Barcelona Supercomputing Center
Centro Nacional de Supercomputación

RED ESPAÑOLA DE SUPERCOMPUTACIÓN

AECT-2019-2-0001 Impact of increased horizontal resolution on seasonal climate forecasts in the northern hemisphere mid- and high-latitudes

1. General Information

Activity Id
AECT-2019-2-0001

a) Activity Title
Impact of increased horizontal resolution on seasonal climate forecasts in the northern hemisphere mid- and high-latitudes

b) Area
Astronomy, Space and Earth Sciences

2. Research Project Description

a) Is this a Test Activity?
No

b) Is this a Long Term Activity that will extend over two application periods?
Yes

c) Brief description of the Project
Climate conditions can affect a range of socio-economic sectors including energy, agriculture, insurance and health. Numerical climate models are the primary tools to make climate predictions on seasonal, decadal and centennial time scales. These models, however, are not perfect and have characteristic weaknesses in the representation of climate features, in particular at the regional scale. This project will explore several pathways of how the state-of-the-art climate models could be improved in their ability to more realistically simulate typical climatological characteristics, including climate extremes and climate variability by increasing model resolution. Specific emphasis will be made on improvements in simulating Arctic climate variability, and how it affects simulated climate over land areas including Europe and Spain. Improved climate models will eventually allow for more accurate

predictions of potential climatic risks, and thereby help users from a range of sectors to be prepared, potentially saving millions of Euros. This activities are aligned with the ongoing H2020 projects APPLICATE and EUCP, two projects with a strong focus on user engagement.

Increased horizontal resolution in the ocean and atmosphere has shown improvements in the seasonal skill of the North Atlantic Oscillation (NAO), winter storminess, and near-surface temperature and wind speed over Europe and North America (Scaife et al. 2014). Using EC-Earth in seasonal hindcasts, Prodhomme et al. (2016) reported improvement in the representation of the Gulf Stream together with a reduction in the summer warm bias in the North Atlantic in the higher resolution version of the model. Additionally, NAO skill and the representation of atmospheric blocking were also improved. For decadal forecasting (forecast ranging from 2-10 years), the benefit of increased resolution is less clear, but that is mainly due to the large amount of computer resources required for such experiments, which made them unaffordable until recently. However, there are several indications that the current generation of CGCM (~1° resolution) is missing key mechanisms to correctly simulate the observed atmospheric teleconnections, therefore improvements can be expected if simulations at higher resolution better represent some of the key mechanisms.

We will explore directly the impact on seasonal prediction skill of increasing horizontal resolution on the oceanic and atmospheric domains of the EC-Earth 3.3 climate prediction system as part of the APPLICATE and EUCP projects. Specifically, we will examine if this change in resolution will lead to 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 regional climate, and its interaction with the long-term climate change, is typically subdued in coarse-resolution models. Finding how much increased horizontal resolution improves the fidelity of climate processes and large-scale dynamics in EC-Earth family of climate models will contribute to HPC intense effort to advance state-of-the-art climate models. Dynamical forecasting systems with practical regional skill in key variables of interest to users are the ultimate goal of climate model development in research and operational centers around the world. 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 two-period 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. BSC is a member of the EC-Earth consortium which is a multi-institutional research activity bringing together climate and computer scientist from 10 European countries (http://www.ec-earth.org/index.php/community/ec-earth-consortium).

References:

-Prodhomme, C., F.J. Doblas-Reyes, O. Bellprat and E. Dutra (2016) Impact of land-surface initialization on sub-seasonal to seasonal forecasts over Europe. Climate Dynamics, 47, 919-935.
-Scaife, A.A., A. Arribas, E. Blockley, A. Brookshaw, R. T. Clark, N. Dunstone, R. Eade, D. Fereday, C. K. Folland, M. Gordon, L. Hermanson, J. R. Knight, D. J. Lea, C. MacLachlan, A. Maidens, M. Martin, A. K. Peterson, D. Smith, M. Vellinga, E. Wallace, J. Waters, A. Williams (2014) Skillful long-range prediction of European and North American winters. Geophys. Res. Lett., 41, 2514-2519.

d) Grants and funded projects related to this activity

Reference code
03168

Project title
Juan de la Cierva (Formación)

Starting date
2018-11-01

Ending date
2020-11-01

Total financing (in EUR)
60.000,00

Financing source
National

Reference code
727862

Project title
APPLICATE

Starting date
2016-11-01

Ending date
2020-10-31

Total financing (in EUR)
8.715.066,00

Financing source
European

Reference code
776613

Project title
EUCP

Starting date
2017-12-01

Ending date
2021-11-30

Total financing (in EUR)
12.999.515,00

Financing source
European

e) Brief description of the Project (if this Activity takes place in the context of a Technology or Industrial Project)

f) Specific Activity proposed

Two sets of retrospective seasonal predictions of seven months initialized twice every year for the period 1980-2015 will be run at standard and high resolution, respectively. Each retrospective forecast is made up from ten ensemble members. For each startdate initial conditions should be available for the ice, ocean and atmospheric components of EC-Earth3.3. The initial conditions will be generated using a five member assimilation simulation with the same model covering the period 1960-2016. These activities are planned over two application periods. The assimilation simulations will last from 2 to 3 months, while the seasonal forecast simulations will last from 3 to 4 months.

In total the assimilation simulation years are 57*5 = 285 for standard resolution and the same 285 years for high resolution.
The seasonal forecasts in years are 36*7*10*2/12 = 420 years for standard resolution and the same 420 years for high resolution.

The standard configuration of EC-Earth3.3 runs optimally using 768 CPUs, while the high resolution uses 1584 CPUs.
The simulated years per day in each configuration is: 15 and 3, respectively.

Total time standard resolution: (285+420)*768*24/15 ~ 900'000 CPU hours
Total time high resolution: (285+420)*1584*24/3 ~ 9'000'000 CPU hours

g) Computational algorithms and codes outline

The EC-Earth3 GCM model has three major components: IFS (atmospheric), NEMO (ocean dynamics+PISCES for ocean biogeochemistry) and OASIS3 (coupler). It is essential to congure and build separate executable for each one of them. For IFS there is a possibility to activate an OpenMP switch but in this case the implemented MPI should be thread-safe. IFS generates 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). In addition to the GCM EC-Earth3 model, this project utilises the LPJ-GUESS dynamic vegetation model and the OSM land surface model in oine conguration. LPJ-GUESS and OSM are also coupled via OASIS3, and are forced by output from coupled EC-Earth3 simulations or reanalysis data. LPJ-GUESS parallelization is done with MPI while OSM is built with OpenMP. For conguring and building the model executable, GNU make 3.81 or 3.81+, FORTRAN 77/90/95 complaint compiler and C++ compiler with preprocessing capabilities and NetCDF4 deployed with HDF5 and SZIP are needed. A newly designed tool for automatic build conguration 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, FCM, bash and perl are essential, and the GRIB_API I/O 1.9.9 or 1.9.9+ and GRIBEX 370 are required for IFS. GNU

date (64-bit) is also required for executing the model with the run scripts. EC-Earth3.3 supports several congurations which have already been tested on various supercomputing platforms, Marenostrum3 and Marenostrum4 among them. In this activity we will use the T511-ORCA025 and the T255-ORCA1 congurations, which corresponds to a spatial resolution of 40km in the atmosphere and 25 km in the ocean, and 80 km in the atmosphere and 100 km in the ocean, respectively.

3. Software and Numerical Libraries

Software components that the project team requires for the activity.

a) Applications + Libraries

NETCDF, R, OPENMPI, UDUNITS, NCO

b) Compilers and Development Tools

GCC, INTEL

c) Utilities + Parallel Debuggers and Performance Analysis Tools

PYTHON, NCVIEW, NCL

d) Other requested software

CDO

e) Proprietary software

4. Research Team Description

a) Personal Data

Name of Team Leader	Juan Camilo Acosta Navarro
Gender	Male
Institution	BSC
e-mail	jacosta@bsc.es
Phone	654499846
Nationality	Italy

b) The employment contract of the activity leader with the research organisation is valid at least 3 months after the end of the allocation period.

Yes

c) Curriculum Vitae of the Team Leader

Dr. Juan Camilo Acosta Navarro obtained a PhD in environmental science from Stockholm University in January of 2017. He has a background on atmospheric dynamics, cloud and aerosol microphysics and the link between remote climatic changes induced by regional radiative forcing with a particular emphasis on Arctic climate and its teleconnections. He is currently a scientific researcher at the Climate Prediction group where his work focuses on understanding drivers of sea ice variability and how it may affect climate locally and remotely. He has published 13 scientific peer reviewed articles in first quartile journals, being first author in four of them (one in Nature Geoscience and one in BAMS) and a book chapter. Dr Acosta Navarro has an h-index of 8 and i10-index of 7 with 220 citations (google scholar). Dr. Acosta Navarro has co-supervised two master theses at Stockholm University and is co-supervising an master student internship from the University of Barcelona. He has also been teaching assistant for two undergraduate courses at Stockholm University. He is currently a Juan de la Cierva fellow.

d) Names of other researchers involved in this activity

Francisco Doblas-Reyes, francisco.doblas-reyes@bsc.es
Pablo Ortega, portega@bsc.es
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Vladimir Lapin, vladimir.lapin@bsc.es

All from BSC

e) Relevant publications

Acosta Navarro, J. C., Ortega, P., García-Serrano, J., Guemas, V., Tourigny, E., Cruz-García, R., ... & Doblas-Reyes, F. J. (2019). December 2016: Linking the Lowest Arctic Sea-Ice Extent on Record with the Lowest European Precipitation Event on Record. Bulletin of the American Meteorological Society, 100(1), S43-S48.

Bellprat, O., Guemas, V., Doblas-Reyes, F., & Donat, M. G. (2019). Towards reliable extreme weather and climate event attribution. Nature communications, 10(1), 1732.

Kushnir, Y., Scaife, A. A., Arritt, R., Balsamo, G., Boer, G., Doblas-Reyes, F., ... & Matei, D. (2019). Towards operational predictions of the near-term climate. Nature Climate Change, 1.

Boy, M., Thomson, E. S., Acosta Navarro, J. C., Arnalds, O., Batchvarova, E., Bäck, J., ... & Castarède, D. (2019). Interactions between the atmosphere, cryosphere, and ecosystems at northern high latitudes. Atmospheric Chemistry and Physics, 19(3), 2015-2061.

Cruz-García, R., Guemas, V., Chevallier, M., & Massonnet, F. (2018). An assessment of regional sea ice predictability in the Arctic ocean. Climate Dynamics, 1-14.

5. Resources

a) Estimated resources required for the Activity for the current Application Period

Requested machine	MareNostrum 4 ((Intel(R) Xeon(R) Platinum 8160, 2.10GHz with Intel(R) Omni-Path / 165888 cores)
Interprocess communication	Tightly Coupled

Typical Job Run				
Number of processors needed for each job		768.00		
Estimated number of jobs to submit		340.00		
Average job durations (hours) per job		3.30		
Total memory used by the job (GBytes)		100.00		
Largest Job Run				
Number of processors needed for each job		1584.00		
Estimated number of jobs to submit		340.00		
Average job durations (hours) per job		16.00		
Total memory used by the job (GBytes)		150.00		
Total disk space (Gigabytes)	**Minimum**	2000.00	**Desirable**	2500.00
Total scratch space (Gigabytes)	**Minimum**	10000.00	**Desirable**	10000.00
Total tape space (Gigabytes) (*)	**Minimum**	0.00	**Desirable**	0.00
Total Requested time (Thousands of hours)		9478.66		

If this activity is asking for more than 10Million CPU hours, you need to justify the amount of resources requested for the activity. (max 1000 characters)

INFORMATION: The estimated cost of the requested hours, considering only the electricity cost, is 10142.1662 euros.

The required resources have to be executed in the selected machines, the other architectures do not fit the requirements to execute the proposal.
** this option implies that if no hours in this machine/these machines are available, the acces committee will reject the full application.

b) Estimate of the total resources that the Activity will require until it is completed (including the present and all the following Application Periods)

Number of application periods expected to complete this Activity
2

Total Requested Time (thousands of hours) expected to complete this Activity (sum of both periods)
9478.66

6. Abstract for publication

A high-resolution climate model could offer a potential improvement for the reconstruction and explanation of observed climate variability and change with better fidelity compared to coarse-resolution equivalent. We examine the impact of an increase in horizontal resolution and dynamical coupling between the atmosphere, ocean and sea-ice on the representation of key physical processes in a state-of-the-art coupled climate model (EC-Earth3.3). A better understanding and representation of those processes is essential to advance the development of seasonal-to-decadal climate predictions and climate projections for the benefit of a wide spectrum of stakeholders.

7. Contact with CURES during last year

Information about the RES Users Committee (CURES).

a) User has contacted the CURES during last year
No

b) If not, indicate why you have not contacted the CURES
Because I have not needed it.

Usage Terms & Conditions

- The Usage Terms & Conditions have been already accepted.