The Royal Society Global Environmental Research Committee (GERC)

Report from GERC on the topic "*Geoengineering the climate*"

The context for GERC reports

The Royal Society's Global Environment Research Committee (GERC) is charged with advising the Royal Society, and interacting with research councils, the environmental science community and other bodies. To do this, it is undertaking a rolling series of reviews of areas of science within its remit. The areas it has identified are (in alphabetical order): Air quality, Biodiversity, Carbon and other biogeochemical cycles, Climate, Natural resources (including land use) and food, Oceans and polar science, Water. In each area, GERC uses its own expertise, and that of a small number of invited experts to consider the questions:

1. What are the hot research topics in this area at present?
2. What is the status of UK science within this area?
3. What are the most pressing research needs in the next 5-10 years?
4. Are there specific areas where UK science should be focussed to meet these needs?
5. How should priority topics be incorporated into multidisciplinary (funded across research councils) issues that Future Earth and its UK committee should consider?

This paper is an additional one resulting from interest in updating knowledge within the Society about Geoengineering, almost 10 years on from its publication of an influential report (Geoengineering the climate, Science, governance and uncertainty; Royal Society, published in 2009). In addition to contributions from its regular and co-opted members, the committee was advised in person by presentations from Myles Allan, Julia Crook, Jo House, Andy Parker, John Shepherd, Phil Williamson and Matthew Watson, and by the participation of Frans Berkhout, Ned Garnett, Tim Kruger, Peter Liss, Ray Pierrehumbert and Steve Smith, as well as Royal Society staff. The resulting paper represents only a snapshot of the issues, and is not a comprehensive survey of the science area. It has been drafted by GERC members, and does not claim to be endorsed by other attendees. It does not represent the view of the Royal Society, but aims to advise the Royal Society Council, and highlights some trends that should inform future activity by the Royal Society, UK Research and Innovation and UK Future Earth.

Membership of GERC (including co-opted members) at the time this topic was discussed (March 2018) was: Prof Eric Wolff FRS (chair), Dr Kirsti Ashworth, Prof Mike Bentley, Prof Peter Cox, Dr Maria Dornelas, Prof Joanna Haigh FRS, Dr Kate Hamer (NERC), Prof Gideon Henderson FRS, Professor David Hopkins, Dr John Ingram, Prof Yadvinder Malhi FRS, Prof Paul Monks, Prof Peter Smith FRS, Prof Martin Solan, Prof Chris Thomas FRS. Dr Scott Hosking acted as Secretary.

Executive summary: Emissions reductions alone are unlikely to be enough to meet the targets on climate agreed in Paris. Some form of greenhouse gas removal (GGR) (or negative emissions) is very likely to be needed, and research into the capacity and feasibility of short-term and long-term options, already underway in the UK, needs to be intensified. Solar radiation management (SRM) raises issues of governance and continuity of deployment that make it appear less societally-attractive than GGR, with questions about the kinds of research that can be carried out. However, opportunities to study natural phenomena such as volcanic eruptions should be grasped, and modelling studies will help to delineate what the risks and potential are. An interdisciplinary research programme is required to assess what role SRM and GGR could play in supplementing mitigation and adaptation as a response to climate change, taking account of their risks compared to those of above-target warming, and aspects such as governance, finance, public perception, and competition for land and resources.

Background

Emissions of greenhouse gases by human activities are changing the climate. In Paris in 2015 nations agreed to the goal of keeping global average warming to well below 2°C above pre-industrial temperatures, while pursuing efforts to keep it below 1.5°C, in order to avoid dangerous impacts. Emission reduction is generally envisaged as the main tool to achieve the Paris goals, which also include achieving net zero emissions in the second half of the century. However current pledges, even if met, do not come close to meeting those targets. This puts the spotlight on the possible use of so-called negative emissions technologies, and more generally on the options for climate interventions often known as geoengineering.

A 2009 Royal Society report on Geoengineering the Climate considered the different techniques proposed, and some of their implications. Broadly speaking, the techniques fall into two groups. Carbon Dioxide (or more generally Greenhouse Gas) Removal (CDR or GGR) tries to reverse the addition of carbon dioxide to the atmosphere, and at one end it includes conventional mitigation techniques such as tree planting. Solar Radiation Management (SRM) seeks to mask some of the climate symptoms of increased greenhouse gas concentrations by reducing the amount of energy (sunlight) reaching the Earth surface. The first aim of the GERC meeting was to assess how the geoengineering options and knowledge about them have evolved in the last decade. This is partly addressed by an informal supplement to the 2009 report that was presented at the meeting. The second aim was to highlight areas where more research is needed, both within the natural sciences and across disciplines.

This report is structured somewhat differently to previous GERC reports. Firstly we record some general points of agreement and disagreement from the day's discussion, and then discuss where natural sciences research might allow particular technologies to be more thoroughly and reliably assessed. Finally we discuss some lines of interdisciplinary research that would allow better assessment of where geoengineering should fit into a portfolio of national and international responses to climate change.

General conclusions and discussion points from the day

- GGR and SRM are very different approaches, and each includes both relatively benign small-scale efforts and huge technological projects with uncertain side-effects. Grouping them together under the term "geoengineering" (or other terms such as "climate intervention") is generally unhelpful as each technique needs to be assessed on its own merits. However, since the term is still sometimes useful and was used in the 2009 report we have retained it where appropriate for this report.
- The main classes of GGR and SRM outlined in the 2009 report remain generally unchanged, and most of the same concerns and caveats expressed at the time remain valid.
- It is very unlikely that the Paris goals can be met through attainable levels of emissions reduction alone.
- Limited research into the feasibility of some geoengineering options has been undertaken, mainly by computer modelling. In the UK this has been through cross-research council initiatives such as SPICE (stratospheric particle injection) and the new GGR programme (2017-2021, totalling £8.6 million).
- There remains a perceived tension between cautious assessment of geoengineering options and the danger that any prospect of alternative solutions may encourage a reduction in appetite for reducing emissions.

Research into specific geoengineering options

In discussing GGR and SRM there was a general view that the need for additional GGR research is pressing, partly because some form of GGR is implicit in the Paris targets. Many (but not all) forms of GGR are also considered more likely than SRM to be politically acceptable. However the view was also expressed that SRM ***research*** may have a role in exploring a possible backup to avoid extremely deleterious effects from large climate changes, and to ensure the any drawbacks are fully appreciated in case less cautious advocates press for early implementation.

Solar radiation management

Stratospheric particle injection (SPI) has received the most attention in recent years. Other forms of atmospheric intervention (such as cirrus cloud thinning), have been studied mainly through climate modelling experiments. As yet field trials of SPI have not been carried out at any significant scale, but various strands of research, which also naturally lead to more general understanding of radiation/aerosol interactions and climate, should be pursued:

- Funders and researchers should be ready to study intensively the next large volcanic eruptions that may affect the stratosphere, as these offer a useful natural analogue for SPI, as well as a test for the models that are being used to assess the positive and negative climate impacts.
- Experiments that seek to study interactions between aerosol, radiation and clouds are needed to improve climate models, but results will also give insight into the impacts of SRM techniques.
- Model studies and intercomparisons such as GEOMIP should continue, and be supported.

If SRM is to be considered seriously there are a number of other issues that need to be considered further:
- SRM involves climate changes that are (more so than for GGR) not just reversals of the changes experienced to date, focussing attention on the idea that climate change and geoengineering produce both winners and losers. Study of this heterogeneity is a prerequisite for any discussion of governance.
- If SRM techniques cannot be maintained indefinitely, they only delay climate change. In the case of significant SRM deployment, dramatic negative consequences are possible if they were stopped suddenly (so-called "termination shock"). Cross-disciplinary research into the likelihood and consequences of disruption to any SRM deployment is essential.
- More research is needed into ethical and governance issues around research and deployment of SRM.

Greenhouse Gas Removal
A UK programme of GGR research, funded by NERC, EPSRC, ESRC and BEIS, commenced recently and covers many areas of GGR. Furthermore the Royal Society and the Royal Academy of Engineering are currently producing a report on GGR. For that reason we do not go into detail here. Bioenergy with carbon capture and storage (BECCS) is often cited as the most likely addition to afforestation as a route to negative emissions, while techniques such as rock weathering, enhanced ocean alkalinity and direct air capture and carbon storage (DACCS) are more distant prospects. Research needs include:
- If BECCS is to play a significant role within decades, a range of demonstration plants for **carbon capture** urgently needs to be tested and implemented; the UK needs to decide whether it wants to be a serious player in what may become a major industry. This obviously goes beyond usual research funding, and more appropriate forms of support may need to be implemented.
- Research into long-term **storage** of carbon dioxide is also a priority, and a topic in which the UK has relevant expertise and appropriate geological resources. This would also be required for DACCS methods.
- Some of the more promising technologies for longer-term deployment also need to be developed and tested at small scale, along with theoretical estimates of scalability, to assess their feasibility.
- Many GGR technologies require large areas of land. Cross-disciplinary research is needed into the competing use of land surface for different technologies, food production, amenity and wilderness.

Geoengineering as part of a portfolio in response to climate change
The supplement to the Royal Society's 2009 report stresses that the various responses to climate change (mitigation, adaptation, SRM and GGR, and allowing impacts and suffering) all have different characteristics. For example, conventional mitigation can only slow (but not reverse) climate change, while GGR could (in principle) reverse it and restore states similar to those experienced previously, but only slowly. SRM could reduce many aspects of climate change quickly, but would create novel states. Adaptation can ameliorate some (but not all) impacts quite quickly, while climate change itself is beneficial to some people but not to others. There is merit in considering what would be the combination of responses that best secures benefits and reduces losses, across the globe and between generations.

The meeting frequently faced the paired questions: "To what extent may geoengineering be necessary to meet the Paris commitments?" and "do the risks of geoengineering outweigh those of much larger climate changes if Paris goals are not achieved?" These two questions, with their many nuances depending on the type and scale of geoengineering and the location and magnitude of benefits or losses of impacted populations, should form the basis for a major line of cross-disciplinary research straddling the natural sciences, economics, law, social sciences and philosophy, and we suggest that Future Earth or other bodies might usefully consider them.