On the Design of an International Governance Framework for Geoengineering

*Ian D. Lloyd and Michael Oppenheimer**

This article explores the global governance options surrounding the deliberate, large-scale manipulation of the Earth's climate system to counteract climate change, known as geoengineering. The term geoengineering encompasses a broad range of techniques with different governance considerations. Here we only consider those methods that affect the net incoming solar radiation to the atmosphere, often referred to as solar radiation management (SRM). We do not consider methods that remove carbon dioxide from the atmosphere, referred to as carbon dioxide removal (CDR), which has separate governance considerations.[1] We pose three questions. Will an international framework on SRM be needed? What are the main characteristics that should be included in the design of a governance regime? Is the proposed governance regime feasible?

The international community is in the early stages of exploring the scientific and political implications of geoengineering, with information-gathering efforts and interest in the topic beginning to expand beyond a small core in the scientific community.[2] The literature to date on SRM governance has focused on ad hoc approaches[3] and formal governance options through the United Nations,[4] with a report by the House of Commons for the joint US–UK hearings on geoengineering supporting formal governance through the UN system.[5] Neither the US nor the UK presently supports a geoengineering governance regime, and both favor making use of existing international mechanisms. The European Union has initiated a program to study scientific and

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1. Shepherd et al. 2009.
2. See, for example, Shepherd et al. 2009; Solar Radiation Management Governance Initiative 2011.
3. Victor 2008.
4. Virgoe 2009.
5. U.K. House of Commons Science and Technology Committee, 2010.

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political issues surrounding geoengineering, and a report by the US Government Accountability Office has recommended a coherent research program in the context of the federal response to climate change.[6]

As explained in this article, SRM deployment would have far greater risk in the near term than conventional greenhouse gas emissions reduction methods. Because of this risk, we argue that the purpose of SRM governance is to deter SRM deployment in the near term to avoid its potential negative climate impacts, but also to ensure that any future decisions on deployment meet normative criteria. This raises two important questions: how would a regime be designed, and what are the incentives to join? First we address institutional design, which depends on problem structure and state preferences. We discuss incentives, which are subject to political processes[7] and dependent on the regime design proposed, after considering SRM regime design.

On the question of regime design, we argue that an international framework will be needed because of the nature of the problem. If other greenhouse gas emissions reduction approaches are regarded as insufficient, states will have incentives to act unilaterally. The outcomes of such actions, however, carry significant uncertainty and could have both positive and negative consequences for all parties. The scientific uncertainty would complicate the decision to deploy and could lead some states to prevent unilateral deployment by others. In addition, unilateral action is problematic because the acting state is unlikely to give much weight to the potential harm it will cause other states when making decisions about risks and uncertainty.

SRM can be viewed as opposite in nature to climate change, in the sense that it requires states *not* to act by deploying SRM at present. However, the structure of SRM as a governance problem may change if scientific uncertainty is reduced, and SRM may become a desirable option for an increasing number of states if greenhouse gas emissions are not capped. A formal governance regime for both experimentation and deployment would stand a better chance than ad hoc approaches of upholding normative principles, such as regulation of the terms for SRM usage by public entities, broad public participation in decision-making about SRM, and obtaining informed consent of affected populations.[8] The regime could also reduce the possibility of skewed risk assessment by states based on the threat of unilateral action, remove decision-making ability from nonstate actors, encourage greater transparency of SRM activities within the public domain, and minimize the risk that SRM would divert effort from mitigation and adaptation.

On the question of incentives for joining an SRM regime, we focus on designing a regime that would be effective, defined as an institution that induces

6. US Government Accounting Office Report, October 2010.
7. Where "political process" refers to the full range of methods that can affect the outcome of multilateral negotiations, including argumentation, persuasion, and bargaining (e.g., Risse 2000; Ulbert and Reese 2005; Grobe 2010).
8. Rayner et al., 2009; Morrow et al. 2009; Schneider 2008; and Jamieson 1996.

cooperation through mutual policy adjustment,[9] and creates positive outcomes that would not otherwise have occurred. The initial goal of the regime would be to uphold a temporary moratorium on SRM deployment and encourage collaboration on scientific research. We argue that restricted membership will be more effective: smaller groups may have a reduced heterogeneity of preferences compared to larger groups, and are more likely to reach collective goals.[10] To maintain legitimacy, membership should include representation from groups of non-SRM-capable states from regions with particular vulnerability to climate change impacts (see the Supplementary Online Materials [SOM]). States are typically unwilling to agree to a highly legalized regime with strong enforcement procedures. A legalized regime is unlikely to be politically feasible as a first step, especially under conditions of high uncertainty. Thus a small body with weak legalization is more feasible initially. The default governance structure is one in which members have equal votes and veto powers, although power constraints may cause an unequal distribution of voting and veto powers.[11] Finally, the regime should allow for subsequent institutional reforms, enabling the regime to proceed in steps that expand membership and deepen legal commitments. As models for our regime proposal, we briefly consider treaties on arms control, stratospheric ozone depletion, and unexplored territory, such as the Outer Space Treaty and the Antarctica Treaty. These treaties are preventative in the sense that they are intended to prevent actions that would alter the status quo, for instance through protecting unexplored territory, preventing the use of CFC technologies, or preventing nuclear testing or the use of nuclear weapons.

The final question addresses feasibility. Even if there are strong normative reasons for an SRM regime, is the proposed regime likely to occur? Will states be better off joining an SRM regime or staying with the status quo and utilizing existing institutions? To answer these questions, we examine the incentives for actors to join, the benefits of cooperation, and the heterogeneity of preferences. We argue incentives to join the regime include having a voice on the SRM issue and "locking in" actors' power to influence collective decisions in the long term, reducing the likelihood of a unilateral intervention and satisfying the "demand for information" through collaborative scientific research. However, power constraints may lead to a sub-optimal regime. Finally, we discuss the question of legitimacy.

The Current State of International Geoengineering Governance

In a comprehensive report on the science of geoengineering, the Royal Society defines geoengineering as "the deliberate, large-scale manipulation of the

9. Keohane 1984, 51–55.
10. See Olson 1965; Downs, Rocke, and Barsoom 1996.
11. "Power" is defined as the ability of A to cause B to act in a way it would not otherwise do; see

Earth's climate system in order to counteract climate change."[12] Geoengineering techniques are divided into two categories: carbon dioxide removal from the atmosphere, and solar radiation management (SRM), concerning the intentional manipulation of incoming solar radiation in the atmosphere. An example of SRM would be the injection of sulfur particles into the stratosphere to replicate the global cooling effect of a large volcanic eruption.

The general discussion of SRM governance in this paper specifically concerns the following SRM techniques:

- Injection of particles (sulfur or otherwise) into the stratosphere above approximately 10 kilometers, where particles have a lifetime of several years, to reflect incoming solar radiation and replicate the global cooling effect from volcanic activity.
- Cloud-whitening techniques, whereby aerosols or water vapor would be sprayed into the atmosphere, creating increased low-level cloud cover to reflect incoming solar radiation.
- Placing a large mirror in space, at a Lagrangian point, where its position is fixed relative to the Earth, or placing a plethora of small mirrors high in the atmosphere.
- Any other current or future technology that could significantly alter the net incoming solar radiation across the Earth's atmosphere in relatively uniform fashion, and would constitute a deliberate human attempt to alter the Earth's climate.

These techniques could create fast and uniform changes to the net balance of incoming and outgoing radiation across the Earth's atmosphere. However, land-based SRM techniques, such as the installation of solar reflectors across a desert, could create different weather and climate impacts depending on where they are deployed. Classes of SRM intervention other than those described in this article could require different governance considerations due to their differing climate impacts.[13]

In terms of governance, provisions for managing carbon dioxide removal are moving forward under existing international treaties such as the UN Convention on Biodiversity (CBD) and the London Convention/London Protocol under the International Maritime Organization. There is currently no clear international treaty to control deliberate, large-scale SRM interventions. We discuss the medium to long-term governance of large-scale SRM interventions that would affect the atmosphere, for which there is the largest gap in international regulation and greatest potential for fast and uncertain impacts on the global

Dahl 1957. "Power constraints" refers to the ability of states to impose their power on others in order to influence institutional design; see Moe 2005.

12. Shepherd et al. 2009.
13. Humphreys 2011.

climate. We only briefly consider the development of principles and norms for short-term SRM experiments, which others have written about.[14]

Scientific Understanding and Uncertainty about the Impacts of SRM Implementation

Implementation of SRM would create a net global cooling effect that would offset global temperature rise from climate change, but its impacts contain great uncertainty. If it were possible to deploy SRM today, it would cause unpredictable and potentially unwanted regional impacts.[15] For instance, SRM would be likely to affect US temperature and rainfall patterns as well as the Asian monsoon system. If the uncertainty of impacts were to be reduced in future, SRM could provide a collective good in the case of a "climate emergency." Once started, however, any SRM intervention would have to continue either indefinitely or until greenhouse gas emissions were reduced, as sudden cessation of SRM activities would create rapid climate warming.

SRM could be used in two scenarios. In the first, conventional emissions mitigation strategies partially address climate change impacts, and SRM implementation would be employed for 50–100 years to counter the residual global temperature rise.[16] In the second scenario greenhouse gas emissions would continue unchecked. To compensate for climate change, SRM would have to be used for an indefinite period in increasingly large measure, and the regional temperature and rainfall changes due to SRM would become more pronounced. The risk of adverse impacts in this second scenario would be much greater because of the scale of the intervention required.

The Problem Structure of Solar Radiation Management

SRM governance is implicitly connected with efforts to mitigate carbon emissions and adapt to climate change. Climate change is a collective action problem, and the success of any global climate agreement will depend on the mitigation efforts of a select few large emitters. The actions of states with low emissions, while politically meaningful, will not have a significant impact on the outcome of mitigation efforts. Attempts by states to negotiate a consensus agreement on binding emissions limits with widespread participation have to date been unsuccessful, with international efforts such as the Kyoto Protocol unable to prevent free-riding due to weak mechanisms for inducing participation and enforcing compliance.[17] The ineffectiveness of international negotiations has led to the emergence of a regime complex of loosely coupled institutions for climate change.[18]

14. See Victor 2008; Morrow, Kopp, and Oppenheimer 2009.
15. Robock 2008; Ricke et al. 2010; Moreno-Cruz et al. 2012; Pongratz et al. 2012.
16. Wigley 2006; Rasch et al. 2008.
17. Barrett 2003.
18. Keohane and Victor 2011.

SRM, however, poses an entirely different governance problem to that of climate change. Because of high scientific uncertainty, SRM interventions carry large risk compared to conventional emissions reduction, and in the near term most states will likely want to prevent SRM based on their own risk-benefit calculus. Keohane and Victor outline these differences: "With geoengineering, action by one or a few actors may be too tempting and need to be prevented, which makes the cooperation challenge the opposite of collective action to control emissions. That is, the challenge in geoengineering is how to make it more difficult rather than easier to act."[19]

Viewed in this way, SRM appears to be a collective action problem in which the goal is to prevent states from acting because SRM deployment by one state could cause negative climate impacts for others. However, as scientific uncertainty is reduced, it is possible that SRM could provide a public good in terms of a controlled, globally agreed short-term (e.g., 5–10 years) intervention to lessen the peak of global temperature rise under an emissions reduction pathway, avoiding the worst climate change impacts and complementing adaptation efforts. Just as likely, the view of SRM may become less favorable as its potentially negative climate impacts are understood more fully. Thus the purpose of SRM governance is not only to deter SRM deployment in the near term, but also to assure that any future consideration of SRM deployment adheres to normative criteria.

The strategic logic of mitigating climate change is different from that of preventing or controlling SRM use. SRM does not have a prisoner's dilemma structure; to act or not act are not the only choices. Multiple countries could act together or separately, and there are many ways to implement SRM in terms of technology, and the location and length of the intervention. In addition SRM does not have the same free-rider problem as climate change. If a country with substantial emissions and resources does not join the SRM regime or implement SRM, the regime can still be effective in preventing deployment in the near term, or encouraging particular forms of implementation in the distant future. SRM is also dependent on the status of the climate change problem. If states can mitigate climate change (through implementation of immediate and sustained reductions in greenhouse gas emissions) then there will be little or no impetus for SRM. If, however, climate change negotiations continue to falter and national actions prove insufficient, then the incentives to use SRM will become greater. Thus SRM implementation depends on the outcomes of climate change negotiations. The impacts following from these outcomes are far from clear-cut, and there will continue to be uncertainty about future climate change impacts. Therefore we assume that the continuing risk posed by climate change demands a need to develop principles and norms for SRM governance. This assumption allows us to compare the SRM governance problem with existing preventative treaties.

19. Keohane and Victor 2011.

The Interests, Preferences, and Resources of States in SRM Governance

In Figure 1 we consider which states or regions are most likely to suffer severe impacts from climate change by 2050, and which states or regions are likely to have the economic and technical capacity to implement SRM. We assume that all states would prefer their own climate benefits to be maximized and SRM risks minimized. Figure 1 divides states according to projected climate change vulnerability and potential capacity to produce and use SRM technology unilaterally. The figure demonstrates a continuum between states with varying degrees of vulnerability to climate change and the potential to implement SRM.

The Need for an SRM Governance Regime

A critical question is whether an international treaty is needed and could be both effective and feasible. We argue that a regime would need to meet a number of normative governance principles for SRM in order to satisfy these criteria. In subsequent sections we address effectiveness and feasibility from a positive state-centric perspective and draw comparisons between the proposed SRM regime and existing international institutions.

A number of normative governance principles have been discussed for the regulation of SRM.[20] These principles include the regulation of SRM activities by public entities (rather than private-sector or military entities); broad public participation in SRM decision-making; a specialized body to conduct independent assessment of SRM impacts; notification, consultation, and informed consent from the affected population as a prerequisite to experimentation and deployment; and the principle that SRM activities should not endanger or violate basic human rights irrespective of potential gains. There are four reasons why a multilateral SRM regime is more desirable for meeting these criteria than unilateral governance:

- International regulations for SRM would remove decisions on SRM deployment away from a community of nonstate actors such as scientists, policy experts, non-governmental organizations, and others. Deployment by nonstate actors would violate most governance principles listed above, including regulation by public entities, broad public participation, and informed consent of affected populations.
- SRM activities should be conducted in a transparent fashion in order to build trust, and avoid the possibility of SRM activities being conducted in a non-public manner by private or military interests. Transparency through an SRM regime would support the principles of public regulation, broad public participation, evaluation of SRM impacts, and informed consent.

20. Rayner et al. 2009; Morrow et al. 2009; Schneider 2008; Jamieson 1996.

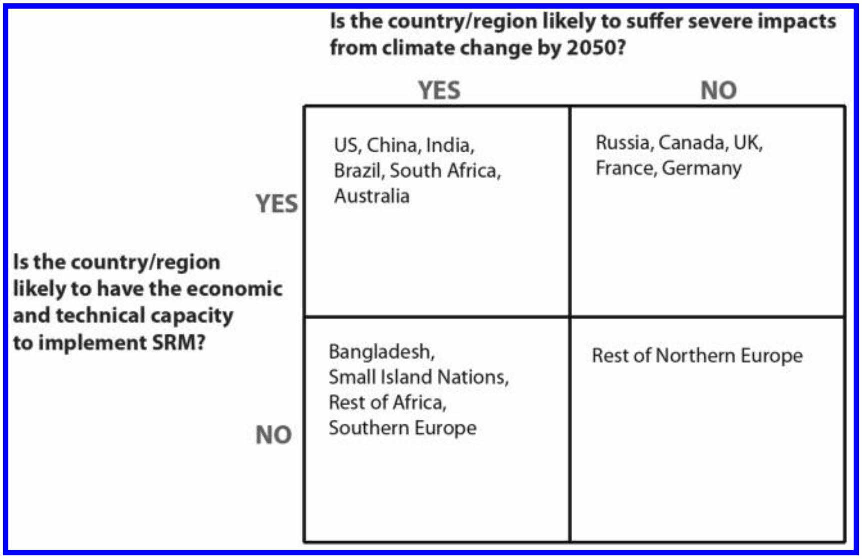

Figure 1
This figure illustrates the potential interest of selected countries in climate change abatement and the capability of each to implement SRM. Specific aspects of projected climate change by 2050 for the purpose of judging its impact on each country include large temperature increases, except for polar regions,[1] and vulnerability to sea level rise.[2]

Also see supplementary online material (http://www.mitpressjournals.org/doi/suppl/10.1162/GLEP_a_00228) for more details about Figure 1.
1. Based on projected temperature changes Figure 10.8 of the IPCC Working Group I report. Meehl et al. 2007.
2. Based on projected sea level rise vulnerability in Figure 8 of the IPCC Working Group II Technical Summary. Parry et al. 2007.

- The incentives to comply with an international framework and the punishments for non-compliance could reduce the likelihood of unilateral action, which in turn would improve the chances of meeting the normative criteria of global public consent for any decision on SRM, if and when needed.
- An effective and legitimate governance regime could reduce the risk of a "moral hazard" dilemma, whereby efforts for mitigation and adaptation are further weakened by the prospect of SRM. That is, by imposing suitable decision-making procedures, a successful regime would make it difficult to invoke the use of SRM, relative to implementing emissions mitigation and adaptation.

Victor argues that norms to govern SRM, along with efforts to expand research, will soon be vital.[21] Victor's ad hoc ("bottom-up") approach to building

21. Victor 2008.

principles and norms for SRM research and deployment may be needed in the short-term both domestically and internationally. For medium to long-term SRM governance, however, we argue that a formal ("top-down") coordinated approach will be needed in order to meet the proposed normative criteria.

In recent reports and hearings, the US and UK governments have demonstrated support for the top-down governance approach. During joint US-UK hearings on geoengineering, one UK member of parliament testified that "there are good reasons for developing international regulatory framework on geoengineering, whether through existing regimes, or new designs for SRM outside of current frameworks."[22] The UK House of Commons' report on geoengineering[23] also supports the eventual adoption of SRM governance through the United Nations.

Design of an International Regime for SRM

Under a rationalist framework of world politics any state may choose to protect its sovereign interests, and international institutions may not be able to prevent unilateral action. Notwithstanding this possibility, neoliberal institutionalists argue that multilateral institutions can enhance the likelihood of cooperation by reducing transaction costs, enhancing the shadow of the future, and building trust through repeated interactions.[24]

First we describe a general analytical framework for SRM regime design. Lessons for SRM governance are briefly considered through comparisons to past international treaties. Finally, the incentives to join the regime are addressed. Briefly, the initial goal of our proposed regime is to place a temporary moratorium on SRM deployment and allow for collaborative scientific research. We propose that an SRM regime should initially have small membership, weak legalization, equal voting powers for members, and the flexibility to allow for future institutional reforms. This flexibility would enable the regime to proceed in a series of steps that allow for broader membership and deeper commitments with time. The regime could be created through the UN but act as a separate international organization with its own membership and different voting roles, following models such as the Montreal Protocol or the Nuclear Non-Proliferation Treaty. It could also have scientific subsidiary bodies to provide technical assessments, as for the United Nations Framework Convention on Climate Change (UNFCCC) or the Montreal Protocol.

The proposed SRM regime is based on positive arguments relating to the effectiveness of institutional arrangements. We draw on existing theories because they provide useful criteria for classifying different features of our regime design, but we do not use theoretical conjectures about regime design as justification. In particular, the rational design (RD) framework, which considers

22. US House Committee on Science and Technology, 2010.
23. UK House of Commons 2010.
24. Axelrod and Keohane 1985.

states as self-interested rational actors that design institutions to advance their joint self-interest, is used to separate regime design into the criteria of membership, scope, and flexibility.[25] However, we do not address the RD criteria of centralization and control in detail, as they may be subject to political process, and, given high uncertainty, the positive implications are unclear.[26] The RD framework does not address legitimacy,[27] which we consider in the context of membership and through a scientific body to provide accountability. For example, the conjecture "larger uncertainty leads to greater centralization" is not empirically proven, and the opposite may be true in the case of climate change. Also, some SRM design features are consistent with principal-agent theory,[28] which explains why states choose to delegate responsibility to international organizations for certain types of problems, such as the demand for information, monitoring and compliance, and credibility of commitments. Finally, we acknowledge that power constraints may make regime design sub-optimal, and any SRM regime may ultimately reflect the interests of a few powerful states.[29]

We identify several characteristics, described in the following paragraphs, as desirable for an effective SRM regime.

Small Membership but Broad Representation

The question of regime membership must address the tradeoff between effectiveness and legitimacy. Small membership is needed for the regime to be effective, inclusive of states in the "yes-yes" box from the illustrative 2x2 matrix shown in Figure 1. This statement is intuitive: smaller groups are more coherent and effective, and do not rely on coercion or positive inducements apart from the collective good itself. As group size increases, the provision of the common good becomes less optimal.[30] The initial inclusion of states that are not capable of performing SRM (outside the "yes-yes" box from Figure 1) would inhibit cooperation.

The case for small membership is supported by, for instance, institutions with initially small membership (which may grow over time), such as the Vienna Convention for the Protection of the Ozone Layer or the Antarctica Treaty, compared to multilateral organizations such as the UN General Assembly (UNGA), the UN Environmental Programme (UNEP), or the UNFCCC. The Vienna Convention process and the Antarctica Treaty have been successful in preventing increased chlorofluorocarbon emissions and protecting Antarctica's natural resources, respectively. Conversely, UNGA, UNEP and the UNFCCC are

25. Koremenos, Lipson, and Snidal 2001.
26. Under the RD framework, Centralization refers to the degree of delegation among institutions (e.g., the centralized Antartica Treaty, versus the decentralized WTO dispute-resolution panels); while Control refers to the rules and procedures for making collective decisions.
27. Wendt 2001.
28. Hawkins et al. 2006.
29. Moe 2005.
30. Olson 1965; Snidal 1985.

large and unwieldy, containing states with a large heterogeneity of preferences and leading in general to weaker effectiveness. We believe that the SRM regime should initially be limited to thirty or fewer states. Even though this number would still contain significant heterogeneity of preferences compared to, say, ten states or less, it would be more effective than the full 197 countries, because outliers who advance extreme proposals would be excluded (assuming they are absent from the "yes-yes" box in Figure 1).

Second, an SRM regime should be designed so that it is legitimate in the practical sense, that is, both members and non-members recognize and abide by the principles and rules set forth by the regime, including normative criteria such as broad public participation and consultation with affected populations.[31] One way to achieve practical legitimacy would be to open the regime to large membership. However, in this scenario the regime would be much less effective due to its disparate actors. As practical legitimacy also depends on effective governance outcomes of the SRM regime, a small membership that includes SRM-capable states makes an effective outcome more likely. To have a satisfactory trade-off between practical legitimacy and effectiveness, a small membership should be maintained. However, to bolster practical legitimacy, non-SRM-capable states that are vulnerable to climate impacts (Figure 1) could be represented by regional groups such as the African Coalition, the Association of South-East Asian Nations (ASEAN), the Alliance of Small Island States (AOSIS), or the Major Economies Forum on Energy and Climate Change (MEF). This representation could possibly take the form of temporary, rotating membership positions analogous to non-permanent members of the UN Security Council.[32]

Weak Legalization to Engage Participation

States are typically unwilling to agree to highly legalized commitments, especially under conditions of high uncertainty,[33] although an SRM regime with precise rules and extensive legalization would be more effective. Such a legalized regime would place a moratorium on SRM deployment, with strict enforcement consequences for non-compliance. The regime could include a clause to allow for SRM deployment after a difficult voting process (for example double- or super-majority), ensuring wide participation and approval in the event that mitigation efforts are deemed inadequate.

While a legalized regime may be a desirable goal, it may not be politically

31. Two elements contribute to practical legitimacy: first, do members regard the *process* of regime formation as one that involves stakeholder input and reflects the values and policies that members believe in and support (input legitimacy)? Second, does the regime produce effective results and justify the regime's existence (output legitimacy)? See Thomassen and Schmitt 1999. We focus on output legitimacy because we are concerned with the effectiveness of the regime rather than the process of regime formation.
32. The UNSC includes five permanent members and ten rotating members elected on two-year terms by two-thirds vote through the UNGA.
33. E.g., Thompson 2010.

feasible, at least at first. The regime design for SRM must account for the political capacity of states to collectively build international institutions, and needs to address the key political tradeoff between participation and depth of cooperation.[34] Thus, when first designed, the SRM regime should have limited legal power, and a small governing body with weak legalization. With future reforms and reduced scientific uncertainty, deeper commitments may be possible.

This approach will help to confine the initial scope of the regime to SRM only, since mitigation and adaptation efforts proceed through the broader UNEP or UNFCCC framework. By creating an SRM regime with small membership and weak legalization, concerns over the moral hazard problem referenced above are reduced, which would be more prevalent if SRM were subsumed into existing global climate or environmental negotiating processes.

Distributed Voting Powers

The default solution in a small, weakly legalized regime is that members should have equal votes and veto powers. However, we do not speculate on the distribution of voting powers because there is too much uncertainty in terms of states' vulnerability to climate change and capacity for SRM deployment. Furthermore the distribution of voting power may be skewed during the bargaining stage through alteration of state preferences by argumentative persuasion,[35] and the outcome of such a political process is unpredictable.

Flexibility

A flexible SRM regime would allow for institutional reforms as the problem structure changes. The regime could be strengthened as uncertainty about SRM decreases, and membership could be expanded.

For UN climate negotiations, increased uncertainty leads to greater institutional flexibility.[36] This finding supports the conjecture posed by the RD framework that increased uncertainty leads to greater flexibility of institutions. Thompson distinguishes between general uncertainty, where actors have equal impact on a global public good (the atmosphere) and particularistic uncertainty, where actors have unequal impact. Thompson finds that "actors faced with general uncertainty have incentives to create institutions with transformative flexibility,"[37] whereby the institution itself can be changed so that actors can respond to new information. The SRM problem also exhibits general uncertainty, whereby actors within the regime membership could have an approximately equal capacity to develop SRM and impact global climate, with the possible exception of vulnerable, non-SRM-capable states that gain representation. Despite differences in problem structure between climate

34. Downs, Rocke, and Barsoom 1996.
35. Grobe 2010.
36. Thompson 2010.
37. Thompson 2010, 25.

change and SRM, Thompson's observation is useful for SRM regime design, and is supported by the strengthening of commitments in the ozone regime (from the Vienna Convention to the Montreal Protocol to the London Amendment) and Antarctica.

Accountability through Collaborative Scientific Research

The SRM regime should contain a subsidiary scientific body that would allow for greater accountability and the coordination of scientific research, following the model set by the UN Convention on Biological Diversity or the UNFCCC technical groups. The scientific body would help to introduce accountability for SRM experiments and deployment through *ex post* and *ex ante* technical assessments. These assessments would inform decision-making for members of the regime who make final decisions on SRM deployment and would reduce abuses of power.

Past Treaties: Implications for SRM Regime Design

In this section, we compare our proposed SRM regime to past international treaties to illustrate characteristics that may be applicable to SRM regime design. The intention of these comparisons is not to build comprehensive inferential claims for an SRM regime, as SRM presents its own unique characteristics that would make such claims refutable. Nevertheless, comparisons to past regimes are instructive. Preventative treaties include:

- *The 1968 Non-Proliferation Treaty (NPT)* set out both to reduce the number of nuclear weapons and allow for peaceful use of nuclear power, and to prevent any further development of weapons by non-nuclear parties. Nuclear proliferation has a somewhat similar problem structure to SRM, but states' capabilities are more advanced and there are key differences. First, the division of states into annexes for SRM would only be relevant if large-scale testing is carried out before any international agreement takes place. Second, the technological challenges associated with SRM are insignificant compared to the challenges of building nuclear weapons, and consequently issues of technology transfer are less important. Finally, the threat of a nuclear intervention is a far greater deterrent than an SRM intervention, which could be stopped after a short period and possibly without the long-term environmental harm longer deployment could cause.
- *The 1959 Antarctic Treaty* declares that Antarctica be used only for peaceful purposes, banning all military activities and promoting scientific cooperation and research. It concerns the regulation of unexplored territory and was created in the spirit of scientific cooperation.
- *The 1967 Outer Space Treaty* also concerns the regulation of unexplored territory and holds similar lessons to the Antarctic Treaty. It states that the "exploration and use of outer space, including the moon and other

celestial bodies, shall be carried out for the benefit and in the interests of all countries" (art. I). States agreed to sacrifice their right to militarize outer space in order to prevent others from doing so, because of strategic uncertainty over who could do so.

- *The 1987 Montreal Protocol* (MP), which controls the phase-out of the production and use of ozone-depleting substances is often held up as an example of a successful environmental agreement. The negotiation process was initiated by UNEP in the early 1980s, leading to the 1985 Vienna Convention, which set out general obligations and procedures including a provision to "take appropriate measures" to protect the environment against human activities that are likely to modify the ozone layer. As scientific and economic uncertainties were reduced, the MP underwent several reforms to implement stricter controls on ozone-depleting substances. It was initially signed by 24 states and has since been ratified by 197 governments. The MP offers an analogy for the involvement of developing states with an SRM regime, who lack the interest or resources to undertake SRM. For the MP, developing states did not have to change their behavior immediately by joining, and could gain a voice in the negotiations.

These treaties suggest two pathways for SRM. The first route would be "national appropriation" as with arms control, whereby some states have strongly invested interests in SRM, and an NPT-type structure could emerge with states divided into two annexes, the "haves" and the "have-nots." Alternatively, SRM could become taboo or subject to tightly controlled implementation much like the mineral exploitation of Antarctica or Outer Space, or to preserve the "common heritage of mankind" as in the case of the military use of outer space. To the extent that past treaties provide guidance for SRM governance, they illustrate a useful distinction. For arms control treaties, states had strongly vested interests and linkages, and complex treaties with mixed success emerged. For instance, India's opposition to the NPT was based largely on division of states into two annexes to account for differentiated nuclear capabilities. Antarctic and Outer Space negotiations began before states became strongly invested and dependent on the unexplored territory and activities of concern became taboo. From a policy standpoint, past treaties suggest that states could negotiate a more effective treaty if they began negotiations early, before interests or dependence on resources grow.

Regarding scientific uncertainty, for Antarctica and the ozone treaties (particularly the Vienna Convention, Montreal Protocol, and London Amendments), high scientific uncertainty led to flexible regimes with initially small memberships that were expanded and legalized over time. For Outer Space, there was low scientific uncertainty and a fixed, one-off agreement. Structural uncertainty over the militarization of outer space provided incentives for states to join. Given the high structural and scientific uncertainty for SRM, this comparison supports a flexible SRM regime design. Antarctica and the MP also contain accountability mechanisms through scientific research and assessment, as proposed for the SRM regime. Thus to the extent that treaty comparisons are valid, Antarctica and the MP support the proposed SRM regime design with a flexible regime that expands and legalizes with time from an initially small membership requiring weak commitments.

Feasibility of the Proposed SRM Regime

We have argued that a new SRM regime with small membership and weak legalization would be most effective in upholding a number of widely held governance principles on SRM. In this section we consider whether the proposed SRM regime is politically feasible. To be feasible, states must determine if the SRM regime is in their self-interest and will leave them better off than unilateral governance or utilizing existing institutions. For instance, it is arguable that the Stockholm Declaration, the Rio Declaration, the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, or others, could be utilized or modified to cover SRM, even though they were not expressly designed for such a purpose.[38] The CBD has already included language on geoengineering methods that affect biodiversity.[39] Given the interests and preferences of states, will states have sufficient incentive to participate and ratify a new SRM regime? What are the obstacles to regime formation?

Rationale for States' Participation

States will seek to join an SRM regime for three reasons. First, and most importantly, states will want to ensure that others do not act unilaterally. With high structural and scientific uncertainty over SRM climate impacts, states will be concerned that the actions of others will cause negative climate impacts for them. If one states acts, then all other states are at risk of suffering adverse climate impacts. Thus states will have strong incentives to join the regime to deter other states from deployment. Participation in a new regime by SRM-capable states would reduce the risk of unilateral action by requiring a temporary moratorium on SRM deployment. Ratification and compliance with the regime would increase the likelihood that any decision on the use of SRM would be collective.

Second, states will want to have a voice in SRM diplomacy and influence the actions of others. An SRM regime could offer states the opportunity to lock in their policy preferences.[40] Powerful states will be willing to accept short-term

38. 1972 UN Conference on the Human Environment (the Stockholm Declaration); 1992 Rio Declaration on Environment and Development; 1978 Environmental Modification Convention (ENMOD).
39. UNEP 2010.
40. As described in principal-agent theory. See Hawkins et al. 2006.

costs in order to create institutions that lock in their power long-term, and less powerful states will want to join those institutions to allow them a greater platform to communicate their interests. For example, the US and Europe established membership and control mechanisms that maintained their power over the long term for institutional arrangements such as the Bretton Woods agreement, the IMF, and NATO.

Third, participating states would stand to benefit from collaboration on scientific research, and accountability of SRM activities would be provided by evaluation of SRM proposals both *ex ante* and *ex post.* Scientific collaboration would build mutual trust and lessen the risk of harmful impacts from unilateral SRM activities.

Obstacles to Regime Formation

A greater extent of heterogeneous preferences could make it more likely that power constraints would lead to a sub-optimal regime.[41] However, a smaller membership generally implies less variation in preferences, since membership would be confined to states with similar interests. These interests may reflect a collective vulnerability to climate change and SRM, the technical capacity and financial means to perform an SRM intervention, and a desire to reduce SRM uncertainty and control the actions of others. With time, these interests may lead to greater convergence of SRM policy preferences, as with other environmental issue areas.[42]

Another possible obstacle to regime formation is legitimacy. We have explored the tradeoff between legitimacy and effectiveness in the context of regime membership; however a full account of the SRM regime's legitimacy merits further exploration.[43] For the regime to be recognized broadly as legitimate, representatives of non-SRM-capable states from vulnerable regions should be included. A scientific body would provide some measure of legitimacy through accountability and transparency. Past treaties such as the MP and the Antarctic Treaty provide precedent for successful regimes that started out with small memberships that were recognized as legitimate, with the intention of future expansion.

SRM entails broader questions for environmental institutional design. Under conditions of high scientific uncertainty it is unclear whether a highly centralized regime (e.g., Antarctica or Outer Space Treaty) or a regime complex (e.g., climate change) may emerge on SRM.[44] In the case of an SRM regime complex, the proposed regime, with small membership, could be coupled to the UNGA or UNFCCC, which would provide an alternative means to achieve legitimacy. Alternatively, coalitions on SRM may form through existing regional

41. Moe 2005.
42. Holzinger, Knill, and Sommerer 2008.
43. The legitimacy of SRM experimentation is addressed in Morrow, Kopp, and Oppenheimer 2013.
44. On regime complexes, see Alter and Meunier 2009; Keohane and Victor 2011.

bodies such as the EU, ASEAN, the African Coalition, or the Major Economies Forum on Energy and Climate.

Conclusion

Potential future SRM deployment presents a threat—albeit an uncertain threat in terms of extent and distribution of impacts—to all states, and thus the goal should be to prevent SRM deployment in the near term. While different in nature, SRM deployment and climate change are inherently connected. SRM is also unique in that states could jointly agree on deployment as a global public good if states are highly vulnerable to climate change, uncertainty about SRM can be reduced sufficiently, and the benefits of acting outweigh the costs. An international regime for SRM is needed to avoid diversion of resources from mitigation of climate change, remove decision-making powers from nonstate actors, encourage transparency, and reduce the likelihood of unilateral action. One area for future research is the governance of carbon dioxide removal.

The SRM regime we propose would encourage collaboration and accountability through a subsidiary scientific body, and would require a temporary moratorium on SRM deployment. The Antarctic Treaty, Outer Space Treaty, and Montreal Protocol provide positive analogies for successful models of international cooperation that are preventative in nature. These treaties show an advantage to beginning negotiations early before states have strongly invested interests, especially when compared to examples from arms control. The regime would initially have limited membership and weak legalization, solely encompass the issue of SRM, and be flexible, allowing for future institutional reforms to encourage deeper commitments and broader membership.

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