Barcelona Supercomputing Center
Centro Nacional de Supercomputación

RED ESPAÑOLA DE SUPERCOMPUTACIÓN

AECT-2018-1-0020 Seasonal-to-decadal predictions of ocean carbon uptake with the EC-Earth Earth System Model.

1. General Information

Activity Id
AECT-2018-1-0020

a) Activity Title
Seasonal-to-decadal predictions of ocean carbon uptake with the EC-Earth Earth System Model.

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
The recent COP21 Paris agreement on climate ties the participating countries (Spain and the whole EU among them) to take actions to reduce anthropogenic carbon emissions in order to contain global warming within 2C by the end of this century. This translates into the necessity to precisely estimate the compatible CO2 emissions well ahead of time to make sure targets are met. However, precision in the estimate of compatible CO2 emissions can be achieved only if all sources and sinks of atmospheric carbon are known with the highest possible accuracy.
The ocean represents one major sink as it takes up about 25% of the anthropogenic carbon emitted by human activities providing an essential service to society1. However, these estimates are highly uncertain because natural variability and ongoing climate change could alter the capacity of the ocean to absorb carbon. Although physical mechanisms are commonly assumed to be the drivers of most anthropogenic carbon uptake, a set of mechanisms involving ocean biogeochemical processes (the so called Biological Carbon Pump, BCP) are key to maintain most of the vertical gradient of dissolved

inorganic carbon which ultimately drives the flux of CO2 between atmosphere and ocean. The BCP is still poorly constrained and the uncertainty in the estimate of its strength is large enough to confound accurate estimates of carbon uptake.

However, besides the complex dynamics specific to the carbon cycle the ocean is characterized by marked decadal oscillations linked to global scale climate modes of variability, which represent a source of predictability on decadal timescale. Over the past few years, near-term climate predictions have emerged as rapidly improving tools at the service of society and decision-makers. The CMIP5 model experiment suite included a set of near-term climate predictions that proved skilful at regional scales2. Moreover, near-term climate predictions have proven their ability to predict global-scale variability mechanisms like, for example, the recent ocean-driven hiatus in the increase of global surface temperature3 or the fluctuations in the strength of the North Atlantic subpolar gyre4.

Near-term climate predictions can be performed using state-of-the-art Earth System Models (EMSs) that include a description of ocean biogeochemistry (thus of the BCP). Producing near-term ocean biogeochemistry predictions is an emerging and promising idea but it has been applied only to two models so far, to investigate the predictability of primary production over the tropical Pacific5 and of carbon uptake over the North Atlantic6. Taking into account these previous attempts we hypothesize that despite its complexity, ocean carbon uptake can be predicted on seasonal-to-decadal timescales using an Earth System Model and state-of-the-art initialization techniques.

Motivated by these challenges, we plan to perform a set of experiments with the EC-Earth ESM within the context of the project : Decadal predictions of Carbon Uptake in the Southern Ocean and impact of the biological carbon pump uncertainty (DeCUSO), recently proposed for funding by the Spanish “Ministerio de Economia, Industria y Competitividad” (Ref.: CGL2017-84493-R). Planned experiments are aimed at assessing the ability to predict the ocean carbon uptake on timescales ranging from one month to one decade ahead.

The Climate Prediction Group within the Earth Sciences department (BSC-ES) is already a regarded member of the international climate science community. Moreover, this project has the potential to place BSC-ES at the forefront of the international scientific community for ocean biogeochemistry and carbon cycle, since decadal predictions of carbon uptake are a new application in Earth System Models, being explored only by two groups worldwide, so far.

Le Quere, C. et al. Global carbon budget. Earth Syst. Sci. Data 8, 605–649 (2016).
Doblas-Reyes, F. J. et al. Initialized near-term regional climate change prediction. Nat Comm. 4, 1715 (2013).
Guemas, V., Doblas-Reyes, F. J., Andreu-Burillo, I. & Asif, M. Retrospective prediction of the global warming slowdown in the past decade. Nat. Clim. Chang. 3, 1–5 (2013).
Wouters, B., Hazeleger, W., Drijfhout, S., van Oldenborgh, G. J. & Guemas, V. Multiyear predictability of the North Atlantic subpolar gyre. Geophys. Res. Lett. 40, 3080–3084 (2013).
Séférian, R. et al. Multiyear predictability of tropical marine productivity. Proc. Natl. Acad. Sci. U. S. A. 111, 11646–51 (2014).
Li, H. et al. Decadal predictions of the North Atlantic CO2 uptake. Nature Comm. 7, 11076 (2016).

d) Grants and funded projects related to this activity

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

f) Specific Activity proposed

This project will be developed in two phases.

Phase 1:

Before performing historical reconstructions and near-term climate predictions with an ESM, the representation of the global carbon cycle should be equilibrated using preindustrial levels of atmospheric CO2. This requires running a long simulation (called spin-up) of the order of at least 3000 years to allow all the relevant biogeochemical tracers to reach a steady-state solution in the interior of the ocean. ESMs are computationally demanding tools especially when run with a representation of ocean biogeochemistry as it is required for a full account of the carbon cycle. For this reason, a proper spin-up of the carbon cycle is seldom carried out by modelling groups. As a consequence, however, most models are not fully equilibrated when used to simulate the historical and future evolution of climate caused by rising atmospheric CO2.

To produce realistic ocean biogeochemical fields it is paramount to produce first a realistic representation of ocean dynamics. To this end, the ocean physical component of EC-Earth, NEMO, will be used in stand-alone mode (i.e. without coupled atmospheric model) to produce ocean dynamics reconstructions where the natural variability is taken into account by forcing the ocean's surface with data from atmospheric reanalysis products and continuously constraining the model' solution towards the observed state of the ocean through sophisticated numerical techniques commonly referred to as data assimilation (or nudging, here used as a synonym).

With NEMO it is possible to assimilate surface observations (2D nudging of salinity and temperature) and/or water column observations (3D nudging). Different combinations of these options will generate different representation of the circulation. To explore extensively the response of NEMO to such combinations we will perform a set of 5 reconstructions:

a) 3D nudging towards salinity and temperature;
b) 3D nudging towards only salinity;
c) 2D and 3D nudging towards salinity and temperature;
d) 2D nudging towards temperature and salinity;
e) 2D nudging towards only salinity.

These reconstructions will be run with NEMO 3.6 version and each of them will be 56 years long (1961 - 2016).

From these simulations the one that gives the most realistic circulation will be selected to generate steady-state ocean dynamical fields to be used in the ocean biogeochemical spin-up. The spin-up will be performed using the ocean biogeochemical component of EC-Earth, PISCES in "offline" mode, that is not integrated within EC-Earth, but driven by these steady-state ocean dynamical fields generated from the selected reconstruction. The spin-up will be run for 3000 years to achieve a steady-state solution for biogeochemical fields. In this phase atmospheric CO2 will be prescribed at preindustrial levels so to obtain a representation of a preindustrial ocean carbon content.

At the end of the offline spin-up we will produce a short extension (120 years) using EC-Earth in fully coupled mode (e.g. atmosphere-ocean-biogeochemistry) to obtain natural interannual variability while still using preindustrial conditions for atmospheric CO2. Next, a historical simulation will be launched for the period 1860-1960 using observed atmospheric CO2.

At this point an ocean biogeochemistry reconstruction for the period 1961-present will be performed using the nudging procedure selected to generate the dynamical fields used for the offline spinup. For this reconstruction we will use NEMO in stand-alone mode but coupled with PISCES. By constraining physical fields we intend to provide close-to-observed forcing to PISCES assuming PISCES will respond by computing a solution for biogeochemistry that is closer to the 'truth' than when using a non-constrained forcing.

Phase 2:

Finally, in the second phase of the project, predictions will be initialized every three years from 1979 to present. Initial conditions for physical and biogeochemical fields will be taken from the ocean biogeochemistry reconstruction. Ten forecast years will be run with 10 members for each forecast start date. The ensemble will cover the period from 1979 to 2025. These simulations will be performed with the fully coupled version of EC-Earth.
Summary of simulations
Simulations done in the first phase of the project:
5 NEMO stand-alone (physics only) x 56 years
1 PISCES offline spin-up x 3000 years
1 EC-Earth fully coupled x 120 years (e.g. spin-up extension)
1 EC-Earth fully coupled x 101 years (historical simulation)
1 NEMO stand-alone+PISCES x 56 years (ocean biogeochemistry reconstruction)
Simulations done in the second phase of the project:
Predictions using EC-Earth fully coupled: 13 start dates x 10 members x 10 years

g) Computational algorithms and codes outline

EC-Earth3 comprises three major components: IFS (atmospheric component), NEMO (oceanic component) and OASIS3 (coupler). It is essential to configure 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 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, 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 supports several configurations which have already been tested on various supercomputing platforms, Marenostrum3 and Marenostrum4 among them. In this activity we will use the T255-ORCA1 configuration, which corresponds to a spatial resolution of 80 km in the atmosphere and 100 km in the ocean. In order to store sources and initial data, the experiments require at least ~100 GB of disk space for each release. Currently, four releases of EC-Earth3 are available, v3.0, v3.0.1, v3.1 and v3.2. This activity is planned to be carried out with the version v3.2.

3. Software and Numerical Libraries

Software components that the project team requires for the activity.

a) Applications + Libraries

BLAS, FFTW, HDF5, LAPACK, NETCDF, R, OPENMPI, UDUNITS, NCO

b) Compilers and Development Tools

GCC, TOTALVIEW, INTEL

c) Utilities + Parallel Debuggers and Performance Analysis Tools

CMAKE, PERL, PYTHON, VALGRIND, NCVIEW, NCL, AUTOCONF

d) Other requested software

GRIP_API, CDO

e) Proprietary software

4. Research Team Description

a) Personal Data

Name of Team Leader	Valentina Sicardi
Gender	Female
Institution	Barcelona Supercomputing Center
e-mail	vsicardi@bsc.es
Phone	934137678
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

The scientist responsible of this proposal is Valentina Sicardi, and is a PostDoctoral research fellow at the Climate Prediction Group, led by Dr. Pablo Ortega, within the Earth Science department led by Prof. Doblas-Reyes of the Barcelona Supercomputing Centre.
Dr. Valentina Sicardi, holds a Masters Degree in Environmental Sciences with majors in Oceanography and Meteorology from the Univerisita' Parthenope, Napoli, (Italy) and obtained a PhD degree from the University of Hamburg for her research at the Max Planck Institute for Biogeochemistry, Jena, (Germany). Since 2010 she has worked at the Earth Sciences Department of the Barcelona Supercomputing Center where she has developed a post-process system to assimilate data with Kalman Filter to improve statistics of air quality forecast. In 2016 she joined the Climate Prediction Group in the same department and at present she is conducting research on the optimal strategy to initialize the climate model EC-Earth for seasonal-to-decadal predictions while also contributing to the coupling of the ocean biogeochemical model PISCES to EC-Earth and the generation of initial conditions for biogeochemical predictions

d) Names of other researchers involved in this activity

Francisco Doblas-Reyes (francisco.doblas-reyes@bsc.es)
Valentina Sicardi (valentina.sicardi@bsc.es)
Eleftheria Exarchou (eleftheria.exarchou@bsc.es)
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Yohan Ruprich-Robert (yruprich@bsc.es)
Juan Acosta Navarro (juan.acosta@bsc.es)

e) Relevant publications

Bernardello, R. et al. (2014) Response of the Ocean Natural Carbon Storage to Projected Twenty-First-Century Climate Change. Journal of Climate 27: 2033-2053.

Bernardello, R. et al. (2014) Impact of Weddell Sea deep convection on natural and anthropogenic carbon in a climate model. Geophysical Research Letters 41: 7262–7269.

Doblas-Reyes, F. J. et al. Initialized near-term regional climate change prediction. Nat Comm. 4, 1715 (2013).

Guemas, V. et al. A review on Arctic sea-ice predictability and prediction on seasonal to decadal time-scales. Q. J. R. Meteorol. Soc. 142, 546-561 (2014).

Guemas, V., Doblas-Reyes, F. J., Andreu-Burillo, I. & Asif, M. Retrospective prediction of the global warming slowdown in the past decade. Nat. Clim. Chang. 3, 1–5 (2013).

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	648.00
Estimated number of jobs to submit	2000.00
Average job durations (hours) per job	1.00
Total memory used by the job (GBytes)	100.00
Largest Job Run	
Number of processors needed for each job	712.00
Estimated number of jobs to submit	3000.00
Average job durations (hours) per job	1.00

Total memory used by the job (GBytes)		100.00		
Total disk space (Gigabytes)	**Minimum**	1500.00	**Desirable**	2000.00
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)		4000.00		

If this activity is asking for more than 5Million 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 4280 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)
4000.00

6. Abstract for publication

The recent COP21 Paris agreement ties the participating countries to reduce anthropogenic carbon emissions in order to contain global warming within 2oC by the end of this century. This translates into the necessity to estimate the compatible CO2 emissions well ahead of time to make sure targets are met. However, precision in these estimates can be achieved only if sources and sinks of carbon are known with the highest possible accuracy. The ocean represents one major sink as it takes up about 25% of the anthropogenic carbon emitted by humans. However, this estimate oscillates because natural variability and ongoing climate change could alter the capacity of the ocean to absorb carbon. Using the EC-Earth Earth System Model, we assess the ability to predict the ocean carbon uptake on timescales ranging from one month to one decade ahead.

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 this is my first application to RES.

Barcelona Supercomputing Center, 2016