Barcelona Supercomputing Center
Centro Nacional de Supercomputación

RES
RED ESPAÑOLA DE SUPERCOMPUTACIÓN

TEMP-2018-3-0097 Predictability of Ocean Biogeochemical Conditions on Decadal Timescales with the Earth System Model EC-Earth.

1. General Information

Activity Id

TEMP-2018-3-0097

a) Activity Title

Predictability of Ocean Biogeochemical Conditions on Decadal Timescales with the Earth System Model EC-Earth.

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?

No

c) Brief description of the Project

With new predictions of future world population reaching 9.6 billion by 2050 (1) and the related spectre of a global food crisis, the necessity to improve our ability to manage world's fisheries has never been more pressing. A fundamental step in this direction and the main goal of this project is the improvement of near-term (i.e. seasonal to decadal) predictions of oceanic Net Primary Production (NPP). NPP is the rate of production of phytoplankton biomass, the primary source of food for marine animal life. A recent study showed the existence of a close relationship between fish biomass and NPP in the open ocean (2). According to "The State of World Fisheries and Aquaculture-2012" (3) (Food and Agriculture Organization - FAO), in 2010 all 6 Atlantic fishing areas identified in the report have shown decreasing trends or considerable fluctuations in catches during the past decades resulting from either environmental variability, fishing pressure or a combination of both. Many studies point to a tight connection between fluctuations in fish populations and both natural climate variability (4) and anthropogenic climate change (5). However, in the past fish stocks management has often relied on the assumption that marine ecosystems were in long-term equilibrium, with fishing pressure being the dominant factor controlling fish populations. This resulted in management strategies based on extrapolations from historical time-series of fish catches, leading in some cases to overestimated sustainable harvest rates that contributed to the decline of fish stocks (6). Therefore, the improvement of ecosystem-based strategies is becoming a priority for near-future fisheries management (7). Over the past few years near-term climate predictions have emerged as rapidly improving tools at the service of society and decision-makers. The 5th Coupled Model Intercomparison Project (8), which contributed to the 5th IPCC Assessment Report, included a set of near-term climate predictions that proved skilful at regional scales (9). 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 temperature (10) or the fluctuations in the strength of the North Atlantic subpolar gyre (11). Near-term climate predictions can be performed using state-of-the-art Earth System Models (ESMs). ESMs are complex tools that attempt to represent all the processes that are of relevance for climate. Among them, ESMs usually include a representation of ocean biogeochemical cycles. EC-Earth (12) will be the model used to develop the activities proposed here and its ocean biogeochemical component PISCES (13) will provide the model estimate of NPP.

Producing near-term predictions of ocean biogeochemistry is an emerging and promising idea but it has been applied only to few models so far, to investigate the predictability of NPP over the tropical Pacific (14) or the global ocean (15) and of the carbon uptake over the North Atlantic (16) or at the global scale in a perfect model set up (17). The research project proposed here will move beyond these attempts by using different and more sophisticated initialization techniques for the physical state of the ocean and, in particular by investigating the improvement in predictability skill derived from the concurrent initialization of reconstructed 3D nutrient fields. We plan to perform a set of experiments with the EC-Earth ESM within the context of two projects in which the principal researcher of this proposal is also the PI: "Near-term predictability of net primary production in the Atlantic Ocean", a Marie-Curie Individual Fellowship (Ref.: NeTNPPAO-708063) and "Decadal predictions of Carbon Uptake in the Southern Ocean and impact of the biological carbon pump uncertainty" (Ref.: DeCUSO-CGL2017-84493-R).

References:
1 Gerland P., et al. Science. 346: 234–237; (2014).
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4 Lehodey P., et al. J. Clim. 19: 5009–5030; (2006).
5 Brander K. J. Mar. Syst. 79: 389–402; (2010).
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14 Séférian, R. et al. Proc. Natl. Acad. Sci. U. S. A. 111, 11646–51 (2014).
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d) Grants and funded projects related to this activity

Reference code	Project title
CGL2017-84493-R	Decadal predictions of Carbon Uptake in the Southern Ocean and impact of the biological carbon pump uncertainty (DeCUSO)

Starting date	Ending date	Total financing (in EUR)	Financing source
2018-01-01	2020-01-31	114.103,00	National

Reference code	Project title
708063	Near-term predictability of net primary production in the Atlantic Ocean

Starting date	Ending date	Total financing (in EUR)	Financing source
2017-02-01	2019-01-31		European

170.121,60

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

f) Specific Activity proposed

Before performing historical reconstructions and near-term climate predictions with an ESM, the representation of the global ocean biogeochemical fields 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. This activity was completed within the framework of the national project (DeCUSO, Ref: CGL2017-84493-R) using computing hours awarded by RES in a previous call (AECT-2018-1-0020 Seasonal-to-decadal predictions of ocean carbon uptake with the EC-Earth Earth System Model). Therefore, this proposal focuses on building upon and expanding the set of simulations carried out within DeCUSO. In particular, here we will test two different initializations techniques with the objective to establish the optimal set-up for ocean biogeochemistry within the prediction system of BSC.

Future near-term climate is the result of two components : a) - atmospheric composition relative to radiatively active gases (including anthropogenic contribution); b) - an internally generated component that represents the natural variability of climate. ESMs can be used to simulate historical and future climate by constraining the radiative forcing (component a) with a time-varying atmospheric composition based on observed data and future emission scenarios, respectively. These simulations do not attempt to phase the model's prediction with the observed natural variability of the climate (component b) and are thus useful only in a statistical sense on centennial timescales. ESMs can also produce climate reconstructions where, besides the radiative forcing, the natural variability is also taken into account by continuously constraining the model' solution towards the observed state of the climate through sophisticated numerical techniques commonly referred to as data assimilation (or nudging, here used as a synonym). Finally, ESMs can be used to perform near-term climate predictions where the radiative forcing is still constrained throughout the simulation but only the simulation's initial state is constrained towards the observed climate through data assimilation, a procedure referred to as initialization. The evaluation of the ability of a model and a particular initialization technique to produce skilful near-term climate predictions is normally assessed by comparing retrospective climate predictions with available observations (or reanalysis products). Retrospective climate predictions, are predictions of the past climate initialized using only contemporaneous information available at the time of starting the simulation. Here, the expressions:

"near-term climate predictions" and "retrospective climate predictions" are used as synonyms.

Because near-term prediction of ocean biogeochemistry is a new field of research there is still a lack of literature as to which, where and how variables should be initialized to perform such predictions. For example, the ocean biogeochemical model could be treated as a passive "passenger" responding to ocean dynamics. In this case, its solution is not interfered with any initialization. On the other hand, some degree of constraint can be applied directly to ocean biogeochemical fields using, for example, climatological observations of macro-nutrients (e.g. nitrate, phosphate, silicate). Furthermore, some regions with particularly poor observation coverage (e.g. Southern Ocean) could be left out of the initialization process. Moreover, near-term predictions can be initialized directly from observations or reconstructions performed with another model or from a reconstruction performed with the same model used for the prediction. Only a couple of the above possibilities (and their combinations) have been tested so far.

Here, we will test two such techniques by producing two sets of retrospective near-term predictions covering the period 1981-2014. Specifically, we will initialize predictions using:

1- physical and biogeochemical fields taken from a reconstruction performed with the full EC-Earth configuration (atmosphere+ocean+ocean biogeochemistry) where only temperature and salinity are nudged.
2- physical and biogeochemical fields taken from a reconstruction performed with the full EC-Earth configuration (atmosphere+ocean+ocean biogeochemistry) where temperature and salinity as well as macro-nutrients are nudged.

For each set, we will initialize predictions every three years starting in 1981 and ending in 2014 and we will run ten forecast years with 10 members for each forecast start date. Simulations performance will be evaluated using a wide variety of prediction scores against available observations. Researchers at BSC develop and distribute a R package designed for forecast verification: s2dverification (= seasonal to decadal verification) which will be the main tool in the evaluation process. The datasets used for the atmospheric and oceanic data-assimilation and initialization will be reanalyses from the ECMWF (European Center for medium Range Weather Forecasts): ORAS4 and ERA40 / ERA-interim or newer if available when the project starts. Observed sea ice concentration and sea ice drift will be prescribed from HadISST, NSIDC or OSISAF datasets or from a newer product if available. An independent dataset used for validation of SST will be the NOAA (National Oceanic and Atmospheric Administration) ERSSTv3b (18). NPP will be validated using three estimates derived from different algorithms: the Vertically Generalized Production Model (19) (VGPM), the Eppley-VGPM (20) and the algorithm proposed by Marra et al. (2003) (21). These algorithms use remote sensing chlorophyll derived from NASA sensors SeaWiFS (1997-2008) and MODIS-Aqua (2002-present). Moreover, surface nitrate will be partially validated using a new product available for the period 2005-2010 (22). Finally, air-sea CO2 fluxes will be validated using a recent observation-based product covering the period 1981-present (23).

The two set of predictions described here will be also compared to one that was already executed within DeCUSO, where physical and biogeochemical fields are taken from an ocean-only reconstruction with only temperature and salinity nudging. Finally, the set of predictions giving the best skill score will be extended to one start date per year to have a more complete assessment of the predictability of ocean biogeochemical conditions.

Summary of simulations

2 EC-Earth (fully coupled model) x 56 years (reconstructions for Set 1 and 2)
Set 1 - 12 start dates x 10 members x 10 years (fully coupled EC-Earth)
Set 2 - 12 start dates x 10 members x 10 years (fully coupled EC-Earth)

Extension of best-performing set: 22 start dates x 10 members x 10 years (fully coupled EC-Earth).

References

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21 Marra,J., et al. LDEO#2003-1, Lamont-Doherty Earth Observatory, (2003).
22 Arteaga L., et al. Geophys. Res. Lett. 42: 1130-1138; (2015).
23 Landschützer, P. et al. Science 349, 1221-1224, (2015).

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, OCTAVE, 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	Raffaele Bernardello
Gender	Male
Institution	Barcelona Supercomputing Center

e-mail raffaele.bernardello@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

Dr. Raffaele Bernardello (Team leader on this project) has a wide experience in the use and development of Earth System Models, particularly on the ocean biogeochemical aspect. During his PhD (Universitat Politecnica de Catalunya, Spain) he implemented a coupled physical-biogeochemical model configuration for the Western Mediterranean Sea to study the interannual variability of phytoplankton blooms and their relation to the export of organic matter (24) . After the completion of his PhD he joined the Ocean and Climate Dynamics group at the University of Pennsylvania as a postdoctoral researcher under the supervision of Dr. I. Marinov. At the same time Bernardello has strictly collaborated with the Atmospheric and Oceanic Sciences department at Princeton University, led by Prof. J. Sarmiento. During this time he has directed his research at unveiling the complex mechanisms regulating the response of ocean carbon uptake to projected physical perturbations driven by future climate change using a climate model, with particular attention to Southern Ocean's dynamics (25, 26). Bernardello then moved to the UK where he accepted a position as a research scientist within the Ocean Biogeochemistry and Ecosystem Department at the National Oceanography Centre (NOC), Southampton. At NOC Bernardello collaborated, among others, with Dr. A. Martin and Prof. S. Khatiwala to investigate the impact on global nutrient distributions of different parameterizations commonly used in ESMs for export and remineralization of organic matter (27). Finally, in 2017 Bernardello joined BSC as a Marie-Curie fellow. At BSC, Bernardello is leading the effort in extending the department's experience in near-term predictions to ocean biogeochemical conditions and the global carbon cycle. Bernardello has been recently granted a national project (DeCUSO Ref:CGL2017-84493-R) to investigate the predictability of decadal variability in Southern Ocean carbon uptake. He is currently supervising one postdoctoral researcher and will start supervising one PhD student over the next year.

References

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27 Bernardello, R. et al. Submitted to Glob. Biogeochem. Cy.

d) Names of other researchers involved in this activity

Francisco Doblas-Reyes (francisco.doblas-reyes@bsc.es)
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Marcus Falls (marcus.falls@bsc.es)
All at Barcelona Supercomputing Center

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	720.00
Estimated number of jobs to submit	3700.00

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		0.00		
Estimated number of jobs to submit		0.00		
Average job durations (hours) per job		0.00		
Total memory used by the job (GBytes)		0.00		
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)		2800.00		

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 2996 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

With new predictions of future world population reaching 9.6 billion by 2050 and the related spectre of a global food crisis, the necessity to improve our ability to manage world's fisheries has never been more pressing. A fundamental step in this direction and the main goal of this project, is the improvement of decadal predictions of oceanic Net Primary Production (NPP). NPP is the rate of production of phytoplankton biomass, the primary source of food for marine animal life. The activities proposed are based on a suite of simulations with an Earth System Model. These simulations include reconstructions of the biogeochemical state of the global ocean for the period 1960 to present and two set of near-term predictions initialized every 3 years for the period 1981 to 2014 to test different initialization techniques.

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 contacted other RES representatives (e.g. Access Committee or User Support).

Usage Terms & Conditions

- The Usage Terms & Conditions have been already accepted.