STRATEGIC CONSORTIUM GRANT

UK-HIGEM: A National Programme in 'Grand Challenge' High Resolution Modelling of the Global Environment between NERC and the Hadley Centre

Executive Summary

Science Aims: *• To achieve a major advance in the fidelity of simulations of the Global Environment by developing an Earth System Model with unprecedented resolution • To perform a 'Grand Challenge' multi-century simulation with the new Earth System Model, thus providing the NERC and wider UK science community with a unique resource for studying mechanisms of climate variability and change on timescales of days to centuries.*

Strategic Aims: *• To integrate the global environment modelling activities across NERC • To support the formation of a national partnership between NERC and the DEFRA/MOD funded Hadley Centre to develop the UK's capability in high resolution Earth System Modelling.*

Climate change, its impacts and the development of strategies to adapt to, or mitigate those impacts, is arguably the greatest challenge facing mankind in the coming decades. The potential changes in our climate arise from the effects of human behaviour, and therefore depend on factors hitherto not encountered. Numerical models of the earth system, based on sound physical, chemical and biological principles, must therefore be the prime approach to providing well-found predictions of climate change. These models must provide the most complete and faithful representation of the global environment system; they must encapsulate our knowledge of the processes and interactions within and between the various components of that system; and they must recognise that, in many cases, those interactions occur on a wide range of spatial and temporal scales, are highly non-linear and may lead to unexpected feedbacks or 'surprises'.

This proposal is for a *strategic* consortium grant to support the formation of a national partnership between NERC and the DEFRA/MoD funded Hadley Centre to develop the capability to perform high resolution modelling (in the first instance, $1/3^0$ ocean, $\sim1^0$ (N144) atmosphere) of the coupled climate system. During the later stages of the project much higher resolutions (e.g. $1/6^0$ ocean, 0.5^0 atmosphere) will be explored, in anticipation of increasing computer power. Such a modelling effort is urgently required to provide the best possible underpinning science for impacts' assessments and the development of adaptation and mitigation strategies.

This proposal represents a radical change in how global environment modelling is conducted in the UK, and will set in place the structures required to bridge NERC and DEFRA interests in predicting the evolution of the global environment during the coming century. It will enable NERC expertise in various aspects of earth system science to be brought to bear on the evaluation and development of the next generation model of the global environment, which will maintain the UK's pre-eminence in coupled climate modelling and climate change prediction. For the first time, many of the principle areas of NERC science are working together, leading to a concerted effort in state-of-the-art climate modelling which hitherto has been somewhat fragmented. By moving towards higher resolution the gap will be narrowed between climate modellers and scientists specialising in particular processes and phenomena in the earth system, itself leading to better integration.

The high-resolution model will be used to perform a multi-century 'Grand Challenge' integration of the current climate. The model will be evaluated comprehensively against observations and detailed models of components of the climate system. The 'Grand Challenge' integration will form the basis for a wide range of research in, for example, extreme events, seasonal to centennial climate variability, and the non-linear interactions between different components of the earth system. The leading role of the Hadley Centre in providing the UK government with advice on climate change will be strengthened by the enhanced collaboration with the NERC community.

The programme will enable the UK to provide well-found predictions of regional climate variability and change and facilitate improved estimates of changes in the occurrence of extreme events and high-impact weather. The modelling infrastructure provided by this consortium will form a core component of NERC's aspirations in Earth System Science and climate change, as articulated in 'Science for a

Sustainable Future', and it will enable the Hadley Centre to deliver to DEFRA the best possible advice on future climate change.

1. Scientific and Technical Rationale

Complex fluid flows in the atmosphere and oceans are a fundamental feature of the Earth system. They transport energy, momentum, and material substances within and between system components. They occur over a wide range of spatial scales, and evolve over a wide range of time scales. 'Small' scales of motion that are known to be important cannot be simulated directly in global models on current computers, and must be parametrised in terms of resolved scales. A clear imperative is to develop models of much higher resolution, so as to be able to simulate explicitly flows down to smaller scales and to capture potential non-linear interactions between different space and time scales, and between different components of the Earth system. Rapid increases in computer power projected for the coming years will enable much higher resolution to be used and will revolutionise global environmental modelling.

The current, state-of-the-art coupled climate models have a typical resolution of $\sim 3^0$ (N48) in the atmosphere and $\sim 1^0$ in the ocean. In neither component are key aspects of the climate system (such as the influence of ocean eddies, orographic forcing of the atmosphere, El Nino, tropical cyclones) adequately represented. There is a strong case for high resolution in all components of the coupled system. For the ocean, there is good evidence that an eddy permitting ocean model provides much better definition of western boundary currents, and also gives a more accurate simulation of equatorial waves, which are a key part of El Nino. High-resolution simulations of the atmosphere have already demonstrated significant improvements in the representation of storm track processes and of the detailed precipitation distribution over the European sector where orographic effects are important (Pope and Stratton 2002).

Non-linear chemical processes in the atmosphere are also highly dependent on resolution. For example, emissions of oxides of nitrogen (NOx) from the surface into a 300km box, say, could have a completely different effect compared with emissions treated at higher resolution. During the coming century the atmosphere will be subjected to increased emissions of a variety of chemically and radiatively active gases. These are likely to have a damaging effect on the ability of the troposphere to remove pollution from the atmosphere (the 'oxidizing capacity'), as well as affecting surface air quality and the growth of many greenhouse gases. The chemistry is known to be highly non-linear so that a crucial aspect (increasingly recognised as being a vital part of the research strategy) is the issue of importance of spatial scales from the local, to the regional, to the continental and global. Innovative software solutions are required to bridge the highly disparate length and time scales.

At the land surface, strong variability in properties such as topographic height, vegetation cover, soil properties, soil moisture and snow cover, occurs at all length scales. These combine non-linearly to produce large variations in surface fluxes of heat, moisture, momentum and carbon dioxide. As a result, the accurate modelling of surface processes in GCMs is strongly constrained by horizontal resolution. Numerous studies (e.g. Taylor and Lebel 1998, Cox et al. 2000) have illustrated that land surface feedbacks can affect the atmosphere at scales from the local up to the global. Explicitly resolving finer scale surface features should lead to improvements in the simulation of climate over continental regions.

Sea ice is highly inhomogeneous, with much of the exchange of heat between ocean and atmosphere taking place over small areas of open water (leads and polynyas) within the ice cover. It is these exchanges of heat that determine the overall growth of the winter sea ice and the consequent modification of ocean water masses through brine rejection. Correct parametrisation of these energy exchanges is essential for realistic climate simulations and requires high-resolution atmospheric and oceanic fields in order to calculate the fraction of open water and its distribution within a grid cell correctly.

High-resolution simulations of the climate system have generally only been run in uncoupled mode and often only at a regional scale where the simulation may be compromised by errors in the boundary forcing. The impact of details in the structures, for example the tightness of the Gulf Stream, on the evolution of the *global* coupled system have yet to be explored properly, although they may be substantial. For example, recent results from a European coupled model have shown a dramatic improvement in the mean tropical climate and the simulation of El Nino when the atmosphere is run at a resolution commensurate with that of the ocean (Gualdi et al. 2002a; Guilyardi et al. 2003). This research illustrates the skills in developing new, coupled climate models that have been established recently within the NERC community and which will be enhanced by the current proposal.

We therefore propose a community programme that will develop and use a state-of-the-art, high resolution (in the first instance, $1/3^0$ ocean, $\sim 1^0$ (N144) atmosphere) coupled model to explore the processes in the climate system that give rise to variability on timescales from days to centuries. The model will be based on the new version of the Unified Model (UM), the Hadley Centre's Global Environment Model HadGEM1. The resolution of the atmosphere and ocean will be increased so that the model will have higher resolution in both components than has hitherto been used in the UK for extended simulations of the *coupled* global environment. The longer-term aspiration is to move to much higher resolution to remove the need for gross parametrisations of key processes (e.g. orographic effects, cloud processes, ocean eddies). Within the latter stages of this project, tests at much higher resolution will commence, building on experience in numerical weather prediction (NWP) at the Met Office, in detailed land, ocean and sea ice models in the NERC Centre/Surveys, and in advanced computational methods (e.g. adaptive gridding) at the University of Cambridge. These developments will push at the limits of global environment modelling, both technically and scientifically, but will mean that NERC and the Hadley Centre are well placed to exploit the continuing increase in computer power (e.g. outline plans for HPCY are for 50Teraflop machine in 2006).

One of the main goals of the consortium is to perform a multi-century 'Grand Challenge' simulation of the global environment, which will form the basis for a wide range of studies, enhancing our scientific capability in understanding and predicting global environmental variability and change. Such a programme will be a critical component of a broader initiative in Earth System Science, which NERC seeks to promote. It will also provide a better description of the regional environment required for the development of adaptation and mitigation strategies.

International developments make this proposal both timely and strategically important for the UK. There is a move to more complete representations of the earth system at much higher resolutions. The Japanese have recently launched the "Earth Simulator", a 40 Teraflop high-performance computer built to run global simulations at unprecedented resolution. In the US, initiatives to develop machines of similar or greater power than the Earth Simulator have been launched (http://www.nersc.gov/news/blueplanet.html), partly justified by the need for much higher resolution and more comprehensive models of the climate system to provide more reliable predictions on timescales of days to centuries (http://www.ultrasim.info/). Early indications are that several climate modelling groups are planning to enter the IPCC 4th Assessment Report with models of similar resolution to that proposed for the initial phases of UK-HIGEM. It is clear that if the UK is to remain at the forefront of climate modelling and prediction, then a move to higher resolution, more comprehensive and better evaluated models is urgently required. This project is designed to start that process.

The UK, through a joint venture between the Hadley Centre and CGAM, is likely to have access to the Earth Simulator in the near future, and will perform a high-resolution, multi-century integration of the current Hadley Centre model with an eddy-permitting ocean (HadCEM). The aim of this consortium is to build on that experience and to set in place the modelling infrastructure at the national level by developing a joined-up programme of research and development. The UK climate community will then be well-placed to: (i) exploit the expected increase in computer power, (ii) remain at the cutting edge of climate modelling and prediction internationally, (iii) provide the background models required for the synthesis and interpretation of the wealth of in situ and satellite observations of the global environment, and (iv) deliver more robust estimates of the regional impacts of climate change required to guide government policy.

This proposal will also provide the high resolution global, coupled modelling that is required to underpin the NERC Thematic Programme in 'Rapid Climate Change'. It will set in place the modes of working together which will be required for a more extensive, nationally integrated programme in the development and exploitation of the next generation global environment model, potentially a core part of the proposed programme in 'Quantifying the Earth System (QUEST)'. Finally, it will enable the UK climate community to make a major contribution to the 4th IPCC Assessment on the sensitivity of climate predictions to model resolution, with particular reference to non-linearity in the interactions between components of the earth system.

2. Partnership

The consortium consists of partners who are already experienced users of the Unified Model. At a later stage, when the mode of working within a joined-up programme within NERC and with the Hadley Centre is well-established, and our capability to undertake high resolution global modelling has been demonstrated, the scope of the consortium should be extended to include other areas of NERC science, such as terrestrial ecology and coastal shelf seas. Additional funds will then be sought to support those activities and to engage those areas of NERC science, as is necessary to progress towards a full Earth System Model. The HIGEM model will form the backbone for such wider Earth System Science studies (e.g. climate-carbon cycle interactions under QUEST), and will provide the benchmark against which a hierarchy of earth system models of varying complexity can be judged.

The consortium represents a close collaboration between the key climate modelling groups in NERC (in NCAS (CGAM, ACMSU), SOC, CEH (Wallingford) and BAS) and at the Hadley Centre; these groups will work together on the model development and evaluation, and on the design and performance of the 'Grand Challenge' integration. They will be joined by other NERC and university groups (ESSC, Cambridge (DAMTP), UEA) who will contribute to the evaluation of particular areas of the model performance. All partners will be involved in applying the results of the integration to a range of scientific issues. The BADC will have lead responsibility for providing e-science methodologies for accessing and visualising the enormous data volumes (of order petabytes) produced by high resolution, multi-century integrations. The following matrix shows the involvement of the various partners in the work packages described in Section 5:

	WP0	*WP1*	*WP2*	*WP3*	*WP4.1*	*WP4.2*	*WP4.3*	*WP4.4*	*WP4.5*	*WP5*	*WP6*
NCAS:CGAM	✔	✔	✔	✔	✔		✔	✔		✔	✔
NCAS:ACMSU		✔	✔			✔				✔	✔
NCAS:BADC				✔							
BAS		✔			✔		✔		✔	✔	✔
CEH(Wallingford)		✔						✔		✔	✔
ESSC				✔	✔			✔			✔
SOC		✔		✔			✔			✔	✔
U. Cambridge						✔				✔	✔
UEA		✔	✔				✔			✔	
Hadley Centre	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	

The Hadley Centre is a key member of the consortium and a major contributor to the programme. Since this project represents a new mode of working in global environment modelling for the UK, it is important to clarify the Hadley Centre's role in the project. Specifically, it will: (i) provide the current working versions of HadCEM and HadGEM1 (representing several hundred person years of model development); (ii) contribute expertise towards constructing HIGEM and on issues related to model stability; (iii) participate in the design of the control integration and in the specification of the diagnostic fields; (iv) contribute to the evaluation of the model through the involvement of its Model Validation Groups; (v) collaborate, and in some cases play a leading role, in areas of science arising from the multi-century control integration; and (vi), in the longer term, perform parallel integration(s) with greenhouse gas scenarios. These integrations will be made available to NERC scientists for collaborative research, but the Hadley Centre will retain its leading role in providing the UK government, through DEFRA, with quantitative advice on climate change.

The proposed staffing structure consists of a team of research and computational scientists working on model development, model evaluation and research into global environment variability and change. A modelling co-ordinator, working closely with the coupled modelling support team at CGAM and with the HadGEM development team at the Hadley Centre, will oversee NERC's contribution to the technical development of the model, and will supervise the performance of the control integration.

3. Key scientific issues

UK-HIGEM is both a scientific and technical programme of research. The proposed model development and 'Grand Challenge' integration will enable the UK climate community to address a wide range of important questions with the following over-arching key science themes:

- Impact of higher resolution on the fidelity of simulations of the global environment.
- Understanding the non-linear processes that give rise to interactions between small spatial scales and larger scales, and between high and low frequencies, within the Earth system.

Specific areas of science that the 'Grand Challenge' integration will enable the consortium to address are described in more detail in the Programme of Research (Section 5, Work Package 5).

4. Key technical issues

The detailed implementation of UK-HIGEM will depend on two major projects; the current development of a new version of the Hadley Centre climate model and the installation at Manchester of the Research Councils' new supercomputer (HPCX, an IBM machine) with a peak performance of ~ 7 Teraflops. The Hadley Centre is developing a new global environment model, HadGEM1, which differs substantially from its earlier coupled model, HadCM3, used for the IPCC 3rd Assessment Report and which formed the basis of HadCEM. HadGEM1 has a new dynamical core, which is non-hydrostatic, has semi-Lagrangian transport and an improved vertical grid, as well as substantially improved parametrisations. It includes a dynamical elastic-viscous-plastic sea-ice model, ocean bio-geochemistry, an aerosol model and an interactive carbon cycle model. The intention is that UK-HIGEM will base its work on HadGEM1, noting that the projected date for finalisation of HadGEM1 is early 2004. In the unlikely event that HadGEM1 is not suitable, we will take the proven version, HadCEM. This decision will only be made with the full participation of the Hadley Centre, consistent with their modelling strategy for IPCC.

The 'Grand Challenge' integration will produce data in quantities that will test our ability to manage and manipulate the data. Efficient handling and dissemination of the data will depend on (i) timely development of the NERC DataGRID, (ii) network bandwidth into the Hadley Centre, and to the HIGEM partners (and concomitant firewall issues), (iii) development of tools for the dynamic caching and simulation subset distribution, and (iv) development of a new information management system.

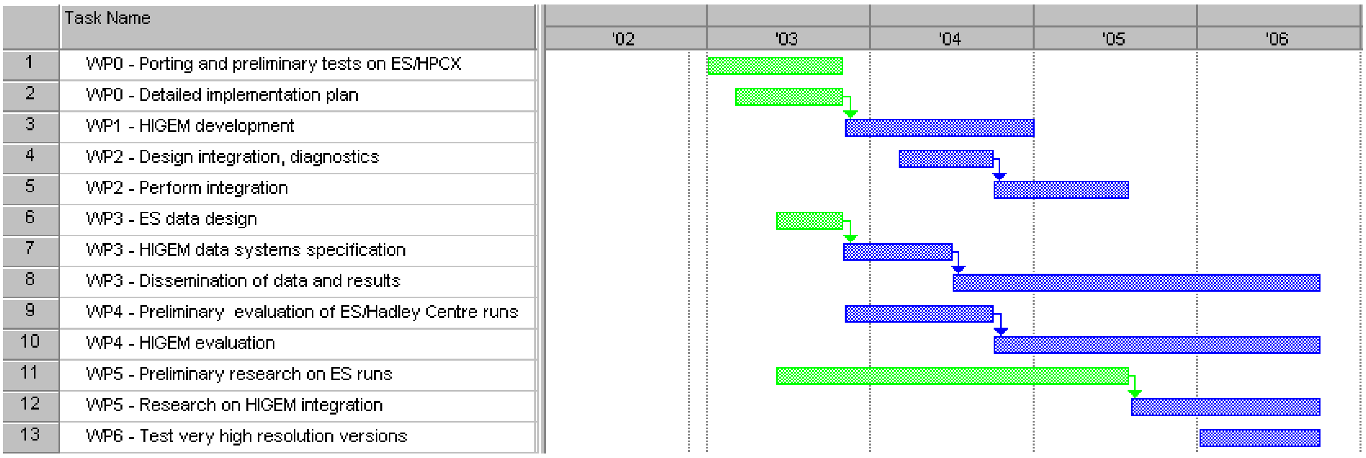
Since UK-HIGEM is technically challenging, it requires a strategy for dealing with the various risks involved. A Risk Register will be maintained and reviewed for the duration of the project. Below is a summary of the current perceived risks to the project:

Item	Risk	Management Strategy
Base model version (HadGEM1)	-Delayed delivery of stable coupled climate at standard (N96 atmos., 1^0 ocean) resolution	-Pre-project involvement in HadGEM1 Tiger Teams -Assess impacts on HIGEM development -Build in flexibility in the implementation and science plans -Develop contingency plans to use HadCEM
Fall-back model (HadCEM)	-Inadequate performance/scaling on HPC platforms available to UK-HIGEM	-Pre-project porting experience (WP0) -Assessment of impact on resources (staff, HPC) -Build in flexibility in the implementation and science plans
HIGEM: -Atmosphere	-Increased resolution requires 're-tuning'	-Use existing experience with high resolution AGCMs.
-Ocean	-Required resolution demands high resource levels	-Assessment of optimal resolution for 'Grand Challenge' integration
-Fully coupled	-Serious model drift	-Managed incremental development of full system based on experience in HadGEM1, HadOPA, SINTEX projects
	-Numerical instabilities	-Build-in flexibility in the implementation/science plans for extended period of model integration -Consider options to minimize numerical instabilities based on Hadley Centre experience
Resource allocation	-HPC inadequate	-Work with NERC HPC Facilities Manager to plan adequate resource strategy -Limit the length of the 'Grand Challenge' integration
	-Data/analysis delays due to networking bottlenecks, middleware insufficiencies	-Work with e-science community to anticipate and mitigate effects

5. Programme of Research

The proposed research is described in a series of Work Packages (WP). Although the current proposal will deliver important advances in global environment modelling and research as listed in Section 6, the strategic nature of the programme means that it should also be viewed as a longer term development. In the expectation that this project will continue beyond the first three years, outline plans for future major areas of work, which build on the expertise gained in UK-HIGEM, are given in Section 7.

Sound project management will be essential for the success of UK-HIGEM, and the strategies to ensure this are discussed in Section 9. The overall progression of the project is outlined in the following GANTT chart, although details will depend on the status of the model and HPCX, as noted in Section 4.



GANTT Chart showing overall progression of the project. Hatched lines represent pre-project and complementary activities. Solid lines represent UK-HIGEM activities.

- ***Work Package 0: Pre-Project Planning and Implementation (Lead: CGAM)***

CGAM and the Hadley Centre have plans for running HadCEM on the Earth Simulator and for using enhanced resolution in the atmosphere prior to the start of this project. HadGEM1 may also be ported to the Earth Simulator within the next year. CGAM has detailed plans in place for porting HadCEM to the HPCX in early 2003 and for testing higher resolution versions of HadAM3. We anticipate that the preliminary work involving porting these codes to these new machines will be in place before the start of the project. A multi-century integration of HadCEM already exists and further extended runs are planned on the Earth Simulator during 2003. Consequently, model output will be available at an early stage to begin the model evaluation, with HadCEM providing the base against which future developments will be assessed.

A detailed implementation plan for UK-HIGEM will be developed prior to the launch of the project. The first task of the Project Manager will be to report on the scientific and technical assessment of the model(s), HadGEM1 and/or HadCEM, based on information and experience gained during 2003 in porting these models to HPCX and the Earth Simulator (WP0) and in assessing their performance. In consultation with the UK-HIGEM Advisory Group (see Section 9), a decision on the appropriate model for UK-HIGEM will be made.

- ***Work Package 1: Development and testing of high-resolution version (HIGEM; ~1^0 (N144) atmosphere, $1/3^0$ ocean) of HadGEM1/HadCEM (Lead: CGAM)***

A team of computational scientists, based on the core computational group at CGAM (currently 5 staff), with additional staff from the various participating centres, and under the leadership of the UK-HIGEM Project Manager, will develop the high-resolution model in collaboration with the Hadley Centre. The team will develop the high-resolution ancillary files (e.g. orography, bathymetry, land surface characteristics) and establish the coupling between high-resolution versions of the atmosphere and ocean. The model will be tested for stability, and in close collaboration with the Hadley Centre, the consortium will consider possible changes to the model to minimize climate drift and systematic errors. The team will also be responsible for ensuring that the model code runs as efficiently as possible on HPCX. A report documenting the technical development of HIGEM and its performance on HPCX will be prepared.

- ***Work Package 2: 'Grand Challenge' multi-century control integration using HIGEM (Lead: CGAM, Hadley Centre)***

On completion of the technical development of HIGEM, the multi-century control integration will be performed by CGAM computational scientists. The length of the integration will be determined by the availability of computing time on HPCX and the model run-time. The basic model archive will contain a selected set of diagnostics, which will be agreed by the consortium and will necessarily be limited by the feasibility of archiving and disseminating very large datasets. The basic archive will be sufficient for many applications. Where more detailed, very high frequency diagnostics are required, particularly for WP4, selected periods of the integration will be re-run as 'Special Observing' Periods (SOPs), where the chosen sections may be related to periods of interesting climate variability, such as active ENSO (El Nino/Southern Oscillation) cycles.

Subsequently, climate change scenario runs may be performed under the leadership of the Hadley Centre, depending on the availability of the computing resources at NERC/Hadley Centre. The aim is to have at least the control integration done in time to contribute results on resolution dependence and non-linear interactions to the IPCC 4th Assessment due to be published in 2007.

- ***Work Package 3: Dissemination, post-processing and visualisation of output from HIGEM integrations (Lead: BADC)***

High resolution climate simulations will produce data in quantities which will test our ability to manage and manipulate them. Along with the model output, there will be substantial quantities of observational data used in evaluating the model, and these will need to be made available between the partners. Amongst the strategies which will be adopted will be: (1) the production of pre-determined post-processed data sets to be held primarily at the BADC; (2) enhanced cataloguing and delivery methods, to allow data held at any HIGEM site to be visible remotely (and thus available for remote manipulation), and; (3) sophisticated subset caching arrangements, allowing parts of high-resolution simulations to be made available at high temporal and/or spatial resolution via a dynamic cache archive to be held at the BADC.

This work will build primarily on two existing initiatives: the NERC e-science project to develop the NERC DataGrid, and a proposed new Hadley Centre simulation distribution system which is under discussion between DEFRA, the Hadley Centre and NCAS, with support from CRU (Climate Research Unit, University of East Anglia). While the latter is only an initiative, it is predicated upon new network links, which will be in place from early 2004, funded by NCAS/BADC strategic funding, and a willingness amongst all the partners to make it happen. The NERC DataGrid activity itself is intimately involved with the US Earth System Grid, whose main aim is to move large amounts of climate data around the US. Thus we already know that much of the technology we need exists; the main priority for HIGEM will be to implement it in the HIGEM environment early in the project. Funding for NCAR visits is requested to ensure effective technology transfer. Relevant data manipulation technology from the EU PRISM project will also be investigated and used where appropriate.

Where appropriate (some observational and preliminary data will need to be embargoed) HIGEM data will also be made available to the wider community via the interaction between HIGEM catalogues and NERC DataGrid catalogues. In addition, HIGEM will build on the development of data services for the UK-Japan project with the Earth Simulator (see WP0) scheduled for 2003. The HIGEM 'Grand Challenge' integration(s) will thus provide a community resource of relevance to a wide range of NERC science. The results of the model evaluation (WP4) and the science arising from the model simulations (WP5) will be disseminated electronically through a web-based information service which will be built in conjunction with the data service

- ***Work Package 4: Evaluation of HIGEM performance (Coordination: CGAM, Hadley Centre)***

A key aspect of UK-HIGEM is the evaluation of the high-resolution model simulations, since the model must be stringently tested against observations if we are to have confidence in climate change scenarios. This will involve the wide range of NERC expertise related to the various components of the earth system. It will exploit recent developments in earth observation for all components of the earth system; it will engage detailed models of the component parts of the earth system for studies of processes and phenomena, highlighting potential processes that are poorly resolved; and it will enable innovative use of advanced computational methods to explore the role of fine scale structures in key processes. As a result of these studies, recommendations for improvements to processes, parametrisations and numerics will arise which will be incorporated into the model, probably beyond the time frame of this current proposal (see Section 7), to aid the development of the next generation, fully comprehensive global environment model.

Although the following sub-packages focus on the various components of the earth system, it is important to stress that in each case the evaluation will be made in the context of the fully coupled system. Understanding the role of non-linear interactions between components of the earth system in the mean climate and its variability will provide the unifying theme. 'Special Observing' Periods (SOP), in which high frequency diagnostics will be archived, will be used to study weather phenomena, chemical mixing and transport, detailed land surface and ocean processes, and so on.

- *WP4.1: Atmosphere (Lead: CGAM, ESSC)*

The emphasis will be on processes and phenomena in the atmosphere on timescales from the diurnal cycle to decades. Atmospheric circulation statistics will be evaluated against the ECMWF 40-year (ERA-40) and NCEP 50-year re-analyses in conjunction with satellite and in situ measurements, building on the experience at CGAM and the Hadley Centre in the comprehensive diagnosis of climate variability and phenomena (e.g. Slingo et al. 2002). Of particular interest are modes of variability such as the Madden Julian Oscillation, ENSO and its global teleconnections, the North Atlantic and Arctic Oscillations. Techniques developed at ESSC to track coherent circulation features in the atmosphere will be applied to the simulation of mid-latitude and tropical storms, compared with the re-analyses (Hoskins and Hodges 2002). Successful simulation of the North Atlantic storm track and Gulf Stream are of particular importance for European climate and will be a focus of this work.

Several long-term satellite datasets will be used to test the simulation of clouds, radiation and precipitation. ESSC will use data with high time and space resolution to examine the performance on scales consistent with the underlying physical processes. A version of the UM radiation code will be used, which simulates the radiances observed by a satellite instrument, taking into account the spectral passband and viewing geometry (Ringer et al. 2002). This allows a direct comparison with the data, avoiding the uncertainties introduced by the retrieval of high-level products. Comparison datasets will include the CLAUS (Cloud Archive User Service) archive of merged, global, infrared window channel brightness temperatures (Hodges et al. 2000), for the period 1983 to 1994, to evaluate the simulation of clouds and the surface. The corresponding archive of water vapour channel radiances from the HIRS instruments for 1979 to 1998 (Bates et al. 2001) will be used to evaluate the model's upper tropospheric humidity. Evaluation of the diurnal cycle in the model during SOPs with high time resolution will use data from several geostationary satellites, including Meteosat Second Generation (MSG), launched in August 2002.

- *WP4.2: Atmospheric Chemistry (Lead: ACMSU, DAMTP)*

The issue of the importance of resolving relevant spatial scales, from the local to the regional, in global models will be addressed. Surface emissions of the oxides of nitrogen (NOx) and hydrocarbons (HCs) are often highly localised in space and, with ozone production potential depending very non-linearly on the mixture of NOx and HCs, model resolution becomes critical. An innovative development will be to use a global chemistry transport model (CTM), which has the facility to increase resolution locally (in three dimensions) via a two-way nesting approach. We will validate our modelling approach by comparison with data collected in intensive field campaigns (to be discussed in more detail as part of WP5).

ACMSU and DAMTP have developed and implemented an adaptive 3D gridding approach on a sphere. The grid adaption can be used dynamically (i.e. grids of finer resolution follow fluid features) and/or in a static, two-way nesting manner. The static nested meshes provide the bridge between the disparate length scale from local to global scale, while the dynamic adaption bridges the gap between the planetary waves (captured by the underlying mesh), to the mesoscale, in order to provide boundary conditions for the nested grids in a continuous, two-way manner (a failing of current limited area models). An important innovation will be the use of autonomous nests, which run at their own optimal (and variable) timestep;

advanced software synchronises the solutions of the nests (and individual dynamic grids) at all points of the computational domain. This is effectively a time (as well as space) adaption approach, which will significantly increase the efficiency of the calculation and also avoid the generation of spurious waves at the interfaces of the fine/coarse nests. The CTM will operate coupled to the GCM, so the nested/adaptive approach does not affect the operation of the GCM.

The proposed CTM (TOMCAT) includes a detailed tropospheric chemistry scheme, which is already currently being implemented in HadGEM1 as part of a joint project with the Hadley Centre, funded by NCAS. As part of a SOP, a baseline run of HIGEM, including chemistry at 1^0 horizontal resolution, will be performed. Output from the model will then be used to initialise (in the case of chemical constituents) and force (in the case of meteorological parameters) a TOMCAT integration including two levels of nesting, at a regional and at an intermediate/urban level. A number of target regions for nesting are obvious. They include megacities, the coastal zone (where local emissions may possibly have a regional impact), the tropopause, etc. Detailed diagnostic studies will compare the two models (UK-HIGEM and the CTM) to investigate the importance of different resolutions. The models will also be compared against available data. We will run in nested mode to cover periods of intensive observations, including the possible field observations to be undertaken during MIRAGE (see WP5), the measurements made in the boundary layer and free troposphere over continental Europe during the NERC EXPORT campaign, and our own local Cambridge measurements, made with a network of lightweight sensors.

- *WP4.3: Ocean (Lead: SOC, UEA)*

The ocean component of HIGEM will be assessed in terms of processes relevant to the coupled climate system and its variability. The meridional heat and freshwater transports and overturning rates in the ocean will be evaluated and compared with estimates from observations. The structure and properties of the water masses participating in the global thermohaline circulation (THC) will be studied, including how these are affected by mixing in passing through critical sills in the seafloor, the positioning of critical current systems (e.g. the Gulf Stream/North Atlantic Current, Antarctic Circumpolar Current), and how variations in the THC are manifested in the SST and involved in air-sea interaction. Detailed comparisons will be made with recent *in situ* observational datasets (e.g. international WOCE (hydrographic) and Argo (profiling floats) programmes), and with available remote sensing datasets describing SST and levels of eddy variability. Valuable comparisons will also be made with the standard resolution HadGEM1 model (evaluation work led by the Hadley Centre), and with the 1/12° resolution OCCAM ocean general circulation model being run in "ocean-only" mode at SOC. This will allow an assessment of the requirement for further increases in resolution in future coupled models.

Modes of variability within the ocean on seasonal to decadal timescales will also be assessed. CGAM will evaluate the representation of El Nino in HIGEM by comparing it with the TAO buoy data and by realisations in other configurations of the Hadley Centre model (Guilyardi et al. 2003). The mechanisms involved in the initiation and decay of El Nino will be analysed based on previous studies (e.g. Guilyardi et al. 2002, Lengaigne et al. 2002). The mean climate and variability of the Indian Ocean will be assessed following earlier research in characterising its interannual variability and its response to El Nino (Gualdi et al. 2002b). In concert with WP4.1, the impact of changes in the interbasin atmospheric water vapour transport, particularly associated with ENSO, on the Meridional Overturning Circulation (MOC) will be studied. This will emphasise the importance of a good simulation of the ocean freshwater budget and its dependence on model resolution in the atmosphere. The comparisons with recent satellite data in WP4.1 will also provide information on changes in the clouds and water vapour through El Nino.

Planetary Rossby Waves are a key component of the ocean circulation. The speed at which these waves cross an ocean basin may play a critical role in setting the timescale for coupled modes of variability (e.g. Latif and Barnet, 1994; Zorita and Frankignoul, 1997), and could prove to be a key to understanding the overall performance of HIGEM. Rossby wave propagation speed and amplitudes may be very different in ocean models with resolutions of 1° and 1/3°, with markedly higher amplitudes at 1/3° resolution (see Cipollini et al., 2000). Rossby wave behaviour in HIGEM will be assessed by comparing their speeds and amplitudes (at various latitudes) with those derived from satellite observations. Furthermore, Rossby waves may also be strongly modified by nonlinear steepening and possible break-up into mesoscale eddies (Willmott, 1985), so that it is important to compare these processes, and their interaction with climate, in a model with at least partial resolution of the ocean mesoscale.

- *WP4.4: Land (Lead: CEH)*

This work package will evaluate how well the HIGEM 'Grand Challenge' integration represents key modes of land surface variability, from the diurnal cycle through to interannual time scales, from the local up to continental space scales, and how this representation is improved on existing simulations. In addition to using climatological mean fields (e.g. precipitation, screen level temperatures), we shall assess the ability of the model to reproduce observations closely linked to surface processes such as soil moisture stress, snow melt, and low frequency variability in leaf area. We will use multiyear satellite datasets and new global and regional soil moisture and flux analysis products (such as those becoming available from the Global Soil Wetness Project and the Land Data Assimilation System). Where appropriate (particularly where suitable and tested aggregation methods are available), SOPs from HIGEM will be compared with data from existing land surface experiments (such as the GEWEX sponsored ARM (Atmospheric Radiation Measurements), GCIP (GEWEX Continental-scale International Project), HAPEX_Sahel (Hydrology-Atmosphere Pilot Experiment), MAGS (Mackenzie GEWEX Study), LBA (Large-scale Biosphere-Atmosphere) etc). Comparisons will be made with selected satellite data, e.g. SSM/I for snow volume estimates and MISR (Multiangle Imaging SpectroRadiometer) and CHRIS/PROBA (Compact High Resolution Imaging Spectrometer/Project for On-board Autonomy) for the surface radiation budget.

- *WP4.5: Polar Regions (Lead: BAS)*

The performance of the model in the polar regions will be evaluated through comparison with reanalyses, station observations, remotely-sensed data and high-resolution regional component models. The emphasis will be on processes that connect the polar regions to the global climate system. The large-scale atmospheric circulation at high southern latitudes will be evaluated, with particular emphasis on the circumpolar trough and principal modes of low-frequency variability, such as the semi-annual oscillation, the Southern Hemisphere Annular Mode/Antarctic Oscillation and the Antarctic Circumpolar Wave. The model's representation of precipitation and the surface mass balance over Antarctica and Greenland will be assessed against the most recent compilations of field data (e.g. Vaughan et al., 1999). Arctic and Antarctic sea ice extents and their variability will be validated using passive microwave satellite observations (e.g. Zwally et al., 2002). The representation of air-sea fluxes within the sea ice zone will be assessed using results from detailed process studies (e.g. Renfrew et al., 2002). The representation of the Antarctic katabatic flow in HIGEM will be evaluated against surface observations (Renfrew and Anderson, 2002) and by comparison with Antarctic regional models (van den Broeke et al, 2002) which will be used to address issues such as resolution dependence, sub-gridscale inhomogeneity etc.

➢ ***Work Package 5**: **Application of HIGEM results to key scientific issues***

Details of the science issues to be addressed by the consortium will be refined as the project progresses based on the current state of knowledge. At the same time a lead partner will be identified for each of the research areas. The following text indicates potential science areas that the consortium will address. They have been chosen not only for the importance of the science, but also for the collaborative, multi-disciplinary nature of the research.

- *Exploring the relationship between extreme events and modes of climate variability*

As the climate changes, so the weather that makes up the climate will also change. A particular concern for the UK is the potential for an increase in the frequency of damaging storms. On the global scale, changes in the frequency of El Nino are posited as a signature of global warming. Floods and droughts have a devastating effect on society, particularly in countries with monsoon climates. There is increasing evidence that changes in land use (e.g. deforestation) are having a substantial influence on their frequency and severity. Land-surface processes and their interaction with the hydrological cycle must be simulated well in order to predict the changing probabilities of such events.

The impact of increased resolution on the simulation of extreme events (e.g. wind storms, floods and droughts) will be determined by comparing analyses of the HIGEM simulation with analyses of other coupled GCM simulations, particularly simulations with HadCM3 and HadCEM. Particular attention will be paid to elucidating the relationships between extreme events and modes of climate variability such as the North Atlantic Oscillation and ENSO. An understanding of such relationships will be useful to: 1) anticipate the impact on extreme events of future progress to still higher resolutions; 2) develop a mechanistic understanding of the impact of climate change on the frequency and characteristics of extreme events. UK-HIGEM therefore has the potential to provide an important resource for the proposed NERC Thematic Programme on 'Forecasting Risk from Extreme Events (FREE)'.

- *Exploring the impact of higher resolution on climate variability at seasonal to centennial timescales*

Of particular relevance to the UK is the potential for rapid changes in the strength of the thermohaline circulation (THC), a focus of the NERC Thematic Programme on Rapid Climate Change. One focus for this work package will be the impact of the higher model resolution on the variability of the North Atlantic sector, with particular emphasis on the ocean's role in such variability. The processes governing the variability of the water masses that form in the North Atlantic and Nordic Seas will be examined. The draw-down into the ocean, and circulation pathways, of these water masses and their anomalies, and their subsequent re-emergence at the sea-surface will be investigated, followed by a study of their possible participation in coupled modes of variability in the Atlantic sector (including their influence on European climate), and in the North Atlantic Oscillation. Particular emphasis will be placed on the role of Rossby Waves, which are sensitive to model resolution.

Intermediate depth water masses have been shown to be potentially sensitive indicators of anthropogenic climate change in the Indian Ocean and elsewhere (Banks et al., 2000). But interpretation of observed water mass changes depends critically on correct model simulation of decadal variability in which mixing by eddies could be critically important (Cox, 1985; Speer et. al, 2000). UK-HIGEM will provide, for the first time, a model with sufficient ocean resolution to allow eddy mixing and other mesoscale effects, alongside sufficient atmospheric resolution to obtain accurate simulation of the storm tracks and weather systems which generate the surface fluxes to drive water mass changes. This will be a unique aspect of UK-HIGEM; no other coupled model to date has such high resolutions in both the atmosphere and the ocean.

Other regions of the world's oceans are also important. For instance, the role of the Southern Ocean as the heat source at the southern end of the North Atlantic thermohaline circulation will be examined. The unprecedented length and resolution of the HIGEM integration will enable decadal and longer timescale modulation of ENSO to be studied. The coupled modes of variability in the Indian Ocean will be investigated. Finally, an assessment of the role of motions at various scales in setting the basic state of components of the climate system will be made by comparisons with lower resolution coupled models such as the standard HadGEM1 model, HadCM3 and HadCEM (led by the Hadley Centre), as well as with CHIME (similar to HadCM3 but with a different, isopycnal ocean component, led by SOC).

Over the past 50 years, annual mean temperatures in the Antarctic Peninsula have increased by nearly 3^0C, making this the most rapidly warming region on the planet during this period. The warming has caused significant deglaciation as well as large changes in local ecosystems. Attribution of this warming to anthropogenic causes or natural variability has proved problematic. On the one hand, current global models do not simulate a large warming in this region in response to increasing greenhouse gas concentrations. On the other, current models reproduce the mean climate of the region rather poorly because they do not resolve key processes (see WP4.5). The multi-century control integration will be used to explore the mechanisms of low frequency variability in the behaviour of the Antarctic climate in an attempt to understand the recent warming of the Antarctic Peninsula.

- *Megacity Impacts on the Regional and Global Environment*

The connection between local processes and the global environment is becoming a major international research theme in atmospheric chemistry. A number of programmes (including NERC's ACSOE and EXPORT) have addressed the influence of continental pollution on the global free troposphere, including the transport of continental pollution between continents. Attention is now turning to smaller scales, to consider the global impact of large local emissions. We will contribute to the NCAR-led MIRAGE (Megacity Impact on Regional and Global Environment), which aims to investigate the global impact of emissions from a large conurbation (probably Mexico City) on a range of chemistry climate questions, including chemical composition, aerosol, local meteorology, radiative forcing and urban metabolism. The measurement phase of MIRAGE is likely to be some time off, but by being involved in the planning phase we will be able to use our high resolution chemical model to pose questions about measurement strategy. Other models, taking different approaches, will be involved. We will benefit considerably by carrying out specific comparisons with these other models. As part of the preparation for MIRAGE, we will also validate the model against other high resolution data sets, ranging from, for example, recent measurements of the fine scale chemical composition and evolution following emissions from the industrialised southern Rhone region (the French ESCOMPTE project), to the very fine scale composition measurements made using a local network of sensors by Dr Jones' group in Cambridge.

- *Exploring the non-linearities in the interaction between the atmosphere and the land surface*

The key research question in this work package is: At what horizontal scales does the explicit representation of the land surface produce significant improvements in the simulated climate? These scales are linked to strong non-linear interactions between the land surface and the atmosphere, which occur at a whole range of spatial and temporal scales. For example, the expansion of boreal forest into areas of tundra over decades relies on planetary boundary layer feedbacks at scales of only a few kms., whilst in semi arid areas, on a daily timescale, the interaction of convective systems with soil moisture may be strongest at the mesoscale. Thus, as we go to finer and finer scale we would expect to resolve explicitly more of the key land atmosphere fluxes, and hence represent the non-linear coupling between the surface and atmosphere more realistically.

To investigate the length scale dependence of land-atmosphere coupling, we will investigate regions where strong feedbacks are observed (for example semi-arid areas and forest/non forest transitions such as Amazonia and boreal forest). We will run experiments designed to isolate the impact of explicitly simulating the land surface (topography, soil moisture, vegetation, snow) at higher resolution. This will provide one tool to evaluate why the 'Grand Challenge' simulation differs from coarser resolution versions over continental regions, and will guide the future development of HIGEM to even finer resolutions (see WP6).

- ***Work Package 6: Pushing at the limits of resolution - looking forward to the next generation supercomputers.***

During the last year of the project, work will commence on test versions of HIGEM that will have significantly higher resolution (e.g. $1/6^0$ ocean, 0.5^0 atmosphere) than the standard version proposed for here. The aim of this work package will be to identify the technical and scientific challenges presented by pushing at the limits of what is currently feasible. It is not the intention to provide a stable model for climate predictions, but rather to demonstrate the potential benefits of resolving more of the climate system, such as ocean eddies, land surface heterogeneity, mesoscale weather systems such as tropical cyclones, squall lines and fronts. Details of this work package will be defined during the later stages of UK-HIGEM in consultation with the UK-HIGEM Advisory Group.

6. Deliverables

UK-HIGEM will set in place a strategic alliance between NERC and the Hadley Centre, which will enable the UK climate community to remain at the forefront of global environment modelling internationally. Further, it will enable NERC/DEFRA to demonstrate the capability for addressing 'Grand Challenge' problems similar in resource implications to areas of particle physics, astronomy, and mapping the genome, thus placing the environmental change community on an equal footing in terms of priorities for the Government Spending Review. Specific deliverables for UK-HIGEM are:

- High-resolution version (initially $\sim 1^0$ atmosphere, $1/3^0$ ocean) of the Hadley Centre Global Environment Model (HadGEM), capable of providing more robust estimates of regional climate variability and change, as well as improved estimates of extreme events and high impact weather (WP1).
- Multi-century 'Grand Challenge' control simulation of the global environment. This will be a key resource for the wider NERC community involved in assessing the impacts of climate variability and change (WP2).
- A coordinated catalogue of HIGEM data held both at the partner sites and adjacent to the supercomputers and in the cache archive at the BADC. Tools to extract and manipulate that data within the HIGEM community (WP3).

- Advanced methods of model evaluation, focusing particularly on interactions between different components of the climate system, through the exploitation of (i) new satellite and in situ observations, and (ii) more sophisticated, very high-resolution models of the component parts (WP4).
- Assessment of the sensitivity of coupled simulations to model resolution, with particular reference to non-linearity in the interactions between components of the earth system (WP4, WP6).
- Advances in our understanding and predictive capabilities of global environmental variability and change, with particular reference to processes and phenomena on timescales from days to decades, extreme events, and the mechanisms of climate variability on seasonal to centennial timescales (WP5).
- Series of joint publications documenting the performance of the HIGEM model, highlighting the dependence on resolution of the non-linear interactions between components of the earth system, and describing the advances in the science of climate variability and change arising from the 'Grand Challenge' integration.
- Modelling framework in which new developments in numerical methods, key processes and sub-models of the earth system can be incorporated efficiently, leading to the creation of the next generation global environment model in partnership with the Hadley Centre.

7. Future prospects

As a strategic programme, UK-HIGEM cannot be viewed as time-limited and it is important to look beyond the 3 years of this current proposal. In the following section, priority areas for future research and model development are identified, some of which may potentially be addressed in the proposed project if progress and HPC availability is better than anticipated:

- ***Integrations and assessment of future climate change based on IPCC scenarios***

The 'Grand Challenge' multi-century control integration with HIGEM will form the basis for predictions of future climate change arising from GHG emission scenarios using a model with unprecedented horizontal resolution. The characterisation of seasonal to centennial climate variability in the control simulation (WP5) will provide the underpinning for the interpretation of scenarios of global environmental change in the coming century.

- ***Development of new parametrisations and sub-models for next generation GEM***

UK-HIGEM will provide the framework in which new developments of key processes in the atmosphere, ocean, land and cryosphere can be efficiently incorporated in the model, leading to the creation of the next generation model. The detailed evaluation of the model in WP4 will point to improvements in various aspects of the model. Further increases in resolution will enable better integration of process-based research within, for example, other parts of NCAS, particularly those that deal with weather, extreme events and physics of the atmosphere.

The investigations of land/atmosphere interactions and scaling undertaken in WP4.4 and WP5 should lead to improvements in the land surface representation - in particular in the description of sub-grid variability (for example in soil properties and soil moisture). New approaches will be developed in the context of a new MO/NERC initiative in land surface modelling (JULES), in collaboration with a recently funded Centre of Excellence in Earth Observation (CLASSIC), and with model developments at ESSC based on combining remotely sensed data with land surface models. Following critical evaluation of the sea ice component of HIGEM in WP 4.5, steps will be taken toward the development of a more sophisticated multi-level sea ice model that will include forcings, such as waves and tidal currents, that are not included in current models. Consideration will also be given to the representation of sub - ice shelf processes that are believed to play a crucial role in the production of Antarctic Bottom Water (Nicholls, 1997).

As well as further increases in horizontal resolution, the model development may also consider the vertical resolution, particularly at the model interfaces and boundaries. This may mean enhancing the ocean vertical resolution in the mixed layer and near the bottom surface. For the land surface, increased resolution in the soils may be necessary to simulate adequately the soil hydrology and its interaction with vegetation.

An important contribution to the development of the next generation GEM, will be the availability of the flexible model coupler being developed in the EU FP5 Infrastructure Programme for Integrated Earth

System Modelling (PRISM). In concert with PRISM, the Met Office is developing a specific modular approach to enable greater flexibility (FLUME: Flexible UM Environment). This will allow new modules to be incorporated more easily within the HIGEM framework and will enable the wider NERC community to become involved in global environment modelling at the highest level.

- ***Development of advanced computational methods to address resolution issues related to key processes and to exploit high resolution EO data.***

Many processes, such as clouds, mixing and chemical transport take place in fine scale structures, which standard climate models cannot resolve. Advanced numerical methods, such as adaptive mesh refinement, and the use of detailed process models, such as cloud resolving models, possibly in the form of "super-parametrizations" embedded in the GEM in order to resolve particular processes explicitly, may be used to explore the importance of representing fine scale structures and also as a longer term approach to global environment modelling. These methods will also enable exploitation of the ultra-high resolution information available from satellites. In particular, satellite data are widely available at spatial resolutions similar to those of cloud resolving models (around 1km), although only the rapid scan data from geostationary satellites can match the models' temporal resolution of a few minutes. At the land surface in particular, such embedded high resolution simulations and the corresponding remote sensing data can be used to investigate the up-scaling of processes to the resolution normally employed in GCMs.

As well as the specific applications noted above, the continued development of HIGEM to higher resolutions and more complete representations of components of the earth system will enable better integration between global environment modelling and the research programmes of the NERC EO Centres of Excellence such as Centre for Polar Observation and Modelling (CPOM), Centre for Terrestrial Carbon Dynamics (CTCD), Centre for observation of Air-Sea Interaction and fluxes (CASIX).

8. Training

The development of the next generation of earth system modellers, capable of working at the technical and scientific limits, is one of the key aspirations of the project. CGAM already has this responsibility for global atmospheric modelling through the UK Universities Global Atmospheric Modelling Programme (UGAMP) and its various support and training activities in the use of the Unified Model. By joining up the UK global environment modelling community through the UK-HIGEM consortium, we plan to extend these activities to the wider NERC community.

In parallel with UK-HIGEM, plans have been developed for a national Summer School in 'Science and Computing for Global Environment Modelling'. Computational modelling on massively parallel machines is one of the main tools of the environmental and climate research community, and the use and further development of models require a broad range of multidisciplinary skills, pertaining to both NERC and EPSRC. Recognising that there is currently no facility to train scientists in the mathematics and science of global environment modelling, Cambridge University (DAMTP), the NERC Institute for Environmental e-Science (NIEeS), CGAM and ESSC are planning an annual 4-week summer school to be hosted at the Cambridge Centre for Mathematical Sciences. The purpose of the summer school will be to train PhD students and new research staff in the use of contemporary models, modelling techniques and computational hardware pertaining to environmental and climate research. As well as lectures on the science underpinning global environment modelling, there will be a strong emphasis on computing practical sessions, including exercises on numerical methods and on code design and performance. UK-HIGEM will be strongly linked to this activity and a contribution towards the costs of the summer school has therefore been included in the budget.

9. Project Management

Overall coordination of UK-HIGEM will be carried out by CGAM under the direction of the lead PI. Exchange of information between the members of the consortium will be achieved by an interactive website, regular team meetings (typically every 3 months, but more often if the work requires it), a 6-monthly newsletter and an annual meeting, possibly held jointly with UGAMP. Costs to cover these activities will be administered centrally from a budget held by the lead PI. The Co-Investigator(s) from the lead organisations identified in Section 4 will be responsible for delivering the various work packages.

Progress will be monitored by an Advisory Group consisting of the Investigators, NERC Science Heads, Hadley Centre collaborators, and a DEFRA representative.

The day-to-day management of the project will be the responsibility of the UK-HIGEM Project Manager who will report to Prof. Slingo, Dr. Steenman-Clark and to the UK-HIGEM Advisory Group. The Project Manager will be responsible for evolving the implementation plan, updating the Risk Register, organising team meetings and coordinating the technical development of HIGEM.

The success of UK-HIGEM will depend heavily on establishing good working relationships between the various participating groups. To this end, an exchange programme will be established whereby staff working on HIGEM can spend extended periods (week to several months) with other members of the consortium. Costs to cover local living expenses will be administered centrally from CGAM. This is particularly important with the imminent move of the Hadley Centre to Exeter. To foster the proposed national collaboration it will be essential for NERC staff to spend time at the Hadley Centre and vice versa.

Good electronic links between the various members of the consortium is crucial. While not all the partners are covered by SuperJANET (Joint Academic Network), new initiatives are underway to ensure adequate network bandwidth. In particular, there will be a new link between the BADC and the Met Office at Exeter (and thus the Hadley Centre), which will make possible new initiatives to make elements of the Met Office Intranet visible to the academic community via a mirror outside the firewall. As a consequence, a key indicator of HIGEM success will be improved information sharing between the partners.

10. Justification of resources

Considerable support for the proposed programme already exists within the core/strategic funding within NCAS, ESSC, SOC, CEH and BAS, and some re-direction of core activities is envisaged if this consortium bid is successful. This programme requires high-performance computing and data-handling infrastructure, which is in place but needs enhancement. The additional funding being sought through this consortium bid is to provide: (i) coordination of the Hadley Centre and NERC activities, (ii) technical support for the development of the high resolution model, (iii) computing resources to perform the ‘Grand Challenge’ integration, and (iv) scientific support to evaluate the model and to exploit the model results. In addition, the consortium will benefit from considerable investment by the Hadley Centre, not only in the provision and development of the model, but also in advice on technical issues and its active collaboration in the evaluation and exploitation of the model results.

11. Relevance to NERC Strategy

This proposal is firmly centred on the strategic and scientific priorities for the UK environmental sciences community as set out in the NERC strategy document for the next 5 years, ‘Science for a Sustainable Future’. UK-HIGEM 'crosses the traditional scientific boundaries of physics, chemistry and biology and focuses on understanding interactions at interfaces within the Earth system', identified as key priorities for NERC. It will 'accelerate the next generation of environmental change models being developed at NERC Research and Collaborative Centres, the Met Office, Hadley Centre and within Universities', one of the delivery mechanisms identified in the NERC strategy.

'Science for a Sustainable Future' has three main themes - (i) Earth's life-support systems, (ii) climate change, and (iii) sustainable economies. UK-HIGEM directly addresses the research priorities of (i) by providing the high-resolution modelling infrastructure required to quantify the water and carbon cycles. It lies at the core of (ii) by providing the modelling framework to 'understand the integrated physical, chemical and biological response to climate variability' and change on an unprecedented range of time and space scales, thereby providing 'meaningful translation of the consequence of global climate change into local impacts'. Lastly, UK-HIGEM will provide the underpinning science and modelling infrastructure for (iii), particularly in the areas of land use patterns and river management.

The training activities proposed within UK-HIGEM will contribute to NERC's strategic objectives for the development of a pool of skilled people, in this case numerical modellers. It will encourage top quality science graduates to enter the field of earth system modelling and will ensure that NERC scientists have opportunities to gain experience of state-of-the-art, multi-disciplinary global environment modelling.

12. Links to other NERC, national and international programmes

The modelling infrastructure and the 'Grand Challenge' control integration, provided by UK-HIGEM, will be relevant to a number of existing and planned NERC programmes, specifically RAPID, FREE, SOLAS and QUEST. The science arising from UK-HIGEM is of relevance to these programmes, and to a wide range of international programmes such as CLIVAR, CliC, IGBP, SCAR. The high resolution climate change scenarios enabled by UK-HIGEM will be important contributions to impacts studies and the development of adaptation and mitigation strategies by the Tyndall Centre and the UK Climate Impacts Programme (UKCIP).

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