Geoengineering Scoping Workshop - Outputs

Date: 19 October 09
Location: London

Background

EPSRC (Engineering and Physical Sciences Research Council) and NERC (Natural Environment Research Council) under the multi-funder research programme LWEC[1] (Living with Environmental Change) intend to provide funding to research within the Climate Geoengineering remit. We aim to fund research which will allow the UK to make informed and intelligent assessments about the development of Climate Geoengineering technologies.

This one day workshop was held to identify the priority themes for future funding activities within Geoengineering.

Aims

Aims of the workshop were as follows:

- Facilitate networking between researchers operating within the remit of Geoengineering.
- Identify the major challenges and opportunities for Geoengineering research.
- Identify potential themes for future funding activities.

Participants

A mixture of participants were selected from their submissions of an Expressions of Interest form. We sought to achieve a diverse range of attendees to reflect the multi-disciplinary nature of Geoengineering. A full list of delegates can be found in Annex A.

[1] See http://www.lwec.org.uk/news-archive/2009/about-living-environmental-change

Agenda

This was a one day workshop. A short warm up session (see Annex B) was held, before then focusing on four main sessions:

- **Session 1:** What Criteria should we use to prioritise the Royal Society Themes? (see Annex C)
- **Session 2:** Prioritising the Royal Society Themes (see Annex D)
- **Session 3:** SWOT- style analysis (see Annex E)
- **Session 4**: Skills, facilities and academic capability required (See (Annex F)

Next steps

The results from this workshop will provide one input to the forthcoming Sandpit being held 15-19 March 2010. **Please note that this date has changed from the date previously advertised.** The sandpit event is likely to focus on themes which emerged from this workshop, namely:

- Side effects / Impacts of Geoengineering
- Reducing uncertainties about Geoengineering schemes
- The extent to which Geoengineering technologies can be controlled. (Including reversibility, the time between deployment and intended effect on climate, and the delay between cessation and the climate response)
- Costs of scheme – v- effectiveness of scheme
- Barriers to deployment

Annex A:

Attendees at the Scoping Workshop

Delegates

Name	Surname	Inst/Org
Icarus	Allen	Plymouth Marine Laboratory
Blanca	Antizar-Ladislao	University of Edinburgh
Ken	Carslaw	University of Leeds
Andrew	Charlton-Perez	University of Reading
Daniel	Coca	University of Sheffield
Hugh	Coe	University of Manchester
Humphrey	Crick	Natural England
Alan	Gadian	University of Leeds
Joanna	Haigh	Imperial College London
Peter	Hall	University of Strathclyde
Gideon	Henderson	University of Oxford
Simone	Hochgreb	University of Cambridge
Tim	Jickells	NERC Theme Leader (Earth system Science)
Manoj	Joshi	University of Reading
Tim	Kruger	Cquestrate & Oxford Geoengineering
John	Latham	University of Manchester & NCAR, USA
Brian	Launder	University of Manchester
Tim	Lenton	University of East Anglia
Jason	Lowe	Met Office
Dan	Lunt	University of Bristol
David	Manning	Newcastle University
Bruce	Moffett	University of East London
Mostafa	Mohamed	University of Bradford
Andy	Parker	The Royal Society
Evan	Parker	University of Warwick
Gillian	Pickup	Heriot-Watt University
Nick	Pidgeon	Cardiff University
Debbie	Polson	University of Edinburgh
Catherine	Redgwell	University College London
Brian	Reid	University of East Anglia
Andy	Ridgwell	University of Bristol
Stephen	Salter	University of Edinburgh
Joan	Sanchez Cuartielles	University of Strathclyde
Jill	Stewart	University of Salford
Parvadha	Suntharalingam	University of East Anglia
Ian	Thompson	University of Oxford
Nick	Watkins	British Antarctic Survey, Cambridge

Annex B:

Warm up session: What is Geoengineering?

In this session groups were given the following scenario and asked to provide a response:

> **You are in a lift with the Prime Minister and he asks you "What is Geoengineering?" What will you say in the 2 minutes you have with him?**

Outputs are presented here for the whole plenary:

CDR

- Green house gas removal (GHGR)
- Lower risk + Slower acting
- Side effects?
- Reversible
- Removal of Methane etc is not included in "CDR", but perhaps 'removal' techniques should be expanded to include methane and green house gases

SRM

- International modification of climate state
- Side effects?
- Reversible?
- Higher risk
- Faster acting

General comments:

- Large scale
- Complimentary to current efforts
- Preventative 'medicine' – v- surgery
- 'Restorative' as opposed to Geoengineering.
- Manipulation of climate systems –v- Environmental systems in general?
- Doing what we have been doing for 200 years. (We don't know what we've been doing – the damage we have caused!!).
- "Plan B" – It's important to explore plan B.
- Are we ready to 'sell it' [the concept] yet? Mindful but uncertain…..We need to build confidence.
- Perception of 'engineering'
- Public perception issues
- Has CCS escaped this definition….. Is this appropriate?
- Not just CO_2 e.g. methane
- Understanding factors / systems that affect climate complexity
- Need better understanding of processes in the atmosphere
- Package of measures and techniques
- Geoengineering is Treating 'illness and symptoms'
- Designed approach that is predictable and controllable
- A priority for the planet - stopping it going into catastrophic failure – needs more money.
- The 'Why?" is to mitigate impacts of CO_2 and other GHG
- Has been non-intentional.
- Deliberate intervention by humans into the earth system.
- Large scale / Range of scales.
- Development of new industrial processes beneficial to the planet
- Better models required quickly

Annex C:

Session 1 "What Criteria should we use to prioritise the Royal Society Themes?"

Session 1: Part A

In this session attendees were asked to discuss and then answer the following question: "What Criteria should we use to prioritise the Royal Society Themes?"

Attendees were provided with the following themes from the Royal Society report [2] :

- **1) Cross-cutting themes**
- **2) General research themes for all CDR methods**
- **3) General research themes for all methods**

Results are presented below in list form:

Group 1

- Will it (each technology) work?
- Timing
    a. Speed of deployment
    b. Duration of effect
    c. Controllability & 'escape routes'
    d. Potential limits (how much can it do?)
- Side effects (both positive and negative)
- Cost effectiveness (of the option/scheme)
- Co-benefits
- Feasibility
    a. Timescale
    b. Physical / Engineering
    c. Cost
    d. Public acceptability
    e. Scalability
- International effort – v – UK
- Risk –v- benefit
- Uncertainty (do we know enough fundamental science?).
- Contribution / impact on decision making
- GELSI – Governance, Ethics, Legal, Societal, Impacts

Group 2

- What does success of the scheme look like?
- How fast can the scheme act?
- Awareness of public perception / Does it address public perception? / Public engagement.
- Addressing "cost of failure"
- What is the "moral hazard"?
- Can we test the scheme without damaging the environment?
- What is the overall environmental cost of the scheme?

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[2] The Royal Society (2009), *Geoengineering the climate: science, governance, and uncertainty.* (p.53 and 54). Available at: http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=10768 [Accessed: 7/12/2009]

- Carbon cost of the scheme
- “Fast to failure”- Identify and ‘knock out’ those options which are not going to work as soon as possible. This will avoid wasting resources, and enable increased focus on a few possible solutions.
- Market driven – v- blue skies research?
- Are/Should/Will industries fund this?
- Cost effectiveness
- Relatively cheap (cost)
- What UK does best?

Group 3

- Local controllability
- Ability to assess viability quickly
- Robust Methodology
- Potential effectiveness and side effects
- Links with appropriate industries
- Gearing through linking with international groups e.g. China and US and India
- Cost / Power (effectiveness of the scheme)
- Public acceptability
- Controllability (speed of reversibility)
- New methods for removing other atmospheric pollutants e.g. methane.
- Appropriate tools and skills available in the UK
- Speed of deployment
- Timescale / Lag between: introduction of scheme to first impact seen, and removal of the scheme to end of impact
- Legal / International / Political relations

Group 4

- More engagement up the TRL scale
- Engaging with industry
- Engage with policy makers
- Engage with the public
- Governance issues – Framework / risk assessment
- Is there enough current knowledge
- Do we understand the underpinning science enough?
- Carbon Trust should support development
- Is the US, or others ahead us in any area?
- Are the wider environmental impacts / issues being considered?
- GeoEng “code of conduct”
- Are we making decisions internationally? What’s going on in Europe?
- Prioritise the science.
- The basic science is only part of it.

Session 1 : Part B

These responses were then 'clustered' in to groups, in order to generate larger / wider topic areas. Results of the clustering are shown below:

- Governability (12 votes)
  - Side effects and risks / risk analysis – impact on approach to governance
  - Legal and political perspectives for international relationships
  - The basic science is only part of the issue
  - We need to choose which area of science to support. How?
  - Engagement with policy makers
  - Do we need a Geoengineering 'code of conduct'
  - Governance issues and risk
  - Governance framework
  - We need a governance code of conduct

- UK capability and potential leadership (8 votes)
  - Is there enough current knowledge?
  - We need to rule out the areas of science where we are way behind
  - Capacity building and UK expertise
  - Are other countries already ahead in some areas?
  - Where can the UK lead? Which area?
  - Contribution to key science questions
  - Appropriate skills and tools available in UK
  - What does UK do best?

- New methods (1 vote)
  - New methods for removing other pollutants e.g. methane

- Local controllability (1 vote)

- Potential effectiveness (13 votes)
  - Climate effectiveness potential

- Leverage of previous investment (1 vote)
  - Leverage from already funded science

- Public acceptability (11 votes)
  - What does success of a scheme look like?
  - Engagement with the public
  - Public acceptability
  - Does research address public perception?
  - Is research aware of public perception?
  - What is the moral hazard of the research?

- Feasibility / Viability (16 votes)
  - Can we test schemes without damaging the environment?
  - Does research address the cost of failure?
  - Engineering feasibility
  - Carbon cost of schemes
  - "Fast to failure"

- Ability to assess the viability of the current science (5 votes)
  - Robust methodology
  - Is there enough basic science to inform a decision?
  - Do we understand the underpinning science enough?
  - Ability to asses viability quickly?

- Future suitability of the intervention? (1 vote)
    - Does it address / consider what the planet will look like at the time that the intervention is used?

- Timescales, duration of effects / impacts (12 votes)
    - Duration of effects
    - Timescales once scheme is in place; when does the impact finish?
    - How fast can the scheme act once introduced?

- Controllability (22 votes)
    - Controllability / speed of reversibility
    - Escape routes

- Is industry doing this? Should they / will they be doing this? (1 vote)

- Engagement with industry / organisations(12 votes)
    - Market driven –v- blue skies
    - Private benefactors e.g. Bill Gates
    - Links with appropriate industries
    - The carbon trust should support development……. Are they?

- Linking with international research groups (5 votes)
    - Gearing through linking with international groups e.g. US, China, India
    - Are we making decisions internationally? Collaborations

- Costs of scheme – v- effectiveness of scheme (25 votes)
    - Cost –v- effectiveness
    - Cost /Power /global economics / Cost of technology
    - Cost –v- Impact
    - Environmental cost of the scheme
    - Cost of research

- Side effects / Impacts of Geoengineering (31 votes)
    - Side effects (+ and -)
    - Are we considering the wider environmental issues enough?
    - Side effects (+ive /-ive) / Co-benefits

- Reducing uncertainties about Geoengineering schemes Uncertainty (19 votes)
    - Does it address uncertainty?
    - Uncertainty – v- certainty – Fund the one which might work!
    - Uncertainty (contribution to decision making)
    - Uncertainty of the scheme

- Speed of deployment and issues around deployment (20 votes)
    - Speed TO deployment
    - Speed of deployment
    - Barriers to deployment

The plenary then voted which they saw as the most important criteria. The top 5, most important areas are shown below:

- **Side effects / Impacts of Geoengineering (31 votes)**
- **Costs of scheme – v- effectiveness of scheme (25 votes)**
- **The extent to which Geoengineering technologies can be controlled (i.e. reversibility, the time between deployment and intended effect on climate, and the delay between cessation and the climate response) (22 votes)**
- **Barriers to deployment (20 votes)**
- **Reducing uncertainties about Geoengineering schemes (19 votes)**

Annex D:

Session 2 – Prioritising the Royal Society Themes

Session 2a - Cross cutting research

In the context of the plenarys' top 5 criteria the attendees were asked to discuss the Royal Society research themes for Cross cutting research, and then to Rank the list of themes in priority order.

Results are shown below:

Cross – Cutting Research Themes	Group 1	Group 2	Group 3	Group 4	Totals	Overall Rank
Extensive climate and Earth-system modelling studies, and where appropriate pilot-scale laboratory and field trials, to improve understanding of costs, effectiveness and impacts, and to enable the identification and characterisation of preferred methods;	6	8	8	7.5	29.5	1st
A comprehensive evaluation is needed of environmental , ecological, and socio-economic impacts of the different methods, relative to those expected under climate change (without Geoengineering);	7	6.5	7	7.5	28	2nd
A review of Geoengineering governance and jurisdictional issues including an analysis of existing international and regional regulatory mechanisms of relevance to the application of Geoengineering methods and their effects, and identification of gaps;	2	4	2	2	10	-
Economic analysis and multi-criteria assessment of the costs, benefits, impacts and risks associated with the range of Geoengineering methods, and evaluation of value of CDR and/or SRM methods relative to mitigation interventions;	8	6.5	6	6	26.5	3rd
Analysis of potential for certification of CDR methods under Kyoto Protocol and carbon trading schemes	4	5	5	1	15	4th
Analysis of ethical and social issues associated with research and deployment including the potential for social and technological lock-in of the different methods;	3	N/A (2)	2	4	9 (11)	-
The impact of Geoengineering research and/or deployment on attitudes to climate change, mitigation and adaption;	1	N/A (2)	4	4	9 (11)	-
Evaluation of public engagement needs and improved methods for public engagement in development & management of Geoengineering methods;	5	N/A (2)	2	4	11 (13)	5th

Session 2b - general research themes for CDR

In the context of the plenarys' top 5 criteria the attendees were asked to discuss the Royal Societys' general research themes for CDR, and then to Rank the list of themes in priority order.

Results are shown below:

CDR Research themes	Group 1	Group 2	Group 3	Group 4	Total	Overall Rank
Estimates of effectiveness at achieving CO_2 concentration reductions, technical efficiency, and costs;	5	5	5	5	20	1st
Evaluation of the time between deployment and achieving the intended effect on CO_2 concentrations, and delay between cessation of activity and CO_2 effect and other environmental impacts;	2	2	3	1	8	4th
Investigation of material consumption, mining, processing and waste requirements;	1	1	1.5	3	6.5	5th
Life cycle analysis of carbon and economic costs (for example) extraction of raw materials, infrastructure development, materials processing, transport and disposal;	3	3	4	2	12	3rd
Potential side-effects (pollution and environmental impacts) of the processes and their products;	4	4	1.5	4	13.5	2nd

Session 2c - general research themes for SRM

In the context of the plenarys' top 5 criteria the attendees were asked to discuss the Royal Societys' general research themes for SRM, and then to Rank the list of themes in priority order.

Results are shown below:

SRM Research themes	Group A	Group B	Group C	Group D	Total	Overall Rank
Life cycle analysis of the financial and carbon costs associated with the development and implementation of the method;	4	1	3	4	12	-
Estimates of effectiveness at achieving the desired climate state, technical efficiency and costs;	7	7	7	7	28	1st
Time between deployment and achieving the intended effect on climate, and delay between cessation of an activity and climate response, and other environmental impacts;	5	5.5	4	1	15.5	3rd
Assessment of the full range of climate effects including properties other than global mean temperature, and including the extent and spatial variation of the impacts;	6	3.5	6	5.5	21	2nd
Investigation into the effects on atmospheric chemical composition and on ocean and atmospheric circulation;	2	3.5	5	3	13.5	5th
Detailed modelling studies to resolve seasonal and regional effects as well as global and annual averages;	2	5.5	1.5	5.5	14.5	4th
Modelling, theoretical studies and long-term empirical research into the impacts and consequences of persistent high CO_2 concentrations in a low temperature world for ecosystem processes and ecological communities;	2	2	1.5	2	7.5	-

<u>Annex E:</u>

<u>Session 3- SWOT-style" analysis</u>

In this session, participants were asked to do a "SWOT-style" analysis, of the Royal Society report on Geoengineering.

Results are shown below for each group:

<u>Group: A</u>

What are the **strengths** of the report?	What are the **weaknesses** of the report?
• Raised Profile of Geoeng • Fair balanced • Broad Remit	• Weak Science basis, therefore not useful. • Repetitive • Didn't identify funding routes
What are the major **opportunities** for research now?	What are the **barriers** to research now? Where are the major challenges?
• UK leadership • Synergy to improve climate understanding • Create an 'international centre' • True Earth system research • Establishing planetary boundaries	• Lack of money (£millions of pounds) • Lack of joined-up funding • Public perception • Lack of political support and awareness • Lack of fundamental knowledge • Inter-disciplinary trained researchers

Is there anything that the Royal Society has missed?
• Methods for removing CH_4 removing N_2o (long-lived greenhouse gases) • Identifying funding priorities for research • Quantification / Verification of cooling effects and carbon removal (methods are lacking). • We are going to have to do global carbon dioxide removal to meet the "2°C" target / 450ppm CO_2 (e) • Effects of CO_2 removal on the atmosphere; decay over time (because of ocean –atmosphere – land exchange)

Group: B

What are the **strengths** of the report?	What are the **weaknesses** of the report?
• Brings respectability to the area • Simplicity • Coherent • Good literature review • Good base for further research • Honest (where there is a lack of understanding)	• Repitious • Some degree of pre-judging and over simplifying • Subjective • "Error bars" in figure 5.1 (Preliminary overall evaluation of the Geoengineering techniques considered in chapters 2 and 3)
What are the major **opportunities** for research now?	What are the **barriers** to research now? Where are the major challenges?
• Climate modelling • Test case / Feasibility investigation • Cross-disciplinary studies, which look holistically. • Field studies of cloud albedo effect	• Money • Practicalities of managing work between disciplines / Research councils • What you need – v- what can be measured in environmental field data. We don't always have the ability to accurately measure and assess what we need to. • Governance • Public perception • Computational limitations

Is there anything that the Royal Society has missed?
• Carbon reduction by channelling light into the Dark ocean • Vegetation change : Studying vegetation change rather than CO_2 removal • CCS • Livestock management – managing land use to avoid desertification.

Group: C

What are the **strengths** of the report?	What are the **weaknesses** of the report?
• Good report • Objective • Valuable milestone • Well articulated at time it was produced • Considers science and society together • Good overview • Impetus behind the report	• Doesn't identify industrial opportunity • Things move on very quickly • Life science aspects e.g. role of plants • Doesn't adopt a systems approach • Doesn't relate to CCS and low carbon energy • Only looks at CO_2 not other gases e.g. methane.
What are the major **opportunities** for research now?	What are the **barriers** to research now? Where are the major challenges?
• Inclusion of biochar into Geoengineering • Suite of options to compare and help prioritise • Use science and engineering to benefit society • To integrate technical, social and environmental research • Raise profile politically and in media • Tension short term –v- long term technologies • See which technologies complement each other • Achieve a win-win with other environmental issues • We have a challenge/ problem to focus on.	• Cross research council working • Lack of interdisciplinary teams across subject (complex systems) • Capacity to deliver into practice (industrial scale-up) • Confidence of the future – "fatalism" • People trained to work in inter-disciplinary systems and in industry for scale-up. • Needs long term commitment and funding • "Last resort / solution" ethos could put back research • Moral hazard • Public perception • Reward mechanisms eg. RAE to recognise interdisciplinary research • Economic impact drivers of research

Is there anything that the Royal Society has missed?
• Ethical issues are not discussed in detail. • Novim report – only briefly cited and is divergent • Direct biological effects on clouds and climate • Plants as a carbon pump rather than a sink • Life science aspects • Sandpit should allow comparison between CDR and SRM • Systems analysis and life cycle analysis • Uncertainty in climate scenarios • Corporate sector and their role. • Where UK can best contribute with limited resources • Skills audit and plan

Group:-D

What are the **strengths** of the report?	What are the **weaknesses** of the report?
• Very good general view • Royal society report is world leading in this area.	• Analysis of technical feasibility and risks of different methods.
What are the major **opportunities** for research now?	What are the **barriers** to research now? Where are the major challenges?
• Private investment • Linking up with other remits • Carbon analysis • More in depth analysis? • Quantitative data? • Methods for CH_4 and N_2O • To do Geoeng research (fill the gaps in RS report) • Co-benefits (food security, energy security, economics, ecosystem services) • Risk management of climate change (& public perception) • Governing the global commons (building on existing legislation)	• Delivery / Industry • Commercial Engagement • Carbon pricing / Trading • Public engagement • Interdisciplinary • Public perception • Public funding
Is there anything that the Royal Society has missed?	
• Methane – role unknown • Funding priorities	

Annex F:

Session 4 - skills, facilities and academic capability required

Given the rank ordered list of research challenges generated in session 2a, 2b and 2c, the participants were asked to consider the skills, facilities and academic capability required to tackle these challenges.

Results are shown below:

Theme ranked 1st for CDR
Estimates of effectiveness at achieving CO_2 concentration reductions, technical efficiency, and costs;

What skill sets do we need to research these priorities?
• Biogeoechemistry – Fate of carbon in soil-plant-groundwater systems • Reaction engineering • Mesocosm studies • Link to food supply and other major societal issues • Geological modelling • Assessment of 'leakage' from biochar and CO2 reservoirs • Broad based Earth system science • Basic earth and life science research skills
What facilities / equipment (if any) do we need to research these priorities?
• Land – Demo sites • Carbon isotope facilities • Solids characterisation • Pilot plant • New research tools (instrument development funding) • Ocean physical and biogeochemical models
Do we have the academic capacity to do this in the UK? If not what do we need to do?
• Yes • No for Air capture: leave it to others who are already far ahead of us.
What other partners should we work with? Is there anyone we should collaborate with?
• Oil industry, Coal industry, power industry • Fisheries / tourist industries for impacts • Mining / Shipping industries for realisation • International science community – linkage to industry need to be done retaining scientific integrity of the process • International links.

Theme ranked 2nd for CDR:- Potential side-effects (pollution and environmental impacts) of the processes and their products;

What skill sets do we need to research these priorities?
• Detailed knowledge of linked biogeochemical processes; response to forcing. • Biogeochemical (and inorganic) cycling of Carbon, nutrients etc. in oceans and soils • Risk assessment – Understanding of protocols / transfer from other experience • Better monitoring tools • Biosensors and bioindicators of impact to ecological functioning • Link to food supply • Better knowledge of ecosystem and ecosystem services
What facilities / equipment (if any) do we need to research these priorities?
• Better tools for assessing conflicting land use demands • Increased level of in situ measurements; Lab studies in critical processes • Ocean physical and biogeochemical and ecological models • Mesocosm tanks for biological manipulation tests • Impacts of the nitrogen cycle of proposed options – modelling studies and insitu measurements
Do we have the academic capacity to do this in the UK? If not what do we need to do?
• Yes, but we need better communication between disciplines • Needs careful multi-disciplinary assessment of land use conflicts – bringing different field together
What other partners should we work with? Is there anyone we should collaborate with?
• Related research ongoing in US and Europe • Industry , farmers • Environment agency • DEFRA • SEPA

Theme ranked 3rd for CDR :- Life cycle analysis of carbon and economic costs (for example) extraction of raw materials, infrastructure development, materials processing, transport and disposal;

What skill sets do we need to research these priorities?
• Economics and earth system sciences • Ecological engineering / Industrial ecology (cf. Yale Uni) • Economic cost ≠ Environmental cost. • Where are the raw materials coming from? • Coupled earth science – economics models • Thermodynamic analysis • Specifications of raw materials
What facilities / equipment (if any) do we need to research these priorities?
Need reliable 'reserves' estimates for $PO_{4....}$Fe…..etc
Do we have the academic capacity to do this in the UK? If not what do we need to do?
Yes but other international groups are ahead e.g. cycling of metals assessed at Yale and elsewhere (c.f. iron fertilisation) For CDR on land – Yes but we are ahead.
What other partners should we work with? Is there anyone we should collaborate with?
Resilience alliance? Minerals / Waste industry – MIRO (mineral Industry research org) BBSRC and its institutes

Theme ranked 1st for SRM: Estimates of effectiveness at achieving the desired climate state, technical efficiency and costs;

What skill sets do we need to research these priorities?
• Understanding of whole climate system
What facilities / equipment (if any) do we need to research these priorities?
• Detailed high resolution earth system models (including stratosphere) and well represented clouds and hydrology • Field tests and ability to measure results • Aircraft and observational activities • Detailed earth system models.
Do we have the academic capacity to do this in the UK? If not what do we need to do?
• Yes very much. • Yes but not yet employed in assessing geoeng • Cloud albedo: yes • Ref Cloud albedo yes good all round coverage • Yes and some experience already
What other partners should we work with? Is there anyone we should collaborate with?
• Many partners in chemistry – climate-aerosol modelling community (US, Canada, Germany, Japan etc) • Cloud albedo: scientists / technologists in US + Europe • US and European – Colleagues in FP7 etc.

Theme ranked 2nd for SRM: Assessment of the full range of climate effects including properties other than global mean temperature, and including the extent and spatial variation of the impacts;

What skill sets do we need to research these priorities?
• Detailed climate and cloud modelling ability, in addition to low resolution and inaccurate modelling tools • Knowledge of detailed processes and networks to couple this to climate studies to improve model capability • Impact modelling (crop yield, heatwave frequency / drought occurrence) • Regional modelling • Better models and understanding of global water cycle especially monsoon systems. Should include direct biological input ice nuclei precipitation • The intersection of complexity science with climate • Need improved understanding of processes as well as improved models • Assessment in the context of sustainability • Process based modelling
What facilities / equipment (if any) do we need to research these priorities?
• Detailed design and practical capability of technologies involved. • Capability of platforms and measurement systems to test field trials should these happen. • Impacts models and regional models • Access to HPC
Do we have the academic capacity to do this in the UK? If not what do we need to do?
• For the SRM-cloud albedo whitening scheme – we do have the capacity. Unfortunately, funding is requires for a field trial. • Aerosol process science – significant capability in the UK – need to develop linkage between this and climate science • Regional models – yes • Comprehensive impacts models only some capability. • More capability in Earth system modelling in the context of 21st century global change.
What other partners should we work with? Is there anyone we should collaborate with?
• For the SRM cloud albedo / whitening scheme, we have collaboration with USA Carnegie institute and Uni of Washington climate centre, who are willing to work with us on this. • Major investments in engineering and testing SRM schemes require international collaborative scientific activities such as some of the major studies to investigate climate processes (e.g. VOCALS) • Collaboration with UK Met office and other climate modelling centres worldwide.

Theme ranked 1st for Cross cutting themes: Extensive climate and Earth-system modelling studies, and where appropriate pilot-scale laboratory and field trials, to improve understanding of costs, effectiveness and impacts, and to enable the identification and characterisation of preferred methods;

What skill sets do we need to research these priorities?
• Climate earth system modellers / Full earth system Modellers • Climate impact modelling : Crop yield, heatwave / drought frequency and severity • Integration of biology (direct effect) with Biometeorology • Climate models should include vegetation / ecosystem feedback • Earth system science including human elements – not just modelling • Clearer understanding of climate processes – specifically in the areas of region scale effects and risks • Design testing and interpretation of pilot scale and field trials and integration of the results • Scientists with interdisciplinary knowledge of the relevant processes (both physical and biogeochemical) • Non-linear system theory / optimisation theory / control theory
What facilities / equipment (if any) do we need to research these priorities?
• Money invested in climate / Earth system model development (e.g. NERC, QUEST, met office models – especially clouds / hydrological cycles • Improved / specific climate (geoeng) impact models. • Detailed high resolution earth system models • Field sites e.g. for biochar addition to fields to asses longterm storage and positive / negative impacts • Strategic long term field experiments and intensive studies to test / verify the schemes • Field data in a suitable form to parameterise models • Extensive model validation with measurements covering a range of biogeochemical regimes • HPC (High performance computing)
Do we have the academic capacity to do this in the UK? If not what do we need to do?
• Mostly - models need to improve in earth systems context. • Some - need improved inputs for modelling capability • Yes – but biology is separate and 'side lined'. (It really shouldn't be) • Ecologists also have an important contribution to make • Yes – In terms of atmospheric sciences • Yes – the UK has a strong track record of internationally collaborative research in process based research in the atmosphere. • More scientists with interdisciplinary knowledge of earth systems physics and biology needed. • Yes UK world leaders
What other partners should we work with? Is there anyone we should collaborate with?
• Other IPCC model groups? • EU groups working on biological Ice nucleation and biosurfactants • Seasonal to decadal prediction community ref: impact of 'switch on' climate forcing • Met office • US groups especially those at NCAR and Princeton GFDL (Geophysical Fluid dynamics Lab)

Theme ranked 2nd for Cross cutting themes: A comprehensive evaluation is needed of environmental , ecological, and socio-economic impacts of the different methods, relative to those expected under climate change (without Geoengineering);

What skill sets do we need to research these priorities?
• Ecological modelling • Assessment of factors other than carbon dioxide, and delta T • Understanding of ecosystem services • Need to improve climate prediction • Global biogeochemical models which include human activity • Interdisciplinary science spanning earth science – policy – legal - ethics etc • Mescosm studies of community response • Historical data (e.g. tree ring analysis) to understand what has changed in ecosystems, how and why
What facilities / equipment (if any) do we need to research these priorities?
• Ecological models for global scale • Biogeochemical models of ocean and terrestrial environments
Do we have the academic capacity to do this in the UK? If not what do we need to do?
• Adapt current e.g. vegetation and land surface models • Yes, but its not a UK only problem……should do it jointly with other nations
What other partners should we work with? Is there anyone we should collaborate with?
• Desert ecosystems respond very quickly to climate change – Work with e.g. Jornada LTER • KE with insurance sector – economic impact of climate variations • EU should see this in future FP calls • Human geographers to asses social-economic impact

Theme ranked 3rd for Cross cutting themes: Economic analysis and multi-criteria assessment of the costs, benefits, impacts and risks associated with the range of Geoengineering methods, and evaluation of value of CDR and/or SRM methods relative to mitigation interventions;

What skill sets do we need to research these priorities?
• Need to establish what to look for / Measure impacts and risk • Risk analysis and cost benefit analysis • Detailed understanding of earth systems • Ecosystem services valuation
What facilities / equipment (if any) do we need to research these priorities?
• High resolution earth system models – with good representation of clouds / hydrology and of evapo transportation / soil hetrogeneity
Do we have the academic capacity to do this in the UK? If not what do we need to do?
[No response]
What other partners should we work with? Is there anyone we should collaborate with?
• We should be working with the rest of the world – especially the USA. We should use £3M to establish an “international centre for climate research and management” – embracing all aspects of geo-engineering including carbon dioxide reduction solar radiation management. International funding is needed and this centre should coordinate all relevant research and development / engagement with the public. Early decisions on climate management are needed. Society cannot live with this risk of catastrophic climate failure, maybe as early as 2050.