Barcelona Supercomputing Center
Centro Nacional de Supercomputación

RES
RED ESPAÑOLA DE SUPERCOMPUTACIÓN

AECT-2017-2-0008 Understanding the sources of model bias in the Tropical Atlantic

1. General Information

Activity Id

AECT-2017-2-0008

Previous Activity Id

AECT-2016-3-0004

a) Activity Title

Understanding the sources of model bias in the Tropical Atlantic

b) Area

Astronomy, Space and Earth Sciences

2. Results of this activity from the previous application periods

a) Description of the results obtained during the previous periods

We have used the standard configuration T255-ORCA1 of the EC-Earth climate model version 3.1, an earlier version of which is described in detail in Hazeleger et al. 2005. The atmospheric component is IFS, has horizontal resolution of approximately 0.7 degrees, and uses 91 vertical levels. The ocean component is NEMO (Madec, 2008), and the so called ORCA1 configuration consisting of a tripolar grid at a resolution of about 1 degree. The LIM2, (Fichefet and Maqueda, 1997; Bouillon et al., 2009) is included in NEMO. The atmosphere and ocean sea-ice components of EC-Earth are coupled every 3 hours with the Ocean Atmosphere Sea Ice Soil coupler version 3 (OASIS3; Valcke, 2006).

We performed and analyzed a set of retrospective predictions (also known as hindcasts). IFS was initialized with ERA-interim reanalysis data (Dee et al., 2011), while NEMO-LIM2 is initialized with GLORYS2V1 reanalysis data (Ferry et al., 2010). The hindcasts were initialized every first of May and every first of November from 1993 until 2009 . To identify the respective contribution of the ocean and atmosphere components of EC- Earth in the development of the SST bias, a series of ocean and atmosphere standalone experiments were performed on ORCA1L46 and T255L91 configurations, respectively. Finally, a coupled historical experiment was run from 1960 to 2000. The total computational resources used for the 1st phase of this activity amounted to 608kh, 104.78 % of the 580kh granted.

We found that the historical simulation has a warm SST bias in the eastern Tropical Atlantic, which along the coast of Angola and Namibia reaches 2 deg C. The bias exhibits a seasonal cycle with a minimum in February-May, and a maximum in August-November. The episodic northward extension of the bias prevents the eastern equatorial Atlantic cold tongue, normally appearing in early summer, from developing. The structure of the SST bias is similar to the one found in most CMIP5 models but has weaker magnitude (e.g. Richter, 2015).

The bias patterns seen in the historical run develop very quickly from the first to the second month in the coupled hindcast experiment in both summer and winter forecasts, and stabilize afterwards to values close to the bias of the historical run. The rapid development of the forecast bias hints at mechanisms with short timescales, such as atmospheric or upper ocean mixing processes.

In the ocean standalone experiment, the bias is present in summer but is significantly smaller than in coupled experiments.. This suggests that (at least) part of the bias originates from unrealistically resolved features in the ocean component of EC-Earth, or deficiencies related to the surface forcing used in the ocean standalone hindcast. The winter forecast with the ocean hindcast does not exhibit the SST bias. This suggests the possible implication of the atmosphere component or/and mechanisms inherent to the ocean-atmosphere coupling in the development of the bias in the coupled simulations.

We have analyzed the surface heat fluxes. We found that strong positive biases (causing warming) in solar fluxes develop close to the east boundary of the Atlantic basin. The cause of solar flux biases is related to the anomalously weak cloud cover. The biases in the clouds and in the solar fluxes are present from the first day of the forecasts also in the standalone atmospheric experiment, suggesting that they are an inherent bias of the atmospheric model.

References

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Fichefet, T. and M. Maqueda, 1997: Sensitivity of a global sea ice model to the treat-ent of ice thermodynamics and dynamics. Journal of Geophysical Research: Oceans (1978–2012), 102 (C6), 12 609–12 646.

Bouillon, S., M. A. M. Maqueda, V. Legat, and T. Fichefet, 2009: Sea ice model formulated on Arakawa B and C grids. Ocean Modelling, 27, 174–184.
Valcke, S., 2006: Oasis3 user guide (prism_2-5). PRISM support initiative report, 3, 64.

Dee, D. P., et al., 2011: The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Quarterly Journal of the Royal Meteorological Society, 137 (656), 553–597, URL http://centaur.reading.ac.uk/24937/.

Ferry, N., L. Parent, G. Garric, B. Barnier, and N. C. Jourdain, 2010: Mercator global eddy permitting ocean reanalysis glorys1v1: Description and results. Mercator-Ocean Quarterly Newsletter, 36, 15–27.

Richter, I., 2015: Climate model biases in the eastern tropical oceans: causes, impacts and ways forward. Wiley Interdisciplinary Reviews: Climate Change, 6 (3), 345–358, doi:10.1002/wcc.338, URL http://doi.wiley.com/10.1002/wcc.338.

b) List of publications, communications in conferences, presentations, patents, etc, resulted in previous periods of this Activity

Exarchou Eleftheria et al, Sources of EC-Earth bias in the Tropical Atlantic, 5th WGNE workshop on systematic errors in weather and climate models, June 19-23, 2017, Montréal, Québec, Canada, oral presentation

Exarchou, E. and C. Prodhomme, and L.Brodeau, and V. Guemas 2017: Origin of the warm eastern tropical Atlantic SST bias in a climate model, to be submitted in Climate Dynamics

3. Research Project Description

a) Specific Activity proposed

With this proposal, we aim to address one of the main research goals of the PREFACE project, which is the understanding of the mechanisms generating the systematic biases in the Tropical Atlantic in global climate models. The model bias is routinely defined as the departure of the model solution from observations after the model has reached its preferred climatological state (i.e. it has reached equilibrium). At equilibrium, the model solution does not change with time (apart from following a seasonal cycle). The analysis of the transient model error, or equivalently the model drift from an initial observed state, while the model converges to its equilibrium, provides insight of the processes that are responsible for the bias development. Whereas transpose-AMIP experiments (Philips et al, 2004), in which an atmospheric model is initialized from observations, have been exploited for a decade to investigate the processes by which cloud biases, for example, develop, this approach applied to the development of surface oceanic biases has not been employed yet and would be highly innovative. If the model drift converges quickly to the model systematic bias, it implies that fast processes, such as the atmospheric surface forcing or the upper ocean mixing, are involved in the error generation. If the model drift converges slowly to the model systematic bias, it suggests that slower processes, such as those related to ocean dynamics, are involved in the bias development, or that the biases are remotely generated and propagate in the Tropical Atlantic.

The pronounced systematic biases in the Tropical Atlantic are present in most CMIP-class global climate models, andcorrespond to a cold bias in the equator and a warm bias along the coast of Namibia and Angola. Possible sources of the model biases, according to previous studies, could involve the coarseness of the model resolution, deficiencies in the parameterizations of subgrid-scale processes, or deficiencies that arise from model numerics (e.g. Huang et al., 2003; Stainforth et al., 2005; Brierley et al., 2008). In particular, insufficient resolution in the atmosphere and in the ocean can be one of the causes of Tropical Atlantic biases. The horizontal and vertical resolution typically used in the atmosphere is not sufficient for resolving small scale processes that are necessary for correctly representing the eastern boundary stratocumulus clouds and the atmospheric boundary height (Large and Danabasoglu, 2006; Richter, 2015). In addition to the errors arising from the coarse atmospheric grid, potential sources of errors could also come from the coarse oceanic grid, which, with the resolution typically used in most models, is not sufficient for resolving the ocean eddies. The ocean eddies have been shown to be important for balancing the surface heating caused by the solar radiation in eastern ocean boundaries (Colas et al., 2012), and might impact the oceanic heat budget, and therefore, the sea surface temperature biases in the Tropical Atlantic. The impact of the model resolution on the model bias remains to date an open question. With the current proposal, we aim to analyze and quantify this impact on theTropical Atlantic biases.

To this end, we propose a suite of experiments, performed with the EC-Earth3.1 global climate model, that allows a systematic approach for identifying the sources of model errors, as discussed and suggested in Vanniere et al., 2014. A part of those experiments has already been completed during the

Phase 1 of this activity. It includes a historical experiment that covers the period between 1960-2000, which is an extension of a long spin-up simulation performed with the same model under pre-industrial conditions, so that the model has reached equilibrium. The comparison of the historical simulation to observations, has allowed an assessment of the systematic model errors, i.e. at the errors of the model at equilibrium. We found that EC-Earth exhibits SST bias patterns similar to those seen in most CMIP5 models but weaker in magnitude. To analyse the model drift, i.e. the transient model error while it converges to equilibrium, we have performed retrospective predictions (commonly known as hindcasts), which are initialized from an estimation of the observed state and are few months long. We found that the model error converges very fast to the bias of the historical simulation, which hints at fast atmospheric processes or oceanic mixed layer processes. To assess the error origin, we have performed two additional prediction experiments: one experiment with the uncoupled ocean model, and a second one with the uncoupled atmospheric model, in standard resolution. The SST bias is very weak, or even absent in some months, in the uncoupled ocean model, which suggests implication of the atmosphere component or/and mechanisms inherent to the ocean-atmosphere coupling in the development of the bias in the coupled simulations. Strong biases in solar fluxes, seen also in the uncoupled atmosphere model, suggest that inherent biases in the atmospheric model play an important role in the formation of the Tropical Atlantic SST biases.

To complete the suite of experiments we further propose for the Phase 2 of the activity to perform a second set of predictions at high resolution. The comparison between the high and standard resolution sets will allow an assessment of the impact of the model resolution on this error. The ocean resolution in the high resolution setup will be sufficient for resolving most eddies in the tropical region, therefore will allow us to examine the impact of resolved eddies on the model biases. Heat budgets will be conducted to narrow down the sources of temperature error. These heat budget will comprise an estimation of the eddy-induced heat transport in the ocean. The role of atmospheric resolution will also be assessed through diagnostics of vertically eddy induced mixing and planetary boundary layer height.

The proposed project will cover the second phase of two consecutive 4 month phases. During the first phase, which was completed in March 2017, the historical simulation in standard resolution covering the second half of the past century was performed (1960-2000). This simulation allowed us to assess the systematic bias in EC-Earth3.1. In addition, a retrospective coupled prediction experiment in standard resolution was performed, initialized every first of May and every first of November between 1993-2009. Two additional uncoupled prediction experiments, one with ocean only and the second one with atmosphere only, were also performed at standard resolution and with the same running setup as the coupled experiment.

Phase 2
During the second phase, a retrospective prediction experiment with the coupled model EC-Earth3.1 in high resolution will be performed, which will have similar running setup as the predictions experiments in Phase 1: 17 years x 2 start months x 5 members = 170 simulations of 4 months length. Benchmarking tests in Marenostum3 suggest that optimum performance for EC-Earth3.1 is obtained when using 1706 processors. The cost of each 4-month long simulation amounts to 8,530 CPU hours (1706 x 5, for 5 hours average job duration). The total cost for this simulation amounts to 170 x 8530 = 1,450,100 CPU hours, or 1,600,000 CPU hours when accounting for repeating failing jobs.
References:
Toniazzo, T. and S. Woolnough, 2013: Development of warm SST errors in the southern tropical Atlantic

in CMIP5 decadal hindcasts. Climate Dynamics, doi:10.1007/s00382-013-1691-2, URL http://link.springer.com/10.1007/s00382-013-1691-2.
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Stainforth, D. a., et al., 2005: Uncertainty in predictions of the climate response to rising levels of greenhouse gases. Nature, 433 (7024), 403–6, doi:10.1038/nature03301, URL http://www.ncbi.nlm.nih.gov/pubmed/15674288.
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b) Computational algorithms and codes outline

EC-Earth3 comprises three major components: IFS, NEMO and OASIS3. It is essential to configure and build separate executable for each one of them. IFS and NEMO fully support a parallel environment, while OASIS3 supports a pseudo-parallel environment. OASIS3 requires Cray pointers. 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, 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 are needed for IFS. To test the model with the run scripts, GNU date (64-bit) is also required.

EC-Earth3 is available in several configurations. In this project we will use two configurations: the standard resolution configuration of T255-ORCA1 which corresponds to a spatial resolution of 80 km in the atmosphere and 100 km in the ocean, and the high resolution configuration of T511-ORCA025, which corresponds to 40 km in the atmosphere and 30 km in the ocean. We also plan to perform ocean-only and atmosphere-only experiments in the standard configuration of T255 and ORCA1. 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. In this project we plan to use the v3.1 version.

Previously performed benchmarking inthe v3.1 version suggest that, taking into account the average load of the Marenostrum queues, optimum performance is obtained when using 502 cores in the standard resolution configuration, and 1706 cores in the high resolution configuration. For the ocean-only and atmosphere-only configurations in the standard resolution, optimum performance is obtained when using 96 and 384 cores, respectively. With the aforementioned number of cores, these configurations run faster than previous experiments at Marenostrum but still remain scalable. The size of the generated output per month of simulation is 2 and 9 GB for the coupled standard and high resolution configuration, and 1 GB for the uncoupled configurations.

4. Software and Numerical Libraries

Software components that the project team requires for the activity.

a) Applications + Libraries
BLAS, HDF5, LAPACK, NETCDF, OPENMPI, MPIBLAST

b) Compilers and Development Tools
GCC, INTEL

c) Utilities + Parallel Debuggers and Performance Analysis Tools
CMAKE, PERL, PYTHON, NCVIEW, NCL

d) Other requested software
JASPER, LIBTOOL, AUTOMAKE, CDO, GRIB_API, GRIBEX, NCO, CDFTOOLS, TCL

e) Proprietary software

5. Research Team Description

a) Personal Data

Name of Team Leader	Eleftheria Exarchou
Institution	Barcelona Supercomputing Centre
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Nationality	Greece

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 Eleftheria Exarchou, and is a PostDoctoral research fellow within the Earth Science department led by Prof. Doblas-Reyes of the Barcelona Supercomputing Centre.

Eleftheria Exarchou has obtained her PhD in 2012 at the Max Planck Institute of Meteorology in Hamburg, Germany. Her work involved working extensively with the Max Planck Earth System Model, where she implemented a tidal mixing parameterization to the ocean model and explored the model's sensitivity to the new mixing scheme. She has also worked as a postdoctoral researcher at the department of Meteorology in Reading, UK, within the framework of the ERC funded SEACHANGE project (Advanced Grant, AdG, PE10, ERC-2009-AdG), where she performed a multi-model intercomparison study in terms of the oceanic heat transport processes. She performed within the framework of SEACHANGE detailed heat budgets and small-scale processes analyses which will be highly beneficial to the work proposed here. She has worked on climate prediction for two years with Prof. Doblas-Reyes and used extensively the Ec-Earth climate model in different configurations and on

Prof. Doblas-Reyes and used extensively the EC-Earth climate model in different configurations and on different platforms (Marenostrum, ECMWF). She has published 5 articles in international peer-reviewed journals and she has presented her results in 10 International conferences. Eleftheria Exarchou, owing to her past work with different climate models at various international research groups, has extensive experience with climate modelling, using different models at different supercomputing platforms. Her deep understanding of ocean dynamics and ocean modelling gives an additional advantage in carrying out this project.

d) Names of other researchers involved in this activity

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e) Relevant publications

Guemas V., F.J. Doblas-Reyes, I. Andreu-Burillo and M. Asif (2013). Retrospective prediction of the global warming slowdown in the past decade. Nature Climate Change, 3, 649-653, doi:10.1038/nclimate1863

García Serrano, J., I. Polo, F.J. Doblas-Reyes and R.J. Haarsma (2013). Multi-year prediction of the Atlantic Niño: a first approach from ENSEMBLES. Revista Física de la Tierra, 25, 57-71.

Bellprat O., Lott, F. C., Gulizia, C., Parker, H. R., Pampuch, L. A, Pinto, I., Ciavarella, A., P. A. Stott (2015). Unusual past dry and wet rainy seasons over Southern Africa and South America from a climate perspective, Weather and Climate Extremes, Volume 9, September 2015, Pages 36-46

García-Serrano J, Guemas V, Doblas-Reyes F, 2015, Added-value from initialization in predictions of Atlantic multi-decadal variability. Climate Dynamics, 44 (9-10), 2539-2555, doi:10.1007/s00382-014-2370-7.

Prodhomme, C., Doblas-Reyes, F., Bellprat, O., and Dutra, E. (2015). Impact of land-surface initialization on sub-seasonal to seasonal forecasts over Europe.Climate Dynamics, 1-17.

6. Resources

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

Requested machine MareNostrum 4 ((Technical description to be confirmed)
Interprocess communication Null

Typical Job Run

Number of processors needed for eachjob 1706.00

Estimated number of jobs to submit		190.00		
Average job durations (hours) per job		5.00		
Total memory used by the job (GBytes)		108.00		
Largest Job Run				
Number of processors needed for eachjob		1706.00		
Estimated number of jobs to submit		190.00		
Average job durations (hours) per job		5.00		
Total memory used by the job (GBytes)		36.00		
Total disk space (Gigabytes)	**Minimum**	6840.00	**Desirable**	6840.00
Total scratch space (Gigabytes)	**Minimum**	6840.00	**Desirable**	6840.00
Total tape space (Gigabytes)	**Minimum**	0.00	**Desirable**	0.00
Total Requested time (Thousands of hours)		1620.00		

If this activity is asking for more than 2Million 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 18516.6 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

7. Abstract for publication

This research project proposes to investigate the systematic model errors in the Tropical Atlantic in the EC-Earth3.1 coupled model using climate simulations initialized from observational data (i.e. climate predictions), to highlight the time development of the biases so as to understand their causes. Investigating the typical sources of the model biases will suggest guidelines for future model development and will contribute to an improvement of the climate predictions and projections in the Tropical Atlantic. This research activity is expected to contribute to a wider effort to improve our capabilities to predict the climate and its impacts in the region of Western Africa, where the consequences of climatic shifts have high socio-economic consequences to the populations through the fisheries and the agricultural activities.

8. 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.

Barcelona Supercomputing Center, 2016