REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: Ireland

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Project Title: High-Resolution EC-Earth Simulations - Ireland's Contribution to CMIP6

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** spienola	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2019	
Would you accept support for 1 year only, if necessary?	YES **X**	NO ☐

Computer resources required for 2019-2021: (To make changes to an existing project please submit an amended version of the original form.)		**2019**	**2020**	**2021**
High Performance Computing Facility	(SBU)	23 million	23 million	20 million
Accumulated data storage (total archive volume)[2]	(GB)	20,000	50,000	70,000

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 annual progress reports 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 etc.

Principal Investigator: Paul Nolan, paul.nolan@met.ie

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Extended abstract

Note that the proposed project is a continuation of a previous Special Project (spienola): "High Resolution EC-Earth Simulations". The goal of this previous research project was to simulate the effects of climate change at the global scale. The first component of the research involved tuning and testing the new version (3.2.3) of the EC-Earth Earth System Model (ESM) in preparation for the upcoming Coupled Model Intercomparison Project Phase 6 (CMIP6) contributions. Once the testing phase was complete, it was planned to run a number of EC-Earth production runs. However, the EC-Earth community have delayed the start of the CMIP6 simulations due to problems with the newest version of the model. The bugs are nearly completely fixed and the CMIP6 production simulations will start in the summer of 2018. Because of these delays, the PI used the resources of the Special Project (spienola) for long-term (~100s years) tuning experiments, validation/test simulations and model development.

The scientific objectives 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.

The impact of greenhouse gases on climate change can be simulated using Global Climate Models (GCMs). Since 1995, the Coupled Model Intercomparison Project (CMIP) has coordinated climate model experiments involving multiple international modeling teams. The CMIP project has led to a better understanding of past, present, and future climate, and CMIP model experiments have routinely been the basis for future climate change assessments made by the Intergovernmental Panel on Climate Change (IPCC), e.g. [1].

EC-Earth is an IPCC-class GCM. The latest version (v3.2.3) was released in spring 2018 and 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. The proposed PI is a current member of the tuning group and has experience running EC-Earth simulations on the Irish Centre for High-End Computing (ICHEC), ECMWF and PRACE (Hermit & Beskow) supercomputing systems. This model is currently being optimized for a standard horizontal resolution of T255 with 91 vertical layers for the atmosphere, and for 1 degree with 46 layers for the ocean. In addition, high-resolution configurations are currently being tested (0.25 degrees in the ocean, and T511 and T799 in the atmosphere). As part of the EC-Earth consortium, researchers at Met Éireann (Irish Meteorological Service) and ICHEC were involved with the development of EC-Earth and have contributed to the CMIP5 experiments, which formed an essential part of the IPCC Fifth Assessment Report (AR5).

CMIP6 is the 6th coupled model intercomparison project in which the EC-Earth community will participate. 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. The specific CMIP6 experimental design is focused on three broad scientific questions; (i) How does the Earth system respond to forcing? (ii) What are the origins and consequences of systematic model biases? and (iii) How can we assess future climate changes given climate variability, climate predictability, and uncertainties in scenarios? [2]. The proposed project will assist in addressing these questions by contributing towards CMIP6 with high resolution (T511, ~39km), and hence more accurate, EC-Earth simulations. The PI 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.

The CMIP5 simulations have demonstrated the added value of enhanced resolution when compared to output from the CMIP3 project [3]. The simulations showed significant improvement in the simulation of aspects of the large scale circulation such as El Niño Southern Oscillation (ENSO) [4], Tropical Instability Waves [5], the Gulf Stream and its influence on the atmosphere [6,7], the global water cycle [8], extra-tropical cyclones and storm tracks [9] and Euro-Atlantic blocking [10]. In addition, the increased resolution enables more realistic simulation of small scale phenomena with potentially severe impacts such as tropical cyclones [11], tropical-extratropical interactions [12] and polar lows. The improved simulation of climate also results in better representation of extreme events such as heat waves, droughts and floods.

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 [13], and usually produces fewer events than observed [14]. The ability of CMIP5 models to simulate North Atlantic extratropical cyclones was assessed by Zappa et al. (2013) [15]. 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. Sillmann et al. (2013) [16] 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 [17]). 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 [16]. Again, this improvement in skill is expected to continue with the higher resolution CMIP6 simulations.

It is expected that the EC-Earth CMIP6 simulations, of the proposed project, 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 data will allow for an assessment of the impact of resolution on the accuracy of climate modelling and will assist in addressing all three of the CMIP6 broad scientific questions. The simulations will likely be included for assessment in the expected U.N. Intergovernmental Panel on Climate Change (IPCC) AR6 reports. In addition, it is expected that the EC-Earth simulation data will be used as a basis for more-focused climate impact studies such as regional downscaling (e.g., boundary conditions provided to CORDEX and national downscaling research groups).

1. Work Plan

After discussion with the EC-Earth community, we are provisionally committed to running the following EC-Earth CMIP6 contributions:

- 3 x T255-ORCA1L75 AOGCM CMIP6 Historical Simulations, 1850-2014
- 12 x T255-ORCA1L75 CMIP6 (3xRCP2.6, 3xRCP4.5, 3xRCP6.0, 3xRCP8.5), 2015-2100
- 2 x T511L91-ORCA025L75 CMIP6 HighResMIP-2 1951-2050 Simulations (200 years).
- To evaluate the impact of increased resolution, the high resolution experiments will be repeated with the standard CMIP6 T255-ORCA1L75 resolution.

The planned simulations, outlined above, are a minimum estimation of our planned CMIP6 contributions. These simulations are expected to start in July 2018. The proposed project will allow for the continuation of these simulations in 2019. The proposed simulations will be managed as follows:

Experiment 1: EC-Earth (T255-ORCA1L46) CMIP6 Contributions (2019/2020)

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

- 3 CMIP6 Historical Simulations, 1850-2014
- 12 x T255-ORCA1L75 CMIP6 (3xRCP2.6, 3xRCP4.5, 3xRCP6.0, 3xRCP8.5), 2015-2100

"SSP-based RCPs" are new versions of the Representative Concentration Pathways (RCPs) that are based on the Shared Socioeconomic Pathways (SSPs) [18,19] 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 [20].

Experiment 2: High-Resolution EC-Earth (T511-ORCA025L75) CMIP6 Contributions (2020/2021)

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 3: Two additional T255-ORCA1L46 Simulations (2020/2021).

To evaluate the impact of increased resolution, Experiment 2 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.

2. Computing Resources

The EC-Earth model (v3.2.2/3) was implemented on the ECMWF (cca), PRACE (Beskow) and local ICHEC machines. The Intel compilers with the standard EC-Earth compile flags were used on each machine.

The following strategies were tested:

- number of IFS cores = number of Nemo cores. One node each for xios and runoff.
- number of IFS cores = 2 x Nemo cores. One node each for xios and runoff.

Scaling results for a one-month simulation (T255T91, ORCA1L75) on the ECMWF and Beskow (PRACE) machines are presented in Figure 1. In each case, one node (32 & 36 cores for Beskow and ECMWF cca, respectively) was used for both xios and rnfmapper. The scaling results demonstrate the feasibility of running a large ensemble of CMIP6 production runs. Furthermore, the analysis establishes the optimal number of CPUs to request per run, while striking a balance between run-time and use of computational resources. The T511-ORCA025L75 EC-Earth configuration was also scale-tested and was found to be approximately 12 times more computationally expensive compared to T255-ORCA1L46.

These results were used to provide the resource request figures of Table 1 using 8 nodes on cca and the following SBU calculation: SBU = compute time × number of physical CPUs × 16.11.

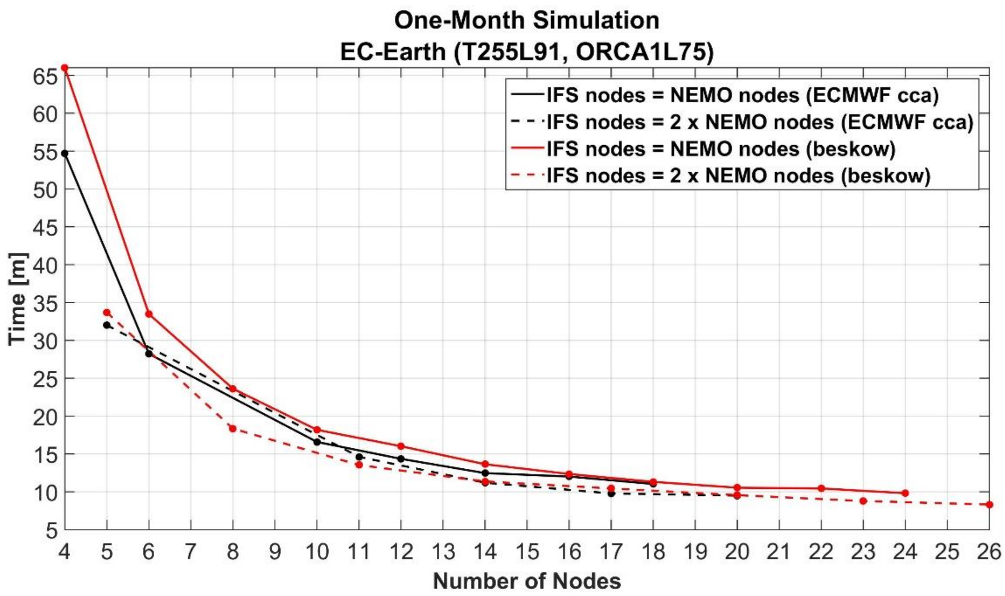

Figure 1. *EC-Earth (T255L91, ORCA1L75) scaling results on ECMWF (cca) and Beskow for a one-month simulation.*

	Description	Simulation yrs.	Total SBUs	Total Archive
Experiment 1 (2019-2020)	CMIP6 T255-ORCA1L46 Contributions	1530	24.5 million	28 TB
Experiment 2 (2020-2021)	CMIP6 T511-ORCA025L75 Contributions	200	38 million	40 TB
Experiment 3 (2020)	T255-ORCA1L46 (same setup as Experiment 3)	200	3.5 million	2 TB
Total			**66 million**	**70 TB ††**

Table 1. Resources required for the proposed experiments.

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 1730*36GB + 200*350GB = 132 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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