OCEAN DYNAMICAL DOWNSCALING OF HADGEM2-ES IN THE TROPICAL ATLANTIC

Luciana Shigihara Lima[1], Douglas Francisco Marcolino Gherardi[2], Leilane Gonçalves dos Passos[3]

National Institute for Space Research, Av. dos Astronautas, 1758, São José dos Campos - SP, 12227-010Brazil,
{luciana.lima; douglas.gherardi}@inpe.br; leilanepassos@gmail.com

ABSTRACT

The Intergovernmental Panel of Climate Change joined efforts with several institutions in different countries to devise strategies to understand how the environment respond to climate change. They developed models that simulate past, present and future climate on a global basis. The grid resolution of these models is quite low, and for this reason some regional processes are not represented. So, for some local studies the grid resolution is increased with downscaling processes. Here, a dynamical downscaling was applied on a tropical Atlantic domain, using HadGEM2-ES outputs as forcing, initial conditions and lateral boundary inputs in a regional model. The regional model used to solve the hydrodynamic equations was ROMS. The outputs were evaluated comparing with remote sensing products, and the result was satisfactory. This technique helped to improve the grid resolution, allowing the visualization of regional ocean processes but reported errors in the equatorial Atlantic persist.

Key words — Climate Models, ROMS, Dynamical Downscaling, Earth Systems, CMIP5.

1. INTRODUCTION

Earth System Models (ESM) seek to represent the interaction between atmosphere, ocean, land surface, and sea ice, along with the biogeochemical processes that interact with the physical system. Although, many processes operating in very small scale are parameterized, the ESM focuses on those processes which are sufficiently pervasive as to be globally significant in terms of their role in climate [1].

These models are advanced compared with coupled atmosphere-ocean general circulation models (AOGCMs), due to the inclusion of the carbon cycle feedback on climate [2] This is important for long-term future projections under different anthropogenic impacts. It permits the analysis of this possibilities of impacts over numerous environments and how they affect the physical and biological processes [3].

The Intergovernmental Panel of Climate Change (IPCC) joined efforts of several institutions around the world working with climate modeling, and organized the Coupled Model Intercomparison Projects (CMIP), summarizing all the outputs from different climate models. These outputs are available for use, and they are helpful to study regional processes and in Regional Climate Models (RCM).

The dynamical downscaling allows the representation of ocean mesoscale processes using ESM solutions on a high horizontal resolution (grid spacing <10 km). This can be achieved by using atmospheric and lateral boundary conditions from a ESM to force a regional model. However, the RCM does not escape the uncertainties arising from the dynamic fields of the ESM, since they are maintained and can be increased in each step of the downscaling process, as well as the RCM cannot modify the large-scale ESM processes.

The ESMs from the Fifth Coupled Model Intercomparison Panel (CMIP5) are known to have a few systematic errors due to the misrepresentations of cloud microphysics, which can be amplified by feedbacks among climate components especially in the tropics [4].

To verify if these models were capable to represent the hydrodynamic processes in the tropical Atlantic, the RCM outputs are validated with remote sensing products and *in situ* data. This work aims at evaluating the downscaling results from the hydrodynamic model on the tropical Atlantic Ocean using remote sensing data. The downscaling outputs are compared with the historical results used as an input in the downscaling process.

2. MATERIAL AND METHODS

The study area is located between the latitudes 25ºS – 10ºN and the longitudes 70ºE – 20ºE, including the tropical Atlantic Ocean, and the continental shelf. The oceanic and atmospheric initial boundary and forcing conditions were provided by the HadGEM2-ES, ensemble r2i1p1 outputs used to run the Regional Ocean Modeling System (ROMS).

The HadGEM2-ES is a ESM elaborated by the Met-Office Hadley Centre, and it is considered state-of-art of Earth System Models [5]. ROMS is a free-surface, terrain-

ISBN: 978-85-17-00097-3

following, numerical model, which solves primitive equations using computational algorithms described in [6].

The ROMS configuration was defined by 30 sigma levels and 1/12º horizontal resolution, with forcing every 6h hours. The period of simulation started in January 1st, 1995 until, December 31th, 2001 with the first two years (1995 and 1996) used for model spin-up. The forcing data used are: specific humidity, surface air pressure, air temperature (at 10 meters), zonal and meridional wind (at 10 meters), precipitation, surface downwelling longwave radiation and net surface shortwave radiation. Initial field and boundary oceanic conditions were: water flux from rivers, sea water salinity, water potential temperature, sea surface height above geoid, zonal and meridional current velocity. The bathymetry used was obtained from ETOPO1.

ROMS outputs were evaluated using SODA 3.4.2 assimilation data for surface ocean currents (0 to 30 meters depth) and salinity, Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) data for Sea Surface Temperature (SST), and surface wind from ERA-Interim (at 10 meters) provided by the European Center for Medium-Range Weather Forecasts (ECMWF).

To evaluate the downscaling experiment, it was calculated the statistical bias (equation 1) and the root mean square error (equation 2).

$$BIAS=\frac{1}{n}\sum_{i=1}^{n}(x_i-y_i) \quad (1)$$

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-y_i)^2} \quad (2)$$

where, n is number of observations, x_i are modeled values and y_i are observed values.

Bias values indicate the systematic model shift from observation and RMSE calculate the deviations from observation.

3. RESULTS

The period of analysis was between January, 1997 and December, 2001, and the results presented are the means for the whole simulation period. The south region of the domain, in general resulted, in the ROMS output, a slight decrease in error when compared to HadGEM2-ES. This presents a negative SST bias in most of the study area, with ROMS outputs presenting a higher negative bias in the equatorial region (Figure 1).

In ROMS outputs, the magnitude of ocean currents (Figure 2), compared with SODA data, presents a positive bias in all domain (mean = 0,12 m.s^{-1}), the downscaling intensified the North Brazil Current. In contrast the Brazil Current in HadGEM2-ES is negatively biased while ROMS output is only weakly biased.

The downscaling of salinity presents a good representation, showing some negative bias (Figure 3) near the Amazon river mouth, which contributes with large amounts of fresh water into the ocean.

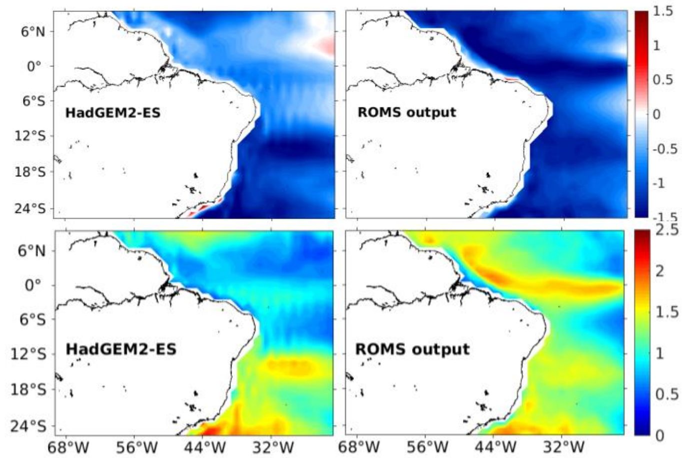

Figure 1: HadGEM2-ES and ROMS output bias (top left and right) and RMSE (bottom left and right) for SST (in ºC), compared with OSTIA data.

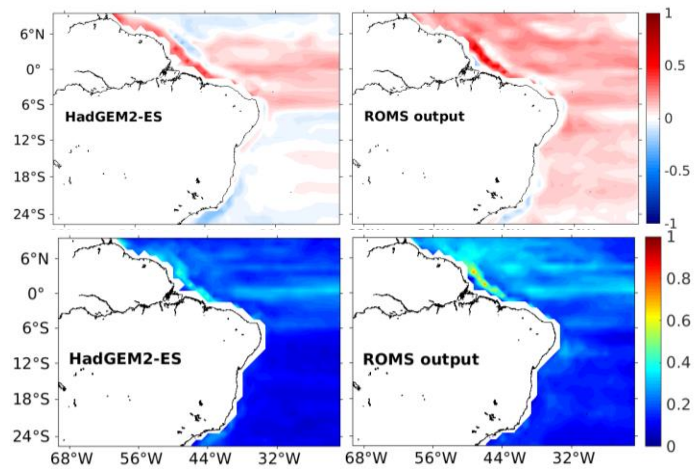

Figure 2: HadGEM2-ES and ROMS output bias and RMSE surface current velocity (m.s^{-1}), compared with SODA analysis.

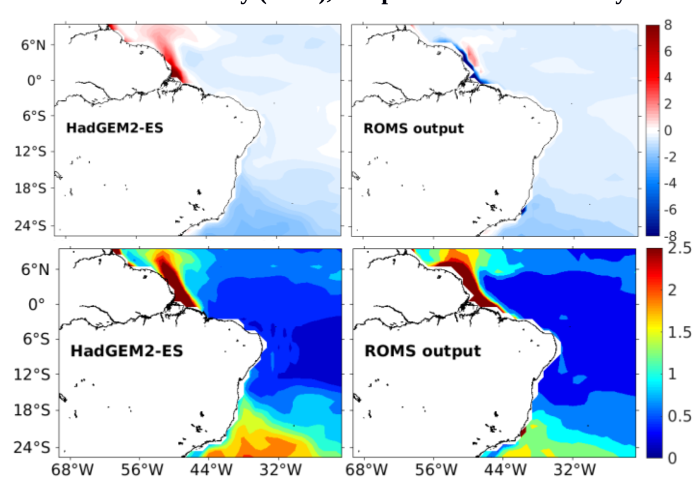

Figure 3: HadGEM2-ES and ROMS output bias and RMSE for surface salinity (PSU), compared with SODA Analysis.

The zonal and meridional wind velocity components were analyzed separately, as shown in figures 4 and 5. HadGEM2-ES presented less intense winds in almost all the domain when compared with ERA-Interim, being stronger to the north of 5ºN. Meridional wind indicates that the winds presents larger differences to the north of 15ºS.

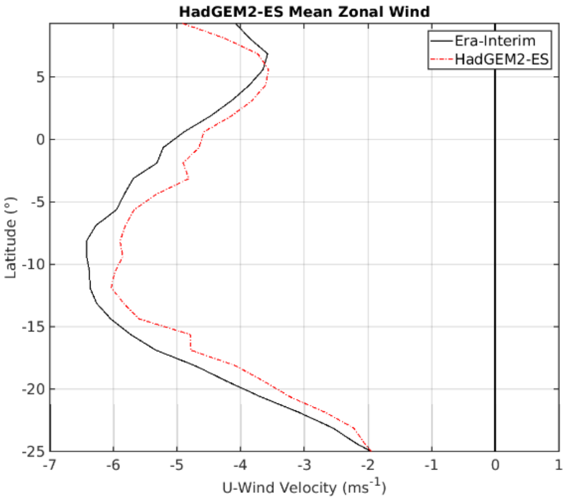

Figure 4: Mean Zonal Wind (m.s^{-1}) compared with ERA-Interim Reanalysis.

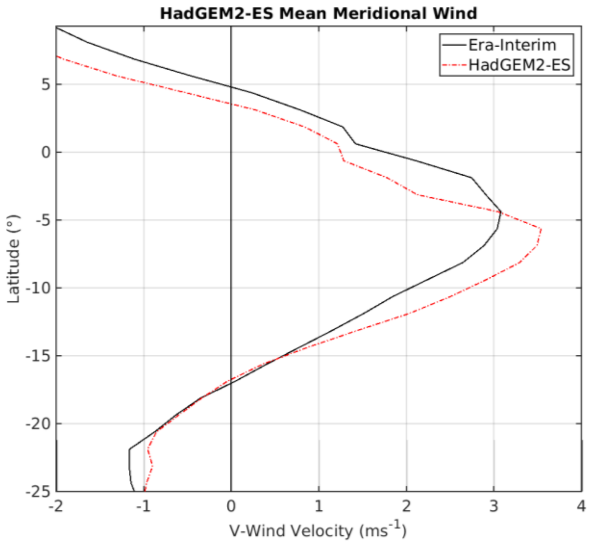

Figure 5: Mean Meridional Wind (m.s^{-1}) compared with ERA-Interim Reanalysis.

The latitudinal mean RMSE was calculated for the magnitude of wind velocity along the complete time series. In the figure 6 is possible to verify that the minor errors are founded near 6ºS for zonal wind, and 15ºS for meridional wind. The major errors are found in the zonal and meridional wind is between 2ºS and 10ºN, and 15ºS to 25ºS. Comparing with figure 4 and 5, which presents the latitudinal mean, is possible to observe the influence of anomalous data in the RMSE while in the media it is smoothed.

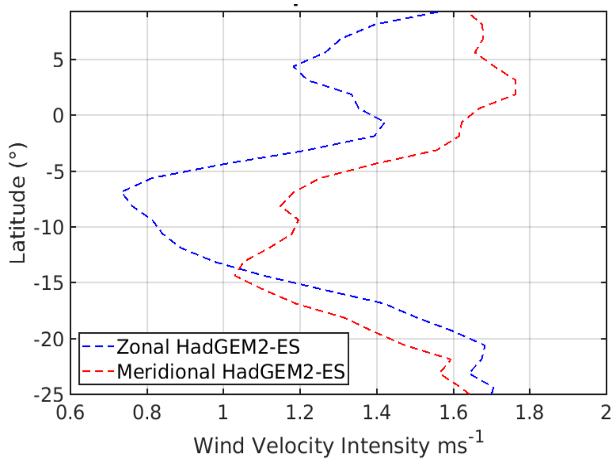

Figure 6: Mean RMSE of zonal and meridional wind magnitude (m.s^{-1}) relative to ERA-Interim Reanalysis.

4. DISCUSSION

The downscaling of the HadGEM-2ES indicates that the equatorial Atlantic region is the most sensitive with larger biases for SST and surface currents. These differences, however, are well within the limits found in other simulations for the region [7,8] using reanalysis data as input in their studies. The ESM is known to present significant shifts in the tropical Atlantic compared with the tropical Pacific. The positive SST bias in the equator is likely to be caused by the fact that the physics of tropical cloud formation in the HadGEM2-ES is still not well parameterized [9]. [10] showed that the errors in the thermocline slope in equatorial Atlantic causes the SST biases in this region because of weak easterlies represented in CMIP models.

Such as pointed out by [11], most climate models of the CMIP5 present problems in the representation of the exchange of energy in the equatorial zone. This problem results in biases of heat fluxes between ocean and atmosphere that can be intensified in downscaling experiments.

5. CONCLUSIONS

Even though the errors found in the downscaling experiment are larger when compared to the ESM, it correctly represented the mean ocean dynamics for the region, resulting in low biases in the variables analyzed.

These efforts serve as a guideline for the future use of downscaling experiments for applications such as biophysical modeling. It also highlight issues that need to be tackled in the future to improve ocean and atmosphere physics in the equatorial Atlantic.

The SST and surface current shifts shown in the downscaling experiment for the historical scenario of HadGEM2-ES are similar to what has been reported for the region using ROMS forced with reanalysis data. These are of low absolute magnitudes and indicate that the downscaling of future climate scenarios, such as from the RCP 8.5, can be confidently performed.

5. ACKNOWLEDGMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

6. REFERENCES

[1] Flato, G. Earth system models: an overview. Wiley Interdisciplinary Reviews: Climate Change, v. 2, n. 6, p. 783-800, 2011.

[2] Flato, G., Marotzke, J., et al. Evaluation of Climate Models. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 741–866, 2013.

[3] Hajima, T. et al. “Climate change, allowable emission, and earth system response to representative concentration pathway scenarios.” Journal of the Meteorological Society of Japan. Ser. II, v. 90, n. 3, p. 417-434, 2012.

[4] Wang, C., et al. “A global perspective on CMIP5 climate model biases.” Nature Climate Change, 4(3), 201–205, 2014.

[5] Caesar, J. et al. Response of the HadGEM2 Earth System Model to future greenhouse gas emissions pathways to the year 2300. Journal of Climate, v. 26, n. 10, p. 3275-3284, 2013.

[6] Shchepetkin, A. F.; Mcwilliams, J. C. The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model. Ocean modelling, v. 9, n. 4, p. 347-404, 2005.

[7] D’Agostini, A., Gherardi, D. F. M., & Pezzi, L. P. Connectivity of marine protected areas and its relation with total kinetic energy. *PLoS ONE*, *10*(10), 1–19, 2015.

[8] Endo,C A. K. E. *Determinação da conectividade ecológica entre as ilhas oceânicas brasileiras e a plataforma continental norte e leste do Brasil.* Dissertation (Master in Remote Sensing) – National Institute for Space Research (INPE), São José dos Campos, 2018.

[9] Richter I., et al. An Overview of coupled GCM Biases in the Tropics. *Indo-Pacific Climate Variability and Predictability*, 213–263, 2016.

[10] DeWtt D. G., Diagnosis of the tropical Atlantic near-equatorial SST bias ina directly coupled atmosphere–ocean general circulation model. *Geophys. Res. Lett.*, 32, L01703, 2005.

[11] Riche, I., & Xie, S. P. On the origin of equatorial Atlantic biases in coupled general circulation models. Climate Dynamics, 31(5), 587–598, 2008.