RT1 ENSEMBLES Periodic Activity Report – 1Sep04-31Aug05

Overview of activities carried out during the reporting period

1. RT1 objectives and major achievements during the reporting period

Aim

The purpose of RT1 is to build an ensemble prediction system based on global Earth System Models developed in Europe, for use in the generation of multi-model simulations of future climate in RT2. The scope includes assembly and testing of Earth System Models, testing of schemes to represent modelling uncertainties, initialisation of models and construction and testing of methodologies for both seasonal-decadal and centennial prediction, based on a multi-model ensemble approach. The ensemble prediction system will provide the basis for the production and use of objective probabilistic climate forecasts within ENSEMBLES.

Primary Objectives

Provision of a set of tested Earth System Models for use in the ensemble prediction system.

Development and assessment of methods to represent uncertainties arising from initial conditions and the modelling of Earth System processes in the ensemble prediction system.

Development and assessment of methods to construct probabilistic forecasts from the results of the ensemble prediction system.

Provision of a tested first release (Version 1) of the ensemble prediction system by month 24, comprising methodologies for prediction on both seasonal-decadal and centennial time scales.

Recommendations for the design of an improved ensemble prediction system (Version 2) by month 60.

Relation to state of the art

RT1 will enhance the current state of the art in ensemble climate prediction by:

- Constructing a European multi-model ensemble for seasonal to decadal prediction, developed from the DEMETER seasonal prediction system and initialised using ERA-40 atmospheric reanalyses, and a dataset of ocean observations and advanced data assimilation schemes developed from the products of ENACT.

- Developing a new approach to ensemble climate prediction based on sampling stochastic parameterisation uncertainties.

- Building on recent development of a perturbed parameter approach to the sampling of modelling uncertainties, to apply the approach for the first time to the simulation of both seasonal to decadal climate and time-dependent climate change on multi-decadal time scales.

- Building new Earth System models from existing component modules, and using these to construct multi-model ensembles which sample modelling uncertainties in the representation of biogeochemical as well as physical processes. The perturbed parameter approach will also be extended to sample uncertainties in biogeochemical feedbacks.

- Providing the first realistic assessment of the practical predictability of climate on the decadal timescale.

- Providing a systematic approach to probabilistic prediction of long term climate change, through a system which has been validated on seasonal and decadal timescales.

Overview of achievements during months 1-12

- New Earth System models have been constructed by MPIMET, METO-HC, CNRS, DMI and INGV
- Substantial progress has been made towards installation of the multi-model ensemble for seasonal to decadal prediction on the ECMWF supercomputer. Pre-production simulations are already in progress in some cases. In order to ensure efficient data archiving and dissemination, a common list of variables (defined in RT2A) has been used to ensure a coordinated approach among partners to data encoding and archiving. Significant efforts have also been made to develop diagnostics for use by other ENSEMBLES RTs, for seasonal to decadal intercomparison, dynamical downscaling and application to impact models. These model outputs have been coordinated so that they can feed into a common database at ECMWF
- Work towards the initialisation of this multi-model ensemble has also progressed significantly. The ENACT database of ocean observations has been updated and distributed to RT1 partners, and wind stress and SST perturbations have been provided for the creation of alternative sets of initial conditions. Technical developments have been made to update and improve systems for the assimilation of ENACT ocean data to initialise the multimodel ensemble integrations.
- Results have been analysed from a large set of decadal hindcasts, constructed from small ensembles of HadCM3 simulations sampling uncertainties in the initial conditions and including anthropogenic and natural variations in radiative forcing. These reveal evidence of skill in predictions of surface temperature up to a decade ahead, both globally and in many regions. Improvements in regional skill are found relative to previously available predictions with the same model that only include projected changes in anthropogenic forcing.
- The perturbed parameter approach to sampling modelling uncertainties has been further developed. New and larger ensembles have been created, analysed and published, demonstrating the importance of non-linear interactions between processes in broadening the range of uncertainty. The approach has also been extended from equilibrium to transient change, by successfully producing an ensemble of simulations in which multiple versions of the atmospheric module of HadCM3 were coupled to the dynamical ocean module. This experiment revealed technical issues associated with the spin up of the model versions, leading to a revised methodology now being used to generate new ensembles simulating the response to SRES forcings.
- Methods of sampling modelling uncertainty and constructing probabilistic predictions have been further developed and reviewed, including strategies for the generation of ensemble members, the use of observational constraints and the effects of prior assumptions in affecting the posterior, likelihood-weighted distributions.
- A joint meeting of RT1 and RT2A was held in Toulouse in June 2005, reviewing progress against deliverables and milestones for months 1-24, and coordinating development of plans for months 13-30. We currently expect to deliver all deliverables and milestones on time.

- We propose to produce distributions of European climate change during the 21st century from the HadCM3 perturbed physics ensembles, by month 24. These will assume that all model versions are equally likely, and will only sample uncertainties arising from surface and atmospheric processes in a single model framework. However, they will serve as interim pdfs which can be used for development work by other RTs.

2. Research Theme Progress

WP1.0: Management of RT1

a) Objectives and starting point at beginning of reporting period

The scope, structure and membership of RT1 had been decided through extensive discussions prior to the start of ENSEMBLES, and a detailed plan for months 1-18 had been produced. Several deliverables and milestones had been agreed. Objectives for months 1-18 are:

Task 1.0.1: An initial meeting of RT1 participants will be held early in the project to discuss the strategy for development of the ensemble prediction system.
Task 1.0.2: An RT1 website will be set up, containing information such as location of model documentation, model output data, contact details, progress reports, summaries of meetings and key scientific developments etc.
Task 1.0.3: Timely delivery of milestones, deliverables and progress reports and representation of RT1 at ENSEMBLES management meetings will be ensured.

b) Progress towards objectives

RT1 was represented at the ENSEMBLES kick-off meeting and six monthly Management Board meetings, at which presentations of plans and progress were given. Scientific discussions were held during the kick-off meeting, which were documented and circulated to partners with a set of actions to promote coordination of initial research. In particular, much discussion followed between partners concerning the scientific design and implementation of the multi-model system for seasonal to decadal prediction, leading to agreement on strategies for hindcast start dates, initialisation techniques, inclusion of forcings and archiving of diagnostics. An RT1 web site was set up, at http://www.ecmwf.int/research/EU_projects/ENSEMBLES/index.html.

A meeting of RT1 participants was held in Toulouse during June 2005, conducted jointly with RT2A. Numerous presentations of initial results and progress were made, and further discussions were held to develop a plan for production of the first annual report and updated 18 month research plan. Progress towards deliverables and milestones was reviewed. All are currently on track.

c) Deviations from the project work programme and corrective actions

None

WP1.1: Construction of Earth System Models for ensemble climate prediction

a) Objectives and starting point at beginning of reporting period

The objective of work package 1.1 is the construction of a range of Earth system models (ESMs) from existing models of Earth system components or coupled model systems, for subsequent application in the “stream 2” simulations of RT2 (by CNRS, INGV, METO-HC, MPIMET), and the development of an efficient high resolution physical climate system model (by DMI) for application in selected periods of stream 2.

At the start of the project a range of coupled physical climate system models was already in use (CNRS: IPSL climate model, INGV: SINTEX, METO-HC: HADCM3, MPIMET: ECHAM5-MPIOM). In addition, the partners also possessed pools of model components (including biogeochemical modules) for the subsequent assembly of more comprehensive ESMs.

b) Progress towards objectives

The Deliverable 1.1 due at month 12 reports on the status of the model development within this work package. For this reason this report is kept brief to avoid duplication.

Within the first 12 months a number of ESMs have been constructed. These ESMs are assembled from existing components and upgraded or improved with respect to previous climate models. The ongoing work includes tests of the current climate models and the extension towards systems including the carbon cycle, or aerosols and their related chemistry. The progress achieved by each partner is summarized below.

CNRS: The new climate / carbon cycle model is assembled, coupling the OPA ocean model, the LIM sea-ice model, the LMDZ atmosphere model, the full ORCHIDEE soil/vegetation model (including carbon component) and PISCES for ocean biogeochemistry. A generic and public version of the VOC (volatile organic compounds) in ORCHIDEE is developed for coupling with the atmospheric chemistry model.

The OASIS3 coupler will be used for the coupling of the IPSL climate model and the LGGE ice sheet model. Both models and the OASIS configuration files are modified for this purpose.

DMI: The preliminary version of the atmospheric model DKCM has been upgraded using the ARPEGE climate version 4 dynamical core and the physical package of a formally released version of ECHAM5 (v5.2). The model runs about 8 times as fast as ECHAM5, implying a great potential for applications requiring high-resolution simulations. The model is tested and its performance is compared with ARPEGE and ECHAM5 as well as with the reanalysis data of ERA40. It is shown that the model simulates the climatology reasonably well with systematic errors that are generally comparable with those in ARPEGE and ECHAM5.

INGV: The new physical core of the Earth System Model has been assembled based on the ECHAM5 (atmosphere) model and OPA8.2 (ocean and sea-ice) model. The technical testing of the new physical core is reaching the final stages. The sensitivity of the new, coupled system to cloud parameters has been documented. Tests of the advection of sea-ice over the Arctic Ocean are in progress. For compactness, this new physical core has been named the EOL model.
The implementation of the coupling of the global version of the Modular Marine Ecosystem Model (MMEM) within the ocean component of the EOL model has also been completed. First test simulations have demonstrated that the coupling is technically robust. A comparison of the EOL+MMEM with a model system where the atmospheric coupling has been substituted with forcing from reanalyses is in progress.

Given the planned objective to construct an ESM focused on simulation of the carbon cycle, the task for the coming months will be to assemble a land vegetation module into the EOL+MME model and to test the simulation of the carbon cycle for present day climate conditions.

METO-HC: The development of HadGEM1 was completed and several standard simulations carried out and assessed, including a multi-century control run with constant pre-industrial forcing, transient experiments with a 1%-per-year increase in CO_2, and “slab-ocean” experiments to quantify climate sensitivity and feedbacks. Overall, HadGEM1 outperforms HadCM3 based on evaluation of a weighted set of variables forming a metric of skill for the simulation of present climate. HadGEM1 (alongside HadCM3) is thus a fully operational and well-documented model, with a growing set of simulations available to contribute to ENSEMBLES Stream 1. Projects are underway to improve the physical and aerosol components of HadGEM1, in particular to characterise and improve its tropical performance including ENSO, and to implement additional Earth System components in HadGEM.

The GloSea model (a variant of HadCM3) has been equipped with time varying anthropogenic and natural radiative forcings, for production of seasonal-to-decadal experiments at ECMWF in accord with those being used in RT2.

HadCM3 and its slab version HadSM3 have been used extensively via parameter-based perturbations to explore uncertainty in climate sensitivity. This work provides a framework for applying similar techniques using HadGEM1 (and other models) in future, subject to the availability of computing resources.

MPIMET: A new land processes package, JSBACH, has been completed. JSBACH includes modules for land surface and vegetation processes, including, for example, stomatal conductance for H_2O and CO_2 fluxes, leaf area, or carbon storage in foliage, stems and soil.

The physical climate model ECHAM5-MPIOM was used as a base for the development of two specific Earth system model configurations: the aerosol system model and the carbon cycle model. The aerosol system model includes the HAM model that computes 7 aerosol modes and various sources and sinks. Sulphate aerosols depend on DMS fluxes from the ocean, as simulated in the marine biogeochemistry model HAMOCC. Anthropogenic emissions of SO_2, black carbon and organic carbon are prescribed. The simulated plankton depends on dust input from the atmosphere. The carbon cycle model includes the JSBACH land processes package. CO_2 is transported in the atmosphere and its concentration depends on the net fluxes to land and ocean. The marine biogeochemistry model HAMOCC includes the marine part of the carbon cycle.
The aerosol and carbon cycle model systems are tested extensively in 20th century experiments and future climate simulations driven by SRES A1B emissions.

c) Deviations from the project work programme and corrective actions

Coupling of chemistry in ESMs is computationally extremely demanding, as reported by CNRS, METO-HC and MPIMET. The usage of such systems seems therefore impractical for the production phase in stream 2. The focus will therefore be on the development and testing of models of the physical system, the aerosol system and the carbon cycle system, for which the expected computational effort seems manageable for their application in centennial time scale integrations for stream 2. This strategy will produce model ensembles of different sizes, the largest for the physical system, which will be an advantage to the seasonal-to-decadal applications.

WP1.2: Developing and testing schemes to represent model uncertainty in seasonal to centennial prediction

a) Objectives and starting point at beginning of reporting period

Results had been published from a 53 member ensemble of equilibrium climate change simulations of HadSM3 (the atmosphere/mixed layer ocean version of HadCM3) run at the Hadley Centre, in which probabilities for climate sensitivity had been estimated by assuming that the effects of uncertain model parameters combine linearly and independently. A multi-thousand member ensemble using the same model, in which non-linear interactions between several key parameters were sampled, had been produced by the climate*prediction*.net team, and was being analysed.

A new stochastic physics scheme was about to be developed at ECMWF and a new multi-model ensemble system was under discussion.

The coupled model EGMAM (**E**CHO-**G** with **M**iddle **A**tmosphere) was already prepared and optimized for simulations within ENSEMBLES and installed at the DKRZ compute server environment (NEC-SX6). First experiments had been performed to test the performance of the model under both present day and pre-industrial conditions. Flux adjustment fields originally calculated with the ECHO-G model were being used at this stage.

b) Progress towards objectives

Centennial prediction

We have completed several items that will contribute to fulfilment of D1.2, which we expect to deliver on time. As well as a high profile paper presenting important early results from the above-mentioned climate*prediction*.net "grand ensemble" (which shows that parameter perturbations often add non-linearly, widening the range of physically plausible model sensitivities (Stainforth et al, 2005)) we have also completed ground-breaking work into issues surrounding the methodology behind probabilisitic climate forecasting, in particular regarding methods for ensemble weighting (Frame et al, 2005) and model error (Allen et al, 2005). These papers have, in turn, led to new work regarding the appropriateness of sensitivity as a policy variable (Frame and Allen, 2005). This work is currently being consolidated, and extended, in a series of articles by members of the Oxford team.

The Hadley Centre have been working with an expert in statistics from the University of Durham, UK, to develop a general methodology for generating probabilistic climate change predictions from small ensembles of climate change simulations. The method uses a Bayesian framework to generate a joint probability distribution that measures the probability of all combinations of values for all uncertain objects in a problem. Key components are; ensembles of complex model simulations in which key parameters are varied, an *emulator* which uses statistical and reduced-complexity physical models to generate pseudo-ensemble members in unsampled regions of model parameter space, and a *discrepancy* term which is intended to account for systematic imperfections in the climate model from approximations, missing processes and “structural” uncertainty, i.e. fundamental deficiencies in the way models represent physical processes. It is intended to develop methods of estimating this term by using results from perturbed parameter ensembles to predict the results of other climate models containing alternative structural assumptions. The discpreancy term has not, to date, been considered in climate predictions for any time horizon, and although this work is focussed on centennial-scale predictions it may also be of use in seasonal-decadal prediction.

In a largely methodological paper, the Oxford ENSEMBLES team addressed the issue of the role of prior assumptions in probabilistic climate forecasts (Frame et al, 2005). A key determinant of future climate change is the climate sensitivity, or equilibrium warming in response to a doubling of CO_2. As an alternative to using the spread of results from climate models or surveys of expert opinion, several studies have attempted to constrain climate sensitivity with a combination of models of varying complexity and recent observations. All have failed to eliminate a high upper bound which, when used in forecasts of 21st century climate change, assigns a high probability to relatively rapid warming. We showed that assumptions made in most papers about the prior distribution of climate sensitivity have a strong influence on the range found for its posterior distribution; equally defensible assumptions give very different results. The impact of these arbitrary assumptions can, however, be substantially reduced by considering their implications for observable climate variables, such as the warming attributable to greenhouse gases over the 20th century. In the absence of non-linear climate change, this yields an objective, observationally constrained 5-95% range for climate sensitivity of 1.2-5.7K.

In Piani et al (2005), the climate*prediction*.net ensemble is used to search for constraints on the response to increasing greenhouse gas levels among present day observable climate variables. The search is conducted with a systematic statistical methodology to identify correlations between observables and the quantities we wish to predict, namely the climate sensitivity and the climate feedback parameter. A predictor of climate sensitivity and the feedback parameter (defined here simply as the inverse of climate sensitivity) is sought among the variables of the 8yr mean control climate for which we have available observational and reanalysis data sets. The focus is on linear predictors to simplify the methodology and minimize the risk of over fitting, but a natural generalization in future work would be to relax the linearity condition. Allowing for correlations between these observable quantities improves the accuracy of the uncertainty analysis. Following the practice of climate change detection studies, we assume the correlation structure of model-data discrepancies can be modelled by internal climate variability, so we begin by projecting both observations and members of the climate*prediction*.net ensemble onto EOFs of 8-year mean climate of the HadCM3 coupled model, with individual variables within these EOFs weighted by the inverse of the globally averaged standard deviation of HadCM3 climate variability. We then find linear combinations of these EOFs (“rotated” or REOFs) such that, when members of the climate*prediction*.net ensemble are projected onto them, the resulting projections are uncorrelated with each other. We assume the quantities we wish to estimate (climate sensitivity and the feedback parameter) can be predicted by a simple linear model. Using this method our best estimate of climate sensitivity is 3.3 K. When an internally consistent representation of the origins of model-data discrepancy is used to calculate the probability density function of climate sensitivity, the 5th and 95th percentiles are 2.2 K and 6.8 K respectively. These results are sensitive, particularly the upper bound, to the representation of the origins of model-data discrepancy.

The book chapter by Allen et al. (2005) focusses on how to quantify and minimise the cumulative effect of structural model imperfections (sometimes called model error) that result either from incomplete observations or understanding or cannot be eliminated because they are intrinsic to the structure of the model. The discussion focusses on minimising the effects of such “model error”. A fundamental issue is the lack of a universal objective metric or norm for model error: expert judgement is required in deciding how to measure the distance between two models or model-versions in terms of their input parameters or structure. Hence, any method of allowing for model error by sampling the space of “all possible models” would require a subjective judgement in deciding how to measure distance within this space. In weather forecasting, model forecasts can be independently verified and falsified by the real world. In climate forecasts – of 2100 temperature for instance – this is not the case. The lack of a falsification/verification procedure presents a problem in determining the relative credibility of different methods, several of which have recently appeared in the literature. However, it does not necessarily follow that we need to treat all forecasts as having equal status. Allen et al argue that an appropriate test is whether or not a forecast is likely to have converged, in the sense that further developments in modelling (increasing model resolution, or including different parameterisations) are unlikely to result in a substantial revision of the estimated distribution of the forecast variable in question. Under this philosophy, the aim is to render model error as irrelevant as possible, by ensuring that our forecasts depend on data and on the constraints that all physically conceivable models share, rather than on any specific set of models. Such “STAble Inferences from Data (STAID) will not change except through the painstaking acquisition and incorporation of new data. Allen et al lay out a methodology for STAID probabilistic forecasting by looking for convergent results across nested ensembles.

The Bayesian approach being developed at the Hadley Centre differs somewhat in philosophy from the STAID approach. While it will give results which (like STAID) are influenced by observational constraints and uncertainties, it is being designed to place greater weight on the spread of outcomes obtained by varying physical parameterisations in GCM ensemble runs according to expert-specified distributions, and will be more dependent on estimates of model error, hence allowing scope for the uncertainty range to narrow in future as model physics improves. The availability of these complementary approaches will place the ENSEMBLES project in the strong position of being able to assess the dependence of the predicted changes on two plausible, but distinct, methodologies.

To date, large perturbed parameter ensembles have been carried out only with the HadSM3 model. However, progress has been made towards investigation of modelling uncertainties in the EGMAM-model, by testing different values in the cloud parameterisation. This was preliminary work for a detailed sensitivity test of time-dependent climate change to parameter perturbations, which has now started.

1. Investigation of the possibilities to implement existing perturbed-physics schemes for the EGMAM model was made in cooperation with ENSEMBLES project partners in order to generate ensembles of perturbed physics model runs.
2. A full ensemble of 20th century simulations (natural experiment, GHG experiment, solar experiment, volcanic experiment, all forcings experiment, 3 simulations each) was created with the ECHO-G model (FUB in RT2A.2). Initial conditions were taken from a long historical simulation (ERIK). (For more information see FUB contributions in RT2A.2) These simulations were used to develop initial schemes to represent model uncertainties. Analysis was performed on global and regional scales. On the global scale, simulations within one experiment are characterised by a comparably small spread. There is a notable signal-to-noise ratio with respect to the GHG and volcanic forcings. At regional scales the focus was on the North Atlantic/European sector, investigating to what extent typical patterns of atmospheric circulation variability are affected by the different (oceanic) initial conditions. We find a very robust 1st and 2nd EOF pattern representing the NAO and a blocking situation.

Seasonal to Decadal prediction

Progress towards designing a new multi-model ensemble for seasonal-to-decadal ensemble prediction has been achieved. The models contributing to this multi-model exercise are IFS/HOPE and IFS/OPA (ECMWF), GloSea and DePreSys (Met Office), ARPEGE/OPA (Meteo-France and CERFACS), ECHAM5/MPI-OM1 (IfM). Most of these models are updates of those used in the DEMETER experiment (Palmer et al. 2004), especially concerning the atmospheric components. Furthermore, GHG, volcanic, solar and aerosol forcings have been included in most of them. It is expected that the improvement of some individual models will benefit the forecast quality of the multi-model predictions. In addition, a new stochastic physics backscatter scheme has been developed at ECMWF to account for uncertainty arising from the stochastic effects of sub grid scale processes (Palmer et al. 2005). The system, initially tested for medium-range ensemble forecasts, is currently undergoing a set of preliminary tests in seasonal forecast mode. In principle, this system will also be relevant to climate prediction on interannual to decadal and longer time scales.

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c) Deviations from the project work programme and corrective actions

There have been changes in the personnel of the FUB. One person assigned to contribute to ENSEMBLES has left the institute and will be replaced in September. One PhD student was employed in March 05. To support the progress of the modelling experiments one part time scientist was hired also in March 05.

The EGMAM model simulated a too warm climate using the old ECHO-G flux adjustments. A new flux adjustment for the EGMAM model was calculated to improve the models climate. The delay caused by this was the reason for the decision to do the parameter sensitivity tests with the ECHO-G model.

WP1.3: Initialisation procedures for ocean component based on observed states

a) Objectives and starting point at beginning of reporting period

The purpose of this workpackage is to develop techniques to initialise ESMs and to represent uncertainties in the initial conditions for ESM integrations, especially in the ocean component.
At the beginning of the reporting period, the ENACT project was not completed. As anticipated, the 6-month overlap between the end of the ENACT project, in which all WP1.3 partners were involved, and the beginning of ENSEMBLES, has led some partners to postpone the start of their work in the project. Therefore, for all partners of the workpackage, the starting point of this report is the end of the ENACT project, which provided a global dataset of in situ ocean observations and a set of schemes for assimilation of the observations to initialise seasonal predictions.

b) Progress towards objectives

During the first year, most activities in this workpackage have been devoted to preparing updated data sets and systems from the ENACT developments:

- METO-HC has upgraded and extended the in situ observation database, which now covers 1958-2004 (see www.hadobs.org, and Ingleby and Huddleston, 2005). This ENSEMBLES product has been distributed to all partners for evaluation, and has also been made available to the FP6 MERSEA project, which contains the major operational ocean monitoring and forecasting agencies.
- ECMWF has produced wind stress and SST perturbation sets to generate alternative initial conditions for ensembles of seasonal to decadal forecasts. The impact of these perturbations is being tested in ensemble forecasts.
- Technical developments have been made to update and improve systems for the assimilation of ENACT ocean data to initialise models for seasonal to decadal prediction. The following bullets briefly summarise more detailed information available from individual partner reports:

- Some partners (ECMWF, CERFACS) have interfaced their system with the new in situ data set and the new perturbation sets, and begun to assess their impacts;
- Optimization of the code and improvement of the model resolution along with better representation of the salinity (INGV);
- Implementation of the ensemble Kalman Filter (EnKF) data assimilation system for the OPA ocean model (KNMI);
- Upgrade of the minimization algorithm and reformulation of the background term in the OPAVAR system (CERFACS);
- Efforts towards a multivariate version of the IfM 3D-Var system have been carried out.

All partners have devoted effort towards validation and further understanding of their system (details in partner reports). KNMI investigated a “tubing”method for ensemble reduction in the Ensemble Kalman Filter (EnKF) system - see Figure 1.3.1 below from Leeuwenburgh (2005) showing rank histograms of several variables obtained from the EnKF. In this method, the ensemble is described by its mean and by several tubes extending in phase space that reach the members most remote from the ensemble mean. To reduce the size of ensembles required in their EnKF implementation, only the ensemble member closest to the ensemble mean and the extreme members of each tube are considered.

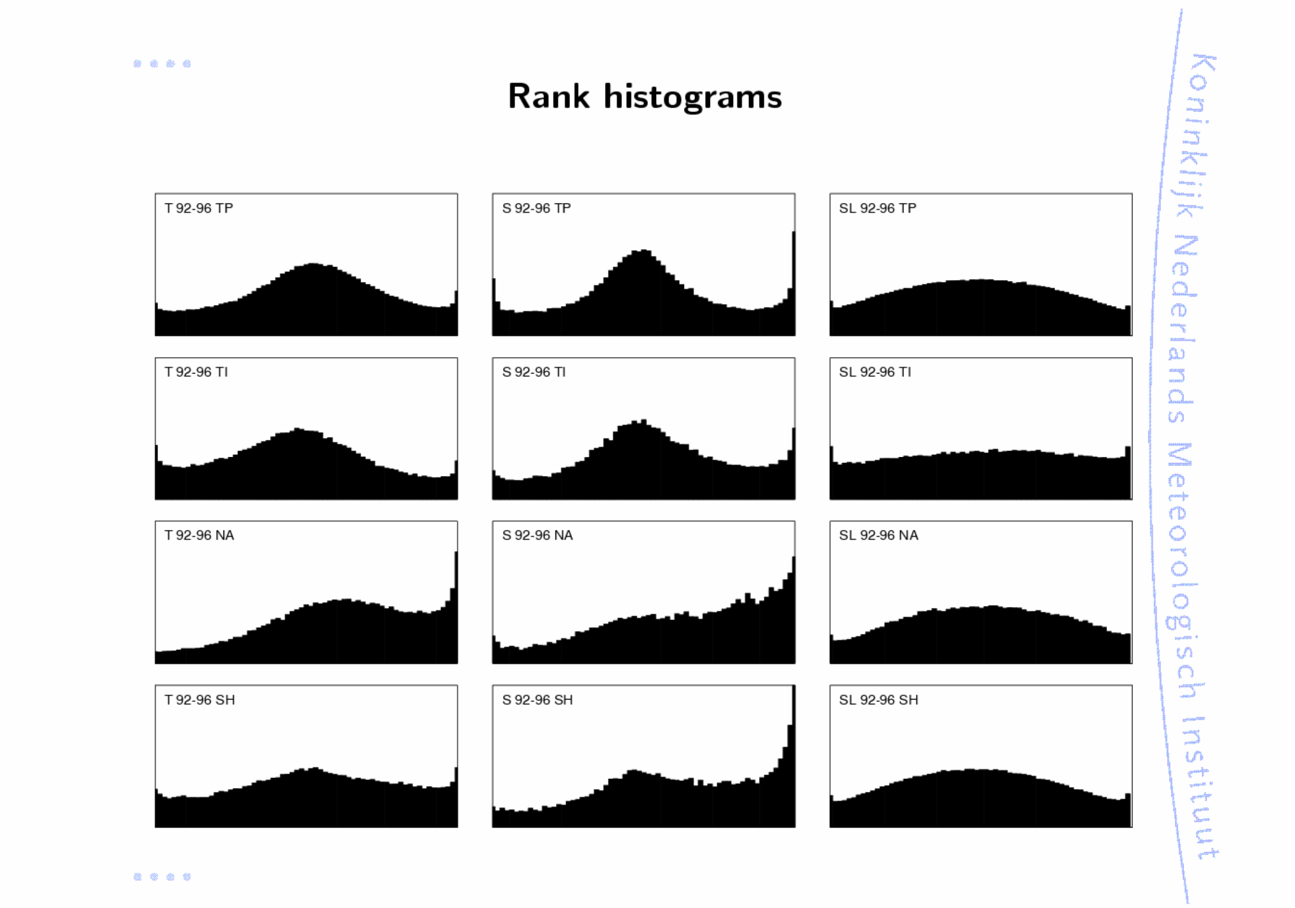

Figure 1.3.1: Rank histograms for temperature (left), salinity (middle) and sea level (right) in four regions (TP: Tropical Pacific, TI: Tropical Indian, NA: North Atlantic and SH: Southern Hemisphere. Those have been obtained from a multi-year ocean reanalysis using the KNMI Ensemble Kalman Filter with 65 members (Leeuwenburgh, 2005). Deviations from a flat histogram indicate problems in the ensemble distribution, e.g. due to model biases, as is the case for salinity.

- An extensive common assimilation diagnostic list has been created by METOHC.

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c) Deviations from the project work programme and corrective actions

None.

WP1.4: Assembly of a multi-model ensemble system, with common output, with installation on a single supercomputer, where appropriate

a) Objectives and starting point at beginning of reporting period

It was shown in the FP5 project DEMETER that seasonal forecasts made with a multi-model system are intrinsically more reliable and, on average, more skilful than forecasts made with a single model system. The seasonal-to-decadal ENSEMBLES multi-model prediction system is mainly based on the DEMETER system. Since DEMETER, many of the component climate models have been upgraded and, in addition, need to be ported to run on newer super-computer architecture.

- At ECMWF, the knowledge of the DEMETER project was expected to be paramount for the local installation of a new multi-model system. Furthermore, the European operational seasonal forecast multi-model system had been started through the collaboration with METO-HC and CNRM.
- At METO-HC, a system for predicting interannual to decadal climate variations had been developed (DePreSys), using the HadCM3 coupled model. This system was due to be the basis for the single-model perturbed physics ensemble, as well as an additional contribution to the multi-model ensemble. Additionally, a version of GloSea, the Met Office operational seasonal forecast system, was available on the ECMWF computer but needed development work to include radiative forcings and for different ensemble generation strategies.
- CNRM counted on the experience developed in the framework of the DEMETER project, as well as on the on-going research experiments continuously carried out to improve and understand the forecast quality of the coupled model.
- IfM had experience in using an old version of the ECHAM5/OM1 coupled model for both seasonal and longer time scale ensemble predictions. This experience was part of the DEMETER project. Work was being carried out on a 3D-Var initialization scheme in the framework of the ENACT project.
- CERFACS had worked in both DEMETER and ENACT to produce ensemble seasonal forecasts and improved ocean initial conditions. For the first task, CERFACS used the coupled model ARPEGE/OPA, while for the second a 3D-Var scheme was developed and tested.
- INGV had worked within DEMETER with the ECHAM4/OPA coupled model and developed a significant experience in archiving model output at ECMWF.
- CNRS-IPSL had made available an extensive knowledge of the OPA ocean model, the basis of many of the coupled models participating in ENSEMBLES.

b) Progress towards objectives

- ECMWF has prepared a new version of the IFS/HOPE coupled model to perform seasonal, annual and decadal ensemble predictions. This system is a considerable upgrade with regard to the version used in DEMETER and includes realistic boundary forcings (greenhouse gases and solar activity). In order to ensure efficient data archiving and dissemination, a common list of variables (defined in RT2A) has been used as a basis to design templates for data encoding and archiving (along with documentation available from the RT1 web site http://www.ecmwf.int/research/EU_projects/ENSEMBLES/index.html) for the other partners running their experiments at ECMWF. These activities will ensure the success of Tasks 1.4.1 - 1.4.3. In addition, work has been carried out to ensure the archiving of 6-hourly model-level data to be used as boundary conditions in downscaling experiments with dynamical regional models. To cope with the requirements of different regional models, a routine to transform global model-level data into pressure-level data has been tested and made available to the RT2B partners.

- At METO-HC, HadCM3, the coupled model used in DePreSys, has been installed on the ECMWF computer, and its performance successfully validated in test simulations. This is an essential step towards generation of the pre-production simulations as described in Task 1.4.1 and 1.4.2. In addition, GloSea has been installed at ECMWF to use greenhouse gas forcing and volcanic aerosols, and is now able to perform simulations with both burst and lagged average initalization methods. Significant efforts have been made to develop diagnostics for ENSEMBLES that are suitable for seasonal to decadal intercomparison, dynamical downscaling and application to impact models. These model outputs have been coordinated so that they can feed into a common database at ECMWF. After some development, the model is now ready for perturbed initial condition experiments starting on 1st and 15th of the month (DEMETER style and lagged average approaches) and research to develop physics perturbations are ongoing.
- CNRM has upgraded the atmosphere model ARPEGE for seasonal forecasting. A set of intermediate hindcast experiments, described in RT2A, has been used to install and check the system on the ECMWF computer. The version for pre-production is ready since June 2005 and will be used to generate ensemble predictions as part of the multi-model experiment. CNRM uses the ocean initial conditions produced by CERFACS.
- IfM has carried out significant work to install the coupled model ECHAM5/OM1 on the ECMWF computer.
- CERFACS uses a coupled model similar to that of CNRM, the work being carried out in a synchronized way between both institutions.
- INGV had not planned any effort during the first year.
- CNRS-IPSL has developed tools that allow a hybrid coupled model to be easily set up within the ORCA2 context. The statistical atmosphere is obtained from flux and SST datasets. At present, this model is computed from ERA-40 fluxes and an example is shown in Figure 1.4.1, although it can be computed from coupled general circulation model (CGCM) fluxes too. When coupled to the ORCA2 ocean component, this allows construction of a hybrid coupled model that mimics the CGCM, but for which optimal perturbations can be computed. The goal is to port existing code to compute ocean singular vectors to the global ORCA2 model in order to provide initial perturbations for ensemble seasonal forecasts carried out with those coupled models on ORCA2.

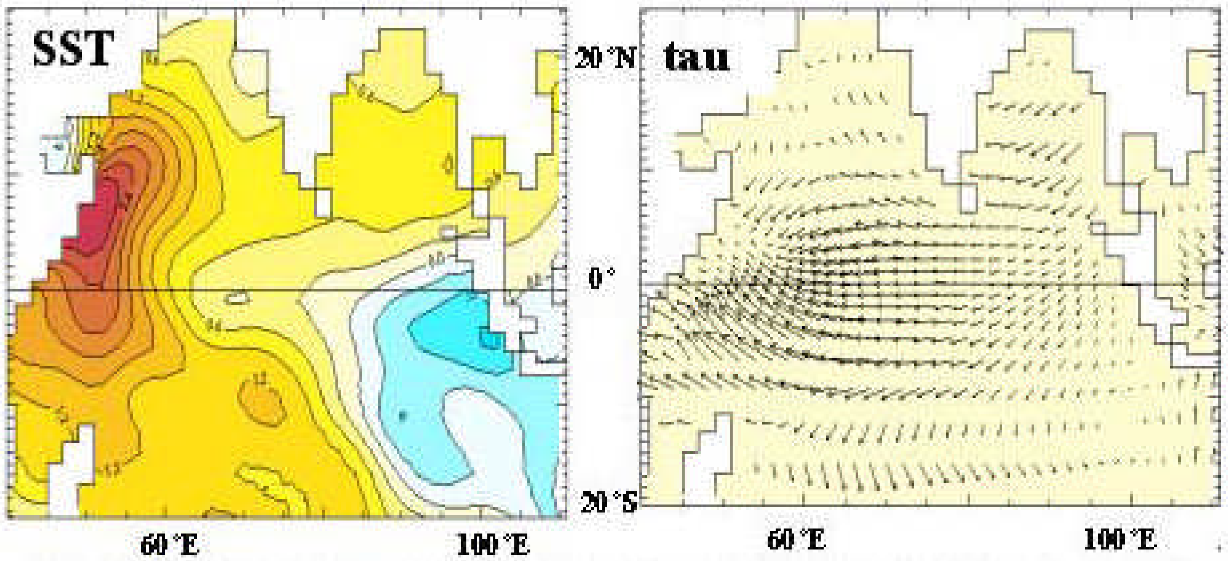

Figure 1.4.1: First pair of SVD patterns for sea surface temperature and ERA40 wind stress anomalies. The pattern explains 68% of the coupled variance between the two fields. The SVD analysis has been performed for the Indian Ocean region.

c) Deviations from the project work programme and corrective actions

None

WP1.5: Generation of pre-production ensemble predictions of climate on the seasonal to decadal timescale, initialised from observations

a) Objectives and starting point at beginning of reporting period

It was shown in the FP5 project DEMETER that seasonal forecasts made with a multi-model system are intrinsically more reliable and, on average, more skilful than forecasts made with a single model system. However, the multi-model approach is not the only one available to deal with model uncertainty. Experiments carried out at METO-HC and ECMWF indicate that other methods, such as perturbing uncertain model parameters, or including stochastic physics, might offer improvements in forecast quality in seasonal-to-decadal ensembles:

- At ECMWF, a completely new version of the stochastic physics scheme (CASBS) was under development. In addition, a new scheme for ensemble generation was being designed. A new version of the atmosphere model including a new boundary layer scheme was being studied. The resulting coupled model IFS/HOPE was devised as a contribution to both the single-model stochastic physics and the multi-model ensembles.
- At METO-HC, a system for predicting interannual to decadal climate variations had been developed, using the HadCM3 coupled model forced with anthropogenic greenhouse gases and sulphate aerosols, and initialised by assimilating observed anomalies of atmospheric winds, temperatures and surface pressure, and analyses of ocean temperature and salinity constructed using an optimal interpolation method based on the use of spatial, temporal and inter-variable covariances obtained from HadCM3. A set of four member ensemble runs, initialised from consecutive days once per season from 1979-2001, had been run but not fully assessed. This system would be the basis for the single-model perturbed physics ensemble, as well as a contribution to the multi-model ensemble. Additionally, a version of GloSea, the Met Office operational seasonal forecast system, was available on the ECMWF computer but

needed development work to include radiative forcings and for different ensemble strategies. This had previously only been used in one ensemble strategy (initial condition perturbations).

- CNRM had worked, before the start of the project, on a previous version of coupled model ARPEGE/OPA to produce 44 years of 6-month hindcasts in the framework of the DEMETER project.
- IfM had experience on using the new ECHAM5/OM1 coupled model on both seasonal and longer time scale ensemble predictions. Work was being carried out on a 3D-Var initialization scheme in the framework of the ENACT project.
- CERFACS had worked in both DEMETER and ENACT to produce ensemble seasonal forecasts and improved ocean initial conditions. For the first task, CERFACS used the coupled model ARPEGE/OPA, while for the second a 3D-Var scheme was developed.

b) Progress towards objectives

- ECMWF has prepared a new version of the IFS/HOPE coupled model to perform seasonal, annual and decadal ensemble predictions. This system is a considerable upgrade with regard to the version used in DEMETER and includes realistic boundary forcings (greenhouse gases and solar activity), which has shown a positive impact in forecast quality at the seasonal time scale, in independent experimentation. The coupled model IFS/HOPE is used to contribute to both the single-model stochastic physics and the multi-model ensembles. The pre-production simulations, a 7-month 9-member ensemble starting on the 1^{st} of May and another 14-month 9-member ensemble starting on the 1^{st} of November over the period 1991-2001, have already been started using the ocean initial conditions generated by WP2A.1. The stochastic physics scheme has been further developed and currently is being coupled to IFS. These activities will ensure success in task 1.5.1.
- At METO-HC, existing DePreSys simulations have been analysed to provide a first indication of prospects for achieving useful forecast skill on interannual to decadal time scales during ENSEMBLES. Skill is found in predictions of globally averaged annual mean temperature throughout the 10 year range of the hindcasts, arising largely from the ability to predict natural climate variations such as ENSO on time scales of 1-2 years ahead, and mainly from the ability to predict observed trends on longer time scales. Whilst global temperature is important for informing greenhouse gas emissions policy, many sectors of industry and commerce require predictions for specific regions. This was assessed by comparing the ability of DePreSys to predict regional patterns of decadal temperature change against previously available predictions with the same GCM that only include projected changes in anthropogenic forcing (ANTHRO) (see Figure 1.5.1). The ANTHRO hindcasts were generally found to be too warm in the tropical Pacific, Indian Ocean, Antarctica, Alaska and Siberia, and too cool in the north Atlantic, western Europe and eastern Asia. Encouragingly, most of these errors were at least partially corrected by DePreSys. Relative to ANTHRO, DePreSys also includes projected changes in natural (solar and volcanic) external forcing, and predicts the evolution of natural internal variability of the climate system by initialising the state of the ocean and atmosphere. The relative importance of these two additional sources of skill is currently unknown, but will be quantified by a new set of hindcasts (currently underway), which include projected changes in natural external forcing but do not explicitly initialise the atmosphere or ocean. This is an essential step towards generation of the pre-production simulations as described in Task 1.5.1, which will include simulations for 1991-2001 sampling uncertainties from uncertain parameters in the HadCM3 surface and atmospheric physics, and further ensembles sampling initial condition uncertainties. In addition, GloSea will be used in a similar setting contributing to both the perturbed-parameter and the multi-model ensembles.

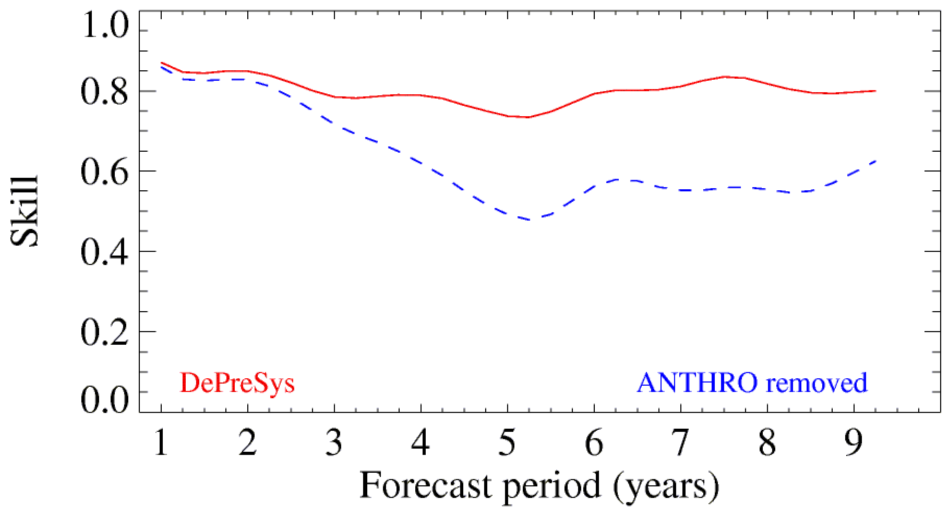

Figure 1.5.1. Skill of predictions of annual mean surface temperature from ensemble simulations of HadCM3, initialised using global, three dimensional analyses of atmospheric and oceanic anomalies, and forced by projections of anthropogenic and natural variations in external forcing. Skill is measured as one minus the normalised error variance between predicted and observed anomalies, where zero representing the skill of a forecast of zero anomaly. The scores shown are averaged over 92 separate ensemble forecasts started from 1st March, June, September and December from 1979-2001 inclusive. Skill is compared against that of a linear trend obtained from previously available HadCM3 simulations driven by increases in anthropogenic greenhouse gases and aerosols, but ignoring natural forcings and the influence of observed initial conditions.

- CNRM has upgraded the atmosphere model ARPEGE for seasonal forecasting. A set of intermediate hindcast experiments, described in RT2A, have been used to install and check the system on the ECMWF computer. The version for pre-production is ready since June 2005 and will be used to generate ensemble predictions as part of the multi-model experiment described in Task 1.5.1.
- IfM has carried out significant work to install the coupled model ECHAM5/OM1 on the ECMWF computer. The pre-production simulations, as a contribution to the multi-model, will start in August.
- CERFACS uses a coupled model similar to that of CNRM. The pre-production simulations have already been partially completed and will be part of the multi-model ensemble.

c) Deviations from the project work programme and corrective actions

- METO-HC expects that perturbed parameter ensembles using DePreSys will begin at the end of 2005. They cannot start earlier as they require knowledge of the climatology of each model version obtained from corresponding ensembles of historical climate change simulations (carried out in WP 1.6), which are still in progress. Some simulations are expected to be available for the assessment due at month 18, however it may not be possible to complete the full set of simulations by that date.

WP1.6: Generation of pre-production ensemble predictions of climate on the century timescale, initialised from model initial conditions

a) Objectives and starting point at beginning of reporting period

Results had been published from a 53 member ensemble of equilibrium climate change simulations of HadSM3 run at the Hadley Centre, in which uncertain parameters in surface and atmospheric parameterisation schemes were perturbed one at a time. A multi-thousand member ensemble using the same model, in which non-linear interactions between several key parameters were sampled, had been produced by the climate*prediction*.net team, and was being analysed. The Hadley Centre was working towards implementation of perturbed parameter ensemble simulations of the transient climate response, using variants of HadCM3 including a fully dynamic ocean.

The coupled model EGMAM (**E**CHO-**G** with **M**iddle **A**tmosphere) was already prepared and optimized for simulations within ENSEMBLES and installed at the DKRZ compute server environment (NEC-SX6). First experiments had been performed to test the performance of the model under both present day and pre-industrial conditions. Flux adjustment fields originally calculated with the ECHO-G model were being used at this stage.

Objectives for months 1-18:

Task 1.6.1: Ensemble experiments to quantify the sensitivity of time-dependent climate change to parameter perturbations will commence using the Hadley Centre coupled model HadCM3. Initially perturbations to physical atmospheric parameters will be investigated, comparing results against ensemble simulations of equilibrium climate change carried out with HadSM3, a variant of HadCM3 in which the atmospheric component is coupled to a simple mixed layer ocean.
Task 1.6.2: The capacity to undertake a similar ensemble with the ECHO model will be developed, using where possible common conventions for parametric perturbation to facilitate, ultimately, the development of a multi-model, perturbed-physics ensemble forecasting system.
Task 1.6.3: Results from a HadSM3 ensemble of limited size with targeted parameter perturbations will be compared with results from a much larger HadSM3 ensemble, designed to sample parameter space more comprehensively and using distributed (Grid) computing instead of conventional resources. This will allow us to assess the sensitivity of results to ensemble system design.

b) Progress towards objectives

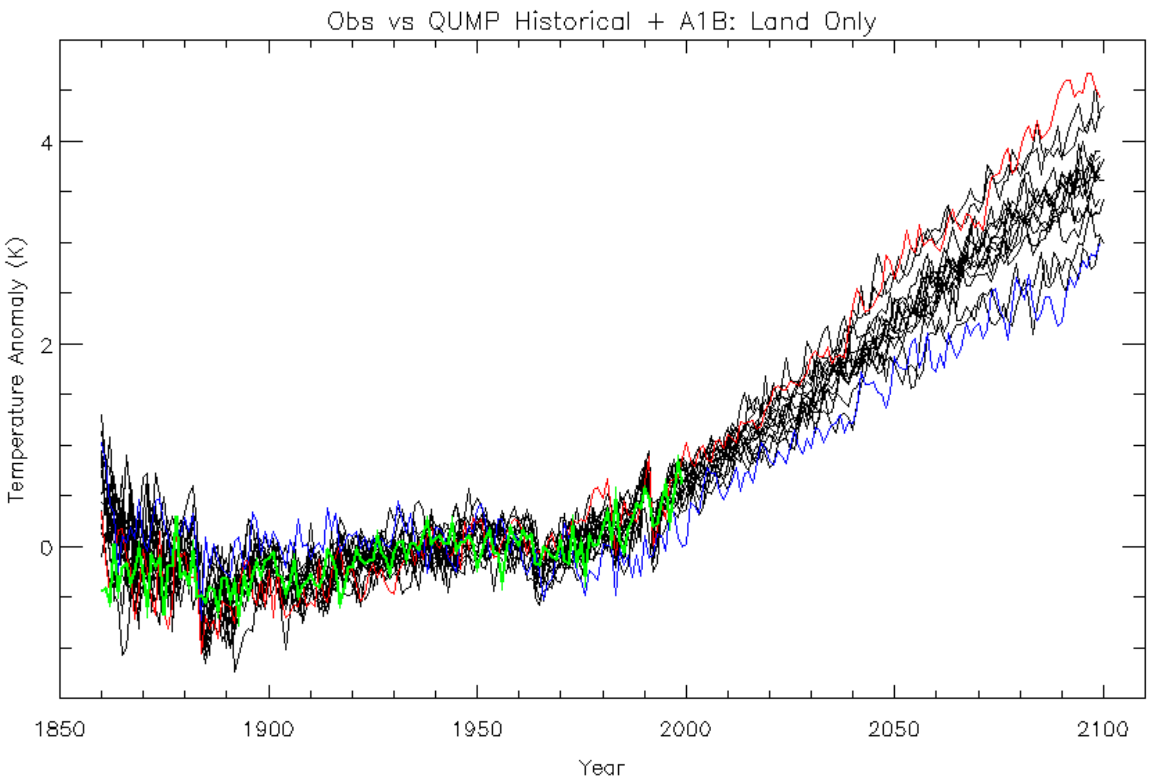

Figure 1.6.1: Anomalies in global mean land surface air temperatures from observations (green line) and from the HadCM3 perturbed physics ensemble (black, blue and red lines, the latter denoting the models with the lowest and highest respective climate sensitivities). Anomalies are computed with respect to years 1900 to 2000 and the model temperatures have been interpolated into the observational grid, and grid-boxes with missing observational data have been omitted.

Task 1.6.1:

Further work was performed to generate an ensemble of 17 versions of the Hadley Centre coupled atmosphere-ocean model (HadCM3) using the "perturbed physics" approach. Model versions differ in the parameters which control parameterised physical processes in the atmosphere, land-surface and sea-ice components. The experiments employ flux adjustments in order to prevent model drift and to improve the model baseline climate, particularly at the regional level. Equivalent experiments with same perturbations made to the atmosphere-mixed layer version of the model (see task 1.6.3) show a high degree of consistency between equilibrium change and transient climate response under simple CO_2 forcing (Collins et al., 2005). The spread in the transient response of the ensemble is of the same order as that seen in the collection of ENSEMBLES and IPCC AR4 models. Experiments forced by historical natural and anthropogenic agents and future anthropogenic agents under the SRES A1B scenario have also been performed (Figure 1.6.1).

Task 1.6.2:

The coupled model EGMAM (ECHO-G with Middle Atmosphere) has been prepared and optimized for simulations within ENSEMBLES and installed at the DKRZ compute server environment (NEC-SX6). First experiments were performed to test the performance of the model under both present day and pre-industrial conditions. Flux adjustment fields originally calculated with the ECHO-G model were used at this stage. The ability to quantify model uncertainties was tested using different variants of the cloud parametrization in the EGMAM control runs. This represents first tests of the sensitivity of time-dependent climate change to parameter perturbations in this model. The results of a full initial condition ensemble of 20th century simulations performed with ECHO-G (RT2A) have been analysed with regard to the sensitivity to forcings and initial conditions of the ocean (WP1.2). The aim will be to optimize the design of future ensemble runs with different perturbation methods developed in WP1.2.

Although not directly funded at this stage of the project, a new Earth System Model (ESM) based on the combination of the coupled atmosphere-ocean model CNRM-CM3 with the Integrated Impact Assessment model IMAGE2.2 (from RIVM, the Netherlands) has been developed during a PhD thesis (Voldoire, 2005). The IMAGE2.2 model simulates not only greenhouse gases and aerosols but also the dynamics of land-cover including land-use changes. In the coupled system, all the anthropogenic forcings (GHGs, aerosols and land-cover) are thus evolving according to the IMAGE2.2 projection in the GCM. Using this new ESM, a first pre-production of an A2 scenario has been performed and compared to the standard A2 scenario of CNRM-CM3. The global mean temperature change is greater in the simulation with the new ESM than in the A2 IPCC simulation with CNRM-CM3. However, a single realization of the experiment is not enough to discriminate the impact of the land-use changes from the impact of aerosols and GHGs forcings, which are not exactly the same as in the IPCC simulation.

Task 1.6.3:

In work prior to ENSEMBLES, the Hadley Centre produced a 53 member ensemble of atmosphere-mixed layer experiments with HadSM3 in which perturbations were made one at a time to 29 atmosphere, land-surface and sea-ice parameters (Murphy et al., 2004). Ranges of parameter values were specified by experts and perturbations were made to both the maximum and minimum of the range. The group have since produced an ensemble of 128 HadSM3 versions in which the 29 parameters are varied simultaneously taking values which are within the ranges specified by experts (16 of the same perturbations were used in the HadCM3 experiments described under task 1.6.1). This allows for non-linear interactions between parameterised processes, thus sampling a potentially wider range of outcomes.

The Oxford group have presented the first results from the climateprediction.net "grand ensemble" (Stainforth et al., 2005) in which 6 parameters are varied. These results showed that perturbations to model physics add non-linearly (and that this non-linearity can be hard to predict) and that the effect of such perturbations is to broaden the range of GCM sensitivities by a large amount. Statistical estimates of model response uncertainty based on observations of recent climate change admit climate sensitivities substantially greater than 5K. Such high responses are not generally used for future climate change projections because they have not been seen in GCMs. The group found model versions which could not be ruled out on the basis of comparison against standard surface climate variables, but with climate sensitivities ranging from less than 2K to more than 11K. The availability of model versions with high sensitivities is critical for the study of possible futures and the assessment of risks associated with specific stabilisation targets. The analysis of the (considerable) dataset is on-going.

Figure 1.6.2 compares results from the three ensembles described above. These ensemble simulations will be utilised in WP1.2 to assess different model weighting techniques.

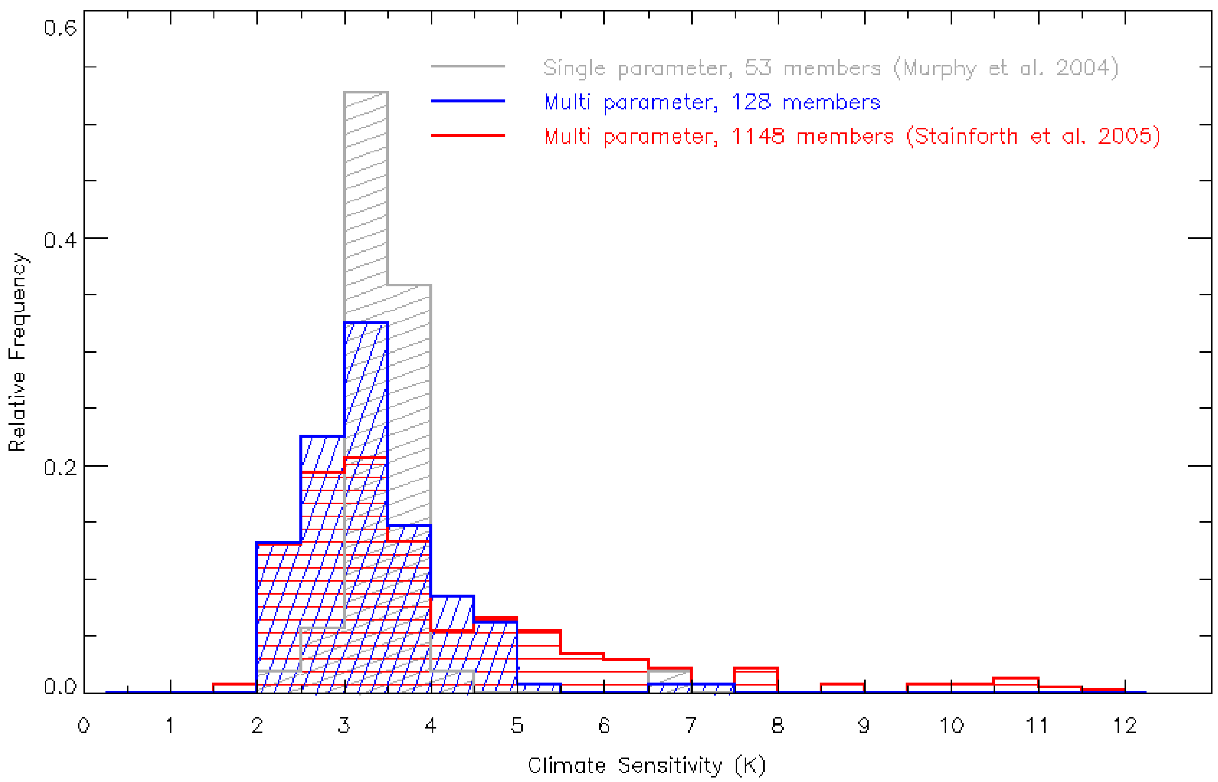

Figure 1.6.2: Histograms of climate sensitivity (the global mean temperature change for a doubling of CO_2) from three ensembles of HadSM3. The grey shaded histogram from a 53 member ensemble in which 29 model parameters are varied one-by-one. The blue histogram is from 128 members in which 29 model parameters are varied simultaneously. The red histogram is from 1148 members (including some with different initial conditions) in which all combinations of the minimum and maximum of 6 model parameters are varied simultaneously.

Collins, M., B.B.B. Booth, G.R. Harris, J.M. Murphy, D.M.H. Sexton, M.J. Webb (2005) Towards Quantifying Uncertainty in Transient Climate Change. Clim. Dyn. Submitted.

Murphy, J.M., Sexton, D.M.H., Barnett, D.N., Jones, G.S., Webb, M.J., Collins, M. and Stainforth, D.A. (2004) Quantification of modelling uncertainties in a large ensemble of climate change simulations. Nature, 430, 768-772.

Stainforth, D. A., T. Aina, C. Christensen, M. Collins, N. Faull, D. J. Frame, J. A. Kettleborough, S. Knight, A. Martin, J. M. Murphy, C. Piani, D. Sexton, L. A. Smith, R. A. Spicer, A. J. Thorpe, M. R. Allen (2005): Uncertainty in predictions of the climate response to rising levels of greenhouse gases. Nature, 433, pp403-406. doi:10.1038/nature03301

A Voldoire (2005): "Including land-cover and land-use changes in a climate scenario of the 21st century". PhD thesis of the University of Toulouse III-Paul Sabatier, defended on 31 March 2005.

c) Deviations from the project work programme and corrective actions

The HadCM3 ensemble experiments described under task 1.6.1 above suffer from reduced-strength northward ocean heat transport as a result of an adjustment of the thermohaline circulation (THC) in all members during the flux-adjustment spin-up phase (described in Collins et al., 2005). This reduced heat transport leads to cooler than expected sea-surface temperatures in the N. Atlantic and Arctic regions and an increase in sea-ice. These biases limit the usefulness of the ensemble for seasonal-to-decadal prediction experiments (WP1.5) and for regionally-downscaled centennial predictions for Europe (RT2B). Hence a further 17-member ensemble with variations in the spin-up procedure has been initiated. These experiments will take some months to run and to analyse and may lead to minor delays in related deliverables and milestones.

There have been changes in the personnel of the FUB. One person assigned to contribute to ENSEMBLES has left the institute and will be replaced in September. One PhD student was employed in March 05. To support the progress of the modelling experiments one part time scientist was hired also in March 05. The EGMAM model simulated too warm a climate using the old ECHO-G flux adjustment. A new flux adjustment for the model was calculated to improve its simulated climate. This was also the reason for the decision to do the parameter sensitivity tests with the ECHO-G model.

d) List of deliverables, including due date and actual/foreseen submission date (see Table 1)

Table 1: Deliverables List

List all deliverables, giving date of submission and any proposed revision to plans.

Del. no.	Deliverable name	Research Theme no.	Date due	Actual/Forecast delivery date	Estimated indicative person-months *)	Used indicative person-months *)	Lead contractor
D1.1	Progress report on the construction and testing of Earth system models	RT1	31.08.2005	31.08.2005			MPIMET
D1.2	Systematic documentation and inter-comparison of ensemble perturbation and weighting methods.	RT1	31.08.2005	31.08.2005			UOXFDC

***) if available**

e) List of milestones, including due date and actual/foreseen achievement date (see Table 2)

Table 2: Milestones List

List all milestones, giving date of achievement and any proposed revision to plans.

Milestone no.	Milestone name	Research Theme no.	Date due	Actual/Forecast delivery date	Lead contractor