REQUEST FOR A SPECIAL PROJECT 2017–2019

MEMBER STATE: Netherlands

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Project Title: EC-Earth high resolution simulations

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.)	2017	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2013-2015: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2015.)	**2017**	**2018**	**2019**
High Performance Computing Facility (units)	50,000,000	50,000,000	50,000,000
Data storage capacity (total archive volume) (gigabytes)	190,000	240,000	240,000

*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): 22 June 2016

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.

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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.

In this special project we will perform simulations with the high resolution versions of EC-Earth_v3.2. Targeted runs as outlined in the HighResMIP protocol will be performed with T511/ORCA025. They will add to the HighResMIP simulations done within the European H2020 PRIMAVERA project. In addition we will perform simulations at T1279/ORCA0125. At this resolution small scale atmospheric and oceanic phenomena, like tropical cyclones, air-sea interaction over SST fronts, and deepwater formation are expected to be significantly better simulated. This enables a better understanding of the physical mechanisms and will be beneficial for the quality of the climate simulations and seasonal to decadal forecasts. Analysis of the runs will be done in collaboration with the other partners of PRIMAVERA and EC-Earth.

Motivation

The High Resolution Model Intercomparison Project (HighResMIP) applies, for the first time, a multimodel approach to the systematic investigation of the impact of horizontal resolution. A coordinated set of experiments has been designed to assess both standard and an enhanced horizontal resolution simulation in the atmosphere and ocean. The set of HighResMIP experiments is divided into three tiers consisting of atmosphere only and coupled runs and spanning the period 1950-2050, with the possibility to extend to 2100, together with some additional targeted experiments. The protocol is outlined in Haarsma et al. 2016. It describes the experimental set-up of HighResMIP, the analysis plan, the connection with the other CMIP6 endorsed MIPs, as well as the DECK and CMIP6 historical simulation. HighResMIP thereby focuses on one of the CMIP6 broad questions: "what are the origins and consequences of systematic model biases?". Up to now 19 modeling centers have indicated to participate in HighResMIP.

In the European project PRIMAVERA project 7 modeling centers (MetOffice, EC-Earth, CEFACS, MPG, AWI, CMCC, ECMWF) will be the first to perform those runs according to the HighResMIP protocol. In HighResMIP, in addition to the three tiers, a number of targeted experiments and the extension to 2100 are part of the protocol. These additional simulations are not performed within PRIMAVERA, to limit the computational burden, but are of great scientific value. We therefore want to use the ECMWF HPC facilities to extend the planned PRIMAVERA simulations, that fit within the HighResMIP protocol.

For the T511/ORCA025 resolution that will be used for the PRIMAVERA, small scale atmospheric phenomena are still marginally resolved and the ocean is only eddy permitting and not eddy resolving. We therefore want to perform additional simulations with the T1279/ORCA0125 resolution in which these phenomena are much better resolved. Coupled runs at this resolution (atmosphere ~15 km and ocean 1/12°) are much higher than planned in PRIMAVERA and HighResMIP (atmosphere ~50 km and ocean 1/4°) and internationally at the forefront. These simulations will have therefore a large amount of added value compared to the other simulations and of great scientific interest.

Of the many phenomena that will likely significantly to be affected by the increase from T511/ORCA025 to T1279/ORCA0125 we will focus initially on:

- *Simulation of tropical cyclones and their transition to extra-tropical storms.* Simulations with SST forced simulations at even T799 revealed that the intensity of hurricanes is still underestimated and even higher resolution is necessary (Haarsma et al. 2013). With these higher resolution simulations we can also further test the hypothesis forward in Haarsma et al. (2013) that extra-tropical storms with tropical origin might reach Europe with hurricane force because that hypothesis depends crucially on the correct simulation of hurricanes.

- *Air-sea interaction over western boundary currents such as the Gulfstream.* Sharp SST fronts have a significant impact on precipitation, deep convection and storm development (Minobe et al. 2008, Small et al. 2014, Scher et al. 2016a, Scher et al. 2016b). Comparison with observations suggests that even higher resolution of EC-Earth T799 is necessary for a correct simulation of precipitation and deep convection over these sharp SST-fronts. This will also affect large scale atmospheric dynamics such as position, strength and variability of storm tracks and blockings affecting the climate over remote regions such as Europe (Small et al. 2014, Schiemann et al. 2016).

- *Dynamics of the Meridional Overturning Circulation (MOC).*

One of the fundamental drivers of climate variability is the MOC, which is associated with deep-convection in the Nordic seas. This deep convection occurs at small scales. An important research question is the impact of increasing resolution on the MOC, in particular the response of the MOC to global warming. Because of the change from eddy permitting (ORCA025) to eddy resolving (ORCA0125) significant changes in deep convection and the dynamics of the MOC are expected. Changes in MOC dynamics will have large impact on Artic processes and Europe, but also outside these regions there will be significant effects.

An example of such effect is the warming hole in the North Atlantic caused by the weakening of the MOC. This will induce an anomalous high over the eastern North Atlantic and the United Kingdom in spring and summer (Haarsma et al. 2015). Comparison of EC-Earth SST forced simulation at T159 and T799 suggests that this anomalous high increases with resolution, thereby enhancing the possibility of summer droughts in a future climate (Van Haren 2015). The impact of resolution is supported by comparison with the ERA 20C reanalysis data set suggesting that CMIP5 models underestimate the amplitude of the anomalous high (Haarsma et al. 2015).

In the analysis of these runs we will focus on these 3 above mentioned topics because they fall within our recent research activities and have a large relevance for the Netherlands and Europe, but as stated before the impact of these runs is much larger. In the PRIMAVERA proposal a wide range of research topics is outlined. Those have overlap with the ones outlined above, but cover a much larger range such as for instance Arctic processes.

The runs will be performed following the HighResMIP protocol (Haarsma et al. 2016) and the data will be stored on the JASMIN server in the UK. This is also where the data of the PRIMAVERA runs will be stored. The runs will be jointly analysed by the PRIMAVERA partners for the wide range of topics as defined in the project proposal. The common protocol and the coordinated data processing and storage on the JASMIN server will enable a joint multi model analyses. The EC-Earth runs of this proposal will thus become part of this multi model analyses, enabling the investigation by many researchers. In addition institutes and researchers outside PRIMAVERA have communicated to the Climate Dynamics panel of CLIVAR their interest in analysing the PRIMAVERA runs.

Both configurations T512/ORCA025 and T1279/ORCA0125 are also used by the Barcelona Super Computing Center for seasonal to decadal forecasts. This institute also participates in PRIMAVERA and it is expected that the joint analysis will be beneficiary for the progress in seasonal to decadal forecasts.

Model configuration

The modelling systems used in this special project will be the CMIP6 high resolution version of EC-Earth, T511ORCA0.25 and the very high resolution version T1279ORCA0125. EC-Earth is a global climate model

developed by a European consortium of climate research institutes (Hazeleger et al., 2010; 2011). EC-Earth 3, the latest version of the model, consists of an atmospheric circulation model based on ECMWF's Integrated Forecasting System (IFS) cycle 36r4, the NEMO3.6 ocean model, which also includes the LIM3 sea ice model.

Workplan and simulations

Targeted simulations with T511/ORCA025.

Apart from the three Tiers in the HighResMIP protocol (Tier 1:AMIP 1950-2014; Tier 2: Coupled 1950-2050; Tier 3: AMIP 2014-2050(2100)), there are a number of additional targeted experiments. Because the end date of Tier 2 and 3 simulations is 2050, with a moderate CO_2 forcing, doubling and quadrupling CO_2 forcing experiments are added as targeted simulations to investigate the model response to strong CO_2 forcing. These are of great scientific value, for instance to investigate the response of the Atlantic Meridional Overturning (AMOC) and the response of tropical cyclones. These runs can be of limited length, in the order 25 years, to obtain useful results (Kuhlbrodt et al., 2015). In addition to the doubling and quadrupling we want to extend the Tier 2 coupled simulations to 2100 to compare with the standard scenario runs.
According to our most recent tests, one year of coupled simulation for T511/ORCA025 requires 200.000 units, with a throughput of 2.3 years per day on 1080 cores. The simulations will produce 1.2 TB/year in grib format for the T511ORCA0.25 resolution and the CMIP6 requested output tables. The CMORIZED data will be stored at the JASMIN server and be used by the entire PRIMAVERA community for analysis, ensuring maximum use of the data.

Simulations with T1279/ORCA0125

The coupled T1279/ORCA0125 version does not exist yet. Simulations with this resolution are not expected before 2018. Testing will start in 2017. We plan to perform two runs of 50 years, on control and one transient. The control will be done in 2018 and the transient run in 2019. The exact design of these simulations will depend on analyses and experiences in PRIMAVERA. We expect these simulations to be about a factor of 4-5 more costly in billing units than the T511/ORCA025 simulations. These numbers are based on preliminary tests on the EC-Earth group at Barcelona Super Computing Center. This would imply 1 million units for one year simulation. The development and testing of the T1279/ORCA0125 will be done in close collaboration with the other EC-Earth partners. To limit the output a selection of the CMIP6 output will be stored. Experience within PRIMAVERA will guide us in the selection. As for the T511/ORCA025 the data will be CMORIZED and stored on JASMIN for analysis by the PRIMAVERA partners.

In a recent ECMWF technical memorandum 799, by S. Boussetta, C. Simarro and D. Lucas (http://www.ecmwf.int/en/elibrary/16377-exploring-ec-earth-32-beta-performance-new-ecmwf-cray-broadwell) assessed the performance of the new release of the EC-Earth coupled system is assessed and shows that, in general the use of the Cray compiler can result in an increase in the system performance up to 34%. This promising result is a strong incentive to run the high resolutions of the EC-Earth coupled system with that compiler at the ECMWF.

In table 1 are outlined the planned simulations, together with the simulation length, data storage and billing units. The columns indicate the years in which the various simulations are expected to be carried out.

Table 1. Planned coupled atmosphere-ocean simulations

	2017	2018	2019
Extension Tier 2: 2051-2100 (50 year control and 50 year transient) with T511ORCA025	100 yrs 120 Tb 20.000.000 units	-	-
Testing with T1279ORCA0125	20 years 20.000.000 units 10 TB	-	-
100 years simulation T1279ORCA0125 (50 years control and 50 years transient)	-	50 yrs 240Tb 50.000.000 units	50 yrs 240Tb 50.000.000 units
Doubling and quadrupling of CO2 with T511ORCA025	50 yrs 60 TB 10.000.000 units	-	-
Estimated total	50.000.000 units 190 TB	50.000.000 units 240 TB	50.000.000 units 240 TB

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