REQUEST FOR A SPECIAL PROJECT 2016–2018

MEMBER STATE: Italy

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Project Title:

Impact of atmospheric stochastic physics in high-resolution climate simulations with EC-Earth

If this is a continuation of an existing project, please state the computer project account assigned previously.		
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2016	
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.)	**2016**	**2017**	**2018**
High Performance Computing Facility (units)	25,000,000	25,000,000	25,000,000
Data storage capacity (total archive volume) (gigabytes)	50,000	50,000	50,000

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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.

Principal Investigator: Dr. Jost von Hardenberg

Project Title: Impact of atmospheric stochastic physics in high-resolution climate simulations with EC-Earth

Extended abstract

Introduction

Modelling climate is currently one of the most computationally challenging problems in science and yet also one of the most urgent problems for the future of society. Thanks to the Intergovernmental Panel on Climate Change (IPCC), there is vast literature on projections of climate change and its most recent assessment shows a large range in the projected global warming, even for identical external forcing. We do not know exactly, and there is no simple way to find out, what proportion of these differences is due to deficiencies in model physics and model resolution, and what part is due to the intrinsic chaotic nature of the coupled climate system.

It is well known that a typical climate model (with a resolution of ~120-km in the atmosphere and ~100-km in the ocean) is unable to represent many subsynoptic-scale systems, and only poorly represents smaller baroclinic features. These models underestimate the number of storms actually observed and poorly simulate the statistics of midlatitude blocking (Jung et al. 2006, Anstey et al. 2013). In fact it has been shown (e.g. van Oldenborgh et al. 2012) that at this low, climate resolution, forecasts systems have pervasive systematic errors which impact both on the mean state of the system and on the (mis)representation of the non-Gaussian probability distribution associated with the climatology of quasi-persistent weather regimes (Dawson et al. 2012). In this latter study it is shown that a low-resolution atmospheric model at T159 (~125km) is not capable of simulating the statistically significant regimes seen in reanalysis, yet a higher resolution configuration of the same model at T1279 (~16km), simulates regimes realistically.

The existence of such regimes (Molteni et al. 2006, Straus et al. 2007) has wider implications in the climate system. There is evidence that in a dynamical system with regime structure, the time-mean response of the system to some imposed forcing, (which here could be thought of as enhanced greenhouse gas concentration), is in part determined by the change in frequency of occurrence of the naturally occurring regimes (Palmer 1999; Corti et al. 1999). As such, a model, which fails to simulate observed regime structures well, could qualitatively fail to simulate the correct response to this imposed forcing.

Whilst few would doubt the desirability of being able to integrate climate models at such a high resolution (i.e. at the resolution used in operational numerical weather prediction (NWP)), there are numerous other areas of climate model development which compete for the given computing resources: for example, the need for ensembles of integrations, to integrate over century and longer time-scales and the need to incorporate additional Earth System complexity. Instead of explicitly resolving small-scale processes by increasing the resolution of climate models, a computationally cheaper alternative is to use stochastic parameterisation schemes. These schemes introduce an element of randomness into physical parameterisation schemes to account for the impact of unresolved processes on the resolved scale flow.

The motivation for including stochastic approaches in our current generation of weather and climate models is two-fold, and is clearly set out in a recent essay by Palmer (2012). Firstly, deterministic parameterisations in sophisticated weather and climate models are inconsistent with the implications of the scaling symmetries in the Navier-Stokes equations, and with the observed power-law behaviour in the atmosphere. This prevents a meaningful separation between resolved and unresolved scales, as is assumed possible in deterministic parameterisation. One important consequence of the power-law structure in the atmosphere is the upscale propagation of errors, whereby errors at very small scales (only resolved in high horizontal resolution models) can grow and ultimately contaminate the accuracy of larger scales in a finite time. A stochastic scheme includes a statistical representation of the small scales, so it is able to represent this process. The second motivation for stochastic parameterisations is that they provide a skilful estimate of model uncertainty due to truncation of the model equations, which is necessary for producing reliable forecasts (Berner et al, 2009; Weisheimer et al, 2011).

There is mounting evidence that stochastic parameterisations prove beneficial for climate simulations (e.g., Lin and Neelin 2000, 2003; Arnold et al. 2013). In two recent papers (Weisheimer et al. 2014, Dawson and Palmer 2014) it has been indeed demonstrated that the simulation of regimes can be significantly improved, even at modest model resolution, by the introduction of a stochastic physics scheme. These results highlight the importance of small-scale processes on large-scale climate variability, and indicate that although simulating variability at small scales is a necessity, it may not be necessary to represent the small-scales accurately, or even explicitly, in order to improve the simulation of large-scale climate.

In the light of the above considerations, this proposal aims to investigate the sensitivity of climate simulations to model resolution and atmospheric stochastic parameterisations, and to determine if higher resolution is useful to facilitate the simulation of the main features of climate variability, including weather regimes. We will use the EC-Earth climate model (Hazeleger et al. 2010, 2012, http://www.ec-earth.org), a state-of-the-art climate model, developed by a large consortium of European institutions, which participated in the recent CMIP5 effort.

Objectives

In this special project we plan to explore the impact of Stochastic Physics (in the atmosphere) in long climate integrations as a function both of model resolution and in coupled and uncoupled configurations. In a first stage the experiments will be a historical and one scenario projection following CMIP5 specifications. These will be followed (in the second and third year of the project) by similar simulations using the new specifications (not yet settled at the time of writing) for CMIP6.

The hindcast simulations will allow us to evaluate if there is sensible improvement in the model climate due to stochastic parameterizations. The future scenarios will allow us to answer another question: what is the expected impact of stochastic parameterizations on future scenarios, under a different anthropogenic forcing? In fact, as discussed in Matsueda and Palmer 2011, the relation between bias in historical simulations and climate change signal may not be a simple linear one. Regional climate change signals in a future projection can be very different between a simulation run at typical climate resolution and one run at high NWP resolution.

Atmospheric stochastic parameterizations have not been tested extensively, up to now, for long climate runs. Particular attention will be placed to the tuning of the model using the SPPT atmospheric stochastic parameterization for climatic applications, with the goal of reaching a realistic representation of the main radiative fluxes and conservation of energy and humidity in the atmosphere. To this end we will perform series of coupled and uncoupled AMIP runs both at standard (T255L91) and higher (T511L91) resolutions.

The results of this project will integrate with the results of the PRACE project Climate-SPHINX, currently running, which is exploring the role of stochastic parameterizations in extreme resolution climate simulations (up to T1279L91) over timeslices, in AMIP mode, with EC-Earth.

Workplan

This study will use the latest version of the EC-Earth model, currently under test and due to be released end of June 2015, EC-Earth v 3.2beta. This version of EC-Earth will be based on IFS cy36r4 for the atmosphere, NEMO 3.6 for the ocean and LIM 3 for sea ice.

EC-Earth 3 has already been implemented and tested by the consortium on CCA.

A preliminary part of the study will be devoted to a series of AMIP and coupled model runs over short periods (typically 5, up to 10 years) aimed at tuning the model in climate mode. In particular the conservation properties in terms of energy, momentum and of water vapor mass of the SPPT scheme will be explored. Preliminary tests currently underway have revealed that this aspect, which is crucial for the radiative balance in long climate integrations, may need to be corrected.

Another aspect which will be taken into account is to update the parameterization of gravity wave drag in EC-Earth, which has currently been developed and tested mainly at the lower resolution T255L91. Preliminary tests have shown that the with the current parameterization the model is not able to reproduce a realistic QBO at higher resolutions, In particular we plan to update and test a scheme similar to that currently in use in the operational IFS model.

After this tuning phase we will perform two sets of experiments:

- **AMIP** experiments: Atmospheric only integrations forced with observed (for the past) and simulated (for the future) sea surface temperatures.
- **Fully coupled** experiments: Experiments carried out including all the Earth-System components, namely Atmosphere, Ocean and Sea-Ice.

The AMIP experiments will be carried out at two different resolutions: standard (T255L91, ~80 km) and high-resolution (T511L91, ~40 km). Coupled experiments will be performed with NEMO in ORCA1 (1 degree) configuration. Each experiment integration will be repeated with the implementation of the stochastic physics in the atmospheric component.

By comparing integrations carried out at different resolutions we will estimate the impact of the increased atmospheric and oceanic horizontal resolution on the simulation of key climate processes and climate variability over multi-decadal timescales.

By comparing experiments with and without the implementation of stochastic physics we will estimate the impact of stochastic physics on the simulation of key climate process and associated climate variability when the model resolution is the same.

By comparing experiments with the implementation of stochastic physics with experiments carried out without stochastic physics, but at higher resolutions, we will assess to what extent the stochastic representation of the sub-grid processes can compare with the explicit representation of them.

The coupled experiments will be carried out at T255L91 resolution, over the standard CMIP5 historical period (1850-2005) and over future scenarios (RCP 4.5, RCP 8.5, 2005-2100).

In the second and third year of the project these experiments will be repeated using the upcoming CMIP6 specifications over the same periods.

Experience with tuning runs in 2013-2014 has shown that at least 500 years are needed to reach approximately statistically stationary conditions under constant forcing conditions, particularly for the equilibration of ocean temperatures. The CMIP6 experiments will require a 500 year-long spinup run, followed by 100 years of pre-industrial control (once with stochastic physics and once without). An existing spinup will be used for CMIP5 runs.

The uncoupled experiments will be performed over the period 1950-2100 using HadiSST v2 SST and sea-ice data as boundary conditions.

Five ensemble members will be produced for uncoupled T255L91 realizations and all experiments will be performed with and without stochastic physics.

Justification of resources/Technical requirements

We estimate that preliminary tuning tests will require about 100 years of integration (10 tests of 5 years each with and without stochastic physics) at each of the two resolutions considered, in AMIP mode.

The total number of coupled integrations (at T255L91) will be 345 years (historical period + 2 scenarios) * (sppt yes/no) = 690 years. The experiments will be performed for CMIP5 and CMIP6 configurations. To these we have to add 700 years for the spinups of the CMIP6 runs. That gives a total of 2080 years.

Uncoupled runs will cover 150 years * 5 ensemble members * (sppt yes/no) = 1500 years at T255L91 and 150 years * (sppt yes/no)=300 years at T511L91.

Scaling tests performed on cca (in the framework of the SPNLTUNE project) have determined that in its current configuration EC-Earth is consuming 10500 SBU/year in AMIP (atmosphere only) mode and 13500 SBU/year at T255L91. At T511L91 this figure grows to 75000 SBU (uncoupled) and to 85000 (coupled).

Following these figures we reach the following requirements:

- Tuning runs: 1,050,000 SBU for the T255L91 tuning and 7,500,000 for the T511L91 preliminary tuning of the stochastic physics.
- uncoupled runs: 15,750,000 SBU (T255L91) and 22,500,000 SBU (T511L91)
- coupled scenario runs: 28,080,000 SBU

The total requirement will be 74,880,000 SBU over three years

Storage requirements are around 26 GB/model-year, assuming 6-hourly output storage and storage of monthly means for NEMO (suitable for testing and tuning purposes). This figure would increase to about 50 GB/model year if 3-hourly output (CMIP5 specs.) are included.

References

Anstey, J. A., P. Davini, L. J. Gray, et al. (2013), J. Geophys. Res. Atmos., 118, 3956–3971

Arnold, H. M., I. M. Moroz, and T. N. Palmer (2013), Philos. T. Roy. Soc. A, 371

Artale, V., P.. Ruti, G. Sannino, E. Palazzi, A. Provenzale, J. von Hardenberg. CASPUR Annual Report, 49-52, 2012

Balsamo G., P. Viterbo, A. Beljaars, et al. (2008). ECMWF Tech. Memo. 563.

Berner, J., G.J. Shutts, M. Leutbecher and T.N. Palmer (2009) J. Atmos. Sci., 66, 603-626.

Ciccarelli, N., J. von Hardenberg, A. Provenzale, et al. (2008) Global and Planetary Change, 63, 185-195

Corti, S., F. Molteni, and T. N. Palmer (1999) Nature, 398, 799–802, doi:10.1038/19745.

Dawson, A. and T. N. Palmer (2014), Climate Dyn. doi:10.1007/s00382-014-2238-x

Dawson, A., T. N. Palmer, and S. Corti (2012) Geophys. Res. Lett., 39, L21805, doi:10.1029/2012GL053284.

Fichefet T and MA Morales Maqueda (1997) J. Geophys Res 102:12609-12646

von Hardenberg, J., Vozella, et al. (2012) Atm. Chem. and Phys., 12(15), 6953–6967

von Hardenberg J., A.Parodi, G. Passoni, A. Provenzale, E.A Spiegel (2008) Physics Letters A, 372, 2223-2229

Hawkins E. and Vidale P. L. (2012) Nature Climate Change, 2, 574–575 doi:10.1038/nclimate1639

Hazeleger, W., X. Wang, C. Severijns, et al. (2012). Climate Dyn., 39, 2611-2629, doi:10.1007/s00382-011-1228-5.

Hazeleger, W. et al., 2010, 91, (2010), Bull Amer Meteor Soc 91: 1357-1363.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp

Jung, T, S. K. Gulev, I. Rudeva and V. Soloviov (2006) Q. J. R. Meteor. Soc. 132, 1839-1857

Kinter, J. L., III, B. Cash, D. Achuthavarier, J. Adams, et al. (2013) B. Am. Meteorol. Soc., 94, 231–245, doi:10.1175/BAMS-D-11-00043.1.

Lin, J. W.-B., and J. D. Neelin (2000) Geophys. Res. Let., 27, 3691–3694.

Lin, J. W.-B., and J. D. Neelin (2003) Geophys. Res. 894 Let., 30, 1163.

Madec G (2008) NEMO ocean engine. Note du Pole de modelisation, Institut Pierre- Simon Laplace (IPSL), France, No 27 ISSN No 1288-1619

Matsueda M. and T.N. Palmer (2011) Geophys Res Let, 38 (5), doi: 10.1029/2010GL046618

F. Molteni, F. Kucharski and S. Corti, 2006 In: "Predictability of Weather and Climate", T. Palmer and R. Hagedorn, Eds., Cambridge University Press, Cambridge.

van Oldenborgh, G. J., F. J. Doblas-Reyes, B. Wouters and W. Hazeleger, (2012) Climate Dyn., 38, 1263-1280, doi:10.1007/s00382-012-1313-4.

Palmer, T. N. (1999) J. Climate, 12, 575–591

Palmer, T. N. (2012) Q. J. Roy. Meteor. Soc., 138, 841–661

Palmer, T. N., F.J. Doblas-Reyes, F. J., A. Weisheimer, and M.J. Rodwell (2008) Bull. Amer. Meteorol. Soc., 89, 459-470

Palazzi, E., von Hardenberg, J., Provenzale, A., (2013) J. of Geophys. Res. – Atm., 118(1), 85–100

Straus, D. M., S. Corti, and F. Molteni, (2007) J. Climate 20, 2251–2272

Weisheimer, A., S. Corti, T.N. Palmer and F. Vitart, (2014) Philos. T. Roy. Soc. A 372 2018 20130391

Weisheimer, A., T.N. Palmer and F. Doblas-Reyes, (2011) Geophys. Res. Lett., 38, L16703