C2G
Carnegie Climate Governance Initiative

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EVIDENCE BRIEF
Governing Solar Radiation Modification

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Summary

This briefing summarises the latest evidence around Marine Cloud Brightening (MCB) and Stratospheric Aerosol Injection (SAI), two important types of Solar Radiation Modification climate-altering technologies. It describes the techniques, explores their technical readiness, current research, applicable governance frameworks, and other socio-political considerations. It provides an analysis of the types of geopolitical issues and concerns, including security, that the technologies may give rise to and how existing governance does or does not help address those. It also provides an overview of key existing governance instruments of relevance to their governance.

About C2G

The Carnegie Climate Governance Initiative (C2G) has no position on whether SAI or MCB should be researched, tested or deployed. It seeks to raise awareness and provide impartial information about these proposed climate-altering technologies with policymakers and catalyse debate about their future governance. C2G has prepared several other briefs exploring various carbon dioxide removal and solar radiation modification technologies and associated issues. These are available on our website.

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Introduction

Four years after the Paris Agreement on climate change, recognition is growing that without a rapid acceleration in action, limiting global average temperature rise to 1.5-2 degrees Celsius (˚C) will not be achieved through emissions reductions or existing carbon removal practices alone. Scientists have begun exploring the additional use of large-scale interventions to limit climate impacts, including Carbon Dioxide Removal (CDR) and Solar Radiation Modification (SRM) techniques (for a review of potential approaches see Zhang et al., (2015)). There are numerous proposed methods of SRM, many of which differ significantly. This briefing focuses on the two approaches to SRM that are thought to have the greatest cooling potential – Marine Cloud Brightening (MCB) and Stratospheric Aerosol Injection (SAI). Other proposed SRM technologies include, for example, cirrus cloud thinning and enhancing surface albedo.

The underlying objective of SRM technologies is to increase the reflectivity, known as "albedo", of the Earth's surface or atmosphere. An increase in the amount of sunlight, known as solar radiation, returning to space would alter the Earth's radiation balance, working like a shade, thus cooling and countering some of the effects of greenhouse warming.

A doubling of carbon dioxide (CO_2) concentrations in the atmosphere from pre-industrial levels to 550 parts per million in ambient air is expected to create 3˚C of global warming (IPCC, 2007). Estimates suggest that if SRM were deployed, it would need to reflect 2% of sunlight back into space, to counter this amount of warming (Shepherd, 2009). However, neither SAI nor MCB is a substitute for emission reductions to net zero, and then net negative, as they do not address the underlying cause of global warming - increased greenhouse gas (GHG) concentrations in the atmosphere (Robock, 2018). These methods would have very little effect on ocean acidification. In addition, given the complexity of the climate system, unintended consequences of deployment of either technology may occur if deployed at climate-altering scales (Russell et al., 2012, Robock, 2018).

Interest in the potential for SRM to either cool the global climate, or temporarily reduce the amount and duration of an overshoot of the Paris temperature goals is growing (Asayama, 2019). This would be a short-term measure and used only if the reduction and removal of CO_2 emissions had not happened fast enough. Such a deployment would end once actions to reduce or remove the excess GHGs had been successful. However, SRM remains a complex technical, socio-political and governance challenge. For example, the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C (2018) notes: "Although some SRM measures may be theoretically effective in reducing an overshoot, they face large uncertainties and knowledge gaps as well as substantial risks, institutional and social constraints to deployment related to governance, ethics, and impacts on sustainable development. They also do not mitigate ocean acidification."

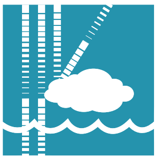
This briefing is not a comprehensive, detailed assessment of SRM, nor of the two techniques discussed here, SAI and MCB. Rather, it provides a description and brief analysis of the technological readiness, the research landscape, and governance, geopolitical, security and socio-political issues associated with them. In section one the technologies are described in turn and section two explores geopolitical issues and concerns that may arise. Tools and instruments of governance that may apply are explored in section three. The IPCC has been tasked to capture global knowledge on SRM techniques and how they impact pathways in their Sixth Assessment Report (AR6), which may provide a more detailed analysis in due course.

SECTION I: Marine Cloud Brightening and Stratospheric Aerosol Injection

Introduction

This section introduces the two main approaches to SRM, briefly describing their technical readiness, current research, applicable governance frameworks, and other socio-political considerations. For information, C2G uses the IPCC's definition of governance - "A comprehensive and inclusive concept of the full range of means for deciding, managing, implementing and monitoring policies and measures. Whereas government is defined strictly in terms of the nation-state, the more inclusive concept of governance recognises the contributions of various levels of government (global, international, regional, sub-national and local) and the contributing roles of the private sector, of nongovernmental actors, and of civil society to addressing the many types of issues facing the global community" (IPCC, 2018).

Table 1 provides an overview of the two technologies, their technological readiness and some of the governance challenges.

Proposed Technology		Readiness and potential	Governance Challenges
	**Marine cloud brightening (MCB)** • Seeding and whitening clouds above ocean surfaces, most likely using sea salt spray, to reflect solar radiation back into space. • There is a potential for rapid regional cooling delivery directly after deployment. • Estimated cost per year of per unit of radiative forcing (W/m^2) is- \$200 Million[1] (Shepherd, 2009).	• Technology theoretical, based on natural analogues and computer models. • Some potential for small scale outdoor experiments by 2020.	• If undertaken within an Exclusive Economic Zone (EEZ), governance would be for the single country. In international waters, regulation would likely be covered by customary international law. • The proposal to use sea salt may in due course be interpreted as a pollutant, and the technique would then be subject to the London Protocol (LP). • Regional variation in impacts (e.g., temperature and hydrological). • Social acceptability remains uncertain.
	**Stratospheric aerosol injection (SAI)** • Reflective aerosols would be deployed in the stratosphere. • Modelling suggests planetary cooling within a year is possible. • The cost per year of reducing radiative forcing by 1 W/m^2 [1] is estimated to be \$5 billion per annum (Stavins & Stowe, 2019). Suggesting the effects of a doubling of carbon dioxide concentrations could be countered for in the order of \$25-50 billion a year.	• Theoretical understandings of the technique only. • Mechanisms for delivery not yet developed. • Attribution detection problematic.	• Governance measures may include state and customary law, the Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC) and amended instruments which could include air pollution instruments, the Vienna Convention and others. • Evidence suggests potential geopolitical and security issues may arise and SRM may strain international institutions and cooperation. Potential for moral hazard and other forms of mitigation deterrence.

[1] A doubling of CO_2 from pre-industrial would create a radiative forcing of 3.7 W/m^2 (Salter 2008) . -1W/m^2 would be the equivalent of reducing the warming effect of a doubling of CO_2 concentrations by 27%.

Marine Cloud Brightening (MCB)

The principle

The fundamental principle underlying MCB is the same as for SAI – they would both seek to increase albedo. In the case of MCB, clouds over the oceans would be engineered to be brighter, increasing the amount of sunlight that is deflected back out into space, hence achieving cooling. As with SAI, MCB would not address the cause of warming, the concentrations of GHGs, and it could also raise questions of moral hazard, i.e., SRM carries risks that it may undermine individual, collective or political incentives for delivering mitigation (Lin, 2012).

The technique and its readiness

In relatively dust-free parts of the marine atmosphere, increasing the number of cloud-condensation nuclei (particles around which droplets of water coalesce to form clouds) has been shown to raise cloud albedo significantly and may also increase cloud longevity (Albrecht, 1989) as demonstrated in situ by the E-PEACE project (Russell et al., 2013). An MCB intervention would seek to increase the number of cloud-condensation nuclei by spraying fine particles – likely of saltwater – into clouds.

The scale of effect of this technique could be very large. For example, a doubling of the natural cloud-droplet concentration of the marine stratus clouds off western coasts of North and South America and the west coast of Africa would compensate for approximately a doubling of atmospheric CO_2 (Latham et al., 2009). However, the potential to scale up MCB to regional scale is unclear.

Distribution mechanisms might be technically uncomplicated. It has, for example, been suggested that solar powered ships or aircraft could routinely deliver the required particles at precisely the locations needed (Wood et al., 2018). However, spray nozzle design to consistently deliver particles of the right size to the right altitude remains a research challenge.

Modelling suggests MCB could be deployed within the Arctic region delivering a rapid cooling effect (Parkes, 2012), slowing ice melt and cooling the Earth more widely in due course (Nalam et al., 2017). However, such a deployment may also drive heat travel from regions to the south of the Arctic into the Arctic region, bringing warmer air to the region, counteracting some of the direct effects of the MCB deployment.

As with albedo enhancement, such as brightening land surfaces, MCB could also be deployed locally, securing regional benefits and such interventions are currently being researched at the Sydney Institute of Marine Science (Ellis-Jones, 2017), or those funded by the Australian national government and Queensland state government which are exploring the use of MCB in Great Barrier Reef protection (BRF, 2018).

Potential risks and key unknowns

SRM modelling studies, although they allow scientists to simulate – and experiment with – alternative conditions, scenarios and pathways in ways that are simply impossible empirically, also occlude certain dimensions with potential relevance especially to governance and geopolitics. McLaren (2018) highlights shortcomings (particularly regarding SAI) in the “literature’s often implicit assumptions of effectiveness, precision and controllability, its metrics and methods of aggregation, and its use of an excessive counterfactual of unabated climate change” (McLaren, 2018). The first of McLaren’s points may lead to an underestimation of risks of failure, moral hazard and uncertain distributional effects. The second downplays potential localised and variegated vulnerability and existing inequalities that might be exacerbated. And the last focuses attention on “technological means of avoiding the extremes of climate impacts and away from moral obligations arising from historic emissions and other injustices of energy systems" (ibid.). The key conclusions from modelling concerning how SRM may affect climate risks are therefore conditional upon the omission of such factors.

Concerning variables that are included in modelling work, a key remaining technical challenge is resolving which particles to use and how to consistently produce a supply of them of an appropriate diameter and quantity at sea. The most likely candidate base material is sea water, a material that, unlike SAI candidate materials (see below) would not have wider environmental or health effects.

It is uncertain how the climate will respond to the large-scale radiative forcing MCB may have the capacity to deliver. Climate models suggest MCB could be very efficient in reducing global warming (Kravitz et al., 2014). However, risks could conceivably include changes in dynamic transport of moisture and air, affecting weather systems and important local climate phenomena such as monsoon rains and ecosystem functioning (Park et al., 2019, Keith et al., 2016, Mercado et al., 2009). Such disruptions could lead to issues such as dryland expansion or flooding, environmental degradation and food security concerns in effected states or regions.

If an MCB deployment that had cooled the planet were terminated over a short time period, a significant and rapid temperature 'bounce back' may result, whilst the climate re-stabilised (Kosgui, 2011). This rapid temperature increase, known as a 'termination shock', could increase temperatures beyond those that would have been experienced had MCB not been undertaken, and could be damaging (Robock, 2018). Such a termination shock has the potential for large-scale environmental, economic and social impacts (Matthews and Caldeira, 2007). However, Parker and Irvine (2018) have argued, in the case of SAI, which is also capable of producing a termination shock, that there are no obvious scenarios under which rapid termination might be allowed to occur under a well-governed system, suggesting that an understanding of the implications of cessation may be sufficient to ensure resilience in the global governance system. This is further discussed in Section II.

Current research activity

In December 2019 the US (United States) government, for the first time, authorised $4 million of funding to the US National Administration and Atmospheric Administration (NOAA) for research on 'solar climate interventions' including 'proposals to inject material to affect the climate' (Temple, 2019). The scope of this investment encompasses both MCB and SAI.

In a linked action, a bill that proposes to enable NOAA to establish a formal climate-altering research programme was introduced to the US Congress, by Californian Congressman McNerney on 19 December 2019. The Atmospheric Climate Intervention Research Act – H.R.5519 (ACIRA, 2019) seeks to 'improve measurement and assessment capabilities for understanding proposed atmospheric interventions in Earth's climate, including as a priority, the effects of proposed interventions in the stratosphere and in cloud aerosol processes' (ACIRA, 2019). This bill aims to improve knowledge of stratospheric chemistry and the potential effects and risks of SAI and MCB. Importantly, it would also grant NOAA oversight authority to review and report on SAI and MCB experiments proposed by other research groups in the US.

No programmes of field work that include small scale deployment are underway. However, the Marine Cloud Brightening Project, based at the University of Washington is leading research activity in the area and has described a research plan (Wood, 2018) to help address some of the remaining challenges which include: MCB field experiments to provide better insight into cloud-aerosol interactions and the effect of MCB on cloud physics; how to generate, deliver and observe particles in an ecologically benign way; and, studying the regional climate implications. At the localised scale, interventions are currently being researched, with funding from the Australian government (BRF, 2018) with a view to reducing seasonal heating, which is causing coral bleaching, over some parts of the Great Barrier Reef. A measure that could benefit the tourist industry linked to the Reef.

Socio-political considerations

There is no established nor theorised market to drive a move toward deployment. Infrastructure (deployment vehicles) are currently not available. Public perceptions and likely responses to MCB are uncertain, although research in the United Kingdom (UK) suggests that a perceived controllability of MCB may reduce citizens' concerns about governance of the technique (Bellamy et al., 2017). Considering the potential issues, alongside the known value of public engagement in technological evolution, calls have been made to explore public perceptions regarding MCB over the Great Barrier Reef (McDonald et al., 2019)

Governance

MCB requires governance, not only because a decision to deploy would amount to an intentional decision to effect the Earth's climate, and therefore all inhabitants, but also because it may affect other systems such as the oceans, weather, agriculture, regional hydrologic cycles, and biological productivity (Shepherd, 2009), affecting states and regions, both positively and negatively, and in different ways. MCB could, then, potentially, generate geopolitical tensions and security-related governance challenges (see Section II for a discussion of MCB and SAI geopolitical and security issues). Furthermore, the possibility of termination shock may raise other decision-making, monitoring and validation governance issues (Kosgui, 2011). Linked to all these effects are questions about the governance of research and scaling up from research to field trials and deployment (SRMGI, 2011, Parker, 2014).

Assuming sea water spray is used for deployment, responsibilities under the United Nations Convention on the Law of the Sea (UNCLOS) and the London Convention and London Protocol (LC/LP) to protect against pollution of the marine environment would not constrain deployment, unless, as noted in section 24 of a report by the Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP, 2018), the deposition of salt particles on the ocean surface were interpreted as the depositing of "wastes or other matter" under the London Protocol. Otherwise, countries would generally be free to conduct MCB on the high seas, provided that this is done with "due regard" for other states' interests. However, if other particles were used, the Conventions and Protocol may become relevant to those seeking to do both field work and to deploy at large scale. Monitoring the effects of deployment would have governance connotations and how MCB might be monitored (both deployment and its effects) is not resolved.

Stratospheric Aerosol Injection (SAI)

The principle

SAI seeks to lower the average global temperature by increasing the amount of reflective aerosol particles in the lower stratosphere. An aerosol is a suspension of fine solid particles or liquid droplets, in air (or another gas) – examples of natural aerosols include fog and dust. Evidence of such particles' effect is available in the natural environment. For example, in 1991, Mount Pinatubo, a volcano in the Philippines, erupted, discharging in the order of 20 million tonnes of sulphur dioxide, (SO_2), into the stratosphere. The resultant sulphate particles from Pinatubo increased global albedo, reflecting enough solar energy back into space to cool the global climate by an average of 0.5˚C over the following two years, after which temperatures moved back to those commensurate with existing GHG concentrations.

SAI would deploy aerosols in the stratosphere located between 7 and 15 kilometres above sea level (Labitzke and Van Loon, 2012). The stratosphere is a relatively stable zone in the atmosphere where there is less vertical than horizontal mixing, meaning an aerosol particle could remain in the stratosphere, reflecting solar radiation for a period measured in years (Keith, 2013). If the injection were to take place in the troposphere (the lower atmosphere) particles would quickly be caught in turbulent air and fall back to ground level in a matter of weeks. It is expected that SAI could have near immediate and direct cooling effects and it is likely to be capable of delivering planetary scale cooling within a year (Keith, 2013).

The technique and its readiness

The aerosol delivery mechanisms are unresolved, although aircraft delivery is expected to be the most practicable and economic method (Robock et al., 2009, Keith, 2013, Stilgoe, 2015). Given stratospheric aerosols' cooling capacity appears to increase with altitude (Krishnamohan et al., 2019), to be fully effective, planes would need to fly at approximately 20,000 metres and be fitted out with spraying kit to deliver particles (Keith, 2013). Nozzles to eject aerosols of the desired size are feasible, but have not yet been developed or tested (see research activity below). Aircraft, whilst capable of flying at 20,000 metres altitude are not, currently, capable of flying at this height with a heavy cargo for extended periods of time (Smith & Wagner 2018).

Two key factors drive interest in SAI; the rapidity with which it may take effect, combined with the high potential cooling efficiency and low direct cost of deployment. It is suggested that 1 kg of sulphur situated in the stratosphere could offset the warming effect of several hundred thousand kilograms of CO_2. Keith (2013) has calculated that the additional radiative forcing of the 240 billion tonnes of carbon released by human activity, since the beginning of the industrial revolution could be reduced by half. By an annual injection of 1 million tonnes of aerosol, meaning that SAI potentially has very large leverage over anthropogenic carbon climate forcing. If a fleet of 20 aircraft were deployed it is suggested that they could deliver enough radiative forcing to produce detectable climate cooling (Keith, 2013) although, because the particles will fall out of the stratosphere over time (estimates suggest in the order of three years), they will need to be continually replaced to maintain the level of cooling. Larger scale effects would require more complex aircraft solutions, but these may be found by adapting existing aircraft technology. Because only small quantities of material may be required to create a detectable effect, there is some concern about how to govern the scale up of any future field trials from small scale projects to research that might change the climate. This is explored further in the research governance section below.

The theoretical relative ease of implementation, combined with the radiative efficiency of aerosols, suggests the direct costs of SAI might be low, relative to cutting emissions (Brahic, 2009). Assessments suggest that SAI could be delivered using aircraft at a cost of less than $10 billion per year for 2 Wm-2 (Stavins & Stowe 2019). For comparison, a doubling of the CO_2 concentration from its pre-industrial value to 550 parts per million of ambient air (ppm) would give a radiative forcing of about 3.7 W/m^2 and an estimated equilibrium global warming of about +3°C (range 2.0 to 4.5°C) (IPCC 2007).

A UK Royal Society review included estimates that deployment costs of SAI could be in the order of 1,000 times less expensive than some other climate-altering technologies. (Shepherd, 2009). However, MacKerron (2014) has drawn attention to the importance of indirect economic costs over direct cost estimates – drawing parallels with SAI and the nuclear industry which was initially expected to provide energy "too cheap to meter" (Strauss, 1954), but which now requires state subsidy to maintain. Many SAI cost estimates exclude, for example, indirect costs such as schemes to compensate "losers", or costs stemming from social or international frictions resulting from SRM (see below). Assessments that include more comprehensive cost assessments, indicate that it would be possible to cut the rate of warming in half (reducing radiative forcing by -0.25 Wm-2) at a cost of $2.25 Billion per annum following a pre-start investment in infrastructure – including aeroplane research and design – of $3.5 Billion (Smith and Wagner, 2018).

Potential risks and key unknowns

Particle choice is unresolved. Particle size is important because the aerosol needs to be as "reflective" as possible and it should remain in situ and stable for as long as possible (Rasch et al., 2008). The larger particles are (larger than two tenths of a micron), the less effective at scattering light they become for a given mass deployed (Keith, 2013). Larger particles also condense, coagulate and increase in size more quickly than smaller particles and would therefore fall out of the stratosphere more quickly than small particles.

The introduction of sulphates, one of several candidate particles, would not create a unique change to atmospheric chemistry because sulphates are continuously introduced into the atmosphere naturally. For example, meteoric dust, volcanic ejections and emissions from marine, terrestrial, chemical and industrial sources all contain sulphates (Keith, 2013). Sulphate interaction within the atmosphere is already occurring and has been researched. For example, it is known that the sulphuric emissions from marine shipping have a cooling effect and, according to Eyring et al, (2010) global mean temperatures could be as much as 0.25˚C lower than they would otherwise have been. These insights play an important role in constructing the case for choosing sulphates over other particles (Shepherd, 2009, Stilgoe, 2015).

The behaviour and interactions in the atmosphere of other possible SAI aerosols are understood in less detail. How aluminium oxide (alumina) impacts on the stratosphere is partially understood following NASA studies motivated by interests in how the Space Shuttle's rocket plume, which included quantities of alumina, might affect ozone (Ross and Sheaffer, 2014). Aluminium oxides are common in natural mineral dusts providing a data resource for future research on their impacts (Lawrence and Neff, 2009). In addition, there is a broader base of knowledge about alumina from its use as an industrial material (Weisenstein et al., 2015). There is a less well-established evidence base for diamond, a material suggested by Keith et al., (2016) for SAI purposes, although there is some evidence that diamond nanoparticles are nontoxic to biological systems (Schrand et al., 2007).

The potential for SAI to lead to ozone loss is considered an important risk of deploying SAI (Morton, 2015, Robock, 2018). Ozone protects all life on Earth from harmful ultra-violet rays (GES-DISC, 2016). Changes in aerosols in the stratosphere could influence its chemistry and reduce ozone abundance in the stratosphere (Tilmes and Mills, 2014). This effect was measured after the 1991 Mount Pinatubo eruption (McCormick, 1995), an example of how existing knowledge can inform understanding of SAI. While the ozone layer is still recovering from the effects of anthropogenic-depleting chlorofluorocarbons (CFCs), studies suggest any new stresses on the total ozone column, particularly at high and mid-latitudes, before 2050, would lead to a considerable increase in ultra-violet light at the Earth's surface (Heckendorn et al., 2009) and recovery in the Antarctic ozone hole could be delayed by at least 40 years (Tilmes and Mills, 2014).

Some potential SAI particles may have the potential to enhance ozone. Alumina is a solid aerosol which would not, of itself, increase the volume of the aqueous sulphuric acid which drives the reactions in sulphates that lead to ozone loss (Keith, 2013). However, they do introduce new risks, possibly including acting as a catalyst causing reactions that may affect ozone (Keith et al., 2016).

Some candidate aerosols may cause harm as they drop out of the stratosphere into the troposphere forming acid rain or air pollution, affecting the terrestrial environment (Keith, 2013). The resulting number of deaths or illnesses is uncertain because the "fall out" would be distributed globally, including over remote unpopulated areas. However, Keith (2013) argues that the death rate would be markedly less than the number of anthropogenic climate change related deaths, that would be avoided through cooling delivered by SAI.

It is uncertain how the climate will respond to the large-scale radiative forcing SAI may have the capacity to deliver. Climate models suggest a theorised ideal compound SAI could be very efficient in reducing model-simulated global warming (Kravitz et al., 2014). However, risks could conceivably include accelerated changes in dynamic transport of moisture and air, affecting weather systems and important local climate phenomena, such as monsoon rains and ecosystem functioning (Keith et al., 2016, Mercado et al., 2009).

In common with MCB, there is a potential termination shock associated with SAI. Although, the rate of change in radiative forcing created by a stopping of SAI would be expected to be slower than with MCB, as the aerosols would remain in situ longer than brightened clouds, it is possible that the rate of termination shock would not be significantly different because of the time it takes for the global climate to warm up.

SAI deployment, if large enough, could change the appearance of the sky. The characteristic blue of a cloud free day might no longer be visible. Rather, the sky could appear to have a high-level thin veiling of mist or cloud (Kravitz et al., 2012). Whilst diffuse light is known to help plants, including crops, grow more quickly, what the emotional and psychological effects on humans and other life might be is unknown.

As with MCB, it has been suggested that SAI could be deployed within the Arctic region. Modelling suggests it has the potential to rapidly reduce the polar amplification, slow ice melt, and reduce global warming (Nalam et al., 2017). However, it may also have similar secondary effects as MCB, including generating heat travel from regions to the south into the Arctic which could counteract some effects of the SAI deployment (Tilmes et al., 2014). In addition, modelling suggests Arctic deployment of SAI could cause the inter-tropical conversion zone to move southward, negatively effecting climates in that region, including the monsoon (Nalam et al., 2017), unless it was balanced by comparable SAI deployment in the Southern Hemisphere (Nalam et al., 2018).

Current research activity

To date, all SAI research has been theoretical – either exploring climate effects, based on climate models (Berdahl et al., 2014, Irvine et al., 2009), potential engineering solutions and, in particular seeking a better understanding of governance issues (Horton et al., 2018, Macnaghten and Owen, 2011, Stavins and Stowe, 2019, Rouse, 2018) and the social appraisal of the technology (Bellamy et al., 2012, Stilgoe, 2015). Work on these areas is continuing with a globally distributed research effort (although most academics working in the field are based in the USA and Europe).

The first SAI related experiment ever to be conducted outside of the laboratory is now in development. Announced on 24 March 2017 (Temple, 2017), the Stratospheric Controlled Perturbation Experiment (SCoPEx) plans to advance understandings about how stratospheric aerosols may be relevant to SAI (SCoPEx, 2019). The project aims to deploy an instrument package, under a controlled balloon, to the stratosphere where it will release between 0.1 – 2kg of calcium carbonate, and potentially sulphate, to create a perturbed air mass of 1km x 100m. The instrument will subsequently measure changes in the perturbed air, including changes in chemistry, aerosol density and how light is scattered (SCoPEx, 2019). The project is funded by Harvard University drawing from a fund raised from philanthropic giving.

The project seeks to learn more about the potential efficiency of SAI, and its risks. The findings may improve the capacity for models to better predict how larger scale deployment could disrupt stratospheric ozone (SCoPEx, 2019). As part of the project's own governance, an advisory committee of experts has been established in part to recognise and identify the social and political implications of conducting the proposed research.

Given the uncertainties described above, further research might help better understand how SAI within the Arctic and other regions may affect climates elsewhere on the planet.

The potential for negative health effects that have been associated with SAI (Effiong and Neitzel, 2016), suggest that further SAI research should seek to better understand the implications of exposure to, and the evaluation of, any toxicological properties of potential sulphates and other materials.

Socio-political considerations

Whilst there have only been a limited number of studies, public responses to SAI have generally been negative. The studies have suggested, for example, that publics are likely to be most concerned about the uncertainty of the effects of deployment and the chances of harmful outcomes arising and what those may mean. Studies have also indicated that the public perceives SRM, and in particular SAI as a very powerful technology with far reaching capacity for effects with which scientists are taking on the role of "playing God" (Macnaghten and Szerszynski, 2013, Pidgeon et al., 2012, Merk et al., 2015, Braun et al., 2018).

There is recognition by some SAI researchers that they are in danger of either lacking or being perceived to be lacking humility, as they work toward developing the means to control the climate, an ambition that Keith (2013) has recognised may appear as hubris. It has been suggested that researcher awareness of the social acceptability of other controversial research fields, such as nanotechnology and synthetic biology may have informed their thinking and encouraged a cautious approach to developing the technique (Sarewitz, 2010).

To date, few non-specialists have participated in debates about the future of SRM. For example, indigenous peoples have figured widely in climate-altering technology literature as a key affected constituency, e.g., in the Arctic. However, some have noted that they have not yet been visible in debates about the future of SRM (Buck, 2018). More generally, there have been few "attempts to explore concerns that populations might harbour and how those concerns could inform ethics and policy discussions" (Carr and Preston, 2017). This limited participation in dialogue about SAI, and the associated low levels of understanding about it (Pidgeon et al., 2012) may, however, be overcome through "rapid, deliberate education of both various publics and those involved in the policy process about what it (SRM) even is, what its potential benefits and risks are, and why it is that scientists are looking at this set of potential technologies" (Wagner and Zizzamia 2019).

There is uncertainty regarding who might choose to deploy SAI, pay for it or any loss or harm that may arise from deployment (Reynolds, 2019). SRM has been identified not necessarily to be a straight-forward humanitarian project but, as suggested by Buck (2012) it could be pursued in the service of a wide range of interests. The involvement of philanthropists in funding research and debates about public funding have in themselves raised important questions about how research and development could or should be driven (Nisbet, 2019), and debates about which interests might be aligned with or antagonistic towards SRM are on-going. Some are concerned that climate sceptics may pivot rapidly from a position of climate denial to strong SRM advocacy (Morton, 2015) and some groups already thought to be spending large sums on avoiding or postponing mitigation, may choose to promote SRM as a way to achieve or protect their business models (McLaren, 2016).

A recent survey of libertarian think tanks shows that most remain unaware of SRM although, a majority of those stating a position favour funding SRM research as an alternative to mitigation (Collomb, 2019). In a detailed statement, Climate Action Network International (CAN), the world's biggest network of Civil Society Organisations (CSOs) working on encouraging government action to address climate change, unanimously recommended adaptation and mitigation as first line solutions in favour of SRM. CAN is also strongly opposed to outdoor SRM experimentation and deployment in the light of the risks associated with it (CAN, 2019).

Among publics there is a loosely formed group, called "Chemtrailers" who believe that aircraft contrails are trails of unknown chemicals sprayed into the atmosphere as a large-scale programme of weather and climate modifications, or population control (Cairns, 2014). This group associates these beliefs closely with SAI. While this is a fringe phenomenon, in 2017, the Cooperative Congressional Election Study suggested 10% of the US population were certain that "the chemtrail conspiracy was completely true" and, a further 20 – 30% thought the theory was "somewhat true" (Tingley and Wagner, 2017). This example illustrates that there are wider issues around trust, politics and communication and shows how technologies conceived in the abstract invariably enter complex societal – and inter-societal – conditions which may be challenging to incorporate into a rounded governance of SRM in the future.

Governance

The need for governance of SAI arises not only from its capacity to intentionally effect the Earth's climate, but also because it may affect other systems such as the oceans, weather, agriculture, regional hydrologic cycles, stratospheric ozone, high-altitude troposphere clouds and biological productivity (Shepherd, 2009) as well as social systems, structures and deeply held values. Given these effects may differentially affect states and regions, both positively and negatively, the deployment of SAI could potentially give rise to geopolitical and associated security-related governance challenges. It has been suggested that these could include risks of conflict, discussed in Section II. In addition, known and unknown human, social and economic effects complicate the issues of governance. Further, the potential for a termination shock, or the issues of moral hazard or mitigation deterrence also raise important issues around decision-making, monitoring and validation (Kosgui, 2011). Linked to all these effects are questions about how to govern SAI research as it moves from modelling and the lab to outdoors (SRMGI, 2011; Parker, 2014).

Given SAI is accompanied by questions about risks, benefits, justice and uncertainties and is politically and economically complex, and because it may also deliver some environmental effects with differential effects on communities, it is suggested, (Stilgoe, 2015, Macnaghten and Owen, 2011, Buck, 2019) that citizens' perspectives on how SAI develops should be drawn into the processes of governance deliberation at the earliest stage in a mode of co-production.

The inclusion of publics has been shown not only to improve the innovation process (Genus and Stirling, 2018) but, in the case of SAI, it has been suggested, it would generate new knowledge about how the technologies and techniques can affect vulnerability and resilience to climate change on community and regional scales (Buck, 2018). It is suggested, then, as recommended to the US government (Parthasarathy et al., 2010) that opportunities to engage citizens in the evolution of any planning should be considered a key part of the process.

The Stratospheric Particle Injection for Climate Engineering (SPICE) research project is a useful case study of unexpected public responses to SAI and the uncertainty and complexity of SAI research governance. The announcement of the project was widely reported in the media in negative terms (Cooper, 2011; Ruz, 2011; Monbiot, 2011; Daily Mail, 2011) and elements of the project were delayed, initially for six months to allow for further engagement with stakeholders. On the day of the announcement to delay the project, a petition (ETC, 2011) was presented to the UK Secretary of State for Energy and Climate Change, calling for a suspension of the project in the light of concerns, and a possible conflict of interest with the Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC) and UN Conference on Sustainable Development. Following consultation, the funders took the decision to further delay elements of the project to allow the project team to undertake wider engagement work (Macnaghten and Owen, 2011).

Table 2. Summary of strengths, weakness and risks of MCB and SAI

Strengths	Weaknesses	Risks
High potential for effectiveness and expected to be capable of delivering planetary cooling.	Although research suggests delivery is technically feasible, the detail of delivery mechanisms is yet to be finalised.	Field trials, deployment, or the threat of deployment may create inter-state and regional tensions (see section II below).
The costs given the potential effectiveness, are low.	Currently there is no clarity about how both technologies will be governed.	If sulphates were chosen as the preferred SAI active agent, they may reduce atmospheric ozone. MCB using sea water would not present such risks.
The functioning of clouds in the atmosphere are reasonably well understood. The understanding of aerosol interactions in the stratosphere are less well known, although studies of volcanic eruptions do provide some insights.	The climate responses to MCB and SAI are uncertain. For example, there is a potential for changes in precipitation patterns.	A potential for large-scale migration following shifts in weather patterns.
Whilst marine vessels and high-altitude deployment vehicles (likely to be aircraft) will be required, no restructuring of global infrastructures or energy supply systems would be required.	More research evidence is required to inform governance discussions.	Climate termination shock, giving rise to a rapid increase in temperatures, could arise if there were an abrupt termination of deployments.
	Neither approach may be socially acceptable.	Ocean acidification would continue unabated if the technologies substituted climate change mitigation measures.

Further discussions led to the eventual complete withdrawal of the experimental elements of the project in May 2012. This decision was made, according to the SPICE project website (Watson, 2012), because of issues of governance and intellectual property.

Due to the potential transboundary impact of SAI, some level of international regulatory governance will be essential, and several current instruments do have traction on SAI (as well as other climate-altering technologies discussed in this brief). Section III of this brief explores some of those instruments, non-binding principles or codes of conduct that would apply in part to SAI. Prior to this discussion, Section II examines SRM geopolitical and security related issues in more detail.

SECTION II: SRM, Geopolitics and Security

Introduction

This section reviews geopolitical and security-related issues, including the threat, use and control of military force, wider questions of statecraft and strategy and more general issues about social, human and environmental safety, in the context of the risks and uncertainties identified in the technology assessments above.

Climate change is already giving rise to global security issues, including tensions driven by climate migration linked to food and water resource depletion and changing disease vectors and ranges. It is creating new risks that governments, institutions and communities are unable to predict or manage. Such risks and the associated stresses work as threat multipliers that aggravate already fragile situations and have the capacity to contribute to social upheaval and even violent conflict (Ruttinger et al., 2015). Climate change was, for example, identified as a threat multiplier in the lead up to the outbreak of the Syrian civil war (Kelley, 2015) where climate related water shortages in Syria, Iraq, and Turkey killed livestock, drove up food prices and affected the health of the people. In response, 1.5 million rural citizens moved to Syria's cities, which were already hosting large numbers of immigrants from the Iraq war creating critical tensions (Kelley, 2015).

How might SRM deployment evolve and why could it create tension?

Although SAI and MCB have the theoretical capacity to rapidly change the climate, it is not the case that any future deployment would be able to cool the planet very rapidly. SAI, for example, would require the slow, continuous deployment of aerosols into the stratosphere by aircraft (or other means) (Keith, 2013). It would in theory require an incremental process with the volume and density of the aerosols increasing over a period of months before their accumulation began to have a measurable effect on temperature (Morton, 2015). In the case of MCB, whilst it could be possible for a single vessel, or a small number of vessels to rapidly deploy and brighten clouds, to have a climate-scale effect that might lead to political tensions would require a large fleet (Shepherd, 2009). MCB, however, would require a smaller scale deployment to achieve localised cooling, for example to protect endangered ecosystems, such as coral reefs, or to cool coastal cities. If those cities were in contested or high-tension regions, a unilateral deployment, without warning or dialogue, might be a trigger for tension – even if the cooling were beneficial to all parties.

The ordering of any potential deployment of SRM in relation to other measures to address climate change is uncertain. For example, SRM deployment might commence after all efforts to reduce emissions have been implemented. SRM might then be deployed to deliver cooling in an interregnum whilst CDR capability (both in terms of technologies and scale) were ramped up until they were altering the climate. At this point SRM could be tapered down as CDR takes effect. A different scenario, for example, might see a deployment of SRM running concurrent with emissions reductions. In such a scenario, CDR techniques would be introduced and ramped up and, when they were having climate-scale effects, the SRM would be tapered down. Other suggestions have included using SRM as an "emergency" tool to deliver cooling in times of crisis. Each of these scenarios creates a different set of governance challenges. For example: who, and using what evidence, decides that emissions reductions and CDR have failed and that it is timely to deploy SRM; or, how might CDR be monitored and verified and who will authoritatively assess SRM and decide when it is time to either deploy, or taper down the deployment of SRM. How this complexity might be unravelled is uncertain in the current governance environment. Who, for example, should host discussions about the ordering of the deployment of imagined technologies and from where would their authority stem?

The gradual nature of the effect on temperature of any large-scale SRM is helpful in the security context. Security mistakes, including conflicts, frequently arise when information and intelligence are scarce and urgent responses are required, characterised by rapid strategic decision-making during which errors and miscalculations can be made (Chalecki and Ferrari, 2018).

However, the global politics of SRM and climate change are complex and uncertain. In the case of SRM they are not underpinned by a tried and tested governance framework (Reynolds, 2019), nor a universally agreed understanding of what the purpose or functioning of the technologies are. Already the range of countries' preferences and perspectives about climate, development, security and other interlinked, broad-scope goals are wide and diverging. Within this context, SRM may be understood extremely diversely, and not necessarily as a necessary emergency measure to arrest dangerous global climate change. It could, for example, be viewed as a threat to newly accessible resources in the Arctic; as a continuation or extension of colonialism; or to continue or even expand existing fossil fuel and extraction economies.

Furthermore, if SRM does offer the capacity, real or supposed, to tailor the climate the promise of gains (or avoided ills) to countries and regions might be large – creating a potential for more tension and contestation (Parker et al., 2018). If climate cooling capability became available through SRM, decisions may need to be taken about what kind of climate societies wish to collectively create. What would be the correct temperature, at what cost and on what basis would that be agreed? In other words, "who would set the global – or local – thermostat?". What might the strategic and geopolitical processes within this decision-making be like and what logics of action would be most prevalent?

Some countries might appreciate a much cooler temperature than others, accept different types or levels of risks than others, or apply different overall framings – and power relations would be key to how these issues play out (Schellnhuber, 2011). What role should scientists have in this? Are they to be the global police for climate protection, or advisors in a much larger process in which their evidence is just part of the noise? Will the powerful regions or states be willing to even entertain debates about sharing or giving up control of the thermostat and will the weaker countries acquiesce to doing so? Or should we, as suggested by Macnaghten (2013), seek a truly plural global dialogue about the future design of our planet? If so, how would that work and who would ultimately make decisions and stand accountable?

Who might choose to deploy SRM, and in what circumstances is unclear (Barrett, 2014), just as the future of the international system could be characterised by consolidation, continuity or a slide into less order. The issues that arise from alternate scenarios are variable. If a global consensus to deploy were reached, underpinned by a process of multilateral dialogue leading to consent and consensus about not only the decision to deploy, but also where, how much, for how long and with what objectives, and this were accompanied by a rigorous, legitimate monitoring and verification programme, security tensions may be small. Alternatively, were a unilateral (or "minilateral") deployment of SRM, without international consultation and with uncertain aims and objectives to be proposed, or to take place, the global community might well respond negatively (Barrett, 2014).

Asymmetrical impacts of SRM

A deployment might improve the climate for some, deteriorate it for others (Robock et al., 2009). Currently, there is insufficient evidence to provide robust insights into what asymmetries might occur in different deployment scenarios, and this may warrant further research. If, after a deployment, negative asymmetries occurred, and harm or loss arose, how this might be compensated – if indeed it could be compensated – by whom and under what jurisdiction has not been discussed in policy arena, although it is explored in some academic literature, for example, Parker et al., (2018) and Chelecki & Ferrari (2018). Further complicating this question is the matter of attribution. Currently, climate modelling is insufficiently sensitive to confidently attribute recent extreme climate events to anthropogenic GHG emissions (Pielke, 2019), although the science is rapidly improving.

There is even less capacity, or even a theoretical methodology, that could determine if an extreme event, or series of events that followed an SRM deployment, were caused by the deployment, the climate change that the SRM was seeking to address or indeed whether they were normal, if damaging, events. Without attribution capacity – and even with it – it may be expected that a country or region, or their citizens, which experienced extreme events post an SRM deployment might perceive those events to be directly linked to the deployment and blame those responsible for the SRM for any harm and loss (Chalecki, 2018). If such a scenario played out between countries, or regions already experiencing political tensions, the implications might be significant. For example, if two bordering countries, both with nuclear weapon capability and in a state of high tension were involved in such a scenario, an escalation of tensions could be highly damaging.

The absence of power to terminate deployment

Currently, there is no in situ governance mechanism, including regulatory frameworks or international law that is suitable for, or capable of providing a framework for SRM (Reynolds, 2019). As such, there are no legal constraints that would preclude any state (or other actor) from choosing to deploy MCB or SAI. Although there are a range of instruments and international mechanisms that might potentially be amended or operationalised to provide a framework, currently this has not begun (Section III reviews those instruments and mechanisms in more detail).

Whether a globally effective international, transparent and accountable governance system, or a polycentric patchwork model of instruments and measures, would be most appropriate for SRM is contested (Nicholson, 2018; Redgwell, 2011; Armeni and Redgwell, 2015). This brief does not explore these issues in detail, but it may be helpful to note some key questions that remain unanswered. These include: how could, or should, a global consensus backed by multiple governments, international organisations, CSOs, environmental and critical groups and others be arrived at? (Macnaghten and Owen, 2011); and, how might, and should, global, transparent, and accountable governance systems, where all actors are able to freely participate in a democratic manner, with full participation of civil society, be operationalised in the context of an individual planetary-scale intervention? (Bellamy et al., 2012).

Unilateral Deployment of SRM

The current lack of governance to stop a determined deployer gives rise to concerns about unilateral deployment. Whilst small states with limited geopolitical power and/or economic strength might be deterred from deploying by the threat of sanctions or even military intervention, powerful states, or a coalition of states working together, may not be so easily deterred. Such a unilateral, ungoverned deployment scenario, if either SAI or MCB were ever to be technically deployable, could then present a serious threat to global security.

Some working on the theoretical deployment of SRM suggest that unilateral deployment is unlikely (Parson and Ernst 2013), contending that it would require physical and technical capability that are greater than would be possible for many but the largest, most powerful countries. Further, Horton (2011) suggests that the normal interdependencies in geopolitics, mutual reliance and the need for cooperation in a globalised world would dissipate a single country's will to act alone and deploy SRM. However, others consider that large, powerful countries and coalitions of smaller states, including those most effected by climate change, for example, by sea level rise, may have the capacity and motivation to act (Ricke, et al., 2010; Chalecki and Ferrari, 2018).

Parker et al., (2018) suggest it would be possible for a large, powerful single state to deploy SRM alone, which, given the minimal governance available at present, and because of such a state's wider political and economic power, may be unstoppable, at least initially. Such an action may be contested and create novel geopolitical problems. If such a state did deploy SRM and significant harm and loss were to arise or been seen to have arisen as a result of that deployment, a situation of geopolitical crisis could arise because of the perceptions of causality, whether or not correct. How the global community would resolve this, unless a form of functioning SRM governance had evolved in advance, is unknown. Barrett (2019) has suggested that, were a single state to consider deploying SRM, any treaty prohibiting it would have little effect, because those states likely to consider unilateral deployment would also be unlikely to be signatories to such a treaty.

In the case of a "coalition of the willing" of smaller states, although not unilateral in the true sense, they would form what Parker et al., (2018) describe as a "minilateral", which would be more robust to any pressures that could potentially be brought to bear on individual states alone. Such a coalition might be viewed as no more legitimate than a small single state SRM deployment, creating similar international tensions as those that arise in the large single state SRM deployment scenario. Were a minilateral group to form, it has been suggested (Lloyd & Oppenheimer, 2014) that such a group could be attractive to others and grow to become a more legitimate and powerful actor.

SRM as a free-driver problem

SRM presents a novel collective action problem, at odds with traditional climate mitigation that is understood as a public good. The benefits of a single country's mitigation are non-rival and non-excludable because, whilst the acting country pays the economic and other costs for their mitigation activities, the environmental benefits that arise are shared around the world. This creates a "free-rider" problem (Stavins et al., 2014) – there is an incentive for countries to take advantage of other countries mitigation efforts, whilst choosing not to take similar mitigation measures themselves. SRM, however, creates what Weitzman (2015) describes as a "free-driver" problem.

As the benefit-cost ratio of SRM is large, a deploying country, or "SRM collective" could choose to deploy SRM to best suit their own perceived climate needs, they would in turn be determining the level of cooling for all other countries in the world. This free-driver problem is important because the newly created climate that is ideal for the deploying party, be that a coalition or single state, may not be desirable for others and the process through which it happened would violate common standards of procedural justice. For example, some are currently benefiting from climate change, and would prefer to retain those benefits. Alternatively, an SRM deployment might cause, or threaten to cause, changes to the non-deploying countries' climates which might include changes in precipitation leading to water resources or food production problems.

The free driver nature of SRM focusses attention on the challenges created by this globally disruptive technology which, without governance debate during the current development phase, will remain a fragmented and ungoverned geo-political environment. The gains for a single country or coalition from deploying SRM may be too politically appealing to deter the decision to deploy (Parker et al., 2018). This might occur if they had been experiencing more frequent extreme weather events that were being associated with climate change and/or they were coming under political pressure to address climate change from citizens or allies, or other political pressures within their country or region. In such a political environment, a country, including even smaller states, may be tempted not to seek multilateral agreement and deploy SRM. In such a scenario, there would be little, or nothing that the international community could do to stop the deployment excluding military interventions, which might in themselves be illegal (see Conflict and war below). Barrett et al., and Gertner (2014 and 2017) have suggested counter deployment could be an alternative to the military response.

Counter deployment

Counter deployment has been defined by Parker, et al., (2018) as "the use of technical means to negate the change in radiative forcing caused by SRM deployment". The idea suggests that a country, or collections of countries might threaten to counteract any cooling effects of SRM deployments of others to either deter deployment in the first place, or to reverse or slow the effects of any actual deployment. What technical means might be used to do this are uncertain and not currently the subject of any research effort. However, they might conceivably include using a warming agent (e.g., the large-scale release of a GHG – or deliberate cessation of mitigation measures) or seeking to neutralise with physical disruption (e.g., removing or chemically altering the deployed aerosols, or changing the characteristics of brightened clouds using very large cloud nuclei). A third option would be direct military action against the deploying infrastructures, a measure that could be interpreted as an act of war.

The outcomes of counter measures are highly uncertain (Parker et al., 2018). Might they, for example, lead to a new type of climate conflict or encourage an "arms race" of ever accelerating deployment and counter deployment? A capability to counter-deploy might be a useful policy tool, both in relation to SRM control, but also more widely within the global political process, and the threat to use countermeasures may be a deterrent. Who should, or might control access to any future counter-measures – individual countries who feel threatened or perhaps an international climate service under the auspices of a treaty or agreement?

Weaponisation and military interest

There has been military interest in weather modification techniques historically, for example Operation Popeye during the Vietnam War sought to influence rainfall patterns to disrupt transport and communication capabilities. Briggs (2013) suggests the less "controllable" or targetable nature of SAI combined with the controversy that is associated with SRM makes it unappealing as a military weapon. It may, though, be the case that were any future deployment to take place, that it would be delivered by military bodies using military infrastructure. SRM may therefore become embedded into wider international strategic and geopolitical interests (Nightingale and Cairns, 2014). This may beset SRM with problems even when used without malicious or strategic intent. As a potential piece of super-critical infrastructure upon which the global climate relied (given the threat of the termination problem), SRM may become the target of security measures to protect against critical civil groups, eco-saboteurs, terrorists, state operations or natural catastrophes. The link between SRM and security institutions and actors would likely be strengthened by this dynamic.

Conflict and war

If SRM were deployed unilaterally, or by a collective of states or others and it caused, or was perceived to have caused large-scale environmental damage, for example, detrimentally changing the monsoon, and affecting millions of people. There are no legal instruments that would legitimise military actions against those who had deployed and caused harm (Chalecki and Ferrari, 2018).

Any retaliation, under the doctrine of just war, would have questionable validity. Whilst states have a right to defend their sovereignty, there is currently uncertainty about states' rights to ecological sovereignty, although there are some limitations on individual states' sovereignty deriving from the duty to avoid harm to others' sovereignty. In addition, whilst in an extreme scenario SRM might create war like environmental damage, this would have occurred without there having been any events that would be recognised as a war within the terms of the Geneva Protocol – creating a contradiction for the current principles of the "Law of War" (Chalecki and Ferrari, 2018). Any retaliation with security forces would be challenging to legally justify and would require new interpretations of the underlying principles of just war i.e., just cause, right intention, proper authority, likelihood of success, proportionality, non-combatants, last resort and comparative justice. None of which, in the case of harm arising from SRM, can be addressed through normal understandings of conflict (Chalecki and Ferrari, 2018). Who, for example, are the non-combatants and how could comparative justice be achieved? However, legal norms and innovations arise in unexpected ways, often in response to dramatic events, for example, as seen in the wake of the 9/11 terrorist attacks. It may therefore be possible for the international community to quickly resolve a legal position in the light of a threatened, or actual military response to SRM.

Termination shock

As noted above, both MCB and SRM carry a potential risk known as termination shock (Jones et al., 2013). If a deployment of either approach to SRM were terminated quickly, climate modelling indicates that global temperatures would "bounce back", rapidly warming the global climate. Such rapid warming might have significant implications on, for example, weather, precipitation patterns and the number and scale of extreme events (Jones et al., 2013). In addition, biodiversity would be impacted as species, whilst adaptable to slow climate change, are severely stressed by rapid change (Shah, 2014). The effect is already being seen in parts of the world with current warming rates, which are substantially slower than changes likely to occur with abrupt SRM termination (Shah, 2014). Climate and the associated ecosystems disruption on the scale possible would create significant challenges for humanity, far more testing than those of climate change to date and would be likely to give rise to profound geo-political tensions issues. However, abrupt termination may be an unlikely scenario.

If an SRM deploying state were to terminate its SRM programme, it would suffer some of the consequences of the termination experienced by other countries. The SRM deploying country, if facing a severe threat from other nations may consider rapid termination as a counter threat. Otherwise, the mutually assured warming and associated harms, and possible countervailing measures such as economic and other sanctions imposed by the global community, suggests there are very few if any circumstances in which a deploying state would choose to terminate (Parker and Irvine, 2018). However, this propensity to avoid termination is likely to be weakened if SRM deploying states are also wealthier and more advanced technologically and hence also among those more able to adapt to effects of sudden temperature changes. Nonetheless, the threat of termination shock would be lessened if more than one state had access to SRM capability. If this were the case any decision to terminate by one country could be countered by a second SRM capable country choosing to deploy to stabilise the climate.

Baum et al., (2013) have suggested that a total societal collapse leading to an existential or extreme crisis for humanity, prompted, for example, by a nuclear war could leave the survivors without the capability to maintain the SRM. The resulting termination shock could then place even further stress on the remaining population creating a "double catastrophe" (Cairns, 2014). An SRM-deploying world could thus be less resilient to systemic shocks. It is challenging to imagine a governance system that would be able to deal with such extreme circumstances.

Geopolitical positioning

Security risks may arise from SRM capability if countries or alliances choose to use the suggestion, or threat of deployment, to gain strategic advantage. Such geopolitical positioning could, for example, be used to create pressure on specific contested, high value regions such as the Arctic, Himalaya or the Middle East, pitting regional or even global actors against each other (Cairns, 2014). The relatively low costs and high leverage that some believe SRM methods permit could conceivably make this an alternative to traditional threats, especially for powers otherwise unable to project power, though the imprecision of the effects would contribute to making this risky. In such scenarios, MCB would perhaps be the technique of choice because of its more controllable capabilities which are not inherent in SAI. An MCB deployment that is or is suggested to be capable of creating drought in the Middle East, for example, whether the claim is indeed accurate, could create pressure on the region to respond, either by meeting any demands made or retaliating in some form. Without any form of governance framework in place, it is difficult to perceive how such scenarios might be avoided or resolved.

Nation state politics

A country may choose to invest in SRM not only in response to climate change, but also for internal political reasons (Morton, 2015). SRM may, for example, be considered politically appealing as an expression of state power because of the potential large-scale impact even if deployment appears unfeasible (in a similar way to nuclear weapons capabilities) (Corry, 2017). Perhaps, given the expected costs of both MCB and SRM, the return on investment in terms of national prestige could be considered value for money for some administrations (Symons, 2019). Then, having invested in and developed a national SRM capability, pressures to deploy may become difficult to ignore for some administrations (Gardiner, 2010). A situation that could create uncertainty in the global climate governance community.

Lockley (2019) has suggested that the use, or proposed use of SRM could lead to civil unrest that could range from protest to direct action against SRM infrastructure and supply chains. Such activities might be internationally co-ordinated and could extend to terrorist interventions. Any terrorist response could be against SRM operations, concentrations of people, political figures or landmarks with the terrorists acting on “behalf” of those experiencing negative effects of SRM deployment. Lockley (2019) also suggests terrorists might choose to seek to damage SRM infrastructure in protest of other perceived injustices not related to SRM or climate change.

Moral hazard and diminished international cooperation.

Stilgoe (2015) and others have discussed the issue of moral hazard. The idea that SRM’s cooling effect could provide certain interest groups with an excuse to continue using fossil fuels at current, or even accelerated rates. This could also happen as a result of theoretical modelling if the promise of SRM identified in modelling studies deters near-term emissions reductions by reducing the perceived future social cost of carbon.

The international community’s work over many years to develop common understandings, principles, rules and targets, such as the UNFCCC in relation to climate change, have been a powerful mechanism for global diplomacy (Depledge, 2005). Whilst they have not yet found complete solutions to climate change, they have played an important role in geopolitics helping bring states together around a common challenge and, through that, developed new understandings and relationships (Bulkeley, 2010). Were, as suggested by Morton (2015), SRM to lead to a souring of international climate diplomacy, and a new framing of the global community’s relationship with CO_2 and the need for reduction, those powerful mechanisms for global discussion may be diminished. There may be a perceived need for less urgent multilateral discussions, or SRM may trigger a more adversarial attitude to climate harms and blame for weather events if SRM introduces a more direct “perpetrator” into global climate negotiations, or otherwise dilutes the strength of relationships and mutual understanding. Conversely, SRM may conceivably galvanise global climate diplomacy (Keith and Parker, 2013), but by introducing new antagonisms is more likely to erode future capacity to work to protect the global climate or other environments and associated issues. Such a scenario could have uncertain potential implications for future global politics, not only in relation to the environment, but more broadly too. However, Morrow (2019) suggests that mission driven research programmes on SAI could, if appropriately shaped, not only forward knowledge about the effects of SAI deployment, but also promote justice, legitimacy and reduce the likelihood of a mortal hazard scenario arising.

United Nations Security Council

In the context of the range of potential scenarios that could theoretically arise as a result of threats to deploy or any actual deployment of SRM or MCB the United Nations Secretary-General and the Security Council may be drawn into the governance process (Jamieson, 2013). The Security Council’s responsibility to work to maintain international peace and security is established in Chapter VII of the UN Charter which allows the Council to “determine the existence of any threat to the peace, breach of the peace, or act of aggression and to take military and non-military action to restore international peace and security" (UN, 2019).

As part of its role the Council can, under the auspices of Article 42 of the UN Charter, recommend methods of adjustment or terms of settlement and can impose sanctions or the use of force to maintain or restore peace.

Whether the Council is an appropriate body to discuss climate change has been a topic of contestation since it was first raised in April 2007, when the Council held its first open debate to discuss possible implications of climate change for international peace and security (Chalecki and Ferrari, 2018). The issue is yet to be clearly resolved, despite an open Security Council debate, held in January 2019, which explored the impacts of climate related disasters on international peace and security (UN, 2019). Any decision by the Council to act against a threat of, or a deployment of, SRM might then create tension within the UN system.

United Nations Secretary-General

To date SRM has not broken through into the UN's current thinking. For example, the 2018 UN Secretary-General's Report, entitled "Gaps in international environmental law and environment-related instruments: towards a global pact for the environment" (UNSG, 2018), requested by General Assembly Resolution (A/RES/72/277) in response to a request by France in 2017 for the UN to create a "Global Pact for the Environment", only mentions climate-altering technologies in passing in a discussion about biological diversity and there is no reference at all to SRM.

Given such limited reference to SRM within the UN system to date, it is unlikely that the Department of Peace Operations (DPO), the department of the UN charged with the planning, preparation, management and direction of peacekeeping operations, nor the UN Department of Political & Peace Keeping Affairs (DPPA), which seeks to prevent and resolve deadly conflicts around the world, will have SRM on their radars. Certainly, neither has published any material relating to the issue to date. It is therefore difficult to predict how the UN Secretary-General, or the Security Council might respond to the availability of SRM or any potential scenarios that give rise to geopolitical or security issues or concerns.

Non-state actors

Current cost estimates for SRM suggest that deployment may be affordable to actors other than countries (Crutzen, 2006; Smith and Wagner, 2018). It has been suggested that large corporations, a so called "Greenfinger" (Victor, 2008) individual acting alone or even a crowd funded initiative could have SRM deployment capability in the future (Morton, 2015). What the motivations for such a deployment might be, or how the global community might respond to deployments by such groups, and what, if any, geopolitical implications there maybe are unclear (Horton, 2019). How, for example, would the global community respond to a crowd funded or philanthropist-sponsored international collective of activists individually self-launching micro aerosol deployment balloons that were easily constructed from freely available components? What might the responses be if either cooling were achieved with only positive effects, or cooling was causing significant environmental, political or even security challenges? A more complex situation could arise if it were only activists from one country that were deploying and a second, unfriendly country was experiencing negative effects.

SECTION III: Governance Instruments

Introduction

There has been considerable generic debate about tools and instruments of governance of SRM over the past decade. Of this, techniques that aim to have a global effect, such as SAI and MCB have been a central topic. This section focuses on current law and some key non-binding principles or codes of conduct that apply. The purpose of the section is to highlight the most important provisions, but not to analyse them in depth. Reynolds (2018), Scott (2013 and 2015) and Redgwell (2011) have produced in-depth descriptions of international law relevant to climate-altering technologies for those who wish to explore further. A brief summary is provided in table 3.

Table 3. The applicability of legal instruments to MCB and SAI

Legal Instruments	Currently applicable	
	Marine Cloud Brightening (MCB)	Stratospheric Aerosol Injection (SAI)
The Convention on Biodiversity (CBD)	Yes	Yes
Vienna Convention on the Protection of the Ozone Layer and the 1987 Montréal Protocol	No	Yes, in relation to aerosols harming ozone only
Environmental Modification Convention (ENMOD)	Only if used as a military weapon	Only if used as a military weapon
The Convention on Long-Range Trans Boundary Air Pollution (CLRTAB)	No	No
United Nations Convention on the Law of the Sea (UNCLOS)	Yes	No
London Convention 1972 and the 1996 London Protocol	No	No
UN Framework Convention on Climate Change (UNFCCC)	Unclear	Unclear
The Paris Agreement 2015	Potentially as an instrument to help enhance transparency and discuss market mechanisms	Potentially as an instrument to help enhance transparency and discuss market mechanisms
The International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL)	No	No

The Convention on Biodiversity (CBD)

The 1993 CBD, with 196 parties has three main goals:

- to conserve biological diversity;
- the sustainable use of biodiversity; and,
- the fair and equitable sharing of benefits arising from genetic resources.

The CBD is one of the few conventions to have discussed climate-altering technologies directly. The initial focus was on ocean fertilisation activities when, at the Ninth Conference of the Parties (COP) to the Convention, it adopted decision IX/16 that urged signatories “to ensure that ocean fertilisation activities do not take place until there is an adequate scientific basis on which to justify such activities, including assessing associated risks, and a global, transparent and effective control and regulatory mechanism is in place for these activities; with the exception of small scale scientific research studies within coastal waters” (CBD, 2008, p.7).

In 2010, with a view to protecting biodiversity, the CBD went further when the Tenth COP encouraged Parties, other Governments and relevant organisations, and requested the Executive Secretary, to take its decision (X/33(8)(w)) that "no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts..." (CBD, 2010, p.5) are taken into consideration where appropriate, when carrying out work on biodiversity and climate change. It should be noted, however, that the CBD recommendation did not include small-scale scientific research studies undertaken in controlled settings that would help identify the potential impacts on the environment. Subsequently, COPs 11 and 13 reaffirmed this decision.

Whilst the CBD position appears strong, it is not binding for Parties, nor is the US a Party. The language used is "soft", only inviting parties to consider guidance rather than requiring parties to comply and it only extends under the CBD's mandate in relation to the conservation of biodiversity and the sustainable use of biological resources (Reynolds, 2018). The CBD evocation of the Precautionary Principle may, however, be an important demonstration of international law's willingness to take such measures in time. However, the limitations of the CBD also highlight that individual extant protocols and conventions as currently constructed could only form an incomplete basis for global regulation (Redgwell, 2011), which forms an important element of governance, because they each apply to discrete, specific topics and issues whereas SAI would operate at scale, across current treaty boundaries.

Vienna Convention on the Protection of the Ozone Layer and the 1987 Montreal Protocol

The 1985 Vienna Convention on the Protection of the Ozone Layer (UNEP, 1985) and the 1987 Montreal Protocol (UNEP, 1987), which have been ratified by 197 states (all UN members and the EU, the Holy See, Niue and the Cook Islands), aim to protect against depletion of the ozone layer. Given that the injection of aerosols and, in particular, sulphates may harm atmospheric ozone they may both be applicable to SAI. However, it is at this stage unclear whether or to what extent, the ozone layer might be damaged by SAI (Keith, 2018), hence the scope of their applicability to SAI is also unclear. A recent request to at the Montreal Protocol to prepare a report exploring the potential impacts of SAI on ozone may help clarify this issue.

Environmental Modification Convention (ENMOD)

The 1977 ENMOD (UN, 1977), formally the 1976 Convention on the Prohibition of Military and Other Hostile Use of Environmental Modification Techniques, prohibits the intentional use of environmental modification by one party against another for hostile purposes, and completely bans the use of weather warfare, activities which have previously been undertaken by the US during the Vietnam War (Hersh, 1972). ENMOD is not expected to be applicable to SAI unless it is used as a military weapon in the first instance. Although SAI may have the potential to be used as such (Brzoska et al., 2012), it is generally considered unlikely (Rayner, 2017). Secondly, the Convention has limited reach – having been signed by only 73 countries, leaving many non-signatory countries free to act, including France, a permanent member of the UN Security Council.

The Convention on Long-Range Transboundary Air Pollution (CLRTAB)

CLRTAB (CLRTAB, 1979) entered into force in 1983. It is implemented by the European Monitoring and Evaluation Programme, under the direction of the UN Economic Commission for Europe. The Convention covers 22 pollutants, the majority of which are pesticides and insecticides. Currently there are 51 signatories and as such the convention suffers from the same coverage challenges as ENMOD. In addition, neither sulphates nor other possible SAI aerosols, nor potential MCB particles are listed as prohibited pollutants. Furthermore, the Convention defines transboundary air pollution as "air pollution whose physical origin is situated wholly or in part within the area under the national jurisdiction of one state and which has adverse effects in the area under the jurisdiction of another state at such a distance that it is not generally possible to distinguish the contribution of individual emission sources or groups of sources" (CLRTAB, 1979, p.2). Given that if SAI or MCB were deployed, it would be possible to identify the sources of the particles (although it should be recognised that this could be a complex task) the Convention would, as drafted, be difficult to apply. Given the Convention is aimed at protecting against pollutants, this creates a paradox in that both MCB and SAI may not be polluting, and may or may not be considered to be pollutants in the context of their function of mitigating the effects of anthropogenic GHG, in themselves considered as pollutants, although not listed in the Convention.

London Convention 1972 and the 1996 London Protocol (LC/LP)

Known as the London Convention, the Convention on the Prevention of Marine Pollution by Dumping of Wastes or Other Matter was adopted in 1972 and came into force in 1975. The London Protocol 1996 came into force in 2006. The two instruments operate in parallel and when the Protocol was adopted, parties agreed no further amendments would be made to the Convention. The Protocol directly addresses SRM (as well as CDR technologies) and it is evolving in the context of the evolving debate about marine "geoengineering". The key article is Article 3.1 which requires Parties to "... apply a precautionary approach to environmental protection from dumping of wastes or other matter..." and this article is amended by Annex 4 to include the placement of matter for marine "geoengineering" activities.

The Parties first discussed climate-altering technology issues in June 2007 when an ocean fertilisation experiment, which sought to place iron particles in the oceans to create an acceleration in plankton growth and therefore CO_2 uptake, was being proposed (Brahic, 2007). Subsequently, in 2008, resolution LC-LP.1(1) decided that ocean fertilisation activities other than legitimate scientific research were contrary to the aims of both instruments. In 2010, the Parties adopted an Assessment Framework for Scientific Research Involving Ocean Fertilisation (OFAF) (resolution LC-LP.2(2)). Whilst neither resolution was legally binding, in 2013 amendments to regulate ocean fertilisation activities by resolution LP.4(8) were adopted. These amendments do not apply to MCB or SAI. However, the Parties' decision to amend the Protocol in response to a potential climate-altering technology demonstrates that, were MCB or SAI to lead to potentially damaging substances entering the oceans, Parties may be willing to exercise power to regulate MCB/SAI research or deployment.

United Nations Convention on the Law of the Sea (UNCLOS)

UNCLOS was adopted in 1982 and amended in 1994 and 1995. Part XII – "Protection and Preservation of the Marine Environment" and Part XIII "Marine Scientific Research" cover the relevant environmental protection obligations under the Convention that apply to MCB activities. The key articles are:

- Article 192 states have a responsibility to protect and preserve the marine environment;
- Article 194 requires states to take measures to prevent, reduce and control pollution of the marine environment. This includes pollution from GHG and marine "geoengineering" activities;
- Article 195 prohibits the transfer, directly or indirectly, of hazards or pollutants from one area into another;
- Article 204(2) requires states to monitor activities which they permit to determine if they may cause pollution;
- Article 206 requires states to assess potential effects of their activities if there are grounds to believe activities may cause pollution/harm;
- Article 210(6) requires compliance with the London Convention/Protocol regarding dumping;
- Article 240(d) requires states ensure that marine scientific research, whether conducted in or

under their areas of jurisdiction or on the high seas complies with the marine environmental protection provisions of UNCLOS;
- Article 257 gives states and competent international organisations the right to conduct marine scientific research in seas beyond the limits of the exclusive economic zone (EEZ) i.e., within the global commons; and,
- Article 263 makes states and competent international organisations responsible for ensuring research is conducted in accordance with the Convention.

Articles 257 and 263 raise interesting questions about: who decides what is and is not legitimate science; who and by what mechanisms do states keep control of science when equipment, funding and information is broadly available; and, how can deployment and research be disentangled for the purposes of the Convention, by whom and to what effect? The potential importance of UN negotiations for a new international agreement under UNCLOS is an evolving Convention and an intergovernmental process is in progress that will lead to an international legally binding instrument under the Convention, on the conservation and sustainable use of marine biodiversity of areas beyond national jurisdiction.

United Nations Framework Convention on Climate Change (UNFCCC)

Adopted in 1992 the UNFCCC provides an overarching framework to intergovernmental efforts to tackle climate change and it may play a role in the global governance of climate-altering technologies such as SAI and MCB in the future. However, what that role might be, if any, is unclear at this time. Three key elements of the Convention in this context are:

- Preamble – "Affirming that responses to climate change should be coordinated with social and economic development in an integrated manner with a view to avoiding adverse impacts on the latter, taking into full account the legitimate priority needs of developing countries for the achievement of sustained economic growth and the eradication of poverty";
- Article 2 – "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner"; and,
- Article 4(1)(d) – "Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems".

Articles 2 and 4 above are referenced in the context of the moral hazard concern that SAI or MCB, if deployed, may offset efforts to reduce GHG emissions.

The Paris Agreement 2015

Adopted in December 2015 the Paris Agreement is an agreement under the UNFCCC. The key purpose of the Agreement is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C. In an analysis of the Agreement, Craik and Burns (2016) have suggested that whilst SAI would not come under the auspices of the Agreement, it could potentially provide the procedural instruments and mechanisms to help satisfy demands for transparency, provide a forum for public debate about SAI and MCB deployment, potentially define market mechanisms to fund any future deployment and create a structure for monitoring and verification. In a later analysis of how climate-altering technologies might be successfully brought into the scope of the Agreement, Craik and Burns (2019) identify the need for clarity about the functioning of accounting and incentive structures for the technologies.

The International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL)

Developed by the International Maritime Organisation (IMO) to minimise pollution of the oceans and seas, the MARPOL Convention focusses on dumping, oil and air pollution from ships. It came into force in 1983 and 156 states are party to the Convention. Reviews of international governance mechanisms pertinent to SRM have generally not discussed the Convention, although Talberg et al., (2017) does mention MARPOL in relation to ocean fertilisation. Dependent on how MCB particles, if ever deployed from ships, are interpreted by the IMO and signatories in the future, the technique could potentially become subject to the Convention. However, what that role might be is unclear.

Research governance

Currently, no researchers are arguing in favour of deploying climate-scale SRM and most work is focused on gaining a better understanding of the potential of SRM and its effects, predominantly through modelling and laboratory-based research. Some are also planning to undertake field trials, for example MCB trials over the Great Barrier Reef and a very small-scale deployment of particles in the stratosphere. Such research is currently being governed through normal research protocols of institutions and professional bodies. However, SRM research is controversial and it gives rise to many questions. This is, in part, encouraging some to promote the idea of a voluntary code of conduct for SRM research, whilst in the US there are proposals for limited oversight responsibilities to be handed to a national science agency (see below).

The Solar Radiation Management Governance Initiative (SRMGI), an international, NGO-driven project working to expand the global conversation about the governance of SRM research has noted the following key questions (SRMGI, 2019):

- Who decides if research proceeds, and what should be researched?
- Who pays for the research? Who benefits?
- What ensures that research is conducted in a transparent manner, and that all results are shared openly?
- How can the different research priorities of different groups be heard?
- What can be done to make sure that SRM research does not distract public and politicians from the task of cutting emissions of greenhouse gases?

In time, field trials may deliver a perturbation of the climate, resulting in an application of SRM with uncertain, difficult to predict effects and risks (Robock, 2009). Where the research/application governance boundary lies is unresolved and it has been questioned whether there should be any delineation between the two, or whether the evolution of the technology from modelling and laboratory research, through to atmospheric testing at scale should be treated as a continuum for governance purposes (SRMGI, 2011 and Parker, 2014). Parsons and Keith (2013) have suggested that a measurement of the cooling effect in watts per square metre of field work would be appropriate. Other measures, such as some form of metric of social response, have also been proposed (Sugiyama, 2017). If a delineation point is required, it is uncertain what that might be and who might decide on it and monitor and verify.

In the light of the complex issues associated with the agenda, several non-binding codes of conduct have been developed by those active in SRM and other climate-altering technologies, such as the Oxford Principles (Rayner et al., 2009), the Asilomar Principles for Research into Climate Engineering Techniques (Asilomar, 2010), the Code of Conduct for Responsible Geoengineering Research (Hubert,

2017) and the Academic Working Group on Climate Engineering Governance (Netra et al., 2018). These principles or codes all recognise that transparency in decision-making, public participation, and open publication of research results are key to ensuring maximum public engagement with, and confidence in, the governance of SRM research (and climate-altering technologies more broadly). However, although such codes encourage researchers to act in measured responsible ways, given they are voluntary and have no forfeiture available, they may not deter a committed researcher.

The proposed US Atmospheric Climate Intervention Research Act – H.R.5519 (ACIRA, 2019), if passed, would not only establish a climate-altering research programme at NOAA, but also grant the Agency oversight authority to review and report on SAI and MCB experiments to the US government. The reach of these powers, if they are granted, remain unclear at this stage pending clarification and discussion during any progress that the Bill makes. However, there is some potential for the evolution of a new research governance mechanism in the US under auspices of the Bill that other states make take interest in.

Other fora or processes

In addition to those described above, other fora or processes that could be involved in the governance of climate-altering technologies include, the UN Environment Assembly, the UN General Assembly, the UN Security Council, nation states, regional bodies such as the African Union and the European Union, research groups, CSOs, commercial interests and publics.

Conclusion

Marine Cloud Brightening and Stratospheric Aerosol Injection, two types of Solar Radiation Modification technology, have been described and their technical readiness, current research, applicable governance frameworks, and other socio-political considerations explored. In the context of this analysis a range of geopolitical, including security issues that the technologies may give rise to were discussed, as were how existing governance instruments do or do not help address those issues.

Currently, there are no measures, other than soft power, that would stop either researchers or states from taking forward field trials or climate-scale deployments. Given that the identified geopolitical and security issues include the theoretical potential for military conflict, enhancing tensions between countries or regions, straining climate diplomacy and wider international cooperation, counter deployment with associated contestation and civil unrest, it is suggested that early discussions about how these technologies might be governed is required.

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Summarised information about the techniques and their governance is available in the
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