NATURAL ENVIRONMENT RESEARCH COUNCIL

Science Theme Reports
NERC Strategy 2007 – 2012
Next Generation Science for Planet Earth

Climate System
November 2007

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Science Theme Report

Climate Systems

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Climate System

Improving predictions, reducing and quantifying uncertainty

1. Introduction

1.1 This report

Theme reports are the core of NERC Science and Innovation Strategy, which sits within the overall strategy for 2007 – 2012 *Next Generation Science for Planet Earth*. The Reports are the culmination of consultation, advice and decision-making that took place over 2006 and 2007. They are working documents that provide the basis for implementation, informing Theme Action Plans. The NERC strategy document contains a summary of the information in the reports. The overall development process for the Climate System theme report is summarised below:

In November 2005 NERC Council identified seven strategic science themes, and a strategy development panel was set up for each theme. The panels' role was to recommend to NERC's Science and Innovation Strategy Board (SISB) NERC's future research priorities within each theme. The Climate System panel met on 22-23 May 2006.

Each panel prepared a report following a common format that was presented to SISB on 11-12 July 2006. At this meeting SISB provided its initial view on the relative priority of the challenges identified within each theme.

Following the SISB meeting some of the panel reports were updated. The conclusions from the SISB discussion together with a response from the panel chair were appended to panel reports and presented to Council on 26 - 27 September 2006. The report was further updated following the discussions at both SISB and Council to reflect the overall priorities agreed at Council for this theme.

A draft NERC Strategy Document was developed from the panel reports and opened to public consultation on February – April 2007. A final version of the Strategy, incorporating recommendations from the consultation, was approved by Council in June 2007 and published in November 2007. In October 2007 the theme reports were updated to reflect this evolution of the strategy document.

1.2 Background

The impacts of changing climate pose the biggest challenge facing humans this century. The decisions that are made must be based on the best possible science. Global human forcing from carbon dioxide and other pollution will lead to regional short range impacts which will cause global and long-term changes in human activity.

1.3 Scope of Theme

The climate system theme comprises those aspects of the Earth System that contribute to climate or are influenced directly by it. The science core has in the past been that of the physical system, but the interactions with the biological and chemical systems are increasingly seen as central in the development of climate and to be fundamental in its impacts. The notion of climate change prediction and the forecasting of daily to seasonal weather as being two quite separate endeavours is starting to disappear and is being replaced by that of the seamless prediction problem from weeks to centuries. Natural climate variability occurs on all time scales and the predictions of most importance for society will be for a rich combination of variability and change.

1.4 Key Drivers

Two key drivers have been identified:

(i) Treasury challenge 5:
"Increasing pressures on natural resources and global climate from rapid economic and population growth in the developing world and sustained demand for fossil fuels in advanced economies."

This challenge states clearly the necessity for more knowledge on and better projection[1] of the influence of human activity on the climate system. The recognition implicit in it is that the real challenge is two-way, crucially including the need for improved knowledge on, and projection of, the impacts on society of the changing climate. These advances will form the basis for UK and global adaptation to climate change. They are also needed to provide a firm basis for UK and other policy makers to consider the mitigation of climate change, and in particular take part in the post-Kyoto negotiations. At the current time the deficiencies in knowledge and in model simulations on even the largest scales highlight the extent of this challenge, but significant progress is possible.

(ii) Importance to society of projections and predictions of climate system on time scales from weeks to centuries and from global to local scales.

This driver would be present even in the absence of the human impact on climate. In developed countries public decision-making would be improved, and business opportunities would be raised and threats diminished if such predictions were available over the range of time and space scales. In developing countries the vulnerability would be diminished and the development opportunities enhanced, as increasingly recognised by DFID. The models would need to be evaluated by confrontation with observations and calibrated in their performance. Uncertainty would need to be handled explicitly and communicated as an integral part of the predictions. The UK would gain benefit in its international relationships because of the intellectual and practical leadership it provided.

[1] predictions based on scenarios of human activity, particularly emissions

2 Key Outcomes

The key outcomes can be seen in the context of the two key drivers identified above:

- The scientific basis for policy and negotiations on the mitigation of climate change;
- Enhancing the safety and well-being of people in the UK and wider;
- Providing the basis for mitigation strategies or adaptation to climate variability and change, so increasing the resilience and decreasing the vulnerability of societies, particularly in developing countries;
- Raising the international profile of the UK;
- Increasing public confidence in climate information through scientific handling and good communication of uncertainty;
- Optimising the opportunities for and minimising the risks to UK businesses.

3 The Science Challenges

The agenda for Climate System science is shifting dramatically. In the past on the one side there were a limited number of climate projections for globally averaged surface temperature aimed at determining the need to mitigate climate change, and on the other side there was weather forecasting, perhaps up to a season ahead. In future, with a background of human influence on climate but also acknowledging the importance of natural variability, there will be predictions from days to decades of climate on a regional and local scale with potential value to a wide variety of users. These will include planners in government and industry, and those in UK businesses keen to seek competitive advantage. The necessary trustworthiness of the predictions will be a function of the strength of the scientific basis on which they are built, and their use depends on the existence of a body of scientific expertise.

Eight science challenges have been identified. These are:

1. Develop high resolution regional predictions for decision making;
2. Enable society to develop mitigation and adaptation strategies through climate science;
3. Improve and expand observations to validate climate change detection and prediction;
4. Increase knowledge of the physical, chemical and biological feedback processes;
5. Improve understanding and modelling of key processes determining the sensitivity of the climate system;
6. Improve understanding of natural variability and the link with climate change;
7. Improve understanding of the changing water cycle and how it will affect water availability and quality ;
8. Increase knowledge of the role of the polar and tundra regions in the global climate system.

Council’s view is that the eight challenges identified by the panel should be viewed as components of a single ‘grand challenge’. Challenge 1 represents the development of the next climate prediction system. Challenges 3 – 8 (not in priority order) represent the necessary fundamental science to achieve this. Challenge 2 represents two-way interactions with users to realise the potential value of predictions.

The eight specific climate system science challenges that have emerged are:

3.1 Challenge 1: Develop high resolution regional predictions for decision-making

The nature of the challenge
Decision-making requires prediction of climate statistics on regional scales and on a range of time-scales from days to centuries. This contrasts with the focus until now on mean fields, planetary scales, and either long period climate change or seasonal forecasts. The challenge is to meet the decision makers' needs whilst not compromising the science**.**

The importance of the challenge
Increasing computer power and knowledge of the climate system encapsulated in more fully developed and tested models give the possibility of performing climate prediction on regional scales and over periods from days to centuries. Along with detailed handling of the uncertainty in the predictions this will enable impacts to be determined and decisions to be made, based on predictions for a range of scenarios for human activity, these usually being performed by the Hadley Centre.

NERC contribution
- Basic work on methodology and techniques;
- High resolution modelling;
- New climate system model components and improved processes;
- Confronting models with observations;
- Exploiting super-computers;
- Climate system data assimilation techniques.

Contribution of others
- Hadley Centre climate model and knowledge in the context of a joint strategy;
- ECMWF seasonal forecasting collaboration;
- Observation datasets for validation testing: NASA, ESA, EUMETSAT, Argo;
- Palaeo-datasets: NOAA, PAGES, CLIVAR and natural archives;
- International collaboration through WCRP and use of IPCC data sets.

Deliverables
- Crucial tool for decision/policy making (mitigation and adaptation):
- More confident predictions at regional and local scale providing improved driving data for off-line impacts models;
- Techniques for handling uncertainty, and the communication of these;
- More accuracy and better appreciation of limitations of predictions;
- Model evaluated against observations on many time and space scales;
- Development of high resolution models;
- Balance of needs of complexity, resolution and uncertainty modelling;
- Assessment of impact of climate variation on pollution;
- Maintenance of UK leadership in high-end climate modelling;
- Optimal use of national super-computing facilities.

3.2 Challenge 2: Enable society to develop mitigation and adaptation strategies through climate science

The nature of the challenge

Climate variability and change have important consequences for society through their impacts on environmental goods and services and accordingly human welfare and economic development. Key to enabling society to develop adaptation and mitigation strategies to climate change and sea level rise is to improve the quality, timeliness and value of climate information for management and planning.

The importance of the challenge

Robust information on climate variability and change and quantification of local and regional impacts are prerequisites for evidenced based policy aimed at reducing vulnerability, improving risk management and increasing the resilience of society. The challenge is particularly important in the context of international development, reconciling the challenges posed by climate change with the Millennium Development Goals.

NERC contribution

- Scientifically based use of global and regional climate model methods;
- Impacts models based on statistical and process based models;

The development of Integrated Assessment models linking climate change models with models from other sectors (e.g. economics, transport, agriculture, biodiversity) within a decision making context;

- The development of interdisciplinary links between the natural sciences and the social, medical and physical/engineering sciences to improve the transfer and use made of climate information.

Contribution of others

- GCM and regional (PRECIS) outputs from Hadley Centre;
- Stakeholder partnerships through UKCIP and other stakeholder groups (e.g. DFID);
- International partnerships in the development of models and impacts studies;
- Co-delivery of adaptation and mitigation strategies;
- Engagement with British Council education and training initiatives;
- Possible links with SARCOF, GARCOF, PRESAO on regional climate outlooks.

Deliverables

- Basis for informed/evidence-based development policy and assessment of "dangerous" in the context of the UN Framework Convention on Climate Change;
- Quantification of how changes in population, energy use and transport may impact on global greenhouse gas emissions;
- Provision of detailed regional assessments on intra-seasonal to multi-decadal time scales of climate change and variability and its impact;
- Integrated assessment models that couple quantification of the impacts to GCMs through regional evaluation of model systems.
- Capacity building and enhanced UK relationship with developing countries.

3.3 Challenge 3: Improve and expand observations to validate climate change detection and prediction

The nature of the challenge
Observations are critically required for monitoring climate, confronting and evaluating models, and providing the initial state for prediction of climate variability and change. Ultimately, the quality of climate change prediction relies on our ability to accurately observe changes that are taking and have taken place in the real world.

The importance of the challenge
Observational systems must be optimally designed, developed and implemented to meet the needs of specific climate issues (including spatial and temporal resolutions, sampling and scale size, and accuracy). The scope includes the full spatial (remote sensing from satellite, aircraft and surface and in situ) and temporal (palaeo to real-time) ranges of measurements.

To achieve decadal scale observational data sets to test and challenge theory and models, we need to address:

- Defining key climate parameters to monitor;
- Early warning of sudden events;
- Process studies;
- Data assimilation techniques and initialisation of model runs;
- Validation of models and measurements;
- Optimised observation systems.

NERC contribution

- Within the international context, take responsibility for specific observational systems, instruments and data;
- Nationally, promote joined-up working with other potential funding partners and make data accessible to wider climate community;
- Production and analysis of observational evidence of palaeo-climates suitable for challenging climate models and understanding;
- Develop climate system data assimilation techniques for use at operational centres.

Contribution of others
USA, Europe and others will provide satellite instruments and data segments in collaboration.
WCRP and IGBP will provide the collaborative context for the research.

Deliverables

- High quality, calibrated and validated data sets for scientists to use with confidence;
- Defined scales of seasonal to decadal variability in key climate parameters, e.g. Atlantic Meridional Overturning Circulation, Earth radiation budget;
- Confronted and tested advanced climate models, validated/calibrated with data over long time scales to develop an effective predictive capability;
- Data available to wide user community;
- Data mining, visualisation and data assimilation techniques.

3.4 Challenge 4: Increase knowledge of the physical, chemical and biological feedback processes

The nature of the challenge
To quantify the feedbacks between chemical process in the atmosphere and ocean and biological processes in the terrestrial and ocean biosphere and to understand how they change as climate changes.

The importance of the challenge
Radiative forcing of climate depends on changing atmospheric composition which itself depends on complex chemical processes in the atmosphere. Carbon dioxide and volatile organic compounds (VOCs) play major roles. Anthropogenic emissions are expected to increase, which would affect atmospheric composition of greenhouse gases and aerosols as well as oceanic chemistry (e.g. pH and carbonate ion concentration through uptake of CO_2). The largest contribution to the present-day flux of VOCs is biogenic and this contribution is expected to change as climate (surface temperature, wind stress, surface moisture) changes. Emissions of gases and particles from the ocean are also very important for atmospheric composition and are climate dependent and will also depend on changing ocean chemistry and its impact on the biological and biogeochemical processes and feedbacks to climate.

NERC contribution
Field data; process studies and modelling; global modelling (including SOLAS, QUEST components, APPRAISE).

Contribution of others
International collaboration through IGBP and WCRP. Use of satellite data: ENVISAT.
Deliverables

- Improved knowledge of:
  - VOC, halogen and DMS emissions from the ocean and land surfaces;
  - Impact of decreasing ocean pH and carbonate ion concentration on marine ecosystems and feedbacks to climate;
  - Impact of the emissions on both oxidising capacity and climate;
- Contribution of new components to climate/Earth system models;
- Opportunity for development of and creative use of new technology.

3.5 Challenge 5: Improve understanding and modelling of key processes determining the sensitivity of the climate system

The nature of the challenge
Our knowledge of many key processes that determine the climate's response to greenhouse forcing is still very poor, and this directly degrades the accuracy of climate predictions using models. Examples include the representation of clouds and their effect on the radiative balance; the influence of aerosols and composition on climate; and the controls on sea-ice distribution, oceanic heat uptake and carbon dioxide uptake by the oceans and land. Many of the processes are linked together by feedback loops which may either enhance future climatic instability or act to oppose the effects of greenhouse gas and other changes.

The importance of the challenge
For a doubling of atmospheric carbon dioxide, the predicted change in globally averaged temperature has remained between 1.5 to 4.5°C for the past 20 years, despite improvements in our understanding of the basic processes at play. This is unacceptable: the wide range of

uncertainty in the crudest measure of climate change must be reduced. This can only be achieved if the models making the predictions have improved representations of the basic processes and feedbacks.

NERC contribution

- Advancement of knowledge of key processes and feedbacks through observational and process studies;
- Encapsulation of advances in knowledge in climate models.

Contribution of others

Hadley and other centres - model comparisons. Collaboration through WCRP

Deliverables

- Improved physical description of key physical processes
- More accurate models, both high level (NERC/Hadley Centre Global Climate Model) and fast “toy” models for specific studies;
- Rigorous application of Met Office coding standards to NERC process-based science;
- Dramatically refined (the often-quoted) IPCC sensitivity range.

3.6 Challenge 6: Improve understanding of natural variability and the link with climate change

The nature of the challenge

How and why climate varies through phenomena such as the El Niño and the North Atlantic Oscillation (NAO), even in the absence of any changing anthropogenic factors, is a fundamental issue in climate science. Climate variability and climate change are intimately related, and establishing how natural modes of climate variability may respond to climate change poses a major research challenge. Many of the feedback processes that govern climate variability also influence the climate response to external forcing.

The importance of the challenge

El Niño, NAO and other internal climate variations can have dramatic effects on local weather and have large socio-economic impacts, and the most important impacts of climate change are likely to be associated with the changing statistics or nature of this variability. Increasing knowledge about internal climate variability and the sensitivity of its statistics to a changing ambient climate is a pre-requisite if recent progress in seasonal and longer-term climate prediction is to be sustained.

NERC contribution

- Increasing knowledge of the modes of natural variability: identify new ones; understand current ones;
- Process studies: ocean/atmospheric processes – composition changes;
- Observation: record must be long enough to detect natural variability.

Contribution of others

- Hadley Centre to lead on operational prediction;
- International collaboration through WCRP-CLIVAR;
- International links – e.g. India, tropics where the impact would be greatest;
- Global observations, including from ESA.

Deliverables

- Better representation of natural variability in climate models and increased ability to handle prediction from weeks to centuries;
- Improved prediction of regional climate, e.g. effects on: El Niño, monsoon, NAO.

3.7 Challenge 7: Improve understanding of the changing water cycle and how it will affect water availability and quality

The nature of the challenge

The availability of water is fundamental for all plant, animal and marine life and it plays a crucial role in the carbon and nitrogen cycles. The cycle of water also lies at the heart of the climate system and there is evidence that it is changing. The challenge is to obtain confidence in the nature of this change and the implications of it.

The importance of the challenge

The current hypothesis is that the global water cycle will become more active, but it is, arguably, the major source of uncertainty in climate prediction on all timescales. Changes in the distribution of precipitation are major drivers of climate variability and predictability through global teleconnections. Key related issues for climate include:

- Strength and variability of the global and regional water cycle in a warmer world;
- Freshwater forcing and salinity budget of the global oceans;
- Terrestrial ecosystems and their dependence on water availability; and
- Fate of polar ice caps and glaciers with consequent sea level rise.

Water availability and water quality will have major implications, societally, economically and politically, in the coming decades so that the ability to predict them is of great importance.

NERC contribution

- High resolution climate modelling (HiGEM-type work);
- Observations: run-off datasets, satellite Argo ocean profiles, aircraft measurements of greenhouse absorption;
- Process modelling: JULES; cloud resolving; radiative transfer model; vegetation, ocean and atmosphere modelling, ice modelling.

Contribution of others

- Satellite data from various agencies and international collaboration through WCRP;
- Models from the Met Office/Hadley Centre.

Deliverables

- Basic knowledge of water through the climate system;
- Reduced uncertainty in regional rainfall associated with variability and change;
- Better parameterised moist processes in models, validated against observations;
- Seasonal/inter-annual variability, and linked to raised greenhouse gases.

3.8 Challenge 8: Increase knowledge of role of the polar and tundra regions in the global climate system

The nature of the challenge
The Arctic and the Antarctic Peninsula appear to be the regions on the planet most sensitive to anthropogenically induced climate change. The Arctic is known to be undergoing marked change with clear evidence of reductions in sea ice, permafrost melt and accelerated melting of the Greenland ice cap. There has been significant warming to west coast of the Antarctic peninsula with associated reductions in ice cover. Understanding the drivers of these changes and their relationship to natural variability and increasing levels greenhouse gas concentrations is of fundamental importance

The importance of the challenge
The current changes in Arctic climate are clearly impacting on the indigenous peoples of the Arctic, already under pressure from globalization. New opportunities may open (e.g. the Northern Sea Route) but melting of permafrost threatens human infrastructure throughout the region and melting of sea ice threatens flora and fauna, including large mammals and fish stocks. Arctic ice melt, including melting of the Greenland ice sheet, may fundamentally change the nature of the global ocean circulation through its effects on the freshwater balance of North Atlantic with drastic consequences for climate, markedly impacting society. The Southern ocean is a significant sink for both heat and carbon dioxide, acting as a buffer against human induced climate change which could be affected by rising temperatures. The formation of sea ice in the Antarctic drives deep ocean currents that carry heat around the globe. Increased loss of ice from the Antarctic ice sheet could have major impacts on global sea levels. Reliable assessment of polar climate change and its links to global climate and development of potential impacts and mitigation and adaptation strategies in relation to polar change is a key societal priority.

NERC contribution
- Provision of a national capability for polar science to carry out both research and long term monitoring;
- Combined use of remotely-sensed data, in situ observations, process studies and modelling to understand and quantify the nature of polar change;
- Development of improved models of sea ice, the Greenland ice sheet, the land surface (including permafrost), Arctic clouds and radiation for application in coupled climate models;
- Development of improved models to predict the loss of ice cover and the changes in snowfall in the polar regions resulting from climate variability and change;
- Quantifying the freshwater balance of the Arctic and its relationship to the wider Atlantic Ocean (links to RAPID);
- Predictions of the future state of the polar regions;
- Build on the legacy of the International Polar Year initiative;
- The issue of methane hydrates is covered within the Earth System Science theme – challenge 1b.

Contribution of others
- Coupled climate model outputs from the Hadley Centre and elsewhere; regional polar simulations;
- Remotely-sensed and in situ data from sustained networks; development of Global Ocean Observing System (GOOS); development of under-ice ocean profiling floats;
- International collaboration through World Climate Research Programme (WCRP) Climate and Cryosphere Project (CliC);

- Collaborative assessments of impacts of and studies of adaptation to Arctic Change through e.g ESRC.

Deliverables

- Better quantification of the nature of polar change and its relationship to climate variability and change;
- Improved representation/parameterisation of ice processes in coupled models;
- Reduced uncertainty in estimates of future polar change and its global consequences including sea level change;
- Delivery of more reliable scenario data for impact and adaptation studies;

4. Meeting the Challenges

The published NERC Strategy highlights some of the ways in which the NERC will be “Meeting the Challenges” for each Theme. These are essentially some of the potential key deliverables. They often cut across several of the Theme’s challenges. For consistency, we have included those for the Climate System theme below, against the challenges that they most strongly relate to. They are not exclusive and may evolve during the Strategy’s lifetime.

"Meeting the Challenges" (From NERC Strategy)	Climate System Challenges							
	1	2	3	4	5	6	7	8
Improve climate models so that they can address issues such as the probability of extreme events, regional storm frequency and more detailed prediction of water resources	X	X			X		X	
Improve understanding of how physical, biological and chemical systems interact to change the Earth's climate and how these processes can be represented in global and regional climate models	X			X	X		X	
Increase knowledge of natural climate variability and diagnose and improve its representation in climate models	X				X	X	X	
Provide accurate observations of the global climate system for long-term monitoring of climate to quantify changes and to test and evaluate climate models			X		X		X	
Quantify polar change and its global consequences, including the impact on sea levels, by improved observation and modelling	X	X			X		X	X
Increase knowledge of the scientific issues in meeting actual or proposed limits on greenhouse gas concentrations, including the role that poorly understood feedbacks may play in efforts to meet these targets	X	X		X				
Determine the likely interactions between climate change and air quality	X	X		X				
Construct integrated assessment models linking climate change with changes in economics, fuel sources, transport, agriculture and the natural world .	X	X						

5 Links and interface issues with the other themes

Climate system variability and change provides a context for all the other theme areas and there are significant linkages with the research proposed.

The strongest link is with the Earth System Science panel, where Earth System Science includes the larger broader aspects of the Earth System looking at the driving forces and feedbacks that drive the Earth System at the global scale (challenge 3). The Forewarning of abrupt changes in the Earth System (challenge 1) also has links with the Climate System theme.

Environment, Pollution and Human Health: The transport and transformation of pollutants (Ch. 2) is very strongly affected by climate, as are the human risks (Ch. 3).

Forecasting and Mitigation of Natural Hazards: Climate variability and change is fundamental to floods, droughts, storms, landslides, coastal flooding and erosion, heatwaves and wildfires.

Biodiversity: Climate is a crucial aspect of the changing environment that will affect biodiversity and ecosystems (Ch. 1b)

Sustainable Use of Natural Resources: climate variability and change gives the context for discussion of sustainable energy production, both “clean” fossil fuels (Ch. 1) and renewables (Ch. 2).

A cross cutting challenge has been identified within the Biodiversity (Ch. 5) and Sustainable Use of Natural Resources (Ch. 4) themes relating to tools to value the environment. Such tools could be applicable in assessing the impact of climate change on society.

6. Implications for the Science Base

In general a good climate system research capability exists in the UK. There is a continued need to build towards inter-disciplinary research on a strong foundation of the basic sciences. The loss of expertise in the satellite instrumentation area may have to be redressed. In areas such as model and instrument development it is necessary to produce funding mechanisms that take account of the long-term nature and reduced publication opportunities.

A climate system programme in NERC should recognise the longer-term nature of some of the research, again particularly in the model and observational areas.

The UK must create mechanisms for the transition of observational systems from research to operations and monitoring.

Integration of climate system research across NERC as well as between the research councils is needed.

The importance of international partners and of the context provided by the international programmes should be recognised.

Long-term strategies for high-end computing, observational systems and data management are required.

7. Synergies and partnerships

- A very strong need for a partnership with the Met Office/Hadley Centre;
- Government: DFID (capacity & development), DTI (energy & other business), DEFRA (climate, in the context of the MetO partnership, flooding & many other areas), BNSC;
- Other Research Councils: BBSRC (crops), EPSRC (statistics & modelling), ESRC/MRC (climate and society - health), UKERC (energy);
- Business: sponsorship and partnership;

- International: the Global Change Programmes, IPCC context, partnerships with developing countries, specific research partnerships (e.g. Earth simulator, Japan).

8. Knowledge

In the context of its partnership with the Met Office/ Hadley Centre, NERC's Climate Research should aim to achieve a higher profile as a source of advice for government, business and the public.

- Key challenge is to improve knowledge exchange within NERC;
- Better exchange of information is needed at the end of a project;
- Resources should be available to ensure effective knowledge exchange;
- Collaboration with industry: funding for knowledge exchange activities;
- Need for partnerships from the very beginning of an activity, throughout the life of a programme and beyond;
- EU – more involvement in the process of designing calls;
- Training: Strategic use of summer schools, and assess the need for relevant MSc courses;
- Knowledge exchange should be acknowledged by researchers and as research outputs.

9 Links and interfaces with organisational themes

Sections 7 and 8 above set out specific opportunities for partnerships and knowledge exchange within the Climate System theme. At a strategic level, these have been incorporated into the corresponding organisational themes of the NERC Strategy