Barcelona Supercomputing Center
Centro Nacional de Supercomputación

RED ESPAÑOLA DE SUPERCOMPUTACIÓN

AECT-2020-1-0023 Global carbon-cycle simulations with the EC-Earth Earth System Model

1. General Information

Activity Id
AECT-2020-1-0023

a) Activity Title
Global carbon-cycle simulations with the EC-Earth Earth System Model

b) Area
Astronomy, Space and Earth Sciences

c) Type of application
Standard Activity for the next 4 months

--- 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?
No

c) Brief description of the Project
The Intergovernmental Panel on Climate Change 5 th Assessment Report (IPCC AR5) concluded that "Cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond", unambiguously identifying the causal link between anthropogenic emissions of carbon dioxide (CO2) and global warming(1) . The IPCC AR5 further summarized that "Cumulative total emissions of CO2 and global mean surface temperature response are approximately linearly related. Any given level of warming is associated with a range of cumulative CO2 emissions, and therefore, e.g. higher emissions in earlier decades imply lower emissions later." The IPCC AR5 also assessed the positive feedback between climate change and the carbon cycle stating: "there is high confidence that

the feedback between climate and the carbon cycle is positive in the 21st century. As a result more of the emitted anthropogenic CO2 will remain in the atmosphere"(1) . These findings highlight the central role of the carbon cycle in the global climate system.

The main goal of the CCiCC (Carbon Cycle Interactions in the Current Century) project is to increase our understanding of the carbon-climate feedbacks and develop systems for climate predictions and projections in support of the Paris Agreement. This project is comprised of 3 objectives: 1) Better understanding of processes controlling the global carbon cycle ; 2) Towards a near-term prediction of the climate and carbon cycle and 3) Reducing uncertainties in climate projections over the 21st century. Related to these topics is the Coupled Climate–Carbon Cycle Model Intercomparison Project (C4MIP) (2) which is one of the projects under the umbrella of the 6th Coupled Model Intercomparison Project (CMIP). Participation in the C4MIP project allows to better quantify how the different participating Earth System Models (ESMs) simulate the coupled climate-carbon feedbacks and to better quantify their biases and errors in simulating the global Earth System, including the atmosphere, ocean, land and carbon budget.

The Climate Prediction Group (CPG) of the BSC is participating in the C4MIP exercise as well as the CCiCC project, using the EC-Earth Earth System Model. Participation in C4MIP is crucial to provide a reference point in understanding the performance of the EC-Earth model and how it compares to other state-of-the art ESMs. This computing project will allow to perform the basic experiments necessary for the participation of the BSC's CPG in the C4MIP project, which will also serve as a preliminary version of a subset of the simulations required for the CCiCC project. Other activities are planned in the future specifically for the CCiCC project, which will expand on the expertise and knowledge gained in the C4MIP exercice, by using an improved land/vegetation model and performing state-of-the-art near-term predictions of the climate system and the global carbon cycle.

Other research projects linked to this computing project are : Decadal predictions of Carbon Uptake in the Southern Ocean and impact of the biological carbon pump uncertainty (DeCUSO), as well as 2 Marie Skłodowska-Curie actions (MSCA) whose beneficiaries are actively involved in this project (including the PI) : NeTNPPAO (Near-term predictability of net primary production in the Atlantic Ocean) and SPFireSD (Seasonal Prediction of Fire danger using Statistical and Dynamical models).

References:

1 - IPCC. in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers. (ed T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J.
2- Jones, C. D., et al. (2016). C4MIP – The Coupled Climate–Carbon Cycle Model Intercomparison Project: experimental protocol for CMIP6, Geosci. Model Dev., 9, 2853–2880, https://doi.org/10.5194/gmd-9-2853-2016.

d) Grants and funded projects related to this activity

Reference code
CGL2017-84493-R

Project title
Decadal predictions of Carbon Uptake in the Southern Ocean and impact of the biological carbon pump uncertainty (DeCUSO)

Starting date
2018-01-01

Ending date
2020-12-31

Total financing (in EUR)
114.103,00

Financing source
National

Reference code
H2020-LC-CLA-2018-2-821003

Project title
Climate-Carbon Interactions in the Coming Century (CCiCC)

Starting date
2019-06-01

Ending date
2019-06-01

Total financing (in EUR)
7.784.750,00

Financing source
European

Reference code
748750

Project title
Seasonal Prediction of Fire danger using Statistical and Dynamical models (SPFireSD)

Starting date
2017-09-06

Ending date
2019-11-04

Total financing (in EUR)
170.121,00

Financing source

European

Reference code
H2020-MSCA-IF-2015-708063

Project title
Near-term predictability of net primary production in the Atlantic Ocean

Starting date
2017-02-01

Ending date
2019-02-01

Total financing (in EUR)
170.121,00

Financing source
European

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

N/A

f) Specific Activity proposed

The set of simulations proposed strictly follows the protocol described for C4MIP. The overall objective of C4MIP is to evaluate the response of the global carbon cycle to the present and future physical climate and its feedback into the climate system. In order to do so, modeling groups need to be able to run their Earth System Models in two configurations:
a) driven by atmospheric CO2 concentrations (concentration-driven)
b) driven by CO2 emissions (emission-driven)
In the first case, the global carbon cycle components are responding passively to the physical climate while the atmospheric CO2 concentration is prescribed from either historical observations or future scenarios derived from socio-economic models. In this configuration the ESM is not able to modify the atmospheric CO2 concentration so there is no feedback of the carbon cycle onto the climate.
In the second case, the global carbon cycle is fully coupled to the climate system and the atmospheric CO2 concentration is updated continuously by the land and ocean components in response to the CO2 emissions prescribed coherently to their concentration-driven counterpart (i.e. from either observations or socio-economic scenarios) . In this case, there is a feedback from the carbon cycle onto the climate system.

The model used to perform the simulation is the EC-Earth Earth System Model version 3.3.2, described in section e) below. The two configurations used required the IFS atmospheric model, NEMO ocean model and LPJ-GUESS Dynamic Vegetation Model. The two configurations differ in performance as the emission-driven configuration needs an extra model component (TM5) to simulate the transport of CO2

within the atmosphere.

Significant effort has been put into finding the optimal computing setup for the two configurations on the Marenostrum4 supercomputer located at the BSC. For the concentration-based runs, the optimal configuration using 1104 cores (23 nodes) allows to perform 1 year of simulation in 2 hours. The emissions-based configuration requires the use of TM5 which limits the number of cores on which the atmospheric model (IFS) can be used. The configuration for this setup is 672 cores (14 nodes), and the time taken to simulate a year is just under 4 hours.

The simulations to perform during this computation project, required to complete the DECK simulations for C4MIP are :

Concentration-driven (total of 1047 years, 1151 considering job failures)):

-piControl (500 years) – Atmospheric CO2 and all other radiatively active gases and aerosols are kept constant at preindustrial levels, representative of year 1850.
-historical (165 years, 1850 – 2014) – Atmospheric CO2 and all other radiatively active gases and aerosols are prescribed according to observed values until the end of year 2014.
-1pctCO2 (141 years) – Atmospheric CO2 is increased by 1% annually until doubling.
-1pctCO2-bgc (141 years) – Atmospheric CO2 is increased by 1% annually until doubling. However, the increase in atmspheric CO2 is seen only by the land and ocean carbon components (not by the atmospheric radiation code).

Emission-driven (total of 851 years, 936 considering job failures):

-online adjustment (100 years) - this is required before starting the piControl in order to minimize the drift.
-esm-piControl (500 years) – Like piControl but with interactive carbon cycle and zeroemission of CO2.
-ems-hist (165 years, 1850-2014) – Like historical but with historical emission of CO2 rather than historical atmospheric CO2 concentrations.
-esm-ssp585 (86 years, 2015-2100) – Future scenario with CO2 emissions following the socio-economic scenario associated with RCP8.5.

g) Computational algorithms and codes outline

The EC-Earth3 GCM (Global Climate Model) comprises three major components: the atmospheric model IFS (Integrated Forecasting System) Cy36r4, the ocean model NEMO 3.6, which also includes the LIM3 sea-ice model, and OASIS3 that couples the main components. IFS is an operational global meteorological forecasting model developed and maintained by the European Centre of Medium-Range Weather Forecasts (ECMWF). NEMO is a state-of-the-art modelling framework for the ocean used for oceanographic research, operational oceanography, seasonal forecasting and climate research studies. The ESM (Earth System Model) version of EC-Earth3 includes additional components, also coupled via OASIS3: LPJ-GUESS dynamic vegetation model, PISCES ocean biogeochemistry model(as a NEMO module) and TM5 global atmospheric transport model. LPJ-GUESS is used to simulate the evolution of the land vegetation and carbon fluxes, PISCES is used to simulate ocean biogeochemistry and CO2 fluxes with the atmosphere and TM5 is used for atmospheric chemistry and transport of trace gases

such as CO2.

In this activity we will use the T255-ORCA1 configuration, which corresponds to a spatial resolution of 80 km in the atmosphere/land and 100 km in the ocean, and 3x2 degrees with 10 vertical levels, CO2-only configuration for TM5. For CO2 emission-driven simulations the full configuration is needed, including atmospheric transport module TM5. On the other hand, for CO2 concentration-driven simulations, a reduced configuration is sufficient (no TM5 needed) resulting in a considerably less computationally demanding implementation. In order to store sources and initial data, the experiments require at least ~100 GB of disk space for each release. This activity will be carried out with EC-Earth version v3.3.2 released in December 2019.

3. Software and Numerical Libraries

Software components that the project team requires for the activity.

a) Applications + Libraries

BLAS, HDF5, LAPACK, NETCDF, R, NCVIEW, NCL, NCO, GRIB, BASH, CMOR, GRIBEX

b) Compilers and Development Tools

GCC, OPENMPI, INTEL

c) Utilities + Parallel Debuggers and Performance Analysis Tools

CMAKE, PERL, PYTHON, VALGRIND, FCM

d) Other requested software

CDO

e) Proprietary software

N/A

4. Research Team Description

a) Personal Data

Name of Team Leader	Etienne Tourigny
Gender	Male
Institution	BSC
e-mail	etienne.tourigny@bsc.es
Phone	+34 934054290
Nationality	Canada

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. Etienne Tourigny has a PhD in Meteorology from the Instituto Nacional de Pesquisas Espaciais (INPE-CPTEC, Brasil) and a M.Sc. in Atmospheric Science from the Université du Québec à Montréal (UQAM). Dr. Tourigny has a strong multi-disciplinary background, having studied physics, computer science, atmospheric science and biosphere-atmosphere interactions. He has professional experience in the Information Technology sector, before transitioning to the climate research field where he developed his expertise in the field of climate seasonal prediction, having studied the impacts of ENSO on precipitation anomalies in the tropical Americas. He contributed to the development of the Brazilian Earth System Model (BESM) at INPE – CCST acquiring in the process a very strong expertise in vegetation and fire modelling as well as in high-performance computing. After joining the climate prediction group at BSC, he obtained a Marie Skłodowska-Curie fellowship on seasonal prediction of fire danger (SPFireSD). During his stay at the BSC he has participated in 3 important H2020 projects (PRIMAVERA, IMPREX and CCiCC), published a paper in the prestigious Bulletin of the American Meteorological Society (BAMS), was involved in 3 RES and ECMWF computing resource projects, which are essential for the production of climate simulations which are used in a number of studies.

He is now one of the researchers of the CPG involved in the Climate-Carbon Interactions in the Coming Century (CCiCC) H2020 project, which will provide substantial funding for the BSC. He is also currently participating in the preparation of several research projects with external collaborators such as ECMWF and other EC-Earth partners. He is currently actively participating in the Climate Prediction's group efforts to produce climate projections and decadal predictions for CMIP6 using the EC-Earth Earth System Model, which will form the scientific basis of the next IPCC Assessment Report. Due to his experience with and knowledge on atmosphere/biosphere interactions and Earth System and vegetation modelling, he is being recognized as his research center's main responsible for the land surface and carbon cycle modelling.

d) Names of other researchers involved in this activity

Raffaele Bernardello (raffaele.bernardello@bsc.es)
Louis-Philippe Caron (louis-philippe.caron@bsc.es)
Pablo Ortega (portega@bsc.es)
Juan C. Acosta Navarro (jacosta@bsc.es)
Pablo Echevarria (pablo.echevarria@bsc.es)
Arthur Amaral Ramos (arthur.amaral@bsc.es)

and most of the Climate Prediction Group at BSC

e) Relevant publications

Acosta Navarro, J.C., P. Ortega, J. García-Serrano, V. Guemas, E. Tourigny, R. Cruz-García, F. Massonnet and F.J. Doblas-Reyes (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, Explainig Extreme Events of 2017, 100, S43-S48, doi:10.1175/BAMS-D-18-0097.1.

Bernardello, R. et al. Impact of Weddell Sea deep convection on natural and anthropogenic carbon in a climate model. Geophys. Res. Lett. 41, (2014b).

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

Caron, L-P, L Hermanson, A Dobbin, J Imbers, L Lledó and GA Vecchi (2018) How skilful are the multi-annual forecasts of Atlantic hurricane activity? Bull Amer Meteor Soc. 99, 403-413.

L. F. C. Rezende; B. C. Arenque; S. T. Aidar; M. S. B. Moura; C. Von Randow; E. Tourigny; R. S. C. Menezes; J. P. H. B. Ometto. Evolution and challenges of dynamic global vegetation models for some aspects of plant physiology and elevated atmospheric CO2. International Journal of Biometeorology. pp. 1 - 11. 2015. doi: 10.1007/s00484-015-1087-6.

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		1104.00		
Estimated number of jobs to submit		1151.00		
Average job durations (hours) per job		2.00		
Total memory used by the job (GBytes)		2300.00		
Largest Job Run				
Number of processors needed for each job		672.00		
Estimated number of jobs to submit		936.00		
Average job durations (hours) per job		4.00		
Total memory used by the job (GBytes)		1400.00		
Total disk space (Gigabytes)	**Minimum**	10240.00	**Desirable**	20480.00
Total scratch space (Gigabytes)	**Minimum**	20480.00	**Desirable**	40960.00
Total tape space (Gigabytes) (*)	**Minimum**	0.00	**Desirable**	0.00
Total Requested time (Thousands of hours)		5057.00		

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 5410.99 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.

6. Abstract for publication

The main goal of the CCiCC project is to increase our understanding of the carbon-climate feedbacks and develop systems for climate predictions and projections in support of the Paris Agreement. Participation in the C4MIP project allows to better quantify how Earth System Models (ESMs) simulate the coupled climate-carbon feedbacks of the global Earth System. This computing project will allow to perform the basic experiments necessary for the participation of the BSC's Climate Prediction Group in the C4MIP project. Participation in C4MIP is crucial to provide a reference point in understanding the performance of the EC-Earth model and how it compares to other state-of-the art ESMs and will also serve as a preliminary version of a subset of the simulations required for the CCiCC project.

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.