REQUEST FOR A SPECIAL PROJECT 2015–2017

MEMBER STATE:	Spain
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Project Title:	High-resolution climate prediction with EC-Earth

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SPESICCF** _________________	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2015	
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.)		2015	2016	2017
High Performance Computing Facility	(units)	37,050,000	37,050,000	
Data storage capacity (total archive volume)	(gigabytes)	12,150	12,150	

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): 14 July 2014

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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**

Seasonal forecasting deals with the problem of producing climate information at time scales between more than two weeks and slightly longer than one year (Luo et al., 2011). At seasonal time scales, the storage of heat and moisture by the ocean and the land and the presence or absence of snow and sea ice become important factors. The feasibility of seasonal prediction largely relies on the existence of slow, and predictable, variations in soil moisture, snow cover, sea ice, and the upper parts of the ocean (Shukla et al., 2006), and how the interactions between all those components. This predictability is primarily, though not solely, associated with the El Niño Southern Oscillation (ENSO). Moreover, the natural variability of temperature and other climate variables at the seasonal time scale should be considered as superimposed on externally forced low-frequency variability due to external forcings: human-induced changes in greenhouse gas and aerosol (GHGA) concentrations, land-use changes as well as natural variations in solar activity and volcanic eruptions.

Current climate forecast systems can provide accurate predictions of the tropical SST anomalies associated with ENSO with forecast times of several months (Saha et al., 2006; Stockdale et al., 2011), although the spread among different forecast systems is substantial, sometimes even differing in the sign of the tropical Pacific SST anomaly (Weisheimer et al., 2009; Alessandri et al., 2010). Over the extra-tropics the skill of current seasonal forecast systems is however very limited (Rodwell and Doblas-Reyes, 2006; Frías et al., 2010), although recent results suggest that an increase of resolution in climate forecast systems is one of the necessary factors to reach a useful level of skill over Europe (Scaife et al., 2014).

For dynamical predictions, initial conditions are usually obtained through data assimilation, a way of optimally combining short-range predictions with observations to obtain an optimal estimate of the state of the climate system. Assimilating observational data in one component of the climate system allows propagating this information to the other components of the system. In this way, the ocean anomalies associated with ENSO events and other modes of ocean variability, soil moisture, snow, and ice cover can be taken into account when initializing the predictions (Balmaseda et al., 2008; Balmaseda and Anderson, 2009). Unfortunately, less information is available about the state of the ocean, the sea-ice, snow, and land than about the atmosphere (Balmaseda et al., 2007; Saha et al., 2010). Owing to many different reasons, among them the initial-condition uncertainty and model inadequacy, the ability to make predictions on time scales longer than 2 weeks is still limited in the extratropics (Lee et al., 2011).

The EC-Earth model (Hazeleger et al. 2012, http://ecearth.knmi.nl, https://dev.ec-earth.org) contributed to the projection and prediction protocols of CMIP5 and is regularly used to perform seasonal predictions, using resolutions of ~0.7º and ~1° in the atmosphere and ocean, respectively. While such resolution compares favourably with other CMIP5 models, it is poor in terms of the resolutions required for an accurate simulation of important modes of climate and weather variability. Higher model resolution has been suggested to significantly improve the climate simulations. 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 IFS-only simulations (the atmospheric component of EC-Earth) after using dedicated, high-end computing resources to enable high spatial resolution. Caron et al. (2011), using a variable resolution atmospheric model, found significant improvements in the representation of Atlantic tropical cyclones in experiments with resolutions ranging from

150 to 30 km. Resolving mesoscale ocean eddies allows for a more realistic representation of ice drift and deformation (Zhang et al., 1999) and frontal scale air-sea interaction (Bryan et al., 2010). Recently, several studies reported the first use of coupled climate models in the resolution range ~50 km (atmosphere) and ~10-30 km (ocean), identifying large improvements in a number of systematic errors seen in lower resolution versions of the same models. These include a reduction in the double ITCZ problem (GFDL CM2; Delworth et al., 2012), improved intensity distribution of tropical rainfall (MIROC4h CGCM; Sakamoto et al., 2012), improved coastal upwelling and ENSO variability (Sakamoto et al. 2012) and improved structure of the North Atlantic Ocean circulation (Delworth et al., 2012).

However, in spite of all these encouraging results, very little is known about the impact of increases in ocean and atmospheric resolution in seasonal predictions in terms of forecast quality. Those systems that have been used at high resolution (Scaife et al., 2014) to make forecasts at the seasonal time scale have not been run at a standard resolution, making impossible the assessment of the critical role of resolution and the justification of the indispensable increase in computing resources.

2. **Scientific plan**

With this proposal we plan to address the impact of an increase in resolution through experiments following the standard seasonal prediction protocols. We will concentrate on the role of the ocean initialisation by using initial conditions from three different ocean reanalyses. We plan to use EC-Earth3, which is one of the few coupled models available that is tuned at different resolutions, including a T511 (~39 km), 91 levels and 0.25° horizontal resolution, 75 vertical levels (HR, T511L91-ORCA025L75) for the atmosphere (IFS) and ocean (NEMO) components, respectively. This configuration will be compared to the configuration at standard resolution (SR) T255L91-ORCA1L46. Compared to the resolution of the model used in CMIP5 simulations and in previous special project proposals to perform seasonal predictions, the horizontal resolution is increased by a factor of up to 4, with an increased number of vertical levels in both ocean and atmosphere by factors of 1.5 to 2. By using the model tuned with two different resolutions we leverage resources from the HiResClim computing project supported by PRACE.

As the ocean is the most important component of the climate system in the seasonal prediction problem, we propose to investigate the impact of the model resolution using initial conditions from three different ocean reanalyses. While different studies have shown the impact of ocean initialisation on seasonal forecast quality (Balmaseda et al., 2009), the impact of the choice of the product has been up to now seldom studied (Matei et al., 2012; Zhu et al., 2013). Recently, the UK Met Office released a new version of its initialization product, GloSea5 (MacLachlan et al., 2014) and using a high resolution version of the ocean and sea-ice model (ORCA025L75). On the other side, ECMWF has recently released its pilot reanalysis performed also with NEMOVAR, ORAP5, and expects to release next year the final version, ORA-S5, with a similar resolution to that of GloSea5, ORCA025L75. Moreover, the CFU team at IC3 has recently completed a set of seasonal hindcasts with EC-Earth3 T511L91-ORCA025L75 using MERCATOR's GLORYS ocean initial conditions (available between 1993 and 2009) at high resolution in the framework of the HiResClim project. The GLORYS ocean initial conditions have been interpolated and extrapolated to create also a equivalent set of ocean initial conditions for the ORCA1L46 configuration. A similar procedure will be used to create initial conditions for the SR configuration for the GloSea5 and ORA reanalyses, which will allow assessing the impact of the resolution. The hindcasts for the SR configuration will be performed using national resources. The use of interpolation and extrapolation to generate the SR initial conditions unavoidably introduces errors in the forecasts, so the results should be interpreted with care.

In all the experiments, the atmosphere will be initialised with ERAInterim data (Dee et al., 2011) interpolated to the corresponding resolution using FULLPOS, the land surface will use data from an offline simulation performed with the ERA-Land system (Balsamo et al., 2014) at the corresponding resolution (T255 and T511), and the sea ice will be initialised following the methodology of Guemas et al (2014) where the sea-ice model is forced by fluxes from reanalyses at the resolution of interest.

The results will be assessed in terms of skill, drift behaviour and reduction of initial shock. The use of different sets of ocean initial conditions will also allow assessing the impact on the ensemble spread of the climate forecasts by sampling part of the observational uncertainty. This aspect can, in the medium term, improve the reliability of the probabilistic predictions that can be issued from the ensemble simulations. Finally, an important sub-product of this special project will be a comparison of the quality of the hindcasts produced with the different sets of ocean initial conditions in the controlled environment that EC-Earth3 provides. A preliminary assessment of a set of hindcasts performed using the current ECMWF ocean reanalysis, ORAS4 (Balmaseda et al., 2013), and compared to the hindcasts performed using the SR GLORYS ocean initial conditions suggest that there are important differences in forecast quality.

3. Experiment description

Three HR seasonal hindcast experiments will be performed in this special project with three different ocean initialisations:

1. GloSea5 ORCA025L75, to be performed in 2015
2. ORAP5 ORCA025L75, to be performed between 2015 and 2016
3. ORAS5 ORCA025L75, which will be available in 2015 and should allow the simulation to be performed in 2016

The experiments will be carried out with EC-Earth 3.1. The hindcast period will be 1993 to 2013, the common period of both GloSea5 and ORAS5, with five-member ensembles and two start dates per year (first of May and November) that will be run for four forecast months. This makes a total of 840 (21 years, 2 start dates, 4 forecast months, 5 members) months of simulation for each experiment. As explained above, ERAInterim-derived datasets will be used for the atmosphere, sea ice and land surface.

The forecast quality assessment will be carried out using the most complete framework available at the time of finishing the simulations and will be based on the new verification packages developed in the SPECS FP7 project. The assessment will focus on seasonal means of temperature and precipitation over the main ocean and land areas, with a special interest in the European and extended Mediterranean area as well as the Arctic, the Northern Hemisphere continental areas. The main teleconnections and modes of variability, like the NAO, ENSO or the preferred weather types in the North Atlantic and North Pacific regions will also be considered.

Table 1 summarises the resources requested. It is based on the idea of performing 840 months of simulations with EC-Earth3.1 in its HR configuration.

	Simulations (months)	Total SBU (kilounits)	Total archive (Gb)
Experiment 1 (2015)	840	23,600	8,100
Experiment 2 (2015-16)	840	23,600	8,100
Experiment 3 (2016)	840	23,600	8,100
Total	2,520	70,800	24,300

Table 1: Resources requested by the experiments proposed. The estimates have been made on the basis of a cost of 28,000 SBUs and 9.6 Gb of output per month of simulation with the T511L91-ORCA025L75 configuration. These estimates have been obtained by running EC-Earth3.0.1 on c2a with a reduced output with respect to the CMIP5 standard.

4. Justification of computing resources

EC-Earth3 comprises three major components: IFS, NEMO and OASIS3. It is essential to configure and build separate executables for each one of them. IFS and NEMO fully support a parallel environment, while OASIS3 supports a pseudo-parallel environment. OASIS3 requires Cray pointers. For IFS there is a possibility to activate an OpenMP switch but in this case the implemented MPI should be thread-safe. IFS generates the output in GRIB format and NEMO in NetCDF, while OASIS3 does not generate any output. At the end of a simulation the three components always generate restarts separately (IFS in binary, and NEMO and OASIS3 in NetCDF format).

For configuring and building the model executable, GNU make 3.81 or 3.81+, FORTRAN 77/90/95 complaint compiler with preprocessing capabilities and NetCDF4 deployed with HDF5 and SZIP are needed. A newly designed tool for automatic build configuration called "ec-conf" can be used. This useful tool requires Python 2.4.3 or 2.4.3+ (although it does not work yet with Python 3.0+). For NEMO, the FCM bash and perl mechanism is essential, as it is the I/O GRIB_API 1.9.9 or 1.9.9+ and GRIBEX 370 mechanism are needed for IFS. To test the model with the run scripts, GNU date (64-bit) is also required.

EC-Earth3 supports more than one configuration, unlike EC-Earth2, which supported the T159-ORCA1 configuration only. These configurations are T159-ORCA1, T255-ORCA1, T255-ORCA025 and T511-ORCA025, which have already been tested on various super-computing platforms. In order to store sources and initial data, the experiments require at least ~100 GB of disk space for each release. Currently, two releases of EC-Earth3 are available such as v3.1 and v3.0.1, although only v3.1 will be used in this project.

In the context of the experiments planned in the proposal, which will use the HR configuration, a benchmarking performed previously suggests that, taking into account the average load of the ECMWF queues, optimum performance is obtained using 2,503 procs. This configuration generates 9.6 GB of output per month of simulation.

The experiments will be run using Autosubmit, a launching and monitoring solution that allows the remote submission of EC-Earth and NEMO experiments remotely. Autosubmit includes in the workflow of the experiments a job that retrieves the data back to IC3's data storage as soon as the simulation corresponding to a member has completed. This means that the estimates for the archive are an absolute upper value in case the automatic download does not perform as expected. It is very likely that this number will approach a figure ten times smaller.

An additional 5% has been added to the total SBU request to allow for the testing of the experimental set up and corrections of eventual initial errors in the set up of each experiment.

5. **References**

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