EXCELLENCE
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THE ROYAL SOCIETY

DISCUSSION MEETING ON
Geoengineering – taking control of our planet's climate

Monday 8 and Tuesday 9 November 2010

Organised by Professor Andy Ridgwell, Professor Chris Freeman
and Professor Richard Lampitt

Programme and abstracts
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Publication order form

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Geoengineering – taking control of our planet's climate

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DAY 1 – Monday 8 November 2010				**DAY 2 – Tuesday 9 November 2010**			
SESSION 1 Chair: Paul Valdes		**SESSION 2 Chair: Brian Launder**		**SESSION 3 Chair: Richard Lampitt**		**SESSION 4 Chair: Andy Ridgwell**	
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10.00	**Andrew Watson** The runaway greenhouse: the last great geoengineering challenge	**14.30**	Discussion	**10.00**	Discussion	**14.30**	Discussion
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11.00	**Carol Turley** Ocean acidification: a powerful argument to reduce future CO_2 emissions	**15.30**	**John Latham** Increasing cloud albedo	**11.00**	**Tim Kruger** An Overview of Proposed Enhanced Weathering Methods	**15.30**	**Jonathon Porritt** Geo-governance: assuring the future
11.30	**Damon Matthews** Cumulative carbon as a policy framework for avoiding dangerous climate impacts	**16.00**	**Joy Singarayer** Cooling with crops	**11.30**	**Naomi Vaughan** Interactions between geoengineering and emissions mitigation	**15.50**	**Robert Watson** Political dimension and perspectives
12.00	Discussion	**16.30**	Discussion	**12.00**	Discussion	**16.10**	Panel discussion/Overview (future directions)
12.30	LUNCH	**17.00**	CLOSE	**12.30**	LUNCH	**17.00**	CLOSE

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EXCELLENCE IN SCIENCE

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Geoengineering - taking control of our planet's climate

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Organised by Professor Andy Ridgwell, University of Bristol, Professor Chris Freeman, Bangor University, Professor Richard Lampitt, National Oceanography Centre, University of Southampton

Synopsis

Society seems unable or unwilling to make the drastic reductions in CO_2 emissions necessary to avoid 'dangerous' (unacceptable) climate change. A new science "Geoengineering" that until recently would have seemed pure science fiction, promises an alternative way of temporarily regaining control of climate. This meeting considers the state of this new science, and its implications to society.

Monday 8 November 2010

9.00 Welcome by Peter Collins, Director, History of Science, Royal Society

9.10 Introduction from Professor Andy Ridgwell

Session 1

Chair Professor Paul Valdes, University of Bristol, UK

9.20 "Dangerous" climate change and geoengineering

Professor John Mitchell, MetOffice, UK

The UNFCCC committed signatories' governments to a voluntary "non-binding aim" to reduce atmospheric concentrations of greenhouse gases with the goal of "preventing dangerous anthropogenic interference with earth's climate system." There is no scientific definition of "dangerous" climate change. However, policies have been directed at keeping warming global mean warming below 2 C, and a number of authors have proposed working definitions which include sudden or potentially irreversible changes in climate state.

Most unmitigated scenarios considered by the Intergovernmental Panel on Climate Changes fourth assessment are likely to lead a global warming of greater than 2 C by the end of this century. Modelling uncertainties make it more difficult to make quantify the likelihood of some of the candidates for sudden or irreversible changes in climate for dangerous climate change.

Given the estimated likelihood of future unmitigated emissions leading to a warming of greater than 2 C, proposals have been made to use geo-engineering to mitigate climate change. Preliminary tests with climate models have indicated that each of the proposed approaches will produce their own characteristic patterns of climate change, though the net changes are generally smaller than in unmitigated scenarios. Given current model limitations, including capability of models to simulate regional climate change, these results need to be treated with caution. The prospects for improving regional simulation of regional climate are discussed.

10.00 The Runaway Greenhouse: the last great geoengineering challenge
Professor Andrew Watson, University of East Anglia, UK

The ultimate climate emergency, from which only geoengineering could save us, is a "Runaway greenhouse" in which the water vapour feedback on climate becomes strong enough to cause surface temperatures to rise beyond the range that life can tolerate. The transition is highly non-linear: as water vapour becomes optically thick, a limit on the outgoing longwave radiation is reached. Surface temperature would then increase to ~1400K with outgoing radiation in the visible and near infrared. As the Sun slowly moves along the Main Sequence and its luminosity increases, we might expect this will be the event which eventually ends all life on Earth. But how long, exactly, do we have? And could we unwittingly bring on such a catastrophe by our current climate-altering activities?

Here we review what is known about the Runaway Greenhouse as applied to the Earth. The good news is that it does not seem possible, even in principle, to trigger the runaway by addition of permanent greenhouse gases such as CO_2 to the atmosphere, however much we release. Also, best estimates of when a natural runaway would occur due to increasing solar luminosity, currently put this at least a billion years in the future. However, there remains uncertainty and a nagging worry that we might have underestimated the danger, because we know insufficient about the actual approach to runaway. For example, much before reaching the runaway limit, Earth would move into a "moist greenhouse" regime, characterised by a wet stratosphere which would destroy the ozone layer. We are still ignorant of some of the important radiative properties of water vapour at high concentrations, and the behaviour of clouds in such a steamy atmosphere. We know therefore, that life on Earth will eventually face annihilation as a result of the runaway greenhouse, but we are unsure just when.

10.30 Tea/coffee

11.00 Ocean acidification: a powerful argument to reduce future CO_2 emissions
Dr Carol Turley, Plymouth Marine Laboratory, UK

Fundamental changes to ocean chemistry are occurring because of continued anthropogenic emission of CO_2 to the atmosphere and its subsequent uptake by oceans. Surface ocean acidity (*p*H) and carbonate ions (used by organisms to make shells and skeletons) are decreasing while bicarbonate ions are increasing. Oceans have already taken up around 25-30% of the CO_2 produced by fossil fuel burning, cement manufacturing and land use changes in the last 200 yrs resulting in a surface ocean *p*H decrease of 0.1, an increase in acidity of ~30%. Continued emissions at the same rate could decrease *p*H by as much as 0.4 by 2100. It is happening now, at a rate and to a level not experienced by marine organisms for possibly ~ 65 million years.

Laboratory experiments, observations and projections indicate that unless we rapidly and substantially reduce CO_2 emission these chemical changes, now commonly referred to as ocean acidification, may result in alterations to future ocean ecosystems that might take millions of years to recover. While ocean acidification is a global issue some regions may be impacted earlier (e.g. estuaries, upwelling waters, polar and sub-polar waters and the deep sea), within the following decade(s). Processes such as calcification, growth, reproduction, digestion, egg and larval development, behavior and recruitment, nutrient generation, the biological pump and biogas production may also be affected. Many of the vulnerable species and ecosystems are important marine food providing organisms or are key habitats for them while others play a role in the global carbon and nitrogen cycles and the formation of climate changing gases.

Ocean acidification is caused directly by CO_2 so solar radiation management geoengineering techniques, which reflect the sun's energy away from the Earth, will not be a solution.

11.30 Cumulative carbon as a policy framework for avoiding dangerous climate impacts
Professor Damon Matthews, Concordia University, Canada

The primary objective of The United Nations Framework Convention on Climate Change is to stabilize greenhouse gas concentrations a level that will avoid dangerous climate impacts. However, greenhouse gas concentration stabilization is an awkward framework within which to assess dangerous climate change on account of the significant lag between a given concentration level, and the eventual equilibrium temperature change. By contrast, recent research has shown that global temperature change can be well described by a given cumulative carbon emissions budget. Here, we propose that cumulative carbon emissions represent an alternate framework that is applicable both as a tool for climate mitigation as well as for the assessment of potential climate impacts. We show first that both atmospheric CO_2 concentration at a given year and the associated temperature change are generally associated with a unique cumulative carbon emissions budget that is largely independent of the emissions scenario. The rate of global temperature change can therefore be related to first order to the rate of increase of cumulative carbon emissions. However, transient warming over the next century will also be strongly affected by emissions of shorter lived forcing agents such as aerosols and methane. Non- CO_2 emissions therefore contribute to uncertainty in the cumulative carbon budget associated with near-term temperature targets. By contrast, long-term temperature change remains primarily associated with total cumulative carbon emissions due to the much longer atmospheric lifetime of CO_2 relative to most other climate forcing agents.

12.00 Discussion

12.30 Lunch

Session 2
Chair Professor Brian Launder FREng FRS, University of Manchester, UK

13.30 Geoengineering the climate: an overview and update
Professor John Shepherd CBE FRS, National Oceanography Centre, University of Southampton, UK

The climate change we are experiencing now is caused by an increase in greenhouse gases due to human activities, including burning fossil fuels, agriculture and deforestation. There is now widespread belief that a global warming of greater than 2°C above pre-industrial levels would be dangerous and should therefore be avoided. However, despite growing concerns over climate change, global CO_2 emissions have continued to climb. This has led some to suggest more radical "Geoengineering" alternatives to conventional mitigation via reductions in CO_2 emissions.

Geoengineering is deliberate intervention in the climate system to counteract man-made global warming. There are two main classes of geoengineering; direct carbon dioxide removal, and solar radiation management, which aims to cool the planet by reflecting more sunlight back to space. The findings of the review of Geoengineering carried-out by the UK Royal Society (see http://royalsociety.org/Geoengineering-the-climate/) are summarized, including the climate effects, costs, risks, and research and governance needs for various approaches. The possible role of geoengineering in a portfolio of responses to climate change is discussed, and various recent initiatives to establish good governance of research activity are reviewed.

Key findings include

- Geoengineering is not a magic bullet and not an alternative to emissions reductions.
- Cutting global greenhouse gas emissions must remain our highest priority –
    - But this is proving to be difficult, and Geoengineering may be useful to support it
- Geoengineering is very likely to be technically possible
    - However, there are major uncertainties and potential risks concerning effectiveness, costs and social & environmental impacts
- Much more research is needed, as well public engagement and a system of regulation (for both deployment and for possible large-scale field tests)
- The acceptability of geoengineering will be determined as much by social, legal and political issues as by scientific and technical factors

14.00 Solar radiation management through stratospheric particle injection
Dr Matthew Watson, University of Bristol, UK

During a recent sandpit event, supported by EPSRC, NERC and STFC, the SPICE project (Stratospheric Particle Injection for Climate Engineering) was selected for funding. The research is divided into three work packages based upon assessing the feasibility of mimicking the climate cooling from large, equatorial volcanic eruptions. In detail, these are focused upon 1. Idealising particle optics and minimising chemical effects, 2. design of a tethered-balloon system to deliver particles to the stratosphere and, 3. modelling impacts of solar radiation management (SRM) on climate and the biosphere. The consortium is a collaboration between the Universities of Bristol, Cambridge, Oxford and Edinburgh, the Met. Office and the Rutherford-Appleton laboratory (the Molecular Spectroscopy and Central Laser Facilities).

14.30 Discussion

15.00 Tea/coffee

15.30 Increasing cloud albedo
Professor John Latham, National Center for Atmospheric Research, USA

The idea behind the marine cloud brightening (MCB) geoengineering technique is that seeding marine stratocumulus clouds with copious quantities of monodisperse sub-micrometre seawater particles could significantly enhance the cloud droplet number concentration thus increasing the cloud albedo and longevity – thereby producing a cooling, which computations suggest could be adequate to balance the warming associated with a doubling of atmospheric carbon dioxide.

We review herein recent research on a number of critical issues associated with MCB: (1) general circulation model (GCM) studies, which are our primary tools to evaluate globally the effectiveness of marine cloud brightening and to assess its climate impacts on rainfall amounts and distribution, as well as on polar sea-ice cover and thickness: (2) high resolution modeling of the effects of seeding on marine stratocumulus, which are required to understand the complex array of interacting cloud processes involved in brightening: (3) microphysical sensitivity studies examining the influence of seeding amount, seed-particle salt-mass, air-mass characteristics, updraught speed and other parameters on cloud albedo change: (4) sea-water spray production by controlled electrohydrodynamic instability, and by microfabrication lithography: (5) computational fluid dynamics studies of possible large-scale periodicities in Flettner rotors: and (6) the planning of a three-stage limited-area field research experiment, which has the objective of developing our fundamental knowledge of marine stratocumulus clouds, testing the technology developed for the MCB geoengineering application, and ultimately, if deemed justifiable, field-testing the idea quantitatively, on a limited (perhaps 100km spatial scale.

16.00 Cooling with crops

Dr Joy Singarayer, University of Bristol, UK

Climate change mitigation by geoengineering may be achieved either by increasing the reflectivity of the planet to incoming solar radiation or by removing carbon dioxide from the atmosphere. Geoengineering schemes typically require considerable financial investment for the development of new infrastructure and technologies. 'Bio-geoengineering' of crops is one such recently proposed method of providing regional climate change mitigation. The scheme is based on the idea that large-scale planting of crop varieties with increased reflectivity to incoming solar radiation, due to variation in leaf glossiness or canopy structure, would have a significant cooling effect. Arable land represents a considerable fraction of global land-use (over 10%), with particularly dense agricultural regions covering Europe, North America and Southern Asia, where the majority of the mitigation would occur. Initial assessment of the potential of crop biogeoengineering used a global climate model to suggest that an increase of 20% in crop canopy albedo could provide Europe with an average summertime cooling of over 1°C (Ridgwell et al., 2009; Singarayer et al., 2009). This would be one fifth of the total mitigation required to regionally offset a doubling of carbon dioxide, or up to 50% of that required to offset summer warming over Europe in the mid-21st century under a moderate global warming scenario (IPCC A1B). Further work is being performed to improve our quantitative understanding of crop albedo variability and incorporate realistic ranges into the models used to assess the impacts on climate and on crop productivity. This talk will present a background to the idea of biogeoengineering and discuss recent studies being undertaken. Cooling with crops may provide a lower level of climate mitigation than other proposed geoengineering schemes. However, it may prove to be lower risk and easier to implement than other methods.

16.30 Discussion

17.00 Close

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Session 3

Chair Professor Richard Lampitt, National Oceanography Centre, University of Southampton, UK

9.00 CO_2 capture from the air

Professor David Keith, University of Calgary, Canada

Capturing CO_2 from ambient air will always be more expensive than capturing from concentrated sources assuming that both facilities operate the same scale and face the same costs of capital, labour, energy and CO_2 disposal. Direct capture of CO_2 from air, "air capture", may nevertheless be an important tool for managing carbon. My discussion of air capture will cover three topics. First, I will describe how a hypothetical generic air capture technology fits into the carbon mitigation puzzle by examining the technical and economic constraints that determine the utility of air capture as a function of its energy intensity and cost. This analysis will focus on the ways in which the marvellous diversity of the global energy system produces niches in which air capture could be important long before we have captured or eliminated CO_2 emissions from stationary sources. Air capture enables a new form physical carbon arbitrage allowing it to exploit differences in the costs of factors such as capital construction and energy that determine the cost of carbon mitigation. Second, I will describe some of the fundamental engineering trade-offs involved in any air capture technology, and provide a brief review of some of the technical options being pursued by various academic groups and start-up companies. Finally, I will describe technology for capturing CO_2 from air being developed by Carbon Engineering a start-up company I founded. Carbon Engineering is developing large-scale contactors for capturing CO_2 using strong hydroxide solutions using technologies derived from commercial forced-draft cooling towers. I will focus on the core design choices in our contactor and provide some insight into how we think about the contactor's technical risk, performance and cost.

9.30 Terrestrial carbon capture: a peatland case study

Professor Chris Freeman, Bangor University, UK

Terrestrial and oceanic ecosystems contribute almost equally to an estimated sequestration of about 50% of anthropogenic CO_2 emissions, and thus already play a role in minimizing our impact on the global climate. Of the C sequestered terrestrially, the majority becomes part of the Earth's soil carbon stores. Northern peatlands cover just 2-3% of the Earth's landmass and yet sequester 455Pg of C, or almost 1/3 of that soil carbon. Peatland ecosystems are thus well established as powerful agents of carbon capture and storage, and the preservation of archaeological artifacts, such as ancient bog bodies, further attest to their exceptional preservative properties. Peatlands, have higher carbon storage densities per unit ecosystem area than either the oceans or dry terrestrial systems. However, despite attempts over a number of years at enhancing carbon capture in the oceans or in land-based afforestation schemes, no attempt has yet been made to optimize peatland carbon storage capacity or even to harness peatlands to store externally-captured carbon. Recent studies suggest that peatlands sequester carbon due to the inhibitory effects of phenolic compounds which create an 'enzymic latch' on decomposition. Here we propose to harness that mechanism in a series of peatland-geoengineering strategies in which molecular, biogeochemical, agronomical and afforestation approaches, increase carbon capture and long-term sequestration in peat-forming terrestrial ecosystems.

10.00 Discussion

10.30 Tea/coffee

11.00 An overview of proposed enhanced weathering methods
Mr Tim Kruger, University of Oxford, UK

The Royal Society, in its recent report on geoengineering, described a number of methods for removing carbon dioxide from the atmosphere. One group of these methods – enhanced weathering – seeks to accelerate the weathering of minerals which acts as a natural sink for carbon. This paper will do two things:

- Assess the six enhanced weathering methods outlined in the Royal Society's report
- Present the argument that should a safe, robust and economic 'carbon-negative' technology be implementable then it would create a moral obligation to match emissions with a comparable removal of carbon dioxide, a global price for carbon and a reduction in demand for carbon-intensive industries.

11.30 Interactions between geoengineering and emissions mitigation
Dr Naomi Vaughan, University of East Anglia, UK

We use a simple carbon cycle-climate model to investigate the interactions between a selection of highly idealised CO_2 emissions mitigation trajectories, carbon dioxide removal (CDR), and solar radiation management (SRM) scenarios. Two CO_2 emissions mitigation trajectories differ by a 20 year delay in the start of mitigation activity. SRM is modelled as a reduction in incoming solar radiation that fully compensates the radiative forcing due to changes in atmospheric CO_2 concentration. Two CDR scenarios remove 300 PgC by afforestation (added to vegetation) or 1000 PgC by bio-energy with carbon storage (removed from system). Our results show that delaying the start of mitigation activity could be very costly in terms of the CDR activity needed later to limit atmospheric CO_2 concentration (and corresponding global warming) to a given level. The effects of applying SRM and CDR together are additive, and this shows most clearly for atmospheric CO_2 concentration. SRM causes a significant reduction in atmospheric CO_2 concentration due to increased carbon storage by the terrestrial biosphere, especially soils. However, SRM has to be maintained for many centuries to avoid rapid increases in temperature and corresponding increases in atmospheric CO_2 concentration, due to loss of carbon from the land.

12.00 Discussion

12.30 Lunch

Session 4
Chair Professor Andy Ridgwell, University of Bristol, UK

13.30 Geoengineering: preparations and options for governance
Dr Margaret Leinen, Climate Response Fund, USA

In four short years discussion of climate engineering has moved from disputes over whether peer-reviewed articles in scholarly journals should be published to a full range of academic and public inquiry: peer-reviewed literature, studies by scholarly societies, international conferences, government hearings, popular science articles, and weblogs. But this field of inquiry is fraught with our understandable concern about the environmental consequences of climate engineering. The social consequences of research on this topic are formidable – from ethical issues to inadvertent provision of tools for hostile action to the societal challenge of taking responsibility for alteration of climate elements. With this array of legitimate concerns, governance is key to the acceptability of further research, especially experimentation. While those interested in conducting research have emphasized the challenge of governing the diversity of proposed technologies, specialists in policy and governance have focused on the range of risks and fears. The combined breadth of governance challenges argues for a stepwise approach that can adapt to the emergence of more information on the technologies and a clearer focus for social concerns. The urgency of the calls for research argues for use of existing governance tools to allow some carefully constrained experimental research. The extreme social concerns argue for a carefully constructed international discussion that includes dialogue with a wide range of concerned constituencies. Finally, the interrelated nature of emissions reduction, mitigation, adaptation to climate change and climate engineering argues that any use of these technologies must not be separate, but be part of the overall climate strategy of nations and the international community.

14.00 Public perception of geoengineering- knowledge, risk and acceptability
Professor Nicholas Pidgeon, Cardiff University, UK

Geoengineering is a prime example of an emerging or 'upstream' technology, since many of its technical aspects, including questions around effectiveness, cost and risks, are highly uncertain. But the question of whether geoengineering will be acceptable to society is not so much a technical issue as a matter of perceptions, ethics and governance. This paper contributes to the emerging debate about the social acceptability of geoengineering by presenting current evidence on public responses to this suite of technologies. We draw upon qualitative data, including from the innovative UK Public Dialogue on Geoengineering 'Experiment Earth', together with the results of a nationwide survey of opinion. Currently baseline knowledge of geoengineering amongst the British public is extremely low, but when given additional information people can engage effectively with the topic. The data indicate that, in general, Carbon Dioxide Removal approaches are preferred to Solar Radiation Management. This research also begins to map out some of the ethical considerations which people will bring to bear on their judgements of the acceptability of geoengineering, as well the constraints that people might wish to see placed upon geoengineering research and deployment. The paper concludes that, aside from technical considerations, public perceptions are likely to prove a key element influencing the debate over questions of both acceptability and governance.

14.30 Discussion

15.00 Tea/coffee

15.30 Geo-governance: assuring the future
Jonathon Porritt, Forum for the Future, UK

Abstract not available at time of going to press

15.50 Political dimension and perspectives
Professor Robert Watson, Department for Environment, Food & Rural Affairs, UK

Tackling human-induced climate change is one of the most serious challenges facing mankind. The climate change experienced now is caused by an increase in greenhouse gases due to human activities. There is widespread belief that a global warming of greater than 2oC above pre-industrial levels would be dangerous and should be avoided. Despite growing concerns over climate change, global CO_2 emissions have continued to climb. This has led some people to suggest geo-engineering alternatives to conventional mitigation.

Geo-engineering comprises a wide range of methods; the removal of CO_2 from the atmosphere and solar radiation management which reflects sunlight. More research is needed, but geo-engineering is very likely to be technically possible and the methods are, relatively, fast acting and cheap. While it is critical for the world to transition to a low-carbon economy, and prepare to adapt to a changing climate, it is also appropriate to assess the opportunities and pitfalls afforded by geo-engineering. The methods do not address ocean acidification and geo-engineering is not a magic bullet. The recent Royal Society Report summarises the risks and potential benefits of the range of geo-engineering options.

An appropriate strategy is to model the range of possible options quantifying to the degree possible the beneficial impacts on the Earth's climate and the range of possible adverse environmental effects. Prior to initiating any large-scale pilot field operations, international agreements should be negotiated given the impacts of any field experiments will have trans-boundary consequences. Cutting global emissions of greenhouse gases must remain a high priority and further, widespread debate and engagement is needed alongside international regulation and governance.

16.10 Future directions/Panel Discussion Overview

17.00 Close

Organiser, speaker and chair biographies

Professor Chris Freeman, Bangor University (Organiser and speaker)
Chris Freeman is currently Professor of Peatland Biogeochemistry at Bangor University where he heads the Wolfson Peatland Carbon Capture Laboratory. He moved to Bangor in 1986, after gaining a part-time BSc at Nottingham Trent University. On gaining a PhD in Bangor, he went on to conduct postdoctoral research at the Institute of Terrestrial Ecology (now formally known as CEH) until 1994. He was awarded a Royal Society University Research Fellowship that year, and held the Fellowship in Bangor. He has since been appointed as Lecturer (2002), Senior Lecturer (2003), and then Professor (2005) at that University. His research interests focus on the causes of the unusually high capacity of peatlands for carbon sequestration, and the role of that ecosystem in influencing climate change. Chris has been a contributing author to more than 90 refereed publications.

Professor David Keith, University of Calgary (Speaker)
Professor Keith has worked near the interface between climate science, energy technology and public policy for twenty years. His work in technology and policy assessment has centered on the capture and storage of CO_2, the technology and implications of global climate engineering, the economics and climatic impacts of large-scale wind power and the prospects for hydrogen fuel. As a technologist, David has built a high-accuracy infrared spectrometer for NASA's ER-2 and developed new methods for reservoir engineering increase the safety of stored CO_2. He now leads a team of engineers developing technology to capture of CO_2 from ambient air at an industrial scale.

David took first prize in Canada's national physics prize exam, he won MIT's prize for excellence in experimental physics, was listed as one of TIME magazine's Heroes of the Environment 2009 and was named Environmental Scientist of the Year by Canadian Geographic in 2006. He spent most of his career in the United States at Harvard University and Carnegie Mellon University before returning to Canada in 2004 to lead a research group in energy and environmental systems at the University of Calgary.

David has served on numerous high-profile advisory panels such as the UK Royal Society's geoengineering study, the IPCC, and Canadian 'blue ribbon' panels and boards. David has addressed technical audiences with articles in Science and Nature, he has consulted for national governments, global industry leaders and international environmental groups, and has reached the public through venues such as the BBC, NPR, CNN and the editorial page of the New York Times.

Tim Kruger, University of Oxford (Speaker)
Tim Kruger is the Head of the Oxford Geoengineering Programme (OGP) at the Oxford Martin School, University of Oxford. The OGP seeks to assess the technical and social issues associated with all proposed geoengineering techniques.

Prior to taking up this post, Tim undertook a detailed assessment (http://www.cquestrate.com/) of the concept of adding alkalinity to the ocean as a means of enhancing its capacity to act as a carbon sink and to counteract ocean acidification.

Professor Richard Lampitt, National Oceanography Centre (Organiser and chair of session 3)
Richard Lampitt is an observational biogeochemist with a main focus on the factors that control the downward flux of material from the top of the ocean into the interior and from there to the seabed. Amongst other approaches this involves long term deployments of sediment traps deep in the water column (eg 3000m). A crucial factor is the export flux of material from the upper mixed layer and he has developed novel ways to make direct measurements of this flux, a notoriously difficult process to measure.

In order to understand the factors that determine the quantity and quality of material mediating this flux, continuous observations are required on a wide range of properties and processes occurring in the upper part of the water column. As a result of this conviction he is heavily involved in the establishment and management of a network of fixed point observatories around Europe. This is the EuroSITES network, a collaborative European endeavour which he coordinates with special responsibility for the observatory above the Porcupine Abyssal Plain in the Northeast Atlantic, the so called PAP site.

He has an increasing interest in issues of direct societal concern and in particular the ways in which the oceans may be encouraged to remove anthropogenic carbon dioxide from the atmosphere. He is co-chair of the ISIS consortium which aims to further research in this area and coordinates the NOC beacon theme on geoengineering which includes such activities.

Professor John Latham, National Center for Atmospheric Research (Speaker)
John Latham (DSc, University of Manchester, PhD University of London), who first proposed the Cloud Albedo Enhancement or Cloud Brightening geoengineering idea (Latham, *Nature*, 1990), is a Senior Research Associate at NCAR, Boulder, Colorado, and Emeritus Professor of Physics, University of Manchester. He was awarded the L F Richardson Prize (1965), the Hugh Robert Mill Medal (1972) and the Gaskell Memorial Medal (1994) by the Royal Meteorological Society and gave its Symons Memorial Lecture in 1979. He was for eight years President of the International Commission on Atmospheric Electricity. His research, largely in the fields of cloud and aerosol physics, atmospheric electricity and geoengineering, has yielded about 180 papers in the peer-reviewed open literature. He was for many years Head of Atmospheric Research at the University of Manchester, where the Latham Atmospheric Sciences Laboratories were inaugurated in 2008.

Professor Brian Launder FREng FRS, University of Manchester (Chair of session 2)
Brian Launder is a Mechanical Engineer, a graduate of Imperial College and the Massachusetts Institute of Technology, who has specialized in the modelling and measurement of turbulent flows in engineering contexts. He served as a faculty member at Imperial College and the University of California before joining UMIST (now the University of Manchester). In 2000 he became regional director of the newly created Tyndall Centre for Climate Change Research, his personal interests being in engineering contributions to reducing CO_2 levels whether by reducing emissions or via geoengineering. In the latter context he has edited (with JMT Thompson) both an issue of Phil Trans Roy Soc (Geoscale engineering to avert dangerous climate change) and the book Geo-engineering climate change: environmental necessity or Pandora's box?. He was also a member of the Shepherd Committee that produced the Royal Society's policy document: Geoengineering the climate: Science, governance and uncertainty.

Dr Margaret Leinen, Climate Response Fund (Speaker)
Dr. Margaret Leinen is Founder and CEO of the Climate Response Fund, a nonprofit organization promoting responsible discussion of issues associated with climate engineering research. Dr. Leinen is an ocean biogeochemist and paleoceanographer whose research includes study of ocean carbon sequestration. She was a professor and Dean of the Graduate School of Oceanography at the University of Rhode Island and served as Assistant Director for Geosciences, U.S. National Science Foundation (NSF) from 2000-2007. Dr.

Leinen was the Chief Science Officer of Climos between 2007 and 2009. She was the Vice Chair of the International Geosphere Biosphere Programme, Chair of the US Global Change Research Program and Vice Chair of the U.S. Climate Change Science Program. She has served as the President of The Oceanography Society, Chair of the AAAS Section on Atmospheric and Hydrospheric Science and was recently elected to the Board of Directors of the American Geophysical Union.

Professor Damon Matthews, Concordia University (Speaker)
Dr. Damon Matthews is Associate Professor and University Research Fellow in the Department of Geography Planning and Environment at Concordia University. He obtained a B.Sc. in Environmental Science from Simon Fraser University in 1999, and a Ph.D. in Earth and Ocean Sciences from the University of Victoria in 2004. Prior to joining Concordia University in January 2007, he held a post-doctoral fellowship at the University of Calgary, and worked as a post-doctoral researcher at the Carnegie Institution at Stanford. Dr. Matthews currently teaches courses on the climate system, climate change and environmental modelling at Concordia University. His research is aimed at better understanding the many possible interactions between human activities, natural ecosystems and future climate change, and contributing to the scientific knowledge base required to promote the development of sound national and international climate policy. Dr. Matthews holds several current research grants for projects to investigate the uncertainties associated with current terrestrial carbon sinks in the context of expected future climate changes. He has published a number of research papers in the area of global climate modelling, with particular emphasis on the role of the global carbon cycle in the climate system, estimating allowable emissions for climate stabilization, and understanding our commitment to long-term climate warming.

Professor John Mitchell OBE FRS, MetOffice (Speaker)
John Mitchell gained a BSc and PhD, Theoretical Physics in from The Queen's University, Belfast. In 1978, took charge of the Climate Change group in what is now the MetOffice's Hadley Centre for Climate Prediction and Research. His main speciality is the climatic effects of increases in greenhouse gases and related pollutants. He was a lead author in the first three IPCC Working Group I reports. He is twice winner of the Norbert Gerbier-Mumm Prize (with colleagues) and received the EGU Hans Oeschger Medal in 2004. He is a past Chief Scientist and Director of Climate Science at the MetOffice, where he is now currently the Principal Research Fellow. He is a visiting Professor Universities of Reading and Exeter and a Honorary Professor at the University of East Anglia.

Professor Nicholas Pidgeon, Cardiff University (Speaker)
Nick Pidgeon is Professor of Environmental Psychology at Cardiff University, where he directs the Understanding Risk Research Group (see www.understanding-risk.org). He currently holds a 3 year Economic and Social Research Council Professorial Climate Leader Fellowship. His research looks at the public acceptability of environmental risks, including the topics of nuclear power, climate change, nanotechnologies and geoengineering. He was a member of the Royal Society / Royal Academy of Engineering nanotechnology study group and a co-editor (with Roger Kasperson and Paul Slovic) of *The Social Amplification of Risk*, Cambridge University Press, 2003. He is co-author of a recent paper on the social and ethical challenges of geoengineering, appearing in the February 2010 issue of the journal *Environment*, and a principal investigator to the EPSRC/NERC project Integrated Assessment of Geoengineering Proposals (IAGP).

Jonathon Porritt, Forum for the Future (Speaker)

Jonathon Porritt, Co-Founder of Forum for the Future, is an eminent writer, broadcaster and commentator on sustainable development. Established in 1996, Forum for the Future is now the UK's leading sustainable development charity, with 70 staff and over 100 partner organisations, including some of the world's leading companies.

In addition, he is Co-Director of The Prince of Wales's Business and Sustainability Programme which runs Seminars for senior executives around the world. He is a Non-Executive Director of Wessex Water, and of Willmott Dixon Holdings. He is a Trustee of the Ashden Awards for Sustainable Energy, and is involved in the work of many NGOs and charities as Patron, Chair or Special Adviser.

Jonathon's involvement in the Green Movement started in the mid-1970s, when he joined the Green Party – he is still a member today. At that time, he was teaching English and Drama in a comprehensive school in West London, after being educated at Eton and Magdalen College, Oxford, where he studied French and German. He spent a lot of time travelling in those days, as the family was living in New Zealand between 1967 and 1973. His father was an eminent surgeon and athlete.

Jonathon became co-Chair of the Green Party in 1980, a position which he held until he took over as Director of Friends of the Earth in 1984. The next six years provided the foundation for the rest of Jonathon's career, as they coincided with a huge surge in interest in environmental issues. In the years after that, he wrote a number of books (including 'Save the Earth', at the time of the Earth Summit in Rio de Janeiro in 1992, which sold more than a million copies) and fronted various television series.

Since then he has been Chairman of UNED-UK (1993-96); chairman of Sustainability South West, the South West Round Table for Sustainable Development (1999-2001); a Trustee of WWF UK (1991-2005), and a member of the Board of the South West Regional Development Agency (1999-2008).

In July 2000, he was appointed by Tony Blair as the first Chair of the UK Sustainable Development Commission, a position which he held for nine years. The SDC is the Government's principal advisory body on all matters relating to sustainable development and acts simultaneously as the 'watchdog' of the Government's performance – a role which led inevitably to some confrontational encounters with Government Ministers! He is still involved in a number of political initiatives today.

His latest books are *Capitalism As If The World Matters* (Earthscan, revised 2007), *Globalism & Regionalism* (Black Dog 2008) and *Living Within Our Means* (Forum for the Future 2009).

Jonathon received a CBE in January 2000 for services to environmental protection.

Professor Andy Ridgwell, University of Bristol (Lead organiser and chair of session 4)
Andy Ridgwell is a Royal Society University Research Fellow at the University of Bristol. Although in practice spending most of his time tending to the every need of 6 cats, his research addresses fundamental questions surrounding the past and future controls on atmospheric CO_2, and the nature of the relationship between CO_2, climate, global biogeochemical cycles, and life. He is also closely involved in research into future ocean acidification impacts and the effectiveness (or otherwise) of geoengineering. His develops his own numerical analytical tools ('Earth system models') to ask questions and test hypotheses regarding the functioning of the Earth system.

Professor John Shepherd CBE FRS, National Oceanography Centre, University of Southampton (Speaker)

John Shepherd is a Professorial Research Fellow in Earth System Science in the School of Ocean and Earth Science, National Oceanography Centre, University of Southampton, UK. He is a physicist by training, and has worked on the transport of pollutants in the atmospheric boundary layer, the dispersion of tracers in the deep ocean, the assessment & control of radioactive waste disposal in the sea, on the assessment and management of marine fish stocks, and most recently on Earth System Modelling and climate change. His current research interests include the natural variability of the climate system on long time-scales, and the development of intermediate complexity models of the Earth climate system for the interpretation of the palaeo-climate record. He graduated (first degree and PhD) from the University of Cambridge. From 1989-1994 he was Deputy Director of the MAFF Fisheries Laboratory at Lowestoft, and the principal scientific adviser to the UK government on fisheries management. From 1994-1999 he was the first Director of the Southampton Oceanography Centre. He has extensive experience of international scientific assessments and advice in the controversial areas of fisheries management, radioactive waste disposal, and climate change, and has recently taken a particular interest in the interaction between science and public policy. He was elected a Fellow of the Royal Society in 1999, participated in the Royal Society study on Ocean Acidification published in 2005, and chaired the study on Geoengineering the Climate published in 2009.

Dr Joy Singarayer, University of Bristol (Speaker)
Joy Singarayer is a lecturer in climate modelling research at the University of Bristol. She has an MSci in physics from Imperial College and obtained her DPhil from Oxford University in 2003. Since then she has been based at the University of Bristol. Her main research involves the use and development of Earth System models to simulate past climate changes on time scales of decades to millennia in order to develop our understanding of the sensitivity of climate to natural and anthropogenic forcing. Related to this, her research has extended to geoengineering to mitigate climate change and, in particular, the potential for biogeoengineering. She is also interested in public communication of science, and has been involved as a consultant for the BBC and co-presenter on the 2009 Channel 4 series *Man on Earth*.

Dr Carol Turley, Plymouth Marine Laboratory (Speaker)
Dr Carol Turley's research has been centred on the ocean's biogeochemical cycles looking at habitats from shallow and deep-seas, estuaries, frontal systems to large enclosed waters. She has ~100 peer reviewed publications. She was a member of The Royal Society working group on ocean acidification and was a lead author on the 2007 Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report on Climate Change. Carol is the Knowledge Exchange Coordinator for the £12M UK Ocean Acidification Research Programme and is a member of other international ocean acidification programmes. She has contributed to several UNFCCC events, including the UN Conference on Climate Change (COP15) in Copenhagen in December 2009 and is a review editor for the 5th IPCC Assessment Report on Climate Change

Professor Paul Valdes, University of Bristol (Chair of session 1)
Prof. Paul Valdes is Professor of Physical Geography and Head of the School of Geographical Sciences. He is an internationally recognized researcher on modelling Earth system change. He has published more than 120 peer-reviewed papers on various aspects of past, present, and future climate change. A few highlights of his research include: (a) the first ever high resolution model integration for the Last Glacial Maximum, (b) Calculation of the global climate response to Amazonian Deforestation, and (c) Documentation of the ability of climate models in simulating storm tracks in present and past climates. He led the team that developed the GENIE model, and leads several large national projects and consortia on climate change.

He is also non-executive director of Greenstone Carbon Management. In 2007, he won a Royal Society Wolfson Merit Award for his work on climate change.

Dr Naomi Vaughan, University of East Anglia, (Speaker)
Naomi Vaughan is a researcher at the Tyndall Centre for Climate Change Research at the University of East Anglia. She studied Geography at the University of Edinburgh and gained her PhD at the School of Environmental Sciences, UEA. The focus of her research is the relationships and interactions between geoengineering and climate change mitigation (the reduction of man-made CO_2 emissions) over a multi-centennial timescale. She is the project manager for a major new EPRSC/NERC project, Integrated Assessment of Geoengineering Proposals (IAGP), which aims to construct and populate an assessment framework for geoengineering interventions, incorporating climate modelling and public and stakeholder engagement.

Professor Andrew Watson FRS, University of East Anglia (Speaker)
Andrew Watson is a Royal Society Research Professor at the School of Environmental Sciences at the University of East Anglia, appointed to that position as part of the Royal Society's 350th anniversary. He researches the global carbon cycle, and the processes that ffect Earth's atmospheric carbon dioxide, both through earth history and on the modern, human-disturbed planet. He studied planetary atmospheres at the University of Michigan, before returning to the UK and working at the Plymouth Marine Laboratory, where he developed tracer techniques that enabled large scale ocean experiments to study mixing, gas exchange, and the role of iron as a limiting nutrient. He is a Fellow of the Royal Society, a member of NERC council, and recipient of the European Geophysical Union's Nansen medal for achievements in marine science.

Dr Matthew Watson, University of Bristol (Speaker)
Matthew Watson has worked in Earth Observation for for fifteen years, using a range of ground- and satellite-based techniques targeted at emissions from active volcanism. He moved to the University of Bristol in 2004 from a research position at Michigan Technological University, following a PhD at Cambridge. He served the UK Govt. as part of SAGE (Scientific Advisory Group for Emergencies) during the recent volcanic ash crisis. Dr. Watson is the principle investigator of the SPICE project, a recently funded EPSRC/NERC/STFC supported effort to investigate the possibility of deliberately injecting highly reflective material into the lower stratosphere to manage incoming solar radiation. Explosive volcanic emissions, such as those from Mt. Pinatubo, provide a benchmark for research into controlling climate.

Professor Robert Watson, Department for Environment, Food & Rural Affairs (Speaker)
Professor Watson's career has evolved from research scientist at the Jet Propulsion Laboratory: California Institute of Technology, to a US Federal Government programs manager/director at the National Aeronautics and Space Administration (NASA), to a scientific/policy advisor in the US Office of Science and Technology Policy (OSTP), White House, to a scientific advisor, manager and chief scientist at the World Bank, to a Chair of Environmental Sciences at the University of East Anglia, the Director for Strategic Direction for the Tyndall centre, and Chief Scientific Advisor to the UK Department for Environment, Food and Rural Affairs. In parallel to his formal positions he has chaired, co-chaired or directed international scientific, technical and economic assessments of stratospheric ozone depletion, biodiversity/ecosystems (the GBA and MA), climate change (IPCC) and agricultural S&T (IAASTD). Professor Watson's areas of expertise include managing and coordinating national and international environmental programmes, research programmes and assessments; establishing science and environmental policies - specifically advising governments and civil society on the policy implications of scientific information and policy options for action; and communicating scientific, technical and economic information to policymakers. During the last twenty years he has received numerous national and international awards recognising his contributions to science and the science-policy interface, including in 2003 - Honorary "Companion of the Order of Saint Michael and Saint George" from the United Kingdom.

EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

Participant List

Title	First Name	Surname	Organisation
Mr	David	Addison	Imperial College London / Virgin Earth Challenge
Dr	John	Allen	National Oceanography Centre
Mr	Rudy	Andria	
Mr	Ben	Aspland	University of Sussex
Dr	Chris	Baker	NERC
Ms	Bernadett	Baracskai	University College London
Dr	Robert	Basto	
Dr	David	Becerra Alonso	ETEA - Cordoba
Mr	Robert	Bellamy	University of East Anglia
Mrs	Melanie	Bennet	University of East Anglia
	Lindsay	Billsborrow	University of Nottingham
Dr	Olivier	Boucher	Met Office
Mr	Kevin	Bourne	Project Hidasta
Dr	Peter	Braesicke	NCAS, University of Cambridge
Ms	Diana	Bronson	ETC Group
	Peter	Challenor	National Oceanography Centre, Southampton
Mr	Andy	Chalmers	DECC
Dr	Andrew	Charlton-Perez	University of Reading
Dr	Peter	Chester	
Mr	Robert	Chris	Open University
	Bo	Christiansen	Danish Meteorological Institute
Dr	Jolene	Cook	Department of Energy and Climate Change
Dr	Adam	Corner	Cardiff University
Dr	David	Cotton	Writer
Dr	Faith	Culshaw	Natural Environment Research Council
Mr	Timothy	Currie	University Of Minnesota -- Geography
Mrs	Paula	Curvelo	Joint Research Centre, European Commission
Professor	Richard	Darton	University of Oxford
Mr	Peter	Davidson	Davidson Technology
	Erin	Dawkins	
	Jennie	Dean	US Navy
Mr	Leon	Dimarco	FSK Technology Research
Dr	Rebecca	Ellis	Lancaster Environment Centre
Dr	Michelle	Felton	University of Bristol

Ms	Amy	Fensome	
Mr	Angus	Ferraro	University of Reading
Professor	Piers	Forster	Uni Leeds
Dr	Tim	Fox	Institution of Mechanical Engineers
Mr	Jeff	Francis	Sound Experience Ltd
Professor	Pierre	Friedlingstein	University of Exeter
Dr	Alan	Gadian	NCAS, University of Leeds
Miss	Maia	Galarraga	Lancaster University
Ms	Natalia	Galin	Center for Polar Observation and Modelling, UCL
	Barbara	Girelli-Kent	
Dr	Colin	Goldblatt	University of Washington
Mr	John	Gorman	
Mrs	Susan	Grayeff	The Technion
	John	Griffiths	
Mr	Matthew	Gross	University of Sussex
Professor	Geoffrey	Hamer	Biofocus Foundation
Mr	Ben	Hargreaves	Professional Engineering magazine
	Rachel	Hauser	National Center for Atmospheric Research
Mr	Peter	Healey	InSIS, University of Oxford
Miss	Kimberly	Henderson	
Mme	Claire	Henrion	ACSEIPICA
Dr	Eleanor	Highwood	University of Reading
Miss	Laura	Hood	Research Fortnight magazine
Dr	Philip	Hopley	Birkbeck College London
Mr	Ivan	Horne	Royal Archaeaological Society
Mr	Mark	Hull	Maney
Mr	Peter	Irvine	University of Bristol
Dr	Andrew	Jarvis	Lancaster University
Miss	Annabel	Jenkins	University of Leeds
Mr	Andrew	Johnson	
	Sanna	Joronen	University of Turku
Dr	Ron	Kahana	BRIDGE, University of Bristol
Dr	Liz	Kalaugher	environmentalresearchweb
	Henrik	Karlsson	Biorecro
	Gergely	Kecskes	
Dr	Boris	Kelly-Gerreyn	National Oceanography Centre, Southampton
Ms	Min Sun	Kim	
Miss	Robyn	Kimber	Virgin Earth Challenge
Mr	Peter	Kirby-Harris	Queen Mary College, University of London

Mr	Yury	Kirdyushkin	
Dr	Jan Ole	Kiso	Department of Energy and Climate Change
Mr	Mike	Koefman	Campaign for a Hydrogen Economy
Mr	D. Dennis	Konadu	Lancaster University
Mr	Torsten	Kowal	ClimAdaptAbility
Mr	Tim	Kruger	Oxford Geoengineering
MR	Scott	Laczay	
Dr	Heike	Langenberg	Nature Geoscience
	Steve	Larter FRS	University of Calgary
Ms	Beth	Lawrence	
Mr	Jonathan	Leake	The Sunday Times
Professor	David	Lee	
	Lena	Lee	DfT
Professor	Tim	Lenton	University of East Anglia
Mr	Andrew	Lockley	
Dr	Jane	Long	LLNL
Dr	Alex	Lubansky	University of Oxford
Mr	Ian	MacKinlay	Retired
Mr	Carman	Mak	University of Cambridge
Mr	Bhaskar	Mallimadugula	Kadambari Consultants Pvt Ltd
	Rosaleen	McDonnell	University of Leeds
Mr	Seann	McKibbin	Research School of Earth Sciences, Australian National University
Mr	John	Meakin	Financial consultant
	Saskia	Messager	
Mr	George	Meyrick	EEBS Ltd
Dr	Joseph	Milton	City University, London
Professor	Marilyn	Monk	Institute of Child Health
Professor	M. Granger	Morgan	Carnegie Mellon University
Mr	Oliver	Morton	The Economist
Dr	Jerome	Moulin	Defra
Mrs	Anita	Muzumdar	Accompanying my husband, Dr. Ashok Muzumdar, who is vision impaired
Dr	Ashok	Muzumdar	Canadian Medical Association
Professor	Richard	Nelmes FRS	University of Edinburgh
Miss	Eloisa	Noble	BBC Science
Miss	Rebecca	Owen	Future Science Group
Mr	Robert	Palgrave	
Dr	Karen	Parkhill	Cardiff University

Mr	Fred	Pearce	Freelance for New Scientist magazine
	Josefina	Perea Diaz	University of W?rzburg
Mr	Edward	Pitt	Student, Oxford University
Mr	Tom	Powell	University of East Anglia
Dr	Fabio	Pulizzi	Nature Publishing Group
Dr	Vivienne	Raper	
Mr	Jesse	Reynolds	University of Tilburg
	Katharine	Ricke	Carnegie Mellon University
Dr	Ruben	Rodriguez De Leon	MMU
Mr	Peter	Russell	
Mrs	Jenny	Russell FRAS	
Professor	Stephen	Salter	University of Edinburgh
Ms	Janine	Sargoni	University of Bristol
	Klaus	Schafler	
Dr	Andreas	Schellenberger	Federal Office for the Environment FOEN, CH
Dr	Jacob	Schneider	University of York
Miss	Catherine	Scott	School of Earth and Environment, University of Leeds
Dr	Chris	Sear	DECC
Mr	Daniel	Seddon	Accenture Climate Change Practice
Mr	David	Sevier	Carbon Cycle
Dr	Kevin	Smith	Science & Technology Facilities Council
Dr	Denise	Smythe-Wright	NOC
Mrs	Susana	Soares	LSBU
Mr	Matt	Spencer	Goldsmiths
Professor	Meric	Srokosz	National Oceanography Centre
Miss	Courtney	St. John	U.S. Navy Task Force Climate Change
Mr	Graham	Stevens	
Professor	Iain	Stewart	University of Plymouth
Dr	Masahiro	Sugiyama	Central Research Institute of Electric Power Industry (Japan)
Dr	Bronislaw	Szerszynski	Lancaster University
Mr	Andrew	Taylor	Land-Atmosphere Resilience Initiative
Mr	Clive	Taylor	FAST
Mr	Richard	Tebboth	Tennoevaeshn
	Neale	Thomas	fred.ltd
Ms	Erica	Thompson	Grantham Institute for Climate Change, Imperial College
Ms	Dominique	Thronicker	University of Stirling
Sir	Crispin	Tickell	

Professor	Martin	Todd	University of Sussex
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Mr	Chris	Vernon	University of Bristol
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Miss	Jo	Wheeler	Freewheel Productions Ltd
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	Thilo	Wiertz	Department of Geography, University of Heidelberg
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Dr	Phillip	Williamson	NERC/Univ of East Anglia
Miss	Jayne	Windeatt	University of Leeds
Dr	Richard	Wood	Met Office/NERC
Mr	Simon	Woolley	Winchester College
Dr	Kathryn	Yusoff	University of Exeter

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