REQUEST FOR A SPECIAL PROJECT 2015–2017

MEMBER STATE: United Kingdom

Principal Investigator[1]: Prof. Tim Palmer

Affiliation: University of Oxford

Address: Department of Physics,
Atmospheric, Oceanic and Planetary Physics,
Clarendon Lab,
Parks Road
Oxford OX1 3PU

E-mail: t.n.palmer@atm.ox.ac.uk

Other researchers: Miroslaw Andrejczuk, Hannah Christensen, Fenwick Cooper, Stefan Juricke, Dave MacLeod, Peter Watson and Antje Weisheimer.

Project Title: The Impact of Stochastic Parametrisations in Climate Models: EC-EARTH System Development and Application

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)		
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2015-2017: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2017.)	**2015**	**2016**	**2017**
High Performance Computing Facility	9,000,000	9,600,000	9,600,000
Data storage capacity (total archive volume) (gigabytes)	5,000	7,000	9,000

*An electronic copy of this form **must be sent** via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date): 30 June 2014

Continue overleaf

1 The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

Principal Investigator: Prof. Tim Palmer

Project Title: The impact of stochastic parametrizations in the EC-EARTH climate model

Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (500,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

Introduction

Current global climate models achieve closure of the model equations through parametrisation of unresolved sub-grid scale processes. These processes are not fully constrained by the grid scale flow, so conventional parameterisation schemes aim to represent the average effect of these small scale processes on the resolved scale. A parameterisation scheme involves a conceptual representation of the physics involved, and necessarily introduces simplifications and approximations to represent these complex processes. The lack of representation of sub-grid scale variability and the uncertainty due to model approximations means that the parameterisation process is a large source of error in climate simulations.

Stochastic parametrizations in atmospheric models have been used for more than a decade. They provide a way to represent model uncertainty through representing the variability of unresolved sub-grid processes. It has been demonstrated (*Buizza et al. 1999, Palmer et al. 2009*) they have a beneficial effect on a spread and mean state for medium- and extended-range forecasts. Additionally, there is increasing evidence that stochastic parametrisation of unresolved processes is beneficial for the climate of the atmospheric model. There is evidence that including stochastic physics can reduce model biases through noise-induced drift (nonlinear rectification) (*Berner et al. 2008*), and that including stochastic physics enables the climate simulator to explore other flow regimes (*Christensen et al. 2014; Dawson and Palmer 2014*). It is also possible that, through representing the variability of unresolved sub-grid processes, stochastic parametrisation schemes could also improve the internal variability of a model's climate. This is of particular interest as there is evidence that deterministic climate models exhibit too little internal variability, especially in the tropics (*Lin et al. 2006*).

Recently, work on the representation and implementation of stochastic parametrizations in ocean models (*Brankart (2013)*), ocean model forcing in a coupled atmosphere ocean system (*Williams (2012)*) and ocean ice models (*Juricke and Jung (2014)*) has started. *Brankart (2013) and Williams (2012)* show significant impact of stochastic parametrizations on mean climate. *Brankart (2013)* investigated the impact of unresolved variability in salinity and temperature on the equation of state and demonstrated that it has a considerable effect on the mean model state in the areas of intense meso-scale activities. *Williams (2012)* showed that there is a significant impact of stochastic perturbations in air-sea fluxes on mixed layer depth and the variability of ENSO. *Juricke and Jung (2014)* found that stochastic parametrization in a sea ice model behaves differently in coupled and uncoupled systems. In a coupled system, stochastic parametrization led to a redistribution of the thickness of the Arctic sea ice volume, whereas in an uncoupled simulation it led to ice volume increase.

At the University of Oxford, development is currently underway of stochastic parametrizations within the ocean model component of the ECMWF seasonal prediction system (i.e. the NEMO model). The scheme is based on the SPPT approach developed for the atmospheric model by *Buizza et al. (*1999); with the hope to improve reliability of the seasonal prediction. Results obtained so far from simulations with the stochastic parametrization in NEMO model with a different representation of stochastic perturbations indicate that stochastic perturbations strongly affects the spread of the ensemble members and when combined with representation of the uncertainty in initial conditions (observational error) leads to an increase in Brier Skill Score. These experiments are continuing. However, because System 4 cannot be run for more than ~20 years it was not possible to investigate the possible impact of stochastic parametrizations on the mean state of the NEMO model on a longer (climate time-scale) integration. Because the ocean has a longer response time than the atmosphere, the short simulations performed so far may not be enough to see the impact of the stochastic parametrizations on the mean model state.

It is important to represent model uncertainty in other components of the global climate system. For example, recent studies of the summer 2003 heat wave (*Weisheimer et al., 2011*) have shown how seasonal simulations of key climatic extreme events are sensitive to the representation of land surface processes in climate models. From this case study, it would appear that the simulation of this particular extreme seasonal anomaly is more sensitive to uncertainties in land surface processes than oceanic processes. At the University of Oxford, work is underway to represent uncertainty in land surface–atmosphere interactions in System 4. This is part of the EU FP7 project "Seasonal-to-decadal Prediction for the improvement of European Climate Services" (SPECS). Both stochastic and perturbed parameter representations of uncertainty in soil moisture parametrisation schemes have been tested, and preliminary results considering forecasts of the 2003 European summer heat wave are promising. It is desirable to test the impact of this scheme on longer timescales – is an improvement in atmospheric variability observed on implementing this scheme in climate-length integrations?

Objectives

The basis of this proposal is to implement stochastic parametrization in the EC-EARTH climate model and investigate its impact on the modelled climate. Oxford University recently joined the EC-EARTH Consortium. Because the EC-EARTH model is based on System 4, all development done so far at Oxford for System 4 may be implemented within the EC-EARTH system. Once the stochastic parametrizations have been implemented in the EC-EARTH system, the impact of stochastic parametrizations on the coupled model mean state can be investigated.

The longer simulations (~100 years) shall provide an insight into what impacts stochastic parametrization schemes in the ocean, land surface, and atmosphere have on the climate model solution. Note that the EC-EARTH development portal currently reports implementation of the atmospheric stochastic parametrization scheme (SPPT) within this model. The work proposed here will therefore complement the development of the representation of model uncertainty in this climate modelling system. Because our results from seasonal runs indicate a positive impact of stochastic parametrizations in the ocean model and land surface schemes, stochastic parametrization of these processes is also likely to be relevant for longer climate runs.

Proposed Integrations

Stochastic NEMO

With the EC-EARTH model offering 1 deg. and 0.25 deg. resolutions of the NEMO model (only 1 degree for System 4) it will be also possible to compare impact of stochastic parametrization in ocean model for different model configurations. In particular, we wish to assess whether the benefits of high ocean resolution can be emulated at lower resolution with stochastic parametrisation of mixing. Should coupled climate modelling system be too expensive to run such simulations (0.25

deg. NEMO is coupled with T511 and T799, whereas 1 deg. model is coupled with T255 and T159) an offline version of the NEMO model may be used to investigate the impact. Investigation of the effect of stochastic parametrization is especially important because although *Brankard* (2014) demonstrated significant impact of the stochastic parametrizations on the mean model state (in uncoupled setup) for a 2 deg. configuration, our tests with a 1 deg. configuration (also uncoupled) showed much smaller effect of this parametrization on mean model state, because the amplitude of the perturbations had to be significantly lowered to keep the model solution stable.

Stochastic atmosphere and land surface

In addition to the stochastic ocean integrations detailed above, which compare and contrast the effects of the stochastic parametrisation schemes and increased model resolution, it is proposed to perform a series of AMIP style integrations at T255 specifically considering the impact of including stochastic parametrisation of the atmosphere and land surface on the model climate. It is proposed to run an ensemble forecast with three members for 100 years (1950-2050). The results will be compared to a similar ensemble forecast with the stochastic physics schemes turned off. The aspects of climate that we will investigate extend beyond previous studies and will include the frequency of extreme events, time scales of variability, the representation of meteorological events such as blocking, and analysis of regime behaviour.

Stochastic ocean, atmosphere and land surface

Finally, a set of coupled runs will be performed for 150 years (1950-2100) considering the impact on the model climate of using multiple stochastic parametrisation schemes in EC-Earth. The stochastic ocean, atmosphere and land schemes will be implemented at T255 with a 1 deg ocean. How do the different representations of uncertainty interact with each other? Which schemes dominate on shorter, and on longer timescales? Is it sufficient to just use a subset of the schemes for representing model uncertainty in EC-Earth? The extended integrations will allow analysis of the impact of stochastic parametrisation schemes on climate change projections.

Technical Requirements

The estimate of computer resources is based on the cost of running ECMWF seasonal forecasting system (cycle 36R4), which is comparable to the cost of running EC-Earth. These figures were obtained from Antje Weisheimer (ECMWF, Oxford).

For the stochastic ocean runs, the IFS at T159 with 91 vertical levels coupled to NEMO at 1 deg resolution costs approximately 3600 SBU and uses 2.6 GBytes per year of integration. For a 100 year run, the total cost of the experiment would be 360,000 SBU and 260 GBytes. We propose to do 10 stochastic NEMO climate runs (3.6 million SBU) in each of the first and second years and 20 in the third year (7.2 million SBU).

At T255, the proposed AMIP style and coupled EC-Earth runs cost approximately 500,000 SBU per 100 years. We propose to run two three-member ensembles for each type of experiment (7.5 million SBU total). In the first year we will run two AMIP ensemble members and one EC-Earth ensemble member both with and without stochastic parameterisation (3.5 million SBU), and in the second year we will run the third AMIP ensemble member and the second and third coupled ensemble members (4 million SBU).

To account for uncertainty regarding costs of experiments on the new CRAY computer, we have increased these estimates by 20%. The total costs are therefore 9 million SBU in the first year and 9.6 million SBU in years 2 and 3, which also allow units for performing test integrations.

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