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Coupled Ocean Atmosphere Processes
and European Climate

Final Report to the Natural Environment Research Council on the Coupled Ocean Atmosphere Processes and European Climate (COAPEC) Directed Programme

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I Introduction

The COAPEC (Coupled Ocean Atmosphere Processes and European Climate) Programme was a NERC directed programme that ran from 1999 – 2006.

The major objective of COAPEC was to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean on seasonal to decadal timescales. To achieve this over-arching objective COAPEC aimed to:

1. Understand the role of coupled processes in the climate system and improve the representation of these processes in models used for climate forecasting.
2. Assess climate predictability in the Atlantic/European sector and contribute to the development of a national capability in climate forecasting.
3. Train scientists in the interdisciplinary skills required for environmental modelling and prediction.
4. Facilitate the exploitation by users of COAPEC research.

These objectives were addressed by targeting 5 key questions:

1. What are the observed characteristics of seasonal-to-decadal climate variability in the Atlantic Sector?
2. How do the mean climate and climate variability in the Atlantic Sector simulated by a Coupled General Circulation Model differ from that observed? How do we correct model deficiencies?
3. What are the physical mechanisms that determine the mean climate and seasonal-to-decadal climate variability in the Atlantic Sector?
4. What processes determine the predictability of climate fluctuations in the Atlantic-European region?
5. How do we bridge the gap between scientific output and societal needs?

A requirement of achieving the programme objectives was to develop a community of researchers in the UK with expertise, not only in using the output from coupled climate models, but also able to run such models in order to investigate the climate system. In addition, the atmospheric and oceanographic research communities needed to work in close collaboration with each other, and with the relatively small community of experts in this field, including researchers at the Met Office Hadley Centre.

The processes investigated within the programme were clearly focussed on the seasonal-decadal time-scales, significantly longer than the time-scales of systems studied in traditional numerical weather prediction, but shorter than the time-scales normally considered by climate change research. These time-scales are highly relevant for policy and industrial decision making.

After the second round of awards had been made, an additional allocation was made to the programme by the NERC, with a specific objective of funding research that would contribute towards “New Observations in Support of COAPEC Science”.

2 Achieving the Scientific Objectives

The programme has made significant advances in our scientific understanding of the relationship between the atmosphere and the ocean and increased the UK science capacity in this important area of climate research. The programme made major advances in answering the 5 key questions, particularly in the field of coupled ocean-atmosphere modelling.

1. What are the observed characteristics of seasonal-to-decadal climate variability in the Atlantic Sector?

Answering this question must be considered fundamental to our understanding of the coupled ocean-atmosphere system. Several projects addressed aspects of this problem, and significant advances were made. Sinha *et al* investigated the eastward propagation of Sea Surface Temperature anomalies in the North Atlantic [63, 64] and showed how they could influence air temperature over western Europe. Work by Ambaum & Hoskins [5, 6] investigated the influence of the stratosphere on the coupled system, proposing alternative mechanisms for ‘long term memory’ in the climate system. Condron & Biggs showed how polar meso-cyclones, intense low-pressure systems, are under-represented in current reanalysis datasets such as ERA-40, by comparisons with satellite imagery. Leadbetter [81] carried out research investigating decadal changes in the ocean heat content in the North Atlantic, using both observational and model data sets. The Great Salinity Anomaly of the North Atlantic is an observed phenomenon that has been considered an advective feature. Work by Bigg *et al* [72, 73] has shown that similar features in coupled models cannot be explained by simple advection but require complex feedback mechanisms.

It should be noted, that these projects recognised a shortage of suitable long-term, consistent, global observational datasets to carry out the required analysis. This lack of data was recognised very early in the programme and was partially addressed by projects to improve the existing datasets of relevant parameters (notably surface fluxes [26, 41, 142-144] and sea-ice thickness) and also by funding of 15 ARGO floats to improve the spatial sampling of the array in the Southern Atlantic, necessary for future climate related research. The results of the ARGO project demonstrated that although advances in the determination of the variability of upper ocean properties was possible [54], even with the addition of these floats, there was insufficient data density in the South Atlantic to provide a significant improvement in the reference velocity estimates for the region.

2. How do the mean climate and climate variability in the Atlantic Sector simulated by a Coupled General Circulation Model differ from that observed? How do we correct model deficiencies?

The research in this area has shown that the Hadley Centre HadCM3 model is remarkably good at representing key aspects of the North Atlantic circulation. Many of the projects investigating the observed variability of parts of the coupled system also considered the representation of the same parts of the system in coupled models, either by diagnosis of control runs of the Hadley Centre’s HadCM3 model, or by carrying out more advanced model runs. Aspects of the system investigated included the propagation of surface anomalies [63, 64], the evolution of subsurface heat and salinity anomalies [27, 35, 53, 81] and the overturning circulation [59].

Investigation of where model deficiencies lie has followed several routes. One study highlighted errors in the simulation of “re-emerging” sea temperature anomalies, which are believed to play an important role in the seasonal predictability of European climate, and pointed to model developments that may be needed to improve the simulation of these

anomalies [35]. Comparisons between related coupled models has highlighted where the representation of the physics in the Hadley Centre Model could be improved. Sea ice modelling is a very complex part of the coupled climate system and “tuning” of model parameters to new observational data sets has taken place [49, 50]. Some of these developments are now being taken forward by the Hadley Centre, or through research undertaken in other NERC funded programmes, particularly RAPID. A new postdoctoral position jointly funded by NERC and the Met Office (details in Section 5.3) is working directly to pull-through the insights gained from COAPEC research to improve the climate models used for operational seasonal forecasting.

3. What are the physical mechanisms that determine the mean climate and seasonal-to-decadal climate variability in the Atlantic Sector?

Many projects addressed improving understanding of physical mechanisms, and the effect on climate simulations of changes in parameterisation of specific processes. Specific areas of focus for were: the role of ocean eddies [30-32, 36-38]; sea ice [60-62]; the formation, evolution and re-emergence of water mass anomalies [27, 35, 53]; the role of the stratosphere [5,6]; and the thermohaline circulation [57, 59]. Important new insights were gained into the heat budget of the coupled ocean-atmosphere system, and the role of heat transport variations in climate variability [57-59, 70].

Several projects specifically addressed the processes that control variability in sea surface temperatures, and the influence of sea surface temperature anomalies on climate. Investigations of the Tropical Atlantic Ocean showed that variability here is only partially attributable to ENSO activity in the Tropical Pacific [28, 29, 35]. Tropical Atlantic sea surface temperature anomalies were found to be triggered by extratropical wave trains generated over the Pacific, with those un-related to ENSO events leading to wind and warm/cold temperature anomalies over Europe. It was also demonstrated that SST anomalies in the Indian Ocean and in the Mediterranean Sea played an important role in the record hot European summer of 2003 [9,10].

Comparing the ocean circulation patterns in different coupled models, with different ocean physics, has provided insights into possible sources of errors in the current models [116-119]. This process is being continued in the RAPID programme model inter-comparison project.

4. What processes determine the predictability of climate fluctuations in the Atlantic-European region?

The programme was intended to improve future prediction of seasonal – decadal climate by operational centres such as the Hadley Centre and ECMWF. A necessary precursor to this is an assessment of the aspects of the climate system, particularly over Europe, which may be considered predictable. Oceanic heat anomalies were found to generate seasonal responses in the Atlantic area atmospheric circulation that were potentially predictable [9, 10, 25, 35], although it was shown that current forecast models have systematic errors that reduce model skill in actually forecasting such events [25, 35].

The decadal and longer term predictability of Atlantic Sector climate was also a significant focus. It was demonstrated that knowledge of oceanic initial conditions can lead to significant predictability of certain variables, such as the Atlantic overturning circulation, a decade or more ahead [13, 16-18, 20]. The uncertainty in predictions that arises from poorly known model parameters was also extensively explored and quantified within the ClimatePrediction.net project [4, 67].

5. How do we bridge the gap between scientific output and societal needs?

Although started before the formal requirement for knowledge transfer activities in directed programmes, this was identified as one of the primary questions for the programme to assess. Projects which focussed on working with end-users of climate forecast information were specifically targeted or funded in a dedicated call, in much the same way that NERC now has a dedicated Knowledge Transfer call for proposals. It was recognised after the first round of funding had been allocated that assessing these more application driven projects with the same criteria as used for blue-skies science was not appropriate. The projects selected had clearly identified end-user partners (e.g. National Grid) and were targeted at specific applications. These projects highlighted the gap in understanding between the majority of the climate science community and the end-users. Both projects worked hard with the respective users to fully understand their requirements and highlighted the necessity of close 2-way collaboration to gain the necessary level of understanding in the first instance. It was also clear that ‘standard’ climate forecast outputs were rarely of direct use to the end users, who had very specific requirements in terms of both products and timing or availability, not always obvious to outside users.

The *climateprediction.net* project [4, 66-67], which was partially funded by the COAPEC programme, aimed to test the concept of running full-climate-resolution atmosphere-ocean general circulation models using idle time on personal computers. COAPEC programme funding allowed the development of the initial model strategy and early development of the distributed computing code. *Climateprediction.net*, formerly the Casino-21 project, was launched to the general public on 12th September, 2003, attracting 25,000 participants within its opening week, of which over 15,000 remain actively engaged in the project. By the end of 2003, participants had simulated over 1 million model-years, which is more than could have been achieved on the Earth Simulator had it been fully dedicated to this project. One of the key aims of *climateprediction.net* is to dispel the mystery that surrounds climate modelling and prediction through direct public involvement in a front-line climate research project. The public awareness of this project has provided a very public “shop-window” to the kind of research carried on within the COAPEC programme.

This aspect of the programme was developed further during the Joint COAPEC / Met Office / ECMWF / NCAS workshop held towards the end of the programme (see §4.3).

In addition to answering these scientific questions, the COAPEC programme had key objectives in community building and knowledge transfer, and achievements in these areas will be detailed later in this report.

3 Programme Outputs

The main scientific outputs have been:

- peer-reviewed publications (see Appendix G)

- PhD Theses (see Appendix G)

- the availability of new coupled climate models for researchers (see §3.3 and Appendix J)

- the availability of output from the Hadley Centre coupled climate model for further research, including a control run on a beowulf cluster, more appropriate for comparisons with experiments run on other PC clusters (see §3.2)

- a number of major meetings and workshops addressing aspects of climate science (see §3.4)

- a Climate Model brochure (see Appendix H) and folder of programme highlights, suitable for public distribution

- key recommendations for the future development of coupled climate modelling in the UK (see Appendix I)

- a patent:

M Allen, University of Oxford: Method and system for producing a weather forecast/ Filed in the USA. A method of generating short-, medium-range and seasonal-timescale weather or climate forecasts by running an ensemble of computer models on a distributed computing system or network. Individual model integrations are interrogated to select those that most closely resemble observed conditions in the present and recent past and the forecast based on a weighted average of future predictions based on this subset of the ensemble. The selection criteria determining which models are deemed to fit the observations most closely may be adjusted to optimise the use of observations in forecasting specific climate variables or geographic regions in order to develop forecasts tailored to particular applications

3.1 Publications

A complete bibliography of published papers and PhDs awarded, as of March 2007, is provided in Appendix G. There is a further PhD thesis that should be finally submitted within the next few months. A special section of the Journal of Climate was dedicated to the COAPEC programme research, which contained a wide range of papers from across the COAPEC science projects. This gave high visibility to the programme in a widely recognised international journal.

The project highlights were published in an easily accessible format for the programme finale event. The resulting folder with a series of inserts is available from NERC publications.

The core team produced a brochure on “Climate Models: Tools for understanding the Earth System” (see Appendix H), to highlight the use of climate models as research tools. This brochure was initially developed as a stand-alone publication for the programme, but after discussions with NERC publicity, it was re-formatted to be published as part of the NERC briefing notes. This brochure was distributed to a wide mailing list, including Members of Parliament, members of NERC council and Science and Innovations Board, steering committee members of other directed programmes as well as many teachers and lecturers. There has been a very positive response, particularly from A-level and further educations

teachers, who are using the brochure as part of their courses. The Royal Society of Chemists is intending to include the brochure in their regular mailings to 6500 school science departments.

3.2 Data Accessibility

A major achievement of the COAPEC programme was access for all COAPEC researchers to the Hadley Centre's HadCM3 control run. Prior to the COAPEC programme, access to data from the Hadley Centre Coupled Climate Models was severely restricted. Only researchers working on contract to the Met Office had direct access to the control runs and even then it was difficult to retrieve the data. The COAPEC programme was developed with strong interaction with the Hadley Centre, members of the Hadley Centre being members of the scientific steering committee. Project investigators were strongly advised to collaborate with the Hadley Centre and most funded projects had a Co-Investigator from the Hadley Centre. This close cooperation led to access to the HadCM3 control run results. This 1000-year data set provides a significant resource for the UK climate community. These data were transferred to the British Atmospheric Data Centre, and have since been released to the wider scientific community. These data have proved a valuable resource in understanding the coupled climate system.

Data from a second control run, carried out by the COAPEC core team on the COAPEC Beowulf cluster, have also been made available to the UK climate community, and now form a key resource at the BADC. Whilst the Hadley centre control run is an important resource for researchers diagnosing the present climate, it has limitations when used as a control against which to compare results of perturbation experiments run using different architectures. The COAPEC run is more appropriate for this purpose.

The COAPEC programme also funded developments in visualising and extracting data at the BADC. This has allowed users, with little or no expertise in the use of Hadley Centre data, to access the data using simple web interfaces. This allows use of the data by a much broader swath of the community, reducing the time taken for researchers to start using the data.

Improving the reliability and accuracy of observational datasets was not initially a primary objective of the COAPEC programme, but at an early stage it was recognised that improved knowledge of the air-sea fluxes would be of significant benefit to the climate community. The SOC climatology, which underwent major improvement with funding from COAPEC, is now used extensively for model validation and climate studies worldwide.

3.3 Climate Model Developments

Development of climate models to investigate the coupled system was an integral part of the COAPEC programme. One IPCC class climate model, CHIME, has been developed as part of the programme, and is now being used within the RAPID programme model inter-comparisons project. Other models developed are given in Appendix J. These models are of varying complexity, with varying representation of the physics of the ocean and atmosphere, allowing investigation of a range of time-scales as well as ocean and atmosphere processes. These models are now available to the wider climate community and are being used to investigate a range of scientific questions.

In addition to developing new climate models, COAPEC successfully encouraged the deployment of the Hadley Centre HadCM3 model on PC (Beowulf) clusters. The support of the core team (discussed more fully later) was central to this development.

3.4 Climate Modelling Meetings

The programme ran annual science meetings for presentation of the latest results by all the project scientists. These events were all fully funded centrally by the programme. This encouraged all the relevant researchers – Principal Investigators, Co-Investigators, Post Doctoral researchers and students – to attend. These meetings were always planned to allow sufficient time for interaction between scientists to discuss further collaboration and encourage development of new ideas from the projects results. Invited keynote speakers from outside the programme highlighted specific areas of research giving a wider overview of the science field. The meetings encouraged development of the coupled climate community, including representatives of both the Met Office and ECMWF. An additional, student meeting was held to allow the students to discuss, and present, their research to an audience of peers, which was well received by the students.

For one year of the programme, the COAPEC researchers were funded to attend the Royal Meteorological Society's biennial conference. This was very successful in encouraging members of the oceanographic community to attend the meeting, which in turn encouraged collaboration and interaction between the atmospheric and oceanographic communities. It also increased visibility of the "coupled" research carried on within the programme. However, presentation to a wider audience meant that only the more advanced (earlier) projects were represented at the meeting and there was less opportunity for presentation and discussion of ongoing research, particularly for students.

When it was recognised that there was a need for workshops targeted at specific aspects of the programme, these were organised along similar lines to the annual meeting – centrally funded from the programme, with attendees not just from within the programme, but from across the community, including ECMWF and the Hadley Centre in particular. Feedback on these meetings was always positive and reports of the meetings, together with copies of the presentations where possible, are available from the COAPEC web site. These provide a useful resource for the wider community as well as the COAPEC researchers.

Specific training courses in climate modelling were also organised, as described in the training section below.

4 Other Achievements

4.1 Community Building

The COAPEC programme was very successful in generating a community of "coupled climate researchers". The UK climate modelling community now includes a greater number of scientists able to run, and analyse output from, climate models. This community has better internal communications and understanding of key issues, allowing the development of initiatives such as the National Centre for Ocean Forecasting. It is, in part, the development of this community and the communication that was engendered that led to the adoption of NEMO as a UK wide community ocean model. This is a very important development as it greatly facilitates the effective collaboration of ocean researchers in the NERC community, at the Met Office and Hadley Centre.

Prior to the start of the COAPEC programme, there was limited UK capability in coupled climate research. Only one or two centres had the capability to run coupled climate models and very few researchers had experience of analysing the output from such models. Building a community of researchers with the skills to analyse the output of climate models and the ability to design and run experiments using climate models was central to the aims of COAPEC. The analysis of data from climate models, especially when dealing specifically

with the coupled parts of the system, requires close collaboration between oceanographers and atmospheric scientists. These two communities were relatively disparate within the UK. As a consequence, there was less collaborative research carried out than the science would support. Many of the COAPEC funded projects included researchers from both the oceanographic and atmospheric sciences and many more collaborative links were formed during the programme. The COAPEC community is made up of both established oceanography and atmospheric science researchers, who have developed new expertise, and a significant number of “new” postdoctoral scientists.

The requirement for a large number of new researchers in this field has resulted in a larger pool of appropriately trained scientists. However, early in the programme this generated a serious strain on the recruitment market and many projects found difficulty in recruiting suitable staff, resulting in delays to the start of projects. In recognition of the shortage of scientists with appropriate training within the UK community, a relatively high proportion of the COAPEC budget was used for funding PhD studentships. This too led to difficulty in attracting sufficient students to fill the available studentships.

It is recommended that for research programmes directed at relatively small communities, staggering the start of research projects and studentships is considered to allow time to recruit the highest quality candidates.

4.2 Training

The Centre for Global Atmospheric Modelling (CGAM) at Reading (now NCAS) ran three training workshops for PhD students and postdoctoral researchers on how to configure and run the Met Office Unified Model (of which the Hadley Centre Coupled Climate Model is one version). These workshops proved a useful introduction to running coupled models for many of the Researchers and Students involved in COAPEC programme, with positive feedback from attendees. As the use of these models becomes more widespread, this training should continue to be encouraged and supported by NERC.

It is recommended that NERC continue to support the provision of training workshops for climate modelling through NCAS or other appropriate centres to continue to increase the UK climate modelling community.

In addition to these formal training opportunities, the COAPEC core team (see §6.2.2) provided a vital training resource for the community. The core team were able to provide support and training in a wide range of coupled modelling issues, including how to use HadCM3 data, porting the HadCM3 model to different architectures and developing new coupled climate models.

4.3 Knowledge Transfer

During the programme, in particular through the User Driven Science projects, it was recognised that there is a major role for the operational centres, such as the Met Office and ECMWF, in taking the ‘pure’ research carried out within NERC funded research projects and programmes, and using this to develop products and services more suited to the needs of end users. Researchers from the Met Office and ECMWF regularly attended the COAPEC annual science meetings and workshops, allowing direct interaction with these key centres. As part of a process to try and identify ways of improving the feed-through of NERC research into these centres, COAPEC ran a specific workshop, after the formal end of the programme. This workshop was endorsed by both the Met Office and ECMWF and had support at high level from both organisations. The executive summary and recommendations of the workshop are

given in Appendix I. These recommendations formed a major input informing the development of the new NERC strategy in the field of climate forecasting.

An additional outcome of discussions with the Met Office, was the joint funding of a knowledge transfer post in climate modelling. This post, joint funded by NERC (using a combination of the residual funds from COAPEC and Knowledge Transfer funds) and the Met Office, represents a major advance in collaboration and knowledge transfer between NERC and the Met Office.

5 Summary of Added Value Delivered by the Programme

- ∞ The development of a community of climate researchers with expertise in running and analysing the output from climate models. The community exists not just across NERC but, crucially, including the Met Office and ECMWF climate forecast centres.
- ∞ Central support and training from the COAPEC core team, providing a major resource for COAPEC researchers.
- ∞ Provision of HadCM3 data at the BADC, both from the Hadley Centre and the COAPEC core team, for the UK research community and development of data access tools to facilitate their use.
- ∞ Availability of a central PC (Beowulf) cluster for the COAPEC community, allowing students and researchers to carry out more extensive model investigations that initially envisioned.
- ∞ Opportunities to present and discuss current research at regular programme meetings, and workshops.
- ∞ Ability to target resources to more user directed science, through dedicated calls, assessed using slightly different criteria to those use for 'pure science' projects

6 Summary of the Programme structure and management

6.1 Management Structure

The COAPEC programme management had 4 key components. These components are listed below, and their key activities are explained in the following section.

Programme Steering Committee

Alan Thorpe (Chair: 1999 -2006), Rowan Sutton (Chair 2006-7), eight scientific members, one representative of the user community and one member from the social science community together with the programme science coordinator, programme coordinator and the atmospheric and marine directorate programme managers.

There were two ad-hoc sub-committees formed during the programme:

- a) User Group sub-committee for pre-assessing proposals to the “User Driven Science” AO
- b) Knowledge transfer sub-group to investigate appropriate activities for the end of the programme.

Both were formed for a single purpose and each met only once.

Programme Science coordinator

Dr Helen Snaith (NOCS). 50% from 2000-2005, 30% from May 2005-Dec 2006.

Programme coordinator and support at Swindon

Lisa Hole (1999-2000), Lesley Aspinall (2000-2004), Mark Ryan (2004), Lucy Ball (2004-2005), Helen Beadman (2005 – 2006) and Sally Reid (2006 -7).

Core Team

Bablu Sinha (NOCS, 2000 - 2005)

Matthew Collins (CGAM, Reading, 2000 - 2003)

Pierre Philippe Mathieu (CGAM, Reading, 2000 - 2003)

Alan Iwi (RAL, 2001 - 2005)

Emily Black (CGAM, Reading, 2003 - 2005)

6.2 Key Management Activities

6.2.1 Steering Committee, Programme Coordinator and Science Coordinator

The scientific objectives of the programme were set by the steering committee, which met up to three times per year over the first few years of the programme. Between formal meetings, email was used to extensively to communicate with the steering committee. The steering committee were responsible for deciding the timetable for Announcements of Opportunity, the programme budget and making recommendations to NERC for project funding.

The science coordinator and the programme coordinator carried out the ‘day-to-day’ management of the programme. This involved ensuring decisions made by the steering committee were carried out, ensuring projects were proceeding on-track and that support was provided where necessary. They were also responsible for organising meetings, both the science content and planning logistics.

Much of the activity of the science coordinator and programme coordinator was condensed into short periods of time, focussed around specific activities, such as announcements of opportunity, annual meetings etc. This meant that such activity had to be planned in advance, as other activities had to fit around these time periods.

The Science coordinator was also responsible for disseminations of information, both within the COAPEC community, and to the wider community. Much of the internal communication was carried out, on a day-to-day basis, using email. A subscription email list was setup at Southampton Oceanography Centre (now the National Oceanography Centre, Southampton – NOCS) to allow email to be sent to the entire community by any member of the list. This allowed easy contact with the group. Ideally, this email list would have been setup centrally at NERC, to give a clearer group “ownership”, eg coapec@nerc.ac.uk, but this was not possible. This could be considered for future programmes.

The science coordinator was also responsible for creating and maintaining the COAPEC web site. This site, coapec.nerc.ac.uk, is the first point of information for all programme documents (eg science plan), reports of meetings, publication lists, contact details etc. During the programme, the site was used extensively for information for the COAPEC community, as well as the wider community, with meeting registration pages, planning pages etc. This site should now be maintained, or the information transferred to a site where it can be maintained centrally, as it still contains useful information. As the science coordinator was directly responsible for the site content, it is physically located at NOCS, but the domain name is easily transferred to another location.

During the programme, the BADC operated a Shared Workspace for the COAPEC community to share information and documents. This workspace was useful for the core team and BADC to exchange information on the status of data accessible from the Hadley Centre, but was otherwise not extensively used.

6.2.2 The Core Team

The core team, led by the science coordinator, was a group of researchers with a dual role in carrying out climate research and providing support to the COAPEC community. Each member of the core team had 50% of their time allocated to “support activities” with the remaining 50% devoted to personal research activities in line with the programme objectives. Each core team member came under the line management of a member of the steering committee, allowing direct reporting on the core team to the steering committee. Each member of the core team had specific key roles;

- ∞ Bablu Sinha was key contact for ocean model development and model coupling, and later also for the Hadley Centre Coupled Climate Model.
- ∞ Matthew Collins was the primary contact for data and the Hadley Centre coupled climate model
- ∞ Pierre Philippe Mathieu was the key contact for seasonal climate forecasting
- ∞ Alan Iwi was responsible for porting models to alternate platforms and issues regarding running the Unified Model
- ∞ Emily Black was the principal contact for User Driven science

The core team personal research was not constrained by the requirements of a funded research programme, which allowed them to develop collaborations with several of the COAPEC researchers to develop aspects of the science that might otherwise have been difficult to follow up. Coming under the line management of members of the steering

committee also allowed direction of their research to areas where it was felt the programme as a whole needed additional resources.

6.2.3 Data Management

Data management was the responsibility of the full steering committee – there was no sub committee set up to have oversight of data management.

The COAPEC programme never realised a formal, agreed data management plan. As COAPEC was not envisioned as a data collection programme, this aspect of the programme was not as well developed as it should have been. This is agreed to be a failing of the programme. The programme did adhere to the overall aims of the NERC data policy. The draft data management plan is given in Appendix C, and was largely adhered to throughout the programme.

As COAPEC was not, primarily, a data collection programme, the major data management requirement was in making external data available to researchers. The British Atmospheric Data Centre (BADC) was funded to provide the required model datasets to the COAPEC programme via an addition to the Service Level Agreement between NERC and the BADC. The science coordinator worked with BADC to ensure delivery of the required data sets and data services.

Only a single project was funded to carry out data collection as part of the additional announcement of opportunity for “New Observations in Support of COAPEC Science” funding. This project provided funding for additional ARGO floats to be deployed in the South Atlantic. All data collected from these floats were covered under existing data agreements with the British Oceanographic Data Centre (BODC). All data collected from the COAPEC funded floats have been included in the global ARGO array data sets.

A data-scoping study was carried out by the COAPEC core team, and results were made available to the COAPEC community using the COAPEC web site and the CAST (Collaboratory for Atmospheric Science and Technology) provided by the BADC for COAPEC use. Reports on data formats and access were also created by both BADC and the COAPEC core team and made available for COAPEC researchers on both these web sites. The BADC held data were all catalogued and searchable on the BADC site.

An additional project at BADC was funded to support development of data access tools for the various model datasets available to the programme.

6.2.4 Project teams and projects

Management of the individual research projects was the responsibility of the project principal investigators. They had full financial responsibility for their own projects and were responsible for providing reporting – through the Output Measures systems in place and also through informal discussions with the science coordinator on progress and possible changes in science objectives. The regular science meetings and workshops organised as part of COAPEC enabled regular updates on project progress. Several projects changed their science objectives during the course of the programme, either for technical reasons, or as a result of other research being carried out either nationally or internationally. The regular interaction of project holders provided a means of ensuring that the overall aims of the programme were still being adequately covered by the range of projects. The core team were also able to develop collaborations with project holders to address any potential ‘gaps’ in the science programme.

6.3 Assessment of management effectiveness

6.3.1 Overall management

The Steering committee formed a very cohesive management structure and the membership remained largely unchanged in its core elements throughout the programme. This gave good continuity to the decision-making, despite changes in the staff at Swindon (see below). The committee were able to manage the budget effectively. It was an aim of the programme to have membership from the social science community and from industry on the steering committee, to better inform decisions on the “user driven science” aspects of the programme. Whilst the industrial representation was well maintained, after an initial change of membership, there was difficulty in maintaining attendance from the social sciences. As this was not core to their own research, clashes were inevitable. It was possible, however, to get useful input at key times, such as when assessing the user driven science proposals.

The Science coordinator role was held by a single person for the entirety of the programme, which also aided in the continuity in the programme. However, the appointment was not made until after the first call for proposals had been made and as such there was difficulty at the start of the programme when several important planning documents should have been generated – including the exploitation and data management plans. Fortunately, the original proposal to NERC for the programme was sufficiently detailed, in terms of science, implementation and exploitation that it could be used as the basis for much of the planning with little modification.

The Science coordinator took 6 months maternity leave during the middle of the programme (Sep 2002 – Feb 2003). This did not appear to have an impact on the operation of the programme. This was partially due to the fortuitous timing; after the award funding was complete and before the completion of the programme, but also largely due to the presence of the core team, who were able to maintain much of the coordination activity between projects.

The core team proved to be a great asset to the programme. The decision was taken to allow the core team to be based at any centre that was involved with the programme. Whilst this made it more complex for coordinating the core team activities, it proved to be highly beneficial to the programme as a whole. Having access to the core team expertise and advice proved beneficial for several projects and ‘local’ support was felt to be an advantage by those sites with a core team member.

It is recommended that future programmes should seriously consider the advantages of having a core team, to provide support to the programmes projects as well as providing a more immediately available scientific resource that can be directed to specific issues.

6.3.2 Effectiveness of Reporting

The output measures were useful for compiling the required annual reports and official statistics of the programme, but were far less effective for reporting on the actual status of projects. There is a tendency for results to only be reported at time of publication – not necessarily at time of completion. The most effective project reporting, in terms of the scientific developments, was at the annual meetings – by means of presentations from each of the projects. Reporting on the financial project status and potential problems, e.g. in terms of staffing or computing difficulties, was most effectively done by direct intervention of the programme scientific coordinator in one-to-one discussions with the PIs. The core team also provided a valuable interface between the different projects, having regular contact with the researchers across the sites involved.

NERC does not have a formal procedure for reporting on the status of PhD projects. This seems a serious flaw in the reporting structure. During the active research stage of the PhD projects, they were treated in the same way as the other project awards, with presentations at annual meetings workshops, interaction with the core team and science coordinator. However, towards the end of the programme, as other activities reduced and the time available to the science coordinator reduced, it was more difficult to maintain contact with all the students. PhD Theses are not sent to NERC by default, and any possible problems with individuals completing their PhD without writing up were not alerted to NERC or the programme. In this instance, there has been a high completion rate – only 1 of 14 PhD topics seems to have a problem over completion, as the student is now employed outside research. However, capturing all the publications from PhD topics is a non-trivial task that could be made simpler by RODS style reporting being extended to PhD projects.

6.3.3 Turnover of NERC Swindon Officer Staff

During the programme, there were six different programme officers with responsibility for the programme. It was fortunate that a single officer was in post for the majority of the programme, particularly over the important time period when the funding decisions were being made. However, the science coordinator, being from outside Swindon Office, relied heavily on the programme administrator for access to, and knowledge of, the systems procedures in use at Swindon. This included financial information, and who to contact for information on policy etc..

7 Conclusions and recommendations;

7.1 Main achievements

The main achievements of the NERC COAPEC Programme may be summarised as:

- ∞ Large number of high quality peer reviewed publications and PhD theses
- ∞ Community of researchers engaged in collaborative research across oceanographic and atmospheric sciences.
- ∞ Training of new, and established, researchers in the use and interpretation of climate models
- ∞ Closer collaboration between NERC researchers and the Hadley Centre in the field of climate research
- ∞ Development of several climate models that can, and are, being used in other research programmes
- ∞ Availability of data from the Hadley Centre Couple Climate Model (HadCM3) control runs, both the Hadley Centre and COAPEC configurations, to the climate community

7.2 Recommendations

7.2.1 Recommendations for future directed programmes

Three recommendations have been made in the previous text:

- ∞ that for research programmes directed at relatively small communities, staggering the start of research projects and studentships is considered to allow time to recruit the highest quality candidates (§Community Building4.1).
- ∞ that NERC continue to support the provision of training workshops for climate modelling through NCAS or other appropriate centres to continue to increase the UK climate modelling community (§4.2).
- ∞ that future programmes should seriously consider the advantages of having a core team, to provide support to the programmes projects as well as providing a more immediately available scientific resource that can be directed to specific issues (§6.2.2).

In addition, we recommend the following:

1. that the long-term maintenance of the Hadley Centre Climate Model data is supported at the BADC, as part of a data management system for all NERC programmes.
2. that NERC consider ‘equal footing’ for EU students applying for NERC studentships. In areas with limited “source” for students, attracting overseas students is important in community building.
3. That NERC allow projects to include un-named researchers above the minimum scale. Where specialised skills are required, and a case be made for particular projects, it should be possible for an award to be made for an unnamed researcher at grade points above the minimum. For some of the COAPEC projects, very specific skill sets were required and it proved extremely difficult to appoint appropriately

trained staff. In these cases, either there was less time allocated to the project or research time was ‘lost’ in training staff.

4. Core Team: In areas of research where there is a recognised need for capacity building, especially from a small skill base, the existence of a core team is highly recommended. The core team could be based at a single location, but should be available to act in a support role for any member of the directed programme community. The core team should, where possible, already have the appropriate skills. However, because the core team can be established before the majority of projects are underway, they have a “head start” in the research that can be passed on, to the benefit of the wider community. The core team research can be directed to fill recognised gaps in the overall programme, whilst still allowing the great potential for ‘unplanned’ research.
5. That NERC consider implementing a form of reporting for PhD studentships, similar to RODS, to allow capture of important programme information (§6.3.2).
6. that NERC resolve the issue of the long-term maintenance of the COAPEC Programme, and similar, websites (see §6.2.1).

7.2.2 Recommendations for further research

The recommendations from the Joint NERC / Met Office / ECMWF workshop on seasonal-decadal forecasting (see Appendix I) has provided significant input to the new NERC strategy with regards to seasonal-decadal forecasting. Some of the key science priorities identified in this document are provided here:

∞ Challenges in fundamental science

While the science that governs global climate change is now well established, understanding of the factors that influence regional and local changes in climate, and their impacts, is much less advanced. Critical questions such as the following raise fundamental scientific challenges.

- How will patterns of precipitation change, and what will be the impacts on water availability, health, agriculture and food supply in vulnerable regions?
- How frequently should European summers as hot as 2003 be expected, and what will be the impacts of future hot summers on water management, health and agriculture?
- Are catastrophic events such as Hurricane Katrina a sign of things to come? Will such events become more frequent in the future?

∞ Challenges in the development of climate prediction systems

The development of systems to predict regional and local climate for time horizons of months-to-decades is still at an early stage. At the heart of a climate prediction system is a numerical model of the climate system, and the improvement of such models is a key challenge. In addition, new methods are needed to combine observations with models in order to initialise climate predictions, and to obtain appropriate measures for the uncertainty of predictions. The UK has been, and is now, an acknowledged world leader in climate prediction. In order to maintain its leadership role, and to capitalize on the unique opportunity for further advances, there is a need for new investments in research to address these challenges.

Predicting regional and local climate of the next few decades is a high-priority natural follow-on to COAPEC science. This challenge will broaden COAPEC's focus on the role of initial conditions to include the joint influence of initial conditions and changing radiative

forcing. Assessment and quantification of model uncertainty (as pioneered by CP.net) will also be expanded. The importance of these challenges is reflected in the new NERC strategy.

It was strongly recommended that the NERC continue funding for a diversity of climate modelling initiatives – including models of all complexities and with different representations of the physics to aid in interpretations of model diagnostics.

7.2.3 Recommendations for Observations

The COAPEC programme has further emphasised the need for long-term observations in support of climate research. This is particularly an issue within the ocean where continuity of measurement programmes is not as well established as in the atmosphere. Measurements are needed for at least 10 years so using responsive and directed mode funding is not well suited. The long-term observations theme within the recently funded Oceans 2025 programme is a welcome step forward as this opens up the possibility for greater continuity, at least for selected measurements.

The challenge now for NERC is to obtain the best research from its investment in long-term measurements. Future responsive and directed mode programmes need to be able to take full advantage of the observational programmes funded by core and managed (usually) by NERC's research centres. NERC needs to alert its communities to the existence of the datasets so that they can be exploited as fully as possible. Also, results from the responsive and directed research programmes should be used to help in designing and maintaining the long-term measurement programmes.

However, there is a wider issue. It is not only the research community that requires longer-term data. Monitoring to ensure compliance with legislation and data for operational oceanography such as ocean forecasting are both growing sectors. The Government's Charting Progress identified inadequacies in monitoring, even in UK waters, and this has led to the UK Marine Monitoring and Assessment Strategy. A common theme in the evidence given to the Science and Technology Select Committee inquiry into marine science is also the need to have a sustained observing system. NERC needs to engage with Government departments and agencies, and with commercial organisations to develop an integrated system that best meets the needs of the UK and its international commitments in a cost-effective way.

7.2.4 Recommendations for Knowledge Transfer

Users are typically interested in very specific aspects of climate or weather, which relate to their particular vulnerabilities. New approaches and mechanisms are needed to extract from climate predictions the application-specific information required for decision making by individual users. There is also a need for climate scientists to work with decision makers in order to better understand the nature and extent of specific weather and climate related risks, and the options available to manage these risks.

An outcome of the joint workshop in 2006 was the following two opportunities for new activities or structures, which more effectively join up basic research with focused work to improve operational systems for climate prediction, and to enhance the value of such predictions to users:

- a) *Development of formalised collaboration between the Met Office and NERC with a specific focus on the improvement of seasonal-to-decadal climate predictions.* It is likely that the NERC side of such a collaboration would be led, in the first instance, by NCAS but would, in time, include other groups as well. The collaboration would focus on pull-through of results from basic research into the improvement of climate predictions. The improvement of climate models would be a specific priority. Such a

collaboration would benefit from coordination between the Met Office and NERC with respect to HPC resources, and from improved internet connections between the Met Office and the academic community. The recently agreed joint project between the Met Office and the NERC COAPEC project (with additional support from NERC Knowledge Transfer funds) is a modest but significant step in this direction.

- b) *A National Institute for Prediction of Environmental Change*. The opportunity exists in the UK for a larger initiative to give focus to the grand challenge of improving predictions, not only of regional and local climate but also its impacts on a broad spectrum of environmental variables. Such an initiative could bring together the breadth of NERC expertise with that in the Met Office and ECMWF. Substantive engagement with the user community, e.g. the Environment Agency and water companies, would be essential.

Further to these recommendations, it is suggested that NERC research projects, especially directed or core strategic, should aim to produce policy-relevant summaries that can be kept on file at Defra, for example. This is done for the Hadley Centre and Defra's Global Atmosphere Division. It could be extended to the Marine Environment Division.

Another suggestion would be to embed scientists for periods in policy departments, as has already been done for the RAPID project amongst others. A more challenging, but potentially profitable, suggestion is to create opportunities for staff within government departments to spend time at NERC centres.

Appendix A : Science Plan

Coupled Ocean-Atmosphere Processes and European Climate (COAPEC)

A Thematic Programme to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean

prepared by

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Coupled Ocean-Atmosphere Processes and European Climate (COAPEC)

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Executive Summary

The goal of COAPEC is to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean on seasonal to decadal timescales. The hypothesis will be tested that anomalies in Atlantic sea-surface temperature can be a useful predictor of climate conditions over the UK and the rest of Europe. The programme will fill a significant gap in understanding the climatic effects of ocean-atmosphere coupling, since the majority of international research effort in this field has concentrated on the Pacific Ocean. The UK is in an excellent position to take a world lead in a critically important area of science. The programme envisages a close partnership between the Hadley Centre for Climate Prediction and Research, which has a state-of-the-art coupled model, and NERC scientists who are internationally recognised experts in modelling the climate system, as well as in the scientific interpretation of results. One objective of this partnership will be to consolidate hitherto separate model development plans to produce a world leading national coupled climate model as the core of an "Earth System Model". The particular contribution of the NERC community to this venture will be to provide the basic scientific understanding and training required to develop a credible predictive tool and to exploit it intelligently.

The impact of climate change on society and the global economy is a highly prominent issue in current political and economic decision making. The benefits of even modest skill in forecasting climate fluctuations would be enormous for a diverse body of users including legislators, decision makers in business and commerce and those charged with the sustainable management of the water, agriculture, fisheries and energy industries. COAPEC is a direct response to a recommendation of the U.K. Expert Panel on Global Environmental Research, with inter-agency ratification, that the development of capabilities in coupled atmosphere-ocean modelling should be a priority for the U.K. Results from COAPEC will make a major U.K. contribution to future intergovernmental assessment reports on climate change, and also to international climate programmes under the, auspices of the World Meteorological Organisation.

The proposed duration of COAPEC is five years. The interdisciplinary nature of COAPEC requires that PDRAs be drawn from a wide variety of disciplines, especially the mathematical and physical sciences. In order that first class training can be provided PDRAs and PhDs will be recruited in stages to peak numbers of 12 PhD students and 24 PDRAs including three core staff. The total cost of COAPEC is ~£5.4 million, including the cost of high performance computing.

Objectives

The major objective of COAPEC is to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean on seasonal to decadal timescales. To achieve this objective COAPEC will:

1. Understand the role of coupled processes in the climate system and improve the representation of these processes in models used for climate forecasting.
2. Assess climate predictability in the Atlantic/European sector and contribute to the development of a national capability in climate forecasting.
3. Train scientists in the interdisciplinary skills required for environmental modelling and prediction.
4. Facilitate the exploitation by users of COAPEC research.

Background

The benefits to society of even modest skill in forecasting climate fluctuations would be enormous. The potential users of such forecasts are diverse; they include policy and decision makers involved in agriculture, fisheries and water resources, all of which require long-term planning to ensure sustainable management of resources. In addition, the insurance and reinsurance businesses are worth billions of pounds to the U.K. There are huge financial benefits to be gained from information that could improve risk assessment even slightly. As an international trading nation whose economy responds strongly to international market forces, the U.K. must have access to the best information on influences on the market, such as climate variability, if quality of life is to be maintained let alone improved.

The processes that affect climate are complex and involve the interaction of the atmosphere with the Earth's ocean, ice and land surface, including the biosphere. Interactions between the atmosphere and the ocean are of particular importance. There is strong evidence that by virtue of its greater heat capacity and slow motion, the ocean lends some predictability to an apparently chaotic atmosphere. Urgent research is required to enable the exploitation of this predictability to its full potential.

COAPEC seeks to build a concerted research programme in the U.K. to study the nature and predictability of coupled physical processes in the atmosphere-ocean-cryosphere system. It focuses on the influence of ocean-atmosphere interactions in the Atlantic sector on seasonal-to-decadal fluctuations in the climate of the U.K. and the rest of Europe. It will exploit high quality observational data sets recently available from satellites (*e.g.* ATSR), in situ observations (*e.g.* WOCE surveys) and atmospheric reanalysis projects (*e.g.* by ECMWF). It will utilise sophisticated numerical models, particularly the UKMO Unified Model (hereafter referred to as the UK Community Climate Model), that have already been developed (but not perfected), so that efforts will be concentrated principally on science issues rather than on building new models. It will use palaeoclimate scenarios as test beds for investigating processes in climate variability and for interpreting predictions of climate change.

There is scope in COAPEC to exploit the research in other NERC Thematic Programmes, specifically ARCICE and the proposed Palaeoclimate Thematic Programme. And it will bring together existing strengths and capabilities in the NERC-supported atmospheric,

oceanographic and polar science communities, building also on strong collaborations with the U.K. weather forecasting agencies: the UKMO and ECMWF.

The U.K. Expert Panel on Global Environmental Research has called for the development of the UK's capabilities in coupled atmosphere-ocean modelling as one of its principal recommendations for research in physical sciences. COAPEC is intended to be a major NERC response to this recommendation. By engaging the expertise of social scientists supported by the Economic and Social Sciences Research Council (ESRC), COAPEC will address a further key recommendation of the Expert Panel, viz the need to bridge the gap between the scientific output of the physical research programmes and user needs.

Research Programme

Background

Three key components of the climate system in the North Atlantic/European sector are: **1) The North Atlantic Storm Track; 2) The Oceanic Gyre Circulation; 3) The Thermohaline Circulation.** COAPEC will address fundamental issues in understanding these components of the climate system. It will examine, in particular, how variability in one component is related to variability in the other components, and to what extent such variability is predictable. COAPEC will also address how processes occurring outside the North Atlantic/European sector influence and interact with local processes. Of particular interest, following the 1997/98 event, will be the influence of El Niño on the atmosphere and ocean in the Atlantic sector.

1. The North Atlantic Storm Track

The weather systems in the North Atlantic tend to grow and decay along a corridor that runs from the east coast of North America to north-western Europe, the so-called storm track. When the storm track extends over Europe in winter there tend to be strong winds, heavy precipitation and mild temperatures. When it is shortened the winter weather in most of Europe tends to be cold and dry.

The North Atlantic Storm Track exhibits variability on a wide range of timescales, the most important mode being the North Atlantic Oscillation (NAO). The period from the 1960's to the 1990's has seen a strong trend in the NAO from low index values to high index values (Hurrell, 1995). This trend was associated with major changes in patterns of storminess (Dickson *et al.*, 1997). Interannual variability in the NAO is probably governed mainly by processes internal to the atmosphere. On decadal and longer timescales, however, the ocean may have a more significant role. The influence of North Atlantic sea-surface temperature (SST) anomalies on the storm track and the related time mean flow is poorly understood. Observed correlations between SST anomalies and anomalies in the atmospheric flow may be evidence of the ocean forcing the atmosphere (Palmer and Sun, 1985). However, attempts to reproduce the observed correlations in atmospheric GCMs forced with prescribed SST anomalies have been inconclusive. Part of the explanation may lie in a substantial seasonal dependence of the response (Peng *et al.*, 1995).

The storm track may also be influenced by remote SST anomalies. El Niño/Southern Oscillation (ENSO) is the dominant mode of interannual variability in the coupled ocean-atmosphere system and its influence is global. The response of the extratropical atmosphere

to ENSO is dominated by the Pacific/North American (PNA) pattern which has a considerable influence on the circulation over the western North Atlantic (*e.g.* Lau and Nath, 1996). ENSO may also induce a remote response in the SSTs of the tropical and subtropical Atlantic Ocean through the modulation of the trade winds. Tropical Atlantic SSTs are known to be correlated with rainfall in the Sahel and in northeast Brazil (Folland *et al.*, 1986; Moura and Shukla, 1981) and have been implicated in the recent active hurricane seasons (Saunders and Harris, 1997). Teleconnections between the tropical Atlantic and higher latitudes may also exist (*e.g.* Sutton and Allen, 1997). An important goal of COAPEC will be to investigate how the influence of ENSO interacts with local processes in the Atlantic/European Sector.

2. The Oceanic Gyre Circulation

The Subtropical and Subpolar Gyres are the two major shallow circulations of the North Atlantic Ocean. Driven primarily by the wind, these gyres include important western boundary currents: the warm Gulf Stream and the cold Labrador Current. Ocean-atmosphere interaction in the vicinity of the Gulf Stream stimulates the development of storms in the atmosphere. Achieving an accurate simulation of the Gulf Stream, and in particular its separation from the coast, remains an outstanding challenge in ocean modelling.

SST in the North Atlantic exhibits considerable variability. On short timescales internal instabilities and fluctuations in the local surface buoyancy fluxes are the most important causes. On longer timescales, changes in the large scale ocean circulation and water masses become significant. Fluctuations in the wind stress curl may, after an interval of some years, generate fluctuations in the strength of the gyre circulation that influence SST (Latif and Barnett, 1994). Fluctuations in buoyancy fluxes can influence the properties of the winter mixed layer and thus thermocline ventilation. Subducted waters may be advected by the gyre circulation, out of contact with the atmosphere for many years, until eventually re-emerging at the surface in the region of the Gulf Stream. COAPEC will improve understanding of the detailed relationships between the space-time characteristics of atmospheric variability and variability in the water mass properties and circulation of the oceanic gyres.

3. The Thermohaline Circulation and the Possibility of Rapid Climate Change

The Thermohaline Circulation (THC) in the North Atlantic carries warm surface waters northward and cold waters southward at depth. As the surface waters travel northward they give up heat to the atmosphere, tending to warm Western Europe. The North Atlantic THC is a crucial element in the global THC. As a consequence, any changes in the North Atlantic THC may have a global impact on climate.

Many factors influence the strength and character of the North Atlantic THC (Schmitz, 1995). Exchanges of heat and fresh water between the ocean and atmosphere are central. Recent work has established important links between the NAO and observed changes in the North Atlantic ocean (Dickson *et al.*, 1997). The presence of sea-ice in the polar oceans, and its formation and melting, also affect strongly the air-sea exchanges. Variability in runoff and in the exchanges between the Arctic and Atlantic oceans can also influence the THC. The detailed relationships between these various factors and the strength of the THC are not understood.

We know that in the past the North Atlantic THC has been in states that are significantly different to the state we observe today. There is evidence that the THC is susceptible to

sudden change, with dramatic consequences for climate. The circumstances that provoke such changes are poorly understood and demand urgent research.

Work Programme

The work programme has four main elements, each of which is identified by a key question. A fifth element targets meeting user needs.

1. What are the observed characteristics of seasonal-to-decadal climate variability in the Atlantic Sector?

The first component of the COAPEC programme focuses on analysis of observational datasets. Adequate documentation of the natural climate variability, particularly the relationship between the atmosphere, ocean and cryosphere, is fundamental underpinning research for COAPEC, essential for model validation. Key data sets include: ocean surface conditions and fluxes derived from ship observations (da Silva *et al.*, 1994; Josey *et al.*, 1996); subsurface in situ ocean measurements, *e.g.* from WOCE; atmospheric reanalyses; satellite altimetry, SST and sea-ice extents.

COAPEC will support:

1. Development from existing observations (notably the WOCE surveys) of new data sets relevant to COAPEC.
2. Analyses of variability in the North Atlantic Storm Track with an emphasis on a) the relationship between the storm statistics and variability in the mean flow, in particular the NAO, b) the relationship between storm statistics and the distributions of SST and sea ice, c) the influence of storm track variability on the surface fluxes of heat, fresh water and momentum.
3. Analyses of variability in a) the Oceanic Gyre circulation and b) the Thermohaline Circulation of the North Atlantic, addressing in particular the relationships between ocean variability and variability in the surface fluxes of heat, fresh water and momentum, and the influence of the ocean circulation on SST and sea ice distributions.
4. Analyses of ocean-atmosphere interactions in the tropical Atlantic, and of relationships between variability in the North Atlantic and variability in other regions, including the role of ENSO.

2. How do the mean climate and climate variability in the Atlantic Sector simulated by a Coupled General Circulation Model differ from that observed? How do we correct model deficiencies?

The second component of the COAPEC programme focuses on evaluating the skill of Coupled General Circulation Models, particularly the U.K. Community Climate Model, in simulating climate and climate variability in the Atlantic Sector, and on understanding and correcting the causes of errors. Errors in CGCMs have a multitude of sources. Significant progress in model development has been achieved through improved parametrizations of, for example, the effects of ocean eddies (Gent and McWilliams, 1990; Gent *et al.*, 1995; Visbeck *et al.* 1997; Killworth, 1997) but better parametrizations for a wide range of physical processes in the ocean, atmosphere and cryosphere are required. Equally important is

improved understanding of how CGCM simulations are sensitive to changes in parametrizations.

A necessary first step in assessing model performance is the evaluation of the mean climate and seasonal cycle. These are fundamental aspects of the coupled system. Simulating well these basic aspects of climate provides a stringent test of a model.

COAPEC will support:

1. Analyses of multidecadal control integration's of the U.K. Community Climate Model, in partnership with the UKMO. Evaluation of the consistency between observations and model simulations of (a) the mean climate and seasonal cycle, (b) climate variability. Controlled experimentation with the same model to elucidate sources of error.
2. Development of parametrizations for key processes in the coupled ocean-atmosphere-cryosphere system.
3. Development and application of novel techniques for comparing coupled models with observations to identify systematic model errors and to translate understanding of model deficiencies into quantitative estimates of confidence in climate forecasts.

3. What are the physical mechanisms that determine the mean climate and seasonal-to- decadal climate variability in the Atlantic Sector?

The third component of the COAPEC programme focuses on the use of models as laboratory tools for controlled experimentation to investigate sensitivities within the climate system and mechanisms involved in climate variability in the Atlantic sector, including the possible use of palaeoclimate scenarios. The coupled ocean-atmosphere-cryosphere system is highly complex and it is only through identifying forcing, response and feedback through well designed model experimentation, often with uncoupled component models and simpler models, that progress in understanding the essential elements of the climate system will be achieved. This will include investigation of the mechanisms through which remote forcing (e.g. ENSO) influences the variability of the Atlantic and European sector.

COAPEC will support:

1. Experimentation with atmosphere, ocean, ice or coupled models to elucidate mechanisms that have a key role in determining the mean state and seasonal cycle of the coupled climate system.
2. Experimentation with atmosphere models to elucidate the mechanisms through which the atmosphere in the N. Atlantic/European region responds to changes in SST and sea-ice distributions, especially in the Atlantic basin and Nordic Seas.
3. Experimentation with ocean or ocean-ice models to elucidate the mechanisms through which variability in the surface fluxes of heat, fresh water and momentum influences simultaneous and subsequent variability in the ocean state, and to evaluate the comparative importance of different surface forcings.
4. Experimentation with coupled models to investigate the mechanisms that determine variability in the Atlantic coupled system, including the sensitivity to non-local

4. What processes determine the predictability of climate fluctuations in the Atlantic- European region?

The fourth component of the COAPEC programme employs the tools and methodologies of the first three components to investigate which processes in the coupled system influence predictability for the Atlantic/European sector.

There is evidence that anomalies in Atlantic sea surface temperature can be a useful predictor of seasonal conditions over the U.K., especially in summer (Colman, 1997). Recent success at ECMWF in predicting the seasonal mean climate for Europe during the strong El Niño of 1997/98 (Stockdale *et al.* 1998) has emphasised the need for understanding the influence of ENSO. On decadal timescales there is evidence of predictability in North Atlantic SST (Sutton and Allen, 1997). The influence on the atmosphere of these SST fluctuations appears to be weak but may nonetheless give rise to some useful predictability (Venzke *et al.*, 1998). Much more research is needed to fully assess the predictability of decadal fluctuations in the climate (Griffies and Bryan, 1997).

The use of coupled models for forecasting presents major challenges. In particular, the WMO (1997) has highlighted the problem of initialising coupled models in a suitably 'balanced' state, which accurately reflects the phase of, coupled modes of variability. Separate data assimilation into ocean and atmosphere models, as currently practised, is unlikely to achieve this adequately.

COAPEC will support:

1. Analysis of observational data sets and experimentation with models to elucidate the links between variability in the oceans and land surfaces, and variability in European climate, with particular emphasis on lag-lead relationships.
2. Experimentation with coupled models to examine the predictability of seasonal-to-decadal climate fluctuations in the Atlantic/ European Sector.
3. Research into the use of coupled models for forecasting seasonal-to-decadal climate fluctuations, including the problems of initialising and assimilating data into coupled models, and the sensitivity of forecasts to model formulation.

5. Bridging the gap between scientific output and societal needs

Improvements in our ability to produce seasonal forecasts and to predict climate changes (natural or anthropogenic) with even a modest measure of skill could bring enormous societal benefits (*cf.* Glanz 1996). But there is a significant gap to be bridged if specialised scientific knowledge is to be used effectively by society. Scientists need to understand the kinds of information that can be acted on by decision-makers, as well as appreciating the organisational and decision-making contexts in which potential users operate. Decision-makers need to be made aware of the limitations of the information being offered. For example, rational cost-benefit analysis of the potential benefits of seasonal weather forecasts and of the various policy options available in response to the threat of anthropogenic climate change, requires a detailed understanding of the nature of uncertainty in climate forecasts. The interpretation and intelligent use of uncertain knowledge requires an effective two-way

system of communication between information providers and users.

Provision will be made within COAPEC to develop such systems of communication. (Up to 5% of the total cost of the project could be set aside for this, depending on the quality of the proposals received.) It is envisaged that social scientists will work with atmospheric scientists, oceanographers, users and decision-makers to seek ways to broaden the uses of COAPEC research by society.

COAPEC will support:

1. A Workshop to communicate the nature and scope of the research to policy makers, the media and other user groups, and interviews with decision makers and users to elicit, and better understand, information needs and the contexts in which forecasts could be used.
2. Active promotion of the public understanding of COAPEC research in close collaboration with national (*e.g.* British Association) and international (*e.g.* UNEP, UNESCO, WMO) bodies charged with promoting public understanding of climate science. The COAPEC project coordinate will be responsible for overseeing dissemination of COAPEC research to the wider public through: public lectures; popular articles, fact sheets and educational materials available over the Internet; and by ensuring a pro-active relationship is established with the media on topical climate issues.

Coupled Model Development

COAPEC PIs are encouraged to make use of existing coupled models such as HadCM3. However, it is envisaged that a modest amount of model development will also be undertaken where this will increase the capability to achieve COAPEC objectives. Anyone who is prepared to contribute staff effort to model development, in partnership with the Core Team and on the understanding that the product will be made generally available to the COAPEC community, is encouraged to contact the Science Co-ordinator.

Training

Researchers investigating the coupled ocean-atmosphere-cryosphere system require a broad range of interdisciplinary skills in meteorology, oceanography, geophysical fluid dynamics, numerical modelling, data assimilation, statistics, and computer science. There is a serious lack of scientists with the required breadth of knowledge and skill to pursue this scientific 'grand-challenge'. The programme will therefore seek to attract talented scientists from related disciplines and will provide training as appropriate. Provision has been made for up to 12 Ph.D. students. Training of students and postdoctoral researchers will involve annual short courses tailor made to the intake of new scientists.

Research Community

The proposal has been developed through meetings involving a broad community of climate, atmospheric and oceanographic scientists, through a major planning workshop, and by correspondence. The following is a summary of the NERC Laboratories, Universities and other organisations that contributed to the proposal and will be involved in implementing the programme.

Meteorologists: Universities of Reading, Edinburgh, Oxford, East Anglia; Meteorological Office, ECMWF.

Physical Oceanographers: Universities of Liverpool, East Anglia, Reading, Oxford, Stirling, Sunderland, Exeter, Keele, London; Southampton Oceanography Centre, CCMS Proudman Oceanographic Laboratory; Meteorological Office.

Sea-ice and Hydrography specialists: British Antarctic Survey; Meteorological Office; Southampton Oceanography Centre; University College, London; Institute of Hydrology, University of Keele.

Social Scientists: Scientists supported by the Economic and Social Sciences Research Council, and statisticians.

Collaboration and Links with other Programmes

COAPEC will seek to build a concerted research programme in the U.K. to study the role of coupled physical processes in the atmosphere-ocean-cryosphere system and to develop the U.K. capability to produce short-range climate forecasts. The use of the U.K. Community Climate Model as one of its core tools will ensure that COAPEC will be closely allied with research at the Met. Office and the Hadley Centre into climate predictability. In collaboration with the Hadley Centre, SOC is involved in a possible project to develop a new OGCM for incorporation in the next generation U.K. Community Climate Model. COAPEC will ensure that this development receives maximum benefit from NERC-related research. COAPEC projects that involve close partnership with the Hadley Centre will have agreed targets and timetables (as indicated under Project Management) to ensure efficient progress where there are project dependencies.

Links already exist with the seasonal prediction programme at ECMWF and these will be developed further through COAPEC. COAPEC will bring together existing strengths and capabilities in the NFRC-supported atmospheric, oceanographic and polar sciences communities, particularly those supported within the UGAMP, OCCAM, LOIS, AIM and ARCICE projects and the proposed palaeoclimate Thematic Programme.

COAPEC will enable U.K. scientists to make significant contributions to international programmes involving coupled modelling and climate predictability. The NAO, Tropical Atlantic variability and the Atlantic THC have been identified as key research areas in the CLIVAR Implementation Plan. The North Atlantic and European Climate is a major focus of EuroCLIVAR. COAPEC will contribute substantially to CLIVAR-related research within Europe and internationally.

Deliverables

The major objective of COAPEC is to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean on seasonal to decadal timescales. The specific deliverables are:

1. Documentation and understanding of the physical mechanisms of coupled processes in the atmosphere-ocean-cryosphere system, especially those relevant to the Atlantic/European sector.
2. Evaluation of the skill with which U.K. climate models simulate the observed climate

and climate variability in the Atlantic and European Sector, and identification of the sources of errors.

3. Improvements to numerical models of the ocean-atmosphere-cryosphere system incorporating improved representations of key physical processes.
4. Assessment of any climate predictability, particularly for the U.K. and the rest of Europe.
5. In partnership with the Hadley Centre, contribute to the development of a world-leading national coupled climate model and associated climate forecasting capability.
6. Scientists trained in interdisciplinary skills for environmental modelling and prediction.

Improved communication between the research and user communities about the requirements for climate information and the potential for making useful long-range forecasts.

Resources

The Atmospheric Science and Technology Board (ASTB) and Marine science and Technology Board (MSTB) have allocated £4.85m to COAPEC over five years. The funding profile of the Programme will be decided by the Scientific Steering Committee.

Project Management

COAPEC involves major scientific challenges. To make progress, close partnerships must be established among COAPEC scientists, and between COAPEC scientists and non NERC-funded partners (*e.g.* the Hadley Centre). For such partnerships to work, the work programme must be well managed, with agreed targets and timetables where appropriate. COAPEC will be overseen by a Scientific Steering Group comprising NERC scientists, scientists from partner organisations, government agencies (*e.g.* Department of the Environment) and members of the user community. Day-to-day management will be by the COAPEC core team of three PDRAs, aided by a half time secretary, whose responsibilities will include preparing progress reports for both a technical and non technical readership. Workshops will be held regularly, culminating in an annual community meeting, with invited international participants. Supercomputer co-ordinators will make provision for COAPEC needs and manage allocation of resources to maximise use.

Data Management

COAPEC will comply fully with NERC's guidelines on data management. The British Atmospheric Data Centre, linked electronically with the British Oceanographic Data Centre, will act as the central metadata location and access point for observational data sets required by COAPEC. BADC will also act as the principal access point for the key extended integrations that are run during the programme. The BADC will supply data to the scientific and user community, together with access software. The core team will develop software libraries for user applications. They will manage a web site, to be hosted at BADC to provide a bulletin board of useful information.

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Appendix B : Implementation Plan

Coupled Ocean-Atmosphere Processes and European Climate (COAPEC)

1 Introduction

COAPEC is a UK NERC (Natural Environment Research Council) thematic programme to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean on seasonal to decadal timescales.

The scientific aims and methodology of the COAPEC programme are described in full in the [COAPEC science plan](#), which constitutes the principal planning document for the COAPEC programme. Within the science plan, the areas of research that COAPEC will fund have been clearly defined. In addition, the Science Plan defines additional aims of training postdoctoral and postgraduate scientists in the breadth of subjects necessary to understand the coupled ocean-atmosphere-cryosphere system. The Science Plan also outlines the programme's aims of creating a "COAPEC community" that can bring together UK climate scientists and act as a UK focus in international programmes such as CLIVAR.

The aim of the COAPEC Implementation Plan is to more closely define the strategy by which the aims of the science plan will be achieved and provide the timetable for activities within the COAPEC programme. It is envisaged that the implementation plan will continue to evolve over the course of the COAPEC programme.

The principal method for achieving the scientific aims of the COAPEC programme will be by means of funding proposals submitted in response to announcement of opportunity (AO) calls. These calls will be made, and the [approved projects](#) funded, according to the timetable set out in §2. Additional calls for [studentships](#) and fellowships will also be made according to the timetable in §2 in order to allow for the training of scientists new to the field, as proposed in the Science Plan. This training will include workshops in coupled modelling.

In addition to funding projects, studentships and fellowships, the COAPEC programme will have a core team, as defined in the science plan. The core team will act as a focus for the COAPEC community and will provide a source of scientific expertise and support for the wider COAPEC community. In addition, they will each carry out personal research that will further advance the COAPEC programme. The roles of the core team are more fully described in §1.2.

To encourage collaboration between COAPEC scientists, a series of workshops and annual meetings is envisaged, as proposed in §2.

The full exploitation of the results of the programme will be realised by following the [COAPEC exploitation plan](#).

The dissemination of data within the Programme and to the wider community will be facilitated by the COAPEC data policy.

1.1 Funding Opportunities

1.1.1 AO Projects

The COAPEC Programme intends to fund two rounds of projects. The first round of projects should begin in 2000, with second round projects beginning in 2001. A third round of projects would start in 2002. The projects are each anticipated to run for 3 years.

Further details on the funded proposals can be found on the [Awarded Grants](#) page of the [COAPEC web site](#).

1.1.2 Studentships

Additional Announcements of Opportunity will be made for studentships under the COAPEC programme. Up to 12 studentships will be funded during the life of the programme. Studentship projects will be assessed by the steering committee in order to make announcements of successful bids as rapid as possible.

Further details on the funded studentships can be found on the [studentships](#) page of the [COAPEC web site](#).

1.1.3 Fellowships

One Announcement of Opportunity for fellowships is expected within the COAPEC programme. The fellowships will be funded for 3 years by the COAPEC programme, and successful applicant will be eligible to apply for an extension to 5 years under normal NERC procedures, in competition with new fellowship applications.

1.2 The Core Team

Three members of the core team were appointed, starting in April 2000 with a fourth core team member appointed in October 2001. After the resignation of two core team members (in February and August 2003) a single replacement post was filled in September 2003 and the existing posts extended to end of August 2005.

The final core team are:

- ∞ Bablu Sinha (N.O.C., Southampton)
- ∞ Alan Iwi (R.A.L.)
- ∞ Emily Black (CGAM, Reading)

Previous core team members were:

- ∞ Matthew Collins (CGAM, Reading)
- ∞ Pierre Philippe Mathieu (CGAM, Reading)

The core team responsibilities include:

- ∞ Support for COAPEC scientists.
- ∞ Independent research along COAPEC themes,
- ∞ Acting as foci for sub-groups of the COAPEC community on topics of relevance to part of the community, possibly involving scientists not part of the immediate COAPEC community

Further details on the core team can be found on the [Core Team](#) page.

2 Timetable

A timetable for the development of the implementation plan for the COAPEC Programme follows.

1999													
ACTIVITY	J	F	M	A	M	J	J	A	S	O	N	D	
1st AO call													
Workshop: facilitate interaction within the research community									21				
1st AO outline bids closing date													
SC meeting: assess 1 st AO outline bids													
Appoint Core Team													
Appoint Scientific Coordinator													

2000													
ACTIVITY	J	F	M	A	M	J	J	A	S	O	N	D	
1st AO full bid closing date		14											
SC meeting: 1 st AO funding decisions													
Produce draft DP													
1st AO projects announced													
KO meeting for 1st round PIs													
SC meeting: finalise 2 nd AO													
Update SP and publish on web													
Issue 2nd AO and 1st studentship AO													
Implement DP													

2001												
ACTIVITY	J	F	M	A	M	J	J	A	S	O	N	D
1 st Studentship AO closing date	16											
2 nd AO closing date		2										
SC meeting: 1 st Studentship AO funding decisions		16										
Draft IP and EP to SC												
COAPEC training course						31						
Publish all plans on web												
SC meeting: 2 nd AO funding decisions							4					
Issue AO for Fellowships												
Issue 2 nd Studentship AO												
Issue 3 rd AO and AO for "User Driven Science" outline bids												
Fellowships closing date									30			
2 nd Studentship AO closing date										5		
"User Driven Science" outline bids closing date										26		
2 nd Annual Meeting										29-30		
SC meeting: 2 nd Studentship AO funding decisions										31		
Appointment of fourth core team member*												
3 rd AO closing date											2	
Expert Panel Meeting: assess "User Driven Science" outline bids												21
COAPEC Newsletter No.1												

2002												
ACTIVITY	J	F	M	A	M	J	J	A	S	O	N	D
Coupled Modelling Workshop		20										
"User Driven Science" full bids closing date			4									
Training Course			14									
Expert Panel Meeting: assess "User Driven Science" full bids			20									
SC meeting: 3 rd AO and "User Driven Science" funding decisions			27									
3 rd Annual Meeting							2-3					
COAPEC Newsletter No.2												

2003												
ACTIVITY	J	F	M	A	M	J	J	A	S	O	N	D
Workshop on Coupled Atmosphere-Ocean Models and their Validation			17									
Interview for Replacement Core Team Post			25									
SC meeting			25									
COAPEC Newsletter No.3												
Workshop on Fluxes						23						
Royal Met Soc Biennial Meeting: in lieu of annual COAPEC meeting								1-5				
Training Course											25&28	

2004												
ACTIVITY	J	F	M	A	M	J	J	A	S	O	N	D
SC meeting	26											
COAPEC Newsletter No.4												
Student Meeting							6					
4 th Annual Meeting							7-8					
J. Climate Special Issue: deadline for submission of papers											8	

2005												
ACTIVITY	J	F	M	A	M	J	J	A	S	O	N	D
SC meeting			1									
COAPEC Newsletter No.5												
Hadley Centre Workshop on Diagnostics			22-23									
Final Meeting/Presentation					24-25							
End of Programme Brochure												
SC meeting											25	

2006												
ACTIVITY	J	F	M	A	M	J	J	A	S	O	N	D
J Climate Special Issue Publication												
KT Event Planning meeting		20										
COAPEC KT Workshop						14-15						
Executive Summary of KT Workshop												

Appendix A Acronyms

AO	Announcement of Opportunity
CGAM	Centre for Global Atmospheric Modelling
DP	COAPEC Data Policy
EP	COAPEC Exploitation Plan
NERC	Natural Environment Research Council
SC	COAPEC Steering Committee
NOCS	National Oceanography Centre, Southampton
SP	COAPEC Science Plan
COAPEC	Coupled Ocean Atmosphere Processes and European Climate

Appendix B Contacts

If you have any comments on this document please send them to

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Appendix C : Data Management Plan

The COAPEC programme never realised a formal, agreed data management plan. The draft data management plan is attached, and was largely adhered to throughout the programme.

COAPEC Data Management

.Summary

The primary aim of data management for the COAPEC programme is to facilitate COAPEC science and ensure that appropriate data produced as part of the programme are available in a form that enables maximum benefit to be derived from the data. The data management can therefore be split into three components. Firstly, to help enable maximum benefit from the data, a strategy is needed for the rapid acquisition and distribution of third party data to the COAPEC community. Secondly, to ensure availability of data during the programme, a strategy is needed for storage and exchange of data as they are produced. Thirdly, to ensure availability of the data after the programme, a strategy is needed for the long-term archiving of the data.

One of the major challenges for data management within COAPEC is the large number of third-party data required for analysis early in the programme. In particular, access to the output from the Hadley Centre HadCM3 1000-year control integrations. The majority of output data produced within the programme will be “time limited”, in that model data are rapidly superseded as modelling techniques improve using knowledge gained during programmes such as COAPEC. Hence, long term archival (more than 5 years) is of less importance than rapid interchange of data within the COAPEC community and dissemination of data to the wider community. To enable maximum benefit from the data, data sets will need to be highly accessibility in terms of conformation to recognised format standards and documentation.

Although there are no observational data collection campaigns as part of the COAPEC programme, it is realised that some of the proposals will use existing observational data to produce enhanced products, such as flux fields, or inversions of existing *in situ* data. These products may prove useful both to the immediate COAPEC community and to the wider NERC and climate communities. Accordingly, some provision is needed within COAPEC to allow publication and dissemination of these products.

.Data Management Objectives

- ∞ To organise access to third party data required for the COAPEC programme.
- ∞ To provide a data management and distribution capability within the COAPEC community.
- ∞ To develop an archive of appropriate COAPEC data for distribution to the wider community.

.Implementation

These objectives will be achieved by the development of a web data catalogue, access to which will be via the British Atmospheric Data Centre (BADC). Third party data will be identified as part of an initial data scoping study (see Appendix A) and throughout the lifetime of the project. The Core Team will organise access to the third party data sets in collaboration with the BADC and give the required technical support for their use. The third party data sets will include output from the Hadley Centre HadCM3 1000-year control integration and European Centre for Medium Range Weather Forecasting (ECMWF) Reanalysis fields.

The Internet, and in particular the World Wide Web, will provide the main interface between researchers, the core team, the BADC and distributed data centres. This will include the searchable data catalogue and interfaces to data products. Information bulletins and details of new data will also be made available via the Internet.

BADC will also hold data provided by researchers, and maintain links to distributed data centres.

.Anticipated Timetable

Activity		2000	2001	2002	2003	2004	2005
Data	Scoping study						
	Catalogue development						
	Ongoing data requirement assessment						
Third	Provision of limited HadCM3 fields						
	Provision of HadCM3 full fields						
	Provision of additional 3 rd party data						
Arc	Data archive population						
	Preparation of final archive						

Activity		2000	2001	2002	2003	2004
Data needs	Scoping study					
	Archive & catalogue development					
	Ongoing					
HadCM3 control	limited time					
Archiving	Data Archive Population					
	Archive system tests and refinement					

.Data Management Deliverables

- ∞ Results of a data scoping study.
- ∞ Provision of third party data, including meteorological analyses, to COAPEC researchers.
- ∞ A data distribution system for the COAPEC project researchers.
- ∞ A long-term archive of COAPEC data for the wider community.
- ∞ A searchable data catalogue.
- ∞ Information and guidance notes on file formats and appropriate metadata.
- ∞ Technical assistance with file formats.
- ∞ Provision of a World Wide Web interface to a trajectory model.
- ∞ Provision of value added products, as identified in the data scoping study.

.Links

Good communications between the BADC, the core team, the distributed data centres and the various COAPEC projects are essential. This will be achieved by attendance of BADC personnel at regular COAPEC meetings, by visits of BADC personnel to sites, both during the scoping study and afterwards for ongoing assessment of data requirements and by informing all researchers of progress through regular information bulletins.

Links to the wider community will be maintained through the provision of general information on the World Wide Web. Links to other sources of useful data and information will be achieved through the BADC web pages.

Appendix D : Exploitation Plan

COAPEC (Coupled Ocean Atmosphere Processes and European Climate) Exploitation Plan

Mission Statement

The COAPEC Programme aims to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean on seasonal to decadal timescales.

1 Introduction

COAPEC is a UK Natural Environment Research Council (NERC) thematic programme to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean on seasonal to decadal timescales.

The full value of a scientific programme, either in commercial or societal quality of life terms, can be attained in a two step process; first the creation and then the exploitation of that knowledge. The [COAPEC Science Plan](#) represents the first step in realising this goal. It outlines the scientific issues central to the COAPEC scientific research, strategies for carrying out this research, and highlights areas that require special attention. The second step will be promoted by implementing this Exploitation Plan. The aim of the COAPEC Exploitation Plan is to identify the potential exploiters of COAPEC research within government and industry, where results from COAPEC will contribute to the development of policy to protect our environment. The [Implementation Plan](#) defines the strategy by which the aims of the Science Plan and the Exploitation Plan will be achieved.

1.1 COAPEC Deliverables

The proposed programme of research for COAPEC will produce the following:

- ∞ Documentation and understanding of the physical mechanisms of coupled processes in the atmosphere-ocean-cryosphere system, especially those relevant to the Atlantic/European sector.
- ∞ Evaluation of the skill with which U.K. climate models simulate the observed climate and climate variability in the Atlantic and European Sector, and identification of the sources of errors.
- ∞ Improvements to numerical models of the ocean-atmosphere-cryosphere system incorporating improved representations of key physical processes.
- ∞ Assessment of any climate predictability, particularly for the U.K. and the rest of Europe.
- ∞ In partnership with the Hadley Centre, contribute to the development of a world-leading national coupled climate model and associated climate forecasting capability.

- ∞ Scientists trained in interdisciplinary skills for environmental modelling and prediction.

1.2 The aim of the Exploitation Plan

The main objectives of the Exploitation Plan are to:

- ∞ Build a community comprised of both academic and non-academic communities, which will generate scientific results, new knowledge and increased understanding.
- ∞ Engage user interest and participation in the Programme through the development of collaborations between users and scientists, which may result in the attraction of co-funding, which could be used to extend the funding profile of the Programme.

2 Engaging user interest and attracting co-funding

2.1 Potential COAPEC Stakeholders

It is envisaged that the major stakeholders in COAPEC will come from the following groups:

- ∞ UK Government Departments - UKMO/Hadley Centre, DEFRA (formerly parts of DETR) and DTI, all have major interests in scientific research on coupled ocean atmosphere processes and their effects on European climate.
- ∞ EC Environment Directorate - the 5th Framework convention announced new funding opportunities for research into the key action on global change in March 1999.
- ∞ Industry - Such areas as Energy, Financial Services (especially Insurance) and Service Industries.

2.2 Why should you – the stakeholder – be interested in COAPEC?

Government and industry have a responsibility to society in terms of wealth creation and quality of life. Therefore, the development of collaboration and participation of government/industry in scientific research is a key objective of NERC policy. Active participation in COAPEC will enable users to be aware of new scientific results at an early stage. Exploitation of improved forecasting skill could have implications for policy makers and Industry in their future planning.

NERC funds can only be used to fund research in academic institutions although, in certain cases, where expert knowledge is required, which is not available within universities, small amounts of funding may be sub-contracted to outside organisations. Co-funding from outside bodies, which needs to be undertaken in collaboration with an academic institution, may take the form of 'help in kind' (e.g. the provision of facilities to carry out research) as well as actual financial contributions. It should be noted that a number of schemes exist which can be used to develop working relationships (see Appendix C: for details).

3 Maximising potential

3.1 Communication

Good communication links between scientific researchers, government and industry will result in more rapid dissemination of new scientific knowledge. This will be achieved through joint meetings between scientists and users, rapid dissemination of key results in the scientific literature and assessment reports, the COAPEC Newsletter and web site (<http://coapec.nerc.ac.uk/>) and, when appropriate, press releases.

Better links should also help government and industry to implement suitable, science-based, policies. There could also be a number of spin-offs from the scientific results, which may not have been considered, but could be exploited by industry.

3.2 Building a community

The successful implementation of the Exploitation Plan, together with realisation of the objectives of the COAPEC Programme will bring value to both the scientific community and government/industry by creating a substantially augmented pool of trained interdisciplinary scientists, available for the solution of complex problems, both in the environmental area and in other disciplines within academia or user organisations. This will result in producing a more educated society.

4 Action plan

The Exploitation Plan is intended as a “living” document that will evolve with time, in conjunction with the [Implementation Plan](#). The COAPEC Steering Committee (SC) and the COAPEC core team will take forward the ideas outlined in this Plan.

4.1 Ways to further collaboration

A number of possible ways to aid the development of joint scientific research ventures between academia and outside organisations have been identified. Other suggestions are welcome

- ∞ Networking: building on existing collaborations (*i.e.* with those organisations with which COAPEC already has contact) and identifying potential new collaborations. The latter may result from COAPEC information dissemination (see §3.1) to increase awareness about COAPEC as well as individual meetings between scientists and users and possibly workshops covering particular areas of science that are of particular significance to COAPEC stakeholders. Potential COAPEC stakeholders have been identified (see §2.1) and will be targeted by the SC, possibly by contacting relevant trade associations in the first instance.
- ∞ Exploitation Plan resource: allocate a small amount of COAPEC funds to manage and facilitate the implementation of the Exploitation Plan.

Appendix A: Natural Environment Research Council – NERC

NERC is the leading UK body for basic, strategic and applied research across the spectrum of the environmental sciences. Its principal budget is from the Office of Science and Technology, complemented by contracts from government departments, other public bodies, the EU and the private sector. NERC is a provider of scientific research, survey and monitoring through its own Centres and Surveys, as well as a customer for work by scientists in university and other institutions.

Mission

The Mission of the Natural Environment Research Council is:

to promote and support, by any means, high quality basic, strategic and applied research, survey, long-term environmental monitoring and related postgraduate training in terrestrial, marine and freshwater biology and Earth, atmospheric, hydrological, oceanographic and polar sciences and Earth observation;

to advance knowledge and technology, and to provide services and trained scientists and engineer, which meet the needs of users and beneficiaries (including the agricultural, construction, fishing, forestry, hydrocarbons, minerals, process, remote sensing, water and other industries), thereby contributing to the economic competitiveness of the United Kingdom, the effectiveness of the public services and policy and the quality of life;

to provide advice on, disseminate knowledge and promote public understanding of the fields aforesaid.

NERC divides its share of the Science Budget into four elements: core strategic, thematic, non-thematic and infrastructure:

Core Strategic funding, typically long term, maintains expertise and knowledge in key areas of the environmental sciences, determined by Council. It supports excellent and relevant research, survey and monitoring; technology development; and the curation, interpretation and supply of environmental data. It meets current needs and forms a basis for meeting future priorities.

Thematic funding encourages scientific excellence and contributes to wealth creation and quality of life through basic, strategic and applied science, technology development, and training, within selected themes. Council's strategic planning, including inputs from Technology Foresight, identifies these themes.

Non-thematic funding fosters excellence by supporting curiosity-driven research, training, and technology development, in areas selected by applicants.

Infrastructure funding provides essential support, equipment, services and facilities for the NERC community.

The ultimate decision making body for NERC is its Council. Council is advised by a Science and Technology Board. Its advice is discussed and assessed by the Resources and Strategy Group before being forwarded to Council.

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The Science & Technology Board is advised by five Peer Review Committees, which assess applications for funding and monitor strengths, weaknesses and opportunities. There is considerable cross-membership between the various boards and committees.

COAPEC is a thematic programme, coming under the remit of both the atmospheric and marine Peer review committees.

Appendix B: Scientific goals of COAPEC

The full text of the COAPEC Science Plan can be found on the COAPEC website (<http://coapec.nerc.ac.uk>). The primary scientific goals of COAPEC are reproduced here.

The overall scientific aim of COAPEC is to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean on seasonal to decadal timescales. The hypothesis will be tested that anomalies in Atlantic sea-surface temperature can be a useful predictor of climate conditions over the UK and the rest of Europe. The programme will fill a significant gap in understanding the climatic effects of ocean-atmosphere coupling, since the majority of international research effort in this field has concentrated on the Pacific Ocean. The UK is in an excellent position to take a world lead in a critically important area of science. The programme envisages a close partnership between the Hadley Centre for Climate Prediction and Research, which has a state-of-the-art coupled model, and NERC scientists who are internationally recognised experts in modelling the climate system, as well as in the scientific interpretation of results. One objective of this partnership will be to consolidate hitherto separate model development plans to produce a world leading national coupled climate model as the core of an "Earth System Model". The particular contribution of the NERC community to this venture will be to provide the basic scientific understanding and training required to develop a credible predictive tool and to exploit it intelligently

The major objective of COAPEC is to determine the impact on climate, especially European climate, of the coupling between the atmosphere and the Atlantic Ocean on seasonal to decadal timescales. To achieve this objective COAPEC will:

- ∞ Understand the role of coupled processes in the climate system and improve the representation of these processes in models used for climate forecasting.
- ∞ Assess climate predictability in the Atlantic/European sector and contribute to the development of a national capability in climate forecasting.
- ∞ Train scientists in the interdisciplinary skills required for environmental modelling and prediction.
- ∞ Facilitate the exploitation by users of COAPEC research.

Appendix C: Partnership Schemes

The NERC participates in a number of Partnership Schemes, some of which are operated nationally while others are specific to NERC. More information on these schemes can be found at the [NERC Industry Gateway web site](#).

NEST scheme. Nest provides a set of services that help exploit science and technology in support of innovation. The objective is to help build sound partnerships for innovation with direct access to the necessary resources, to improve the connectivity between the problem and solution holders, to help stimulate and facilitate new partnerships: <http://www.nest.ac.uk/> and <http://www.nerc.ac.uk/industry-gateway/partnership.htm - nest>.

TCS (formerly known as the Teaching Company Scheme) is operated by the Teaching Company Directorate (TCD). The Directorate is dedicated to helping industry innovate through collaboration with research and education. TCS enables firms to take advantage of the wealth of scientific, engineering and technological knowledge and business management expertise available in the “knowledge base”. Each TCS Programme involves one or more high quality graduates (TCS Associates) working in a company for two years on a project that is central to the company’s needs. TCS Programmes are jointly supervised by representatives of both the knowledge base and the company partners: <http://www.tcd.ac.uk/> and <http://www.nerc.ac.uk/industry-gateway/partnership.htm - tcs>.

Connect A/B. Connect A is a NERC programme to be used for pump priming funding for short research projects, workshops or seminars to a maximum value of £5k normally with industrial relevance. This does NOT need to have industrial support, but it can be a useful source of funds to scope the possibility of a TCS programme for example. Connect B is a NERC standard type grant award that requires 50% funding from industry up to £200k for innovative partnerships: <http://www.nerc.ac.uk/industry-gateway/partnership.htm - Grants>.

Industrial CASE scheme. A postgraduate training scheme where the idea is generated by industry and the University is selected by the industrial partner. The project is co-supervised: <http://www.nerc.ac.uk/industry-gateway/partnership.htm - Studentships>.

Faraday Partnerships are an EPSRC programme that focuses on improving the interaction between the British research base and industry, through the involvement of intermediate organisations: http://www.epsrc.ac.uk/EPSRCWEB/MAIN/Ind_Uni/FundMech/faradays.htm.

Appendix D: Contacts

If you have any comments on this document please send them to

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Appendix E : List of Awards

First Round

Investigators	Institutions	Title	Researchers
Dr M Allen Prof A Thorpe	Oxford Met Office	Public involvement in climate forecasting under COAPEC	Dave Frame (Oxford) Dave Stainforth (Oxford)
Dr G Bigg Dr W Turrell	Sheffield SOAEFD	Salinity minima in the Nordic and Arctic Seas: coupled climate anomalies?	Martin Wadley (UEA)
Dr K Haines Dr S Josey	Reading NOCS	On the evolution of observed oceanic heat anomalies and those in HADCM3	Chris Old (ESSC, Reading)
Dr K Heywood Dr D Stevens	East Anglia	How well to coupled models portray the observed thermohaline circulation?	Louise C Sime (UEA) Related research by Alberto Naveira Garabato (UEA)
Prof B Hoskins Dr D Marshall	Reading	Mechanisms of North Atlantic Ocean-Atmosphere Interaction	Manoj Joshi (Reading) Maarten Ambaum (Reading)
Dr S Josey	NOCS	Balancing the Atlantic Heat and Freshwater Budgets	Jeremy Grist (NOCS)
Dr P Killworth	NOCS	An eddy-resolving coupled ocean-atmosphere model for climate research	Andy Hogg (NOCS)
Dr B Lawrence Dr L Gray Dr M Allen Dr J Palutikof Dr T Haine	RAL Oxford East Anglia John Hopkins, Baltimore	Predictability of the coupled ocean-atmosphere system in the North Atlantic/European sector	Scott Osprey (RAL) Tim Osborn (UEA)
Dr S Laxon Dr D Feltham	UCL	Optimisation of an Arctic sea ice model using spaceborne estimates of ice thickness	Paul Miller (UCL) Related research by Douglas Cresswell (UCL)
Prof J Marotzke Prof J Shepherd Dr N Wells	NOCS	North Atlantic decadal variability in different thermohaline circulation regimes: A hierarchical coupled ocean-atmosphere modelling approach	Matthew Brand (NOCS)
Dr A Matthews Dr G Bigg Dr D Stevens	East Anglia Sheffield East Anglia	Ocean-atmosphere coupling in tropical Atlantic warm events and their impact on European climate	Itsuki Handoh (UEA)
Dr R Sutton Prof A O'Neill	Reading	Northward Heat Transport in the Atlantic Ocean and Atmosphere	Len Shaffrey (Reading)
Dr R Williams	Liverpool	The role of oceanic ventilation in the coupled climate system	Chris Wilson (Liverpool)

Second Round

Investigators	Institutions	Title	Researcher
Dr A New Dr N Wells	NOCS	North Atlantic variability and predictability, and impacts on European climate, in UK coupled models	Alex Megann (NOCS) Bob Marsh (NOCS)
Dr R Sutton Prof A O'Neill	Reading	Seasonal Forecasting for Europe: The Role of the Atlantic Ocean	Steve George (Reading)
Prof P Valdes Dr J Bamber Prof J Shepherd	Bristol NOCS	The role of sea ice on seasonal to decadal variability in the North Atlantic	Joy Singarayer (Bristol) Bob Marsh (NOCS)

Third Round

Investigators	Institutions	Title	Researcher
Dr MR Allen	Oxford	A synthetic analog approach to seasonal forecasting	

Project funded under the call for "New Observations in Support of COAPEC Science"

Investigators	Institutions	Title	Researcher
Dr BA King	NOCS	Argo floats in the South Atlantic	Mike Sparrow (NOCS)

Projects funded under the call for "User Driven Science"

Investigators	Institutions	Title	Researcher
Dr GR McGregor Prof JI Petts	Birmingham	Climate information for the health sector	Michelle Cox, Zhiqiang Cui & Anna Tripp (Birmingham)
Dr DB Stephenson Prof A O'Neill Dr R Sutton	Reading	Quantifying the economic value of coupled ocean-atmosphere model ensemble forecasts for decision making within the UK energy industry	Sergio Pezzulli (Reading)

PhD Studentship Awards

All the studentships have now been completed.

Principal Investigator	Project	Location	Student
Dr Grant R Bigg	The impact of polar mesocyclones on deep water formation	University of Sheffield	Alan Condron
Prof Harry L Bryden	Variability in North Atlantic Water Mass Transformations around the Subpolar Gyre	National Oceanography Centre, Southampton	Richard Levine
Dr Karen Heywood	Does the Southern Ocean influence European Climate?	University of East Anglia	Glen Richardson
Prof BJ Hoskins	Climate Variability in the N Atlantic/European Region	University of Reading	Evangelos Tyrlis
Prof Jochem Marotzke	The predictability of climate parameters in eddy-resolving ocean-atmosphere models	National Oceanography Centre, Southampton	Fiona McLay
Dr Adrian Matthews	Intraseasonal European climate variability via tropical - extratropical interaction	University of East Anglia	Oliver Charlesworth
Prof Alan O'Neill	Potential Climate Predictability on Multi-Annual Time Scales	University of Reading	Pascal Mailier
Dr Kelvin Richards	The role of the ocean in climate variability	National Oceanography Centre, Southampton	Clotilde Dubois
Dr Mark Saunders	The Seasonal Predictability of European Extreme Weather (CASE sponsored by Deutsche Bank)	University College London	Fiona Parton
Dr David B Stephenson	Complexity in North Atlantic Weather and Climate	University of Reading	Tim Mosedale
Dr NC Wells	Impact of the ocean cross equator heat transport on the SST 'dipole'	National Oceanography Centre, Southampton	Adam Blaker
Dr Ric Williams	Impact of interannual changes in the coupled atmosphere-ocean on the European Shelf	University of Liverpool	Susan Leadbetter
Prof Jochem Marotzke	A tied studentship on the project North Atlantic decadal variability in different thermohaline circulation regimes: A hierarchical coupled ocean-atmosphere modelling approach	National Oceanography Centre, Southampton	Marc Lucas
Dr Adrian Matthews	Coupled ocean-atmosphere modes in the tropical Atlantic. A tied studentship on the project: Ocean-atmosphere coupling in tropical Atlantic warm events and their impact on European climate	University of East Anglia	Patricia O'Mahony

Appendix F : Financial Summary

	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	Total
Allocations	21,000	287,000	888,000	1,567,000	1,210,000	844,491	406,771	158,000	5,382,262
Programme Administration	7,000	7,000	8,000	8,000	4,521	4,451	5,655	2,300	46,927
Awards		71,517	552,890	966,668	738,254	389,339	157,471	14,376	2,890,516
HEI Awards		5,563	38,227	74,306	180,435	154,760	77,094	11,225	541,611
PhD Awards		1,184	1,628	1,139	6,040	0	221	1,481	12,658
Steering Committee	965								
Science Meetings		6,000	7,607	5,629	10,679	17,391	2,895		50,201
KT Workshop							69	4,830	4,899
Support time							2,422		2,422
Clivar Workshop Sponsorship							224		224
Student Travel Fund					7,900	479	2,039		10,418
FINALE Event							24,147	219	24,366
Sci Co-Ordinator	7,010	23,442	33,421	28,824	29,372	24,708	14,463	25,828	187,068
Data Management		5,000	8,800	11,200	5,000		8,500		38,500
Services & Facilities			66,441	197,000	50,000	43,000	15,000		371,441
Other Spend			53,388	44,521	47,778	51,382	25,572		272,219
CGAM Core Team		94,231	94,873	103,713	106,483	3,200		2,871	405,371
CCLRC Core Team			31,400	56,000	74,300	60,000	49,200	0	270,900
CCLRC Beowulf Cluster				66,600		44,000	21,800	0	132,400
Publicity	5,956	19,296						9,709	34,961
	20,931	286,621	887,808	1,566,857	1,262,563	792,710	406,771	72,838	5,297,100

Appendix G : Publication List

Note: This list includes all those publications of which we are aware as at March 2007.

Names appearing in bold are COAPEC programme PIs, CoIs or funded PostDocs or PhD students.

Refereed Papers

- 1- **Allen, M.R.** and W.J. Ingram (2002). Constraints on future changes in climate and the hydrologic cycle. *Nature*, **419(6903)**, 224-227.
- 2- **Allen M.R.** (2003). Liability for climate change. *Nature*, **421(6926)**, 891-892.
- 3- **Allen M.R.** and R. Lord (2004). The Blame Game - who will pay for the damaging consequences of climate change? *Nature*, **432(7017)**, 551-552.
- 4- **Allen M.R.** and **D.A. Stainforth** (2002). Towards objective probabilistic climate forecasting. *Nature*, **419(6903)**, 228.
- 5- **Ambaum, M.H.P.** and **B.J. Hoskins** (2002). The NAO troposphere-stratosphere connection. *J. Climate*, **15(14)**, 1969-1978.
- 6- **Ambaum, M.H.P.**, **B.J. Hoskins** and **D.B. Stephenson** (2001). Arctic Oscillation or North Atlantic Oscillation? *Journal of Climate*, **14(16)**, 3495-3507. And see corrigendum (2002), *J. Climate*, **15(5)**, 553.
- 7- **Ambaum, M.H.P.** and **D.P. Marshall** (2005). The effects of stratification on flow separation. *J. Atmos. Sci.*, **62**, 2618-2625.
- 8- **Bigg, G.**, S.R. Dye and **M.R. Wadley** (2005). Interannual variability in the 1990s in the northern Atlantic and Nordic Seas. *J. Atmos. Ocean Sci.*, **10(2)**, 123-143.
- 9- **Black, E.** and **R. Sutton** (2007). The influence of oceanic conditions on the hot European summer of 2003. *Climate Dynamics*, **28**, 53-66.
- 10- **Black, E.** M. Blackburn, G. Harrison and J. Methven (2004). Factors that contributed to the European Heatwave in Summer 2003. *Weather*, **8**, 217-223.
- 11- **Blaker, A.T.**, **B. Sinha**, V.O. Ivchenko, **N.C. Wells** and V.B. Zalesny (2006). Identifying the roles of the ocean and atmosphere in creating a rapid equatorial response to a Southern Ocean anomaly. *Geophys. Res. Lett.*, **33(6)**, L06720, doi:10.1029/2005GL025474.
- 12- Coelho, C.A.S., **S. Pezzulli**, M. Balmaseda, F.J. Doblas-Reyes and D.B. Stephenson (2004). Forecast calibration and combination: A simple Bayesian approach for ENSO. *J. Climate*, **17(7)**, 1504-1516.
- 13- **Collins, M.** (2002). Climate predictability on interannual to decadal time scales: The initial value problem, *Climate Dynamics*, **19**, 671-692.
- 14- **Collins, M.** (2000). The El-Niño Southern Oscillation in the second Hadley Centre coupled model and its response to greenhouse warming. *J. Climate*, **13(7)**, 1299-1312.
- 15- **Collins, M.** (2000). Understanding uncertainties in the response of ENSO to greenhouse warming. *Geophys. Res. Lett.*, **27(21)**, 3509-3513.
- 16- **Collins, M.** and **M.R. Allen** (2002). Assessing the relative roles of initial and boundary conditions in interannual to decadal climate predictability. *J. Climate*, **15(21)**, pp3104-3109.

- 17- **Collins, M.**, M. Botzet, A. Carril, H. Drange, A. Jouzeau, M. Latif, O.H. Otteraa, H. Pohmann, A. Sorteberg, **R. Sutton** and L. Terray (2006). Interannual to decadal climate predictability: A multi-perfect-model ensemble study. *J. Climate*, **19(7)** (COAPEC Special Issue), 1195-1203.
- 18- **Collins, M.**, **D. Frame**, **B. Sinha** and **C. Wilson** (2002). How far ahead could we predict El Niño? *Geophys. Res. Lett.*, **29(10)**,
- 19- **Collins, M.**, T.J. Osborn, S.F.B. Tett, K.R. Briffa and F.H. Schwingruber (2002). A comparison of the variability of a climate model with palaeo-temperature estimates from a network of tree-ring densities. *J. Climate*, **15(13)**, 1497-1515.
- 20- **Collins, M.** and **B. Sinha** (2003). Predictability of decadal variations in the thermohaline circulation and climate. *Geophys. Res. Lett.*, **30(6)**, 1306, doi:10.1029/2002GL016504.
- 21- **Collins, M.**, S.F.B. Tett and C. Cooper (2001). The internal climate variability of HadCM3, a version of the Hadley Centre coupled model without flux adjustments. *Climate Dynamics*, **17**, 61-81.
- 22- **Condron, A.**, **G.R. Bigg**, and I.A. Renfrew (2006) Polar mesoscale cyclones in the northeast Atlantic: Comparing climatologies from ERA-40 and satellite imagery, *Monthly Weather Review*, **134**, 1518-1533.
- 23- Smith, R.S., **Dubois, C.** and **Marotzke, J.** (2006). Global Climate and Ocean Circulation on an Aquaplanet Ocean-Atmosphere General Circulation Model. *J. Climate*, **19(18)**, 4719-4737.
- 24- Ferranti, L., E. Klinker, A. Hollingsworth and **B.J. Hoskins** (2002). Diagnosis of systematic forecast errors dependent on flow pattern. *Q. J. R. Meteorol. Soc.*, **128(583)**, 1623-1640
- 25- **George S.E.** and **R.T. Sutton** (2006). Predictability and skill of seasonal forecasts made with the ECMWF Seasonal Forecasting System II. *Q. J. R. Meteorol. Soc.*, **132(619)**, 2031-2053.
- 26- **Grist, J.P.** and **S.A. Josey** (2003). Inverse analysis of the SOC air-sea flux climatology using ocean heat transport constraints. *J. Climate*, **16(20)**, 3274-3295.
- 27- **Haines, K.** and **C.P. Old** (2005). Diagnosing natural variability of the North Atlantic water masses in HadCM3. *J. Climate*, **18**, 1925-1941.
- 28- **Handoh, I.C.**, **G.R. Bigg**, **A.J. Matthews** and **D.P. Stevens** (2006). Interannual variability of the tropical Atlantic independent of and associated with ENSO: Part II. The South Tropical Atlantic. *Int. J. Climatol.*, **26**:1957-1976 doi:10.1002/joc.1342
- 29- **Handoh, I.C.**, **A.J. Matthews**, **G.R. Bigg** and **D.P. Stevens** (2006). Interannual variability of the tropical Atlantic independent of and associated with ENSO: Part I. The North Tropical Atlantic. *Int. J. Climatol.*, **26**:1937-1956 doi: 10.1002/joc.1343
- 30- **Hogg, A.McC.**, **W.K. Dewar**, **P.D. Killworth** and J.R. Blundell (2006). Decadal variability of the midlatitude climate system driven by the ocean circulation. *J. Climate*, **19(7)** (COAPEC special issue), 1149-1166.
- 31- **Hogg A.McC.**, **W.K. Dewar**, **P.D. Killworth** and J.R. Blundell (2003). A quasi-geostrophic coupled model: Q-GCM. *Monthly Weather Review*, **131**, 2261-2278.

- 32- **Hogg, A.McC., P.D. Killworth**, J.R. Blundell and **W.K. Dewar** (2005). Mechanisms of decadal variability of the wind-driven ocean circulation. *J. Phys. Oceanogr.*, **35**, 512-531.
- 33- Hurrell, J.W., M. Visbeck, A. Busalacchi, R.A. Clarke, T.L. Delworth, R.R. Dickson, W.E. Johns, K.P. Koltermann, Y. Kushnir, D. Marshall, C. Mauritzen, M. S. McCartney, A. Piola, C. Reason, G. Reverdin, F. Schott, **R. Sutton**, I. Wainer and D. Wright (2006). Atlantic climate variability: a CLIVAR perspective. *J. Climate*, **19**:5100-5121
- 34- Inatsu, M. and **B.J. Hoskins** (2004). The zonal asymmetry of the Southern Hemisphere storm-track. *J. Climate*, **17(24)**, 4882-4891
- 35- **Iwi, A., R.T. Sutton** and W. Norton (2006). Influence of May Atlantic Ocean initial conditions on subsequent North Atlantic winter climate, *Q. J. R. Meteorol. Soc.*, **132(621C)**, 2977-2999.
- 36- Johnson, H., R.S. Kovats, **G. McGregor**, J. Stedman, M. Gibbs, H. Walton, L. Cook and **E. Black** (2005). The impact of the 2003 heat wave on mortality and hospital admissions. *England Health Statistics Quarterly*, **18**.
- 37- Johnson, H.L. and **D.P. Marshall** (2002). A theory for the surface response to thermohaline variability. *J. Phys. Oceanog.*, **32**, 1121-1132.
- 38- Johnson, H.L. and **D.P. Marshall** (2002). Localization of abrupt change in the North Atlantic thermohaline circulation. *Geophys. Res. Lett.*, **29(6)**, 7-1 to 7-4.
- 39- Jones, C. D., **M. Collins**, P.M. Cox and S. Spall (2001). The carbon cycle response to ENSO: A coupled climate-carbon cycle model study. *J. Climate*, **14**, 4113-4129.
- 40- **Josey, S. A.**, E.C. Kent and **B. Sinha** (2001). Can a state of the art atmospheric general circulation model reproduce recent NAO related variability at the air-sea interface? *Geophys. Res. Lett.*, **28(24)**, 4543-4546.
- 41- **Josey, S.A.**, R.W. Pascal, P.K. Taylor and M.J. Yelland (2003). A new formula for determining the atmospheric longwave flux at the ocean surface at mid-high latitudes. *J. Geophys. Res.*, **108(C4)**, doi:10.1029/2002JC001418.
- 42- **Mailier, P., D.B. Stephenson**, C.A.T. Ferro and K.I. Hodges (2006). Serial Clustering of Extratropical Cyclones. *Monthly Weather Review*, **134**, 2224-.
- 43- **Mathieu, P-P., R.T. Sutton**, B. Dong and **M. Collins** (2004). Predictability of winter climate over the North Atlantic European region during ENSO events. *J. Climate*, **17(10)**, 1953-1974.
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- 45- **McGregor, G.R., M. Cox**, Y. Cui, Z. Cui, M. K. Davey, R. F. Graham, and A. Brookshaw (2006). Winter-Season Climate Prediction for the U.K. Health Sector. *Journal of Applied Meteorology and Climatology*, **45(12)**, 1982-1792.
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- 48- McLaren, A.J. and **R.G. Williams** (2001). Interannual variations in the thermodynamics of subduction over the North Atlantic. *J. Phys. Oceanogr.*, **31**, 3284-3294.
- 49- **Miller, P., S.W. Laxon** and **D.L. Feltham** (2005). Improving the spatial distribution of modeled Arctic sea ice thickness. *Geophys. Res. Letts.*, **32**.
- 50- **Miller, P., S. Laxon, D. Feltham** and **D. Cresswell** (2006). Optimization of a sea ice model using basin-wide observations of Arctic Sea ice thickness, extent and velocity. *J. Climate*, **19(7) (COAPEC Special Issue)**, 1089-1108.
- 51- **Mosedale, T.J., D.B. Stephenson** and **M. Collins** (2005). Atlantic atmosphere-ocean interaction: A stochastic climate model-based diagnosis. *J. Climate*, **18(7)**, 1086-1095.
- 52- **Mosedale, T.J., D.B. Stephenson, M. Collins** and T.C. Mills (2006). Granger causality of couple climate processes: Ocean feedback on the North Atlantic oscillation. *J. Climate*, **19(7) (COAPEC Special Issue)**, 1182-1194.
- 53- **Old, C.P.** and **K. Haines** (2006). North Atlantic subtropical mode waters and ocean memory in HadCM3. *J. Climate*, **19(7) (COAPEC Special Issue)**, 1126-1148.
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Appendix H : Climate Model Briefing Note

Climate models

Tools for understanding the Earth system

Climate change is one of the most important environmental issues we face this century. The top research priority for the Natural Environment Research Council is to gather knowledge about climate and what controls it, and then use that knowledge to predict future changes.

Predictions are made using climate models. Here we describe what climate models are, what they do and how much we can trust them.

Coupled Ocean-Atmosphere Processes and European Climate (COAPEC)
This brochure is a product of the Natural Environment Research Council's COAPEC programme. COAPEC aimed to determine how coupling between the atmosphere and the Atlantic Ocean over seasons to decades affects climate, especially in Europe. A major focus of COAPEC research has been developing and evaluating climate models and their use to understand climate processes.



pressure

What is a climate model?

A climate model is a computer program designed to simulate Earth's climate. Climate models are based on mathematical equations that describe the behaviour of the atmosphere and ocean, and their interactions with other components of the Earth system, such as the cryosphere (ice sheets, glaciers and sea-ice), the land surface and the biosphere (living organisms, particularly plants).

A model's core equations, which are derived from the laws of physics, describe how temperature, pressure, winds (or currents) and other variables in the atmosphere and oceans change over time. Additional equations describe chemical and biological aspects of the climate system.

In a model, the climate variables are represented on a three-dimensional grid covering the atmosphere and the oceans. The spacing between grid points in the atmosphere is typically a few hundred kilometres horizontally and 500 metres vertically. Figure 6 shows the grid structure of a climate model schematically.

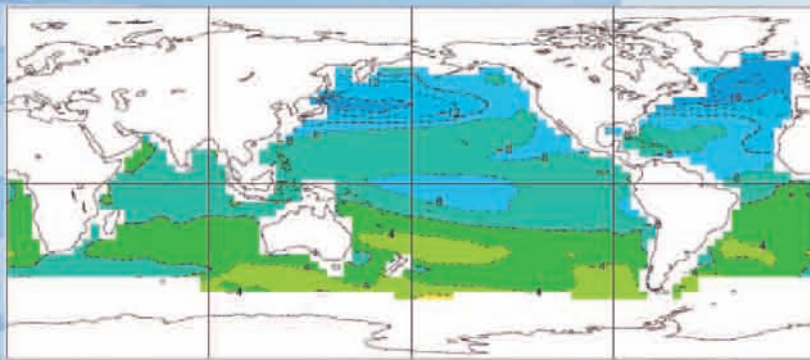
How do climate models help us understand climate?

The climate system is very complex, and this makes understanding it difficult. To make scientific progress, we need to explore mechanisms and test theories by carrying out experiments. It is not feasible to experiment on the climate system itself, nor is it possible to reproduce the full complexity of the climate system in a laboratory. Climate models offer us the best possible alternative – a numerical laboratory where we can address vital questions.

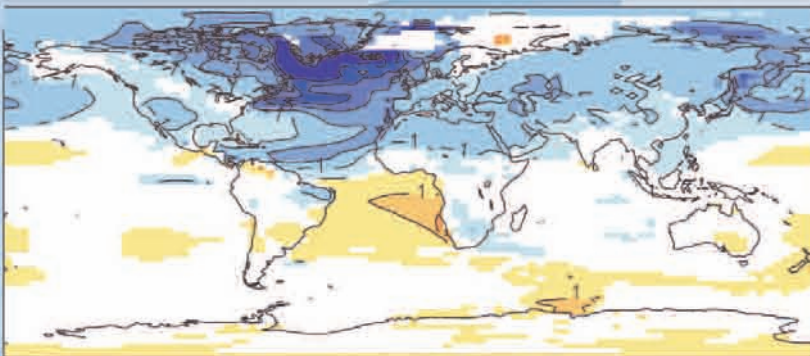
- How will the climate change in response to rising levels of greenhouse gases?
- What would happen to the climate of Europe if the Atlantic Ocean's thermohaline circulation (the current that carries warm water to northwestern Europe) were to stop?
- What controlled Earth's climate in the past?

temperature

Dr Seong-Joong Kim, Duke University



1. Results from a climate model experiment estimating how global sea-surface temperature at the last glacial maximum, approximately 21,000 years ago, differed from the present day.



2. A climate model experiment that shows how turning off the thermohaline circulation could affect surface temperatures across Europe.

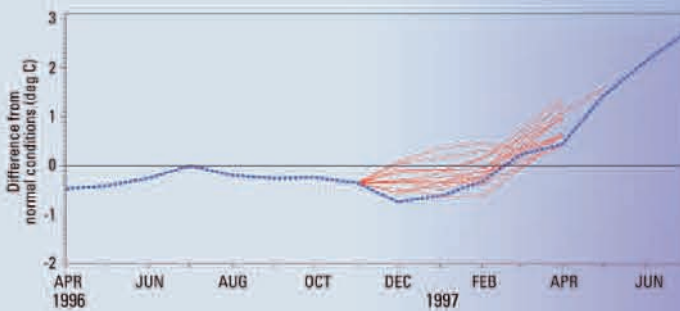
Dr Michael Vellinga, Met Office, Hadley Centre

What makes scientists trust climate models?

Climate researchers are confident that climate models can accurately represent key aspects of the climate system:

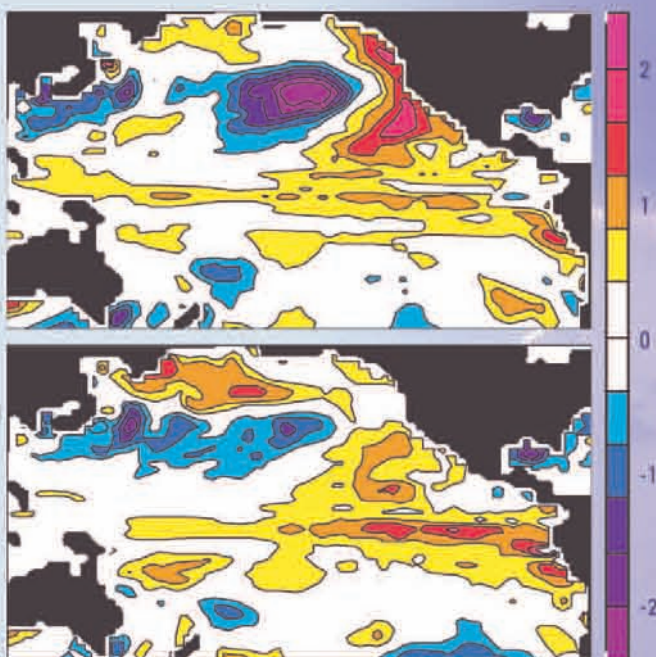
- The core of a climate model uses well-understood physical, chemical and biological equations and principles.
- Climate models are continually evaluated against datasets of real observations. The results show that the models can reproduce many aspects of present and past climate, including the overall strength and pattern of recent observed climate change.
- Prediction is often considered the ultimate test of understanding. It has been shown that climate models can successfully forecast the weather, and even major climate phenomena such as El Niño (see figures below).

Climate models are the only scientifically credible tools for making detailed predictions about climate on a regional scale. Nonetheless, because climate models are mathematical approximations of the climate system and not the system itself, their results must be treated with due scientific caution.



3. It is clear from this graph that climate models can correctly predict climate events, such as the onset of the 1997-1998 El Niño. The graph shows the actual (blue) and forecast (red) sea-surface temperature in the equatorial Eastern Pacific; the red lines represent several different forecasts, all of which predict the timing accurately.

Figure from ECMWF Newsletter, no 7.



4. This model correctly forecast the main pattern of warmer- and cooler-than-usual sea surface temperatures (anomalies) during the 1997-1998 El Niño six months before they occurred. The upper panel shows the actual temperature anomalies in the Pacific Ocean in May 1997. The lower panel is the prediction made in December 1996 – before the onset of the El Niño.

Figure from ECMWF Newsletter, no 7.



cryosphere osphere



Questions asked about climate models

Are climate models too simple? They ignore lots of things...

Climate models include as many physical, chemical and biological processes as possible. If a particular climate model is to be a useful tool, researchers must be sure it adequately describes the phenomena of interest. Current models are certainly good enough to simulate large-scale climate phenomena. Identifying the limitations of a particular model is part of the process that stimulates further improvements and advances our understanding. Developing climate models is a 'grand challenge' and, over time, they have become much more comprehensive and accurate. But there is still a long way to go!

Are climate models too complex? Don't we need simpler models to understand processes properly?

Simple models, perhaps based on only one or two equations, can give valuable insight into a particular mechanism. However, they are not in themselves sufficient. They inevitably neglect or greatly simplify a host of interactions that operate in the real climate system. So scientists use a hierarchy of mathematical models for climate research, ranging from the simplest to the most complex. Climate models provide tools to describe climate complexity, and explore the extent to which particular mechanisms might be relevant. Because of the numerous interactions and feedbacks in a climate model, experiments can produce unexpected results, and scientists sometimes go back to simpler models to investigate these. Climate models can also be a useful source of new ideas.

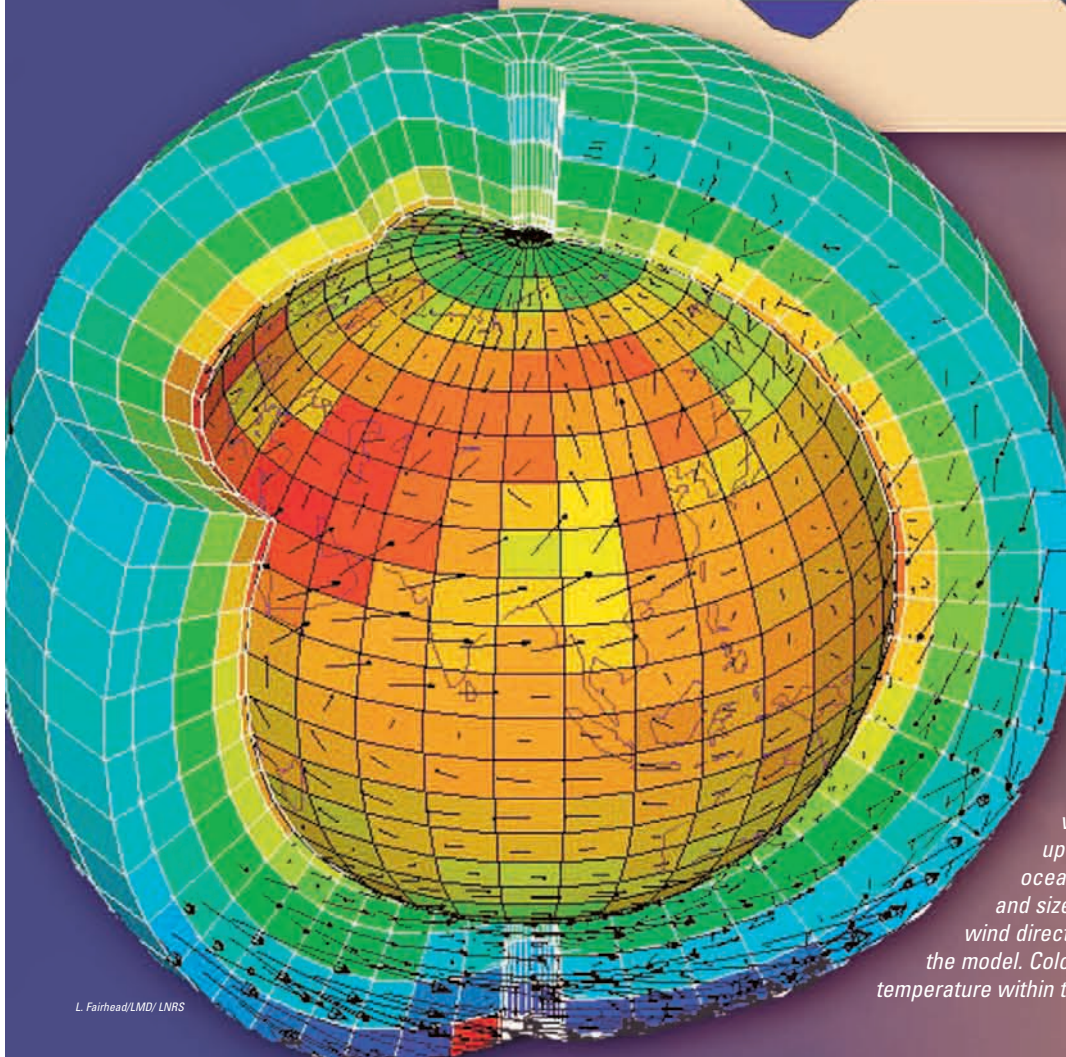
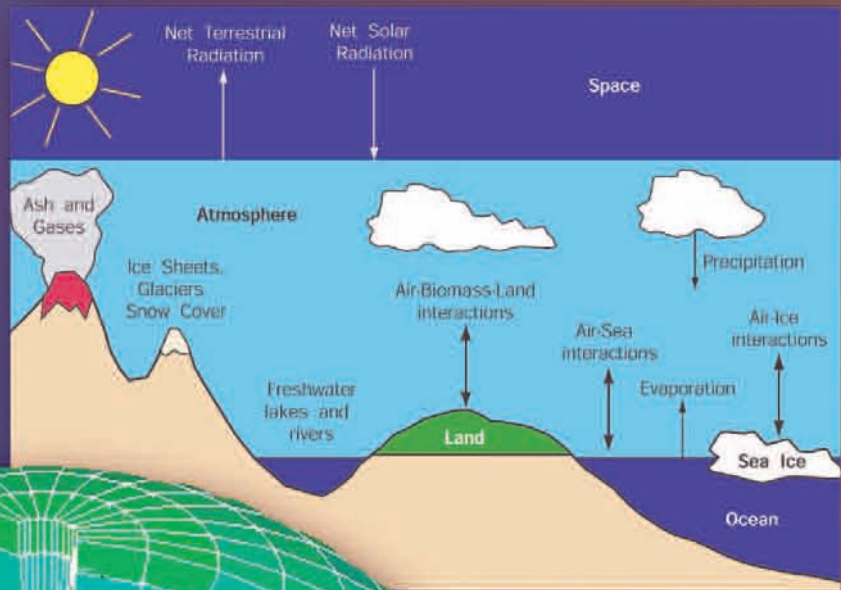
Aren't climate models tuned to give the right answer? If so, how can you possibly evaluate them?

Before a particular climate model is used, it is tuned to reproduce a large-scale average climate that agrees with actual observations. The tuning process does involve fixing values for some variables that we're uncertain about. But tuning does not change the core model equations and these constrain the outcomes the model could produce – so climate models cannot be tuned to give any 'desired' answer. Once set up, models are not re-tuned for different situations without very good physical reasons.

Climate models sometimes disagree. Can they be trusted?

All climate models are based on the same basic physics, but they differ in some other details. So, although they broadly agree, they can generate different outcomes. Studying what makes models disagree is an important area of research that advances our understanding. Comparing results from different models helps us assess uncertainty, enabling us to estimate the likelihood of various changes to our future climate.

5. The components of the climate system. State-of-the-art climate models include representations of all of these components and the interactions between them.



6. Climate models use horizontal and vertical grids to divide up the atmosphere and oceans. The orientation and size of the arrows show wind direction and strength in the model. Colours denote temperature within the grid box.

L. Fairhead/LMD/ CNRS

predictions modelling

forecasting

Contacts

Natural Environment Research Council (NERC)

Tel: 01793 411500, www.nerc.ac.uk

NERC collaborative centres with a major focus on climate models:

NERC Centres for Atmospheric Science (NCAS)

Tel: 0113 3435158 or 0113 3436408, <http://ncas.nerc.ac.uk>

National Oceanography Centre, Southampton

Tel: 023 8059 6666, www.noc.soton.ac.uk

Other NERC centres working on climate change:

British Antarctic Survey

Tel: 01223 221400, www.antarctica.ac.uk

British Geological Survey

Tel: 0115 936 3100, www.bgs.ac.uk

Centre for Ecology & Hydrology

Tel: 01305 213500, www.ceh.ac.uk

Centre for Polar Observation and Modelling

Tel: 0207 679 3031, www.cpom.org

Centre for Terrestrial Carbon Dynamics

Tel: 0114 222 3803, www.shef.ac.uk/ctcd

Environmental Systems Science Centre

Tel: 0118 378 8741, www.nerc-essc.ac.uk

Plymouth Marine Laboratory

Tel: 01752 633100, www.pml.ac.uk

Tyndall Centre for Climate Change Research

Tel: 01603 593900, www.tyndall.ac.uk

For more information:

climateprediction.net

The largest experiment to produce a forecast of the climate in the 21st century.

www.climateprediction.net

Hadley Centre for Climate Prediction & Research

Tel: 0870 900 0100,

www.met-office.gov.uk/research/hadleycentre

Intergovernmental Panel on Climate Change

www.ipcc.ch

International Geosphere-Biosphere Programme

www.igbp.kva.se

UK Environmental Change Network

Tel: 01524 595800, www.ecn.ac.uk

UK Climate Impacts Programme (UK CIP)

Tel: 01865 285717, www.ukcip.org.uk

World Climate Research Programme

www.wmo.ch/web/wcrp/wcrp-home.html

This brochure was produced by Emily Black, Pierre-Philippe Mathieu and Rowan Sutton in collaboration with the COAPEC steering committee and NERC's Communications team.

Front cover: Surface temperature output from a climate model. Blue indicates low temperature and red indicates high temperature. Simulations like this are used to explore scenarios for future climate.

The UK's Natural Environment Research Council funds and carries out impartial scientific research in the sciences of the environment. NERC trains the next generation of independent environmental scientists. NERC invests 28% of its total expenditure on climate research through collaborative centres, dedicated research centres and in universities across the UK.



Appendix I : Knowledge Transfer Workshop Exec Summary & Recommendations

Towards Better Seasonal-to-Decadal Climate Predictions: a joint COAPEC / NCAS / Met Office / ECMWF Workshop

Executive Summary

1. We live at a time of increasing awareness of human vulnerability to climate variability and change. The southeast of England is currently subject to major restrictions on water use, partly as a consequence of an unusually dry winter. In 2003 the UK and much of Europe suffered from a record heat wave which caused tens of thousands of premature deaths. Elsewhere in the world high-impact weather events such as Hurricane Katrina have caused deaths, major displacement of human populations, and billions of dollars of damage.

2. While these individual events cannot be directly attributed to a particular cause, there is now compelling evidence that the likelihood of similar high-impact events is increasing as a consequence of anthropogenic climate change. It follows that governments, organisations and individuals will need to pay increasing attention to weather and climate related risks.

3. Development of appropriate strategies to manage weather and climate risks requires information about future climate. The key **user need** is for trustworthy (unbiased, reliable, minimum uncertainty) predictions of regional and local climate and its impacts. Predictions are particularly needed for time horizons of months-to-decades ahead, corresponding to the typical planning time horizons of many organisations.

4. Meeting this user need presents an unprecedented "**grand challenge**" to the scientific community. There are many dimensions to this challenge:

- **Challenges in fundamental science**

While the science that governs global climate change is now well established, understanding of the factors that influence regional and local changes in climate, and their impacts, is much less advanced. Critical questions such as the following raise fundamental scientific challenges.

- How will patterns of precipitation change, and what will be the impacts on water availability, health, agriculture and food supply in vulnerable regions?
- How frequently should European summers as hot as 2003 be expected, and what will be the impacts of future hot summers on water management, health and agriculture?
- Are catastrophic events such as Hurricane Katrina a sign of things to come? Will such events become more frequent in the future?

- **Challenges in the development of climate prediction systems**

The development of systems to predict regional and local climate for time horizons of months-to-decades is still at an early stage. At the heart of a climate prediction

system is a numerical model of the climate system, and the improvement of such models is a key challenge. In addition, new methods are needed to combine observations with models in order to initialise climate predictions, and to obtain appropriate measures for the uncertainty of predictions.

- **Challenges in bridging the gap between climate forecasts and user decisions**

Users are typically interested in very specific aspects of climate or weather which relate to their particular vulnerabilities. New approaches and mechanisms are needed to extract from climate predictions the application-specific information required for decision making by individual users. There is also a need for climate scientists to work with decision makers in order to better understand the nature and extent of specific weather and climate related risks, and the options available to manage these risks.

5. The above challenges are considerable, but there is now an unprecedented opportunity to achieve major advances. This opportunity arises from several developments:

- a) Interest in climate change issues amongst UK politicians, notably the Prime Minister, is very high. Other important international policy issues, e.g. Africa, also have important climate dimensions. The international COP/MOP process has begun to give greater attention to adaptation issues (in addition to mitigation). Likewise, DEFRA and MoD are showing increasing interest in the climate of the next few decades. Climate change is a priority issue for the 2007 Comprehensive Spending Review.
- b) Establishing a position as a world leader in the provision of seasonal-to-decadal regional and local climate predictions is a major economic opportunity for the UK. Climate change is happening and businesses will increasingly need to factor weather and climate risks into their planning. Consequently, there will be a growing demand for the best possible advice about future climate. It is almost inevitable that the need for this advice will spawn the development of a substantial consultancy industry, which will be reliant on public sector investments for the provision of both raw climate forecasts and expertise in the form of trained climate scientists. As an already acknowledged leader in global climate prediction, the UK is ideally placed to become a leader in the provision of the new regional, local and near-term climate predictions required by businesses, thereby stimulating the development of a UK based consultancy industry that could have worldwide reach.
- c) Great progress has already been achieved toward the development of a UK national strategy for climate model development which effectively integrates expertise at the Met Office and Hadley Centre, in the NERC community, and elsewhere. Internationally, the EU ENSEMBLES project and ECMWF are playing key roles in achieving coordination across Europe. This coordination includes the important development of multi-model ensembles.
- d) Until now predictions for seasonal-to-decadal time horizons have not been considered a priority in the development of climate models. This situation is now changing as it is increasingly recognised that the prediction problem is fundamentally "seamless" across time horizons, and that progress in predictions for seasonal-to-decadal time horizons can have real benefits for improving both longer range climate predictions and shorter range weather forecasts.

- e) Major advances in computer power now make possible simulations and predictions of climate at unprecedented spatial resolution. The ability to achieve higher resolutions is a critical tool for establishing the robustness of predictions of regional and local climate and its impacts.
- f) The advances in computer power have also enabled the development of ultra high-resolution regional models which, in conjunction with new high resolution satellite observations, provide an unprecedented opportunity to develop improved parameterisations for climate models. New approaches to parameterisation (e.g. "stochastic physics") also have the potential to make a major contribution.
- g) The global array of ARGO floats now provides observations of the subsurface ocean – essential for initialising climate predictions - in unprecedented detail.
- h) The development of application models (e.g. for health, agriculture) now offers a sound basis for extracting from climate predictions the specific information required for user decision making. There is huge potential to develop such models to cover a much broader range of applications.
- i) In 2005 the Met Office issued, for the first time, a high profile seasonal forecast for the forthcoming winter. This forecast demonstrated a very high level of user interest in, and need for, forecasts of this type.

6. The UK has been, and is now, an acknowledged world leader in climate prediction. In order to maintain its leadership role, and to capitalize on the unique opportunity for further advances, there is a need for new investments in research to address the challenges indicated under point 4. In addition there is a need for new activities or structures, which more effectively join up basic research with focused work to improve operational systems for climate prediction, and to enhance the value of such predictions to users. Two specific opportunities, which may be considered alternatives or complementary, are:

- a) *Development of formalised collaboration between the Met Office and NERC with a specific focus on the improvement of seasonal-to-decadal climate predictions.* It is likely that the NERC side of such a collaboration would be led, in the first instance, by NCAS but would, in time, include other groups as well. The collaboration would focus on pull-through of results from basic research into the improvement of climate predictions. The improvement of climate models would be a specific priority. Such a collaboration would benefit from coordination between the Met Office and NERC with respect to HPC resources, and from improved internet connections between the Met Office and the academic community. The recently agreed joint project between the Met Office and the NERC COAPEC project (with additional support from NERC Knowledge Transfer funds) is a modest but significant step in this direction.
- b) *A National Institute for Prediction of Environmental Change.* The opportunity exists in the UK for a larger initiative to give focus to the grand challenge of improving predictions, not only of regional and local climate but also its impacts on a broad spectrum of environmental variables. Such an initiative could bring together the breadth of NERC expertise with that in the Met Office and ECMWF. Substantive engagement with the user community, e.g. the Environment Agency and water companies, would be essential.

Appendix J : Climate Models Developed under COAPEC

The following climate models are available for use by Climate researchers and were developed, or partially developed, through COAPEC programme funding.

CHIME

National Oceanography Centre, Southampton

CHIME - the Coupled Hadley-Isopycnic Model Experiment – is a new IPCC class coupled climate model. CHIME uses the same atmosphere and ice component models as HadCM3. It also has similar horizontal resolution for the ocean, but it represents the ocean's vertical structure very differently. This formulation follows isopycnic (constant density) surfaces, rather than fixed depths. We expect it to more accurately represent the ocean, eg. by preserving water mass properties better. This new model means that the UK no longer relies on predictions from a single type of model.

FORTE

National Oceanography Centre, Southampton

FORTE is an intermediate complexity model, sitting between high end (IPCC-class) climate models such as HadCM3 and CHIME, and reduced physics or box models. FORTE is used to investigate fundamental climate processes and to test hypotheses, as it runs ten times faster than other primitive-equation based climate models. This allows for long integrations and large ensembles. COAPEC researchers used it to underpin investigations ranging from the relative effects of mountains and ocean on European climate, to the ocean's influence on atmospheric storm tracks.

C-Goldstein

National Oceanography Centre, Southampton

C-GOLDSTEIN is an Earth system model of intermediate complexity. It efficiently addresses coupled processes involving the atmosphere, ocean and sea-ice. C-GOLDSTEIN includes a fully 3D frictional geostrophic ocean component, but retains high integration efficiency (20,000 years of integration run in about a day on a PC). We coupled a frictional geostrophic ocean to a simple energy moisture balance model of the atmosphere and a standard thermodynamic model of sea-ice. We later coupled it to a low-resolution general circulation model of the atmosphere and an elastic-viscous-plastic model of sea-ice rheology. The original C-GOLDSTEIN model proved versatile in studies for which we needed several ensembles of 100-1000 simulations.

Q-GCM (Quasi-Geostrophic Coupled Model)

National Oceanography Centre, Southampton

The coupled models used to predict our climate have long possessed enough grid points to describe the natural atmospheric length scale (about 1000km), so that the atmosphere in the models has realistic variability. However, the models lack enough grid points to describe the ocean's natural length scale (about 30km). This means the models' oceans have far less variability than researchers have observed. Does this matter? Could the real ocean's natural variability play a role in decadal climate variability, and if so, how? We do not yet have the computing power to fully answer this question, but we do a good job with slightly simplified models. We developed the Quasi-Geostrophic Coupled Model, a quasi-geostrophic

representation of the ocean, coupled to a quasi-geostrophic atmospheric model, to answer these questions.

CARGO (Coupled Atmosphere - Reduced Gravity Ocean)

University of Reading

We developed CARGO to determine how better-resolved small-scale oceanic features such as western boundary currents, geostrophic eddies and Kelvin waves affect the coupled climate system. CARGO is an atmospheric general circulation model (the Reading Intermediate General Circulation Model at T31 resolution) coupled to a reduced-gravity model of the Atlantic (with between 1/6 and 1/12 degree lateral resolution); climatological sea surface temperatures are prescribed over the remainder of the oceans. We are using CARGO to study how a weakened Atlantic overturning circulation affects the atmosphere.

HOPE – Stochastic

Rutherford Appleton Laboratory

We developed a hybrid coupled climate model to investigate seasonal predictability of Western-European climate. This model comprised a fully dynamical ocean (HOPE) and an atmosphere consisting of: a regressive model, driven by underlying sea surface temperature and a stochastic model, driven by a representation of internal atmospheric variability. The hybrid coupled climate model reproduced the same geographic annual variability of sea surface temperature as the model it was derived from. Like previous models of its kind, the hybrid coupled climate model produced less interannual variability than the forced HadAM3 runs.