RT1 ENSEMBLES Periodic Activity Report – 1Sep06-31Aug07

Executive Summary

Work performed and results achieved: RT1

- Further improvements have been made to the new set of complex Earth System models constructed for use in stream 2 decadal-centennial climate projections.
- The set of stream 1 s2d hindcasts has been augmented by further simulations, and the skill of the stream 1 experiments has been documented in greater detail (D1.8).
- An ensemble of ocean analyses has been provided for initialisation of the stream 2 s2d hindcasts, and modelling groups have provided improved and more efficient global models in preparation for stream 2.
- RT1 partners have published and submitted the first papers demonstrating that additional skill can be obtained in annual to decadal climate projections of global and regional surface temperature, by initialising the ocean component of coupled climate models.
- The perturbed parameter approach to decadal to centennial prediction has been developed, by (a) augmenting HadCM3 simulations to include ensembles of transient climate change sampling ocean and sulphur cycle uncertainties; (b) developing Bayesian statistical techniques with the eventual aim of converting the ensemble runs into probabilistic regional climate predictions; (c) comparing ensemble climate change simulations between two different models (EGMAM and the mixed-layer ocean version of HadCM3); (d) production and analysis of a very large ensemble of perturbed parameter transient climate simulations using HadCM3L (HadCM3 with a lower resolution ocean component, run using public resource distributed computing via climate*prediction*.net).

Expected end results : RT1

- Further development and assessment of methods to construct probabilistic forecasts from the results of the ensemble prediction systems, on both seasonal to decadal and longer time scales.
- Assessment of the potential for a unified prediction system covering both seasonal to decadal and longer time scales.
- Recommendations for the design of an improved ensemble prediction system by month 60.
- Key changes since last year: Work on the construction of new earth system models is now complete. Work on ocean initialisation procedures has also been completed, and the Stream 2 seasonal-decadal hindcast experiments have been started. Papers demonstrating the skill of initialised annual to decadal climate projections have been produced. Significant progress has been made towards the production of probabilistic global and regional climate predictions based on perturbed physics ensembles.

Intentions for use and impact

The ensemble prediction system produced by RT1 will be used by other ENSEMBLES RTs to provide detailed predictions of climate variability and change, and its impacts, using a suite of modelling tools. The development of systematic approaches to the quantification of uncertainties is expected to provide a significant and original contribution to worldwide research into global climate prediction, and the combination of techniques used previously for seasonal and long term forecasting will lead to a new facility to predict climate variations on interannual to decadal time scales.

Overview of activities carried out during the reporting period

1. Project 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 provides the basis for the production and use of objective probabilistic climate forecasts within ENSEMBLES.

1.1a 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.

1.1b Relation to state of the art

RT1 is enhancing 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.

1.2 Summary of recommendations from previous reviews

The review of year 2 of ENSEMBLES commented as follows:

"RT1 and RT2A: It is recommended that the groups use the spring 2007 meeting with RT4 (and hopefully RT5) to establish cross-cutting groups that will examine the application of cutting-edge evaluation methods to the different types of ensemble simulations."

"**RTs 1, 2A, 2B and 3**. Performance-based weighting of model results needs a more definite plan. Issues that must be resolved soon include (i) selecting the basic criteria for an interim weighting, (ii) deciding how to weight GCM-RCM systems in combination and (iii) agreeing on a cross-verification framework for testing weighting schemes. In the longer term, the project should seek to (iv) combine the physical insights from RT4 and RT5 studies with the statistical expertise within the RT 1 and 2 communities, in order to derive more reliable probability distributions of change."

We believe these comments are directed principally at the problem of weighting GCM simulations of long term climate change according to the fit to observations. However work in RT1 is aimed at the wider problem of constructing probabilistic long term climate predictions. This does indeed involve consideration of weighting issues, but also of a host of additional topics, such as how to design ensembles of GCM simulations to quantify uncertainties, whether to construct probabilistic predictions by filling some space of possible models, or some space of possible observational uncertainties, how to account for structural modelling errors, how to combine ensembles of simulations sampling uncertainties in different Earth system processes, how to produce multivariate regional predictions consistent with observed and simulated relationships between different variables etc. Since we aim to produce multivariate regional predictions suitable for a wide range of users, it is critical that the observational constraints we use constitute a balanced set which avoids focusing excessively on some particular subset of climate processes (e.g. regional cloud feedbacks). It was clear from the above-mentioned workshop that much remains to be done to develop a balanced set of process-based observational criteria which fulfils this requirement. We do not, therefore, believe the time is yet right to prioritise the issue of process-based constraints above the other major issues we need to deal with. However, we are implementing plans to assess observational constraints based on metrics derived from large-scale aspects of historical climate change, and present day mean climate fields of a range of different variables. By combining these criteria, we will be able to move beyond published examples of constrained GCM projections, and this will provide a baseline to which consideration of more specialised process-based constraints can be added, as they become available. We will maintain close contact with RT4 and RT5, to keep this question under review.

1.3 Overview of achievements during months 25-36

- The simulation of the climate and carbon cycle by the new Earth system models of METO-HC, CNRS and MPIMET has been improved. Further development of new coupled atmosphere-ocean models (DMI, CNRM) has also been achieved. This new suite of models will be used in the stream 2 decadal-centennial climate projections.

- ECMWF carried out a thorough assessment of the skill of the Stream 1 s2d hindcast experiments (D1.8)
- METO-HC has augmented the stream 1 s2d hindcasts with a set of initial condition and perturbed parameter decadal ensemble hindcasts using the DePreSys system, and additional experiments with the GloSea model to investigate the impact of lagged initial conditions.
- IfM produced decadal hindcasts using the ECHAM5/MPIOM model, initialised from three historical analyses produced by assimilation of SST. The hindcasts (submitted for publication) showed skill in projecting proxy indicators of the North Atlantic meridional overturning circulation, and in surface air temperature in a number of regions. Decadal hindcasts using an earlier version of the DePreSys system, demonstrating the potential to achieve improved skill in predictions of global and regional surface temperature, were also published. These papers from RT1 partners provide the first documented evidence that initialisation of GCMs can improve the skill of climate predictions on the annual to decadal time scale.
- An updated version of the EN3 data base of ocean temperature and salinity observations was released (available from http://www.hadobs.org)
- An ensemble of ocean reanalyses was produced by CERFACS for the period 1960-2005 (see D1.9), for use in the initialisation of stream 2 s2d hindcasts.
- Seasonal-to-decadal partners prepared for the stream 2 simulations by implementing improvements to their modelling systems, porting new models to the ECMWF supercomputer, and developing strategies to improve archiving of data and computational efficiency (important given the expanded set of hindcasts involved in stream 2). The stream 2 simulations are now in progress.
- ECMWF has further developed its scheme to represent stochastic parameterisation uncertainties. The new scheme (SPBS – Spectral BackScattering) introduces flow-dependent stream function perturbations on the near-grid scale (like the previous version – CASBS), but the perturbations are now generated using a method which allows better scale selection.
- Progress has been made towards the generation of probabilistic regional climate predictions based on perturbed parameter ensembles of HadCM3. This includes the generation of ensemble simulations sampling uncertainties in transient climate change from ocean and sulphur cycle processes, and further development of statistical techniques to convert the ensemble runs into probabilities using a Bayesian framework, including the effects of structural modelling errors estimated by including results from other climate models.
- Large perturbed parameter ensembles of HadCM3L transient climate change simulations have been produced via climate*prediction*.net, and are being analysed with a view to the construction of likelihood-weighted predictions based on the goodness of fit of ensemble members to observed historical climate change.
- Perturbed parameter climate change simulations have been produced using the EGMAM model, and are being compared against simulations using the atmosphere-mixed layer ocean version of HadCM3, in order to understand similarities and differences in the impacts of corresponding parameter changes in the two models.

- RT1 organised a workshop on s2d activities in ENSEMBLES (Barcelona, June 07), as part of a wider meeting of the CLIVAR Working Group on Seasonal to Interannual Prediction. This facilitated assessment of methodologies for the generation of s2d forecasts, collaboration with user groups in ENSEMBLES and other projects, progress with the stream 2 simulations, and possible future research directions.
- RT1 partners also participated in a joint ENSEMBLES-CFMIP Workshop on cloud feedbacks (Paris, April 2007), exchanging information between groups involved in process-based understanding of climate change feedbacks and groups involved in the generation of observationally-constrained climate predictions.

- We have delivered all deliverables and milestones due during months 1-36, and are on track to meet future commitments.

2. Research Theme Progress

WP1.0: Management of RT1

a) Objectives and starting point at beginning of reporting period

During the second year of ENSEMBLES, a joint RT1/2A workshop had been held, at which the status of our major workstreams on the development of Earth system models, s2d ensemble predictions and centennial ensemble predictions had been reviewed. All standing management tasks (representation of RT1 at Management Board and Annual Assembly meetings, ensuring timely delivery of milestones, deliverables and other reports) had been carried out. A dedicated RT1 web site containing information such as location of model documentation, model output data, contact details, progress reports, summaries of meetings and key scientific developments, had been developed at ECMWF. Participation of RT1 groups in workshops on seasonal to decadal prediction activities (Bareclona 2007), and physically-based understanding of climate feedbacks (Paris 2007) had been planned. Liaison with impacts groups had also been initiated, with a view to collaborating on the use of interim pdfs of future climate change to drive a range of impacts models in RT6.

Objectives for months 25-42 are:

Task 1.0.2: The RT1 website will be maintained and developed, 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.
Task 1.0.5: A workshop for the seasonal to decadal partners of RT1 will be held in Barcelona, during June 2007, as part of a larger meeting of the CLIVAR Working Group on Seasonal to Interannual Prediction. This will expose the ENSEMBLES work to a wide international community of modellers and users, including downscaling and applications scientists.
Task 1.0.6: RT1 will contribute to a workshop in Paris during spring 2007, organised by RT4, and also including partners from RT2A and RT5. The purpose will be to address how the current understanding and evaluation of physical processes may help to constrain climate predictions, focusing mainly on the impacts of water vapour and cloud feedbacks.

b) Progress towards objectives

Task 1.0.2: The RT1 web pages at ECMWF at
http://www.ecmwf.int/research/EU_projects/ENSEMBLES/index.html
have continued to be maintained, updated and further developed. The lay-out has been improved and made clearer. More information on all available experiments and their preliminary results on the s2d range, on Data Archiving and Dissemination, on meetings and on the collaboration with the AMMA project, have been published.

Task 1.0.3: All milestones, deliverables and progress reports due during the year were successfully delivered. RT1 was preresented at ENSEMBLES management meetings in Lund in Nov 2006 and in Venice in May 2007, and presentations of progress and plans were given. A progress meeting was held during the Annual Assembly. RT1 also ran a breakout session on “Exploitation of the ENSEMBLES Phase I Prediction Systems”, which resulted in further collaboration with impacts groups in RT6, facilitating use of interim probability distributions of long term future climate change by those groups. We also fostered the collaborations and links to other RTs from our s2d activities, particularly the application (RT6) and downscaling (RT2B) communities.

Task 1.0.5: A workshop for the seasonal to decadal partners of RT1 was held in Barcelona, during June 2007, as part of a larger meeting of the CLIVAR Working Group on Seasonal to Interannual Prediction. This offered the opportunity to expose the ENSEMBLES work to a wide international community of modellers and users, including downscaling and applications scientists. Milestone report M1.7 summarised the meeting, which included discussions on alternative approaches to deal with model uncertainty, development of seamless prediction systems, data dissemination, ocean data analysis, downscaling, user applications, and progress with the ENSEMBLES stream 2 simulations. Following this meeting, a proposal for a break-out session for the Fourth Annual Assembly (Prague, Nov 2007), was submitted to RT0, on “Assessing and developing ENSEMBLES approaches to climate prediction from a season to a few decades ahead”. A proposal was also circulated to s2d partners to canvass potential interest in developing a coordinated multi-model climate prediction experiment for up to 30 years ahead.

Task 1.0.6: Participation of selected RT1 partners was arranged for the CFMIP/ENSEMBLES Workshop on assessment of cloud and water vapour feedback processes in GCMs, held in Paris in April 2007. RT1 provided examples of how perturbed physics ensembles are being systematically designed to sample modelling uncertainties and construct probabilistic predictions, and how these can be constrained by observational metrics drawn from present day climate, or error tendencies in short-range weather forecasts.

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

METOHC, CNRS, INGV, MPIMET had developed coupled atmosphere ocean models, and Earth system models including the carbon cycle and/or the aerosol system. DMI had tested its high resolution atmosphere model and started the development of a new coupled atmosphere ocean model.

b) Progress towards objectives

The simulation of the climate and carbon cycle has been improved in the ESMs of METOHC, CNRS, INGV and MPIMET, in preparation of the stream 2 simulations. DMI has continued the development of its coupled atmosphere ocean model.

1.1 METOHC

Starting point of work at beginning of reporting period

Development of the new models intended for stream 2, namely HadGEM2-AO for the physical plus aerosol system, and HadCM3C for the physical plus aerosol plus carbon cycle system, was at an advanced stage. However, work was still ongoing to complete tuning and evaluation of the performance of the models in control mode, and to check the ability of HadCM3C to maintain a stable climate with interactive CO_2 emissions as well as to mimic transient changes in historical CO_2 concentrations.

Progress towards objectives

Development of both the HadGEM2-AO and HadCM3C models for stream two work has been completed, including tuning.

The HadGEM2-AO model (physical plus aerosol system) is a significant advance on the HadGEM1 model used in stream one, with improved ENSO simulation, reduced systematic errors including land surface temperature biases, general improvements in simulated atmospheric aerosols and their radiative effects, and the inclusion of mineral dust as an interactive aerosol. HadGEM2-AO achieves considerable improvements over HadGEM1 in many aspects of its mean climate, and represents an even more significant advance over HadCM3 (Figure 1.1.1).

Write-up of a model technical description and evaluation of initial results for HadGEM2-AO has started (Dearden et al. 2007). A paper describing the sea ice formulation and performance of HadGEM1 (the sea ice scheme is very similar in HadGEM2-AO) was published in Journal of Geophysical Research (McLaren et al., 2006).

The HadCM3C model (physical plus aerosol plus carbon cycle system) couples the standard HadCM3 coupled atmosphere-ocean model to the MOSES 2/TRIFFID land surface scheme, and includes the new HadOCC ocean biogeochemistry model, an interactive sulphur cycle scheme which explicitly models the direct and the 1st indirect effects of sulphate (Jones et al, 2001, JGR-Atmospheres, 106 (D17): 20293-20310). As this model is designed to explore parameter-based climate prediction uncertainties, calibrated flux adjustments are also employed to reduce climate drift. This model can be thought of as a higher ocean resolution version of the HadCM3LC model used in previous carbon cycle studies (e.g. Friedlingstein et al., 2006; J. Climate, 19: 3337–3353) with the addition of an interactive sulphur cycle, aerosol direct and first indirect effects, and some other physical corrections/improvements.

Tim Johns attended an RT2A meeting in Copenhagen in July 2007, at which HadGEM2-AO and HadCM3C model development status was presented and stream 2 experimental design issues were discussed.

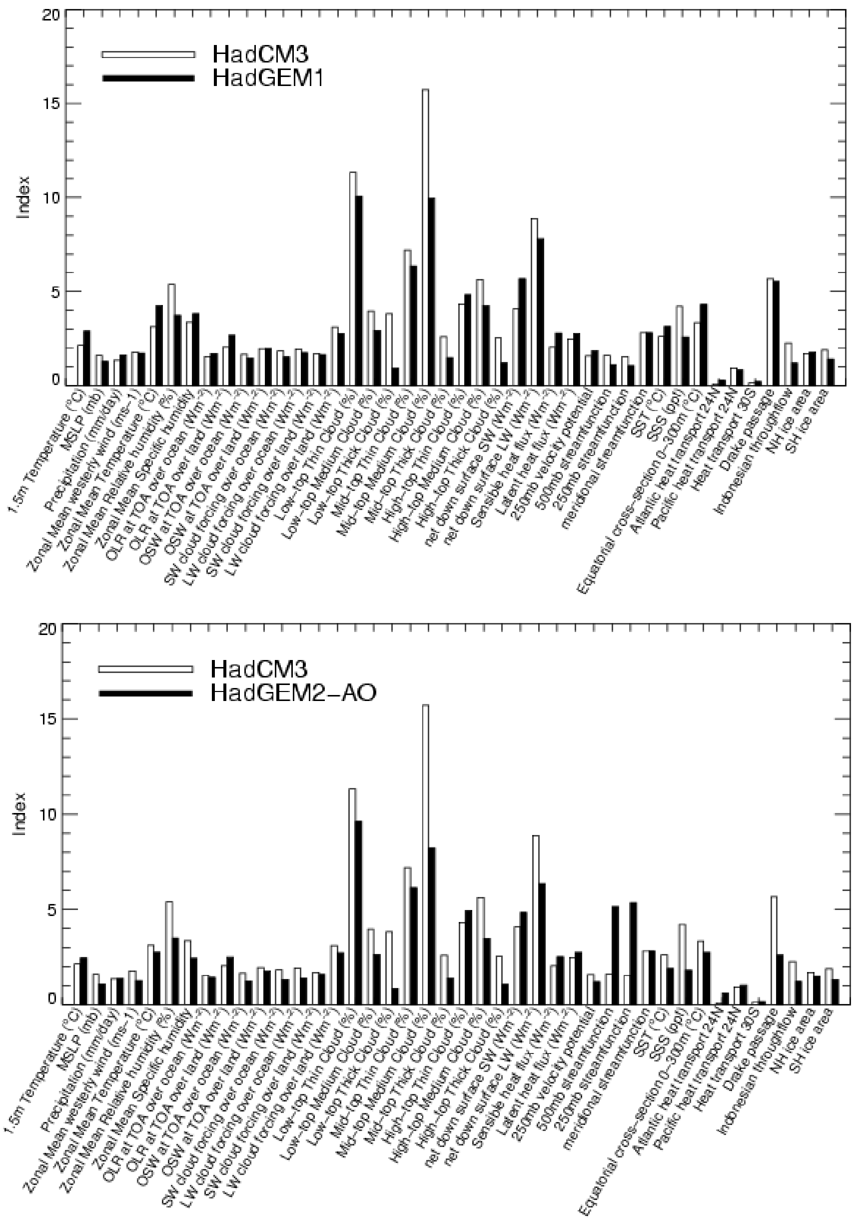

Figure 1: Comparison of a non-dimensional index of model skill compared with observed climatological fields between HadCM3 (open bars), HadGEM1 (filled bars – top panel) and HadGEM2-AO (filled bars – bottom panel). Rms errors are normalised by the spatial average of internal climate variability estimated from HadCM3's control run for each variable shown, larger normalised rms errors being represented by longer bars. The index is similar to the CPI defined and used by Murphy et al., 2004 (Nature, 430: 768-772) but contains more variables including some oceanic and sea ice ones. The model data comprise averages of a 20-year period early in the third century of the HadCM3 and HadGEM1 control simulations (referenced to the start of the spin-up) and the initial 20-year period of the HadGEM2-AO control simulation. (Note that the 500mb and 250mb streamfunction elements for HadGEM2-AO should be ignored as the calculations are currently incorrect due to a software problem.)

References

Dearden, C. and co-authors, 2007. A metric based approach to model evaluation across a range of space and time scales. (Draft manuscript in preparation)

McLaren, A.J., H. T. Banks, C. F. Durman, J. M. Gregory, T. C. Johns, A.B. Keen, J. K. Ridley, M. J. Roberts, W. H. Lipscomb, W. M. Connolley, and S. W. Laxon, 2006. Evaluation of the sea ice simulation in a new coupled atmosphere-ocean climate model (HadGEM1). Journal of Geophysical Research, 111, C12014, doi:10.1029/2005JC003033.

1.2 CNRS

Starting point of work at beginning of reporting period

The IPSL physical model had been successfully coupled to ORCHIDEE and PISCES, the land and ocean carbon cycle model respectively. Historical and SRES-A2 simulations had been performed in the context of the C4MIP project (Friedlingstein et al., J. Climate, 2006).

Progress towards objectives

Interactive aerosols have been implemented in the atmospheric LMDz GCM. Test are ongoing within the coupled AOGCM.

1.3 DMI

Starting point of work at beginning of reporting period

The atmospheric module of the Danish Climate Model (DKCM-A) was validated and tested for enhanced horizontal resolution (T159). The model had also been modified to include varying greenhouse gases and aerosol for scenario simulations. The development of the fully coupled DKCM had been started.

Progress towards objectives

The method for inclusion of varying greenhouse gases and aerosols in the DKCM-A has been further tested and ameliorated. The DKCM-A with this new feature was used to perform the RT2A high resolution (T159) time-slice experiments forced with the boundary conditions provided by DMI's simulation with MPI's coupled model (ECHAM5/MPI-OM) for the A1B scenario.

The development of the fully coupled DKCM has been continued. The Coupled DKCM consists of the DKCM-A, the ocean model NEMO that includes the OPA9 ocean general circulation modelling system and the LIM2 sea-ice model, and the OASIS3 coupler. The technical aspects of coupling the three modules together have been made, and are being further improved. Testing and optimization of the codes is ongoing. The model will be available for use in stream 2 centennial integrations in RT2A later this year.

1.4 INGV

Starting point of work at beginning of reporting period

At the beginning of the reporting period, initial tests of the INGV-ESM with active carbon cycle were underway.

Progress towards objectives

During the past year, extensive tests have been performed to evaluate the carbon coupling between the vegetation and the atmosphere and between the atmosphere and the ocean of the INGV-ESM. Results of these tests give confidence in the construction of the Earth System Model, and a pre-industrial simulation with the carbon cycle model is now in progress. This simulation will be compared with a multi-century simulation performed with the physical core of the ESM.

1.5 MPIMET

Starting point of work at beginning of reporting period

The physical climate model (ECHAM5/MPIOM) and the carbon cycle model (ECHAM5-JSBACH/MPIOM-HAMOCC) had been integrated in the COSMOS package, together with the PRISM coupler (OASIS3) and the standard compile and running environments (SCE and SRE). This package allows to configure the above mentioned models, among other combinations, and to run simulations at two base resolutions: T31L19/GR3.0L40 and T63L31/GR1.5L40, the latter higher resolution version being about 10 times more expensive.

Progress towards objectives

Extensive tests of the carbon cycle model led to adjustments and model improvements concerning the CO_2 fluxes between the atmosphere, ocean and land. The computation of CO_2 fluxes between the atmosphere and the ocean has been moved from the ocean model to the atmospheric model and atmospheric CO_2 is removed from or released in the atmospheric boundary layer instead of the lowest layer. Technical improvements of the ocean model led to an increase of the computational efficiency by about 20% on the NEC-SX6. Tests are focused on the version that will be employed for stream 2 simulations:

Atmosphere + Land/vegetation:	ECHAM5-JSBACH at resolution T31/L19
Ocean incl. Ice + marine biogeochem.:	MPIOM-HAMOCC at resolution GR3.0/L40
Coupler:	OASIS3

This model configuration was used in a multi-century control simulation to achieve a better tuning of the climate and the carbon cycle. This model has achieved a stable climate and CO_2 cycle and is ready for transient simulations for stream 2.

c) Deviations from the project work programme and corrective actions

As indicated above, the CPU time available during 2007 and 2008 for the MPIMET Earth System model necessitates the use of a reduced horizontal resolution T31/L19 for the atmosphere and GR3.0/L40 for the ocean model.

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

METO-HC had worked towards the implementation of a Bayesian framework for probabilistic climate prediction, generating perturbed physics ensembles simulations of equilibrium and transient climate change with the HadCM3 model system, and developing emulation and pattern-scaling techniques required to estimate results for parts of the model parameter space not sampled directly by GCM simulations. UOXFDC had produced, and begun analysis of, a large perturbed physics ensemble of transient climate change simulations from the climate*prediction*.net project. ECMWF had begun testing an updated version of their stochastic representation of unresolved processes, aiming to improve on that used in the stream 1 seasonal-decadal simulations. FUB had developed a perturbed physics approach for application in the EGMAM model, and had produced an ensemble of control climate simulations.

The objectives for months 25-42 were to proceed with the aims of further developing alternative methods of sampling modelling uncertainties in ensemble climate prediction, and of weighting members of ensembles through comparison with the present climate state and/or historical climate changes, building on work carried out during months 1-25 (see D 1.2). Methods of combining different approaches (e.g. multi-model, perturbed parameter and stochastic parameterisation ensembles) will also be developed, since these may outperform any individual approach. Specific tasks are listed below, and reported on in the following section.

Task 1.2.4: The Hadley Centre will continue the implementation of the Bayesian technique for generating probabilistic predictions from small ensembles of complex model simulations. The experiments run under WP1.6 will be used, together with statistical and reduced-complexity models, to further refine the emulation technique to sample points in a wider model-parameter space for which simulations do not exist. The multi-model output will be utilised to produce a first implementation of the discrepancy term designed to take into account structural uncertainties.

Task 1.2.5: Oxford will continue development of a methodology for probabilistic climate forecasting which seeks to minimise model bias and maximise the dependence of the forecast distribution on the data used to constrain it. Such “stable inferences from data” (STAID) forecasts are set up to minimise the effect on the forecast of the prior beliefs of the experimenter.
Task 1.2.6: Development of methods of comparing alternative methodologies (1.2.4, 1.2.5) so as to maximise the useful information in forecasts will be undertaken by the Hadley Centre and Oxford.
Task 1.2.7: The FUB will develop and test schemes to represent model uncertainties by perturbing selected parameters (cloud parametrization, stratospheric representation) of the EGMAM-model and by variations in the model components.
Task 1.2.8: At FUB a stochastic parametrization scheme will be developed for use in centennial predictions with EGMAM. The effects of stochastic parametrization schemes in centennial model runs will be analysed and compared with the effects of such schemes on different time scales. The ability of the technique to represent modelling uncertainties will be tested. Different methods to weight ensemble members in stream one simulations will be developed. In the project months 25 to 42 an evaluation of different methods for model weighting in multi-model centennial predictions will be provided. This will lead to a method for generating probability distribution functions from ensembles of simulations.
Task 1.2.9: To account for the effects of unresolved processes the latest version of the IFS/HOPE model (Cy30R1) will be run at ECMWF with and without stochastic perturbations for the stream 1 seasonal-to-decadal set of experiments. The Cellular Automaton Stochastic BackScattering (CASBS) scheme used here introduces streamfunction perturbations on the near-gridscale and is motivated by the notion that a fraction of the dissipated energy will scatter upscale and inject kinetic energy into the resolved flow. For this purpose a cellular automaton is utilised to generate a spatially and temporally correlated pattern which is weighted with to the flow dependent dissipation rate from numerical dissipation and friction from deep convection and gravity/mountain wave drag. A new version of CASBS, version 1.2, will be used which incorporates a cosine weighting of the cellular automaton pattern that is different to previous CASBS versions. Furthermore, a different way of computing the dissipation from convection will be used, which is now based on mass flux formulation.
Task 1.2.10: A simple weighting of models used for climate change experiments will be set up by DMI. This will be based on the ability of the individual Earth system models (in un-flux-corrected mode) to simulate different aspects of the climatological annual cycle which is the most simple example of a forced climate signal where both the forcing and response is well known.

b) Progress towards objectives

Task 1.2.4: Further implementation of the Hadley Centre Bayesian technique for producing PDFs has been achieved in this period. The emulation of equilibrium responses based on output from the O(100) member ensemble of the Hadley Centre model coupled to a simple mixed-layer ocean has been interfaced to the time-scaling method which uses output from transient model simulations. In addition, a first step at calculating likelihood-weighted PDFs with some estimate of the discrepancy term (which quantifies uncertainties arising from structural modelling errors) has been performed in the case of the equilibrium response. Early indications are that the method produces sensible-looking results but further tests are required. A paper describing the approach has also been published (Murphy et al., 2007).

Interim joint PDFs of changes in European temperature and precipitation were supplied to RT6 for use in impacts modelling. The PDFs were based on time-scaled patterns of equilibrium change produce from a O(100) member ensemble run at the Hadley Centre. Updated PDFs will be provided later in the project, based on a more complete implementation of the aforementioned Bayesian technique.

Task 1.2.5: Frame et al. (2007) provides an overview of the philosophical implications of various methodologies for analysing and quantifying model uncertainty. This will serve as a background material for deliverable D1.12.

Building on the work of Frame et al. (2007), and using results from the climate*prediction*.net ensemble generated, in part, under WP1.6, Oxford has continued to work on a method of presenting future forecasts known as "likelihood profiling".

Task 1.2.6: Output from ensemble experiments run by METO-HC and UOXFDC has been used to assess uncertainties in the emulation techniques developed under task 1.2.4 and a paper has been produced (Rougier et al., 2007).

Task 1.2.7: A 30 member perturbed physics ensemble of the EGMAM versions was generated by perturbing relevant parameters in the cloud physics schemes of the GCM. These model versions were integrated under a preindustrial control climate into a pseudo equilibrium where the atmosphere shows full adjustment to the changes in the cloud parameters but the ocean is still not equilibrated.

The integration of perturbed model versions with doubled CO_2 concentration was started and more than ten simulations are already finished. A comparison with the pre-industrial control simulations enables an analysis of the uncertainty in climate sensitivity of the EGMAM model due to uncertainties in the cloud parameterisations. Preliminary results show a clear signal of the perturbations in the climate sensitivity, leading to differences of up to 2°C.

A cross-model study was done to identify corresponding parameters in the cloud parametrisations of EGMAM and HadSM3/HadCM3. Due to the use of the same parameterisation scheme for large scale precipitation, these models provide an excellent framework for a multi-model, perturbed physics comparison. Preliminary results show a consistent global signal in climate sensitivity across the models due to perturbations in corresponding parameters. However, strong regional differences indicate different impacts on physical processes in the atmosphere. Additionally, signals originating from the use of different ocean models will be further investigated.

To enable a better understanding of the different responses of the models to the perturbations, a resampling of the uncertainties in the EGMAM cloud parameterisation with the HadSM3 model was done using the climateprediction.net infrastructure. Results are expected for project month 42.

Task 1.2.9: For the s2d simulations three approaches to model uncertainty have been explored in the stream 1 simulations: the multi-model approach, the perturbed physical parameter approach and the stochastic physics approach. While sets of experiments using preliminary versions of these three methodologies had been completed by the beginning of the reporting period, continuation and further developments were planned for year 3 of the project.

ECMWF has continued developing their scheme to account for the effect of unresolved processes in the IFS/HOPE model. The version of the scheme used for the preliminary assessment in the first 2 years of the project was called CASBS and was based on a Cellular Automaton for Stochastic Back Scattering of energy as a non-local and quasi-random pattern generator. During the reporting period a different version of the stochastic physics scheme, called SPBS for Spectral BackScattering, has been developed originally for application to ensemble weather forecasting on the medium-range. SPBS is similar to CASBS in that it introduces flow-dependent streamfunction perturbations on the near-gridscale, and is motivated by the notion that a fraction of the dissipated energy will scatter upscale and inject kinetic energy into the resolved flow. In contrast to the CA, however, the perturbations are now generated in spectral space using a spectral Markov chain which allows better control of the wave number forcing and thus scale selection. A different method to compute the dissipation from convection is used, which is now based on a mass-flux formulation.

The implementation of the stochastic physics schemes in the IFS/HOPE T159L62 environment (higher resolution than in previous experiments) required the development of a more advanced restart capability to ensure a correct and efficient restart of the coupled system. This new capability has been extensively tested and is in use now.

The new SPBS scheme is currently being used to run seasonal and interannual forecasts as an additional input to the stream 1 data set. We expect the simulations to be finished at the end of month 36.

LSE: Stainforth et al. (2007) documents and disseminates our advances in our understanding of the various types of uncertainty whose understanding is critical to climate science. The strengths and weaknesses of ensemble experiments of the past are noted and considerations for the design of future experiments are provided.

D1.12: Background material produced as part of Frame et al. (2007), which focusses on the philosophical implications of methods for obtaining probabilistic forecasts.

Papers

Murphy, J. M., Booth, B. B. B., Collins, M., Harris, G. R., Sexton, D. and Webb, M. 2007. A methodology for probabilistic predictions of regional climate change from perturbed physics ensembles. *Phil. Trans. R. Soc. A*, **365,** 1993-2028. (doi:10.1098/rsta.2007.2077)

Rougier, J., Sexton, D.M.H., Murphy, J. M. and Stainforth, D.A. 2007. Emulating the sensitivity of the HadAM3 climate model using ensembles from different but related experiments. *J. Climate*, submitted.

Frame, D.J., Faull, N.E., Joshi, M.M. and Allen, M.R. 2007. Probabilistic climate forecasts and inductive problems. *Phil. Trans. R. Soc. A*, **365**, 1971-1992.

Shutts, G. and Palmer, T.N. 2007. Convective forcing fluctuations in a cloud-resolving model: Relevance to the stochastic parameterization problem. *J. Climate,* **20**, 187-202.

Stainforth, D.A., Allen, M.R., Tredger, E.R., and Smith, L.A. 2007. Confidence, uncertainty and decision-support relevance in climate prediction. *Phil. Trans. R. Soc. A*, **365**, 2145-2161.

c) Deviations from the project work programme and corrective actions

None.

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

a) Objectives and starting point at beginning of reporting period

CERFACS had started work towards the production of an ensemble of ocean reanalyses for the stream 2 seasonal-decadal hindcasts. ECMWF had already produced ocean analyses for use in the stream 2 simulations. INGV had upgraded their previous ocean data assimilation system, and adapted it to the ocean model used in their ENSEMBLES simulations. METO-HC had progressed towards release of an updated version (EN3) of the global ocean observations database. IfM-

GEOMAR had assessed the stream 1 seasonal hindcasts, finding evidence that SST nudging could potentially provide skilful initialisation of the ocean thermohaline circulation, but also indicating that assimilation of SST anomalies, rather than full SST, might be required. For this reason, decadal hindcasts had yet to be performed.

b) Progress towards objectives

METO-HC (3 funded person-months):
The 1950-2005 ocean database (EN3) was released in February 2007 and it is available to all partners via http://www.hadobs.org. The main changes for EN3 are an updated input of data sources and a revised climatology used for initial conditions and relaxation. Some problems with the Indian Ocean PALACE data were identified and further investigation is ongoing.

The paper "Quality control of ocean temperature and salinity profiles - historical and real-time data" by B. Ingleby and M. Huddleston has been published in the Journal of Marine Systems, 65, 158-175.

ECMWF did not have any person months in this work package during the reporting period. Ocean analyses to be used in the stream 2 simulations for the full ERA-40 period had already been provided before.

IfM-GEOMAR (3 funded person-months):
During the past year, IfM performed three coupled analyses with nudging to observed SST anomalies, instead of full SST as done previously. While the strength of the meridional overturning circulation (MOC) is still overestimated by the analyses, the temporal variability matches nicely the Gulf Stream Position index (Fig. 1.3.1a); taken here as a proxy for MOC variations. The simulated MOC evolution is also consistent with ocean general circulation model (OGCM) simulations (not shown). The MOC changes are forced by variations in Labrador Sea convection, which also match available observations well (Fig. 1.3.1b). Labrador Sea convection in turn is forced through the atmospheric response (Fig. 1.3.1c), but also by the heat flux provided to the ocean by the SST nudging (not shown). The excessively strong response of the MOC in our simulations was traced back to the neglect of salinity in our analysis scheme. Salinity observations were neglected due to their sparseness. The results described here contributed to an internal ECMWF report. The three analyses were used to perform decadal hindcasts described in section WP1.5 of report.

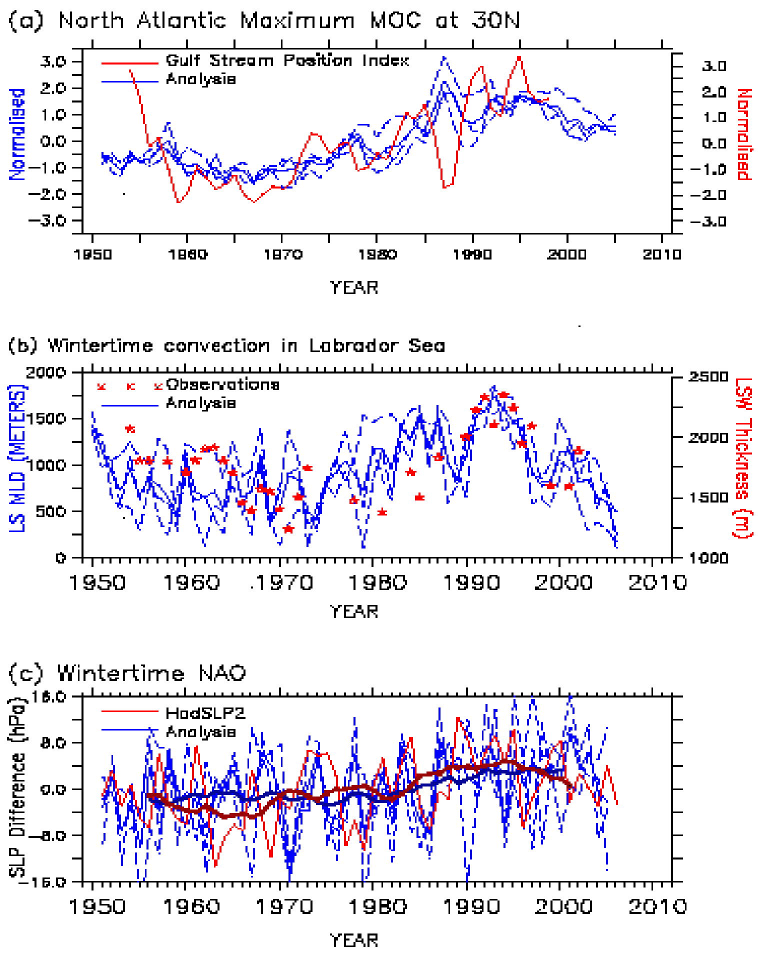

Figure 1.3.1: (a) Strength of the meridional overturning circulation at 30ºN from the analysis together with the Gulf Stream position index, a proxy for the strength of the MOC. Annual mean values are shown; both time series are normalised to unit standard deviation. (b) Wintertime Labrador Sea (60-50ºW, 55-65ºN) mixed-layer depth from the analysis and observed annual Labrador Sea Water thickness. (c) Wintertime (DJF) North Atlantic Oscillation (NAO) Index variations from observations and from the coupled analysis. The eleven-year running mean for observations and analysis are shown in dark red and blue, respectively. Analysis ensemble members (dashed lines) and the ensemble mean (thick solid line) are shown.

CERFACS (5 funded person-month and 5 unfunded):
CERFACS has produced an ensemble of nine 3D-Var ocean reanalyses over the 1960-2005 period, thus providing initial conditions for stream 2 seasonal to decadal hindcasts. These experiments have been described in Deliverable D1.9. Data are available at ECMWF, and will be archived in the common ENSEMBLES data set.

INGV:
INGV has produced a 46-year ocean reanalysis and has contributed to D1.9.

c) Deviations from the project work programme and corrective actions

Due to lack of manpower the KNMI EnKF assimilation scheme has not been, nor will it be, implemented in the MPI model. IFM will instead focus efforts on the new area of decadal forecast initialisation.

IFM will investigate methods to reduce biases in their SST initialisation scheme, by extending it to account for salinity variations. Possible methods include using temperature-salinity relations derived from observations or from coupled model simulations to constrain salinity anomalies. This will require 3 funded person-months.

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

The purpose of this workpackage is to install a forecast system at ECMWF with common archiving to be used in the production of the hindcasts of Streams 1 and 2.

Starting point of work for WP1.4 (Participants: ECMWF, METO-HC, CNRM, IfM, CNRS-IPSL, LSE, INGV, CERFACS):
By the end of the second year of the project, all partners had a stable forecast system running on the supercomputer at ECMWF and, in the case of INGV, on their own supercomputer. INGV installed the latest version of the INGV coupled model on its supercomputer, the atmospheric component of the coupled model being ameliorated by implementing an improved representation of the surface physics. In most cases, these systems were used for the Stream 1 simulations as required in WP1.5. However, many partners had carried out a substantial amount of work to port new, more efficient versions of their systems, which should also take advantage of the new ocean initial conditions created in WP1.3. In addition, the scripts for the archiving of both the atmosphere and ocean outputs were prepared.

b) Progress towards objectives

The progress in WP1.4 during the last year is as follows:
- **Task 1.4.6:** INGV has implemented in the latest version of the INGV coupled model a DEMETER-like methodology to perturb oceanic initial conditions based on the new set of perturbations produced at ECMWF[1]. The procedure to archive atmospheric forecast outputs in the required grib format and the oceanic outputs in the required netCDF format has been implemented. METO-HC has ported to and tested on the ECMWF computer the new Met Office Hadley Centre model HadGEM2-AO.
- **Task 1.4.7:** ECMWF has worked on increasing the computational efficiency of the new stochastic physics scheme by introducing a restart facility. This is required due to the substantial amount of annual and decadal integrations scheduled for Stream 2. Besides, following the developments in WP1.2, a new version of the backscatter scheme, the spectral backscatter scheme (SPBS), has been introduced. Different versions of the IFS/HOPE coupled model based on the latest developments in the PBL and convection schemes have been implemented to perform reduced sets of decadal hindcasts. In this context, an option to perform decadal hindcasts with observed SSTs has also been introduced. ECMWF has provided technical support to all the partners to run and/or archive their hindcasts.
- **Task 1.4.8:** IfM ported the MPI model to the new computer at ECMWF. Scripts were created to run the seasonal, annual and decadal hindcasts, including the implemention of the external radiative forcing strategy used by the METO-HC DePreSys system. Work on the optimisation of hindcast data archival was initiated, but not completed, due to lack of man-power. A PhD student has now been hired to contribute to these activities. Also, due to lack of man-power, it was decided not to implement the EnKF developed by KNMI.

c) Deviations from the project work programme and corrective actions

IfM will no longer implement the EnKF due to lack of man power.

[1] See http://www.ecmwf.int/research/EU_projects/ENSEMBLES/exp_setup/ini_perturb/index.html

LSE will not use the 3 funded and 1 unfunded person-months they planned to use during months 25-42.

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

The objective is to test methodologies for probabilistic climate prediction on seasonal to decadal time scales accounting for modelling and initial condition uncertainties in ensemble prediction.

Starting point of work for WP1.5 (Participants: ECMWF, METO-HC, CNRM, IfM, CERFACS, INGV):
The pre-production simulations for Stream 1 with three alternative approaches to deal with model uncertainty were almost completed, a preliminary evaluation of the skill of the hindcasts had been performed and the hindcast data had been disseminated. CNRM had worked on preparing a new version of ARPEGE. INGV had not planned any effort in the first 24 months.

b) Progress towards objectives

The progress in WP1.5 during the past year is as follows:

- **Task 1.5.4:** Additional seasonal hindcast experiments have been done by the METO-HC using lagged ocean initial conditions rather than perturbed initial conditions. A set of hindcasts has been initialised 2 weeks prior to the standard start dates to enable studies on information retention and decay in the forecasting system. ECMWF has tested a new cycle of IFS coupled to HOPE based on the latest developments in the PBL and convection schemes. A version suitable for the Stream 2 decadal hindcasts is still under research, awaiting the availability of a new radiation scheme more adequate for climate simulations. In the meantime, an additional set of Stream 1 decadal simulations has been carried out with correction of a bug in the forecast albedo. This new set provides a reduced surface temperature bias, although still suffers from an important drift in the tropical oceans due in part to a radiation imbalance.
- **Task 1.5.5:** ECMWF has carried out a thorough assessment of the skill of the Stream 1 simulations. This work has been summarized in the deliverable D1.8.
- **Task 1.5.6:** The initial METO-HC Stream 1 perturbed physics ensemble (hereafter DePreSys_PPE_old) was significantly less skilful than the original DePreSys system (DePreSys_orig). Further investigation revealed that the DePreSys_PPE_old assimilation integrations incorrectly used the dataset of solar and volcanic forcing intended for the hindcast runs, and the atmosphere assimilated only surface pressure, incorrectly omitting the analysed three-dimensional potential temperature and winds. Furthermore, the DePreSys_PPE_old ocean analyses were created using covariances from the standard HadCM3 member (Smith and Murphy, 2007), rather than from each perturbed model version. The Stream 1 perturbed physics ensemble (DepreSys_PPE) was therefore repeated with these deficiencies corrected, resulting in a significant improvement in skill (Figure 1.5.1).

Figure 1.5.1*: Comparison of DePreSys_PPE with DePreSys_PPE_old (see text) hindcasts of Niño3 surface temperature. Anomaly correlation coefficient (ACC, left) and root-mean-square error (RMSE, right) are computed from May and November start dates for the period 1991 to 2001, using ERA40 as verification. The blue shading denotes the 5-95% region where differences between DePreSys_PPE and DePreSys_PPE_old are not significant.*

The Stream 1 initial condition ensemble (DePreSys_ICE) was also completed, enabling the relative importance of uncertainties in initial conditions and model errors to be assessed. The perturbed physics hindcasts (DePreSys_PPE) of Niño3 surface temperature are consistently more skilful than DePreSys_ICE throughout the first year (Figure 1.5.2). Furthermore, the ensemble spread is larger for DePreSys_PPE than for DePreSys_ICE (Figure 1.5.2, dashed curves in right panel). However, the ensemble spread is still smaller than the root-mean-square error (RMSE), suggesting that the total uncertainty in the initial conditions and/or model formulation has not yet been included.
At lead times beyond 8 months there are encouraging signs of improved skill in DePreSys_ICE relative to DePreSys_orig, particularly in the Niño3 region (not shown). However, DePreSys_ICE is significantly less skilful than DePreSys_orig during the first few months of the hindcasts (Figure 1.5.3). A possible reason for this could be the use of model monthly climatologies interpolated from seasonal mean data in DePreSys_ICE. The transient integrations from which the DePreSys_ICE climatologies are calculated have therefore been repeated, saving the required monthly mean fields, and sensitivity experiments to assess the impact of changing the model climatology will be performed shortly. On decadal timescales, the warm bias relative to DePreSys_orig reported previously remains in both DePreSys_PPE and DePreSys_ICE. Investigation into the possible cause of this bias is ongoing, although it is likely that changes in external forcing introduced during an upgrade of the sulphur cycle may play a role.

We note also that a paper has been published (Smith et al., 2007), describing hindcasts from DePreSys_orig carried out prior to ENSEMBLES. With this and the recent work of IfM (see task 1.5.8 below), RT1 partners have provided the first results showing that initialisation of complex climate models has potential to improve the skill of climate projections on annual to decadal time scale.

Figure 1.5.2*: As Figure 1.5.1, but comparing DePreSys_PPE with DePreSys_ICE. The dotted curves in the right panel are the ensemble standard deviations.*

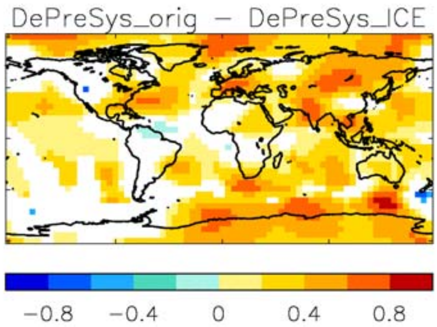

***Figure 1.5.3**: Difference between DePreSys_orig and DePreSys_ICE ACC for the first month of the hindcasts.*

Refs:
Smith, D. M. and J. M. Murphy, 2007: An objective ocean temperature and salinity analysis using covariances from a global climate model. J. Geophys. Res., 112, C02022, doi:10.1029/2005JC003172
Smith, D.M., Cusack, S., Colman, A.W., Folland, C.K. and J.M. Murphy, 2007: Improved surface temperature for the coming decade from a global climate model. Science, 317, 796-799.

- **Task 1.5.7:** IfM has completed a detailed analysis of its Stream 1 simulations and also of the decadal simulations performed for Stream 2. On the seasonal timescale, a careful comparison with results of the MPI simulations from the DEMETER project has shown that the substantially improved hindcast skill of the ENSEMBLES version of the model is due to improved model physics, and not to better initialisation. A scientific article on these results is in preparation.
  The results for the decadal timescale have been submitted for publication. Skilful predictions of surface temperature changes averaged over years six to ten of the hindcasts are obtained over large parts of the North Atlantic, Europe, North America and Northern Africa (Fig. 1.5.4a). The level of skill is well above that of persistence in all these regions, except for parts of Northern Africa (Fig. 1.5.4b). Persistence, the prediction that assumes no change from the initial conditions, is commonly used as a benchmark for skill. The 20th century simulations show skill over parts of Northern Africa, North America and Europe, but no skill over the North Atlantic Ocean, except in the vicinity of the equator (Fig. 1.5.4c), where a pronounced trend is observed. Of these regions, the climate model forecast is substantially more skilful over the North Atlantic and Western Europe. While over North America both the dynamical forecasts and the 20th century simulation show similar levels of skill, the dynamical forecast's skill is, however, more extensive. It follows that in these regions a significant fraction of the skill arises from the initialisation of the North Atlantic Ocean, as opposed to external radiative forcing. The analyses themselves (Fig. 1.5.4d) provide the upper limit of skill of our forecast system, as they include observed SST anomalies and known external radiative forcing. The skill of the analyses is higher than that of both the dynamical hindcasts and 20th century simulations, over all three land regions, indicating a rather high potential for decadal predictability. As described in the WP1.3 report, the skill of the dynamical forecasts arises from initialisation of the MOC (this can also be seen by comparing red and blue curves in Figure 1.5.5a).
  The Atlantic MOC fluctuations at 30°N are predictable out to a decade in advance, with the hindcasts capturing the observed low frequency variations in the gulf-stream position index (GSI), and ensemble spread generally small compared to the signal (Fig. 1.5.5a). The observed external radiative forcing only (20th century) simulations have no skill in reproducing the GSI. Fluctuations in the AMO and western European and North American surface temperature are also predictable out to a decade in advance (Fig 1.5.5b, c and d). Unlike for the MOC, the external radiative forcing also provides predictability for these indices. However, the dynamical hindcast's skill is larger. Hindcast skill for global mean temperature (Fig. 1.5.5e) is also high, but less than when only external radiative forcing is

considered. This is partly because major volcanic eruptions are not included in the hindcasts, particularly El Chichón in 1982 and Pinatubo in 1991, and partly due to our overly strong MOC fluctuations contributing to global mean temperature changes.

Using our hindcast setup, we forecast, taking into account projected anthropogenic forcing, that over the next decade the Atlantic meridional overturning circulation (MOC) will weaken to strengths of the 1970's (Fig. 1.5.5a). As a result, North Atlantic sea surface temperature (SST) and North American surface temperature (SAT) will cool by 0.1K relative to present day values, while European SAT will increase marginally (Fig 1.5.5b, c, and d). Global mean temperature increases, but at a significantly slower rate than expected from anthropogenic forcing alone (Fig. 1.5.5e).

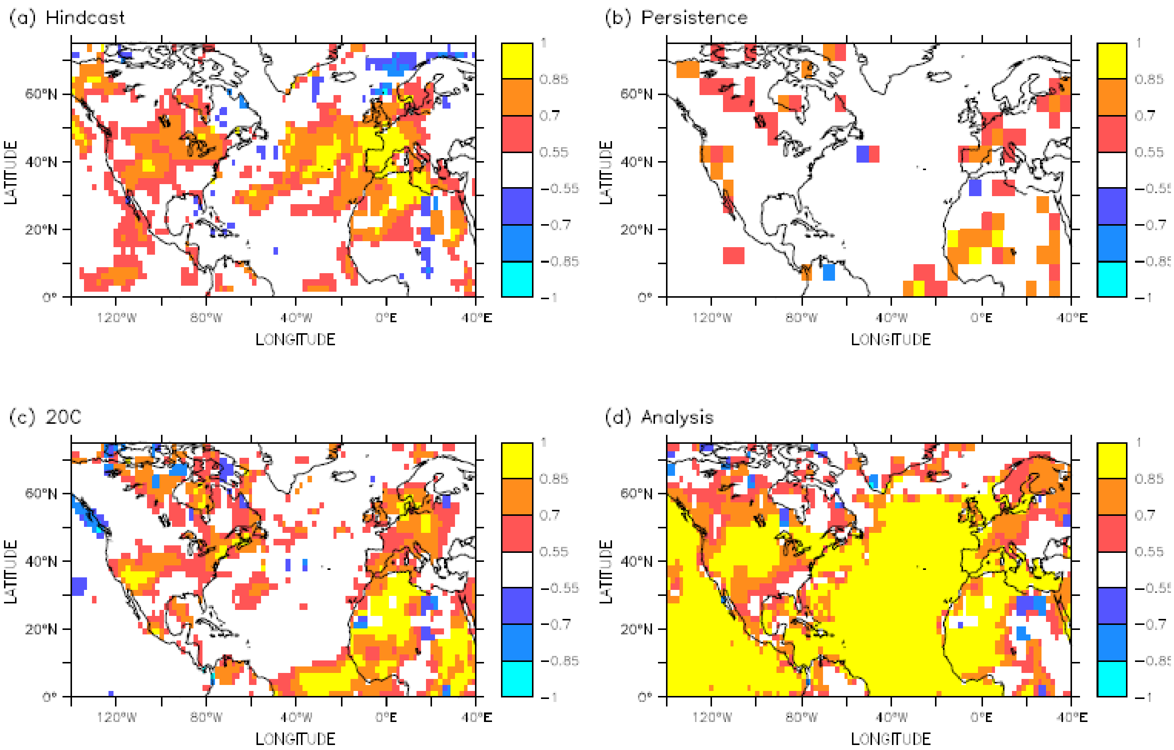

Figure 1.5.4: *Correlation between observed and predicted five-year mean surface temperature variations over the period 1960 till 2005. (a) As dynamically predicted by three-member ensemble hindcasts with ECHAM5/MPIOM CGCM for lead years 6-10. (b) As in (a) except as predicted by a persistence forecast. (c) As predicted using only observed radiative forcing. (d) As in (c), except with coupled model SST relaxed to observations. See text for experimental details. Correlations are computed from nine evenly distributed predictions (i.e., 7-degrees of freedom); values exceeding 0.66 are significant at the 95% level assuming a 2-sided student-T test. SST observations are from HADISST27, and land surface temperature observations are from CRUTEMP328. There is considerable skill in predicting decadal Atlantic Sector climate variability.*

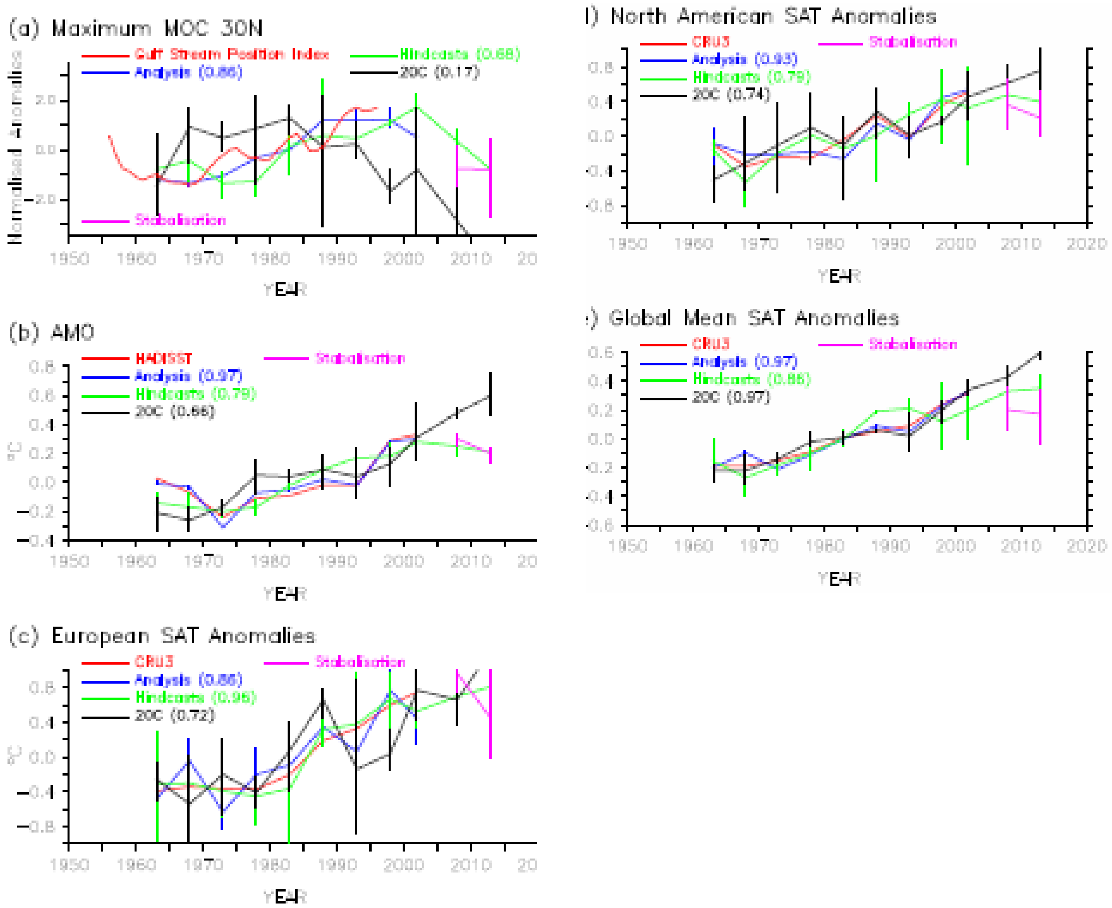

Figure 1.5.5: *Decadal hindcasts/forecasts time series averaged over hindcast years 6-10 of (a) maximum MOC strength at 30ºN, (b) AMO (SST averaged over 75-7.5ºW, 0-60ºN), (c) European surface temperature (averaged over 5ºW-10ºE, 35-60ºN), and (d) North American surface air temperature (averaged over 110-90ºW, 30-50ºN), and (e) global mean temperature. To facilitate comparison, all time series in this figure are scaled to match the observed standard deviations, and have zero mean over the period 1965-2004. This corrects for the generally too strong variability of our hindcasts that is primarily due to the overly strong MOC variability of our analysis (see methods for further details); no other corrections are applied. Shown in all panels are observations (red), the analysis (blue), dynamical hindcasts (green), 20C simulations including changes in radiative forcing but lacking initialisation from observations (black), and dynamical forecast with radiative forcing stabilised at 2000 values (purple). Vertical bars indicate the ensemble spread. Correlation with observations is indicated in brackets. Observations of the Gulf Stream index position is from Frankignoul et al., SST are from HADISST, land temperature from CRUTEMP3, and global mean temperature from HadCRU3. The multi-decadal evolution of key climate variables is well captured by the dynamical predictions.*

- **Task 1.5.8:** CNRM has worked on their contribution to the Stream 2 simulations. During the first months of the year, the new version (ARPEGE 4.6) was tested with 4-month winter cases (NDJF) in the same framework as Stream 1. It appeared that a low value for the orographic gravity-wave drag yielded better results. Once the choice of the atmospheric model was done, given the fact that the ocean and sea ice models are the same as in Stream 1 and that the ocean initial conditions are provided by CERFACS, the remaining choice was the atmosphere initial condition. The classical solution (used in DEMETER and in Stream 1) consists in interpolating ERA40 model level analysis on the ARPEGE grid. The problem is that Stream 2 goes beyond ERA40 (which ends in 2002) and the operational ECMWF analyses may be different in the case of variables for which no observation is used (soil moisture, snow cover), because the ECMWF model resolution and physical parameterizations are different. Two different approaches to solve this problem have been tested. In the first one, a 44-year (1958-2001) simulation of ARPEGE relaxed every 6h

towards ERA40 and the operational analyses is carried out. Only atmospheric variables (temperature, wind and pressure) are relaxed. These fields should not depend too much on the ECMWF version of the model since they are corrected by observations at each analysis step. The ARPEGE states from this simulation are used as starting situations for seasonal forecasts with two start dates and over four months (NDJF and MJJA). In the second approach, we first run a 44-year ARPEGE simulation driven by the observed SST. Then a monthly climatology from this experiment is computed, as well as a climatology of the ERA40 fields. A pseudo-ERA40 series is created by adding the 6-hourly ERA40 departures to the ERA40 climatology and the ARPEGE climatology. In a second 44-year ARPEGE simulation, the model is relaxed towards this new series. By doing this, we get initial situations that have now the same climatology as ARPEGE, and then do not drift during the hindcast integrations. We run a third hindcast experiment (NDJF and MJJA with 9 members and 44 years). The comparison of the scores of the 3 approaches shows that the second one (simple relaxation) is slightly better. With the hindcast system defined above, we have run the 14-month winter cases, and the 7-month spring, summer and autumn cases of almost all years. We are just missing the last 4 years because the ocean initial conditions are not yet ready. Therefore, the Stream 2 hindcasts with the CNRM system is about to be completed and the ENSEMBLES database will be fed in the same way as for Stream 1. In the meantime we have evaluated the winter scores (DJF), which compare well with DEMETER scores over the common period (1960-2001).
A semi-automated procedure for the production of seasonal to annual hindcasts has been implemented and tested for the latest version of the INGV coupled model. Using the previous version of the INGV Seasonal Prediction System that was developed in the framework of the EU project DEMETER, a preliminary assessment has been performed of the impacts of the improved ocean initial conditions produced in WP1.3 on the skill of the hindcasts. Using these developments, the RT2A Stream 2 seasonal hindcast simulations have been started.
IfM has performed its decadal simulations for Stream 2 and is in the process of archiving the data. Case studies for the years 2005 and 2006 using ECHAM5 at T213L31 resolution have been initiated.

- CERFACS did not have any effort during this period.

c) Deviations from the project work programme and corrective actions

None.

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

Starting point: METO-HC had produced a 17 member perturbed physics ensemble of transient climate change simulations with HadCM3, sampling multiple perturbations to atmosphere model parameters controlling key climate processes. UOXFDC had developed a method for generating very large perturbed physics ensembles of the HadCM3 model, and had commenced simulations via public-resource distributed computing facilities through climate*prediction*.net. EGMAM had generated a perturbed physics ensemble of control simulations using the EGMAM model, looking at perturbations to five cloud parameters. CNRM had analysed a transient simulation of its CNRM-CM3 coupled model coupled to the impact assessment model IMAGE 2.2, and had used the results to inform development of an improved version, which had been run in control simulation mode. Work was in progress to re-introduce the indirect effects of aerosols into this model.

Objectives for months 25-42

Task 1.6.4: Ensemble experiments will be performed to test the sensitivity of the rate of transient climate change to key parameters in the ocean component of the HadCM3 model. Perturbations will initially be made to single parameters in isolation but the validity of further ocean-parameter ensemble experiments will be assessed. A small ensemble of HadCM3 experiments with perturbations made to sulphur-cycle component parameters will be initiated. A version of HadCM3 with interactive carbon-cycle dynamics will be developed and the validity of a carbon-cycle parameter perturbation study assessed.
Task 1.6.5: Analysis will begin of the HadCM3L coupled model ensemble developed and launched under climatepredction.net during months 13-25. Different methods of analysing large ensembles will be tested, in particular, weighting ensemble members according to their simulation of past climate in order to produce uncertainty estimates of future climate change.
Task 1.6.6: The 30 member perturbed physics ensemble of EGMAM versions will be integrated with doubled present day CO_2 concentrations to allow an assessment of the uncertainty in the climate sensitivity of EGMAM. Results will be compared with the perturbed physics ensembles produced by other project partners. This will build towards the development of a multi-model, perturbed-physics ensemble forecasting system, which may be used to generate probability distribution functions of the multi-model ensembles in RT2A. CNRM will perform a small ensemble of climate simulations in order to explore the sensitivity of the climate response to different ocean initial conditions.

b) Progress towards objectives

Meetings, collaborations and publications:

- A breakout session on “Exploitation of the ENSEMBLES Phase I Prediction Systems” was run at the ENSEMBLES General Assembly in Lund in Nov 2006. This resulted in additional cross-cutting collaboration aimed at facilitating use of probabilistic results from the RT1 climate change projections, and the impacts modelling community in ENSEMBLES (see bullet below).
- A number of representatives of RT1 attended the joint ENSEMBLES-CFMIP Workshop on cloud feedbacks in Paris in May 2007. The meeting was designed to act as a catalyst for joint research on process-based constraints on climate predictions.
- Falk Niehorster from FUB paid an extended visit to the UK in spring/early summer 2007. He spent time in three ENSEMBLES institutions; the Met Office, the University of Oxford and the London School of Economics.
- Glen Harris from the Met Office attended the RT6 meeting in Finland in April and supplied a preliminary set of probabilistic predictions of future change in European temperature and precipitation. These PDFs will be used in impact assessment research.
- A number of publications were prepared for a special issue of the Philosophical Transactions of the Royal Society A on “Ensembles and probabilities: A new era in the prediction of climate change”. Those arising from ENSEMBLES include; Collins (2007), Murphy et al. (2007), Frame et al. (2007) and Troccoli and Palmer (2007).

Task 1.6.4: A 16-member ensemble of HadCM3, with multiple, simultaneous perturbations to parameters in the ocean component has been spun up and initial control and simple climate change experiments completed (Figure 1.6.1). Eighteen ocean-model parameters and switches were perturbed according to a Latin Hypercube design and each experiment uses a unique flux-adjustment term to prevent climate drift and improve the credibility of the regional simulation of mean climate conditions. In each member the atmospheric parameters were kept fixed at their standard values. The perturbations have a relatively small impact on the time-rate of change of global mean temperature in comparison to that found in an ensemble with perturbed atmospheric parameters. Further investigation has revealed that the spread in both the effective feedback parameter and the ocean heat uptake efficiency are of the same order of magnitude as that which would be expected on the basis of natural variability. However, some significant regional spread in temperature and precipitation is evident. Further work is required to understand these findings.

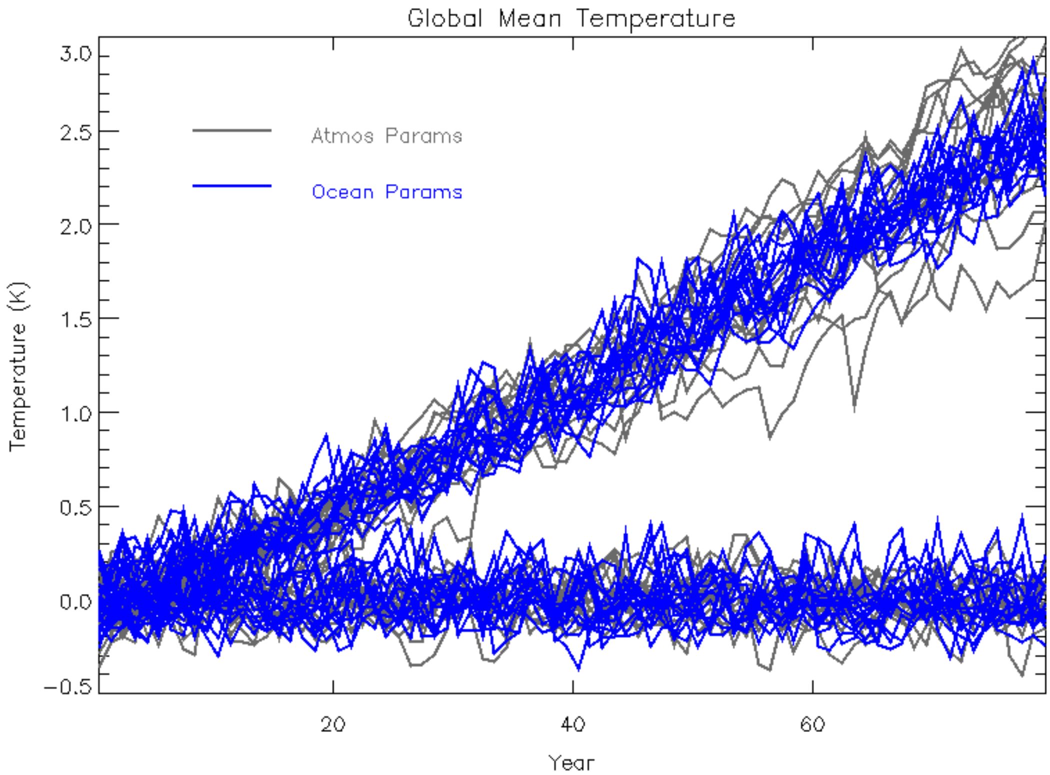

Figure 1.6.1. *Global mean temperature anomalies from two perturbed physics ensembles. Grey lines – perturbations to parameters in the atmospheric component of HadCM3, blue lines – perturbations to parameters in the ocean component. The horizontal lines are from control experiments with fixed 1860 radiative forcings, the other experiments have a 1% per year compounded increase in* CO_2.

A different 16-member HadCM3 has also been performed with perturbations to only parameters in the sulphur-cycle module of the model (figure 1.6.2). Eight parameters/switches were perturbed, again following a Latin Hypercube design. In this case, experiments were performed with historical radiative forcing in the past and forcing under the SRES A1B scenario for the future. Examination of the sulphate burdens show that the perturbations have a significant impact on the sulphur-cycle of the model, yet there is little detectable influence on ensemble spread in global mean temperature. Again, however, some significant impacts on regional changes were found. Further investigations are planned.

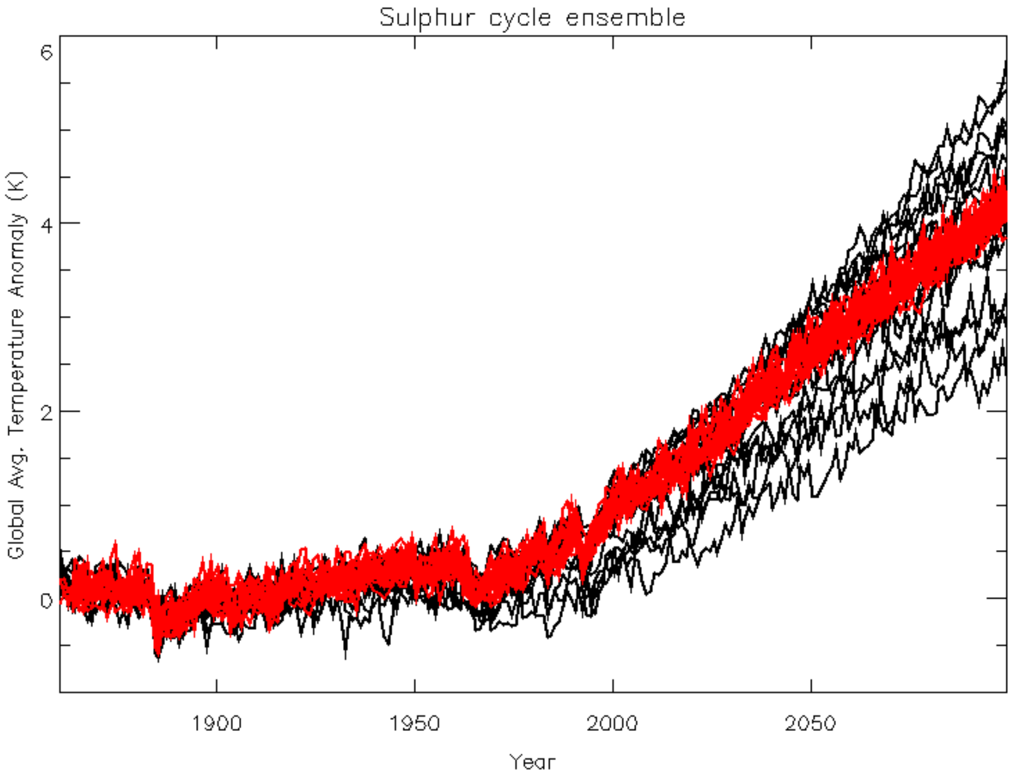

Figure 1.6.2. *Global mean temperature anomalies from two perturbed physics ensembles. Black lines – perturbations to parameters in the atmospheric component of HadCM3, red lines – perturbations to parameters in the sulphur-cycle component. The experiments are forced with historical natural and anthropogenic factors over the period 1860-2000 and with future forcings under the SRES A1B scenario.*

Some progress has been made in setting up the version of HadCM3 with an interactive carbon cycle and preliminary experiments with standard parameter settings have been performed. Perturbed-parameter ensemble simulations will be described in future reports.

Task 1.6.5: Analysis has begun on the several thousand member ensemble of HadCM3L coupled model simulations launched under the climateprediction.net experiment. A paper is currently in progress looking at global and regional forecasts of climate change, based on the ensemble of simulations. Ensemble members are weighted according their closeness of fit with observations of past climate (see figure 1.6.3). Model data from the experiment has now been made available to the scientific community here: http://results.cpdn.org

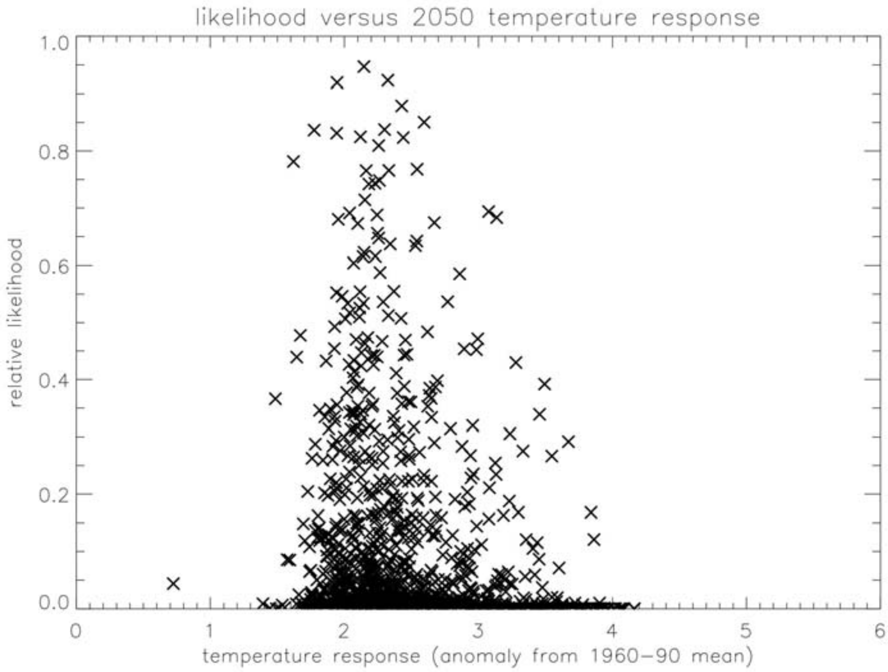

Figure 1.6.3: Likelihood versus global temperature response for climateprediction.net simulations. Each cross represents one simulation. Likelihood is calculated for each simulation by goodness of fit with observations of 20th century temperature.

Task 1.6.6: The integration of the perturbed model versions in a doubled CO_2 concentration was started and more than ten simulations are already finished. A comparison with the pre-industrial control simulations enables an analysis of the uncertainty in the climate sensitivity of EGMAM due to uncertainties in the cloud parameterisations. Preliminary results show a clear signal of the perturbations in the climate sensitivity, leading to differences of up to 2°C.

During a visit at the Met Office-Hadley Centre and the University of Oxford results of similar perturbed physics experiments performed by these groups were exchanged and additional common setups for simulations were agreed to enlarge the set of comparable perturbed physics simulations with these models. Preliminary results show a consistent global signal in climate sensitivity across the models due to perturbations in corresponding parameters. But strong regional differences indicate different impacts on physical processes in the atmosphere. Additionally, signals originating from the use of different ocean models will be further investigated.

Several recent improvements have been introduced into the CNRM coupled model, CNRM-CM3, as part of the preparation of the improved version (CNRM-CM4) to be used for the stream two simulations planned in RT2A. The two major improvements are (i) better conservation of the non-solar heat flux exchanged between the atmosphere and ocean models, achieved by upgrading the non-solar flux subgrid re-partition algorithm and (ii) the re-introduction of the first indirect effect of aerosols. These improvements have allowed considerable reduction the cold biases in global temperature of the CNRM-CM3 version used in IPCC and stream one simulations. This upgraded version (CNRM-CM3+) has been used to perform a control simulation, and the preproduction runs of the 20-th century climate that had been planned in RT1 as a validation test of the methodology to be used for stream 2.

As a first step for the validation of the new version a 280-yr pre-industrial control experiment and a 1860-2000 historical experiment were run with this upgraded version of the model. In the new control experiment the ocean and surface atmosphere temperature are better simulated, and the associated drifts are much smaller (fig. 1.6.4). However, a significant surface temperature positive bias now appears in the Arctic as a result of the less extensive simulated sea ice. In the new 1860-2000 historical experiment (red curve), the global average 2m air temperature increases in two phases: from 1900 to 1930 and from 1970 to 2000 with a stabilization between 1930 and 1970. This behaviour is rather different from that of the IPCC-AR4 simulations performed with CNRM-CM3 (dark blue and green curves) and more consistent with observations (black curve).

As the first validation step had confirmed the satisfactory evolution of the CNRM-CM3+ version, we have been able to apply it to perform the pre-production simulations that had been planned in WP1.6 for validating the methodology to be applied in stream two, and for assessing the impact of different ocean initial conditions. In order to follow closely the stream 2 methodology the land-use changes during the 1860-2000 period have been taken into account, using the observed annual 0.5° maps on crop and pasture fractions provided by N. de Noblet for the LUCID project. The annual variations of natural forcings due to solar and volcanic variability were also taken into account. An ensemble of three historical simulations was run over the period 1850-2000, starting from 3 different initial ocean conditions selected from the control simulation and characterized by different phases of the North Atlantic Meridional Overturning Circulation. As can be seen on the figure, these three simulations (light blue, violet and dark yellow curves) do not differ much from 1860-2000 experiment performed in step 1 (red curve) in terms of global mean temperature, but within this ensemble the phase of the multidecadal variability differs from one experiment to another, particularly during the 19th century and early 20th century.

The completion of these 3 simulations formally ends our contribution to WP1.6. Results from these simulations can be provided on request to other partners in RT1. As all our resources in this WP have been used up, further use and analysis of these simulations will be made within other work packages (RT2A and RT4).

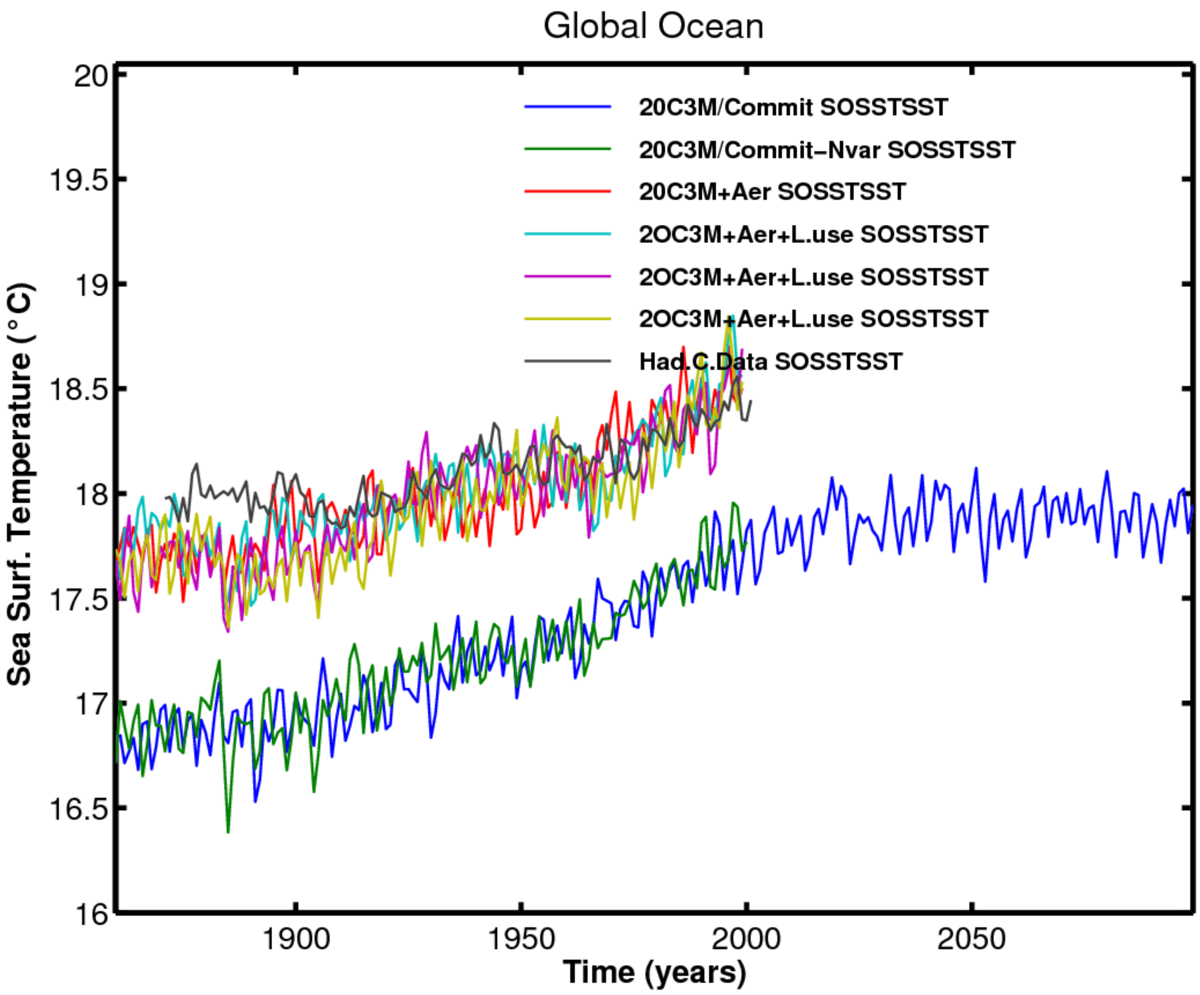

Figure 1.6.4: *Global mean sea surface temperature series from the stream 1 simulations (blue and dark green) and the new preproduction runs. The observed SSTs from Hadley Centre data are shown in black. Legend for the colors: - dark blue: stream 1 CNRM-CM3 simulation with GHG and sulphate aerosol direct effect and constant concentrations after 2000 - green: similar simulation with addition of solar-volcanic forcings – red: new simulation with updated version CNRM-CM3+ with GHG and aerosol direct and indirect effect – light blue, violet, dark yellow: similar simulations with addition of land-use changes and solar-volcanic forcings starting from 3 different ocean conditions.*

References

Collins, M. Ensembles and probabilities: a new era in the prediction of climate change. Phil. Trans. R. Soc. A 365. (doi:10.1098/rsta.2007.2068)

Murphy, J. M., Booth, B. B. B., Collins, M., Harris, G. R., Sexton, D. & Webb, M. 2007 A methodology for probabilistic predictions of regional climate change from perturbed physics ensembles. Phil. Trans. R. Soc. A 365. (doi:10.1098/rsta.2007.2077)

Frame, D. J., Faull, N. E., Joshi, M. M. and Allen, M. R. Induction, decisions and climate science. Phil. Trans. R. Soc. A 365. (doi:10.1098/rsta.2007.2069)

Huebener, H., Cubasch, U., Langematz, U., Spangehl, T., Nierhorster, F., Fast, I. and Kunze, M. Ensemble climate simulations using a fully coupled ocean-troposphere-stratosphere General Circulation Model (GCM). Phil. Trans. R. Soc. A 365. (doi:10.1098/rsta.2007.2078)

Troccoli, A. and Palmer, T. N. Ensemble decadal prediction from analysed initial conditions. Phil. Trans. R. Soc. A 365. (doi:10.1098/rsta.2007.2079)

c) Deviations from the project work programme and corrective actions

None.

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
D1.8	Updated assessment in terms of forecast quality and potential economic value of the relative merits of the multi-model approach, the perturbed parameter approach, and the stochastic physics approach, to representation of model uncertainty in seasonal to decadal forecasts.	RT1	28.02.2007	28.02.2007	10	10	ECMWF
D1.9	Report on the production of OPA/NEMO analyses and initial conditions for use in seasonal to decadal Stream 2 hindcasts	RT1	30.06.2007	30.06.2007	6	6	CERFACS
D1.10	Set of hindcasts using the lagged average method and earlier start dates carried out with GloSea following the stream 1 setup.	RT1	31.08.2007	31.08.2007	4	4	METO-HC
D1.11	Scientific report/paper documenting the improved seasonal hindcast skill of the ECHAM5/OM1 coupled model in the ENSEMBLES stream 1 simulations, relative to DEMETER, and the model improvements responsible.	RT1	28.02.2008	28.02.2008	3		IfM

D1.12	Interim probability distributions of transient climate change over Europe will be produced, for use by other RTs in testing methodologies for prediction of climate change impacts.	RT1	28.02.2008	28.02.2008	12		UOXFDC
D1.13	Scientific report/paper documenting the seasonal hindcast skill of the most recent version of the stochastic physics scheme developed at ECMWF.	RT1	28.02.2008	28.02.2008	6		ECMWF
D1.14	A comparison of perturbed physics ensembles constructed with different models.	RT1	28.02.2009	28.02.2009	10		FUB
D1.15	Report describing improved probabilistic predictions of 21st century climate over Europe, obtained by combining global model Hadley Centre perturbed physics ensemble results, multi-model ensemble results, and observational constraints.	RT1	31.05.2009	31.05.2009	8		METO-HC

***) 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
M1.5	ESMs fully prepared for stream 2 centennial experiments including the physical system, aerosol system and carbon cycle system, dependent on partner.	RT1	28.02.2007	28.02.2007	MPIMET
M1.6	Completion of the Stream 2 OPA/NEMO analyses and initial conditions.	RT1	30.06.2007	30.06.2007	CERFACS

M1.7	A workshop organized jointly with WGSIP (the CLIVAR Working Group on Seasonal to Interannual Prediction) will be held in Barcelona on the 4-8 June 2007 to gather scientists working on seasonal-to-decadal forecasting from different continents.	RT1	31.08.2007	31.07.2007	ECMWF
M1.8	Completion of the seasonal-to-decadal Stream 2 hindcasts, WP1.4/WP1.5/WP2A.1.	RT1	31.08.2008	31.08.2008	ECMWF, METO-HC, CNRM, INGV, IfM, CERFACS
MM1.3	Specification of a “second generation” ensemble prediction system (Version 2).	RT1	31.08.2009	31.08.2009	ECMWF,METO-HC