OPINION

Research on global sun block needed now

Geoengineering studies of solar-radiation management should begin urgently, argue **David W. Keith**, **Edward Parson** and **M. Granger Morgan** — before a rogue state decides to act alone.

SUMMARY

- Field testing is required to understand the risks of solar-radiation management (SRM)
- Linked activities must create norms and understanding for international governance of SRM
- If SRM is unworkable, the sooner we know, the less moral hazard it poses

The idea of deliberately manipulating Earth's energy balance to offset human-driven climate change strikes many as dangerous hubris. Solar-radiation management (SRM), a proposed form of geoengineering, aims to reduce Earth's absorption of solar energy by, for example, adding light-scattering aerosols to the upper atmosphere or increasing the lifetime and reflectivity of low-altitude clouds. Many scientists have argued against research on SRM, saying that developing the capability to perform such tasks will reduce the political will to lower greenhouse-gas emissions. We think that the risks of not doing research outweigh the risks of doing it. SRM may be the only human response that can fend off rapid and high-consequence climate impacts. Furthermore, the potential of unilateral deployment of SRM poses environmental and geopolitical risks that can be managed best by developing widely shared knowledge, risk assessment and norms of governance.

SRM has three essential characteristics: it is cheap, fast and imperfect. Long-established estimates show that SRM could offset this century's global average temperature rise at least 100 times more cheaply than emissions cuts. A few grams of sulphate particles in the stratosphere could offset the radiative forcing of a tonne of atmospheric carbon dioxide. At about US$1,000 a tonne for aerosol delivery, that adds up to just billions of dollars per year. This low price tag is attractive, but it raises the risks of single groups acting alone, and of facile cheerleading that could promote exclusive reliance on SRM.

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High leverage

SRM could alter the global climate within months — as suggested by the 1991 eruption of Mount Pinatubo, which cooled the globe about 0.5 °C in less than a year by injecting sulphur dioxide into the stratosphere. In contrast, because of the carbon cycle's inertia, even a massive programme of emission cuts or CO_2 removal will take many decades to slow global warming discernibly. SRM's speed provides strong grounds to pursue it as a hedge against the real but unlikely possibility that climate is much more sensitive than expected to rising levels of greenhouse gases, or against extreme impacts such as major ice-sheet collapse. Because of the high level of uncertainty, even cutting emissions by an order of magnitude cannot ensure that climate effects will be held at acceptable levels.

These qualities make SRM a promising tool against climate change. But it is vital to remember that a world cooled by managing sunlight will not be the same as one cooled by lowering emissions. An SRM-cooled world would have less precipitation and less evaporation. Some areas would be more protected than others from temperature changes, creating local 'winners' and 'losers'. SRM could conceivably weaken monsoon rains and winds. It would not combat ocean acidification or other CO_2-driven ecosystem changes, and it would introduce other environmental risks such as delaying the recovery of the ozone hole. Initial studies[1] suggest that the known risks are small, but unanticipated risks remain a serious underlying concern. If the world relies solely on SRM to limit warming, these problems will eventually pose risks as large as those from uncontrolled emissions.

To posit a binary choice between SRM and cutting emissions creates a false and dangerous dichotomy — like previous suggestions of a binary choice between mitigation and adaptation. A prudent climate strategy requires adaptation and deep cuts in global emissions. We must develop the capability to do SRM in a manner that complements such cuts, while managing the associated environmental and political risks.

The path through this thicket involves two activities that must both begin immediately: a carefully designed, incremental, transparent and international programme of SRM research; and linked activities to create norms and understanding for international governance of SRM.

Research so far has consisted largely of a handful of climate-model studies, using very simple parameterization of aerosol microphysics. More complex models should be developed, and linked to global climate models. Field tests will be needed, such as generating and tracking stratospheric aerosols to block sunlight, and dispersing sea-salt aerosols to brighten marine clouds. Such tests can be small: releasing tonnes, not megatonnes, of material.

Dearth of data

Decades of upper-atmosphere research — such as that done to investigate the effect of supersonic passenger aircraft — has produced a mass of relevant science. But, except for a recent, small Russian test, there have been no field tests of SRM. Until now, there has been essentially no government research funding available for SRM anywhere in the world; although a few programmes for geoengineering have begun in the past few months. The environmental hazards of SRM cannot be assessed without knowing the specific techniques that might be used, and it is impossible to identify and develop techniques without field testing.

It is often assumed, for example, that a suitable distribution of stratospheric sulphate aerosols can be produced by releasing sulphur dioxide in the stratosphere. In fact, new simulations[2] of aerosol physics suggest that the resultant aerosol size distribution would be skewed to large particles that are relatively ineffective. Several aerosol compositions and delivery methods may offer a way around this problem, but choosing between them and quantifying their environmental effects will require in-situ testing. NASA's ER-2 high-altitude research plane might be used to release aerosols into the stratosphere, and to fly through the plume to assess the effects. Such tests take years to plan and cost millions of dollars.

It would be reckless to conduct the first large-scale SRM tests in an emergency. Experiments should expand gradually to scales big enough to produce barely detectable climate effects and reveal unexpected problems, yet small enough (of the order of hundreds of kilotonnes) to limit risks. The ability to detect the climatic response to SRM grows with the test's duration, so starting sooner reduces the scale of experiments needed to give detectable results by any future date — say by 2030. A later start delays when results will be known, or requires a bigger intervention to detect the response (Fig. 1).

SRM research should not be entrusted exclusively to either its proponents or its adversaries. Instead, there may be value in a 'blue team/red team' method, in which one team is charged to propose an approach that is as effective and low-risk as possible, and the other works to identify all the ways in which it can fail. Such an adversarial approach may increase the quality and utility of information available to future decision-makers, who might have to decide on SRM deployment in conditions of urgency or even panic. An international research budget growing from about \$10 million to \$1 billion annually over this decade would probably be sufficient to build the capability to deploy SRM and greatly improve the understanding of its risks.

Global governance

Building responsibly towards future SRM capability will also require surmounting new problems of international governance. These are quite unlike the problems of emissions governance, in which the main challenge is motivating contributions to a costly shared goal. For SRM, the main problem will be establishing legitimate collective control over an activity that some might seek to do unilaterally. Such a unilateral challenge could arise in many forms and from many quarters. At one extreme, a state might decide that avoiding the effects of climate change on its people takes precedence over the environmental concerns of SRM and begin injecting sulphur into the stratosphere, with no prior risk assessment or international consultation. If this were a small state, it could be quickly stopped by the intervention of larger nations. If it were a major state, that might not be possible.

Alternatively, a nation might grow frustrated at the pace of international cooperation and establish a national programme of gradually expanding research and field tests. This might be linked to a distinguished international advisory board, including leading scientists and retired politicians of global stature. It is plausible that, after exhausting other avenues to limit climate risks, such a nation might decide to begin a gradual, well-monitored programme of SRM deployment, even without any international agreement on its regulation. In this case, one nation — which need not be a large and rich industrialized country — would effectively seize the initiative on global climate, making it extremely difficult for other powers to restrain it.

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No existing treaty or institution is well suited to SRM governance. Given current uncertainties, immediate negotiation of a treaty is probably not advisable. Hasty pursuit of international regulation would risk locking in commitments that might soon be seen as wrong-headed, such as a total ban on research or testing, or burdensome vetting of even innocuous research projects.

A better approach would be to build international cooperation and norms from the bottom up, as knowledge and experience develop — as happened, for example, with the landmine treaty, which emerged from action by non-governmental organizations (NGOs). A first step might be a transparent, loosely coordinated international programme supporting research and risk assessments by multiple independent teams. Simultaneously, informal consultations on risk assessment, acceptability, regulation and governance could engage broad groups of experts and stakeholders such as former government officials and NGO leaders. Iterative links between emerging governance and ongoing scientific and technical research would be the core of this bottom-up approach.

Opinions about SRM are changing rapidly. Only a few years ago, many scientists opposed open discussion of the topic. Many now support model-based research, but field testing of the sort we advocate here is contentious and will probably grow more so. The main argument against SRM research is that it would undermine the already-inadequate resolve to cut emissions. We are keenly aware of this 'moral hazard', but sceptical that suppressing SRM research would in fact raise commitment to mitigation. Indeed, with the possibility of SRM now widely recognized, failing to subject it to serious research and risk assessment may well pose the greater threat to mitigation efforts, by allowing implicit reliance on SRM without scrutiny of its actual requirements, limitations and risks. If SRM proves to be unworkable or poses unacceptable risks, the sooner we know this, the less of a moral hazard it poses; if it is effective, we gain a useful additional tool to limit climate damages.

It is a healthy sign that a common first response to geoengineering is revulsion. It suggests that we have learned something from past instances of over-eager technological optimism and subsequent failures. But we must also avoid over-interpreting this past experience. Responsible management of climate risks requires sharp emissions cuts and clear-eyed research and assessment of SRM capability. The two are not in opposition. We are currently doing neither; action is urgently needed on both. ■

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Further reading accompanies this article online at go.nature.com/Jtdd8b.

IMAGE: F. M. I. FLORES; DATA SOURCE: REF. 3

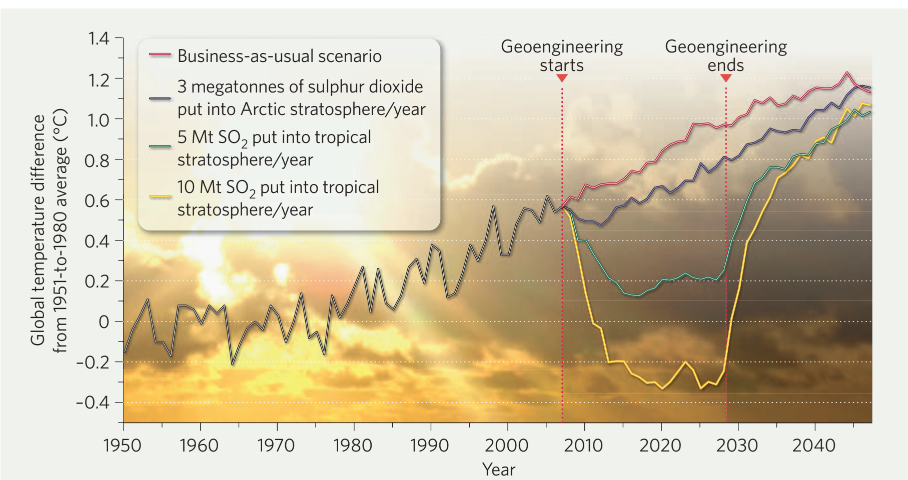

Figure 1 | Turning down the heat. A model[3] shows how quickly solar-radiation management (SRM) might alter global temperature, and how conditions might rebound after the geoengineering stops.