REQUEST FOR A SPECIAL PROJECT 2020–2022

MEMBER STATE: SPAIN……..…………………………………………..…

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Project Title: Near-term Climate Prediction at High Resolution…………….……

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If this is a continuation of an existing project, please state the computer project account assigned previously.	**SPESICCF**________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2020	
Would you accept support for 1 year only, if necessary?	YES X	NO ☐

Computer resources required for 2020-2022: (To make changes to an existing project please submit an amended version of the original form.)		**2020**	**2021**	**2022**
High Performance Computing Facility	(SBU)	66M	66M	
Accumulated data storage (total archive volume)[2]	(GB)	60,000	60,000	

[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] These figures refer to data archived in ECFS and MARS. 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.

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Extended abstract

I – Scientific plan

The future evolution of climate in the near term, from a few months to a decade or so ahead, is of significant importance to our modern society. Decision makers in many sectors of the economy and those concerned with human climate resilience can benefit greatly from authoritative, skilful and reliable predictions of the near-term climate. On these time scales, climate is impacted by internal low frequency variability from the oceans, atmosphere, land, and cryosphere, in addition to changes due to anthropogenic or natural forcing. Near-term climate prediction (NTCP) is concerned with the climate evolution and the changes in regional conditions that determine the probability of extreme events, such as frequency and intensity of heat waves and cold snaps, tropical and extratropical storms, inland flooding and droughts. Recent research has revealed considerable potential for NTCP when coupled climate models are initialized by the contemporaneous climate state, particularly in the oceans.

This project will capitalize on the recent development of a high-resolution version of EC-Earth to perform two distinct set of climate predictions at high-resolution. This new version of EC-Earth, developed within the H2020 project PRIMAVERA, has a spatial resolution of 40 km in the atmosphere and 25 km in the ocean. Noteworthy improvements when increasing resolutions have been obtained in the simulation of El Niño Southern Oscillation (ENSO) (Shaffrey et al. 2009, Masson et al. 2012), 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), jet stream (Lu et al., 2015), storm tracks (Hodges et al. 2011), Euro-Atlantic blockings (Jung et al 2012), tropical cyclones (Bengtsson et al. 2007), tropical-extratropical interactions (Baatsen et al. 2014, Haarsma et al. 2013), monsoons (Sperber et al. 1994; Lal et al. 1997; Martin 1999), heat waves and droughts (Van Haren et al. 2015) and sea ice drift and deformation (Zhang et al 1999; Gent et al, 2010). Furthermore, there are several indications that the current generation of CGCM (~1° resolution) is missing key mechanisms to correctly simulate the observed atmospheric teleconnections. The hope is that improvements can be expected if simulations at higher resolution better represent some of the key mechanisms, improvements which would then translate into higher prediction skill, in particular for extreme events. In fact, Scaife et al. 2014, has shown, with a different forecast system, that increased horizontal resolution in the ocean and atmosphere improves the seasonal skill of the North Atlantic Oscillation (NAO), winter storminess, and near-surface temperature and wind speed over Europe and North America .

As mentioned above, the project is divided into two distinct and independent sets of experiments, which roughly correspond to year 1 and year 2 of the projects. For the first part of the project, we aim to estimate and understand the climate impacts of the Atlantic Multidecadal Variability (AMV) in order to determine their predictability, while in the second part, we aim to investigate the impact of increased resolution on seasonal forecast skill.

<u>Part 1 - Predictability of the impacts linked to the Atlantic Multidecadal Variability</u> (year 1)

During the last century, the North Atlantic sea surface temperature (SST) exhibited both long-term warming trend and multidecadal fluctuations. This multidecadal variability is referred to as the Atlantic Multidecadal Variability (AMV). The AMV has been associated with marked climate anomalies and associated human impacts over many areas of the globe. This includes droughts over Africa (in particular the extremely severe and long-lasting 70s-80s Sahelian drought, responsible for 100,000 human deaths) and North America, decline in Arctic sea ice, changes in Atlantic tropical cyclone activity, and the recent global temperature hiatus. The North Atlantic SST is also a main actor of the European climate variability. Previous studies argued for the existence of a causal link between the warm phase of the AMV and warm conditions over Central Europe, dry conditions over the Mediterranean basin, and wet conditions over Northern Europe, modulating the river streamflow and the electricity production. The AMV appears also to impact the location and activity of the North Atlantic storms by modulating the North Atlantic Oscillation (NAO) activity and the atmospheric large scale dynamics. Given the numerous climate impacts of the AMV and their related consequences on human society, predicting its evolution and its teleconnections is of high interest for stakeholders and policy decision makers.

Recently, the climate science community has conducted internationally coordinated retrospectives decadal forecasts (hindcasts). This exercise consisted in integrating Coupled Global Climate Models (CGCMs) initialized from the available observations and comparing their outputs to observations. Results form these hindcasts highlight that the North Atlantic basin is the most predictable region of the world at multi-year to decadal timescales. However, to date, decadal predictions show only limited prediction skill over continents, with no real contribution from ocean initialization. This limited prediction skill questions the ability of current CGCM generation to represent the climate impacts of the North Atlantic SSTs and in particular those of the AMV.

The main objective of the first set of experiments is to better understand the climate impacts of the observed AMV in order to estimate their predictability. This will be done by performing idealized experiments with EC-Earth3 CGCM in which the North Atlantic SST will be restored towards the observed AMV anomalies. We will particularly focus on the AMV impacts on the occurrence of weather extremes such as Tropical Cyclones, heat waves, and heavy precipitation events.

Idealized AMV experiments will be performed following the protocol from the Climate Model Inter-Comparison Project (CMIP6; cf. DCPP-Component C, Boer et al. 2016), as presented in Ruprich-Robert et al. (2017). Two sets of experiments will be performed, called AMV+ and AMV-, in which time invariant SST anomalies corresponding to the positive and negative phases of the observed AMV are imposed over the North Atlantic, respectively. In these experiments the model daily SST is restored to the observed AMV anomalies superimposed on the model's own daily climatology over the North Atlantic region form 0^{o} to 73^{o}N. Outside of the restoring region, the model evolves freely, allowing a full response of the climate system.

The simulations will be performed with a high-resolution version of the EC-Earth3 (ORCA025L75 – T511L91) and will be compared to a similar set of experiments performed at standard resolution (ORCA1L75-T255L91). Comparison between the two sets of experiments will provide information on the added-value of increasing resolution. This second sets of experiments at standard resolution will be run in parallel on our local machine.

<u>Part 2 - Seasonal Forecasts at High Resolution</u>

In this second part, we will explore the impact of increasing horizontal resolution on the oceanic and atmospheric domains on seasonal prediction skill of EC-Earth3 through retrospective seasonal predictions of seven months initialized twice every year for the period 1980-2018. Specific emphasis will be made on improvements in simulating Arctic climate variability, and how it affects simulated climate over land areas including Europe, and climate extremes. Specifically, we will examine if this change in resolution leads to a better representation of internal variability of the North Atlantic mixed layer, surface fronts and ocean heat transport, Arctic sea ice cover, and mid-latitude surface pressure, precipitation and temperature. The natural variability of these elements of the regional climate, and its interaction with the long-term climate change, is typically subdued in coarse-resolution models. We expect that the increase in resolution will improve the representation of the sea ice edge, which should then impact the atmospheric response to sea ice changes and the forecasting of cold air outbreaks, polar cyclones and other atmospheric phenomena that also affect lower latitudes. Incidentally, the experiments will also include any impact stemming from the use of higher horizontal resolution initial conditions. The numerical climate experiments of this activity and follow-up analysis will enable us to demonstrate the importance, as well as limitations, of specified increase in horizontal resolution in ocean, sea ice and atmosphere important for the development and application of EC-Earth climate model.

These high-resolution seasonal forecasts will be compared to a second set performed at standard resolution (T255-ORCA1) on our local machine.

We note that it is possible that a first version of EC-Earth4, for which the technical development is now starting, might be available by year 2 of the project (2021). If that is the case, we would consider performing the second part of the project using this latest version of the model. In which case, the number of start dates and members will be adjusted according to the computing cost of that new version.

II – Justification of the computing resources requested

Several tests have already been done in order to evaluate the performance of EC-Earth, evaluating different metrics such as speedup and efficiency. The results of these tests show that optimum performance is obtained when using 1730 cores for the high resolution coupled experiments. This configuration provides a compromise between the required amount of resources and the computational cost, taking into account the scalability of the parallel application and the average load of the platform. This configuration was also thoroughly tested during the previous special project, which was used to perform HighResMIP within the context of PRIMAVERA. Using this configuration, **one year of simulation requires ~336,000 SBUs**.

Part 1 - Predictability of the impacts linked to the Atlantic Multidecadal Variability

For this first part of the project, we will produce two ensembles (AMV+/AMV-) of 10 year-long simulations, keeping external forcing conditions at fixed level. This is done in order to focus on the internal climate response and to capture the potential response and adjustment of other oceanic basins to the AMV anomalies.

2 ensembles x 10 members x 10-year = 200 years
200 years x 336,000 SBU/year = **67M SBUs**

These simulations can start on day one of the project and will be completed as soon as computing resources will allow us, as this experimental setup has already been tested in the previous special project.

Part 2 - Seasonal Forecasts at High Resolution

The seasonal forecasts will cover the period 1980-2018 and will be initialized on one start date (either May 1st and November 1st, still tbd) for each year. Each retrospective forecast will be composed of 10 ensemble members and run for a 6-month period.

39 start dates x 10 members x 6/12 year-long simulations = 195 years
195 years x 336,000 SBU/year = **65M SBUs**

The final estimate is for a total request of 132M SBUs, or **66M SBUs/year**. This leaves very little buffer for failing jobs that will need to be repeated. In case job failures become an issue, we can scale back each set of experiments, by either reducing the number of start dates and/or the number of members.

The experiments will be run using Autosubmit, the launching and monitoring solution developed by the applying team that allows the remote submission of EC-Earth and NEMO experiments. Autosubmit includes in the workflow of the experiments a job that retrieves the data back to the department data storage as soon as each chunk of simulation has been completed. This means that the storage space that will be required for these experiments will be much smaller than the total output generated. Based on past projects which have used a similar configuration, we estimate that a storage space in the range of 60 Tb will be required. Around 500 GB of “home” space will be required to host the code and its modified versions.

III – Technical characteristics of the code to be used

EC-Earth3 is a global coupled climate model, which integrates a number of components in order to simulate Earth systems. EC-Earth3 consists of two main components which are coupled using a library known as OASIS3-CMT. These two main components are the IFS model for the atmosphere, developed by the ECMWF, and NEMO for the ocean, developed by the European consortium. EC-Earth uses the MPI paradigm in order to distribute the workload on a supercomputer, using a specific number of task or processes for NEMO and IFS, the OASIS3-CMT coupling is used to communicate directly IFS and NEMO. It is essential to configure and build a separate executable for each one of them. The resolution proposed here (T511: ~425,000 grid points, ORCA025: ~1,475,000 grid points) will help efficiently share calculations between 1000-1500 sub-domains, increasing the range of efficient compute-core usage per model executable. 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 executables, GNU make 3.81 or 3.81+, FORTRAN 77/90/95 compliant compiler with pre-processing 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 that are needed for IFS. To test the model with the run scripts, GNU date (64-bit) is also required.

The simulations will require MPI libraries and runtime facilities (MPICH2, MPICH-MX, HP-MPI, OpenMPI, INTEL-MPI), optimization and data handling tools, such as BLAS, LAPACK, HDF4, HDF5, NETCDF, PARMETIS, SCALAPACK, P-NETCDF, UDUNITS, GRIB_API, CDFTOOLS v2, CDO, NCO and general configurations tools, such as PERL, PYTHON, AUTOCONF and AUTOMAKE.
The Autosubmit software (Asif et al., 2014) will be used to manage the workflow and ensure a uniform and optimal use of the resources.

IV – References

Asif, M., A. Cencerrado, O. Mula-Valls, D. Manubens, F.J. Doblas-Reyes and A. Cortés, 2014: Impact of I/O and data management in ensemble large scale climate forecasting using EC-Earth3. Procedia Computer Science, 29, 2370-2379.

Baatsen, M., R. J. Haarsma, A. J. Van Delden, H. De Vries, 2014: Severe autumn storms in future western Europe with a warmer Atlantic ocean. Clim. Dyn., 45, 949-964. DOI:10.1007/s00382-014-2329-8

Bengtsson, L., K. I. Hodges, M. Esch, N. Keenlyside, L. Kornblueh, J.-J. Luo, and T. Yamagata, 2007: How may tropical cyclones change in a warmer climate? Tellus, 59A, 539-561.

Boer G. et al. 2016: “The Decadal Climate Prediction Project (DCPP) contribution to CMIP6”. Geoscientific Model Development, 9,3751-3777.

Chassignet, E.P., and D. P. Marshall, 2008: Gulf stream separation in numerical ocean models. In: Hecht, M., Hasumi, H. (eds.), Eddy-Resolving Ocean Modeling, AGU Monog. Ser., 39-62.

Demory, M.-E., et al. (2014). The role of horizontal resolution in simulating drivers of the global hydrological cycle. Clim. Dyn., 42, 2201-2225.

Gent, P. R., S. G. Yeager, R. B. Neale, S. Levis, and D. A. Bailey, 2010: Improvements in a half degree atmosphere/land version of the CCSM. Clim. Dyn., 34, 819–833, doi:10.1007/s00382-009-0614-8.

Haarsma, R.J., W. Hazeleger, C. Severijns, H. de Vries, A. Sterl, R. Bintanja, G.J. van Oldenborgh and H.W. van den Brink, 2013: More hurricanes to hit Western Europe due to global warming. Geophys. Res. Lett. doi:10.1002/grl.50360.

Hodges, K. I., et al., 2011: A comparison of extratropical cyclones in recent re-analyses ERA-Interim, NASA MERRA, NCEP CFSR, JRA-25. J. Clim., 24, 4888-4906.

Jung, T., et al., 2012: High-resolution global climate simulation with the ECMWF model in project Athena: Experimental design, model climate, and seasonal forecast skill. J. Clim., 25, 3155-3172.

Kuwano-Yoshida A, Minobe S, Xie S-P, 2010: Precipitation response to the Gulf Stream in an Atmospheric GCM. J. Clim 23, 3676–3698.

Lal, M., U. Cubasch, J.P. Perlwitz, and J. Waszkewitz, 1997: Simulation of the Indian monsoon climatology in ECHAM3 climate model: Sensitivity to horizontal resolution. Int. J. Climatol., 17, 847-858

Martin, G. M., 1999: The simulation of the Asian summer monsoon, and its sensitivity to horizontal resolution, in the UK meteorological office unified model. Q.J.R. Meteorol. Soc., 125: 1499–1525. doi:10.1002/qj.49712555703

Masson, S., P. Terray, G. Madec, J.-J. Luo, T. Yamagata, and K. Takahashi, 2012: Impact of intra-daily SST variability on ENSO characteristics in a coupled model. Climate Dynamics, 39, 681-707

Ruprich-Robert et al. (2017): "Assessing the Climate Impacts of the observed Atlantic Multidecadal Variability using the GFDL CM2.1 and NCAR CESM1 Global Coupled Models". Journal of Climate, 30.8, 2785-2810.

Scaife, A.A. et al., 2014: Skillful long-range prediction of European and North American winters. Geophys. Res. Lett., 41, 2514-2519.

Shaffrey, L. C., et al., 2009: U.K. HiGEM: the new U.K. High-Resolution Global Environment Model-model description and basic evaluation. J. Clim., 22,1861-1896.

Sperber, K. R., H. Sultan, G. L. Potter, and J. S. Boyle, 1994: Simulation of the Northern Summer Monsoon in the ECMWF Model: Sensitivity to Horizontal Resolution. Mon. Wea. Rev., 122, 2461–2481.

Van Haren, R., R. J. Haarsma, H. de Vries, G. J. van Oldenborgh and W. Hazeleger, 2015: Resolution dependence of circulation forced future central European summer drying. Env. Res. Lett., 10, 055002. DOI: 10.1088/1748-9326/10/5/055002.

Zhang, Y., Maslowski W., Semtner, A.J, 1999. Impact of mesoscale ocean currents on sea ice in high-resolution Arctic ice and ocean simulations. J Geophys Res, 104, 18409-18429, doi:10.1029/1999JC900158.