The Alliance for Just Deliberation on Solar Geoengineering

Forum for Climate Engineering Assessment

The Solar Geoengineering Ecosystem:

Key Actors Across the Landscape of the Field

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1. Introduction

As individuals and organizations start to engage in and learn about solar geoengineering (also known as solar radiation modification - SRM), it is challenging to know where to start. This report, a collaborative effort between The Alliance for Just Deliberation on Solar Geoengineering and the Forum on Climate Engineering Assessment, aims to provide an assessment of the SRM field across different sectors, institutions, and geographies. We hope this can provide a useful foundation for understanding where the SRM ecosystem is and how it might evolve. Recognizing that we cannot hope to capture every actor or activity, we hope to update this report periodically with major updates.

There are numerous overarching sectors, subsectors, and institutions. These sectors inherently overlap in numerous forms and will continue to intersect in new ways as the field evolves. Figure 1 illustrates these overarching sectors, and some examples of current ways different types of institutions interact.

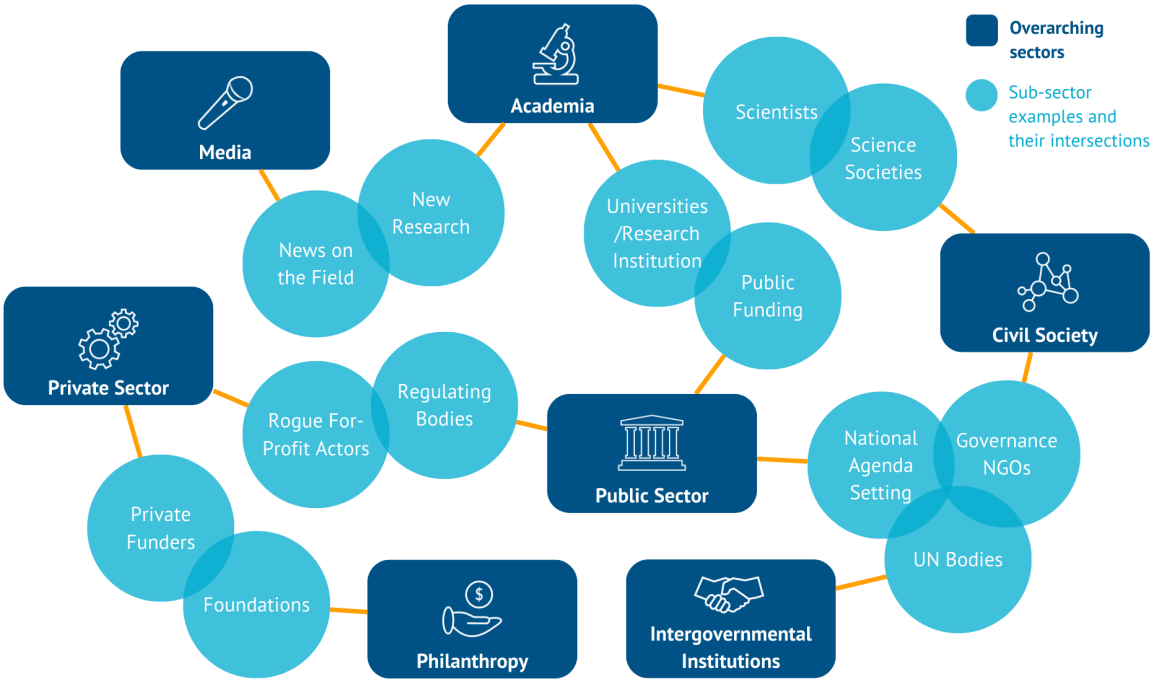

Figure 1 illustrates the overarching sectors in the SRM field, some examples of subsectors and institutions, and the different ways in which they interact with each other. There are many other ways these sectors overlap, and new collaborations or intersections will continue to evolve.

2. The Ecosystem

2.1 United Nations and other major international entities

2.1.1 United Nations Environment Program (UNEP)

In early 2023, UNEP released a report reflecting the findings of an independent, multidisciplinary expert panel convened to assess the current state of SRM science and governance.[1] The panel consisted of nine members across a range of geographies and backgrounds. Among the conclusions of the experts were the following:

- While SRM is not a substitute for mitigation, it "is the only option that could cool the planet within years";
- Deployment of SRM could pose serious risks to human institutions and ecosystems;
- While deployment is not warranted at this point, an international assessment may help us identify potential negative consequences of SRM and to weigh benefits against risks;
- SRM research should be equitable, transparent, and inclusive, including the engagement of stakeholders from the Global South.

UNEP subsequently concurred with the key conclusions of the panel's report, finding that "large-scale or operational deployment" at this time would be "not necessary, viable, prudent or sufficiently safe," while encouraging transparent, inclusive research on SRM options.[2]

2.1.2 United Nations Environment Assembly (UNEA)

The United Nations Environment Assembly, comprised of all member States of the UN, is the highest-level decision-making forum on environmental issues at the global level. It meets every two years and sets priorities for global environmental policy and the progressive development of international law.[3] In 2019, the United States joined Saudi Arabia and Brazil in scuppering a resolution entitled "Geoengineering and Its Governance" submitted by Switzerland (alongside Burkina Faso, Federated States of Micronesia, Georgia, Liechtenstein, Mali, Mexico, Montenegro, Niger, Republic of Korea, and Senegal) at the 4th United Nations Environment Assembly.[4] [5] If passed, the resolution would have requested that the Executive Director of the United Nations Environment Program prepare an assessment of both solar radiation modification and carbon dioxide removal approaches, including the current status of science, potential risks and benefits and governance.[6]

2.1.3 UN High-Level Advisory Board on Effective Multilateralism

In 2022, the UN Secretary General appointed the High-Level Advisory Board on Effective Multilateralism to proffer recommendations on addressing global challenges and to further the Sustainable Development Goals. It culminated in the release of a report this year that included a recommendation for establishment of a forum for the governance of climate-altering technologies.[7]

2.1.4 UN Human Rights Council

At its Forty-Eighth session in 2021, the United Nations Human Rights Council adopted resolution 48/14. The Resolution requested that, *inter alia,* the Advisory Committee of the Human Rights Council conduct a study (in conjunction with the Special Rapporteur on the promotion and protection of human rights in the context of climate change) on "the impact of new technologies for climate protection on the enjoyment of human rights," and prepare a report to be submitted at the Council's Fifty-Fourth Session in September of this year.[8] To date, the Advisory Committee has received inputs from a small number of States, as well as a number of NGOs and academics, many of which address SRM.[9]

A first draft of the prospective report was shared at the Advisory Committee's 29th Session in February 2023, and a subsequent advanced unedited version in August 2023.[10] [11] The final report was submitted to the 54th session in September 2023.[12] The draft report addresses both CDR and SRM approaches. The report includes some pejorative comments about SRM. It states that in contrast to CDR approaches, SRM "introduces a 'mask' to the climate change problem by altering the Earth's radiation budget, rather than attempting to address the root cause of the problem."[13] Moreover, the draft portrays SRM as "ungovernable in the current state of international relations," and cites moral hazard, security, and environmental concerns,[14] Despite these concerns the Committee advocates continued research on SRM, as "the technology presents at the moment the only "plan B" for the planet."[15] However, the draft also emphasizes the obligation of states to develop human rights safeguards, including for approaches that may have transboundary impacts.[16] Further, the report advocates for the need to build better and early governance frameworks: "All the above leads to the conclusion that the deployment of NCTPs today would be contrary to the human rights and environmental framework. Even in the hypothetical scenario that there is no choice but to deploy NTCPs to address climate overshoot, the potential vastness of the adverse impacts and risks make imperative that a strong global rights-based governance framework, be set-up well in advance."

2.1.5 Intergovernmental Panel on Climate Change (IPCC)

The Sixth Assessment Report of the IPCC includes fairly extensive coverage of SRM, including in all three work group reports.[17] The Cross Working Group (CWG) on SRM provides the most comprehensive coverage. The CWG noted that modelling studies have demonstrated the potential of SRM to ameliorate some of the impacts of climate change, including extreme temperature and precipitation extremes, loss of Arctic sea ice, changes in the frequency and intensity of cyclones and decreases in soil moisture.[18] However, the CWG's findings also emphasizes potential risks, including many discussed earlier in this report, including an array of potential threats to ecosystems or human

systems.[19] In the context of governance considerations, the CWG also emphasizes the potential for engendering threats to peace and security due to potential "conflicting temperature preferences" by countries.[20]

2.1.6 The United Nations Educational, Scientific and Cultural Organization

The United Nations Educational, Scientific and Cultural Organization (UNESCO) has started engaging in governance and ethics discussions about SRM over the last few years.[21] In August 2023, UNESCO released a draft version of a report, entitled "World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) on the ethics of climate engineering" for public comment.[22] The draft is subject to further discussion within the Commission before its final adoption. The document states that it "does not necessarily represent the views of the Member States of UNESCO." The report makes recommendations towards robust governance for both research and potential deployment, inclusion in decision-making for civil society and marginalized communities, and capacity building. A final report is expected in late 2023.

2.1.7 World Meteorological Organization

The World Meteorological Organization (WMO) and the United Nation Environment Programme led the 2022 quadrennial report of the Scientific Assessment Panel to the Montreal Protocol on Ozone Depletion, published online in early 2023.[23] Chapter 6 of this report assesses SRM for the first time, entitled "Stratospheric Aerosol Injection and Its Potential Effect on the Stratospheric Ozone Layer." This chapter assesses different SAI impacts under different climate change scenarios and injection strategies, and discusses uncertainties and modeling constraints.

2.1.8 WCRP Climate Intervention Task Team

The World Climate Research Programme (WCRP) Climate Intervention Task Team was established in April-May 2022, with 18 members, to identify current research efforts into SRM (what they call Solar Climate Intervention) across their internal and external landscape, and to determine whether and how WCRP ought to engage with the subject. Further, the team was tasked with determining the value WRCP could add to existing research efforts and identify research gaps the organization could fill, along with identifying partners for international and transdisciplinary research.[24] WCRP "consists of scientists selected by mutual agreement between the three sponsoring organizations (WMO, the International Science Council, and the Intergovernmental Oceanographic Commission of UNESCO) and representing climate-related disciplines in atmospheric, oceanic, hydrological and cryospheric science."[25]

2.1.9 Other

There are other intergovernmental or international organizations that are starting to show interest in this space, including the Inter-American Institute for Global Change Research and the Organisation for Economic Co-operation & Development.[26] [27]

2.2 International Treaty Regimes

2.2.1 London Convention/London Protocol

In the face of increasing concern about ocean iron fertilization experiments, a carbon dioxide removal approach, the Parties to 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention)[28] passed a resolution in 2008 establishing a regulatory framework for the approach.[29] Among the elements of this framework were that such activities should be limited to "scientific research proposals"[30] and subject to a risk assessment framework that the Parties subsequently established in 2010.[31]

Subsequently, the Parties to the London Protocol[32] passed an amendment to the Protocol to regulate "marine geoengineering," defined capaciously enough to encompass some SRM approaches: "deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long lasting or severe."[33]

This amendment, which establishes a regulatory framework similar to that outlined in the 2008 resolution of the Parties to the London Convention, has not gone into effect, having only been accepted by six Parties to the Protocol to date.[34] However in 2022, the Parties to the Convention and Protocol issued a statement intended to exert more control over emerging climate geoengineering approaches with an ocean component. The Parties indicated that two carbon dioxide removal approaches beyond ocean iron fertilization, as well as two solar radiation approaches, marine cloud brightening, and the use of bubbles to make oceans more reflective, should be subject to the regulatory approach established in the London Protocol amendment.[35]

2.2.2 Convention on Biological Diversity

The Parties to the Convention on Biological Diversity[36] have also weighed in on climate geoengineering. In a resolution passed in 2010, the Parties provided that "no climate-related geo-engineering activities that may affect biodiversity take place" until there's an "adequate scientific basis on which to justify such activities and assessment of risks has occurred, with the exception of "small scale scientific studies," and subject to risk assessment.[37] In 2012, the Parties established an extremely broad definition of the term "geoengineering activities" as "any technologies that *deliberately reduce solar insolation* or increase carbon sequestration from the atmosphere on a large scale and that may affect biodiversity."[38]

2.2.3 Montreal Protocol

In the 1985 Montreal Protocol, parties agreed to adopt measures to reduce or prevent human activities that have or are likely to have adverse effects resulting from modification of the ozone layer. SAI inherently falls under such assessment. In 2022, the Scientific Assessment Panel to the Montreal Protocol began to assess SRM for the first time - see section 2.1.7.

2.2.4 Environmental Modification Convention

The Convention on the Prohibition of Military or any other Hostile Use of

Environmental Modification Techniques (ENMOD Convention) is part of international disarmament law, intended to protect the environment in the event of armed conflict.[39] Specifically, "States parties undertake not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to another State party."[40] While SRM may not specifically fall under such intentional environmental modification in the context of limiting harm from climate impacts, it could either be perceived as such if the risks are considered too high, or used with ill-intent.

2.3 Key National Actors

2.3.1 United States

There has been modest support for SRM research in both the Executive Branch and Congress in recent years. In Congress, a series of hearings on SRM were held over 2009-10 by the House Committee on Science and Technology,[41] and further hearings were held in 2017 by the House Committee on Science, Space, and Technology.[42] In 2020, the House Select Committee on the Climate Crisis recommended the establishment of a federal research program on 'atmospheric climate intervention' approaches,[43] but the House did not act.

From 2020-2023, the National Oceanic and Atmospheric Administration (NOAA) has received $22 million for its Earth's Radiation Budget research initiative for stratospheric observational and modeling capabilities, including in the context of marine cloud brightening.[44] Under the 2022 Consolidated Appropriations Act, the Office of Science and Technology Policy (OSTP) is directed to develop an interagency group to manage research and risks associated with "climate intervention." [45] The initiative is to be coordinated with NASA, NOAA, the Department of Energy, and other relevant agencies.

The interagency group was also tasked with establishing a five-year plan for publicly funded work on solar geoengineering research, including considerations of transparency, engagement and risk management.[46] On June 30 of this year, the OSTP released its report.[47] The report is divided into two parts: an initial research governance framework and a research plan. The report notably excludes space-based approaches, on the grounds that they are not deemed feasible in the near term and poses greater governance challenges than atmospheric options).[48]

In an overarching sense, the report employs a "risk vs. risk" framing, i.e., consideration of the potential risks and benefits to human health and well-being relative to "plausible trajectories of ongoing climate change not involving SRM."[49]

Some of the key conclusions of the report are as follows[50]:

- A federal research program could help society engender "a broader basis of trust" about SRM.

- Any research program should encompass "observations, experimentation and modeling." The report also concluded that "outdoor experiments would be valuable."

- A research program should include socio-economic considerations, including cultural, moral, ethical and security considerations;

- Any large-scale federal research program should consider engaging in international cooperation. This may include partners with particular expertise in pertinent aspects of SRM, financial capacity, and access to particular ecosystems, as well as countries with limited capacity or opportunities to engage in such research;

- Large-scale federal multi-agency research on SRM should be coordinated by the United States Global Change Research Program.

It should be noted, however, that the White House did not expressly endorse a full-scale SRM research program, noting that it was fulfilling a mandate by Congress to prepare this report.[51] Also, it emphasized in a statement accompanying the report that "there are no plans underway to establish a comprehensive research program focused on solar radiation modification."[52] Moreover, there doesn't appear to be a lot of appetite in Congress for SRM research thus far, outside of a few dedicated advocates.[53]

In March of this year, NOAA announced that it had launched SABRE, a project designed "to provide baseline observations of the stratosphere and other elements of Earth's climate system to inform evaluations of potential future efforts to slow global warming by modifying the amount of heat captured by the atmosphere." The project is employing a converted bomber to facilitate this research over the Arctic.[54] Particularly pertinent to SRM will be the use of instrumentation to gather granular measurements of aerosols and trace gasses in any area of the atmosphere that has not been extensively sampled.[55]

A consortium of researchers from the University of Washington's Atmospheric Intervention Research Program, Pacific Northwest National Laboratory and the Palo Alto Research Center coordinate the Marine Cloud Brightening Project.[56] The project seeks to, *inter alia,* analyze cloud-aerosol data to inform the development of aerosol-cloud interaction models, develop spray technologies to increase brightness of low-lying clouds, and conduct small-scale field experiments.[57]

In 2021, the National Academy for Sciences, Engineering & Medicine (NASEM) published a consensus study report, setting forth recommendations for research and governance of SRM approaches.[58] This report followed from previous publications by NASEM on climate geoengineering, including a chapter in a 1992 book on climate policy,[59] and two 2015 climate intervention reports on SRM and CDR.[60]

Among the conclusions of the report, which excluded space-based options, were the following[61]:

- A transdisciplinary research program, with a budget of $100-200 million over five years (centered in the United States) can help to reduce uncertainties in both the scientific and social context;

- The research program should include "exit" ramps for terminating a research program if an discrete option is deemed ineffective, or posing unacceptable risks;

- Limited outdoor experimentation should ensue, but only if "small enough to limit impacts;"

- The research program should include allocations for governance and public engagement.

The intelligence community in the U.S. has also been modestly engaged in SRM. The Central Intelligence Agency was a requester and sponsor of the 2015 NASEM report on SRM.[62] Additionally, in March 2021, the Office of the Director of National Intelligence included geoengineering in their Global Trends 2040 report.[63] This report found it increasingly likely that "states and nonstate actors will more aggressively research, test, and possibly deploy geoengineering measures." Finally, the National Intelligence Estimate, a report requested under Executive Order in January 2021 to assess the "national and economic security impacts of climate change" was published in October 2021.[64] The report, "Climate Change and International Responses Increasing Challenges to US National Security Through 2040," stated as a Key Judgement that there is a "growing risk of conflict over water and migration, particularly after 2030, and an increasing chance that countries will unilaterally test and deploy large-scale solar geoengineering—creating a new area of disputes. They further state that there is a growing risk of unilateral testing and possible deployment of large scale SRM.[65]

2.3.2 China

The Chinese government conducted an SRM research program between 2015-2019.[66] The approximately $2 million program was funded by the Ministry of Science and Technology, employing 15 faculty members and 40 students across three institutions.[67] The program explicitly eschewed development of SRM technologies or outdoor experiments, focusing on policy and governance issues and potential impacts of deployment of SRM approaches.[68] Funding for these programs allegedly continued after this point also, but there's very few details.[69]

2.3.3 Europe

The Stratospheric Particle Injection for Climate Engineering (SPICE) program was a UK-based SRM project launched in 2010 and funded by the universities of Bristol, Cambridge, Oxford and Edinburgh.[70] It was funded for 3.5 years by a number of UK research entities. The project's overarching purposes were to assess the interaction of heat and light radiation with aerosol particles, optimal delivery systems for particle dispersion in the stratosphere, and modeling of the implications of particle releases with contemplated delivery systems.[71] However, the project was upended in advance of an outdoor experiment to inject water into the atmosphere with a weather balloon when it was discovered that two scientists associated with the project had not revealed patents for technologies similar to those to be used in the experiment.[72] They also received significant pushback from a subset of NGOs.[73]

In 2022, the Commission established a funding opportunity for SRM under the rubric of Climate sciences and responses program of the EU's Horizon Europe Framework Programme.[74] Ninety-seven proposals were submitted, and Commission decisions are expected in July 2023.[75] Previously, two other projects that discuss SRM in detail have been funded by the EU's Horizon 2020 research programme - Ethics for Technologies with High Socio-Economic Impact and GeoEngineering and Negative Emissions Pathways in Europe.[76] [77]

In June 2023, in a Joint Communication to the European Parliament and the Council focused on the nexus of climate and security, the High Representative of the European Union for Foreign Affairs and Security Policy addressed the question of geoengineering, with a focus on "solar radiation modification."[78] The communication emphasized that the "risks, impacts and unintended consequences that these technologies pose are poorly understood, and necessary rules, procedures and institutions have not been developed."[79] However, notably the High Representative called up the EU to "assess comprehensively the risks and uncertainties of climate interventions, including solar radiation modification," guided by the precautionary principle.[80] Frans Timmerman, the EU's climate chief argued against unilateral research, but concluded that such activities "should be discussed in the right forum, at the highest international level," suggesting that the UN might be the appropriate institution.[81] Subsequent to the Joint Communication, the European Commission's Group of Chief Scientific Advisors released a Scoping Paper on SRM in August 2023. The paper concludes that "The EU needs to address risks and potential benefits connected to SRM. It should also be ready to engage actively in discussions on international level to address governance issues related to SRM regarding its research, small tests and potential deployment. At the same time, the EU needs to define how to regulate SRM research in the EU. The potential application of any SRM method, including for research, would have to be fully aligned with the broader EU policies, including with climate policy objectives."[82] In October 2023, the Scientific Advice for Policy by European Academies body (SAPEA) announced it will "draft an Evidence Review Report on Solar Radiation Modification, covering all relevant fields. This Report will then inform a Scientific Opinion of the Group of Chief Scientific Advisors."[83]

2.3.4 Australia

There has been a modest solar geoengineering program in Australia for a number of years, including some field research. In 2020, scientists from Southern Cross University and the Sydney Institute of Marine Science sprayed trillions of nano-sized ocean salt crystals into the air from the back of a barge. The purpose was to test the prospects for brightening low-altitude clouds in an effort to protect the Great Barrier Reef from bleaching.[84] The researchers indicated that there were future plans to scale up the experiment and determine if cloud-brightening could be effectuated, as well as impacts on the local climate.[85]

The Australian national government, in collaboration with the government of Queensland, have also funded small-scale field research of the placement of biodegradable polymer film in certain portions of the ocean to reflect solar radiation back to space in an effort to lower sea surface temperatures.[86] However, it is unclear if the new center-left federal government will pursue further geoengineering initiatives.[87]

2.3.5 Russia

Some of the seminal work on the potential deployment of stratospheric aerosols to effectuate cooling was conducted by researchers led by climate scientist Mikhail Budyko.[88] The mantle was subsequently picked up by Yuri Izrael and his team of researchers, including a proposal to deliver approximately one million tons of sulfate to the stratosphere.[89] Izrael, together with a team of scientists from the Institute of Global Climate and Ecology, subsequently conducted a series of field experiments to test the effectiveness of sulfur aerosol injection, including spraying aerosols into the troposphere by helicopter.[90] While the momentum of the program was upended by Izrael's passing in 2014, Russian research on SRM remains extremely influential in international scientific assessments.[91]

2.3.6 Other National Programs

India has conducted solar geoengineering research on a small scale for more than a decade.[92] The Indian government's Department of Science and Technology has been tasked with assessing the potential implications of SRM deployment for developing countries.[93] Research has included modeling assessment of the potential impact of SRM on the global water cycle and extreme weather events in the Bay of Bengal, including cyclones.[94] New Delhi's Council on Energy, Environment and Water has also convened three international conferences to identify India's potential role in governing SRM at the regional and global level.[95] India's principal scientific advisor has contended that SRM could "end up concentrating power in rich countries or nonstate actors in the global north," but for the Global South, may appear appealing given the context of dire climate consequences faced by them."[96]

There are also individual universities across many different countries that are engaging in early stage modeling or social science research in SRM.

2.4 NGOs

2.4.1 NGOs Focused on SRM

2.4.1.1 SilverLining

SilverLining is an NGO that advocates for research on "climate intervention" approaches, with a focus on SRM. It advocates for, *inter alia,* $2.6 billion in new annual funding by the U.S. government for climate research emphasizing aerosol influences on climate (including improved modeling and analysis, observations, SRM research, and socio-economic studies, and international scientific programs) over the next five years, promotion of international scientific research cooperation, and support for expansion of international cooperation on SRM in intergovernmental bodies.[97] Its support for SRM research includes its $7 million Safe Climate Research Initiative, which to date has provided funding research to, *inter alia*, the United Kingdom's Meteorological (MET) Office, the U.S. National Center for Atmospheric Research (NCAR), and research teams at 11 universities including the University of Washington, the University of Exeter, and Université de la Réunion.[98] It has also developed a five-year roadmap for a coordinated SRM research program.[99] Notably, it spent more on

lobbying last year ($320,000) than many major environmental groups, including the World Resources Institute, Wildlife Conservation Society and the Clean Air Task Force.[100] SilverLining does not list its funding sources publicly.

2.4.1.2 The Alliance for Just Deliberation on Solar Geoengineering (DSG)

DSG was launched in April 2023 by Shuchi Talati, formerly Chief of Staff in the U.S. Department of Energy's Office of Fossil Energy and Carbon Management in the Biden-Harris Administration, and a former Deputy Director of Policy at the carbon removal NGO, Carbon180. DSG's overarching mission is to facilitate "just and inclusive deliberation about research and potential use of solar geoengineering,"[101] with a focus on the Global South and climate vulnerable communities. It contemplates a community-focused approach that seeks to develop governance capacity in conjunction with local partners, including civil society and policymakers, deliberative polling to assess views of solar geoengineering in the Global South, and network and community building, including convening opportunities for NGOs to facilitate discussions about SRM.[102]

DSG has received funding from Preston-Werner Ventures, the Astera Institute, the LAD Climate Fund, Open Philanthropy, Grantham Foundation, and Open Society Foundation.[103]

2.4.1.3 Climate Overshoot Commission

The Climate Overshoot Commission is a bit of a hybrid organization, comprised of professional policy actors and academic experts across the Global North and South,[104] with a Secretariat hosted by the Paris Peace Forum, a civil society organization focused on global governance.[105] The organization is dedicated to avoiding "climate overshoot," i.e. temporary exceedance of temperature goals.[106] It convened six in-person meetings throughout the world to assess the role of a number of approaches to avert overshoot, including SRM. This work culminated in a final report by the Commission in advance of COP28, released in September 2023 that included a series of recommendations to reduce climate risk across the portfolio of responses.[107] For SRM, the recommendations include to:

- Adopt a moratorium on large-scale solar radiation modification
- Expand research governance
- Expand research and subsequent co-evolution of governance
- Produce and international, independent scientific assessment periodically

2.4.1.4 Carnegie Climate Governance Initiative (C2G)

C2G was founded in 2017 as a project of the Carnegie Council for Ethics in International Affairs led by Janos Pasztor, and "seeks to catalyse the creation of effective governance for climate-altering technologies," encompassing both SRM and CDR approaches.[108] Its work has included production of a large number of publications on SRM science and governance, infographics, and podcasts in multiple languages.[109] C2G has hosted numerous convenings and workshops across the Global North and

South, and is a major proponent of dialogue, governance and understanding of SRM by government, intergovernmental, and UN institutions, including UNEA.[110]

However, C2G will be sunsetting its operations by the end of the year. C2G has received funding from Open Society Foundations, The IKEA foundation, Children's Investment Fund Foundation, Macarthur Foundation, and others.

2.4.1.4 The Degrees Initiative

The Degrees (DEveloping country Governance REsearch and Evaluation for SRM) Initiative is an NGO that seeks to engage the Global South on SRM issues, with an emphasis on modeling, founded by Andy Parker.[111] Its previous iteration, the Solar Radiation Management Governance Initiative (SRMGI) was founded as a partnership between Environmental Defense Fund (EDF), the Royal Society, and The World Academy of Sciences (TWAS).[112] Its current primary funder is Open Philanthropy. Previous funders including Climate Pathfinders Foundation, the InterAcademy Panel, the European Climate Foundation, Zennström Philanthropies, the Carbon War Room, the Safe Climate Research Initiative, the Pritzker Innovation Fund, Matt Cohler, Bill Trenchard and the LAD Climate Fund, and the Fund for Innovative Climate and Energy Research.[113] Degrees bills itself as "the largest SRM research initiative in the world by scientists." To date, its Degrees Modelling Fund (DMF) has provided over $1.8 million to 150 researchers, supporting 26 projects in 21 countries.[114]

Most recently, Degrees announced an allocation of $900,000 in new solar geoengineering modeling funding for researchers in 15 countries including Benin, Nigeria, Uganda, Chile and India.[115] The funding is intended to assess potential impacts of SRM deployment for these countries.[116]

2.4.1.5 Others

Other NGOs focused on SRM include youth-led organizations, such as Operaatio Arktis based in Finland and SRM Youth Watch.

2.4.2 Environmental NGOs engaging on SRM

2.4.2.1 Environmental NGOs engaging on SRM research and governance

The Environmental Defense Fund in its "position on geoengineering" has declared its support for small-scale research on SRM options, with parallel development of SRM governance regimes. It currently opposes deployment "for the foreseeable future" due to "ecological, moral and geopolitical concerns.[117]

The Union of Concerned Scientists opposes deployment on the same grounds, and also supports modeling research, observational studies and public engagement to help guide decisions about potential "small-scale outdoor experiments."[118]

The Natural Resources Defense Council also opposes deployment on the grounds of both "known risks" and potential "unintended/unknown adverse impacts." However, it supports "carefully designed

experiments," including potential outdoor ones, subject to independent review and "sufficiently small to avoid a detectable effect on climate systems."[119]

The Brookings Institution has called for an "international governance regime for geoengineering," which it defines as SRM. This would include interim efforts by the United States to foster debate on geoengineering in international fora, and fostering development of a code of conduct for global geoengineering research.[120]

Resources for the Future has established a Solar Geoengineering program to assess potential risks, benefits and uncertainties "as one approach among others to address climate change."[121] This program is primarily focused on social science questions, including governance, public risk perceptions and moral hazard. The program has produced a number of publications,[122] including a number of reports by non-RFF scholars that were supported by an RFF funding opportunity that focuses on social science questions associated with SRM.[123] RFF has also convened several workshops and conferences on SRM.[124]

The Center for Climate and Energy Solutions (C2ES) wrote a series of white papers in 2020 with support of expanded SRM research and international governance.[125]

The International Center for Future Generations (ICFG) is a European-based think tank, with a mission to "equip policy makers with the knowledge and tools to address current and future high-risk technological advancements."[126] ICFG has a focus on three major topics, climate change, technology and democracy, and biosecurity.[127] It has recently announced its intention to hire a Program Lead Climate Engineering Governance, with an initial focus on "Solar Radiation Management."[128] Contemplated responsibilities include co-creation and management of a "Climate Engineering Governance Program," mapping of technological approaches and governance, interfacing with EU officials, including briefings and workshops, and collaboration with other civil society organizations.[129]

2.4.2.2 NGOs opposing SRM research expansion

The Climate Action Network (CAN) in its "Position on Solar Radiation Modification (SRM)" takes a firm stand against SRM deployment, contending that transboundary risks militate against deployment. Moreover, CAN also "strongly opposes" outdoor experiments, both because it views this as a "slippery slope" to deployment, and because it believes that useful experiments would have to be of such a scope as to be equivalent to deployment.[130]

The Friends of the Earth in 2021 declared its support for what it portrayed as a "moratorium" on "geoengineering" imposed by the Convention on Biological Diversity. It defined the term "geoengineering" to encompass both SRM and CDR approaches. It contended that geoengineering experiments would have to be deployed on "a massive, global scale" to influence global temperatures, which it argued would pose unacceptable risks.[131]

The ETC Group is not strictly focused on geoengineering issues, but devotes substantial portions of its resources to the topic. ETC opposes all forms of geoengineering, with the possible exception of agroecological approaches that may effectuate carbon removal. ETC collaborates with Biofuelwatch,

the Heinrich Böll Foundation (a major funder of ETC) and the Global Forest Coalition on Geoengineering Monitor, an information clearinghouse on geoengineering issues.[132] Geoengineering Monitor steadfastly opposes both SRM and CDR approaches, concluding, "geoengineering techniques do nothing to address the root causes of climate change, and evidence points to a high likelihood that rather than improving the climate, they would make things worse—potentially in catastrophic fashion."[133] ETC also coordinated the drafting of a "Manifesto Against Geoegineering"[134] in 2018, signed by more than a hundred international, regional, and national organizations. The Manifesto called for, *inter alia,* a ban on geoengineering field experiments and deployment, cessation of all planned outdoor geoengineering experiments, and a robust multilateral governance system.[135]

2.5 Professional Societies

2.5.1 American Geophysical Union

The American Geophysical Union (AGU) issued a statement on "climate intervention research" (encompassing both SRM and CDR) in 2018, and revised and reaffirmed it in 2023. The current incarnation recommends substantial support for research by funding agencies, and advocates for field experiments. The statement emphasizes the need for transparency, assessment of impacts, and participation of potentially impacted stakeholders, with particular attention to the most vulnerable.[136]

In 2022, AGU initiated a process of building an ethical framework for climate intervention research.[137] The principles are focused on both CDR and SRM, and "will focus solely on the ethics of the research, experimentation and deployment of such measures, not the development of policy around the measures." The process includes several opportunities for stakeholder engagement and expert discussion. The Framework also promotes governance frameworks for research and post-project monitoring of experiment and transparency in communicating results of experiments.[138] The final principles are scheduled to be published in 2024.

2.5.2 Meteorological Societies

In February of 2022, the American Meteorological Society (AMS) recommended "an accelerated and robust climate intervention research program, which encompasses both SRM and CDR options[139] and associated governance framework, to inform public policies."[140] While not advocating development of deployment platforms for climate intervention approaches, the AMS supported study of potential deployment scenarios and strategies. It advocated for a research program that would include assessment of the scientific and technological prospects of climate interventions, quantification of potential environmental consequences of climate interventions, and "continuous and enhanced observation of the Earth system."[141]

The United Kingdom's Meteorological Office has also issued a position on "geoengineering," which it defines to encompass both "greenhouse gas removal (GGR)" and "solar radiation modification."[142] In the context of SRM, the Met, while acknowledging many of the risks discussed in this report (and

stating that this approach is more "controversial" than GGR), concludes that geoengineering is increasingly part of the global discussions to determine how to meet the Paris Agreement goal. Moreover, it indicates its desire to engage in climate modeling, though it eschews field experiments.[143]

2.6 Private Sector

2.6.1 Make Sunsets

In April 2022, Make Sunsets,[144] a for-profit company launched by two veterans of Silicon Valley companies, deployed a helium balloon over Mexico. The balloon was filled with a few grams of sulfur, and it was hoped that the balloon would burst in the stratosphere and release sulfur dioxide particles that would exert a cooling effect.[145] It is not clear what transpired subsequently, as the balloon was not outfitted with monitoring equipment.[146]

The company stated that it planned to increase the sophistication of future launches, including adding monitoring equipment, but it was already offering "cooling credits" to the public soon after the initial launch.[147] The company's experiment was met with heavy criticism by members of the SRM science and policy community, as well as others.[148] Scientists, including from SRM research proponents, such as SilverLining, have questioned the viability of precise quantification of cooling from aerosol injection, and subsequent transition into "credits."[149] Others contend that decisions about SRM deployment need to be made by governments, backed by public support.[150]

In January 2023 , the government of Mexico issued a press release, prohibiting solar geoengineering experiments in Mexican territory.[151] Mexico is also trying to persuade other governments to ban SRM activities in their jurisdictions.[152] Make Sunsets subsequently responded that it would not proceed with further experiments "until we come up with a way to collaborate with the Mexican government."[153] However, the company appears to have simply shifted its deployments to the United States in the interim. As of July 1, the company claims to have launched 22 balloons, apparently all from the United States,[154] and claims to have "offset 3,411+ton-years of warming."[155]

Boost VC, an early-stage venture capital firm that invests in "deep tech"[156] has provided $500,000 to the company.[157] Another VC firm, Pioneer Fund, also lists the company in its investment portfolio.[158]

2.6.2 OHB

In April, 2021, OHB System AG, a subsidiary of the German space and technology group, OHB SE announced a collaborative initiative with eight research institutes from five countries[159] to establish a "competence network" on space-based geoengineering approaches.[160] The research is touted as interdisciplinary, including aerospace engineering, atmospheric research, modeling and social science

aspects, including communications and ethics.[161] To date, there does not appear to be any deliverables, though the OHB site indicates that the principals are meeting monthly.

2.7 University Research Centers

2.7.1 Harvard University

Harvard University, led by Dr. David Keith, built the Solar Geoengineering Research Program (SGRP) under the Center for Environment (Dr. Keith has since moved to the University of Chicago). The program's mission is to "further critical research on both the science and governance of solar geoengineering."[162] SGRP publicly shares all funders and does not take funding from sources that have a majority of their profit from the fossil fuel industry.[163] SGRP is supported by Bill Gates, the William and Flora Hewlett Foundation; The Open Philanthropy Project; the Pritzker Innovation Fund; The Alfred P. Sloan Foundation; VoLo Foundation; The Weatherhead Center for International Affairs; and several individuals, including G. Leonard Baker, Jr.; Alan Eustace; Ross Garon; John Rapaport; Michael Smith; Bill Trenchard.[164]

The largest project under SGRP is the Stratospheric Controlled Perturbation Experiment (SCoPEx), led by Professor Frank Keutsch.[165] The overarching purpose of SCoPEx is to ground truth and fine-tune SRM computer models through experiments, especially in the context of aerosol microphysics and atmospheric chemistry.[166] The contemplated primary instrument for conducting such experiments is a scientific balloon, powered by airboat propellers. The cynosure of the research agenda is to release 100 grams-2 kilograms of calcium into the atmosphere at a height of 20 kilometers, and to use onboard sensors to measure changes in the perturbed air mass, including changes in aerosol density, atmospheric chemistry and the scattering of light.[167]

The Research team and the University established an independent advisory committee to provide advice on the research and governance of SCoPEx in July 2019.[168] The committee reports to the Vice Provost of Research, and only has the authority to make recommendations. The committee developed a framework of research governance, which was made public, that includes financial review, legal review, scientific merit review, and public engagement (societal review).[169]

However, SCoPEx has faced challenges. Harvard researchers planned to launch its balloon into the stratosphere in the summer of 2021 over Kiruna, Sweden, a small town in the north. The objective was to run a few tests of the instruments and a dry run with the gondola, without the release of any materials into the atmosphere.[170] However, in February of that year, a group of environmental organizations and the Saami Council, representing Saami indigenous peoples' organizations in Sweden, Norway, Finland and Russia, proffered a letter to the project's Advisory Committee.[171] The writers called for the experiment to be scrapped on several grounds, including "risks of catastrophic consequences," inadequate representation of potentially affected group on the project's Advisory Committee, and a failure to address broader ethical issues, including moral hazard and questions of governance.[172]

The Advisory Committee subsequently recommended that societal engagement should ensue before the engineering test flight was conducted and recommended the experiment's suspension in the interim.[173] The experimental team accepted this recommendation and has indicated that it will not proceed without a formal recommendation from the Advisory Committee to Harvard that the experiment proceed.[174] In 2022 the Advisory Committee did release guidance on how local public engagement for SCoPEx should be structured.[175]

2.7.2 University of Chicago

In April 2023, it was announced that Professor David Keith, one of the primary researchers in Harvard's Solar Geoengineering Research Program, had joined the faculty of Department of Geophysical Sciences at the University.[176] Keith is slated to head up the school's new Climate Systems Geoengineering Initiative, which will explore both CDR and SRM approaches. The Initiative is designed to bring together current researchers at the university with interests in geoengineering, hire new faculty, and work with partners locally and globally.[177]

2.7.3 UCLA

The Geoengineering Governance Project of the UCLA Emmett Institute on Climate Change and the Environment focuses on legal and policy issues associated with both SRM and CDR geoengineering, with a focus on governance issues. The Project is headed up by Professor Edward A. Parson.[178] It receives substantial support from the Open Philanthropy Foundation. The Project's work includes supporting teaching on the topic of SRM, scholarly publications (more than 50 to date), a Summer School on Geoengineering Governance, diplomacy exercises on how to govern SRM, and government briefings.[179]

2.7.4 Forum for Climate Engineering Assessment (FCEA), American University

The Forum for Climate Engineering Assessment (FCEA)[180] is a research center based in the School of International Service at American University. While FCEA originally focused on both SRM and CDR geoengineering approaches, the CDR component of its work was subsequently moved to American's Institute for Carbon Removal Law & Policy, which was established in 2018.[181] FCEA is a dormant organization currently due to funding constraints. Its most recent activity was work on scenarios modeling from 2019-2021.[182]

2.8 Scientific Modeling Initiatives/Scientific Community Support

There are two primary SRM modeling initiatives at the international level, the Geoengineering Modeling Intercomparison Project (GeoMIP)[183] and the Geoengineering Large Ensemble (GLENS).[184] Approximately a decade ago, a group of researchers, drawn primarily from the academic and government sectors,[185] established GeoMIP to coordinate SRM computer modeling experiments, initially coordinated in parallel with the "Implications and Risks of engineering solar radiation to limit climate change" (IMPLICC) project of the European Union.[186]

GeoMIP's experiments are segmented into three "suites." The first suite is comprised of "Solar Radiation Management schemes," with four main experiments focused on various configurations of sulfur aerosol injection on planetary energy balances.[187] The second suite of three experiments focuses on sea spray geoengineering and marine cloud brightening.[188] The most recent suite focuses on solar dimming, stratospheric aerosols and cirrus cloud thinning.[189] GeoMIP's research has resulted in more than 145 peer-reviewed publications and technical reports/non-peer-reviewed publications.[190] The project most recently outlined an agenda for future experiments, including consideration of sulfur injections in polar regions, isolating uncertainties related to several critical parameters, including dynamics simulations, assessment of sensitivity to aerosol parameterization, and potential configuration of future marine cloud brightening experiments.[191] GeoMIP has been recognized as the most comprehensive multi-model assessment of SRM impacts to date.[192] There has also been some preliminary research conducted under the rubric of the Agricultural Model Intercomparison and Improvement Project (AgMIP) to assess the potential impacts of SRM deployment on agriculture.[193]

In February of 2023, 110 physical and biological scientists studying climate science and impacts signed a letter in support of scientific research to assess the effectiveness of SRM approaches, including under different climate scenarios and capabilities for detecting and attributing the impacts of SRM interventions.[194] The scientists emphasized that they did not support deployment currently; recommending that such a potential decision be preceded by a comprehensive international assessment and cooperative international decision-making.[195] Moreover, another group of scientists also recently called for a research program on SRM and drafted a broad set of principles to guide research.[196]

2.9 Voluntary Codes of Conduct

In March, 2010, the Asilomar International Conference on Climate Intervention Technologies was convened in California. It was organized by Margaret Leinen of the Climate Response Fund and chaired by Michael MacCracken of the Climate Institute. The conference brought together a substantial group of prominent atmospheric scientists, as well as a handful of law and policy experts including myself. In November of 2010, a set of recommendations growing out of the conference were issued.[197] The recommendations included a focus on promoting collective benefits, develop liability mechanisms and standards of proof for potential damages growing out of research, a call for open and collaborative research and iterative evaluation and assessment of research results.[198]

Following publication of a seminal report on both CDR and SRM geoengineering approaches by the UK's Royal Society in 2009,[199] the UK House of Commons Select

Committee on Science and Technology initiated an inquiry on governance considerations for geoengineering. This culminated in the development of a code of conduct called the "Oxford Principles."[200] The principles include regulation of geoengineering as a public good by appropriate bodies at the State and international level, meaningful public engagement in geoengineering decision-making, ideally with prior informed consent, transparency in terms of the results of

geoengineering research, independent impact assessment, and establishment of governance structures prior to deployment "wherever possible."[201]

On the other side of the calculus is the call for an International Non-Use Agreement on Solar Geoengineering.[202] The initiative was launched in January of 2022 by a Coordinating Group of sixteen academics from around the world.[203] To date, it's been signed by more than 440 academics from more than 60 countries.[204] The letter calls for an International Non-Use Agreement premised on five core commitments and measures:

- A commitment to prohibit national funding agencies from funding supporting development of solar geoengineering technologies both domestically and through international institutions;
- A commitment to ban outdoor experiments for solar geoengineering;
- A commitment to not grant patents for solar geoengineering technologies;
- A commitment to non-deployment of solar geoengineering approaches developed by third parties;
- A commitment by international institutions to not support solar geoengineering.[205]

The drafters of the proposed agreement contemplate that its operationalization could begin with a coalition of like-minded governments declaring their opposition to development and deployment of SRM. They believe this would ultimately exert substantial influence on potential sources of funding, e.g., agencies or philanthropies, or corporations, and could exert pressure on key international institutions.[206]

2.10 Media

Over the last 2-3 years, media coverage of SRM has dramatically increased from numerous outlets. Media representations of SRM are deeply influential for public perception.[207] Major outlets that are providing consistent coverage of SRM include (but are not limited to): MIT Technology Review, Science/Nature, Politico (E&E News), Axios, The New York Times, Washington Post, Foreign Policy, Science News, and The Guardian. These outlets are largely based in the Global North, with coverage starting to grow in some regions of the Global South.

Fictional portrayals of SRM in books, film and television are gaining popularity as well, with recent depictions including the Apple TV show "Extrapolations" in 2023, the novel *Ministry of the Future* by Kim Stanley Robinson in 2020, and the novel *Termination Shock* in 2021 by Neal Stephenson.

2.11 Funding

There are numerous known and unknown funders across, both from philanthropic foundations and individuals. There has been a noticeable increase in funders in SRM across various types of institutions over the last 2 years as momentum in the field has shifted. Known funders for different institutions are listed in relevant sections.

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