GERC paper on priorities in the science area: Climate

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 the one resulting from the discussion about Climate, held in May 2016. In addition to contribution from its regular and co-opted members, the committee was advised in person by Professor Stephen Belcher (representing the UK Met Office/Hadley Centre), Dr Steve Woolnough (representing NERC's National Centre for Atmospheric Science), and Professor Gabi Hegerl (University of Edinburgh) and in writing by Professor Jonathan Gregory (University of Reading).

The resulting paper of course represents only a snapshot of issues, and is not a comprehensive survey of the science area. It does not represent the view of the Royal Society, but is merely one element of advice to the Royal Society Council. Exclusion of a topic from this document does not negate its importance, and many areas that are already under intense research are not highlighted here. However, we hope that this document will put a spotlight on some trends that will inform future activity by the Royal Society, Research Councils (and in future UKRI), and UK Future Earth.

Membership of GERC (including co-opted members) at the time this topic was discussed was: Professor Eric Wolff FRS (chair), Dr Helen Beadman (NERC), Professor Peter Cox, Professor Gideon Henderson FRS, Professor David Hopkins, Professor Joanna Haigh FRS, Dr Sandy Knapp, Professor Yadvinder Mahli, Professor Paul Monks, Professor Martin Solan, Professor Chris Thomas FRS, Dr John Ingram, Professor Corinne Le Quéré FRS. Dr Scott Hosking acted as Secretary.

Executive recommendations of GERC on the topic "Climate"

GERC recognises a number of areas of science where conditions are now ripe for progress to be made, and recommends that NERC and other UK funding agencies should take note of these in deciding priorities for funding in the next few years. The 2015 climate agreement in Paris has highlighted two linked high level issues that require multidisciplinary research as a priority. We recommend that the Royal Society should consider initiating a study on one or both of these questions, and that UK Future Earth should consider them as priorities:

- What are the pathways to reach a target of 2° and aspiration towards 1.5°?
- If (as seems inevitable) negative emissions are required to meet the targets, what are the engineering and economic routes to, and social implications of, achieving them?

Main document

Climate science spans a wide remit, including observational science, climate processes, Earth system modelling, palaeoclimate, and impact studies. It interfaces with areas of science such as ecology, conservation, and health, and with the societal, economic and engineering aspects of change. There are a number of contexts for the present discussion. Firstly the IPCC AR5 defined the state of the art in 2013. CoP21 in Paris set an ambitious target to keep the global temperature rise "well below 2˚C" and pursue efforts to limit it to 1.5˚C. The World Climate Research Programme (WCRP) has defined 7 grand challenges: many of our identified priorities closely correspond to one of these. Furthermore many of the UN Sustainable Development Goals are fundamentally connected with climate change.

GERC discussed a wide range of topics, which have been here grouped under some overarching questions. Some topics are well-addressed by existing programmes; topics where we felt that a new or enhanced programme is timely are listed as a solid bullet; topics where a multidisciplinary programme (eg under UK FE) would be most appropriate are listed with an arrowed bullet.

What is the allowable carbon budget for a given global temperature target?

- o A crucial step in defining the allowable carbon budget for the CoP21 (or any other) climate targets would be to narrow the uncertainty on climate sensitivity at a global scale. Over recent years it has become apparent that answering this question centres on better understanding and representation of cloud processes.
- There is a huge range of projections for how global land carbon storage will change in future. This is caused by large uncertainties in (land) C cycle feedbacks. Good representations of the N cycle, of permafrost and peatland carbon, and of the demography of vegetation are urgently needed to improve this situation. Better combinations of data and models, and use of emergent constraints may allow progress without increasing model complexity. The response of the Southern Ocean carbon sink to climate change also has large uncertainty and decadal variability that can similarly be tackled by a combination of data and models.
- The possibility of making gains through changes in emissions of short-lived climate forcers (such as methane, black carbon and ozone) is ripe, but requires consideration of trade-offs and co-benefits. How can air quality and climate be balanced, and what are the societal implications of trying to limit agricultural emissions of methane?

How can we improve predictions of regional and decadal climate change?

- o Better prediction of regional change is crucial for developing and implementing appropriate adaptation measures. Improvements in regional forcing are a focus of existing work within the UKESM framework, in which aerosol-climate coupling is being better implemented.
- A major improvement in regional prediction requires that the thermodynamic knowledge underpinning global change be supplemented by an improved understanding of the climate dynamics that controls major modes of variability, teleconnections, storm tracks, etc. The UK, through the Met Office, NERC centres and universities, has significant expertise in this topic "where weather meets climate" and is well-placed to make progress.
- Progress is particularly urgent for decadal-multidecadal climate variability. The instrumental record is not able to fully sample the system behaviour. Palaeoclimate samples additional scenarios, and poses challenges based on observations such as stronger variations in ENSO strength and the water cycle than climate models suggest. Better methods for integrating paleoclimate observations and insights with predictive climate modelling are needed.
- Improving regional climate prediction is key to two of the most pressing areas for impact studies. The first of these is the water cycle, where even the gross directions of changes are still under discussion. The increasing period over which satellite observations exist, combined

with advances in high resolution modelling, now make realistic the prospect of improved hydrological prediction.

- Extremes drive much of the cost of climate change. The improvements in understanding the processes of regional climate change would also benefit understanding of extremes. Together with improved documentation of past extremes, and improvements emerging as a result of the higher resolution of climate modelling, it should become easier both to attribute the causes of extreme events, and predict their frequency in the future.
- ➢ The whole topic of regional and decadal prediction, including water and extremes, lends itself to inclusion in multidisciplinary projects of the sort that UK FE might promote. What are the costs, co-benefits and risks of physical or policy adaptations in response to decadal regional predictions?

What long term changes are we already committed to, such as ecosystem change due to ocean acidification or sea level change due to loss of polar ice?

- Among the long-term challenges is the inevitability of sea level rise. The future of the polar ice sheets, together representing many metres of sea level change, is still poorly constrained. Observations of ice-mass loss from the GRACE satellites provide information about the accelerating rates of modern loss. Evidence that sea level was 6-9 m higher than today under conditions from the last interglacial demonstrate the potential for very significant future change. Improved understanding of the stability of Greenland and Antarctic ice Sheets to both atmospheric and ocean warming are urgent. Furthermore, assessments of their response under a range of scenarios, including ones where targets are overshot and then recovered, are needed.
- Past research programmes have highlighted the impacts of ocean acidification on marine species. However, the ecosystem response and the implications for ecosystem services to ocean acidification and to multiple stressors remains unclear.

An obvious focus for an interdisciplinary study would centre on the 1.5° aspiration, or the 2° target. These targets imply rapid mitigation and most likely "negative emissions". This raises a series of questions, which include climate science (what would be the climate change resulting from each scenario?), but which all offer possible wide topics for UK FE to consider.

- ➢ What are the societal, engineering and economic implications of reaching these targets?
- ➢ If such targets involve negative emissions, how are they to be achieved? What are the engineering solutions and social constraints, and what are the trade-offs from the economic, agricultural and societal costs of implementing them?
- ➢ What are the additional costs or benefits (in the widest sense: for climate, economy and society) of different ways of overshooting and then returning to the chosen target?
- ➢ What are the societal costs of substantially exceeding the 1.5 or 2^{o} target?

The UK has great strength in almost every area of climate science. The UK Met Office is highly respected, and through the Hadley Centre it provides a world class resource in climate modelling. NERC centres and UK universities host centres of excellence in every sector of the Earth system, in observational and palaeoscience, and in many aspects of the science of climate impacts. The UK is therefore well-placed to take a leadership role in global programmes, and to provide a natural science leg for multidisciplinary studies that could be pursued under UK Future Earth and the GCRF.

Many of the priorities highlighted here are also among the WCRP Grand Challenges or other international initiatives. UK funding mechanisms do not lend themselves to rapid engagement with such initiatives, and as a result leadership opportunities may be missed.