

REQUEST FOR A SPECIAL PROJECT 2016–2018

MEMBER STATE: Ireland

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Project Title:
High Resolution EC-Earth Simulations

If this is a continuation of an existing project, please state the computer project account assigned previously.	SP _____	
Starting year: <small>(Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)</small>	2016	
Would you accept support for 1 year only, if necessary?	YES <input checked="" type="checkbox"/>	NO <input type="checkbox"/>

Computer resources required for 2016-2018: <small>(The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2018.)</small>	2016	2017	2018
High Performance Computing Facility (units)	14,000,000	16,000,000	16,000,000
Data storage capacity (total archive volume) (gigabytes)	22,000	22,000	22,000

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 2015

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.

1. Scientific Background

The aims of the proposed project are two-fold;

- i. to assess the improvements of the EC-Earth global coupled climate model in the representation of important climate processes with high-resolution global model resolutions (~39km) and
- ii. to contribute to the preparation and running of the EC-Earth CMIP6 experiments.

Recent simulations with global high-resolution climate models have demonstrated the added value of enhanced resolution compared to the output from models in the Climate Model Intercomparison Project Phase 3 (CMIP3) and CMIP5 archive. The simulations showed significant improvement in the simulation of aspects of the large scale circulation such as El Niño Southern Oscillation (ENSO) (Shaffrey et al 2009), Tropical Instability Waves (Roberts et al 2009), the Gulf Stream and its influence on the atmosphere (Chassignet and Marshall 2008; Kuwano-Yoshida et al 2010), the global water cycle (Demory et al. 2014), extra-tropical cyclones and storm tracks (Hodges et al. 2011) and Euro-Atlantic blocking (Jung et al 2012). In addition, the increased resolution enables more realistic simulation of small scale phenomena with potentially severe impacts such as tropical cyclones (Zhao et al. 2009), tropical-extratropical interactions (Haarsma et al. 2013) and polar lows. The improved simulation of climate also results in better representation of extreme events such as heat waves, droughts and floods (CMIP, 2015).

The proposed project will focus, in particular, on the impact on increased model resolution on the accuracy of simulated extreme weather events and North Atlantic cyclone activity. In addition, the impact of climate change on European extreme weather events and North Atlantic cyclones will be assessed.

Studies have shown that, even at 50-km grid spacing, GCMs severely under-resolve tropical cyclones, resulting in a substantial truncation of the intensity spectrum of simulated storms (Zhao et al. 2009), and usually produces fewer events than observed (Camargo, 2013). The ability of CMIP5 models to simulate North Atlantic extratropical cyclones was assessed by Zappa et al. (2013i). The authors found that “systematic biases affect the number and intensity of North Atlantic cyclones in CMIP5 models. In DJF, the North Atlantic storm track tends to be either too zonal or displaced southward, thus leading to too few and weak cyclones over the Norwegian Sea and too many cyclones in central Europe. In JJA, the position of the North Atlantic storm track is generally well captured but some CMIP5 models underestimate the total number of cyclones”. Despite these biases, the representation of Northern Hemisphere (NH) storm tracks has improved since CMIP3

and some CMIP5 models are capable of realistically representing both the number and the intensity of North Atlantic cyclones. In particular, some of the high resolution atmospheric models tend to have a better representation of the vertical tilt of the North Atlantic storm track and of the intensity of cyclones in DJF. This improvement in skill is expected to continue with the higher resolution CMIP6 simulations.

Feser et al. (2014) conducted a review of studies of storms over the North Atlantic and northwestern Europe regarding the occurrence of potential long-term trends. Storm trends derived from reanalyses data and climate model data for the past were mostly limited to the last four to six decades. They found that “the majority of these studies find increasing storm activity north of about 55–60°N over the North Atlantic with a negative tendency southward”. Furthermore, “future scenarios until about the year 2100 indicate mostly an increase in winter storm intensity over the North Atlantic and western Europe. However, future trends in total storm numbers are quite heterogeneous and depend on the model generation used”. Zappa et al. (2013ii) analysed a CMIP5 ensemble of 19 GCMs and found a small, but significant, increase in the number and intensity of winter cyclones associated with strong wind speeds over the United Kingdom by the end of the century. A recent study with a very high resolution version of the EC-Earth model (Haarsma, et al., 2013) suggests an increase in the frequency of extreme wind storms affecting Western Europe in future autumn seasons due to climate change.

Sillmann et al. (2013) assessed the performance CMIP5 GCMs in simulating climate extremes indices defined by the Expert Team on Climate Change Detection and Indices (ETCCDI), and compares it to that in the previous model generation (CMIP3). They found that “for the precipitation indices, the intermodel uncertainty in the CMIP3 and CMIP5 ensembles is comparable, but the CMIP5 models tend to simulate more intense precipitation and fewer consecutive wet days than the CMIP3 models, and thus are closer to the observations”. This improvement is partly attributed to the generally higher spatial resolution of CMIP5 models compared to CMIP3 (the effect of increasing resolution on precipitation extremes has been discussed, for instance, in Wehner et al. [2010]). Results indicate that for the temperature indices, the performance of the CMIP3 and CMIP5 multimodel ensembles is similar in regard to their ensemble mean and median, but that the spread amongst CMIP3 models tends to be larger than amongst CMIP5 models despite the larger number of models in the CMIP5 ensemble (Sillmann et al. 2013).

CMIP6 is the 6th coupled model intercomparison project in which EC-Earth will participate. A novel aspect of CMIP6 is that the work will now be separated into two elements: 1) to run a small set of standardized experiments, and 2) to provide standardization, coordination, infrastructure as well as documentation functions that allow the simulations to be made available to the broader community (Meehl et al., 2014). EC-Earth participated in CMIP5 with EC-Earth V2.3 and will do so in CMIP6 with a model that includes biogeochemical cycles and atmospheric chemistry.

EC-Earth is a global coupled climate model, which integrates a number of component models in order to simulate the earth system. It is developed by a consortium of European research institutions. The goal of EC-Earth is to build a fully coupled Atmosphere-Ocean-Land-Biosphere model, usable from seasonal to decadal climate prediction and climate projections (Hazeleger et al. 2010; 2011). The atmospheric component of EC-Earth is based on the Integrated Forecasting System (IFS) which is developed at the European Centre for Medium-Range Weather Forecasts (ECMWF). The ocean component is based on Nucleus for European Modelling of the Ocean (NEMO) which is a global ocean circulation model. As part of the EC-Earth consortium, researchers at Met Éireann have implemented the EC-Earth model on various supercomputer platforms and have contributed to CMIP5 experiments, which formed an essential part of the IPCC Fifth Assessment Report (AR5).

EC-Earth v3.2beta is currently being tested by the EC-Earth community. This version is based on a newer cycle of the ECMWF IFS atmospheric model (c36r4), the NEMO ocean model (v3.6), the LIM3 sea ice model, TM5 atmospheric model, LPJ-GUESS vegetation model and the PISCES ocean biogeochemistry model. Coupling is provided by OASIS3-MCT. This model is currently being optimized for a standard horizontal resolution of T255 and 91 vertical layers for the atmosphere, and for 1 degree and 46 layers for the ocean. In addition, high-resolution configurations of this version are currently being tested (0.25 degrees in the ocean and T511 and T799 in the atmosphere). Jung et al. (2012) and Kinter et al. (2013) found significant improvements in the simulation of many atmospheric features such as the prediction of tropical precipitation and the frequency/intensity of both tropical and mid-latitude cyclones in high-resolution IFS-only (atmospheric component of EC-Earth) simulations.

It is envisaged that the proposed EC-Earth CMIP6 simulations will provide sharper and more accurate projections of the future global climate and lead to a better understanding, not only of the physical climate system, but also of the climate impact on societies. The high-resolution simulations will allow for an assessment of the impact of resolution on the accuracy of climate modelling. In addition, the proposed EC-Earth simulations will be used as a basis for more-focused climate impact studies such as regional downscaling (e.g., boundary conditions provided to CORDEX).

2. Work Plan

The activities in the period 2016-2018, using computing resources from this Special Project, will aim mainly at:

Experiment 1: Scaling experiments of EC-Earth

EC-Earth v3.2 will be implemented and scale-tested to determine the optimal number of CPUs to use for the proposed simulations. In addition, the optimal sharing strategy of CPUs between EC-Earth components (IFS, NEMO etc.) will be investigated. The scaling experiment will be run for the following EC-Earth standard configurations; T255-ORCA1L46, T511-ORCA025L75 and T799-ORCA025L75. The simulations will be run for a period of one-month with both a varying number of CPUs and different sharing schemes of CPUs between the EC-Earth components. This will result in approximately 120 month long simulations (3 EC-Earth configurations × 10 scaling experiments × 4 CPU sharing strategy experiments). The simulations will be profiled in order to highlight and fix potential bottlenecks. The results will be shared with the EC-Earth community. For experiment 1, storage requirements will be kept to a minimum as the model output will be deleted on completion of the scaling experiments. Experiment 1 will be complete within 1 to 2 months.

Experiment 2: EC-Earth (T255-ORCA1L46) CMIP6 Contributions

Met Éireann will commit to running the following EC-Earth T255-ORCA1L46 AOGCM CMIP6 Contributions:

- 5 CMIP6 Historical Simulations, 1850-2014 (approximately 825 years)
- 5 CMIP6 ScenarioMIP-4 SSP3_70 Simulations 2015-2100 (430 years)

“SSP-based RCPs” are new versions of the Representative Concentration Pathways (RCPs) that are based on the Shared Socioeconomic Pathways (SSPs; O’Neill et al., 2014; van Vuuren et al., 2014) and new Integrated Assessment Modeling (IAM) model simulations derived from them. The SSPs are five (SSP1-5) new societal development pathways that have been developed to provide descriptions of future societal conditions that serve as the basis, both for deriving forcing pathways and for characterizing vulnerability and mitigative capacity important for IAV (impacts, adaptation and vulnerability) and IAM studies (CMIP5, 2015).

The SSP3_70 scenario represents the medium to high end of the range of plausible future forcing pathways. It fills a gap in CMIP5 forcing pathways that is particularly important because it represents a forcing level common to several (unmitigated) SSP baselines. These baseline scenarios will be very important to IAV studies interested in quantifying “avoided impacts,” which requires comparing impacts in a mitigation scenario with those occurring in an unmitigated baseline scenario (CMIP5, 2015). This scenario will be used as the basis for the CMIP6 ensemble runs.

In order to assess the influence of internal variability on climate outcomes (while also economizing on model runs) CMIP have requested that modellers run multiple initial condition ensemble members only for one scenario, namely SSP3_70, based on the assumption that variability estimated for one scenario can be applied to outcomes for others. The relatively high forcing level reached by this scenario by the end of the 21st century will enable the exploration of potential changes in internal variability as a function of global characteristics (radiative forcing or global average temperature change) and therefore still serve the purpose of estimating variability and applying its statistical characteristics to other scenarios, despite the characteristics of land-use and Near Term Climate Forcers emissions that set this scenario somewhat apart from the others (CMIP5, 2015).

Experiment 3: EC-Earth (T511-ORCA025L75) CMIP6 Contributions

Met Éireann will commit to running the following EC-Earth T511-ORCA025L75 AOGCM CMIP6 Contributions:

- 2 CMIP6 HighResMIP-2 1951-2050 Simulations (200 years).

The high-resolution coupled runs will consist of pairs of both scenario (historic for the past and SSP2-4.5 for the future) runs and, for comparison, control runs using fixed 1950s forcings. This will allow an evaluation of the model drift in addition to the climate change signal.

The start year of the integrations is chosen as 1951 to cover significant historical changes. The mid-term period, 1951-2050 is relevant for decision makers. Due to limited computer resources an equilibrated initial ocean state is not feasible. Possible solutions to circumvent this are bias correction or the interpolation of an initial state of the low resolution DECK runs. For the latter a prerequisite is that the dynamics of the low- and high-resolution ocean model are sufficiently similar.

It is expected that the high-resolution SSP2-4.5 simulation data will be used by CORDEX (regional downscaling) for cloud resolving simulations.

Experiment 4: Two additional T255-ORCA1L46 Simulations.

To evaluate the impact of increased resolution, Experiment 3 will be repeated with the standard CMIP6 T255-ORCA1L46 resolution. The experimental set-up and design of the standard resolution experiments will be exactly the same as for the high-resolution runs. This enables the use of HighResMIP simulations for sensitivity studies investigating the impact of resolution.

3. Justification of Computing Resources

The EC-Earth configurations of the proposed project were scale-tested on a local machine (ICHEC, fionn). The architecture and compilers (intel) are similar to the ECMWF cca machine. However, the ECMWF architecture is more powerful (Intel Xeon CPU E5-2695 2.40GHz Vs. Intel Xeon E5-2697 2.7GHz) so the scaling results presented below are conservative. In addition, the use of hybrid MPI/openMP will be investigated on the ECMWF machine. Previous studies have shown a speedup of 10-15% using a hybrid implementation. The scaling results, presented below, are for a slightly

older version of EC-Earth (version 3.1) but preliminary scaling experiments show similar execution times for the 3.2beta version.

Figures 1 and 2 present scaling results for a one-month simulation using the T255L91-ORCA1L46 and T511-ORCA025L75 configurations, respectively. The T799-ORCA025L75 configuration was also scale-tested (not shown).

These results were used to provide the resource request figures of Table 1 using the following SBU calculation: $SBU = \text{compute time} \times \text{number of physical CPUs} \times 16.28$.

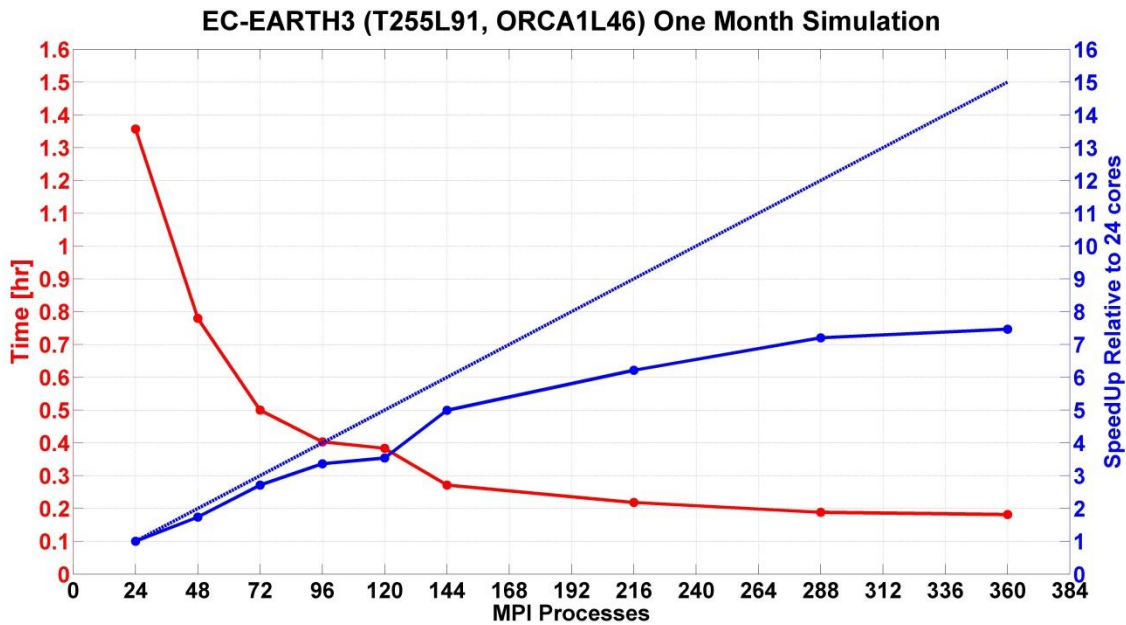


Figure 1. EC-Earth (IFS T255L91,ORCA1L46) timings (red line) and speedup (blue line) for a one-month simulation on the ICHEC system, fionn. The dashed blue line represents the ideal speedup. A total processes per NEMO process ratio of ~3 was found to be optimal.

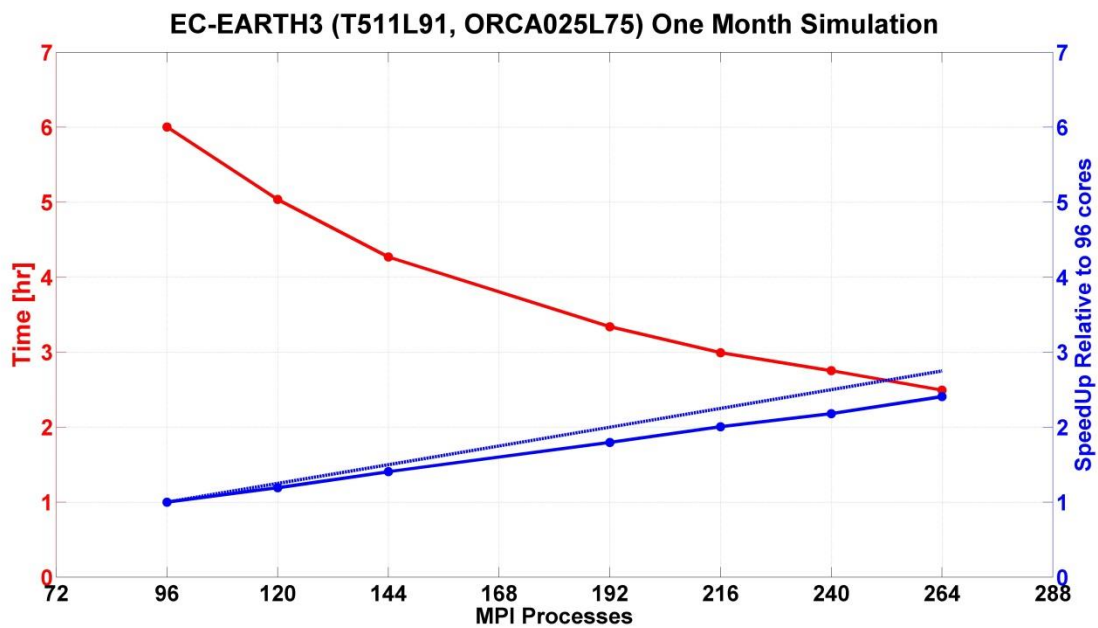


Figure 2. EC-Earth (T511L91,ORCA025L75) timings (red line) and speedup (blue line) for a one-month simulation on the ICHEC system, fionn. The dashed blue line represents the ideal speedup. A total processes per NEMO process ratio of ~2 was found to be optimal.

	Description	Simulation yrs.	Total SBUs	Total Archive
Experiment 1 (2016)	Scaling Experiment	10	4 million	1TB
Experiment 2 (2016-2017)	CMIP6 T255-ORCA1L46 Contributions	1255	12 million	24 TB
Experiment 3 (2017-2018)	CMIP6 T511-ORCA025L75 Contributions	200	28 million	37 TB
Experiment 4 (2017)	T255-ORCA1L46 (same setup as Experiment 3)	200	2 million	4 TB
Total			46 million	66 TB ††

Table 1. Resources required for the proposed experiments.

As the scaling results are conservative, an additional percentage has not been added to the total SBU figures of Table 1 to allow for the testing and initial crashing of the simulations.

The T255L91-ORCA1L46 and T511-ORCA025L75 simulations will produce 36 and 350 GB of data per simulation year, respectively. This will result in a total archive volume of $1455 \times 36 \text{GB} + 200 \times 350 \text{GB} = 122 \text{TB}$. The experiments will be run using Autosubmit, a launching and monitoring solution that allows the remote submission of EC-Earth experiments. Autosubmit will include in the workflow of the experiments, a job that retrieves the data back to a proposed EPA/ICHEC data storage facility as soon as a simulation restart-chunk has completed. This will ensure a smooth, non-disruptive transfer of data. Therefore, the estimates for the archive are an absolute upper value in the event that the automatic download does not perform as expected or the setup of the local data storage facility is delayed ††. In the unlikely event of a long-term delay in the setup of the local storage facility, arrangements will be made to store the data on an alternative data server of an EC-Earth partner.

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