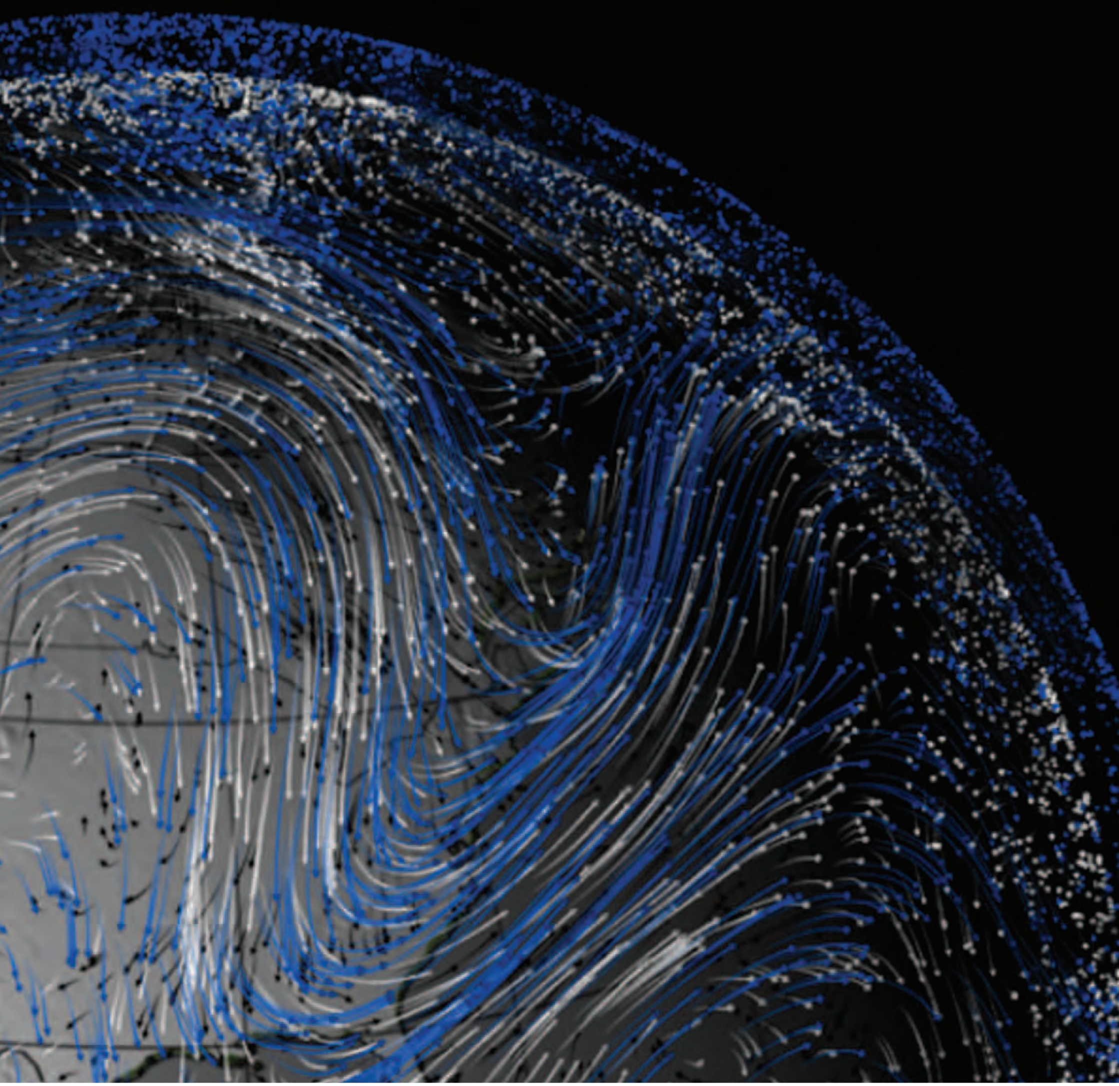
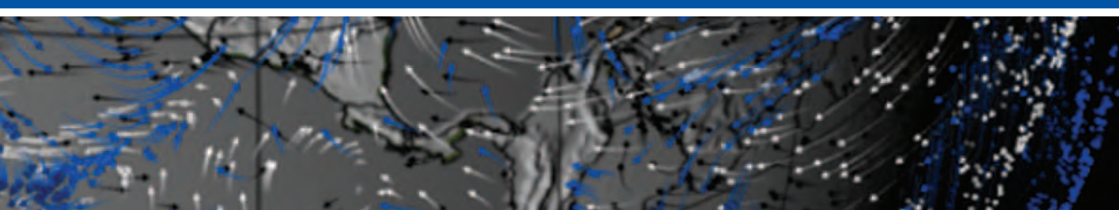


Solar radiation management: the governance of research



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The cover image, from NASA's Earth Observatory, is taken from a Modern Era Retrospective-analysis for Research and Applications (MERRA) reanalysis project at NASA's Goddard Space Flight Center, that combines satellite measurements of temperature, moisture, and winds. It shows a strong high-pressure system stalled over the central United States in the summer of 1988. Winds circled the high pressure ridge, pushing air south over the Midwest. The resultant drought and heatwave causing an estimated $40 billion in damage and 5,000 to 10,000 deaths.

The arrows indicate wind trajectories, while color indicates wind height. The length of a line equates to wind speed (stronger winds get longer lines). Black arrows trace the low-altitude winds that carry moisture, the winds most relevant to the 1988 drought . These winds are about 1,500 meters (4,900 feet, 850 millibars) above the surface. White arrows are winds at 5,400 meters (18,000 ft, 500 mb), and blue arrows are high-altitude winds at about 9.2 kilometers (30,000 ft, 300 mb).

The image is intended to convey the great complexity of the weather systems that are currently being affected by climate change, which solar geoengineering interventions would seek to address if ever deemed safe and desirable to deploy.

Solar radiation management: the governance of research

Contents

Summary

Background

In September 2009, the Royal Society published a report that reviewed ideas for deliberately intervening in the climate to counteract global warming - techniques collectively described as 'geoengineering' (Royal Society 2009). The report recommended that the scientific and governance challenges posed by geoengineering should be explored in more detail, and that future work should take into account the significant differences between the two classes of methods: carbon dioxide removal (CDR) and solar radiation management (SRM).

As its own contribution to taking forward the 2009 report's recommendations, in March 2010 the Royal Society entered into a partnership with the Environmental Defense Fund (EDF) and TWAS, the academy of sciences for the developing world, to look in greater depth at the governance issues raised by research into SRM methods. This project is known as the Solar Radiation Management Governance Initiative (SRMGI).

SRM[1] refers to proposals to cool the Earth by reflecting a small percentage of inbound sunlight back into space, in order to reduce global warming. The limited research done to date on SRM (mainly computer modelling), indicates that:

- it could reduce global temperatures very quickly, within a few months of deployment
- it could reduce (but not eliminate) regional temperature and precipitation changes due to climate change, with a minority of areas potentially experiencing greater change
- it could be deployed cheaply (relative to the cost of implementing greenhouse gas (GHG) emissions reductions)

but

- it would mask only some of the effects of increased atmospheric levels of GHGs and thus is not comparable to and not a substitute for reductions in GHG emissions
- there would be unanticipated side effects, both physical and socio-political, as there is a high level of uncertainty about the impacts of the proposed interventions
- without reductions in the atmospheric concentrations of greenhouse gases any SRM intervention would need to be sustained for a long time, and there would be a large and rapid climate change if it were terminated suddenly.

[1] Also known as sunlight reflection methods or solar geoengineering. Some commentators prefer to refer to geoengineering as climate remediation or intervention.

SRMGI focuses on SRM research and not CDR research as:

- SRM has a greater potential for doing harm if the science is not thoroughly researched
- SRM could be pursued unilaterally, by countries or individuals, with the effect of increasing international tensions or even conflict
- there are few governance arrangements in place to ensure that any SRM research that is undertaken is done safely, transparently and responsibly.

Aims and scope of the report

This short report summarises the evidence gathered and issues raised over the initial year of project, which included an international conference at the Kavli Royal Society International Centre in March 2011. The report reflects the rich deliberations that took place there, but does not make prescriptive recommendations. Indeed, easy resolution of some of these issues may be impossible at this early stage of the global conversation on the governance of SRM research, given the scientific and institutional uncertainties that surround SRM.

The project and the preparations for the March 2011 conference drew on input from a group of 27 experts from 17 countries, with backgrounds in: climate science; international relations; development; ethics; international institutions; governance of technology; risk management; engineering; environmental policy and law[2].

Discussions at the March 2011 conference were further enriched by input from a range of non-governmental stakeholder partners. While not formally endorsing the project, these organisations helped to broaden the evidence and viewpoints that the project incorporates[3]. A number of background papers were also prepared prior to the March 2011 meeting (available at www.srmgi.org/documents).

Deliberately intervening in the Earth's climate with the aim of moderating global warming, or even attempting research in this area, raises a complex mix of scientific, ethical, political, social and technological questions. This project has attempted to frame those challenges and explore different perspectives on how they might be resolved. It has also tried to stimulate a broader international discussion that will help governments and policymakers to consider SRM research more productively.

SRM has the potential to be either very useful, or very harmful, for people and the planet. It is impossible to know at this stage whether the technology will be

[2] See appendix 1 for a full list of working group members.

[3] See appendix 1 for a full list of partner organisations.

feasible or whether its consequences would be acceptable. The likelihood of resolving this uncertainty depends on being able to govern any future research effectively and responsibly.

Emerging conclusions

The March 2011 conference did not attempt to reach a consensus or to make recommendations. However, based on the deliberations, the following general conclusions emerged and were widely supported.

Message 1

Nothing now known about SRM provides justification for reducing efforts to mitigate climate change through reduced GHG emissions, or efforts to adapt to its effects. The evidence to date indicates that it could be very risky to deploy SRM in the absence of strong mitigation or sustainable CDR methods.

Message 2

Research into SRM methods for responding to climate change presents some special potential risks. Governance arrangements for managing these risks are mostly lacking and will need to be developed if research continues.

Message 3

There are many uncertainties concerning the feasibility, advantages and disadvantages of SRM methods, and without research it will be very hard to assess these.

Message 4

Research may generate its own momentum and create a constituency in favour of large-scale research and even deployment. On the other hand, ignorance about SRM technology may not diminish the likelihood of its use, and in fact might increase it.

Message 5

A moratorium on all SRM-related research would be difficult if not impossible to enforce.

Message 6

Some medium and large-scale research may be risky, and is likely to need appropriate regulation.

Message 7

Considering deployment of SRM techniques would be inappropriate without, among other things, adequate resolution of uncertainties concerning the feasibility, advantages and disadvantages. Opinion varied on whether a moratorium on deployment of SRM methods would be appropriate at this stage.

Message 8

The development of effective governance arrangements for potentially risky research (including that on SRM) which are perceived as legitimate and equitable requires wide debate and deliberation. SRMGI has begun, and will continue to foster, such discussion.

Message 9

International conversations about the governance of SRM should be continued and progressively broadened to include representatives of more countries and more sectors of society. Appropriate international organisations should also be encouraged to consider the scientific, practical and governance issues raised by the research of SRM methods.

Introduction

1.1 Background

The slow progress of international climate negotiations has led to increased concerns that sufficient cuts in greenhouse gas (GHG) emissions may not be achieved in time to avoid unacceptable levels of climate change. Even where it is possible, the costs of adapting to climate change may make implementation inaccessible to poorer countries. The failure in mitigating and adapting to climate change to date has heightened interest and speculation about the possibility of geoengineering: deliberate large-scale intervention in Earth's climate system in order to reduce global warming.

1.1.1 Geoengineering the climate: science, governance and uncertainty (2009)

The Royal Society 2009 report *Geoengineering the climate: science, governance and uncertainty* concluded that solar radiation management (SRM) does not present an alternative to GHG reductions (see Box 1.1 for more details). However, it may one day be a useful way to augment mitigation and adaptation responses, and it may be the only option for reducing global temperatures quickly in the event of a climate emergency.

The report concluded that geoengineering should therefore be researched transparently, responsibly and internationally, whilst also highlighting the complex and serious governance issues that such research raises: 'the acceptability of geoengineering will depend on social, political and legal issues as much as on scientific and technical factors'. It recommended that the governance challenges of geoengineering should be addressed in more detail, and that the Royal Society should work with international partners to develop norms or a code of practice for research.

1.2 Aims and scope of SRMGI

In 2010, following the recommendations of *Geoengineering the climate*, the Royal Society, Environmental Defense Fund (EDF), and TWAS, the academy of sciences for the developing world, launched the Solar Radiation Management Governance Initiative (SRMGI) to explore the possible need for special governance of research into SRM approaches to reducing climate risk (note: the extent to which SRM research can be defined and is special is discussed in Section 3.1).

Governance of SRM research, rather than deployment, is the focus of SRMGI. Assessing deployment is impossible at present given the paucity of data about impacts and effectiveness. As a result deployment is likely to be many years away from happening if it is ever deemed appropriate (see box 1.1).

This report is an account of the activities and discussions from March 2010 through the conference in March 2011. It is intended to serve both as a record of those deliberations and a basis for further efforts to facilitate a progressively wider conversation about governing SRM research. The report is intended for a very diverse audience, including citizens, policy-makers and researchers, specialists and non-specialists and covers a wide range of disciplines.

In the interest of providing useful background information for those whose expertise lies elsewhere the report deliberately includes material that might be regarded as elementary by some specialists. As this is not a traditional consensus-based policy report, but one that reflects a number of different possibilities and perspectives, the views outlined in it do not necessarily reflect the policy positions of the participating organisations.

Box 1.1 What is SRMGI?

SRMGI is a cooperative, international, NGO-driven initiative, co-convened by the Royal Society, EDF and TWAS. The initial intention of the initiative was to try to develop specific governance recommendations for SRM research. However, it was recognised early in the process that it would be more helpful and realistic to 'open up' discussions of SRM governance by exploring and recording the different perspectives that exist, rather than 'closing down' discussions by producing prescriptive recommendations.

Objective

The initiative aimed to foster an interdisciplinary and international discussion to develop ideas on how SRM research could appropriately be governed, appropriately scrutinised and carried out responsibly. This was done by assembling a working group and a range of international partner NGOs, and by producing background papers on SRM research governance, hosting an international conference, and by publishing this report of the process. It is hoped that the deliberations initiated by this process, and the resulting insights, will inform the policies developed within governments, institutions and scientific communities, across the globe.

The long-term objective of SRMGI is to build a diverse community of well-informed international stakeholders engaged and able to contribute to these ongoing debates. The exercises used at the conference on mechanics, international governance and international collaboration are in appendix 3.

Process

The terms of reference and focus were shaped by a steering group comprising 9 international experts[4] co-chaired by Professor John Shepherd FRS (Royal Society), Professor Steven Hamburg (EDF) and initially also Professor Carlos Nobre (TWAS).

[4] See appendix 1 for a list of steering group members.

The steering group invited a working group of 27 members from 17 different countries to explore the different governance issues. The working group members produced background papers on:

- the mechanics of SRM governance
- the international dimensions
- thresholds and categories of research
- goals and concerns regarding research.

The background papers are available to download at www.srmgi.org/background-papers-for-2011-srmgi-conference/documents. The papers were informed by a public call for submissions, which returned 30 responses (see Appendix 1), as well as input from the range of stakeholder partner organisations. These NGOs do not necessarily formally support SRMGI or this report, but agreed to take part in order to enrich the range of perspectives being heard, and because they consider the good governance of SRM research (to the extent to which it can be identified and is special) to be important. Appendix 1 lists all the partner organisations. They come from the natural and social sciences, public policy and civil society, from developed and developing countries. Their diversity reflects the wide range of views that exist about SRM research. All are non-governmental organisations because at this stage it was felt that the selection of any subset of governments to participate would be arbitrary, and would politicise a process designed to be as open as possible.

The issues addressed by the background papers were discussed at the SRMGI conference, which took place at the Kavli Royal Society International Centre on 22–24 March 2011, and brought together working group members and stakeholder partners. No attempt was made to reach consensus on the desirability of any one governance arrangement over another. Rather, participants tried to critically examine different institutions and arrangements, ranging from no special governance to complete prohibition.

All perspectives on governance arrangements for SRM research were considered valid in this process, as long as they were not based upon inaccurate scientific information (but recognising there may be different interpretations of the science). This aimed to foster non-adversarial discussion, where differences of perspectives could be explored and recorded without having to be resolved for a consensus statement. The openness of the process, including the presence of the press (operating under the Chatham House rule) at the 2011 conference, has led to robust discussions of different governance options.

SRMGI is a self-organised and voluntary activity. It has no formal mandate and is not democratically representative. Its scope is limited because, due to the novelty of SRM concepts (and climate remediation in general), many areas of potentially useful analysis have not yet been explored. Nevertheless, it is hoped that SRMGI may be effective in initiating a conversation that is inclusive and useful.

1.3 Why focus on governance of SRM?

There are two main classes of geoengineering methods, and this initiative (SRMGI) focuses on SRM rather than carbon dioxide removal (CDR). While both fall under the broad definition of 'geoengineering', the issues raised by each are distinct. Please see Box 1.2 for an explanation of the basic science and potential implications of SRM.

Box 1.2 What is SRM?

Geoengineering, defined by the Royal Society (2009) as 'the deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming', is divided into two primary techniques: carbon dioxide removal (CDR) and solar radiation management (SRM).

SRM methods aim to cool the planet by blocking or reflecting a small percentage of light and heat from the Sun (solar radiation) back out into space. Commonly discussed examples of SRM include brightening marine clouds, introducing reflective aerosols into the stratosphere, making parts of the Earth's surface more reflective by painting roofs white or planting lighter coloured crops and positioning 'sun shades' in space. Of these, marine cloud brightening and stratospheric aerosols are generally considered to be among the most potentially feasible options. (See Royal Society (2009) for specific references supporting the material in this box.)

Marine cloud brightening

Marine stratus clouds have been estimated to form over a substantial fraction of the ocean surfaces, where they reflect some sunlight back into space, cooling the Earth. It may be possible to make these clouds brighter, allowing them to reflect more sunlight. The most commonly proposed method involves spraying seawater droplets into the lower atmosphere, creating more 'cloud condensation nuclei' around which cloud droplets form. This is expected to brighten the clouds in localised areas above the oceans, causing a greater proportion of sunlight to be reflected.

Some computer model simulations suggest that if deployed widely, cloud brightening could cool the Earth sufficiently to offset the predicted temperature rises from a doubling of CO_2 in the atmosphere. The technique would have the advantage that the material (sea water) being released into the environment is believed to be relatively benign. Also, if the process were to be discontinued, effects on global temperature would cease within roughly ten days.

However, as with all SRM techniques, the likelihood, severity and geographical range of side effects remains uncertain. For example, cloud brightening would cause large localised cooling, and so could modify weather patterns both locally and further afield, including rainfall over adjacent land areas, and ocean currents and upwelling. Furthermore, the technology required to reliably produce a fine mist of droplets from sea water has not yet been demonstrated.

Stratospheric aerosols

Large volcanic eruptions release millions of tons of sulphur dioxide into the Earth's upper atmosphere (the stratosphere), which react to form tiny particles – aerosols – in the form of sulphates. These aerosols then circulate the planet on the stratospheric winds and block out a small amount of inbound sunlight. This phenomenon temporarily cools the Earth, sometimes detectably for a year or two depending on the size of the eruption. The artificial injection of aerosols to mimic this natural phenomenon could also produce a cooling effect. It has been suggested that releasing a sufficient quantity of aerosols (such as sulphate particles) could reduce some of the effects of climate change at relatively low cost. Furthermore, the cooling effects of stratospheric aerosols are expected to be relatively evenly distributed around the world.

However, this technique also carries the risk of modifying large-scale weather patterns and precipitation (tropical monsoon systems in particular). The hazy skies resulting from aerosol introduction could also negatively affect solar power generation, astronomy, remote sensing, and (depending on the choice of aerosol) stratospheric ozone levels. In addition, there would also be effects on plant productivity due to reduced direct sunlight and increased diffuse sunlight, but it is thought that not all changes would necessarily be adverse.

Finally, on a practical level, the full costs and feasibility of delivering suitable aerosols into the stratosphere are currently unknown since the technology required to do so has not been developed. It has been suggested that it would be very difficult to produce sulphate droplets of a small enough size to scatter sunlight effectively, and that massive amounts of sulphate injections would be required.

General characteristics of SRM

Computer models have shown that it should be possible to reduce the global temperature quickly if SRM techniques were deployed on a large scale, and this is borne out by real world experience of volcanoes. However, the temperature changes caused by SRM would reduce but not precisely cancel the effects of global warming, since the latitudinal distribution of solar energy is different to that of greenhouse warming. This would probably result in some overcompensation of the heating near the equator, and under compensation near the poles.

Hydrological cycles are likely to be affected by SRM, including possibly significant effects on tropical monsoons. Modelling has indicated that SRM would probably reduce the hydrological changes caused by global warming, but would be unlikely to eliminate them completely, and may over-compensate for them in some areas. Whilst such changes are very difficult to predict with high confidence, models suggest there will be both hydrological winners and losers.

SRM deployment could also have unpredictable and unexpected environmental effects; if so it could conceivably lead to climate changes that are worse than the 'no SRM' option. SRM would not address other issues related to increased concentrations of atmospheric greenhouse gases, such as ocean acidification.

Computer modelling and desk studies have indicated that the most promising SRM technologies, unlike CDR, would probably be relatively cheap to deploy in comparison to mitigation activities, and could potentially reduce global temperatures to their pre-industrial levels within a few years of deployment (Royal Society 2009). This may lead to a temptation by some to develop SRM programmes rapidly and unilaterally. As the effects of SRM are (like those of change) not currently predictable in detail (Royal Society 2009), such unilateral efforts could lead to international tension or even conflict. This is especially true because it will be difficult to establish whether any specific drought/flood or heat/cold wave was or was not the consequence of deployment of SRM. While SRM technology (including research and deployment) appears to be more easily attempted at a large scale than most CDR methods in the near future, it is likely to be much harder to manage politically and to avoid serious and unanticipated negative impacts.

At present there are few international governance mechanisms to ensure that SRM research would be transparent, safe and internationally acceptable[5]. This is especially important for large-scale field research, which could have significant intended and unintended consequences that would not be restricted by national borders.

Large-scale field research could also be controversial not only because it may cause environmental damage, but also through the suggested commitment to develop and deploy SRM technologies that doing the research might imply. Attitudes towards these complex issues are explored in the next section on goals and concerns about SRM development.

[5] See appendix 3 for analysis of the relevant existing mechanisms.

1.3.1 Governance challenges

While understanding the science is crucial for well-informed discussions of SRM, the physical implications are only part of the story. The basic attributes of SRM – the rapid speed with which it could take effect, the uncertain size and distribution of its effects (both desired and undesired) and its potentially cheap deployment costs – raise a host of complex political, social and ethical issues. For example:

- Given that large experiments, let alone deployment, could affect the climate of the entire planet, who should decide where and when such experiments should occur? Is it possible to come to such a decision democratically?
- What would happen if a country decided to deploy SRM despite widespread global opposition? Could this lead to military conflict?
- How would the rest of the world react if a coalition of developing countries, suffering greatly from the effects of a changing climate, decided to deploy SRM?
- If large-scale research programmes do proceed, how is it possible to avoid investment in SRM technology creating vested interests in using it?
- How would research on SRM affect international and national efforts to reduce carbon emissions?
- How would liability and compensation for adverse impacts be handled? What would happen if a country were to experience an extreme weather event shortly after a large SRM experiment, yet it was not possible to determine whether the research was to blame for the weather events?

The motivation for SRM research: goals and concerns

2.1 Introduction

If handled well, SRM might one day be able to reduce some environmental risks from climate change. This could be especially valuable for those populations most vulnerable to the effects of climate change. However, if handled poorly, SRM could further increase environmental insecurity, delay necessary cuts in GHG emissions, and could be used by small groups or special interests to the detriment of other people.

In recent years there has been vibrant, and often fiercely contested, debate over the potential benefits and drawbacks of SRM technologies. The debate has been, and continues to be, global in its scope, involving researchers, NGOs, natural and social scientists, philosophers, ethicists, and the media. It has played out not only in published literature and the media, but also in the corridors of research institutes and the sidelines of meetings. Consequently, providing a rigorous analysis of the range of opinions is extremely difficult at this stage.

This chapter outlines some of the motivations for researching SRM, and the concerns associated with research – publicly and privately expressed as well as anticipated. These goals and concerns represent the breadth of opinion and this report does not attempt to evaluate their scientific or policy merit, nor whether one is more valid than another.

Given the uncertainty over the possible benefits and drawbacks of SRM, discussions about research governance can become ‘proxy debates’ for unstated goals and concerns about the use of technology and the distribution of power that it may confer. Such discussions also reflect different perspectives and values regarding climate change mitigation or adaptation efforts. Hopes and concerns expressed about possible SRM research may reveal some of the unstated assumptions about SRM. Understanding where divergent views arise from differing facts and values, and different interpretations of agreed facts, should inform decision-making about SRM governance.

Box 2.1 Potential motivations for SRM deployment

There are a number of different roles that SRM may perform if the technology can be developed and demonstrated to be effective. Hopes over the eventual application of SRM, whether stated or not, can provide the foundation for the motivation to conduct research.

Emergency response

Because of the long lifetime of carbon dioxide (CO_2) in the atmosphere, even if CO_2 emissions were greatly reduced, atmospheric CO_2 concentrations would only fall very slowly. Additionally, the climate system is not in equilibrium with the current CO_2 concentration, so even if emissions were stopped today, it is projected that the Earth would warm another 0.5°C (Solomon *et al* 2007). It would therefore take many decades for reductions in GHG emissions to start reducing the global temperature.

In contrast, SRM could start cooling the Earth within months of deployment, and could be the only option for reducing temperatures on time scales that are relevant to imminent or ongoing climate crises. It might therefore be worth researching SRM in order to understand whether or not it represents a viable emergency response.

Alternative to emissions cuts

Efforts to reduce GHG emissions are expensive, politically challenging and some may simply fail. SRM research could indicate whether SRM is a feasible and acceptable additional or alternative way of addressing climate change. Mitigation and graduated SRM deployment need not be mutually exclusive policies (although SRM could be used to justify the 'business as usual' use of fossil fuels), and SRM could be deployed to obviate the need for only the most expensive and politically difficult emissions cuts. SRM, however, cannot serve as a substitute for all emissions reductions (Royal Society 2009).

Counteracting effects of pollutant cuts

Some kinds of air pollution (eg sulphur emissions from burning fossil fuels) have a short-term cooling effect on the Earth by reflecting sunlight. Reductions in this 'cooling' air pollution are beneficial to many people and ecosystems, but without accompanying abatement in CO_2 emissions they are also further exacerbating the rate of climate change, although by an uncertain amount. SRM could intentionally replace the existing cooling effect caused by this pollution, but in a more controlled manner and without the direct negative effects on human respiratory and ecosystem health.

Buying time

The length of time required to phase out fossil fuels, and to modify the various global human systems contributing to climate change, may be longer than the time available to avoid serious adverse impacts. In this case, SRM might have the potential to temporarily stabilise the global temperature and its associated effects, while providing time to reduce GHG emissions.

2.2 Possible goals of SRM research

2.2.1 Precautionary principle

A precautionary approach would be to carry out research on SRM in case it could be useful for reducing environmental risk with acceptable adverse impacts. If it really were possible to diminish risk and damage with an SRM deployment, it could be argued that *not* researching SRM would be imprudent. Both taking and avoiding SRM action without adequate knowledge could be potentially dangerous, and a rushed decision on SRM deployment (even if multilateral) could lead to perverse outcomes. A precautionary approach could therefore suggest facilitation of relevant research, rather than no action.

2.2.2 Encouraging commitment to emissions cuts

The prospect of SRM development might motivate increased mitigation efforts, as it could demonstrate the serious concern about climate change. SRM research might also determine the limits of the technology: if research suggests that there is in fact no viable 'plan B', it might further focus the attention of politicians and publics[6] on 'plan A' (mitigation and adaptation).

2.2.3 Research benefits

Research into SRM is likely to provide new insights into climate science and the functioning of the Earth as a system. Additionally, exploring SRM and its implications offers the opportunity to develop new models of governance in areas such as climate, technology and environmental politics. Conducting research would also increase understanding of potential implications if the decision to deploy SRM was ever taken.

2.3 Concerns associated with SRM research

2.3.1 Moral hazard

Research into SRM could present a 'moral hazard'. If people (or governments) *feel* that they could be protected against the potential consequences of climate change, they may be less likely to take the actions necessary to reduce greenhouse gas emissions. In that case emissions would continue and rise (probably at a faster rate) and conceivably increase the eventual desire to deploy SRM technology. Any research into SRM could also divert valuable intellectual and financial resources away from climate research, including applications for climate mitigation and adaption.

2.3.2 Political ineptitude

Even from what little we know of the possible physical impacts of SRM deployment, it is possible to extrapolate a wide range of political implications

6 This report refers both to the public and to publics (in the plural) as seems to be most natural in the context. We recognise that there is a difference of usage of these terms between professionals in the field and the general public (!), and have tried to maintain a balance between consistency and readability. Regardless of the precise wording, it is clear that there is a diverse array of possible publics - nationally and internationally - and that these are heterogeneous and resist generalisation.

that could be as serious as the physical consequences. Unilateral deployment, or even deployment that enjoyed widespread international support, could be politically divisive. The slow progress of current climate change negotiations implies that our political institutions do not yet have the capacity to handle development of SRM responsibly.

2.3.3 Slippery slope or technology 'lock in'

Even very basic and safe research into SRM could be a first step onto a 'slippery slope' towards deployment. Research could create momentum for development of SRM technology, as well as a lobbying constituency of scientists, engineers, investors and government agencies with an interest in pursuing SRM, leading to its eventual deployment. This constituency could use its influence to override moral and other objections or to unduly influence public opinion.

Allowing SRM research, and thereby making it the status quo, could also create an inertia opposing the cessation of research even if there is evidence of overwhelming negative impacts. Building the consideration of exit strategies – for both research and deployment – into SRM research governance would add a further layer of complexity, but would represent a prudent precaution.

2.3.4 Uncertainties

There are many uncertainties about the actual climatic impacts and unintended consequences of SRM research and deployment. Research will reduce these uncertainties, but it cannot eliminate them completely. There will be some uncertainties that are unlikely to be significantly reduced when intervening deliberately in something as complex as the Earth system and climate.

2.3.5 Global inequity

SRM research could constitute a cheap fix to a problem created by developed countries, while further transferring environmental risk to the poorest countries and the most vulnerable people.

Further, the SRM decision-making process (eg who decides if and when large-scale experiments are undertaken or deployment occurs, and where to set the 'global thermostat') could further exacerbate divisions between developed and developing countries over global climate politics. Just as the effects of global warming will be highly variable around the world, the deployment of SRM would probably affect countries in different ways. Reaching agreement over the ideal global climate could be extremely difficult, so any SRM decision-making will probably be dictated by traditional power relations. As a result, development and control of SRM could give rise to conflict and even violence.

2.3.6 Misuse of technology

While research would ideally be transparent, international and include a diverse range of participants, it could be undertaken in secret by governments, military programmes or private actors, for their own purposes rather than for public benefit.

2.3.7 Perception

SRM may be developed regardless of the perceptions of diverse publics. If programmes purport to research SRM for public benefit – which appears to be the dominant framing at this time – then those responsible for overseeing the research need to make every effort to ensure that the public understands and agrees that it wants to pursue this option, and is consulted as inclusively as possible in decision-making processes throughout any research programme (and deployment, if that happens). This process needs to allow for the possibility of volatile public perception, especially if unexpected climate- or SRM- related problems emerge. It represents an enormous challenge, as discussed later in this report.

The terms 'radiation' and 'management' are also worrying in this context. 'Sunlight reflection methods' has been suggested as an equally accurate and more easily understandable terminology (Ken Caldeira pers comm). However, attempts to change language used to describe solar geoengineering could be seen as an attempt to rebrand an unpopular concept.

2.3.8 Hubris and interference with nature

Artificial interference in the climate system may be seen as hubristic: 'playing God' or 'messing with nature', which is considered to be ethically and morally unacceptable. While some argue that human beings have been interfering with the global climate on a large scale for centuries, SRM involves *deliberate* interference with natural systems on a planetary scale, rather than an inadvertent side effect. This could be an important ethical distinction.

2.4 Conclusion

There is a wide range of motivations for conducting SRM research, not least its potential to address several concerns about climate change. However, there are also wide-ranging concerns. Opening up debate is more important at this stage than closing it down with prescriptive policy statements, and encouraging conversations about the goals and associated concerns of SRM is the first step towards forming norms through which a thoughtful and appropriate research regime can operate.

Definitions and categories

3.1 Defining SRM research

In considering possible needs for governance of SRM research, it is necessary to ask what SRM research actually is. In particular: can it be operationally defined, is it special in relation to other potentially risky environmental research and, if so, how and why? Much SRM research may in practice be very similar to other climate-related research, and mainstream climate-related research may be undertaken for reasons that have nothing to do with SRM, but can nevertheless be relevant[7]. For example, real-world testing of the cooling effects of aerosols would be important climate research regardless of its relevance to SRM. The difference between a climate aerosol experiment and an SRM aerosol experiment might only be the intentions of the researcher. It is widely considered that the intention of the research does matter, but considering this when establishing guidelines for research is quite difficult[8].

This 'dual use' nature of some SRM-related research is significant for governance. Restrictions on SRM research could possibly be circumvented by researchers claiming that they were studying something else (eg 'global dimming', the effects of volcanoes, the effects of aerosols in the atmosphere, or cloud formation and brightness). Curbs on research that is regarded as SRM-related could therefore also impede useful environmental research.

It can be argued that SRM research cannot be tightly defined, precluding the possibility of a good governance regime aimed specifically at SRM. This argument can be extended to suggest that the governance of SRM research should be part of broader frameworks for research activities that pose potential risks, especially those that may extend across international boundaries, or affect a global commons (such as the oceans). The counter argument is that where SRM research can be sufficiently clearly defined, suitable governance mechanisms should apply.

3.1.1 Is SRM research special?

Most scientific research is already governed by systems of norms and rules that cover funding, research and the publication and use of findings. In many countries controversial areas of research (eg those involving stem cells, animals or human subjects) are strictly governed by regulation, while most other areas rely on bottom-up governance through norms, codes of conduct and systems of peer review. In many countries decisions on the funding of individual scientific research projects are decided by merit review (eg by the scientific community closest to the frontiers of that research). However, the public interest is usually a

[7] To this extent it is no different to other areas of scientific work that are regulated – synthetic biology for instance, where fundamental work on cell-biology not directed specifically at synthetic biology can be applied to deliberate attempts to create artificial life.

[8] Including intention in governance decisions can be done at the large-scale programme funding level (both nationally and internationally) but remains difficult at the level of individual projects.

factor in deciding high-level priorities, especially for strategic research, and what programmes are funded.

The key question is therefore whether research explicitly focussing on SRM has any characteristics that warrant particular (and possibly novel) forms of oversight. There are several reasons to apply special scrutiny to research focussing explicitly on SRM research, whether or not it is publicly funded, although these reasons (listed here) do not necessarily imply that all types of SRM research need to be tightly regulated.

- SRM research can be considered to be strategic research since it examines a possible response to a global problem, and is not only born out of scientific curiosity. The wider publics have legitimate interest in what kinds of responses are being explored on their behalf and whether that exploration poses a risk to them. Whether SRM research should be supported with public funds, and what types of SRM research should be undertaken, are important issues for public debate. Consequently, even SRM research that is of minimal risk (such as lab-based experiments) might warrant public oversight, as is the case for research into synthetic biology.
- Since climate change is a global problem, research into possible SRM methods to respond to climate change should be open to global scrutiny. SRM research is not special in this sense: global governance mechanisms for climate change mitigation and adaptation already exist. However, research into technologies that, if deployed, would intentionally change the living conditions of most people, has not previously been proposed. The contrasting opinions regarding whether SRM represents an alternative or a complement to climate change mitigation and adaptation suggests that SRM research may warrant a different form of global governance.
- Similarly, the impacts of large-scale SRM research are unlikely to be confined to one national jurisdiction. The trans-boundary nature of such research would probably warrant some form of global governance.
- There are numerous examples of technological trials being conducted by researchers from developed countries in developing countries, without adequate attention being given to the interests or informed consent of the affected population. This is generally regarded as unjust, and research on SRM technology intended to have global effects may be regarded similarly.
- SRM raises particular concerns about interfering with complex natural systems. Global publics may disapprove of perceived attempts to 'meddle with nature' on a large scale and are likely to support attempts to regulate such activities.
- Any response to a global problem might be rejected as illegitimate and unacceptable if the majority of the world's population played little role in creating the problem or approving the response.

As most SRM technologies are currently 'upstream' (ie in their infancy) their properties and implications are largely unknown, and will only emerge if research continues. This is an example of Collingridge's (1980) 'technology control dilemma': Ideally, appropriate safeguards would be put in place in the early stages of the development of a technology. However, it is not clear in the early stages what these safeguards may need to be, and by the time the technology has been widely developed it may be too late to build in desirable governance arrangements without major disruption.

Researchers should (and generally do) recognise that their work is conducted in a political and social context, and that public oversight even of lab-based experiments is not unreasonable in particular circumstances.

Some of these concerns might be addressed by appropriate public involvement in the allocation of research funding (Gibbons 1999). Where this already occurs, current mechanisms to encourage public engagement may be sufficient to deal with some of the issues raised by SRM research.

3.2 Categorising SRM research

There is a very wide range of possible SRM-related research activities, from computer models to real world tests on a global scale, designed to affect the climate over a number of years. Participants in the SRMGI process generally agreed that differentiated governance arrangements for different kinds of SRM activity could lead to more effective governance than a 'one-size-fits-all' approach, where the same rules would apply to computer modelling as apply to planetary-scale tests. The need for differentiated governance is most apparent in research that uses observations of natural phenomenon in nature (eg volcanic eruptions) as the basis of better understanding of potential SRM technologies versus experiments in the environment where materials are added.

Moreover, 193 countries have in effect already approved this differentiated approach to governance of geoengineering research through the 2010 decision by the UN Convention on Biological Diversity (CBD). The negotiated text encourages Parties to consider ensuring 'that no climate-related geo-engineering activities that may affect biodiversity take place... with the exception of small scale scientific research studies that would be conducted in a controlled setting air...' (CBD 2010). The CBD did not define large scale or small scale, but the acceptance that different research activities require differentiated governance arrangements was clear among the delegates that agreed to this language.

The discussions at the 2011 SRMGI conference used and developed the categorisation of SRM related activities in Table 3.1. The assignment of possible types of experiments to different risk categories is itself based on contingency and uncertainty, especially within categories 3 and 4, where impacts are hypothetical. The question of what is 'at risk' (eg human health, environmental resources, political stability) may be contested. The assignments will have to be revised as new evidence emerges.

Table 3.1 Possible categories of activities to be considered.

'Indoors' activities and passive observations	1 Non-hazardous studies: no potential environmental impacts (eg theoretical computer/desk studies)	Activities with negligible direct risk
	2 Laboratory studies or passive observations of nature: a not involving potentially hazardous materials b conducted within an appropriately contained laboratory environment involving potentially hazardous materials, with no deliberate release thereof, and no intentional environmental impacts c environmental measurements with relevance to proposed SRM techniques (eg observations of the reflectivity of different types of clouds or surfaces, or the consequences of large volcanoes)	
'Outdoors' activities	3 **Small field trials**: field trials involving activities (including release of materials to the environment) of a magnitude, spatial scale and temporal duration that may lead to locally measurable environmental effects that are considered to be insignificant at larger scales[9]	
	4 **Medium and large-scale field trials**: field trials involving activities (including release of materials to the environment) of a magnitude, spatial scale and temporal duration that may lead to measurable environmental effects, which are considered to be significant and: a Medium field trials: have effects of local or regional extent (but not extending across national boundaries) b Large field trials: have global or large-scale effects, potentially extending across national boundaries	Activities with potentially direct risks
	5 Deployment activities (including release of materials to the environment) potentially leading to environmental effects of a sufficient magnitude and spatial scale to affect global and regional climate significantly and lasting for more than one year[10].	

3.2.1 Caveats

Boundaries between some of the categories in Table 3.1 cannot be defined by science alone. This categorisation is one possible way of organising SRM research activities and going beyond a 'one-size-fits-all' governance regime. It provided a useful basis for discussion, but it is not a consensus view. Other ways, for instance, would be to organise SRM governance based on existing governance mechanisms such as international treaties, or to separate research into two basic categories – that on the impacts of SRM deployment from research, and that on the physical feasibility of deployment.

[9] The upper limit for this category needs to be defined, and should probably include a 'safety factor' to take account of the possibility of overlapping and/or cumulative effects of multiple experiments if these are of sufficient scale and duration.

[10] The suggested duration of one year here is tentative and would also need to be determined in due course.

No framework for differentiating among types of research and their differentiated need for governance is inherently superior, but the category system in Table 3.1 has the advantages of being clear, accessible and reflecting the full range of potential SRM research activities.

The category system does not imply that SRM research should necessarily be expected to progress from Category 1 to Category 5. This is not a ‘road map’ for research, and Category 5 is not a destination that many participants, if any, wish to reach. Indeed it can be argued that even research with no potential for environmental impacts should not proceed, for three reasons:

- the ‘slippery slope’ argument, which sees the categories as stages on the path to deployment
- the ‘moral hazard’ argument (see chapter 2)
- the ethical argument that some people feel that deliberate climate intervention would be morally unacceptable.

Participants recognised the legitimacy of these arguments, although some felt that at least research in the lower categories (which is deemed to be safe) should be allowed. Even though many participants were deeply sceptical of the idea of SRM deployment, there was little appetite at the conference for a complete ban on all research, with many favouring strong multilateral governance regimes.

3.2.2 Assessing risk

A further aspect of differentiation among categories of research is that physical risk, as evaluated by technical experts, is certainly not the only consideration. Public perception of potentially controversial environmental research is also important, and there are a number of factors that have been shown in the social sciences to influence acceptability of technologies.

For example, the acceptability of field experiments might vary depending on who was conducting the tests, with research undertaken by publically funded universities perhaps receiving a different popular reaction to research undertaken by a military organisation or an oil company. Other factors may include, but are not limited to:

- who funds the research
- the purpose of the research
- how familiar the activities are
- how reversible the effects of experiment are
- perceptions of trust, liability arrangements and consent.

The background paper *Thresholds and Categories*[11], in particular Table 4.1, illustrated some possible qualitative factors, with suggestions of how these may affect perception and hence acceptability.

3.2.3 Defining category boundaries

If defining categories of research for differentiated governance proves to be practicable and useful, it will be necessary at some stage to define the thresholds between the categories and to describe how they correspond to different governance options. This was not attempted at the 2011 conference, as such refinement should be attempted only after a broader and more general discussion of the relevant issues has taken place.

Discussions suggested that determining these thresholds would necessarily combine the selection of guiding values for the endeavour, relevant factors in the physical and social systems, and consideration of uncertainties.

Defining thresholds, especially as the scale of likely impact increases, entails a mixture of technical and value-based judgments with regard to the tasks described above. It is now widely acknowledged in the policy literature that science and values interact dynamically in the process of risk analysis, even at early stages when risks are first being assessed (FAO 2002). Risk identification and assessment is not simply a technical problem, but involves a process of selection that depends on a characterisation known as 'framing' (NRC 1996). Developing the technical capacity to estimate risk will be critical, as well as developing a means of incorporating qualitative factors into the decision framework in a practicable way.

The following chapter outlines the overarching governance issues of relevance to all categories of SRM research. Chapter 5 discusses the specific governance issues for the five categories of SRM research.

[11] Available to download at www.srmgi.org/background-papers-for-2011-srmgi-conference.

General governance considerations

4.1 Introduction

In this chapter the general governance considerations that apply to SRM research are examined. The basic physical characteristics of SRM (outlined in chapter 1), and the many competing goals and concerns associated with the development of these technologies (outlined in chapter 2), underpin the argument that the governance of SRM research deserves careful attention. It seems clear that large-scale SRM interventions would pose potential risks and provoke contending views that would require effective governance, whether these interventions are undertaken as operational deployments or as large-scale research. It is less clear, and less widely agreed, that smaller-scale SRM research activities pose similar challenges that would require new governance mechanisms, but some SRMGI participants hold this view.

This chapter does not take a view on what kinds of SRM research require what kinds of governance, or what approach to organising governance is likely to be most effective. Rather, it considers:

- the specific functions that SRM research governance might perform
- existing international treaties and organisations of potential relevance to SRM research, and the extent to which they might be applicable
- alternative ways of coordinating and delivering the governance of SRM research, and their advantages and disadvantages
- how a phased and adaptive approach to SRM research governance might proceed.

The specific governance issues and questions that arise for each of the categories of SRM research (as defined in chapter 3) are considered below in chapter 5.

4.2 Defining governance

There was some confusion amongst participants over what the term "governance" encompassed. A broad definition is used here, including the resources, information, expertise, and methods needed for the control of an activity, in order to advance the potential societal benefits provided by SRM, while managing associated risks. Governance therefore does not refer only to 'hard' regulation, where an authority simply bans or controls particular activities. While this is one possible governance activity, there are many other 'soft' governance processes that do not involve directly granting or denying permission for research, such as allocation of research funding, norms about transparency and plagiarism, and requirements for reporting of activities and results.

4.2.1 The function of governance

To understand potential governance options for SRM, it is helpful to consider the variety of functions that these may need to perform. While there is no definitive list of these, the following appear to be important:

- making decisions regarding proposed SRM projects, either regarding the provision of funding or regarding authorisation to proceed
- establishing requirements for the disclosure and dissemination of information and norms to promote safe management, to bodies involved in governance and to the interested public
- assessment of the scientific and technical competency and value of proposed SRM interventions, and public consultation
- monitoring and oversight of interventions that are already underway, updating assessments of their risks and value, and adjusting these as appropriate
- provisions for liability and compensation in case of claims of harms caused by SRM projects
- provisions to anticipate, manage, and resolve potential conflicts associated with SRM.

4.3 Relevant governance mechanisms

There already exist many governance processes of relevance to SRM research, which deliver some of the governance functions outlined above. There is a hierarchy of governance mechanisms to deal with other sorts of scientific and engineering research, and these could be adapted and applied to governance of SRM.

4.3.1 Scales of regulation

The range includes the following types and scales of regulation (including 'soft' regulation by norms and standards of behaviour):

A individual regulation (by the researchers themselves)

B peer regulation (by colleagues)

C professional regulation (by a professional body)

D institutional regulation (eg by the laboratory, university, company)

E local/regional governmental regulation (eg local zoning, safety, and environmental controls)

F national regulation

G international regulation

Most of these (A to E) would already apply to SRM research, *before* any additional SRM-specific restrictions were adopted.

At the national level (F), these mechanisms include standard procedures for approval and funding of research, and regulating health, safety and environmental impacts and risks. Similarly at the international level (G), there are already organisations and treaties with mandates that are potentially relevant for a future governance system for SRM research. These treaties and organisations are discussed in detail in appendix 3, which analyses each one's relevance to SRM, scientific and governance capacity, and legitimacy.

4.3.2 Building on prior experiences

It will also be important to draw on governance models and lessons learned from other controversial areas of science and technology. It is easy to miss opportunities for social and policy learning from one technological 'episode' to the next. For example, debates over nuclear power in the 1960s and 1970s profoundly shaped responses in Europe to genetically modified (GM) crops in the 1990s, and the GM controversy in turn shaped the recent reception of nanotechnologies.

There is a need to ensure greater opportunities for systematic reflection and policy learning across different technology domains. As the *Royal Commission on Environmental Pollution* argues in a recent report (RCEP 2008): 'There are no simple and straightforward solutions to the control dilemma. It is possible, and indeed essential, to narrow the gaps through concerted efforts in research and by tightening and extending existing regulations. But the governance of emerging technologies in the face of ubiquity, ignorance and uncertainty. . .will mean looking beyond traditional regulation for other, more imaginative solutions, often involving a wider range of actors and institutions than has been customary in the past.'

4.3.3 International organisations and treaties

There is a long-standing principle of customary international law – the responsibility to avoid trans-boundary harm – that has been interpreted since the mid-20th century to include environmental harms (Handl 2007). While this principle could impose obligations on parties considering doing SRM, its implications are vague and its operational significance limited. Consequently, its role in discussions over SRM is at best to provide a broad normative background for states' attempts to agree on their specific duties.

A number of international organisations and treaties within and outside the UN umbrella already govern a range of issues that overlap somewhat with those of SRM governance. However, the overlap for any one organisation is generally small, addressing only part of the full range of issues involved. No existing international organisation or treaty has the specific mandate or technical capacity to govern all the political, socioeconomic, ethical, and physical dimensions of SRM research, deployment, and impact.

For example, the CBD's decision at the 10th Conference of the Parties (COP) in Nagoya in 2010 to recommend prohibition of large-scale testing in the absence of regulatory frameworks and minimised uncertainty represents a UN body's first intentional governance decision on geoengineering and hence SRM (CBD 2010). However, this decision was made in the context of potential adverse biodiversity impacts, and without any mandate or opportunity to consider other dimensions of

SRM benefits or impacts (eg to vulnerable human populations). Since it is embedded in a non-binding COP decision which employs vague and weak language, and since the CBD has minimal compliance structures and ambiguous connections to the mandates of other treaties that have a clear climate mandate, it is unclear what (if any) *legal* precedent the CBD decision sets. Nonetheless, the *normative* precedent of such a decision remains very significant, and lays foundations for shaping further discussions about the international governance of SRM.

International governance of SRM, where required, might be accomplished by co-opting one or more existing international organisation or treaty to incorporate SRM. Alternatively, a *new* organisation or treaty could be created and introduced into the existing global environmental governance landscape with a specific mandate to govern SRM research (and possibly future deployment).

To consider both options, it is necessary to assess the current landscape of international organisations and treaties of potential relevance to SRM. These include the CBD, International Maritime Organisation (IMO), United Nations Environment Programme (UNEP), United Nations Framework Convention on Climate Change (UNFCCC), Convention on Long-Range Transboundary Air Pollution (CLRTAP), Convention on the prohibition of military or any hostile use of environmental modification techniques (ENMOD), Montreal Protocol, Antarctic Treaty System, Outer Space Treaty, and United Nations Convention on the Law of the Sea UNCLOS). These are discussed in detail in appendix 3 and others are also listed below, clustered into thematic groups:

1. Prohibitory regimes:
   - ENMOD (1977)
   - Biological and Toxin Weapons Convention (1975)
2. Comprehensive but spatially limited regimes:
   - UNCLOS (1982)
   - Antarctic Treaty System (1959)
   - Outer Space Treaty (1967)
3. Regimes controlling specific international environmental issues:
   - the stratospheric ozone regime: the Vienna Convention (1985) and Montreal Protocol (1987)
   - CLRTAP (1979) and its eight protocols
4. Regimes in which decisions relevant to SRM have been taken:
   - Convention on Biological Diversity (CBD (1992)
   - London Convention (1972) and Protocol (1996) (LCP)[12]

12 Decisions taken under the LCP so far relate only to Ocean Fertilisation (a CDR method rather than SRM) but the general approach to R&D may be relevant to SRM.

The international governance of SRM research poses many novel challenges as there is no existing international regime that covers precisely what is contemplated for SRM. No existing international treaty, institution or regime exercises detailed governance authority over an area of scientific research deemed to be of international interest or concern – ie assesses, scrutinises, controls, and/or approves or disapproves, research proposals. Any one of the existing relevant regimes would require considerable development in order to deliver the necessary governance functions required for SRM, and there is no obvious leading choice as to which regime (or regimes) would be best suited for this.

4.3.3.1 CDR governance

Besides existing governance regimes that overlap with SRM, parallels can also be found in other fields of scientific research, such as ocean fertilisation experiments. While ocean fertilisation falls under the CDR category of geoengineering, rather than the SRM category (the focus of this report), it nevertheless offers some useful insights. It is relevant to SRM because it similarly represents a form of research that entails considerable risks needing careful governance. Also, like SRM, it has potential effects spanning international boundaries, and raising difficult questions of accountability and global equity.

Box 4.1 Ocean fertilisation

How is ocean fertilisation governed?

Ocean fertilisation has been the subject of resolutions by the London Convention (LC) and the London Protocol (LP), as well as the Convention on Biological Diversity (CBD), although these resolutions are not legally binding.

In 2008, The LC/LP adopted a non-binding resolution on the regulation of ocean fertilisation, with the main agreements being that:

- given the present state of knowledge, ocean fertilisation activities other than legitimate scientific research should not be allowed
- scientific research proposals should be assessed on a case-by-case basis using an assessment framework to be developed by the scientific groups
- until guidance is available, Contracting Parties should be urged to use utmost caution and the best available guidance to evaluate scientific research proposals in order to ensure protection of the marine environment consistent with the LC/LP
- there should be further consideration of a potential legally binding resolution or an amendment to the LP.

An Ocean Fertilisation Assessment Framework (OFAF) was subsequently adopted by the LC/LP in 2010, for determining whether proposed ocean fertilisation research represents ‘legitimate scientific research’ consistent with the aims of the LC/LP. The parameters considered include, but are not limited to: the type of material to be added to the oceans, where and how it will be added, what effects there might be on the marine environment, and how the impact of the material will be monitored.

Since 2008 the LC/LP Parties have considered a wide range of options for regulating ocean fertilisation. They are now also considering a broader approach that would enable the regulation of other types of marine geoengineering besides ocean fertilisation – for example, by amending the LP to cover other types of marine geoengineering through a flexible mechanism, or adopting an interpretative resolution that would be legally binding.

Regarding the CBD, it followed the approach of the LC in its 2008 decision IX/16(C):

"… requests Parties and urges other Governments, in accordance with the precautionary approach, to ensure that ocean fertilization 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. Such studies should only be authorized if justified by the need to gather specific scientific data, and should also be subject to a thorough prior assessment of the potential impacts of the research studies on the marine environment, and be strictly controlled, and not be used for generating and selling carbon offsets or any other commercial purposes".

The ambiguity of the term 'coastal waters', and the fact that small-scale near-shore studies are meaningless for ocean fertilisation field trials led to a swift response from the Intergovernmental Oceanographic Commission's Ad Hoc Consultative Group on Ocean Fertilisation, which drew attention both to the need for clarification of the language of the CBD decision and challenging the scientific assumptions underpinning it.

What can we learn from the governance of ocean fertilisation?

At present ocean fertilisation is not subject to a legally binding regime, although LC/LP contracting Parties are making progress towards that end. It is anticipated that the eventual legally binding regime will constitute a more robust governance regime for ocean fertilisation experiments. International negotiations for such a regime will almost certainly be protracted due to the need to gain the agreement of a wide range of countries with disparate interests and varied levels of knowledge about ocean fertilisation activities. The procedures can seem bureaucratic, but there is some flexibility in the sense that the interpretation, implementation and enforcement of such agreements is the responsibility of the Contracting Parties, rather than the LC/LP. In theory, the only significant loophole is that not all States are Contracting Parties. In practice, however, all of the States with ocean fertilisation interests and capacity are involved. However, note that Article 210(6) of UNCLOS has the effect of making the LC/LP applicable to all Parties to UNCLOS.

In addition to the lessons that can be learned about the governance of research through international conventions, ocean fertilisation may also provide examples of the ways in which commercial ventures can engage in the conduct and governance of scientific research.

In 2007, Planktos Inc planned to disperse up to 100 tons of iron in a 10,000km^2 area approximately 350 miles west of the Galapagos Islands in order to stimulate phytoplankton blooms. It also planned a further six large-scale iron experiments in other locations in the Pacific and Atlantic Oceans. Each of these studies were to be, in the company's own words, 'at least one to two orders of magnitude larger and at least four to six times longer than any of the ten previous international research efforts in this field'. However, due to the opposition of a large number of countries in South America, the Caribbean and Europe, Planktos was unable to carry out any experiments and ceased to exist shortly thereafter.

Another corporation, Climos, adopted a much lower profile, engaging with consultants and academics and preparing a Code of Conduct for ocean fertilisation studies. Climos gained representation at LC/LP meetings through the International Emissions Trading Association (IETA) from 2008 and was able to engage in discussions. It had originally talked about carrying out a 40,000 km^2 fertilisation experiment. However, it is yet to carry out any field experiments, although it is still in business.

Ocean fertilisation also provides a useful parallel because its governance is already being addressed under two international conventions; and, as discussed, international governance of this sort has been proposed as one credible option for SRM research.

4.4 Alternative approaches to governance

At least four distinct forms of governance for SRM research have been explored:

- a collection of independent national policies
- a non-governmental, transnational code of conduct
- adapting existing international environmental instruments and institution(s)
- the formation of a new international instrument or institution.

Table 4.1 provides an overview of benefits and drawbacks of these four governance forms. While no attempt was made to evaluate these options comparatively, participants generally agreed that, as a minimum, international coordination from an early stage of national-level SRM research and governance activities was desirable to minimise the potential for future conflicts.

Table 4.1 Benefits and drawbacks in adopting different governance options for SRM.

Governance regime option	Potential benefits of this approach	Potential pitfalls and drawbacks of this approach
National-level policy driven	• protects sovereignty of nations in making their own decisions, which could reduce some tensions • could be implemented relatively quickly (at least in the case of developed states with strong environmental law and regulatory systems already in place), though this could potentially take years rather than months • clear enforcement mechanisms through national law (private suit and/or regulatory enforcement action) • could act as a building block for international negotiations so that when that process begins, the key differences of opinion are already on the table, thus potentially moving the deliberations forward quicker (bottom up approach)	• could create more tensions than it avoids, especially if some nations move aggressively into technology development; could begin an SRM race fuelled by national self-interest, instead of global consensus • states might 'compete' for SRM business (flags of convenience), though in short term difficult to see significant economic benefits in so doing (though could be geopolitical benefit) • some nations could get so far ahead in terms of technology development, research, and knowledge of the issues that inclusion of others later on is difficult; future relinquishing of such advantages could create difficulties
Non-governmental codes of conduct	• lack of bureaucracy creates more flexibility in regulation • could be implemented relatively quickly, as long as all are willing to abide by the rules (although this would depend on how long it takes to engage interested parties) • may be generated by non-state actors/geoengineering stakeholders • potential for inclusion of a variety of stakeholders making it easier to negotiate such codes informally than at formalised international negotiations. However, with each group included the efficiency of generating consensus and concrete rules may decrease because of diversity of perspectives	• if lack of elected official engagement in decision-making, this could create perception that a relatively select group is having unfair say in the issue and create pushback • could lead to perceptions of illegitimacy if those involved in research lead the governance framework as well • could lack enforcement power

[13] See appendix 2.

Table 4.1 (continued)

Governance regime option	Potential benefits of this approach	Potential pitfalls and drawbacks of this approach
	• potential for inclusion of a variety of stakeholders making it easier to negotiate such codes informally than at formalised international negotiations. However, with each group included the efficiency of generating consensus and concrete rules may decrease because of diversity of perspectives	
Co-opt existing international environmental institution(s)	• could be quicker and easier than building a new institution, but be just as strong/enforceable • using institutions with high degree of legitimacy would make governance stronger/more definite	• these institutions might not be flexible enough to deal with rapid new understandings and developments from SRM research • the decision-making structure for SRM research, testing, and deployment could become very complicated (particularly if multiple institutions become involved), resulting in an opaque/non-transparent and difficult to manage system • unclear what existing institution would want to take this on
Develop a new international institution	• could fill in regulatory gaps that other institutions cannot; handles the aspects of SRM governance that no other institution has been designed to tackle • various aspects of institution (eg enforcement mechanisms) can be tailored specifically to the SRM issue • need for flexibility in institution could be satisfied (are existing regimes flexible enough?) • could be supplemented with soft law initially to allow for flexibility in near term whilst stricter rules are evaluated and considered; this would lessen pressure on the new institution to create regulatory certainty right away, which could result in a suboptimal framework	• time lag for creation and implementation of new institution could be longer than the implementation time for the other three options, and potentially too long without other regulation filling the space • yet another governance institution and negotiating arena might complicate an already knotted political debate, especially for existing climate negotiations • generating legitimacy in such an institution requires time to build confidence among Parties in the consistency and saliency of the institution • since there are so many facets to SRM issue, it could be too much for a single institution to take on; various related subtopics could be more efficiently negotiated in separate forums

This is far from an exhaustive list of potential governance pathways. However, discussion of these options at the conference, particularly through exploratory scenario-based exercises[13] was useful for developing a common understanding of diverse perspectives and the challenges inherent in developing an effective and equitable SRM governance regime. This simple framework hopefully provides a foundation for further discussion and dialogue about the governance of emerging SRM research and technologies.

4.5 Adaptive development of governance instruments and institutions

Institutionalisation can proceed in numerous ways, from a purely consultative body to formal treaties or institutions and all the intermediaries. For instance, governments could:

- meet as a consultative body, whilst providing resources for staff support or an international assessment process, even while all project approval decisions remain with national officials
- meet as a consultative body, negotiating agreed text in the form of soft-law instruments that could, for example, state agreed practices and criteria for risk assessment, or practices for public consultation and participation. These would be non-binding, at least initially, but could still represent sufficiently strong agreement to create an expectation that governments would normally follow them
- contribute research funds to support collaborative projects with international participation.

Decisions about both institutionalisation and participation could be revisited and changed over time. This is typical of international action on other novel issues, and could be a useful approach for SRM: starting with a purely consultative body and moving towards increased institutionalisation or codification as experience accumulates, knowledge is gained, mutual confidence builds among participating governments, and the need for decision-making capacity grows more acute.

Similarly, participation could expand over time and the set of participants need not be fixed. There may be value in starting discussions early among governments considering establishing SRM research programmes, particularly at the informal official-to-official level. However, other governments may want to contribute, perhaps initially via a 'price-of-entry' model, where governments have to pay, or meet certain conditions, in order to participate in governance activities. Any increase in the scale, prominence, and potential controversy of SRM would increase the pressure to expand SRM discussions. Such an expansion would help to establish a legitimate forum for international decision-making regarding large-scale SRM research. This is not to pre-judge the eventual level of participation, although it must eventually grow beyond the initial small group of nations that begins to discuss SRM.

A number of questions will arise as institutionalisation and participation are resolved. For example, would the members of any newly created international body act under instruction from their governments, or on their own judgements?

As participation expands and decision-making is formalised, what decision rules are used, such as consensus or qualified or weighted super-majority? Does this body provide funding or other support for proposed projects, or just permission? Does it provide explanation or reasoning in support of its decisions, and if so, in what form? Is there any recourse or appeal from its decisions? Is the SRM governing body intended to expand to reach the capacity and legitimacy needed to handle future decisions and conflicts over deployment, or would a separate body be created at some future time if there was interest in deployment?

4.5.1 Application to SRM research

For SRM research in general, but for category 3/4 experiments in particular, some participants favoured an adaptive or iterative approach, which allows for governance arrangements to be developed and modified as the implications of the technology become clearer, rather than instituting comprehensive regulations at the outset.

As SRM technologies are still nascent and evolving, any governance schemes could quickly become out of date. Risk assessments at an early stage would be speculative, particularly for early project proposals, and it would be extremely difficult to conduct a comprehensive risk assessment of all future research projects before some SRM research has been carried out. Risk assessment could therefore be an adaptive process, learning from early small experiments and advancing knowledge to inform future assessments.

SRM governance also needs to remain flexible to allow for non-state actors to participate. Flexibility will also allow governance to be scaled up if and when the risks of SRM research become larger and better understood. Some participants even argued that it was unrealistic that an appropriate governance programme for SRM research could be designed at this early stage.

Other participants were concerned that flexible governance (even just at the early stages) may be unacceptable to those who are fearful of the slippery slope, or of possible hidden agendas of those who want to research SRM.

4.6 Cross-cutting governance considerations

The following chapter outlines the specific issues and questions that arise for each of the categories of SRM research (as defined in chapter 3). However, there are some key 'soft' governance considerations that apply to all SRM research, albeit to varying degrees across the categories. These are outlined below.

4.6.1 Research transparency

Participants agreed that transparency of research activities and open publication of results (both positive and negative) would be a very important factor affecting public perception and governance mechanisms across all categories of SRM research. Participants were highly supportive of an international register of experiments to facilitate the sharing of information.

4.6.2 Public engagement

Both national and international institutions are only just beginning to address SRM research. The evolution of governance of SRM research, nationally and internationally, will depend significantly on which actors get involved and at what stage. The specific agendas and institutions or publics to which these actors respond will also have a considerable influence.

Only a handful of actors in global (environmental) governance have begun to form coherent views on SRM regulation. Ad hoc scientific task forces have played a significant role in shaping the evolution of SRM governance so far: aside from SRMGI, these have included the United States Bipartisan Policy Center (Bipartisan Policy Center 2010) and the 2010 Asilomar II conference (Climate Response Fund 2010, Kintisch 2010). Parliamentary inquiries in the United Kingdom (House of Commons 2010) and congressional inquires in the United States (US House of Representatives 2009) have also raised the profile of SRM research and governance (Olson 2011).

Civil society actors are starting to play an increasingly prominent role in shaping policy discourse. Engaging the breadth of emerging stakeholders in the dialogue is essential to deciding the most appropriate formulation of SRM research governance regime, although this will not be an easy undertaking.

4.6.2.1 Objectives of public engagement

Developing public trust in principles and institutions governing SRM requires a process of interaction and dialogue between technical and value-based perspectives on the problem. The goal should be a mutually deepening understanding of the underlying problems, technical issues, and policy options among experts, stakeholders and lay public representatives.

It may be useful to engage the public directly to help orient policy-makers around public values. This process should not be equated with educating the public. Numerous public engagement methodologies exist – deliberative polling, focus groups, citizens' juries, consensus conferences, stakeholder dialogues, internet dialogues, deliberative mapping – all of which have their own merits and shortcomings. However, the most successful engagement comes from putting aim before method.

The objectives of any public engagement process should be clear from the start. It might simply be designed to gather information about public opinion – or, at the other end of the spectrum, to influence a policy decision. In disentangling the different reasons for public engagement, a useful distinction can be made between *normative*, *instrumental* and *substantive* motivations (Stirling 2008).

The *normative* view states that such processes should take place because they are the right thing to do: dialogue is an important ingredient of a healthy democracy. The *instrumental* view holds that engagement processes are carried out because they serve particular interests. For example, governments or research funders may want to engage in order to build trust in science and demonstrate their competence. From a *substantive* perspective, engagement processes aim to improve the quality of decision-making, to create more socially robust scientific and technological solutions. From this point of view, citizens are seen as subjects, not objects, of the process. They can actively shape decisions, rather than having their views canvassed by other actors to inform the decisions.

According to Stirling (2005) substantive approaches are particularly important when there are 'intractable scientific and technological uncertainties . . . as a means to consider broader issues, questions, conditions causes or possibilities.' Stirling goes on to make a helpful distinction between processes that aim to *open up* a debate, and ones that aim to *close it down*. For engagement to be meaningful, it needs to look at who frames the visions and purposes of a new technology, and to allow publics to ask the questions that they consider most important. For example: why this technology? Why not another? Who needs it? Who is controlling it? Can they be trusted? Who benefits from it? Will it improve the environment? What will it mean for people in the developing world?

4.6.2.2 Method

Public engagement is not a matter of asking people, with whatever limited information they have at their disposal, to say what they think the effects of ill-defined innovations might be. Rather, it is about moving away from models of prediction and control towards a richer public discussion about the visions, ends and purposes of science and technology.

Moving from category 1 to 5 there are progressively stronger grounds for informing and consulting the public. Yet since awareness of SRM geoengineering is at present confined mainly to a minority of specialists in only a few countries, and processes for engagement with diverse publics are in their infancy, this represents a considerable challenge. The aim should not be *representativeness* – directly engaging with a diverse array of potential publics worldwide – so much as *social intelligence-gathering* (Demos 2004) – improving the robustness of analysis and decision-making, through the inclusion of public attitudes, values and opinions. If this can be achieved, it should contribute to better governance and provide a forum for the early expression of opinions and concerns.

4.6.3 Participation and legitimacy

Any governance arrangements or decisions should ideally be perceived as widely as possible as legitimate, both nationally and internationally. Legitimacy is ultimately determined by widespread acceptance, regardless of the origin of the entity or procedures concerned (Habermas 1996). For example, customary international law is, based on a widespread practice, accepted as law, rather than formal agreement. Some bodies (including governments) are recognised as legitimate without having a democratic or participative basis.

There are a number of features of entities and processes that are generally considered to promote legitimacy. For instance, participation in decision-making is a key feature of a process that will be perceived as legitimate. Nevertheless, participation is only one element of the set of attributes that could make any proposed SRM research experiments publicly acceptable and enhance legitimacy.

4.6.3.1 Attributes contributing to legitimacy

The list below summarises the attributes that emerged from the discussion of SRM research and from wider debates about research, technology and governance (especially at the international level). This list is not exhaustive, and some attributes may even be contradictory. However, these are all concerns that different people, groups of people and/or countries may have that would affect their perception of the legitimacy of SRM research. The requirements will tend to be more stringent for the higher categories of research activity.

Ethical issues

- minimise interference with nature
- good intentions
- capability should not drive intent
- science for society (not for its own sake)
- equity (including intergenerational)

Procedures

- ‘fair’ process
- presence (especially participation in decisions)
- transparency
- peer review
- penalties (for adverse outcomes)
- active consent

Outcomes

- equitable
- positive for most (with compensation for others)
- contribution and capacity
- dispute resolution and enforcement

For the highest categories, whose effects may extend beyond national boundaries, developing an international consensus at an early stage would be useful. The definition of the boundary between category 3 and category 4 research is an important issue that could be the focus of a useful and informative debate. A side benefit of these deliberations would be building capacity and establishing confidence in the process.

4.6.3.2 Who participates?

Participants of the SRMGI conference considered the kind of institution or body that would be qualified to take important decisions on SRM research. Possible variations of who participates included:

- all countries (or other entities) who wish to participate
- those countries or entities who contribute funds to research programmes can have a seat at the table ('pay to play')
- a self-selected group of countries or entities, with or without financial contribution.

Participants felt that the more countries that participate the more legitimate the governance arrangements could be, but the less likely and slower the process would be to achieve clear agreement: there would be an inclusivity-efficiency trade-off. Being able to make decisions in a timely manner, unimpaired by its own deliberative processes, was widely seen as important for any governing entity.

Inclusivity was generally agreed to be particularly important for category 4 research. Since the effects of such field experiments could reach beyond national borders, it would be important not to exclude those most likely to be affected by experiments from the decision-making process.

Wide participation in SRM governance could minimise the likelihood of countries acting unilaterally: if governance was based on an exclusive 'club' countries might circumvent the governance arrangements as SRM could have a relatively low 'entry price'.

The most inclusive (and potentially legitimate) option would be to involve every country or entity that wishes to participate in the generic governance decision-making, with operational supervisory activities probably being delegated. The inability of the UNFCCC to agree on effective action to mitigate climate change was seen as a possible counter-example to the utility of this approach.

The least inclusive option is based on a (potentially small) group of countries (or other entities) being responsible for governance decisions. In the 'pay to play' scenario the decision making is restricted to only the countries (or entities) that contribute financially. This mechanism has the advantage of pre-selecting the countries with the capacity to engage in the process, but raises clear concerns regarding equity and legitimacy.

4.6.3.3 Unrepresented constituencies

There are a number of constituencies that could be greatly affected by SRM and climate change, who do not enjoy formal representatives in most governance forums (including future generations and threatened non-human species, for example). 'Ombudsmen' could be appointed to any advisory or decision-making bodies, to represent the views of these absent stakeholders. However, lack of representation for such constituencies is not unique to SRM governance.

4.6.4 Monitoring, compliance and verification

A strong and transparent verification and compliance regime could increase international trust and cooperation over SRM research, and provide reassurance that no one was ‘cheating’ and doing field research secretly. Such checks could possibly elevate the integrity of the process.

Opinion amongst participants was divided on whether compliance could be taken care of voluntarily, subject to social and scientific norms. Even if an advisory body were formed to give specific guidance there remained concerns for some over leaving compliance to an informal, voluntary process.

4.5.5 Liability and compensation

Cause and effect are likely to be less clear for the impacts of outdoors SRM research than for an oil spill or nuclear accident, for example. Consequently, establishing mechanisms to deal with project failures, such as liability and compensation, would be a significant challenge.

Category-specific governance considerations

5.1 Introduction

Chapter 4 reviewed the governance questions that may apply by all kinds of SRM research, recognising that many of the issues – such as participation, legitimacy or public engagement – become more pronounced as the categories, and the risks, rise. This chapter explores the individual categories in more detail, and examines the governance challenges at each stage.

5.2 Category 1: non-hazardous studies and category 2: laboratory studies

5.2.1 Definition and examples

These are research activities anticipated to have zero or negligible potential environmental impacts (eg theoretical computer/desk studies and experiments in enclosed laboratories). Most SRM research conducted to date fits into these two categories. Examples include:

Category 1

Research to date	Computer models of how the world's climate system would react to reduced incoming solar energy (eg Rasch *et al* 2008, Robock *et al* 2009, Jones *et al* 2010b)
	Computer models of the effects of brightening clouds above the oceans (eg Jones *et al* 2010a)
	Literature reviews of the effects of volcanic eruptions on incoming solar radiation (eg Robock and Mao 1995, Stenchikov *et al* 1998, Robock 2000, Caldeira and Wood 2008, Kravitz *et al* 2010, Kravitz and Robock 2011)
	Social science research into SRM: ethics, public dialogue, legal/institutional research (eg National Environment Research Council (NERC) public dialogue (NERC 2010), *the Oxford Principles* (House of Commons 2010) and *Asilomar principles* (Climate Response Fund 2010, Kintisch 2010))
Possible future research projects	Continued modelling work on the implications of different SRM techniques on temperatures, the hydrological cycle, ocean circulation and mixing, impacts on land plant and phytoplankton growth, impacts on biodiversity
	Continued and expanded public dialogue exercises, internationalised where possible
	More thought, debate and publication on the ethics of SRM
	Continuations of the *Geoengineering model intercomparison project* (GeoMIP) (Kravitz *et al* 2011)

Category 2

Research to date	Spray testing of nozzles for sea water for marine cloud brightening (Latham *et al* 2011, Neukermans *et al* 2011)
Possible future research projects	Research into different aerosols for possible release into stratosphere
	Observations of the effects of volcanic eruptions
	Laboratory tests of spray systems for aerosols

5.2.2 Governance

Activities in these categories inherently involve negligible risk of physical harm[14] as they are conducted 'indoors' without releasing materials into the environment. Research carried out in the library or laboratory – regardless of whether it relates to SRM – is already subject to a number of governance arrangements. For example, funders decide which research programmes to support, laboratories have health and safety standards, and the scientific profession maintains conventions about publication of results and methods.

Where indoors research raises contested ethical concerns (eg with stem cells) or involves potentially dangerous materials (eg research on radioactive substances), additional oversight that is enforced by national governments is the norm. In a few cases where indoors research has the potential for direct implications beyond national boundaries there can be additional, internationally agreed, governance arrangements (such as the Biological and Toxin Weapons Convention[15]).

5.2.2.1 Is category 1 and 2 research special?

The key question for categories 1 and 2 is whether it is qualitatively different from other forms of indoor scientific research, and therefore whether it should be subject to specific and additional governance requirements. Most indoors SRM research (such as computer modelling) is almost identical to climate research activities that are already widespread and ongoing around the world. Where SRM research could differ is in the anticipated implications for potential future expansion, including policy decisions regarding climate change response, and deployment.

Category 1 and 2 research was widely agreed not to be sufficiently unusual or dangerous to warrant dedicated forms of 'hard', regulatory governance, even amongst those who were more concerned about the 'slippery slope' possibility. The information gained from indoor research (modelling work in particular) was generally felt to help inform future policy-making about higher category SRM research and potential deployment.

14 With the possible exception of activities from category 2b of Table 3.1, which would involve lab-based research on potentially hazardous chemicals, for which formal risk assessments would be needed. The participants were not aware of any specific SRM-related research done in this category to date, but tests of aerosol formation using SO_2 and H_2S would be examples.

15 Available at www.opbw.org

5.2.2.2 'Soft' governance

However category 1 and 2 activities might benefit from some SRM-specific 'soft' governance activities. Arrangements that encouraged international cooperation and transparency on this kind of research were widely supported. Cooperative international research might help foster the strong networks and international trust that would help negotiate the more difficult challenges of higher category research, if it is undertaken.

There was a range of views on whether 'soft' governance would be best overseen by a comprehensive international regulatory regime, by national governments working outside a formal regime, or by voluntary regulation by academic communities.

5.3 Category 3: small field trials

5.3.1 Definition and examples

Category 3 research involves experiments conducted outside the lab and in the real world that are nevertheless considered to be 'safe'. Such experiments might involve testing components of SRM delivery systems, and exploration of some of the basic science of SRM. Testing measurable large-scale climatic effects of SRM intervention would fall outside this category as this would not be of negligible risk.

Even with no significant environmental impact, category 3 experiments differ qualitatively and symbolically from activities in categories 1 and 2, since they cause environmental perturbation in order to gain knowledge about the potential effects and risks of SRM. Little research that would fit into category 3 has been done to date (see below).

Category 3

Research to date	Field experiments on the optical properties of artificial aerosols (Izrael *et al* 2009)
Possible future research projects	Lynn Russell (University of California, San Diego) funded by the US National Science Foundation, *Eastern Pacific emitted aerosol cloud experiment* (Russell *et al* 2011).
	Stratospheric particle injection for climate engineering (SPICE) project[16]

5.3.2 Governance

5.3.2.1 Is category 3 research special?

As with categories 1 and 2, consideration should be given to whether category 3 SRM research is qualitatively different from existing activities to determine if it warrants special governance processes.

16 See http://gow.epsrc.ac.uk/ViewGrant.aspx?GrantRef=EP/I01473X/1

By definition this research has no harmful physical impacts, and its *quantitative* effects are no greater than a great number of activities that are already acceptable. Existing regional and national mechanisms would be applicable and might provide sufficient practical safeguards.

However, the same slippery slope and lock-in arguments apply as they do for indoor research, and there is a general presumption in favour of public consultation for any novel environmental perturbation.

5.3.2.2 Defining 'safe'

Turning category 3 from a concept into a useful reality needs a reliable and trustworthy system to determine which field experiments are sufficiently safe to undertake. The key governance question is how to determine and apply the upper boundary of category 3 (as is already done routinely for many occupational and environmental hazards).

This is a non-trivial question. Science alone cannot neatly classify possible activities as either 'safe' or 'unsafe', since these are socially constructed concepts. Therefore, establishing the boundary between categories 3 and 4 (ie what is acceptably low risk) has to be made via a political process informed by the best scientific advice.

Although the boundary between safe and unsafe real world experiments is 'fuzzy', it should still be feasible to construct a reliable and acceptable system for determining what goes into category 3. There is no single clear point at which taking an aeroplane flight crosses from being 'safe' to being 'unsafe' and all flights involve incurring a certain level of risk. However, most people are comfortable with this risk if they trust the engineering, health and safety procedures established to ensure passenger safety. Similarly, if desired, it should be possible to agree an acceptable low (negligible) level of risk associated with small-scale SRM research.

Setting aside the slippery slope and moral hazard concerns, some category 3 examples are likely to be widely accepted as safe, such as using a single nozzle to spray small quantities of seawater into the air to test the spraying capacity. However, whether claims made by researchers that an experiment is safe are accepted will depend on the level of trust in the system of governance.

5.3.2.3 The category 3/4 boundary

Who should oversee any governance arrangements, and how, tends to get more difficult with higher category geoengineering research. Difficult practical questions over SRM governance present themselves when research leaves the laboratory. For example, who would determine the level of risk that is deemed negligible and acceptable (the category 3/4 boundary)? What kind of inputs would be required to make that decision? Which body or bodies would enforce this determination by approving that proposed studies were indeed in category 3?

A premature commitment to a particular governance system may not be desirable, since accumulated knowledge and regulatory experience may serve as an important guide to designing technology-appropriate governance arrangements.

Two specific possible arrangements for category 3 research, an 'allowed zone' and the use of advisory panels, are discussed below.

5.3.2.4 Allowed zone

An 'allowed zone' would set parameters in which any experiments could take place without additional approval (eg beyond standard local, regional and national requirements, and those for transparency and full reporting).

Possible parameters for aerosols experiments might include total amount of aerosols released, total area over which they are released, maximum radiative forcing, and duration of release. Morgan and Ricke (2010) present a more complete discussion of the 'allowed zone' idea.

A defined allowed zone could streamline the approval of any small experiments that operate within agreed, safe limits, without each experiment or research programme having to go through a specific and time-consuming approval process for little public benefit.

However agreeing the parameters for an allowed zone is a substantial challenge, as there are many dimensions that might need defining. Once the specific parameters are determined then the safe levels for each dimension must be agreed.

Enforcing an allowed zone also has its particular problems. What if a safe amount of aerosols was agreed, for example, but then several different experiments ran simultaneously within the same region of a country?

5.3.2.5 Advisory panels

Expert advisory panels could be established to determine whether a proposed research project or experiment falls into category 3. Such panels would not necessarily have to have the authority to approve or ban particular projects, but if appropriately constituted, could provide the reassurance necessary for category 3 research to go ahead. It might be possible to set them up more quickly and easily than agreeing binding international rules regarding small scale 'outdoors' SRM research.

Advisory panels can also broaden the range of input into decision-making, as they can include lay representatives of civil society or vulnerable groups, as well as relevant experts. An example is provided by the criteria and process to be used under the LC/LP to determine what is 'legitimate scientific research'[17]

[17] See www.imo.org/OurWork/Environment/SpecialProgrammesAndInitiatives/Pages/London-Convention-and-Protocol.aspx

[18] Unless the moral hazard and slippery slope arguments are regarded as overwhelming.

Both allowed zones and advisory panels could work at national or international level, and be informed by national or internationally agreed standards. National level governance arrangements tend to protect national sovereignty and could be implemented more quickly than international systems. National level decision-making might be appropriate for category 3 experiments, since by definition there is no trans-boundary harm.

However, early internationalisation of SRM governance could be desirable. A well-conducted exercise of reaching international agreement on the category 3/4 boundary could aid the development of governance structures that could oversee more contentious, higher category, activities (if ever required). Even if the internationalisation of category 3 governance is not formally agreed, there may be strong benefits to information sharing and informal consultation.

In theory category 3 is a simple and useful concept: a transparent and trusted system determines what field research is acceptably low-risk, allowing safe experiments to proceed, as the public can be confident that they do not pose a threat[18]. There are many possible field experiments with negligible associated risk that would be useful for finding out more about SRM to inform future decisions. Indeed, small-scale and safe field experiments were considered acceptable by the Parties to the CBD, although small-scale activities were not defined (CBD 2010).

5.4 Category 4: medium and large-scale field trials

5.4.1 Definition and examples

Category 4 experiments are those that are anticipated to affect the environment in a measurable and significant way. This would include both medium (nationally localised) and large (potentially trans-national) field trials.

Experiments on this scale are not imminent or may even never be undertaken. Many participants expressed concern about this category of experiments, hoping that they will not be needed. However, as research at this scale might be proposed in the foreseeable future, the difficult research governance issues of category 4 are worth considering.

There is a very wide range of activities in category 4 from those not quite small enough to be placed in category 3, through to planetary scale SRM tests. There is some merit in separating research into category 4a and 4b, as outlined in Table 3.1. For 4a measurable effects are contained within national boundaries, whereas for 4b, effects cannot be restricted to one country. There are arguments that this distinction is impractical, as countries come in a variety of sizes, and the threshold below which effects are restricted within one country is not clear, and might be impossible to agree in practice. This can only be determined over time and by political processes. However, the national/international split may provide a useful theoretical basis for analysis, as it is an important political and jurisdictional distinction.

Category 4

Activities to date	None
Possible future activities	Tests of stratospheric aerosols or cloud brightening at a global scale, designed to provoke a response in the climate

5.4.2 Governance

Very difficult governance challenges begin to arise where SRM research is conducted outside the laboratory, and when it is not clear that the planned experiments pose negligible risks. Desired and undesired effects that are not contained within political boundaries raise the most acute questions of ethics, democracy, equity, power relations and decision-making.

Additionally, for large-scale experiments it might be difficult to identify which impacts are caused by the SRM testing and which are the product of natural meteorological variation. As well as providing an obstacle for scientists seeking to understand the effects of SRM, this lack of identifiable cause-and-effect could make some aspects of the governance of high-category SRM research difficult.

5.4.2.1 Is category 4 research special?

As with research in lower categories, considering whether and how category 4 activities differ from ongoing activities will help determine whether any special governance is warranted.

Some research in category 4b might not be quantitatively different in its effects on the climate from existing and legal activities. For example, industrial processes (such as burning coal) already release tens of millions of tons of sulphur into the atmosphere. The resultant sulphate aerosols reflect some sunlight back into space and cool the planet by a significant amount (Solomon *et al* 2007), so acting as a form of inadvertent solar geoengineering. Some large-scale SRM experiments could ultimately have climate effects of a similar magnitude to current industrial activities.

SRM techniques may present their own particular risks, however, and may have significant qualitative differences with ongoing processes. Even smaller tests within category 4a, where effects were restricted within national boundaries, would probably have localised meteorological impacts (eg signals in changed weather over perhaps 100-1000 km scale over a period of a week). Such effects could exceed thresholds defined for regulatory scrutiny of non-research activities in air and water pollution laws, for example (although such thresholds are not consistently defined across jurisdictions). Even where processes are physically comparable to ongoing activities, there will be concern about activities intending to cause deliberate climate intervention. Therefore new and/or extended governance processes, at least at national level, could be needed even for small experiments in category 4.

For large field trials, in category 4b, perturbations of weather systems would become large enough that they would begin to have discernible environmental impacts at continental, hemispheric, or global scale. Effects would not be restricted by national boundaries, so international scrutiny or engagement is needed. Even if category 4b experiments were proposed purely for reasons of advancing knowledge, their implications would elevate them to the level of international politics and could pose risks of dispute and even conflict if not handled appropriately. It is likely that early, safer research would have helped to better identify and characterise the risks that large experiments could pose before such challenges were faced. Institutions of governance and international norms would have had time to develop, and might hopefully already reflect a cooperative, internationalised approach to SRM research, with legitimate capacity for assessment, decision-making, and conflict resolution.

5.5 Category 5: deployment

5.5.1 Definition

Category 5 involves activities (including release of materials to the environment), which could lead to environmental effects of a sufficient magnitude and spatial scale to affect global climate significantly, lasting for more than one year (say).

No activities in this category have been undertaken to date. By definition such activities would not constitute research, so would require different governance arrangements. However, it was difficult to discuss research without also referring to deployment, so a brief account is given here.

Deployment is qualitatively different from the other categories because such activities are carried out with the specific intention of altering the Earth's climate. Many participants favoured a moratorium on activities in this category, in line with the CBD decision (CBD 2010), due to the potential danger of large unintended consequences and the lack of governance arrangements to control them.

Since activities in this category are likely to be many years away from being deemed necessary, a strong and credible moratorium on deployment might serve to reassure concerned citizens that early deployment is not the goal of research, while allowing appropriately vetted research to proceed.

5.5.2 Governance

Deployment of geoengineering technologies would not only require different governance arrangements, but would pose serious governance challenges. For example, it may be impossible to reach agreements that are acceptable to all parties owing to significant differences based on geopolitical, ethical, equity and climate issues.

Participants agreed that the first priority should be to avoid a situation in which deployment may be considered a necessity and unilateral action is considered. Thus, how to deal with the governance of deployment should be carefully considered in advance, although the general sentiment among participants was that these difficult issues do not have to be completely resolved at this time.

5.6 Conclusion

In general, participants agreed that deployment-scale activities should not be undertaken at this time, while allowing, within an appropriate governance framework, research activities that are observational, or conducted ‘indoors’, as well as ‘outdoors’ research that would have negligible impacts.

There is a clear need to decide what may be regarded as ‘negligible impacts’, which is unlikely to be easy. Such decisions may have to be initially taken at a national level, but an international approach involving transparency and cooperation would provide greater legitimacy, and commence building the institutions and international trust needed to manage larger SRM challenges. There was widespread support for an early international approach to research governance, based on transparency, cooperation and building trust.

Activities that are neither deployment-scale nor involve negligible risks, ie those in category 4, are much more difficult to address and their governance will need more attention from academia, policymakers and civil society. It is likely to be a number of years before it is necessary to make the tough decisions for such experiments, and there is no need to define and resolve all the governance issues immediately.

Some initial governance structure may nevertheless be desirable, and early-stage research may help to inform decisions on whether and when large-scale field research becomes desirable, while building the governance institutions to eventually make decisions on risky field activities.

Conclusion

The governance of SRM is a substantial challenge, as the technology is relatively poorly understood, and it has the potential to be either very beneficial or very dangerous. Furthermore, attitudes to SRM are informed by contrasting views on climate change and global environmental politics, and differing values of ethics, equity and justice. Compounding this, such viewpoints are based only on the sparse information currently available on the characteristics and impacts of these (potential) technologies.

There was broad agreement among SRMGI participants that appropriate research will make it easier to assess the feasibility, risks and impacts associate with SRM, and to reduce uncertainties. However, more information about SRM could increase or decrease the likelihood of its use (depending on the results obtained). On the other hand, lack of information about SRM may not necessarily decrease the likelihood of use. Moreover, some were concerned that any form of research could be seen as endorsement of a technology that they hope will never be implemented. The value of more information is therefore judged to be positive in relation to assessment, but unpredictable in relation to the likelihood of deployment.

Most disagreements on SRM are not soluble at this stage, due in part to a lack of information about SRM technologies and their potential impacts. SRMGI discussions have deliberately attempted to consider the full range of views on research governance and have not tried to reach any sort of consensus. However, some broad areas of agreement have emerged.

6.1 Is SRM research special?

While SRM research has parallels with other forms of controversial research, participants generally agreed that some categories of SRM research would warrant governance beyond that already in place for other fields of enquiry, for a combination of factors.

- SRM research could be risky at larger scales, and could provoke international tensions.
- SRM is, and will continue to be, highly controversial. Much of the controversy surrounding SRM research stems from concerns about its potential final destination: large scale testing and deployment, which could be done unilaterally.
- Early collaboration on governance activities could be important for promoting cooperation on riskier SRM research (if it ever proceeds), and avoiding unilateralism.

As climate change continues, it is plausible that risky forms of SRM research might be proposed. Since governance arrangements to manage such activities are mostly lacking, these should be developed before any such proposals are considered. Consideration needs to be given to ensuring that the consequences of research do not exacerbate the effects of climate change that SRM is meant to address.

6.2 Differentiated governance

Participants agreed that the wide differences among types of SRM technologies, and types of research, suggest that flexible regulatory and governance arrangements could be most effective. There was some agreement that an adaptive approach to governance could be preferred. This could take two or more forms.

6.2.1 'Hands off' approach

One approach would be to take a 'hands-off' approach early in the research program and to gradually increase the extent of governance arrangements as research becomes increasingly risky, where risks are defined in terms of physical harms that may be caused by research and testing. While there would be no demand for *controls* on research and testing that have negligible physical risk (categories 1 and 2), transparency through the open publication of SRM research results would be considered desirable.

Within SRMGI there was a high level of support for an international register of SRM research and experiments as a means of facilitating information sharing. While there was little opposition to real world tests that are technically safe (eg in category 3), there were divergent views on how best to agree on what is and is not technically safe (in category 3 versus 4), and how to incorporate non-technical issues. Serious consideration of controls on 'outdoors' research and testing that do have potentially direct risks (category 4) would be deferred until that kind of activity is actually proposed, which is expected to be many years away.

6.2.2 Comprehensive governance framework

A second approach to flexible governance would be to pursue early progress towards a more comprehensive governance framework within which regulation would be developed and modified as the technical and socio-political implications become clearer. This approach is motivated by concerns that, while physical risks may be insignificant in the early stages of research, research programs themselves change the social and political environment in which later, riskier research would take place.

Such an approach is envisioned as reducing the chances that the governance problem will become 'harder' as research advances, because the hard issues are present from the outset or can be anticipated. Moreover, it also addresses the possibility that physically risky testing may be proposed sooner than anticipated, ensuring that the governance mechanisms would be in place when needed. This approach would build on the currently patchy moves towards a governance system, including national systems and decisions by the CBD and LC, to develop a system that is inclusive in scope and representation and easily adapted to changing circumstances.

6.2.2.1 Moratorium

There was broad agreement among SRMGI members that considering deployment of SRM techniques would be inappropriate without, among other things, adequate resolution of uncertainties concerning feasibility, advantages and disadvantages. Opinion varied on whether a moratorium on deployment of SRM methods would be appropriate at this stage. No future technology should be implemented without a thorough characterization of its potential environmental and social impacts, and appropriate arrangements put in place for its effective and equitable governance.

6.3 What might a governing entity be like?

While SRMGI discussions have begun to address the complex issue of who might govern SRM research, this matter requires much more extensive deliberation. Nevertheless, it was generally agreed by participants that the more countries involved in SRM governance, the more legitimate the governance arrangements could be, but the less likely and slower the process would be to achieve clear agreement. Managing the trade-off between inclusivity and effectiveness will be central to ensuring that decisions can be taken in a timely manner without being impaired by deliberative processes. There is no institution or international convention adequately equipped to govern SRM research at present.

6.4 SRM governance in the future

It remains to be seen whether SRM policy will avoid the same complex and encumbering political debates that have so far stalled progress on climate change mitigation and adaptation. The development of effective governance arrangements for SRM research, which are perceived as legitimate and equitable, will require wide debate and deliberation. SRMGI has begun to open up such debates, and will continue to do so, progressively bringing in representatives from more countries and sectors of society.

6.5 SRM as a response to climate change

Nothing known currently about SRM methods of geoengineering provides any reason to reduce efforts to mitigate climate change by reducing greenhouse gas emissions, and to adapt to its effects.

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Appendix 1

List of working group, staff list, review panel, stakeholder partners, conference attendees and list of submissions

Working group

Name	Affiliation	Nationality
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Professor Paul Crutzen ForMemRS	Max Planck Institute, Mainz	Netherlands
Dr Arunabha Ghosh	Council on Energy, Environment and Water	India
Dr Steven Hamburg*	Environmental Defense Fund	USA
Professor Clive Hamilton	Centre for Applied Philosophy and Public Ethics	Australia
Professor David Keith	University of Calgary	Canada/USA
Professor Peter Liss FRS	University of East Anglia	UK
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Professor Granger Morgan	Carnegie Mellon University	USA
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Professor Ted Parson	University of Michigan	Canada
Dr Atiq Rahman*	Centre for Advanced Studies	Bangladesh
Professor Phil Rasch	Pacific Northwest National Laboratory	USA
Professor Steve Rayner	University of Oxford	UK/ USA
Professor Catherine Redgwell*	University College London	UK
Professor Alan Robock	Rutgers University	USA
Dr David Santillo	Greenpeace	UK

Name	Affiliation	Nationality
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Dr Pablo Suarez	Red Cross/ Red Crescent Climate Centre	Argentina
Dr Akimasa Sumi	University of Tokyo	Japan
Senator Liz Thompson	Barbadian Senate, Rio + 20	Barbados
Professor Eduardo Viola	University of Brasilia	Brazil
Professor David Winickoff	University of California, Berkeley	USA
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* = Steering Group member		

Note: Professor Carlos Nobre* (TWAS) was initially a co-chair of SRMGI but was unable to continue in this role. Dr Peter McGrath (TWAS) was also a member of the steering group.

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Review Panel

The Royal Society gratefully acknowledges the contribution of the review panel. Members of the panel were not asked to endorse the conclusions or messages contained within this report.

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Stakeholder partners

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Call for submissions

The following organisations and individuals provided written submissions to inform the study. Organisations and individuals who asked not to be listed have been omitted from the list below.

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Royal Meteorological Society	Contact: Paul Hardaker
Dean Rose	--
Brian Sandler	--
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Stephen Satler	University of Edinburgh, Scotland
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Additional appendices

Appendix 2: Conference breakout exercises available at www.srmgi.org

Appendix 3: Analysis of existing international organisations and treaties potentially relevant to SRM research available at www.srmgi.org

Appendix 4: Funding of SRMGI

SRMGI was funded by the three convening organisations, and by contributions from:

The Carbon War Room

The Carbon War Room is an independent, global, non-profit organisation that harnesses the power of entrepreneurs to unlock gigaton-scale, market-driven solutions to climate change. While its primary focus is on carbon mitigation, it recognises the need to investigate all aspects of the solution, including the controversy surrounding SRM, where it sees a pressing need for strong international governance.

Zennström Philanthropies

Founded in 2007, Zennström Philanthropies' mission is to support and engage with organisations that fight for human rights, to work to stop climate change and encourage social entrepreneurship in order to protect our natural environment and allow those who live in it to realize their full potential.

The Fund for Innovative Climate and Energy Research (FICER) at the University of Calgary.

The Fund for Innovative Climate and Energy Research (FICER) exists to accelerate the innovative development and evaluation of science and technology to address carbon dioxide and other greenhouse gas emissions and their environmental consequences. Grants for research were provided to the University of Calgary from gifts made by Mr. Bill Gates from his personal funds. The activities of the Fund for Innovative Climate and Energy Research fall outside the scope of activities of the Bill & Melinda Gates Foundation. FICER is not a Foundation project and has no relationship with it.

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