REQUEST FOR A SPECIAL PROJECT 2018–2020

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.palner@atm.ox.ac.uk

Other researchers: Dr K Strommen
Dr D MacLeod
Dr S Juricke
Dr H.M. Christensen
Dr A Weisheimer
Dr P Watson

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** GBTPSP_________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2018	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2018-2020: (To make changes to an existing project please submit an amended version of the original form.)		**2018**	**2019**	**2020**
High Performance Computing Facility	(SBU)	13,000,000	11,000,000	13,000,000
Accumulated data storage (total archive volume)[2]	(GB)	6,000	10,000	10,000

***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):

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[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.

[2] If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year.

Principal Investigator: Prof Tim Palmer

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

Extended abstract

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages).

Following submission by the relevant Member State the Special Project requests will be evaluated by ECMWF as well as the Scientific and Technical Advisory Committees. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Large requests asking for 10,000,000 SBUs or more will receive a detailed review by members of the Scientific Advisory Committee.

All accepted project requests 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 subgrid 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. Indeed, recent work (Watson 2017) shows evidence that stochastic physics improves tropical rainfall variability, in particular by improving the frequency of intense rainfall events.

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.

In the special project spgbtpsp preceding this, we successfully implemented new stochastic schemes in all components of the IFS model. In the atmosphere, a modification of the default stochastic scheme SPPT, titled 'ISPPT' (Independent SPPT) was constructed. In SPPT, all the physics tendencies of the model are perturbed with the same factor. In ISPPT, one can choose exactly which combination of tendencies one wants to be perturbed identically or independently, thus allowing for a much more flexible scheme. Initial tests indicate an improved skill at forecasting tropical precipitation (see Christensen 2017). In the land-scheme, a 'perturbed parameter' approach was implemented, and found to improve both forecast reliability, as well as giving an improved forecast of the 2003 European heatwave (MacLeod 2016). In the ocean, several new schemes were developed, adding perturbations to 1) the Gent-McWilliams eddy parametrization, 2) the turbulent kinetic energy vertical mixing scheme and 3) the enhanced diffusion vertical mixing scheme for unstable stratification (see Juricke et al 2017). The new schemes include stochastic perturbations to surface and bottom boundary stresses, horizontal diffusivity and viscosity, a stochastic albedo parametrization for sea ice melt conditions and a perturbation to the ice strength parametrization as part of the sea ice.

The atmosphere and land schemes have been tested in an atmosphere-only configuration of EC-Earth. Coupled testing, including testing of all schemes together, has not so far been possible due to delays in the release of a coupled version of EC-Earth 3.2. Therefore the full impact of having a completely stochastic EC-Earth is still unknown. Preliminary testing of the atmosphere-only runs is underway and indicates significant changes in mean states and variability.

Besides understanding the impact of these new schemes on mean and variability, it is of great interest to understand the impact on regime behavior. Dawson and Palmer (2014) already showed that including stochastic physics can improve the regime structure in the North Atlantic. Christensen (2016) showed that ENSO variability can be greatly improved with stochastic physics, and Strommen (2017) showed an improved Asian monsoon with the introduction of stochastic physics. A better understanding of the ability of stochastic physics to improve such large-scale modes of variability could lead to further improvements and increased skill in forecasting e.g. the NAO or the Asian summer monsoon, both extremely important drivers of local weather, and would potentiall also be of great use in seasonal forecasting.

Objectives

In the first incarnation of this special project, the schemes were successfully implemented and preliminary testing in an atmosphere-only mode of EC-Earth begun, including efforts to tune the strength of the new schemes to allow for realistic energy fluxes. The basis of the continuation of this project is to continue with this testing and evaluation in atmosphere-only runs, and prepare the schemes for coupled simulations. Once EC-Earth 3.2 is ready for coupled climate runs, we will investigate the impact of the schemes in this context, and ultimately prepare an optimal version of EC-Earth 3.2 which has stochastic components in all the components (atmosphere, land, ocean and ice). The impact of this will then be investigated on both the mean state, variability, and climate sensitivity in longer 100 year runs.

In addition, we will aim to investigate the impact of the schemes on various modes of variability, including North Atlantic regime structure, ENSO and the Asian monsoon, where stochastic physics has previously shown itself to be beneficial.

Proposed Integrations

Preliminary Coupled Tuning

Tests in atmosphere-only mode indicate the new schemes, particularly ISPPT, has a big impact on the energy budget of the model. A number of 10-20 year runs (1990-2010) will therefore be carried out in coupled mode to allow the new schemes to be adequately tuned to have a realistic energy budget, based on observational estimates (Trenberth 2009). Tuning will be done relative to the default coupled EC-Earth version 3.2.3, once it is released, and will be based on a resolution of T255 in the atmosphere and a 1 degree NEMO ocean.

Short term climate simulations

Once the schemes have been adequately tuned, we will perform an ensemble of simulations for the different set-ups. For each set-up (default deterministic, default SPPT, ISPPT, stochastic land, stochastic ocean, and a fully stochastic version) 5 simulations will be carried, each 20 years long, starting in the years 1960, 1965, 1970, 1975 and 1980. This will allow us to robustly estimate the fast changes induced by the schemes independently of a particular ocean state and thus estimate the basic impact of the schemes on means, variances. We will also focus our efforts on analyzing the impact on North-Atlantic regime behavior.

Long-term climate simulations

Once the schemes are adequately tuned and we have identified an optimal set-up for the fully stochastic EC-Earth, we will investigate the long-term impact on the mean and climate sensitivity by performing several 100 year simulations (1950-2050) using the Primavera protocol from the Horizon 2020 Project of the same name. This will be done for the default deterministic set-up, a set-up with the default SPPT, and then with our new schemes. In the first instance only one ensemble member will be done for these, and then further members will be added later based on performance.

Technical Requirements

The estimate of computer resources needed is based on the simulations carried out in the previous incarnation of this special project, which ran EC-Earth at T255 resolution on CCA with Intel compilers. Cray compilers have not been tested, but are more efficient and so our estimates with Intel compilers should provide an upper bound.

Running 10 years of EC-Earth in coupled mode at T255 resolution with a 1 degree NEMO ocean, and standard output, costs around 160000 SBUS and produces around 1.4 TB of raw, unprocessed output (assuming output is written at 6 hourly intervals). If only monthly means are kept the total size is around 9 GB, while if a combination of monthly and daily means are kept the total size is around 80 GB. These will be the numbers used for estimates of SBUs and storage space required.

In the first year we will aim to finish coupled tuning and perform the short-term simulations. Doing a 5 ensemble simulation, each member at 20 years, for six different set-ups is estimated to require around 9.6 million SBUs, rounded up to 10 million to allow for extra costs incurred in the event that extra restarts are required due to premature termination. We expect that adequate tuning will require another 100 years of simulation time, adding a 1.6 million additional units. Adding a buffer of 1 million SBUs for potential bug fixing brings our estimate for year 1 to 13 million SBUs.

In the second year we will perform our long term climate simulations. As other institutions will already be performing deterministic simulations of EC-Earth at T255 resolution with a 1 degree NEMO under the Primavera protocol, we will focus on simulations with stochastic physics, namely SPPT, ISPPT, Land-scheme, Ocean scheme and our optimal fully stochastic EC-Earth, i.e. 5 different configurations. This adds up to 500 years of coupled simulation, around 8 million units. Allowing a buffer of 2 million SBUs for a potential second stochastic configuration adds up to 10 million units. In addition, parts of these runs will be done at high frequency output (3 hourly as opposed to 6 hourly), which will increase the cost for these parts. Therefore we have added an extra 1 million SBU buffer to account for this, adding up to 11 million SBUs.

In the third year additional ensemble members will be added to the long climate simulations. We will focus there on runs with regular SPPT and our optimal fully stochastic set-up. Any extra members for these two schemes adds another 3.2 million SBUs. Our aim will be to have 5 ensemble members in total, meaning we will want to add 4 more members for these two schemes, adding up to around 13 million SBUs.

In terms of storage space, the long-term simulations following Primavera protocol will have output stored on a separate, dedicated server. Therefore the requirements for storage at ECFS are estimated based on the short-term ensemble simulations and the need to have a temporary buffer for storing long-term simulation output prior to file transfer.

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