized to varying degrees by international law institutions ranging from the ICJ to the World Trade Organization (the "WTO").[158] The *Rio Declaration* describes the content of the principle in this way: "Where there are threats of serious irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."[159] The necessity of taking precautions against possibly irreversible damage outweighs any empirical uncertainty. The International Tribunal for the Law of the Sea (the "ITLOS") has held that the precautionary principle is integral to the obligations of due diligence in the no-harm principle, in that states are to err on the side of precaution in decision-making and policy formulation in the event of uncertainty regarding possible harm.[160]

In the context of geoengineering, however, there may be cross-cutting arguments regarding application of the precautionary principle. On the one hand, there is the argument that caution should be exercised before engaging in efforts that may pose clearly identified risks, as well as significant and complex unintended and irreversible consequences to the

of Provisional Measures, 2003 ITLOS Rep. 10; *see also* SANDS ET AL., *supra* note 144, at 203–05.

156. ILC, *Articles on Prevention*, *supra* note 144, art. 4; *see* SANDS ET AL., *supra* note 144, at 215–17; MAYER, *supra* note 131, at 74–75.

157. BODANSKY ET AL., *supra* note 26, at 53; MAYER, *supra* note 131, at 73–74.

158. Arg. v. Uru., 2010 I.C.J. 14; Hung. v. Slovk., 1997 I.C.J. Rep. 7; *see* Yan Cai & Eunmi Kim, *Sustainable Development in World Trade Law: Application of the Precautionary Principle in Korea-Radionuclides*, 11 SUSTAINABILITY 1942 (2019).

159. *Rio Declaration*, *supra* note 143, princ. 15; *see also*, MAYER, *supra* note 131, at 73; SANDS ET AL., *supra* note 144, at 217–28.

160. Responsibilities and Obligations of States with Respect to Activities in the Area, Advisory Opinion, 2011 ITLOS Rep. 10, ¶ 131; *see also* Brunée, *supra* note 144; Jervan, *supra* note 144, at 72.

climate system and the environment. What is more, the precautionary principle is typically understood to create a presumption that places a heavy burden of proof on those advocating for the risky activity.[161] Thus, from this perspective, the precautionary principle is invoked to oppose SAI, since it involves considerable risks, and the uncertainty regarding those risks should not prevent us from deciding to avoid that risk altogether. On the other hand, there are significant risks of irreversible harm associated with *not* pursuing SAI—that is, failure to reduce atmospheric temperatures during the period of transition to new energy sources and reduction of GHG concentrations may condemn us to a global temperature increase of 2° to 3° Celsius by the end of this century.[162] From this perspective, the precautionary principle is invoked to argue that scientific uncertainty regarding the precise nature and magnitude of the risks posed by SAI efforts should not delay implementation of SAI. While the exact risks posed by SAI are unclear, there is little uncertainty that it is an effective and inexpensive method of avoiding almost certain environmental degradation.[163] In our view, the former position is more in keeping with the principle, particularly as it operates in climate change law, but we recognize that reasonable people may disagree on this point.

In short, these principles operate together to create a web of obligations requiring states to cooperate in meeting defined climate change mitigation objectives, err on the side of caution in the event of uncertainty regarding the nature of risk involving significant harm, and affirmatively take action to prevent conduct within their territory that runs the risk of causing harm to other states. What is more, these principles have been further reinforced, in some ways quite explicitly for application in the climate change and geoengineering context, by the work of the ILC, to which we turn next.

3. International Law Commission Principles

While the no-harm principle, which is recognized as customary international law, has been extended to encompass harm to areas beyond

161. Sands et al., *supra* note 144, at 222; Cass Sunstein, The Laws of Fear: Beyond the Precautionary Principle 15–20 (2005); *see also*, Frédéric Sourgens, *The Precaution Presumption*, 31 Eur. J. Int'l L. 1277 (2020).

162. See discussion *supra* Part I.

163. Sourgens, *Geo-Markets*, *supra* note 80, at 84 (discussing the cost-benefit analysis of invoking the precautionary principle and how it may have negative impacts on economic growth).

the territory and jurisdiction of neighboring states, there remains some ambiguity regarding the exact scope of the general obligation to prevent harm to the global commons. The ILC took up aspects of this issue as it relates to the atmosphere.[164] In the 2021 ILC *Draft Guidelines on the Protection of the Atmosphere* (the "*Atmospheric Guidelines*"),[165] it emphasizes that the atmosphere is a natural resource that is essential for sustaining life on Earth and human health and welfare, and is thus a common concern of humankind.[166] The primary purpose of the guidelines "concern the protection of the atmosphere from atmospheric pollution and atmospheric degradation."[167] "Atmospheric pollution" is defined as "the introduction or release by humans, directly or indirectly, into the atmosphere of substances or energy contributing to significant deleterious effects . . . of such a nature as to endanger human life and health and the Earth's natural environment;" while "atmospheric degradation" is defined as "the alteration by humans, directly or indirectly, of atmospheric conditions having significant deleterious effects" similar to those for pollution.[168] The type of sulfate-based SAI efforts discussed earlier would clearly fall within the scope of both of these definitions.

The *Atmospheric Guidelines* provide that states have the obligation to protect the atmosphere by exercising due diligence to "prevent, reduce or control atmospheric pollution and atmospheric degradation."[169] This is followed more specifically with an obligation to undertake environmental impact assessments of any proposed activities within their jurisdiction or control, "which are likely to cause significant adverse impact on the atmosphere."[170] In a provision most specifically directed to possible geoengineering, Guideline Seven provides that "activities aimed at intentional large-scale modification of the atmosphere should only be conducted with prudence and caution, and subject to any applicable rules

164. ILC articles are typically considered to be generally (though not without exception) reflective of customary international law, and, to the extent certain provisions are not yet considered custom, they are often the articulation of emerging and crystallizing principles of custom. *See*, SHAW, *supra* note 139, at loc. 29615–75.

165. Int'l L. Comm'n, *Draft Guidelines on the Protection of the Atmosphere*, 2(2) Y.B. INT'L L. COMM'N, U.N. Doc. A/76/10 (2021).

166. *Id.* pmbl.

167. *Id.* guideline 2.

168. *Id.* guideline 1.

169. *Id.* guideline 3.

170. *Id.* guideline 4.

of international law, including those relating to environmental impact assessment."[171] This is clearly designed to implicate the due-diligence requirements of the no-harm principle. In addition, the guidelines reiterate the obligation of states to cooperate with one another and with the relevant international organizations for the protection of the atmosphere.[172] They remind states that compliance with international law obligations to protect the atmosphere may be either facilitated or enforced through a number of different mechanisms, though the guidelines do not themselves provide for any such mechanisms.[173]

The ILC also released two other instruments that sought to advance the development of customary international law principles governing the transboundary harm caused by activities that are not unlawful or in violation of any legal obligation. These are the *Draft Articles on Prevention of Transboundary Harm from Hazardous Activities* (the "*Prevention of Harm Articles*"),[174] and the *Draft Principles on the Allocation of Loss in the Case of Transboundary Harm Arising from Hazardous Activities* (the "*Allocation of Loss Principles*").[175] In these two instruments, the ILC somewhat controversially made a distinction between harm caused by actions that violated an international legal obligation and transboundary harm caused by activity that was itself lawful.[176] While we need not delve into the details of either that controversy or the substance of the two instruments here, we note that they may serve to further strengthen the obligations on states to engage in due diligence and to take all appropriate measures to prevent harm to other states, including by non-state actors operating within their territory[177]—ILC articles are widely understood to either codify existing principles or advance and crystallize emerging norms of

171. *Id.* guideline 7.

172. *Id.* guideline 8.

173. *Id.* guideline 11.

174. ILC, *Articles on Prevention*, *supra* note 144.

175. Int'l L. Comm'n, *Draft Principles on the Allocation of Loss in the Case of Transboundary Harm Arising from Hazardous Activities*, 2(2) Y.B. Int'l L. Comm'n, U.N. Doc. A/61/10 (2006) [hereinafter ILC, *Allocation of Loss*].

176. On the controversy regarding this distinction, see Shaw, *supra* note 139, at loc. 29823.

177. ILC, *Articles on Prevention*, *supra* note 144, arts. 1, 2. The Commentary to the Draft Articles notes that the term "significant" is to be understood as something more than "detectable" but may be less than "serious" or "substantial." *See* para. 4 of Commentary under art. 2.

customary international law.[178] The *Prevention of Harm Articles* go on to require states to take steps to implement all of its provisions, through legislation or administrative action, and reiterates the obligation of states to cooperate within one another in good faith in preventing transboundary harm. Several states have already begun to do so.[179] The *Allocation of Loss Principles* exhorts states to take all measures to provide adequate compensation for any transboundary harm caused by hazardous activity and to impose liability on states for the activities of non-state entities causing transboundary harm from within their territory.[180]

While many of the ILC articles, such as the famous *Articles on State Responsibility*, are typically viewed as reflecting or codifying existing customary international law,[181] aspects of these three recent instruments of the ILC are clearly designed to self-consciously nudge the development and expansion of customary international law. In this respect, they are more aspirational than reflective of existing law and might be characterized as soft law. Nonetheless, some aspects of all three instruments clearly build on and reinforce existing principles of customary international law, particularly those related to the no-harm principle regime, which would be relevant to the governance of unilateral SAI. As we will return to below, these ILC instruments could also play an important role in informing the development of new governance structures for atmospheric SRM.

* * *

The foregoing review covers only the more obvious and likely constraining elements of existing global governance structures. What emerges from this examination is that there are multiple sources for, at a minimum, obligations on states to: (i) engage in due diligence, including the conduct of environmental impact assessments, prior to undertaking any activity that might cause harm to other states or the global commons; (ii) notify and consult with other states that might be harmed by such activity; and (iii) cooperate with those states regarding how to

178. *See, e.g.*, SHAW, *supra* note 139, at loc. 7980–93.

179. Directive 2004/35/CE, of the European Parliament and of the Council of 21 April 2004 on Environmental Liability with Regard to the Prevention and Remedying of Environmental Damage, 2004 O.J. (L 143) 56 [hereinafter European Environmental Liability Directive].

180. ILC, *Allocation of Loss*, *supra* note 175, pmbl., princ. 4.

181. SHAW, *supra* note 139, at loc. 29615–75.

manage this risk. If a state were to proceed with an SAI deployment in disregard of these requirements, and it does cause harm, it could be found responsible for violating these principles and be required to make reparations.

At the same time, it also emerges that there are few mechanisms in place to enforce these obligations ex ante, and it is unclear precisely how much deterrence these obligations would exercise on the conduct of states convinced that SAI efforts were necessary to reduce the risk posed by the short-term consequences of increasingly severe temperatures. What is more, there is little in the way of an overarching institutional framework that can be said to "govern" the kinds of issues that unilateral SAI efforts are likely to trigger. We return to this issue in Part IV, but before doing so, we turn to consider the extent to which unilateral SAI efforts might increase the risk of armed conflict, and why that underappreciated and under-examined risk is so important when considering the need for governance.

III. The Risk of Armed Conflict

In Part I, we examined the strong incentives for engaging in SAI, as well as the considerable risk of both direct and indirect harms that SAI poses to the environment and to the climate system. We also explained the increasing possibility that some states, or even non-state actors, may nonetheless attempt to engage in unilateral SAI efforts. In Part II, we explored the existing international law and other forms of international governance structures that may operate to limit or deter such action, and noted that these constraints are rather weak and uncertain. This combination of strong incentives for action, the risk of harm from such action, and the absence of effective legal constraints, should be cause for considerable apprehension. And it is indeed the basis for many concerns that have been raised elsewhere regarding possible unilateral SAI efforts. On the other hand, as we discussed briefly above, some argue that due to the future warming already baked into the climate system, the risk of harm posed by *not* doing everything we can to moderate rising temperatures, including the use of SAI in the short term, is actually greater than the risk of harm that SAI poses.[182] Those who take this view argue

182. *See, e.g.*, Sourgens, *Geo-Markets*, *supra* note 80; Sourgens, *The Dark Sun Network*, *supra* note 80; Jay Michaelson, *Geoengineering and Climate Management: From Marginality*

that employing some form of SAI as a temporary stop-gap measure to moderate global temperature until we can bring emissions down is the lesser evil.[183]

There is, however, a second-order or knock-on risk posed by unilateral SAI efforts that is under-appreciated and under-theorized in this debate: The risk that a unilateral effort to engage in SAI will provoke an armed response leading to armed conflict. This risk is often gestured to in passing as a "geopolitical risk," including by such institutions as the IPCC,[184] UNEP,[185] and the U.S. national intelligence community,[186] but this risk has not been unpacked and explained, and thus it is not sufficiently accounted for in the debate on SAI. This risk is certainly not sufficiently considered by policymakers trying to balance the risks of action and inaction on the geoengineering front. In our view, this risk, when fully appreciated, likely tips the balance of precaution and prudence firmly in favor of constraint on SAI, and adds to the urgency of establishing a strong global governance structure for atmospheric SRM in general and SAI in particular.

In this Part, therefore, we unpack and explain this risk. We begin by explaining why it is that unilateral SAI deployment would likely be viewed as such a threat to national security that it could provoke an armed response. We then examine how and why the weakness of yet another international law governance structure—the jus ad bellum regime, which is designed to prohibit the unilateral use of force and maintain international peace and security—would be unlikely to prevent such a use of force against a rogue SAI perpetrator. To do this, we explore in some detail how the jus ad bellum regime has been weakened over the last several decades by states trying to relax its strictures to permit uses of force against other purportedly novel threats, and how these efforts

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to Inevitability, *in* CLIMATE CHANGE GEOENGINEERING, *supra* note 73, at 81; Horton, *supra* note 80; REYNOLDS, *supra* note 70, at 198 (arguing that it is at a minimum too early for any binding legal agreement constraining development).

183. *See, e.g.*, Benjamin K. Sovacool, *Reckless or Righteous? Reviewing the Sociotechnical Benefits and Risks of Climate Change Geoengineering*, 35 ENERGY STRATEGY REV. 100656 (2021) (for a balanced analysis); *see also* David Keith & Douglas MacMartin, *A Temporary, Moderate and Responsive Scenario for Solar Geoengineering*, 5 NATURE CLIMATE CHANGE 201 (2015).

184. IPCC, *AR-6*, *supra* note 3.

185. UNEP, *One Atmosphere*, *supra* note 6.

186. NATIONAL INTELLIGENCE ESTIMATE, *supra* note 16.

would serve as precedents for claims that force could be legitimately used to defend against the threat of unilateral SAI deployments.

A. SAI as Threat to National and International Security

The starting point of assessing this risk is understanding the threat that unilateral SAI would pose to other states. Given the nature and gravity of the possible harms that a unilateral SAI effort might cause to other states, some of the most vulnerable states would likely view such unilateral efforts as a threat to national security, and by extension, to international peace and security. This is particularly so if the SAI perpetrator persists in the face of international objection and condemnation. In thinking through why states might frame the risk in this way, we note that an increasing number of government agencies in a growing number of states already characterize both the direct and indirect consequences of climate change itself as a national security threat.[187] Direct effects that have national security implications include sea-level rise threatening population centers, increased extreme weather events, increasingly intolerable wet-bulb temperatures in certain regions, food and water insecurity caused by changing weather patterns, and the resulting internal and external population displacements. Indirect and second-order effects are extensive, but include political instability and institutional failure in the more vulnerable states. All of these effects will in turn drive armed conflict. Moreover, these risks have been explicitly identified by an increasing number of states as a threat to national security and as a strategic issue for national security planning.[188]

Some of the possible effects of a global SAI effort pose the same kinds of threats to national security as some of the consequences of climate change itself. These include the disruption and alteration of monsoon patterns, causing differentiated and new areas of flooding and drought, leading to severe water and food insecurity. In addition, SAI may cause increased acidification of the ocean, resulting in the collapse or migration of certain fish stocks and thus similarly impact food security. All

187. *See, e.g.*, National Intelligence Estimate, *supra* note 16; DoD Climate Change 2019 Report, *supra* note 18; NIC, Implications for US National Security, *supra* note 18; UK MOD, Global Strategic Trends, *supra* note 18, at 30–56; *see also* Stewart Patrick, Reflecting Sunlight to Reduce Climate Risk: Priorities for Research and International Cooperation (2022).

188. *See* authorities cited *supra* note 18.

of these changes will contribute to political instability and potentially violent conflict in different areas of the world.[189] Furthermore, these risks will be exacerbated by the creation of a potential termination shock that will only grow the longer the program runs. Many states may view the potential termination shock that would be created as yet another threat to national security being created by the capricious state proposing to undertake an SAI program unilaterally.[190]

As illustrated by the ENMOD treaty regime, the international community has already explicitly recognized in a multilateral treaty that "environmental modification techniques having widespread, long-lasting or severe effects" may pose a threat to national security, at least where such modification efforts are undertaken for a hostile purpose aimed at causing harm to another state.[191] It is but a small conceptual step to go from recognizing that such "hostile use" of climate modification for the "purpose of causing harm" to other states constitutes a threat, to recognizing that reckless disregard for the harm from such climate modification would similarly constitute a threat to national security. Indeed, some have suggested that such willful disregard for the harm to other states might already bring unilateral SAI efforts within the scope of the "hostile purpose" concept contemplated by ENMOD.[192] In any event, the states that are likely to suffer the most severe harmful consequences from a unilateral SAI effort, such as the possible disruption of a crucial monsoon pattern, are likely to view such a program as a threat to national security regardless of whether there is any explicit and directed hostile intent, or whether there is any treaty provision that can be invoked to define it as such.[193]

B. Possible Use of Force to Prevent Unilateral SAI

If we consider a situation in which a country with the capacity to engage in SAI announces that it is about to embark on a unilateral

189. *See supra* Part I.

190. *See* authorities cited *supra* note 71 (detailing termination shock).

191. *See* discussion *supra* notes 107–12; ENMOD, *supra* note 107, pmbl., art. I.

192. *See, e.g.,* Lin, *supra* note 108, at 185–86.

193. There are debates regarding the extent to which, and in what circumstances, intent is considered a necessary element for defining an action as a threat to national security, a use of force, or act of aggression; see, for example, Tom Ruys, "Armed Attack" and Article 51 of the UN Charter: Evolutions in Customary Law and Practice 157–67 (2010).

program regardless of international objections,[194] how are states likely to respond to such a perceived imminent threat to national security? There would no doubt be diplomatic efforts within the international community to dissuade the government from engaging in such a program unilaterally. Such efforts would include formal claims that the action would be unlawful, constituting a violation of a range of legal regimes we discussed in Part II. States would also likely raise the issue before the U.N. Security Council.[195] There might be the imposition of increasingly harsh economic sanctions if time permitted, whether authorized by the Security Council pursuant to Article 41 of the U.N. Charter, or as autonomous sanctions undertaken by the most threatened states, collectively or individually.[196] Yet, as Part II examined in detail, existing international legal regimes and governance arrangements are insufficient to constrain such unilateral action. And, if diplomatic and non-violent modes of persuasion are unsuccessful, and the "rogue state" continues on course to commence the SAI program, there remains the significant risk that states would perceive the threat to national security as being sufficiently grave to justify a resort to the threat or use of force to prevent it.[197] In short, there is a real risk that unilateral SAI could lead to armed conflict.

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194. As discussed earlier, the technical feasibility and relative cost brings it within reach of many countries, including several in the Global South most vulnerable to climate change.

195. The U.N. Security Council has addressed climate change as an issue potentially implicating international peace and security. S.C. Res. 2349, ¶ 26 (Mar. 31, 2017). For more on the role of the Security Council in addressing climate change, see, for example, CLIMATE CHANGE AND THE UN SECURITY COUNCIL (Shirley V. Scott & Charlotte Ku eds., 2018); Mark Nevitt, *Is Climate Change a Threat to International Peace and Security?*, 42 MICH. J. INT'L L. 527 (2021) [hereinafter Nevitt, *Threat to International Peace*]; Mark Nevitt, *Climate Change and the Specter of Statelessness*, 35 GEO. ENV'T L. REV. 331 (2023) [hereinafter Nevitt, *Specter of Statelessness*].

196. As discussed above, the Montreal Protocol includes provisions requiring trade restrictions against states violating the Protocol, and there is increasing debate over the implementation of sanctions in the form of carbon border adjustments on products imported from states not complying with Paris Agreement obligations; see, for example, Olivier Blanchard et al., *The Portfolio of Economic Policies Needed to Fight Climate Change*, 15 ANN. REV. ECON. 689 (2023).

197. This Section draws upon parts of previous writing on this issue by one of the authors: Craig Martin, *Atmospheric Intervention*, *supra* note 21; Craig Martin, *Geoengineering and the Use of Force*, OPINIO JURIS (Jan. 20, 2021), http://opiniojuris.org/2021/01/20/geoengineering-and-the-use-of-force/ [https://perma.cc/T3XA-WK6Y]; Craig Martin, *Climate Wars and Jus ad Bellum, Parts I & II*, OPINIO JURIS (Aug. 13, 2020), http://opiniojuris.org/2020/08/13/climate-wars-and-jus-ad-bellum-part-ii/ [https://perma.cc/S4GR-NF62].

We have so far examined how one body of international law and institutional structures may be insufficient to effectively prevent a unilateral SAI effort, and how that raises the risk that states will consider the use of force in response. The next question is whether there is another international law regime and institutional framework that will effectively prevent such a use of armed force and the eruption of armed conflict. Here we turn to examine a second international law regime that comes into play here—the legal regime in international law designed to condition and constrain the use of force, which is known as the jus ad bellum regime. In order to assess the nature of this risk of armed conflict, we must explore whether, how, and to what extent that regime might successfully constrain or prevent a use of force in response to a unilateral SAI effort. The more effective this regime would be, the lower the risk of such a use of force, and thus the risk of armed conflict as a consequence of unilateral SAI deployment.

In other words, understanding how the jus ad bellum regime would operate in these circumstances is key to understanding the magnitude of the risk of armed conflict. Unfortunately, in our view, the jus ad bellum regime is unlikely to provide a very effective constraint. As we explain below, the jus ad bellum regime has been weakened over the last several decades by states attempting to relax or adjust its standards and doctrines precisely to allow for a greater latitude of armed action in response to novel threats—threats such as nuclear proliferation, transnational terrorism, and the prospect of cyber-attacks. In the face of the prospect of unilateral SAI programs, we may anticipate similar efforts to relax the regime's strictures to permit or justify a use of force in response to the threat posed by unilateral SAI action. The legal regime has indeed been made more vulnerable to such efforts by the precedents set by the efforts to expand the scope of permissible action—and indeed, a further weakening of the jus ad bellum regime might be one more collateral harm resulting from unilateral SAI efforts. We proceed to explain these points in more detail.

C. Operation of Jus ad Bellum Regime to Constrain the Use of Force

The primary source of the modern jus ad bellum regime is the U.N. Charter. Article 2(4) prohibits the threat or use of force against the territorial integrity or political independence of any state, or in any other

manner inconsistent with other principles of the United Nations.[198] The prohibition is widely viewed as constituting a jus cogens norm, admitting of no derogation.[199] The Charter itself provides for two "exceptions"[200] to this prohibition (aside from the consent of the target state),[201] namely: (i) a use of force by member states authorized by the U.N. Security Council, pursuant to Article 42 of the Charter, to address a threat to international peace and security; and (ii) a unilateral use of force by a state (or states) as an exercise of individual or collective self-defense in response to an armed attack, pursuant to Article 51 of the Charter.

The initial question, then, is whether a use of force in response to, and to prevent, a unilateral SAI operation would fall within either of these two exceptions, so as to be permissible. If not, then such a use of force would be prima facie prohibited. With respect to the first exception, it would certainly be within the authority and jurisdiction of the U.N. Security Council to authorize a use of force by member states to prevent a unilateral SAI effort. The coordinated action by the Security Council to approve such a use of force is, however, quite unlikely given the current structure and dynamics of the Security Council. Similarly, the U.N. Security Council could approve other forms of pressure against the state proposing to engage in SAI action, such as ordering economic sanctions

198. U.N. Charter art. 2(4).

199. Some would argue that it is only the prohibition on the use of force which rises to an act of aggression that constitutes the jus cogens norm: see discussion on this point in RUYS, *supra* note 193, at 25 (noting that while the majority of jurists would extend jus cogens to cover any use of force in violation of Article 2(4), some limit it to uses of force that constitute an act of aggression).

200. There is some debate over whether self-defense should be understood as an exception to the prohibition itself, or an exception, for instance, to the requirement that the Security Council respond to all acts of aggression. *See, e.g.*, Adil Ahmad Haque, *The United Nations Charter at 75: Between Force and Self-Defense—Part Two*, JUST SEC. (June 24, 2020), https://www.justsecurity.org/70987/the-united-nations-charter-at-75-between-force-and-self-defense-part-two/ [https://perma.cc/2HMW-F8RZ]; Federica Paddeau, *Military Assistance on Request and General Reasons Against Force: Consent as a Justification for the Use of Force*, 7 J. ON USE FORCE INT'L L. 227 (2020) (noting that the notion that self-defense is an exception to the prohibition poses theoretical problems for the idea that the prohibition on the use of force is a jus cogens norm).

201. While counterintuitive, consent may be given, for instance, to allow some other state to use force against a non-state actor within the territory of the consenting state. On the debate regarding the operation of consent in relation to the prohibition on the use of force, see, for example, Paddeau, *supra* note 200, and Eliav Lieblich, *Why Can't We Agree on When Governments Can Consent to External Intervention? A Theoretical Inquiry*, 7 J. ON USE FORCE INT'L L. 5 (2020).

against the state, which might reduce the probability of a unilateral use of force against the offending state—but, again, the dynamics of the Security Council could make such coordinated action unlikely.

With respect to the second exception, that of unilateral use of force in self-defense, the question is whether an armed intervention to prevent unilateral SAI efforts could satisfy the conditions for the exercise of the right of self-defense. If such a use of force cannot fit within the scope of the current doctrine of self-defense, a further question is whether there would be sufficient pressure to either expand the right of self-defense to accommodate an armed response against unilateral SAI. There might even be sufficient pressure to create a new exception to the prohibition altogether—there have been efforts to create new exceptions to the prohibition precisely to accommodate new and novel perceived threats in recent years. The final question is whether the prohibition might, even without any expansion or relaxation of standards, simply fail to constrain such a use of force, unlawful though it might be, if the threat were perceived to be sufficiently grave. We turn to examine these issues in turn—but in short, while a unilateral use of force in response to a rogue SAI effort is prohibited by the current jus ad bellum regime, there could be legitimate collective armed intervention authorized by the Security Council, and in any event the regime could not be counted on to effectively constrain unilateral uses of force in response to states mounting rogue SAI programs.

1. Use of Force Authorized by the U.N. Security Council

The operations of the Security Council could actually serve to increase the risk of the use of the force. In the first place, it could authorize the use of force against a state threatening to engage in unilateral SAI efforts—a legitimate use of its power, certainly, but no less violent for it. On the other hand, in practice, its dysfunction makes such authorization unlikely and increases the risk of unilateral uses of force in response to SAI efforts.

To explain, the most well-established and accepted avenue for a legitimate use of force in response to some perceived threat to collective national security is to obtain authorization from the U.N. Security Council. This would be the natural starting point for mounting collective action to prevent unilateral SAI efforts. The first step of this process requires the U.N. Security Council to identify the SAI effort as a

threat to international peace and security under Article 39 of the Charter.[202] Leaving aside the potential politics of such a process, unilateral SAI efforts would very likely come within the scope of such recognition. There has been increasing attention on the role of the Security Council in combating climate change,[203] and several scholars have argued that the U.N. Security Council could declare climate change itself to constitute a threat to international peace and security.[204] The Security Council has already expanded the scope of Article 39 determinations to include non-traditional security threats such as the Ebola pandemic,[205] and it has held debates on the topic of climate change within the scope of international peace and security.[206] If the U.N. Security Council determined that a proposed unilateral SAI effort constituted a threat to international peace and security, that would open the door to authorizing collective action to respond to the threat, whether in the form of non-violent measures such as economic sanctions pursuant to Article 41, or the use of force in accordance with Article 42 of the U.N. Charter.[207]

The U.N. Security Council *could*, therefore, authorize a use of force against a state deemed to constitute a threat in this fashion, just as it has authorized uses of force for purposes of humanitarian interventions.[208] The rationale for such a use of force would be more compelling than the justification for humanitarian intervention. Recall that under the "responsibility to protect" doctrine that provides the theoretical rationale for U.N. authorized humanitarian intervention, a state is said to lose or abdicate some of its sovereign rights against intervention when it causes

202. *See generally* Christine Gray, International Law and the Use of Force 341–86 (4th ed. 2018); Gary Wilson, The United Nations and Collective Security (2014); Loraine Silvers & Sam Daws, The Procedure of the UN Security Council (4th ed. 2014).

203. *See, e.g.*, Climate Change and the UN Security Council, *supra* note 195.

204. *Id.*; *see also* Nevitt, *Threat to International Peace*, *supra* note 195; Nevitt, *Specter of Statelessness*, *supra* note 195; Pierre Thielbörger, *Climate Change and International Peace and Security: Time for a Green Security Council?*, *in* From Cold War to Cyber War 67 (Hans-Joachim Heintze & Pierre Thielbörger eds., 2016).

205. S.C. Res. 2177 (Sept. 18, 2014).

206. *Climate Change Recognized as 'Threat Multiplier', UN Security Council Debates Its Impact on Peace*, UN News (Jan. 25, 2019), https://news.un.org/en/story/2019/01/1031322 [https://perma.cc/E529-4V48].

207. *See generally* Nevitt, *Threat to International Peace*, *supra* note 195; Nevitt, *Specter of Statelessness*, *supra* note 195.

208. *See, e.g.*, S.C. Res. 1973 (Mar. 7, 2011).

sufficient suffering to populations within its own territory.[209] By that logic, however, a state should surely lose some of its sovereign rights if its actions cause or disproportionately contribute to significant human suffering in populations outside of its own borders and, indeed, in several regions around the world.[210]

The Security Council, however, is notoriously dysfunctional and prone to gridlock, with one permanent member or another all too often likely to exercise its veto. Thus, it is highly likely that any state that has the capacity to mount unilateral SAI efforts will have political allies on the Security Council, and be able to frustrate any initiatives to designate the effort as a threat to peace and security, or authorize an "atmospheric intervention" in response to it.[211] What is more, as mentioned earlier, precisely because of such gridlock, the Security Council may even fail to mount the kind of pressure against the rogue SAI state, through such mechanisms as resolutions authorizing economic sanctions, that might make the prospect of unilateral uses of force less likely. In the face of such inaction by the Security Council, some states are likely to claim the right to intervene unilaterally as an act of self-defense pursuant to Article 51 of the Charter, or to claim some new sui generis exception to the prohibition on the use of force.

2. The Exercise of the Right to Self-Defense

The only other currently accepted exception to the prohibition on the use of force is the right of self-defense, as provided for in both Article 51 of the U.N. Charter and customary international law. The exercise of that right is only permissible in response to an armed attack, which the ICJ has

209. *See generally* Int'l Comm'n on Intervention and State Sovereignty, The Responsibility to Protect: Report of the International Commission on Intervention and State Sovereignty (2001) [hereinafter R2P Report]. The R2P Report is also explained in U.N. High-Level Panel on Threats, Challenges and Change, A More Secure World: Our Shared Responsibility, U.N. Doc. [ST/]DPI/2367 (2004) [hereinafter A More Secure World], and in U.N. Secretary-General, *In Larger Freedom: Towards Development, Security and Human Rights for All*, U.N. Doc. A/59/2005 (Mar. 24, 2005). *See also* Gareth Evans, *The Responsibility to Protect: From an Idea to an International Norm*, *in* Responsibility to Protect: The Global Moral Compact for the 21st Century 15 (Richard H. Cooper & Juliette Voïnov Kohler eds., 2009).

210. This argument is developed more fully in Martin, *Atmospheric Intervention*, *supra* note 21, at 378–80, 396–99.

211. *Id.*

characterized as the "most grave form" of "a use of force."[212] The notion that self-defense is only permissible in response to an armed attack is quite well settled.[213] Despite earlier debates over whether certain forms of non-military action, such as economic sanctions, fall under Article 2(4)'s prohibition against the use of force, it is now well settled that use of force is limited to military force, and by extension, that an "armed attack" triggering the right of self-defense is a most grave form of such a use of force.[214] Many would find it implausible to argue, even within the context of the more recent debates to be explored further below, that the currently understood concepts of "use of force" or "armed attack," could be stretched to include an imminent or ongoing unilateral SAI program. Nonetheless, recent experience suggests that when the threat of harm posed by a unilateral SAI effort looms large, some states may attempt exactly such an argument.

For instance, twenty years ago, it would have been difficult to understand a cyber-attack as being sufficient to trigger the right to use force in self-defense, or even as constituting a use of force at all. Now, however, the *Tallinn Manual 2.0*,[215] relying on the ICJ *Advisory Opinion on the Legality of the Threat or Use of Nuclear Weapons*,[216] and state practice in relation to other non-kinetic weapons, suggests that cyber operations that cause damage and injury of sufficient scale and effect (that is, equivalent to the effects of a kinetic armed attack) could constitute an armed attack triggering the right of self-defense.[217] Several Western states have since

212. Military and Paramilitary Activities in and Against Nicaragua (Nicar. v. U.S.), Judgment, 1986 I.C.J. 14, ¶ 191 (June 27); *see also* Ruys, note 193, at 139–43 (detailing the scale and gravity threshold). *See generally* Ruys, *supra* note 193 (explaining the current law on armed attack and self-defense).

213. This is despite the many vigorous debates over the various elements and parameters of that test. In short, self-defense is a use of force available only in response to armed attacks, which are themselves a form of a use of force. *See* Ruys, *supra* note 193, at 139–43.

214. Adil Ahmad Haque, *"Clearly of Latin American Origin": Armed Attack by Non-State Actors and the UN Charter*, Just Sec. (Nov. 5, 2019), https://www.justsecurity.org/66956/clearly-of-latin-american-origin-armed-attack-by-non-state-actors-and-the-un-charter/ [https://perma.cc/F9PH-TJF3] (examining the drafting history of the U.N. Charter and debates over the meaning of "use of force" in Article 2(4)); *see also* Shaw, *supra* note 139, at loc. 37842–74; Olivier Corten, The Law Against War 79–83 (2d ed. 2021).

215. Tallinn Manual 2.0 on the International Law Applicable to Cyber Operations (Michael Schmitt et al. eds., 2d ed. 2017).

216. Threat or Use of Nuclear Weapons, Advisory Opinion, 1996 I.C.J. 226 (July 8).

217. Tallinn Manual 2.0 on the International Law Applicable to Cyber Operations, *supra* note 215, at 339–48.

adopted as formal policy the position advanced by the *Tallinn Manual 2.0*, raising the question of whether such an interpretation is emerging as a new principle of customary international law.[218] This, of course, opens the door to arguing that other non-military non-violent operations that cause damage of sufficient scale and effect to a state may likewise come within the scope of the concepts of "use of force" and even "armed attack."

This response to the threat of cyber operations is just one example of efforts over the last several decades to relax the doctrine of self-defense in order to provide states with more latitude to respond to new and evolving threats. In the early 2000s, the United States attempted to establish a doctrine of "preventative self-defense," which would permit a use of force in response to the perceived threat of rogue regimes developing weapons of mass destruction, even in the absence of any imminent armed attack. This was followed by efforts to establish an "unwilling or unable" doctrine, as an expansion of the doctrine of self-defense, which would justify military strikes against armed groups operating in the territory of states unwilling or unable to control their activities—even over the host state's objections. In doing so, the unwilling or unable doctrine sought to weaken the existing requirement to establish a sufficient connection, or "substantial involvement" in the language of the ICJ, between the host state and the armed group as a necessary condition for the exercise of self-defense against the armed group.[219]

In sum, the efforts to entrench these doctrines threatened to undermine the established standards relating to the scale, gravity, and immediacy of

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218. For review and analysis of, and links to, several of these national statements, see, for example, Michael Schmitt, *New Zealand Pushes the Dialogue on International Cyber Law Forward*, JUST SEC. (Dec. 8, 2020), https://www.justsecurity.org/73742/new-zealand-pushes-the-dialogue-on-international-cyber-law-forward/ [https://perma.cc/DZ8Q-UXEY]; Michael Schmitt, *France Speaks Out on IHL and Cyber Operations: Part II*, EJIL:TALK! (Oct. 1, 2019), https://www.ejiltalk.org/france-speaks-out-on-ihl-and-cyber-operations-part-ii/ [https://perma.cc/6H86-QRSN]; and Michael Schmitt, *Israel's Cautious Perspective on International Law in Cyberspace: Part II (jus ad bellum and jus in bello)*, EJIL:TALK! (Dec. 17, 2020), https://www.ejiltalk.org/israels-cautious-perspective-on-international-law-in-cyberspace-part-ii-jus-ad-bellum-and-jus-in-bello/ [https://perma.cc/9MW2-JLRU].

219. For analysis of this pressure in the context of the unwilling or unable doctrine by one of the authors, see Craig Martin, *Challenging and Refining the "Unwilling or Unable" Doctrine*, 52 VAND. J. TRANSNAT'L L. 387 (2019) [hereinafter Martin, *"Unwilling or Unable"*]. *See also* Jutta Brunnée & Stephen J. Toope, *Self-Defence Against Non-State Actors: Are Powerful States Willing but Unable to Change International Law?*, 67 INT'L & COMPAR. L.Q. 263 (2017).

the concept of "armed attack" as the triggering condition for self-defense. We need not get into the details of precisely how such claims sought to revise the contours of each of these elements of the doctrine of self-defense, but it is sufficient to note that all of these efforts have attempted to alter the nature or timing of the acts that provide a legitimate exercise of the right of self-defense, and thereby relax the principles that constrain the use of force in self-defense. The point here is that these past efforts to relax the doctrine of self-defense, for the purpose of responding to apparently novel threats, provide us with a basis for predicting that similar efforts will again be made to relax the doctrine to allow responses to the threat posed by unilateral SAI efforts. In other words, the actual or imminent launch of an SAI program that threatens potentially catastrophic climate consequences may not fit within the current understanding of an "armed attack" justifying a use of force in self-defense, but precedent suggests that we may anticipate claims that this threat is sufficiently analogous to an armed attack, and that the doctrine should be expanded to permit a use of force against such SAI rogue states. Even more disturbing, precedent also suggests that even if such efforts to expand or relax the doctrines of the jus ad bellum regime are not entirely successful, the normative power of the regime has not been sufficient to prevent powerful states from invoking these novel arguments to justify using force in response to these new threats in any event—as graphically illustrated by the invasion of Iraq and the various episodes of the "global war on terror."

3. New Exceptions to the Prohibition on the Use of Force

There would no doubt be strong resistance against such efforts to relax the doctrine of self-defense. Indeed, there has been fierce resistance to several of the efforts described above, with the development of "preventative self-defense" having been effectively blocked,[220] and resistance to the entrenchment of the "unwilling or unable" doctrine still ongoing.[221] But pressure to relax the jus ad bellum regime is likely to extend in another direction as well, in the form of calls for a new exception to the prohibition on the use of force altogether. The framework and rationale for such

220. Ruys, *supra* note 193, at 321–23 ("[P]ut briefly, international lawyers agree virtually unanimously that preventative self-defence patently lacks any basis in international law.").

221. *See* Martin, *"Unwilling or Unable," supra* note 219; Brunnée & Toope, *supra* note 219.

an exception would likely be modeled on relatively recent arguments in favor of an exception to permit unilateral "humanitarian intervention."[222] The theoretical foundation for humanitarian intervention was developed in the "responsibility to protect" doctrine, which suggests that a state abdicates some of its sovereign rights against intervention if it commits or permits the gross violation of human rights within its territory.[223] According to this rationale, force is further justified because allowing such harm to go unchecked risks creating instability and violence that will spill across borders and threaten international peace and security.[224] There have been strong arguments that a new principle of customary international law is emerging that recognizes unilateral humanitarian intervention as a third exception to the prohibition on the use of force.[225] While this exception has not yet been recognized, support for it is very much a part of the current discourse on the jus ad bellum.

We may anticipate efforts to similarly develop a distinct exception for the use of force in response to the threats posed by unilateral SAI efforts. One of us has written on the possible future development of arguments to permit the use of force against so-called "climate rogue states" in response to the ever-worsening consequences of the climate change crisis, with such an "atmospheric intervention" being developed as an exception similar to humanitarian intervention.[226] Similar arguments could be expected for responding to the threat of unilateral SAI efforts, modeled on those of humanitarian intervention. If unilateral intervention against a state might be permitted to prevent it from harming people within its own territory, then surely there is even greater justification for armed intervention against a state attempting to modify the atmosphere to prevent it from harming vast swaths of humanity in other regions of the

222. *See, e.g.*, Harold Hongju Koh, *Humanitarian Intervention: Time for Better Law*, 111 AJIL UNBOUND 287 (2017) [hereinafter Koh, *Humanitarian Intervention*]; Christine Gray, *The Use of Force for Humanitarian Purposes*, *in* RESEARCH HANDBOOK ON INTERNATIONAL CONFLICT AND SECURITY LAW 12–14 (Christian Henderson & Nigel White eds., 2013); Sir Nigel Rodley, *Humanitarian Intervention*, *in* THE OXFORD HANDBOOK OF THE USE OF FORCE IN INTERNATIONAL LAW loc. 25299 (Marc Weller ed. 2018) (ebook).

223. *See, e.g.*, R2P REPORT, *supra* note 209; A More Secure World, *supra* note 209; Evans, *supra* note 209.

224. *See supra* note 209 and accompanying text.

225. *See, e.g.*, Koh, *Humanitarian Intervention*, *supra* note 222; Louis Henkin, *Kosovo and the Law of "Humanitarian Intervention"*, 93 AM. J. INT'L L. 824 (1999).

226. Martin, *Atmospheric Intervention*, *supra* note 21, at 396–99.

world—or so the argument would go.[227] What is more, such arguments will be advanced with far greater vigor and passion than those in support of humanitarian intervention—the rationale for humanitarian intervention is driven by a mixture of altruism and abstract principles, while claims for atmospheric intervention to prevent unilateral SAI efforts will be driven by naked self-interest and mounting internal pressure arising from public fear.

* * *

In sum, governments already quite clearly and explicitly view the consequences of climate change as a threat to both national security and to international peace and security. Thus, some governments would similarly view the risk of harm posed by unilateral SAI efforts as a threat to their security. Without sufficiently institutionalized and enforceable international law and policy constraints to prevent such unilateral SAI activity, there is a considerable risk that states would consider resorting to armed force to do so. Then, the question becomes whether there are sufficient legal constraints to prevent such a unilateral use of force, and thus limit the risk of armed conflict in response to unilateral SAI. This requires assessing whether the jus ad bellum regime would provide such a constraint.

The foregoing analysis suggests that the current jus ad bellum regime would impose only a weak check on such a use of force. Indeed, depending on which states were proposing to undertake the SAI activity and the configuration of political dynamics at the time, the jus ad bellum regime could enable the use of force through a U.N. Security Council authorization, and thereby increase the risk of armed conflict. But even in the more likely event that the U.N. Security Council remained uninvolved, recent history suggests that states would be inclined to engage in a unilateral use of force to address the threat, and advance creative ways to justify that use of force as being compliant with an adjusted and relaxed jus ad bellum regime. In short, the more seriously states view the threat posed by unilateral SAI efforts, the more pressure there will be to relax the constraints on the use of force to permit military action to address the

227. *Id.* It should be noted that, as with the precautionary principle discussed earlier, humanitarian intervention arguments could also be employed in the other direction, to defend unilateral SAI deployment as itself being a form of humanitarian intervention aimed at protecting the populations in regions most vulnerable to rising temperatures. Thanks to Mark Nevitt for this point.

threat. The further weakening of the jus ad bellum regime itself, and the undermining of the international rule of law more generally, would be yet another collateral harm caused by the unilateral SAI effort.

The forgoing analysis explains how attempts to engage in unilateral SAI programs at scale would create a significant risk of armed conflict. In our view, this additional risk significantly strengthens the argument for prudence, and for a much stronger global governance of geoengineering activity. We turn next to discuss what form such governance should take.

IV. Toward Stronger Atmospheric Governance

There is an increasingly widespread recognition of the urgent need for a more robust global governance framework for geoengineering generally, and atmospheric SRM in particular. Aside from the growing body of academic literature across disciplines that echoes this claim,[228] important institutional bodies, including the U.S. Congress[229] and the White House,[230] the IPCC,[231] and UNEP,[232] have also emphasized the growing need for stronger governance. But much of the discussion of geoengineering governance has been broad and diffuse, with differing ideas about what form such governance should take, widely varying notions of what its primary objectives should be—from facilitation and encouragement at one end, to prohibition and constraint at the other—as well as a general failure to distinguish between the different forms of geoengineering, and few concrete proposals.[233] In this Article, we have explained why

228. *See, e.g.*, Reynolds, *supra* note 70; Du, *supra* note 10; Wil C.G. Burns & Andrew L. Strauss, *Introduction: The Emerging Salience of Geoengineering*, *in* Climate Change Geoengineering, *supra* note 73, at 1; Daniel Bodansky, *The Who, What, and Wherefore of Geoengineering Governance*, 121 Climate Change 539 (2013); *What is C2G?*, Carnegie Climate Governance Initiative, https://www.c2g2.net/what-is-c2g/ [https://perma.cc/8YTX-HSZ2] (last visited Nov. 12, 2024).

229. White House SRM Report, *supra* note 6.

230. *Id.*

231. IPCC, *AR-6*, *supra* note 3.

232. UNEP, *One Atmosphere*, *supra* note 6.

233. Burns & Strauss, *supra* note 228; Du, *supra* note 10; Reynolds, *supra* note 70. For discussion of the definitional issues, see Janos Pasztor, former Executive Director of Carnegie Climate Governance Initiative and U.N. Assistant Secretary-General for Climate Change, on *43. Janos Pasztor on Global Climate Policy and Geoengineering*, Challenging Climate (Feb. 6, 2024), https://www.challengingclimate.org/1873533/episodes/14206978-43-janos-pasztor-on-global-climate-policy-and-geoengineering [https://perma.cc/37LB-8S34] [hereinafter *Janos Pasztor*].

there is an urgent need for the establishment of a governance regime that focuses specifically on SAI and is able to regulate and constrain possible unilateral SAI efforts. In this Part, we provide some preliminary ideas on how and in what form such a regime might be established.

A. Form and Substance of an SAI Global Governance Model

Before grappling with the issues relating to geoengineering governance, it is necessary to first clarify what we mean by the concept of "global governance."

1. Defining Global Governance

Global governance has a range of different meanings. It is understood by many international relations scholars to involve an array of transnational mechanisms, including, but not limited to, legal rules, established norms, and formal inter-state institutions, together with other processes and systems, many of which are not centered in states, and all of which operate in combination to influence and shape the behavior of state and non-state actors.[234] A central theme running through these approaches is the importance of non-state actors, and both formal and informal transnational relationships operating at various levels among both states and non-state actors.[235] This transnational and multi-level perspective may be a far more sophisticated model for understanding the actual behavior-shaping dynamics of relations among states and non-state actors within the international system, and may be helpful in developing the optimal design for certain forms of governance structures. It differs from the "old governance model," which is a more centralized, top-down, state-centric,

234. *See* Weiss, *supra* note 10; *see also* David Kennedy, *The Mystery of Global Governance*, 34 OHIO N.U. L. REV. 827 (2008); Dingwerth & Pattberg, *supra* note 89; Thomas Weiss & Rorden Wilkenson, *International Organization and Global Governance in a Turbulent World*, *in* INTERNATIONAL ORGANIZATION AND GLOBAL GOVERNANCE (Thomas Weiss & Rorden Wilkenson eds., 3d ed. 2023); Chiara Armeni, *Global Experimentalist Governance, International Law and Climate Change Technologies*, 64 INT'L & COMPAR. L.Q. 875, 878 (2015). This international relations perspective would appear to have much in common with theories of international law compliance, such as Harold Koh's transnational process theory. *See* Harold Hongju Koh, *Why Do Nations Obey International Law?*, 106 YALE L.J. 2599 (1997); *see also* Anne-Marie Slaughter, *International Law in a World of Liberal States*, 6 EUR. J. INT'L L. 503 (1995).

235. *See* Rafael Duarte Villa & Haroldo Ramanzini Junior, *Crisis and Changes in International Governance in the Dawn of the 21st Century: Rethinking the Spheres of International Politics*, 64 REV. BRASILEIRA DE POLÍTICA INTERNACIONAL 1 (2021).

and formalized legal structure.[236] For reasons we develop further below, we are of the view that the form of governance required to address the risk of unilateral SAI activity in the short term aligns with the "old governance model," with a legally binding agreement and a formal institutional framework to oversee implementation and enforcement. It is in this sense that we use the term "global governance."

Regardless of approach, there are important ideas about the necessary components of any effective and legitimate form of governance, or what are often referred to as the essential elements of "good governance."[237] Many of these elements or characteristics overlap in important ways. The fundamental starting point is legitimacy: meaning that the governance framework and institutional structure must be perceived to be legitimate by states and other stakeholders.[238] This, in turn, depends on several of the other fundamental characteristics of good governance, such as: (i) transparency in the institutional decision-making and other processes, as well as clear lines of accountability; (ii) fair and adequate representation of, and participation by, the affected stakeholders, which should involve an element of inclusiveness for minority groups and the more vulnerable stakeholders; and (iii) adherence to principles of equity and fairness in decision-making that results in the equitable distribution of benefits and burdens that accounts for marginalized and vulnerable stakeholders. Rounding out these features is the idea that good governance should not only be founded upon the international rule of law, but it should operate in a manner that strengthens the rule of law.[239] These features of good governance must inform any proposal for a global governance structure for SAI.

2. The Features of a Global Governance Model for SAI

As previously discussed, the idea of an overarching governance structure for all forms of geoengineering is not helpful, because the underlying assumptions and specific concerns of a governance structure designed to constrain unilateral SAI deployment will differ from those grounding

236. *See* John Gerard Ruggie, *Global Governance and "New Governance Theory": Lessons from Business and Human Rights*, 20 GLOB. GOVERNANCE 5 (2014).

237. *See, e.g.*, Ngaire Woods, *Good Governance in International Organizations*, 5 GLOB. GOVERNANCE 39 (1999).

238. *See generally* Sebastian Oberthür et al., *A Sectoral Perspective on Global Governance: Analytical Foundation*, EARTH SYS. GOVERNANCE, June 2021, at 1; Weiss & Wilkenson, *supra* note 234; KLABBERS, *supra* note 89.

239. *See, e.g.*, Woods, *supra* note 237; Weiss & Wilkenson, *supra* note 234.

the governance of other forms of geoengineering.[240] Thus, we argue that it is necessary to establish a global governance framework specifically for the purpose of constraining and controlling all SAI development efforts, including overseeing any large-scale experimental atmospheric deployment, and even more particularly, prohibiting any unilateral efforts to deploy SAI. The form, functions, and structure of this framework will be determined by this objective, with unilateral SAI deployment being the core behavior that is to be governed and constrained. A state-centric, top-down, legally-binding agreement with a formal institutional structure to oversee implementation and possible enforcement, and to provide a forum for formal collective decision-making, will be best suited to achieve these objectives. Only such an approach will effectively address the risks associated with unilateral action, whether it be by states or non-state actors who are subject to the jurisdiction of state parties to the treaty. This is, after all, how the international community tends to approach the governance of other serious global threats, such as nuclear proliferation and the development of other weapons of mass destruction,[241] and even environmental threats such as harm to the ozone layer.[242]

At the same time, developing such a governance structure requires a multilateral effort, including at least those states that have the resources and technical capability of engaging in SAI at some scale, but ideally also those states that are most likely to suffer the worst adverse impacts of any such effort. It could conceivably begin as a "mini-lateral" effort involving a subset of those states, along the lines illustrated by the development of the *Montreal Protocol* (discussed further below), the *Partial Test Ban Treaty* ("PTBT"), and several other mini-lateral efforts that grew into broader multilateral legal regimes.[243] But the aim should be to develop a true

240. Rayner et al., *supra* note 89; Du, *supra* note 10, at 95–96; *Janos Pasztor*, *supra* note 233.

241. For discussion of the Nuclear Non-Proliferation Treaty, see *infra* note 247 and accompanying text; Michael Bothe, *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction*, U.N. Audiovisual Libr. Int'l L. (Sept. 3, 1992), https://legal.un.org/avl/ha/cpdpsucw/cpdpsucw.html [https://perma.cc/PG9C-RC2L]. *See also* Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction, Oct. 10, 1980, 1975 U.N.T.S. 45.

242. For discussion of the Montreal Protocol, see *infra* Part IV.B.1.

243. *See* Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, Aug. 5, 1963, 14 U.S.T. 1313, 480 U.N.T.S. 43 [hereinafter PTBT]; Montreal Protocol, *supra* note 62.

multilateral regime that is not only structured to impose constraints on state parties but also incorporates the key features of good governance discussed above—namely: legitimacy, accountability, transparency, representativeness and inclusion, equity and fairness, and adherence to the rule of law.[244] Indeed, as much of the literature on global governance suggests, these mutually reinforcing features are essential to the effectiveness of any governance regime over time.[245]

The concrete details of what this multilateral agreement would look like will be the product of negotiation and thus subject to myriad variables and compromises as it takes shape. It would not be fruitful to make overly detailed substantive proposals in this Article. But we do suggest some features that we think would be important for such a multilateral SAI agreement. As mentioned, the object and purpose of the treaty should be to govern the development and possible deployment of SAI efforts, establish a collective decision-making process for approving any such deployment, and prohibit any unilateral deployment. To achieve these objectives, it should establish or designate an institutional body to engage in a range of functions, including: monitoring and reporting of SAI-related activity of states; sharing information among the state parties on research and development; establishing more detailed guidelines regarding experimentation; and developing mechanisms for implementation of the regime created by the treaty. In this manner it would resemble the governance structures provided by the *Nuclear Non-Proliferation Treaty* ("NPT") and the International Atomic Energy Agency ("IAEA").[246] Related to this, the treaty should provide for a broad-based decision-making process for approving any deployment of SAI, including for any atmospheric experimentation above some threshold scale.

Similarly, there are some core substantive principles and rules to consider at the outset of the negotiation process for establishing this structure. First and foremost, a core provision would be the prohibition of any deployment without the requisite approval, much like the prohibition of nuclear proliferation in the NPT,[247] or the limitations on nuclear testing

244. *See supra* text associated with notes 235–38.

245. *See supra* authorities in notes 235–36, 238.

246. Treaty on the Non-Proliferation of Nuclear Weapons, July 7, 1968, 729 U.N.T.S. 161 [hereinafter NPT]; *see also The IAEA and the Non-Proliferation Treaty*, Int'l Atomic Energy Agency, https://www.iaea.org/topics/non-proliferation-treaty [https://perma.cc/W7CA-YM43] (last visited Nov. 12, 2024).

247. NPT, *supra* note 246.

under the nuclear weapons test ban treaties.[248] Ideally, there should be provisions regarding the monitoring for such unauthorized deployment, together with dispute resolution and enforcement provisions in the event of non-compliance.[249] It would also be helpful to incorporate a number of the rules and principles of international law discussed in Part II, codifying or crystallizing their application in the context of SAI deployment. These include the no-harm principle, the principles of cooperation and precaution, as well as the principles and guidelines developed by the ILC, particularly the ILC *Guidelines on the Protection of the Atmosphere*. Aside from reinforcing the specific obligations for the parties to the treaty, this move could further advance the process of crystallizing these as principles of customary international law, restraining even those states not yet party to the treaty.[250] What is more, these customary international law principles as well as the ILC principles and guidelines discussed above all impose obligations on states to regulate the actions of private actors, such as the corporate ventures that were discussed earlier.[251] In similar fashion, the treaty regime should require state parties to monitor for and prohibit any actions of non-state actors within their territory or under their jurisdiction from engaging in any conduct that the state party itself is prohibited from undertaking. Thus, the reach of the regime would extend to constrain the potential actions of non-state actors.

The foregoing provides just a broad-brush sketch of some of the key features for a possible framework for the governance of SAI. But how is such a model to be brought into existence? How realistic might such a proposal be, given the grave nature of the risk and the urgent need for rapid response on the one hand, and on the other hand, the enormous difficulty of coordinating collective action, and the time typically required to negotiate this kind of multilateral agreement and establish the supporting institutional framework? Added to this is the difficulty of standing up a new structure that incorporates and reflects the essential features of good governance, particularly the crucial feature of legitimacy. While a potentially daunting challenge, it is made more plausible

248. PTBT, *supra* note 243; *see also* Comprehensive Nuclear-Test-Ban Treaty, Sept. 10, 1996, A/50/1027 [hereinafter CTBT].

249. *See, e.g.*, Du, *supra* note 10; Rayner et al., *supra* note 89.

250. On this process of crystallization of custom, see North Sea Continental Shelf Cases (Ger. v. Den.; Ger. v. Neth.), 1969 I.C.J. Rep. 3 (Feb. 20); Shaw, *supra* note 139, at loc. 7151.

251. *See supra* text associated with, and authority in, notes 6 and 80.

because there are two institutional structures already in place that could help catalyze the process, providing the fora for initial proposals, analysis, negotiations, and even implementation. We turn to examine these next.

B. Institutional Origins for an SAI Governance Model

In thinking about the development of this kind of governance model, a review of how international environmental law regimes have evolved over time may provide some insights. First, there is the way in which the form and structure of treaties have been modeled on prior treaty regimes dealing with tangential issues. Second, there is the manner in which some of the most successful binding multilateral agreements have emerged as more specific protocols negotiated under the umbrella of initial broad framework agreements.

One example of modeling is illustrated by the negotiations of the *Montreal Protocol*, and in particular, some of its specific market and enforcement mechanisms which were heavily influenced by the 1985 *Helsinki Protocol* on sulfur dioxide emissions.[252] Another example is the *Kyoto Protocol to the United Nations Framework Convention on Climate Change* ("*Kyoto Protocol*"), which was in turn modeled on the *Montreal Protocol*.[253] Turning to examples of the second phenomenon of more specific protocols emerging from broad framework agreements, the *Helsinki Protocol* emerged from the *UNECE Convention on Long-Range Transboundary Pollution*;[254] and as will be discussed in more detail below, the *Montreal Protocol* emerged from the *Vienna Convention on the Protection of the Ozone*. Similarly, both the *Kyoto Protocol* and the *Paris Agreement* were established as protocols under the UNFCCC. In keeping with this pattern, an SAI governance structure, including the multilateral agreement discussed above, could be both modeled on successful related regimes, and developed as a specific protocol under the umbrella of either the *Montreal Protocol* or the

252. Montreal Protocol, *supra* note 62; Helsinki Protocol, *supra* note 136. For more history of the Montreal Protocol, see, for example, Barratt-Brown, *supra* note 62, and Richard Benedick, *Montreal Protocol on Substances that Deplete the Ozone Layer*, 1 INT'L NEGOT. 231 (1996).

253. Kyoto Protocol to the United Nations Framework Convention on Climate Change, Dec. 11, 1997, 2303 U.N.T.S. 162 [hereinafter Kyoto Protocol]; *see* Bryan A. Green, *Lessons from the Montreal Protocol: Guidance for the Next International Climate Change Agreement*, 39 ENV'T. L. 253 (2009).

254. Convention on Long-Range Transboundary Air Pollution, Nov. 13, 1979, 1302 U.N.T.S. 217.

UNFCCC itself—a process that would be far more expeditious than starting from scratch.

1. The Montreal Protocol

As discussed earlier, the *Montreal Protocol* was adopted in 1987 to establish legally binding obligations to govern the phasing out of substances that were harming the ozone.[255] At the time of its adoption, there were only twenty-four original signatories, but by 2009, all member states of the United Nations had acceded to the treaty. The *Montreal Protocol* has been extremely successful in mobilizing compliance with its provisions requiring the phase out of ozone-depleting substances. It has a secretariat that oversees data reporting and monitors the compliance of state parties to the treaty. The secretariat includes institutional bodies that provide support for capacity building and financial incentives, as well as an implementation committee that reviews cases of non-compliance.[256]

It also provides an institutional framework, which includes an Open-Ended Working Group, within which further amendments and protocols can be negotiated. This process was illustrated by the successful negotiation of the *Kigali Amendment* to the *Montreal Protocol* between 2009 and 2016.[257] That process began with a proposal by the Federated States of Micronesia and Mauritius to amend the *Montreal Protocol* to regulate hydrofluorocarbons ("HFCs"), which, while related to chlorofluorocarbons, do not actually affect the ozone, but are highly potent GHGs. The Open-Ended Working Group is comprised of not only state-parties and the secretariat but also representatives from U.N. agencies such as UNEP, environmental groups, and even industry representatives. It began deliberations in 2009 on possible amendments to incorporate a phase-down of HFCs as part of the *Montreal Protocol*. By 2011, a meeting of the parties ("MOP") established a contact group to begin the process of analysis and preliminary discussions. It continued work over the next four years, and by 2015, proposals were developed for final negotiations, which resulted in a final text that was adopted in 2016. The implementation committee and the MOP to the *Montreal Protocol* provide oversight of compliance

255. *See supra* Part II.A.4.

256. *See* Barratt-Brown, *supra* note 62; Benedick, *supra* note 252; Green, *supra* note 253.

257. Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, Oct. 15, 2016, C.N.730.2017. Treaties-XXVII.2.f [hereinafter Kigali Amendment].

with *Kigali Amendment* commitments and financial assistance to parties in finding HFC alternatives.[258]

The *Kigali Amendment* serves as a clear illustration of one path available for quickly developing an SAI governance model within the *Montreal Protocol* itself. The form of multilateral agreement discussed above could be proposed within the *Montreal Protocol* process as a possible amendment to the *Protocol*. As discussed in Part I, sulfate-based SAI efforts would have harmful effects on the ozone, and thus a proposal to govern such SAI efforts would be within the scope of the *Montreal Protocol*. Furthermore, the *Kigali Amendment* provides a precedent for the state parties negotiating amendments to extend the *Protocol* beyond its original object and purpose to regulate emissions that are unrelated to depleting the ozone layer but are nevertheless crucial for responding to climate change. An amendment to the *Montreal Protocol* to govern SAI deployment would be entirely consistent with this precedent. Finally, if such an agreement were to be adopted as an amendment, the institutional apparatus of the *Montreal Protocol* could be easily adjusted and supplemented to serve as the institutional framework for implementing and overseeing the SAI governance amendment. As illustrated by the speed with which the *Kigali Amendment* was developed, this avenue for developing an SAI governance structure could provide an expeditious avenue for meeting the risk posed by unilateral SAI deployment.

2. The UNFCCC

Another possible avenue would be to have the issue taken up by the Conference of the Parties ("COP") to the UNFCCC, with the goal of developing an SAI governance regime under the umbrella of the UNFCCC. Some argue that the governance of SAI is outside the scope of the UNFCCC.[259] But as explained in Part II, governing SAI arguably prevents "dangerous anthropogenic interference in the climate system," one of the explicit objectives of the UNFCCC; and to the extent that pursuing an SAI effort may detract from or undermine mitigation of GHG

258. Eric A. Heath, *Introductory Note to Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (Kigali Amendment)*, 56 INT'L LEGAL MATERIALS 193 (2017); *see also* MAYER, *supra* note 131, at 54–55, 120–21.

259. *See, e.g.*, DU, *supra* note 10, at 174 (though, again, this is on the assumption that the purpose of the SRM governance would be for facilitating SRM research and deployment).

emissions, it would certainly implicate the core objects and purposes of the UNFCCC.[260]

The idea behind using the UNFCCC as an institutional forum and framework for conducting negotiations on an SAI governance model is similar to the above discussion regarding the *Montreal Protocol*—it has the institutional structure well suited for negotiating such a treaty. As will be familiar to most readers, the COP is the primary decision-making body that meets annually. It is supported by a secretariat and a number of subsidiary bodies, the key ones for our purposes being the Subsidiary Body for Scientific and Technological Advice ("SBSTA") and the Subsidiary Body for Implementation ("SBI"). Both of these provide technical information, analysis, assessments, and advice to the COP, and as the names imply, also assist with implementation and compliance.[261] What is more, the COP is supported by specific ad hoc working groups for purposes of facilitating and managing focused negotiations, such as the Technology Executive Committee, and the Ad Hoc Working Group on the Durban Platform for Enhanced Action ("ADP"), in the case of the *Paris Agreement*.[262] The ADP, for instance, played a crucial role in the negotiation of the *Paris Agreement*.[263] Additionally, various entities within the UNFCCC institutional apparatus work closely with other international organizations, such as the World Meteorological Organization, UNEP, and IPCC. The SBSTA and SBI in particular received input from all of these organizations during the development of the *Paris Agreement*.[264] Finally, the *Kyoto Protocol* and the *Paris Agreement* have their own institutional structures and implementing entities, such as

260. See *supra* Part II.A.1 for discussion.

261. UNFCCC, *supra* note 25, arts. 8, 9, 10; *see also Subsidiary Body for Implementation (SBI)*, U.N. Climate Change, https://unfccc.int/process/bodies/subsidiary-bodies/sbi [https://perma.cc/9SZK-9WB8] (last visited Nov. 10, 2024). For more on the role of the SBSTA and SBI within the UNFCCC, see, for example, Bodansky et al., *supra* note 26, at 141–48; and *Governing and Subsidiary Bodies*, U.N. Climate Change, https://unfccc.int/process-and-meetings/bodies/governing-and-subsidiary-bodies [https://perma.cc/V6PE-2NNE] (last visited Nov. 10, 2024).

262. *Technology Executive Committee: Strengthening Climate Technology Policies*, TT:CLEAR, https://unfccc.int/ttclear/tec [https://perma.cc/AL4P-3DSE] (last visited Nov. 10, 2024). On the role of the ADP, see, for example, Bodansky et al., *supra* note 26, at 113–15.

263. Ad Hoc Working Group on the Durban Platform for Enhanced Action, Draft Paris Outcome, U.N. Doc. FCCC/ADP/2015/L.6/Rev.1 (Dec. 5, 2015).

264. Du, *supra* note 10, at 173–74.

technology and capacity building committees. But these institutional structures and entities were outgrowths of, and continue to be supported by, the entire apparatus of the UNFCCC.[265] These precedents provide possible models for how an SAI governance agreement could be relatively quickly developed and supported within the framework of the UNFCCC.

3. Conclusion on Montreal and UNFCCC

The primary advantages of proceeding under the umbrella of either the *Montreal Protocol* or the UNFCCC are speed and effectiveness. Both provide an institutional apparatus in which proposals can be initiated, analyzed, and moved quickly towards serious negotiation with extensive bureaucratic and technical support. But another powerful advantage of working through either of these fora is that they would both help ensure the incorporation and realization of most of the essential features of good governance discussed above.[266] Both the *Montreal Protocol* MOP and the UNFCCC COP represent all the member states of the United Nations, ensuring maximum representation and inclusivity.[267] Transparency and accountability in the negotiating process are built into both structures and would likely be similarly entrenched in any agreement developed within these frameworks. The principle of CBDR is of course explicitly part of the UNFCCC legal framework, but fairness and equity are similarly reflected in the *Montreal Protocol.* Thus, negotiations under either would be predisposed to incorporate and reflect these principles in the resulting governance model. All of this would lead to the most crucial feature for any governance model, which is legitimacy.

One of the primary drawbacks to proceeding within either the *Montreal Protocol* or the UNFCCC is that both structures operate by consensus, which makes collective action and agreement more difficult. This does pose challenges, though it is not as daunting as it might seem at first blush. Under their consensus model, not every state party must sign on to every resulting agreement—rather, no agreement can be reached

265. BODANSKY ET AL., *supra* note 26, at 200–01, 246–47; MAYER, *supra* note 131, at 134–35, 139–40.

266. *See supra* notes 234–36 and accompanying text.

267. For parties to each treaty, see *Multilateral Treaties Deposited with the Secretary-General*, U.N. TREATY COLLECTION, https://treaties.un.org/Pages/ParticipationStatus.aspx?clang=_en [https://perma.cc/SQ28-W9UB] (last visited Nov. 11, 2024).

over the explicit objection of any one state party.[268] The distinction is important. To illustrate, several states did not ratify the *Kyoto Protocol* (including, famously, the United States), but it was nonetheless developed under the UNFCCC and opened for adoption without objection from any states. However, it does mean that compromise is necessary, and certain provisions and positions may be seriously diluted to overcome the objections of any hold-out states. This was reflected, for example, in the negotiation of the *Kigali Amendment*, where late changes had to be made to stave off India's objection.[269] While this consensus requirement does pose a challenge to the expeditious negotiation and adoption of new instruments, it is yet another feature that ensures broad buy-in and legitimacy for any resulting agreement.

Of course, while this would be a multilateral effort, as a practical matter a more limited set of states would likely play a central role in the negotiations. This group would likely include the United States, China, Russia, India, Japan, Brazil, and the major European nations, as well as the European Union as a bloc. Of these, the relationships between the United States, China, and Russia will likely pose the biggest political problems.[270] Russia has on occasion indicated support for SRM.[271] On the other hand, what little literature exists suggests that China's scientific and policy communities are currently skeptical of geoengineering.[272] In general, Chinese commentators have emphasized the potential risks related to geoengineering and the necessity of addressing climate change through existing multilateral agreements, notably the *Paris Agreement*.

268. *See, e.g.*, Antonio La Vina & Cecilia Guiao, *Building Consensus in the UNFCCC*, Climate & Dev. Knowledge Network 1 (2013), https://cdkn.org/sites/default/files/files/Background-Paper-Tony-La-Vina-Consensus-building-in-the-UNFCCC.pdf [https://perma.cc/7455-ZD6P]; Leonardo Massai, *Dealing with "Consensus" at the UN Climate Talks*, Climalia, http://www.climalia.eu/dealing-consensus-un-climate-talks/ [https://perma.cc/YH2M-F69V] (last visited Nov. 12, 2024).

269. *See, e.g.*, Lynn L. Bergeson, *The Montreal Protocol Is Amended and Strengthened*, 26 Env't Quality Mgmt. 137 (2017).

270. *See*, Patrick, *supra* note 187.

271. *See, e.g.*, Martin Lukacs et al., *Russia Urges UN Climate Report to Include Geoengineering*, The Guardian (Sept. 19, 2013); Jonathan Oldfield & Marianna Pobereshkaya, *Soviet and Russian Perspectives on Geoengineering and Climate Management*, 14 WIREs Climate Change 829 (2023).

272. Bettina Bluemling et al., *Seeding the Clouds to Reach the Sky: Will China's Weather Modification Practices Support the Legitimization of Climate Engineering?*, 49 Ambio 365 (2020).

This suggests, albeit circumstantially, that China may be receptive to an effort to strengthen governance of SAI under the aegis of the UNFCCC and other existing international agreements pertaining to climate change.[273] At least one commentator, moreover, has proposed that geoengineering represents a promising area for expanded U.S.-China cooperation on climate change.[274] It may be that as with the negotiation of the *Paris Agreement*, a U.S.-China bilateral agreement on how to constrain SAI could serve as a crucial aspect of a successful development of an SAI governance model.

Conclusion

Climate change is a so-called "wicked problem,"[275] and the international community is struggling to cooperate in addressing the root causes of the problem. We are not on track to meet GHG emission targets, and thus we are going to overshoot the temperature goals for the end of the century. The world is going to experience temperature increases that will create escalating pressure on governments to do something to deal with the extreme heat. While SAI does nothing to address the actual causes of climate change, it could feasibly, cheaply, and effectively moderate global temperatures. But it poses significant risks of harm to the climate, the environment, biodiversity, and indirectly to socio-political stability, and it would distribute these harms unevenly. Some argue that the risk posed by failing to act to address the increasing heat outweighs the risks associated with undertaking SAI as an interim measure. Even as this debate proceeds, there is a growing and very real risk of unilateral action on the part of states that are most vulnerable to temperature increases. While climate change is a collective action problem that incentivizes free-rider behavior and inaction on the part of individual states, SAI in contrast

273. Scott Moore & Eyck Freymann, *China Doesn't Want a Geoengineering Disaster*, Foreign Pol'y (Feb. 21, 2023), https://foreignpolicy.com/2023/02/21/china-geoengineering-rules-climate-change/ [https://perma.cc/84RA-7MUU].

274. Patrick, *supra* note 187.

275. So-called "wicked problems" are complex social issues that are inherently difficult to resolve due to the complex interconnected nature of the variables implicated, including multiple stakeholders with differing interests and perspectives. The term was first coined and explained in Horst Rittel & Melvin Webber, *Dilemmas in a General Theory of Planning*, 4 Pol'y Scis. 155 (1973). For recent discussion, see Brian Head, Wicked Problems of Public Policy: Understanding and Responding to Complex Challenges (2022).

creates a free-driver problem that incentivizes unilateral action. Yet there is no global governance structure in place to regulate or constrain such action. As we have explained, a mix of tangentially related treaties and customary international law principles might operate to impose liability for harm caused by unilateral action, but it is not likely to operate to effectively constrain it ex ante.

What is not sufficiently developed and understood in the debates and discourse around the possibilities of SAI, and particularly the risks posed by unilateral SAI deployment, is the distinct and additional risk that it could give rise to armed conflict. There is the very real prospect that unilateral implementation of an SAI program would be viewed as a threat to the national security of objecting states, triggering a use of force in response to prevent or terminate the SAI deployment. A second international law regime, the jus ad bellum regime, would be the legal regime expected to constrain such a use of force, but the experience of the last few decades, and particularly the responses to new threats such as nuclear proliferation, transnational terrorism, cyber operations, and humanitarian crises, suggests that states would seek to relax the constraints of the jus ad bellum regime, reinterpret its limits, or simply ignore it altogether if the threat was perceived to be sufficiently grave. In short, one international law regime would fail to constrain unilateral SAI deployment, the threat of which could prompt other states to consider armed force in response, and a second international law regime would in turn be unlikely to constrain such unilateral uses of force—and thus, unilateral SAI poses the risk of armed conflict.

This distinct risk of armed conflict adds to the arguments in favor of a global governance regime established separate and apart from governance developed for other forms of geoengineering, specifically for the purposes of regulating SAI, and more particularly for constraining any unilateral SAI programs. The massive indirect costs and externalities associated with SAI, including so many potentially irreversible harms, unintended consequences, and how the harms are likely to be unevenly distributed among the peoples of the world, all provide reason enough to argue that there is an urgent need for a robust governance structure in place to shape the appropriate decision-making process regarding the experimentation, development, and any final deployment of SAI efforts. And the additional risks associated with unilateral SAI efforts, and particularly the risk of armed conflict, require a specific governance structure that

has as its object the strict regulation of any development of SAI and the prohibition of any unilateral action.

This governance structure should be in the form of a multilateral treaty, but shaped by the principles of good governance, and modeled on other treaty regimes such as the NPT. The *Montreal Protocol* and the UNFCCC regimes have the related subject-matter expertise, support, and institutional structures that could make either of them an ideal forum within which to develop such a regime expeditiously, and with the requisite legitimacy. In our view, the overlooked risk of armed conflicts in response to unilateral SAI efforts makes the need for governance of SAI all the more urgent. As the old saying goes, you may not think you have anything to do with war, but when it comes, it will have everything to do with you.