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EC - EARTH

Science and implementation plan

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EC-EARTH

Science and Implementation plan[1]

De Bilt, 25 July 2007

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Preface

There is an increasing need for meteorological institutes and academic institutions to inform policy makers on climate change and to provide quantitative climate information. The climate projections are used for developing mitigation and adaptation strategies. However, there is still large uncertainty on the degree of climate predictability and on interactions between components in the earth system. This requires more research to unravel the feedbacks and quantify the uncertainties. A modeling system of the earth system is required to provide quantitative projections and to perform research on climate predictability and earth system feedbacks . This report describes the motivation and implementation plan for using the modeling system of the European Centre for Medium Range Weather Forecasting (ECMWF) for these purposes.

Using an operational system for weather forecasts and seasonal predictions has tremendous advantages. New developments in atmospheric and oceanic modeling can be taken over by earth system scientists. It is also a scientific challenge, since the earth system behaves differently on short time scales than on longer time scales which can give rise to different numerical requirements.

The EC-EARTH initiative brings scientists from member states of ECMWF together and will provide them a common earth system modeling framework. It will stimulate joint research and lead to a new earth system modeling framework within Europe.

Wilco Hazeleger
KNMI
Head, Global Climate Division
De Bilt, July 2007

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Part I: EC-EARTH science plan

1. Introduction

Numerical modelling of the Earth System is an important research and development topic with practical applications in meteorological, ocean, hydrological and environmental forecasting, basic science and climate change.

On the global scale, general circulation models have been developed over the past few decades. The early efforts were for separate atmosphere and ocean models. Later, coupled models have become the norm and an indispensable means in climate and climate change research. These models have been successful in simulating present-day climate and are being used for seasonal to interannual predictions and projections of climate change. Regional models have also been developed for a more detailed study of regional climate change and process-studies on higher resolution than what is presently practically attainable with global models. Output from these global and regional models is increasingly used as basis for adaptation and mitigation strategies.

Climate and forecasting applications share a common ancestry and also build on the same physical principles. Nevertheless, climate research and forecasting are commonly seen as different applications. Applications such as seasonal forecasting, reanalyses and decadal predictability studies fall in between them. The concept of "seamless prediction" (cf. WCRP) is emerging to forge forecasting and climate change into a joint topic. The concept also extends the focus of the physical climate system toward a comprehensive view of the Earth System in which feed backs with the biosphere are included.

Indeed, efforts are underway in a few countries (Japan, United Kingdom, Canada, USA, Germany) to pursue what has become known as Earth System Models (ESM). These build on state-of-the-art coupled atmosphere-ocean general circulation models and increasingly incorporate dynamic vegetation, atmospheric chemistry and carbon cycle components as well as ocean biogeochemistry. In Europe, the PRISM project can be considered as starting point to build a unified model framework for ESMs.

The need for an Earth System model is recognized by various ECMWF Member States (MS). For technical and scientific reasons it would be attractive to increase the collaboration on modelling efforts at ECMWF. This would strengthen the joint efforts on overall model development and build further on strategies developed in the EU-PRISM project. A joint project would be beneficial to individual MS because it offers the opportunity to use computational infrastructure efficiently, share expertise between MS and ECMWF, and limit the number of different model frameworks currently in use for forecasting and climate applications by MS.

This document builds on the discussions at recent meetings of representatives of ECMWF member state representatives kindly hosted by ECMWF. The outcome of the meeting was that, indeed, there is both a need and means to initiative a joint effort on an ESM that would build on existing activities at ECMWF and national activities and contribute to the long-term strategies. This document substantiates the common objectives, model requirements, resources and presents a tentative time line of the proposed development of EC-EARTH. In addition to the science plan, a detailed technical implementation plan is included. The proposed plan is the first phase of the project, with the main goal of establishment a first version of EC-EARTH.

2. Goals of the EC-EARTH initiative: the Science case

The rationale for the development of an Earth System model arises from a number of common goals shared by partners in this project. These goals are not only set by the scientific programs of the partners, but also by the need to forecast changes in climate and the need of practical applications for relevant climate information. In the following a number of goals are shortly discussed.

1) Study global change and variability in multi-decadal integrations
In modern climate science, many aspects of climate variability and change are investigated using general circulation models. Also, there is a need for projections of future climate on a global, continental and regional scale. Many aspects of global change are not understood yet. For instance the response of dominant patterns of climate variability (such as the NAO, AMO, ENSO, PDO) to changes in greenhouse gas concentrations. The science of global change requires numerical experimentation with earth system models. Large ensemble integrations of typically a few decades to centuries are needed to sample natural variability and to evaluate extremes.

2) Explore interannual to multi-decadal predictability
Predictions are made routinely from daily to seasonal time scales. Weather forecasts up to 10 days ahead show good skill. For the tropics, where oceanic and atmospheric variations are strongly coupled, seasonal forecasts can be made. The memory resides in the ocean in general and with proper initial conditions skillful forecasts can be made for, for instance El Nino and the Indian Ocean Zonal Mode. Recently, decadal predictability has gained interest. At the decadal time scale, climate change processes and mechanisms of natural variability come together. One aspect is changes in the Atlantic Meridional Overturning Circulation which may be predictable on decadal time scales. These changes can couple to atmospheric variations in the North Atlantic region. To address decadal predictability, careful initialization of the state of the atmosphere and ocean, in particular the deep ocean, is needed. The World Climate Research Program stimulates this development in a “seamless prediction” theme under the COPES framework. A comprehensive model system with initialization procedures for the atmospheric and oceanic state, comparable to those in NWP models, is necessary to explore decadal predictability.

3) Study feed backs in the earth system
Physical feed backs in the earth system have been extensively studied, but uncertainties still exist on, for instance cloud feed backs and lapse rate feed backs. The current generation of state-of-the-art GCMs contain first order biases that limit

there applicability. Consequently there is considerable spread in the climate sensitivity that is not the result of internal climate dynamics. Experimentation is needed to understand processes that generate them and improve the models. Except for physical feed backs, interaction with atmospheric chemistry and the biosphere gains increasing attention. Variations in atmospheric composition, including aerosols, induces variations in radiative transfer and hence impacts the radiative balance and the general circulation. Spatial and temporal variability in the composition have been observed (e.g. global ozone distribution), but interactive atmospheric chemistry has hardly been implemented in current climate models. Also, interaction with biogeochemical cycles and ecosystems is of large interest. Carbon concentrations in the atmosphere rise less than the anthropogenic emissions due to uptake by the ocean and land and carbon concentrations exhibit considerable interannual variability. Responses of the marine and terrestrial ecosystems to climate variability and climate change and their feed back to the physical climate system are not well known and subject to new lines of research. Atmospheric chemistry modules and biogeochemical modules are starting to get implemented in climate models, making them true earth system models.

4) Develop global climate change scenarios as new European contributions to international efforts (such as IPCC)
Related to the first goal, there is a need to contribute to international efforts to assess climate change quantitavily and make projections for future climate under prescribed emission scenario's of greenhouse gasses and aerosols. The main focus is the 21st century, but longer outlooks should be feasible.

5) Provide an advanced modelling tool for the investigation of mitigation options
Increasingly, policymakers interact with scientists to gain knowledge on the impact of policy measures on climate. Mitigation policies, such as the use of sustainable energy or storage of carbon, are developed to limit changes in greenhouse gas concentrations and aerosols. Ultimately it is strived for to limit the effect of anthropogenic climate change. To evaluate the impact of e.g. emission controls on atmospheric composition change, dedicated earth system model integrations are necessary.

6) Sensitivity studies of the global climate system
As an addition to climate change scenarios that prescribe the temporal evolution of the external forcing based on more or less likely assumptions we will also perform long-term climate simulations with an external forcing that is vastly different to present day conditions. Conceivable studies of that kind are paleoclimate reconstructions, but also simulations under very extreme assumptions about future climates. These studies help us to better understand the physics of the climate system. A coupled Earth System Model additionally gives us the opportunity to study feedback between the components.

7) Provide global climate scenarios (boundary conditions) for MS regional climate and impact studies
Many applications of climate change are on a regional or local level. In particular, adaptation strategies need to be devised based on regional information on climate variability and change. Computational limitations require that global model

simulations have a relatively coarse resolution (O 100 km). This global climate information has to be downscaled to regional scales. To do this in a dynamic and consistent way, a global model should provide boundary conditions to regional models. Ideally, both models should have the same physics package.

8) Teleconnections and regional impact
The climate system varies on different temporal and spatial scales. Global and regional scales can interact locally, but local climate can also be influenced by a remote disturbance. A typical example is the influence of El Nino on the local climate far away from the Pacific Ocean. These remote effects can only be studied with global models that include the large scales. We plan to study the impact of global scale phenomena (e.g. Arctic Oscillation, NAO, ENSO) on the regional climate by first performing an extended simulation with the global climate model and then select suitable periods for the downscaling with regional climate models.

In order to reach these goals we propose as an overall objective:

> *Develop a global Earth System model consisting of a state-of-the-art atmospheric general circulation model, a state-of-the-art ocean general circulation model, a sea-ice model, a land model, and an atmospheric chemistry model.*

At a later stage modules for the marine and terrestrial biogeochemical cycles as well as a dynamic vegetation model are also foreseen. This Earth System model has been nicknamed EC-EARTH (an earth system model based on ECMWFs NWP model).
A sufficient high-resolution for the physical modules must be obtained to simulate realistically the large scale circulation and internal variability in the atmosphere and ocean. The model should be able to produce stable runs without flux corrections. The model should be computationally efficient for making multi-decadal runs “routinely”.

Since the priority of the goals and specifics may differ between MS, it is essential for the MS to be able to perform integrations themselves. The existing integrations of for instance IPCC are too generic.

3. The use of ECMWFs IFS for EC-EARTH

Earth system models are being developed at a number of major climate modelling centres around the world and some of them are truly community models. These models descended from numerical weather prediction (NWP) models and ocean models used in process studies that were first developed in the 1970s. Over time, the development of climate models drifted away from development in NWP models. In particular, the parameterizations are developed often independently. Also, NWP models are linked to sophisticated data assimilation schemes to make forecasts.

In this project different member states of ECMWF propose to merge these approaches. We suggest to use ECMWFs Numerical Weather Prediction model (IFS) as atmospheric and land component and the OPA ocean model as climate model and to further develop it into an earth system model (i.e. include chemical processes).

Moreover we intend to use the tools of IFS for climate research. Currently, the IFS-OPA configuration is being developed as seasonal forecast system at ECMWF. The development of this system into a climate model implies a substantial effort as the seasonal forecast systems are not devised for multi-decadal integrations. However, there are good reasons to follow this path. Here we list the main reasons:

1) Using physical constraints in Numerical Weather Prediction (NWP) models for climate models

Constraints in climate models are different from those in NWP models. In both approaches physical arguments can be made for those constraints. One of the constraints set for NWP models is that initial tendencies should be correct. For climate models this is not relevant in general, as long as the tendencies in the mean should become negligible to avoid model drift. So physically unrealistic balances can arise in climate models jeopardizing the physical basis of the model. Climate models should be put to the test and also produce realistic initial tendencies. This is but one example of NWP requirements that from a physical point of view should be captured in climate models as well. Another example is the parameterization of physical processes such as convection, clouds and precipitation. In climate models, often reference profiles are used in parameterizations. NWP models often use parameterizations that are closer to the physics of the respective processes, e.g. TKE schemes for convection.

2) Using physical constraints in climate models for NWP models

The argument mentioned above can be reversed. Climate models have physical constraints that are not of immediate relevance to NWP models. Most of these are related to long term behaviour of the model or climate drift. For instance, a closed radiation budget is extremely important for long-term integrations, but less relevant on daily to monthly time scales. Nevertheless, the first principles on which the models are based are the same and applicable on all these time scales. Therefore, it is anticipated that if the physics is implemented more concisely in both EC-EARTH and the NWP mode, it would be beneficial for both modelling approaches.

2) Using NWP and seasonal forecasting data-assimilation procedures for predictability studies

There is extensive experience with initialization of both the ocean and atmosphere for seasonal and shorter term predictions. There is increasing interest to expand the predictability horizon to decadal time scales. One of the potential applications is early warning of abrupt climate change associated with a strong reduction of the Atlantic Meridional Overturning Circulation. Also, changes in sea ice cover and thickness and the interaction with climate is of interest. With the tools and data sets in place for initialization (ie. the ocean and atmosphere analysis), ECMWFs system is very suited for decadal predictability studies.

3) Using data-assimilation procedures for specific ensembles

Except for decadal predictions starting from analyzed fields, there is a need for ensembles integrations around specific climate events (for instance, extreme droughts or extreme storms). In particular for downscaling studies and applications for adaptation to climate change measures, ensembles around specific climatic states are useful. As for decadal predictions, the tools that enable initialization of the atmosphere and ocean is extremely useful for this purpose.

4) Using a common model framework and tools
There is an advantage in using a common model framework for weather and climate applications, in particular for meteorological institutes that are engaged in climate research. The use of a common framework, common diagnostics and common tools fosters cooperation between the meteorological and climate research communities.

4. Requirements

To meet the objectives mentioned in section 3 a flexible modular Earth System model will be constructed that consists of the following modules that can run in stand-alone and in coupled configurations:

The initial set-up is foreseen to consist of:
1. global state-of-the-art primitive equation model for the atmosphere
2. global state-of-the-art primitive equation model for the ocean
3. dynamic sea-ice model
4. atmospheric chemistry model
5. land-snow model
6. coupler

The final set-up would incorporate also
7. dynamic vegetation and terrestrial biogeochemistry model
8. ocean biogeochemistry model

A resolution of at least T106 (or T95L) for the atmosphere and 1 degree for the ocean is envisaged. The output of the model should be suitable for use as boundary conditions of regional climate, impact and environmental models. At a later stage, nesting in the atmosphere model should be explored. As regular experiments with global truly eddy-resolving model runs with the ocean module are not feasible yet with current computing power, the ocean component needs to have a nesting option to obtain high resolution regionally. This will also be beneficiary for regional applications of the model.
As computing power will increase, the horizontal and vertical grid spacing of the physical components will be enhanced. The models need to have the capacity to do this in a flexible manner. Related to this, development towards non-hydrostatic dynamical cores should be a possibility in the near future.

Common frame work

A common modelling frame work should be used with common strategies for setting up experiments, input/output formats based on international standards (such as NetCDF which is widely used in the climate research community), and a version management system, i.e. accepted codes that are accessible for all partners.

The model should be portable between a number of hardware systems. Using the experience from the EU-PRISM and GEMS projects, suitable coupling strategies will be implemented.

ECMWFs prepIFS system can be the basis for a user-friendly shell to set up experiments and version management system. Ideally, model developments within EC-EARTH will be implemented in operational versions of IFS and vice versa. As development takes time and in order to have a stable version for some years it is suggested to merge EC-EARTH with operational IFS once every few years, in phase with the development of the seasonal forecast system (Figure 1). Here the project differs from the development of ECHAM which also has IFS as basis, but doesn't merge anymore with the NWP model.

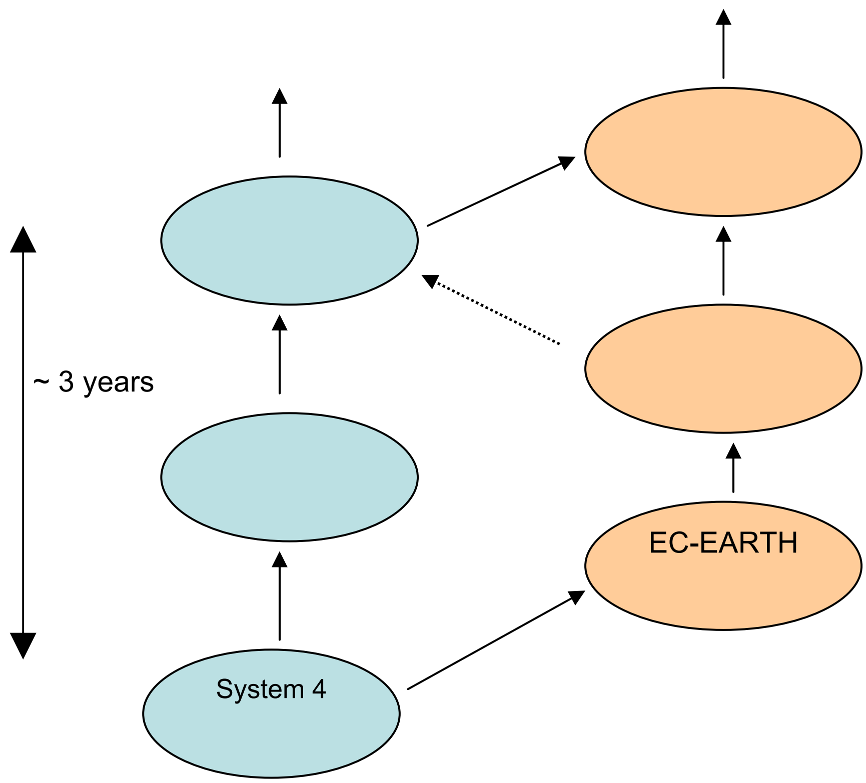

Figure 1: Schematic of time schedule of EC-EARTH development. The left hand side shows the development of IFS, the right hand side that of EC-EARTH. Merging occurs about every 3 years.

Proposed initial configuration

We envisage that partners may use different model configurations, at least in the starting phase of the programme. Existing modules will be used. In this way the joint system retains aspects of a multi-model ensemble. The model framework will be a common one. The basis of the model will be the IFS model of ECMWF. A proposed initial configuration will consist of the following modules to be coupled interactively using software developed in the PRISM (coupler) and the GEMS (atmospheric chemistry) project:

1. IFS model of ECMWF as atmospheric and land surface component
2. Global OPA (NEMO) ocean models, and accompanying sea ice models as ocean-sea ice component
3. TM5 model as chemistry component
4. The OASIS coupler

From early on, efforts might be spent also towards implementing the following modules:

5. LPJ as dynamic vegetation component
6. The green ocean model as ocean biogeochemistry/ecosystems component

Although T106 resolution and 1 degree ocean resolution is aimed at to begin with, even coarser resolution versions should be constructed for efficient testing of the system.
Other modules could be added over time, also depending on possible additional partners' expertise. The envisioned modular structure should enable that different modules exist

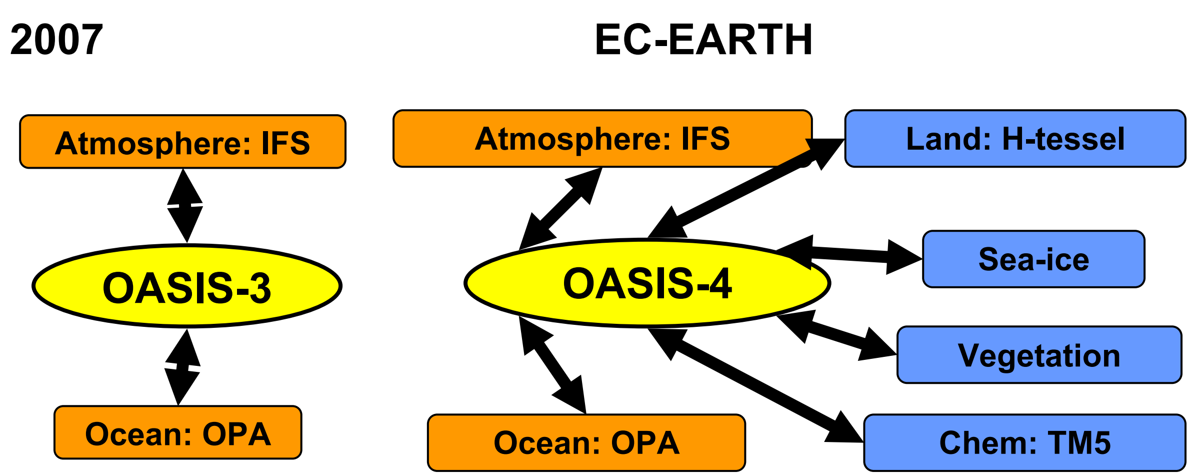

Figure 2: Schematic picture of EC-EARTH, compared to the prototype of ECWMFs System 4 seasonal forecasting system that will be come in use in Summer 2007.

A detailed technical implementation plan is added to this document and we refer to that for more information.

5. EC-earth projects

Member States have formulated plans to use EC-EARTH. In the following we present a short overview of projects.

Belgium
TBD

Denmark
DMI will contribute to EC-EARTH with an additional atmospheric module, the atmospheric Danish Climate Model (A-DKCM), to retain features of a multi-model ensemble of the EC-EARTH. The A-DKCM is developed by combining the dynamical core of IFS and the ECHAM5 physical parameterization package, thus it is computationally as efficient as the IFS. DMI will work on coupling the A-DKCM with other modules in EC-EARTH as specified in section 4.
Projects (2007):

1) Development: DMI will technically couple A-DKCM to NEMO using OASIS, and then test and tune the coupled system (1 fte);
2) Evaluating the influence of different physical parameterizations to model climatology in A-DKCM and IFS;
3) Changes in tropical hurricanes in future climate;
4) Changes in characteristics of ENSO in feature climate.

Future projects:

1) Continuation of system development using A-DKCM following the EC-EARTH framework;
2) To simulate the historical climate changes in the past and to develop the climate change scenarios of the 21st century;
3) To study the influence of sea ice to deep ocean circulation and climate variability.

Ireland
TBD

Italy
In Italy, ISAC-CNR and ICTP will be the main users of EC-EARTH. The EC-EARTH model will be used mainly for understanding climate variability of the past, research on seasonal prediction, and for investigation on future climate scenarios.

Current projects(2006-beginning of 2007):

ISAC-CNR and ICTP are doing pre-studies with their own respective models (the high-resolution model Globo for ISAC and the ICTPAGCM for ICTP).

Future projects (2007-2010):

1. ISAC-CNR will test the physical parameterizations of GLOBO within the IFS model.

2. ISAC-CNR/ICTP research topics
To use ensembles of GCM simulations can provide reliable estimates of the effects of internal vs. external variability in large scale flow properties. ISAC-CNR/ICTP plan to make use of ERA40 re-analysis data and large sets of ensemble simulations with (coupled and forced) GCMs (i.e. the EC-EARTH model, [possibly] GLOBO and the ICTPAGCM) to investigate the following specific topics related to the large scale variability of the atmosphere and the ocean:
- Interannual to decadal Sahel and Indian rainfall variability.
- Decadal variability of the ENSO-monsoon relationship.
- Decadal variability of the NAO and its connection to tropical SSTs.
- Regime behaviour of extratropical flow and its potential changes in climate change scenarios.

3. ICTP could provide and help to couple the ICTPAGCM as an option to the EC-EARTH model.

4. A low-order flux-correction scheme could be tested within the EC-EARTH environment.

5. ICTP will couple the grid-based hydrological model CHYM to EC-EARTH and test the model.

<u>Netherlands</u>
In the Netherlands KNMI will be the main user of EC-EARTH. EC-EARTH will be the Dutch community earth system model that will be used for science and for projections for future climate. In particular the development of biogeochemical components will be done in cooperation with universities. In the following, first ongoing activities are described. In these projects a fully coupled model is not needed yet. Then a more general outlook to future use of EC-EARTH is given.

Current projects (2007):

1) Development: KNMI contributes with 2 fte to development of EC-EARTH. This includes: set up of the IFS model for long runs, assist in development of a coupled ocean-atmosphere model based on ECMWFs System 3, testing new land modules (H-TESSEL and C-TESSEL) and coupling to an atmsospheric chemistry module (TM5).
2) Changes in storm track dynamics in future climate
3) Mechanisms of tropical Atlantic variability.
4) Evaluating new land schemes for EC-EARTH
5) Evaluating cloud feed backs and parameterizations in a global atmospheric model
6) Evaluating the impact of ozone variability in a global atmospheric model

Future projects (2007-2010)

1) Development: assist in setting up
2) Contribute to international model intercomparison projects (e.g. CFMIP for evaluating cloud feedbacks, LUIP for evaluating impact landuse changes on climate).
3) Ensembles of specific future global climate scenario's for downscaling to regional level
4) Testing biogeochemical components for implementing in earth system components.

KNMI will cover expenses of technical support for EC-EARTH at ECMWF for the consortium for a period of 2 years.

Portugal

In Portugal EC-Earth activities will be developed by the Institute of Meteorology (IM) and by the University of Lisbon (IDL-UL). Both institutions are interested in climate change scenarios and its downscaling. IDL-UL, in close collaboration with IM, is also interested in model development, namely in parametrization.

Current projects (2007)

1) Offline simulations with TESSEL and H-TESSEL, for drought characterization in the reanalysis years.
2) Storm tracking in the Atlantic from ERA-40 reanalysis.
3) Iberian upwelling. Simulation with coupled atmosphere ocean regional models.
4) Gravity wave drag. Evaluation of shear effects on surface gwd.

Future projects (2007-2010)

1) Dynamical downscaling of climate scenarios, with emphasis on Iberia and the Atlantic Islands. Impacts on Iberian upwelling.
2) Regional climate ensembling. Evaluating uncertainty in regional forecasts in the current climate. Apply to future climate with different realizations of IFS scenarios.
3) Storm tracking in climate scenarios.
4) Drought characterization in climate scenarios.
5) Cloud and turbulence parametrization in GCMS and mesoscale models.
6) Parametrization of snow in GCMs.

Spain

In Spain, the Climate Research Laboratory (LRC) in Barcelona and the future Catalan Institute for Climate Sciences (IC3) to be created by the end of 2007, will contribute with a full-time senior technician to support development and implementation of EC-EARTH (located in Spain). Fror the year 2008 onwards, the development of EC-EARTH at IC3 can be backed strongly on the new Unit for Modelling and Computational Development specifically created to work on the advancement of

model architecture. LRC/IC3 is within EC-EARTH specifically interested in the task of the portability of the source code to different platforms.
The scientific aspects we are especially interested in are:

- Decadal predictability and climate change experiments with high-resolution over the Mediterranean area. IC3 will have a special interest in regional studies aiming at addressing current and future climate in the Mediterranean region and in this framework we plan at least, to couple a high-resolution ocean model such as OPA/NEMO for this purpose, which we could provide for EC-EARTH.
- Analysis of large-scale phenomena under climate change and its translation to regional climate. This research includes ENSO, Asian and African summer monsoons and sensitivity of the North Atlantic/European climate to certain processes and features
- 3)Seamless prediction with experiments at different temporal scales in the spirit of developing the concept supported by WCRP of the development of forecast systems across a continuous range of time scales.
- 4)Prediction with stochastic physics experiments for climate change studies.

Sweden

In Sweden both the Rossby Centre (SMHI) and the Meteorological Institute at Stockholm University (MISU) have shown interest in the development of a global climate model. Both institutes are leading contributors to a national research proposal that is dedicated to adaptation and mitigation of climate change. One of the cornerstones of the proposal is to obtain a global climate model for providing the boundary conditions for regional climate and impact models.

The Swedish research interests are regionalization of climate change scenarios, the climate of the Arctic, and the interaction between global and regional scales. The contribution to EC-EARTH will be a sea-ice model that can be coupled to IFS through the Oasis coupler. Furthermore, work is in progress with an externalised land surface model for HIRLAM that possibly could be added to EC-EARTH at a later stage.
It is important to have a local version of a global climate model to have full control over the simulations. Thus, we will also contribute to increase the portability of the code to MS computing centres, i.e. Linux clusters.

Switzerland

TBD

6. Project Structure and Time line

The EC-EARTH project is an initiative of a consortium consisting of member states of ECMWF that have a need for a comprehensive earth system model. Currently this includes: Belgium, Denmark, Italy, Ireland, the Netherlands, Portugal, Spain, Sweden and Switzerland. More partners are expected to join. EC-EARTH is being considered as an ECMWF Prediction Application Facility (PAF). As such EC-EARTH will be available to the member states of ECMWF at no cost, the model will not be used for commercial use and data policy of ECMWF will be followed.

Before the PAF will be proposed (anticipated in summer 2007), a Memorandum of Understanding between ECMWF and participating member states will be drafted. Member states will seek funding for development of EC-EARTH. In particular, to find means for stationing an EC-EARTH developer at ECMWF. Until that time, development will be done at the institutes in the member states themselves.

In the first phase of the project (2-3 years), which is described here, the model will be developed and most resources are dedicated to setting up the sysem. However, research will be done in parallel with the development at the cost of the MS.

It is suggested that the project will have a steering committee that contains 1 member of ECMWF and 4 representatives from participating member states. The steering group members will rotate on a 2-yearly basis. The steering group will oversee development of EC-EARTH, review scientific projects and their progress and seek alternative funding for development of EC-EARTH. The terms of reference for the steering committee will be drafted together with the Memorandum of Understanding.

The project will consist of a development and a science project branch. In phase with different stages in development, science projects will be started. Also, at different stages in development demonstration runs will be made.

A tentative time line for EC-EARTH development is roughly as follows:

7-2006 12-2006	*Science & Implementation Plan *(prep)IFS stand-alone *Testing chemistry coupling in IFS
1-2007 6-2007	*Memorandum of Understanding for partners *Couple IFS and slab-ocean to OASIS-3 *Testing IFS-slab ocean *Optimization IFS-slab *Demonstration IFS-chemistry coupling
7-2007 12-2007	*Implementation prototype System 4 *Technical coupling IFS-OPA/NEMO *Implement new sea-ice module *Adjust stripped version of System 4
1-2008 6-2008	*Optimalization IFS-OPA/NEMO-seaice-land (EC-EARTH) *Externalize land module
7-2008 12-2008	*Demonstration EC-EARTH
1-2009 6-2009	*Start climate scenario's with EC-EARTH *Implement biogeochemical modules

PART 2. Technical implementation plan

1. Visionary outline

EC-EARTH is a coupled Earth system model build around IFS as the atmospheric component. Its design follows a modular concept with components for the atmosphere, ocean, etc., interacting through a common coupler. The code is maintained in a repository at ECMWF, but can be ported to different platforms, i.e. to Linux clusters.

2. The first phase in the development of a coupled Earth System Model

- Develop a coupled model, at least atmosphere-ocean coupled with internal treatment of land-surface and sea-ice
- Reduce output, save only monthly means with option for saving 6-hourly instantaneous fields for driving other models (regional models, transport model, etc)
- Perform long runs (decadal and possibly centennial) to test long-term stability and variability
- Port code to different platforms to involve more users and developers.

3. Purpose of this implementation plan

The implementation plan describes the steps that are necessary to transform the current coupled version of IFS to a coupled climate system model. It defines priorities for the different tasks. It also presents a timeline and the distribution of the workload among different partners.

4. EC-EARTH development tasks

Legend:

	done, tested and delivered
	work in progress
	somebody should really take care of this

	Description	Responsible	Delivery date (anticipated)
Coupler	OASIS-4 OASIS-3	ECMWF	Jan 2007
	Easy to configure for new combinations of component models		
	Efficient at run-time		
	Supports so-called interactive ensembles, e.g., several instances of the same atmosphere model coupled to one ocean model forced by the mean fluxes of the atmosphere models.		
Atmosphere	IFS running in climate mode Decadal long simulations	KNMI	Done
	Atmospheric mixed layer model		
	Prescribed meteorology (T2, U10, PRCP) to drive other components (dummy atmosphere)		
Ocean	OPA/NEMO	ECMWF	
	Mixed layer model (slab ocean) configurable for various levels of complexity, e.g. with or without Ekman transport.	KNMI	
	Prescribed SST	KNMI	Done
Sea-ice	Dynamic and thermodynamic sea ice model	SMHI	
	Thermodynamic sea ice model		
	Prescribed sea ice fields	KNMI	Done
Land-surface	IFS land model (HTessel for hydrology, CTessel for hydrology and carbon cycle)	KNMI	
	Land bucket model		
	Prescribed land model (temperatures, moisture, snow)		
Land-ice	Ice-sheets, glaciers		
Chemistry	TM5 coupled off-line	KNMI	
	TM5 coupled on-line	KNMI	
Vegetation	Interactive vegetation?		

	Description	Responsible	Delivery date (anticipated)
Model config	Initial state from observations or from restart files of previous runs New experiments can be started from a restart file to test sensitivities, or to avoid costly spin-ups	ECMWF +KNMI	
	Parameter settings of component models can be exchanged between different configurations. This to support sharing results from tuning experiments.		
	Runs can be stopped and restarted.		
	Results from restarted runs are binary identical to results from continuous runs. This allows rerunning experiments with additional output and aids in solving problems.		
	Results on different platforms are climate-identical. A test experiment and validation data (and tools?) is available.		
Model runs	Decadal and multi-century runs are possible. Post processing of accumulated fluxes needs to be changed.	ECMWF	
	Ensemble runs are possible		
	Hindcast runs are possible		
	IPCC-style scenario integrations are possible		
	Spin-up runs with each component are possible especially with the ocean model.		

	Description	Responsible	Delivery date (anticipated)
	Output is reduced compared to operational model. Reduction is done in the model during the integration. This reduces the total IO load compared to reduction in a post-processing step. Selection of required output variables should be easy. Output directly as monthly means (no post-processing before archiving)		End of 2007
	Output is available for monitoring during the simulation.		
	Basic diagnostics such as global mean quantities are available at time step resolution.		
	Output contains meta data by preference according to NetCDF CF standards.		
	Optional output at 6- or 12-hours intervals to generate boundary conditions for limited area models (e.g. regional climate models)		
Source code repository	Source code can be easily modified and recompiled at the repository		done
	Version management		
	The source code is maintained centrally at ECMWF.		
	The source code is portable to different platforms.	ECMWF+ KNMI+SMHI	
	An initial experiment setup (a complete set of source code, configuration, compile and run scripts plus required data files) can be produced at ECMWF. prepIFS is extended to pack model code and necessary data for initial experiment for easy export ("Export button"). Modifications of the makefiles/scripts may be necessary on the local platform.		

	Description	Responsible	Delivery date (anticipated)
	Support for other platforms than ECMWF supercomputers (e.g. compiler options)		
prepIFS	A portable version of prepIFS is available and can be used to set up experiments outside of ECMWF		
Other	Tools for tuning the model.		
	Automatic distribution of workload		