Downscaling from the ocean to the regional level: an approach to the Portuguese Exclusive Economic Zone

L. Pinto[1], F. Campuzano[1], M. Juliano[2], R. Fernandes[1] and R. Neves[1]

[1] *MARETEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal.* ligia.pinto@tecnico.ulisboa.pt

[2] *LAMTec-ID, Universidade dos Açores. Edifícios da Marina, Apartado 64, 9760-412 Praia da Vitoria, Portugal.*

Abstract

The Lusitania model is a 3D baroclinic regional model covering a wide area of the eastern Atlantic Ocean, including the Portuguese Exclusive Economic Zone (EEZ), and the Western Mediterranean Sea. The model is forced by the MyOcean general circulation model, the FES2004 global tide solution and the atmospheric forcing provided by the NCEP Global Forecasting System (GFS). The Lusitania application is able to represent the main oceanographic processes as temperature and salinity fronts and gradients, and the general circulation patterns of the Eastern Atlantic Ocean and Western Mediterranean Sea. The model domain's limits were set to provide modelling results to the Portuguese EEZ and to supply boundary conditions to more refined regional models for the Portuguese continental coast, Madeira and Azores archipelagos and to areas that could be defined of interest following a cascade downscaling technique. A general description of the Lusitania application will be provided and model results will be shown.

Keywords: Portuguese EEZ model, Operational model, MOHID modelling system, Downscaling technique

1. INTRODUCTION

Portugal is a coastal nation formed by the continental territory and two archipelagos, Madeira and Azores Islands. The Portuguese Exclusive Economic Zone (EEZ) is one of the largest EEZ in the world with 1,727 km^2 and this area can be increased in the near future to 3,877 km^2. Thus, Portugal includes a vast area of the Atlantic Ocean which resources could be exploited economically while, under the EU Marine Strategy Framework Directive (MSFD), its waters should be protected and monitored. Keeping a good environmental standard of the marine and coastal waters is therefore of vital importance for Portugal and its economy.

In order to provide support to the MSFD aims, namely to generate solutions to be used by smaller regional models, an application running the MOHID model (www.mohid.com.) for the current Portuguese EEZ extension was developed. Lusitania model aims to provide hydrodynamic modelling results to the Portuguese EEZ and to improve boundary conditions for the Portuguese regional seas (Madeira, Azores and Iberian zone).

Downscaling of ocean models can be done directly to the regional seas, however the use of an intermediate level has scientific and socio-economic advantages and the Lusitania model aims to take advantage of both. An offline downscaling philosophy will be applied to Lusitania model results in order to provide boundary conditions to the Portuguese continental coast, the Madeira and the Azores archipelago regional models.

2. Lusitania application

The Lusitania application is a system based on the MOHID model (Neves, 2013), an open source numerical model (www.mohid.com). MOHID is a three-dimensional water modelling system, developed by MARETEC (Marine and Environmental Technology Research Center) at Instituto Superior Técnico.

This application covers a wide area of the eastern Atlantic Ocean and the Western Mediterranean Sea. The domain's limits were set to cover the current Portuguese EEZ and also to simulate accurately the water fluxes in the Strait of Gibraltar, as these fluxes affect the water circulation on the southern coast of the Iberian Peninsula.

The Lusitania application is composed of two nested model domains (Level1 and Level2) with 0.08° resolution. The Level1 consists on a 2D barotropic model covering the geographic area 24.63ºN-47.91ºN and 37.83ºW-9.45ºE. Level1 is forced along its open boundaries by tidal components obtained from the FES2004 global tide solution (Lyard et al., 2006) with admittance included. The Level2 consists on a 3D baroclinic model covering an area slightly smaller (26.07ºN-46.47ºN and 36.39ºW-8.25ºE) and vertically discretised in 50 layers, 7 sigma coordinate layers in the top eight meters followed by 43 Cartesian layers with increasing depth thickness.

Two sources of data were combined to obtain the Lusitania model bathymetry: the EMODNet Hydrography portal (http://www.emodnet-hydrography.eu) complemented by the 30" resolution global bathymetry data SRTM30_PLUS (Becker et al., 2009) in the regions where EMODNet data was not available.

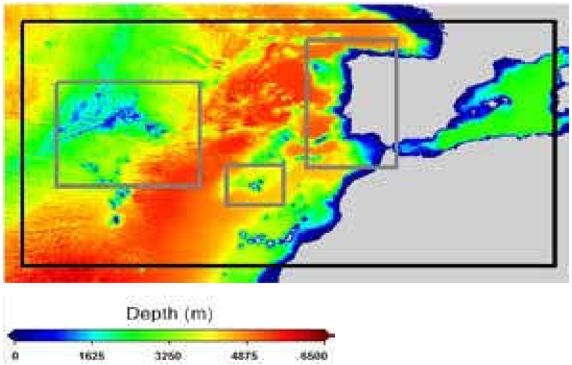

Figure 1 Bathymetry for the Lusitania Level1 grid (whole domain), Level2 grid (area within the black square) and the domains of the regional models (grey squares) for the Portuguese continental coast, Madeira and Azores archipelagos.

The Level2 domain was forced by the tidal computed by Level1domain along with atmospheric forcing provided by the NCEP Global Forecasting System (GFS) and the MyOcean general circulation model results (MyOcean catalogue product ID: GLOBAL-ANALYSIS-FORECAST-PHYS-001-002). The GFS model provides information about the air temperature, atmospheric pressure, wind and solar radiation with a horizontal resolution of 0.5°. Initial and boundary conditions for currents, sea temperature and salinity were obtained from the MyOcean product with a horizontal resolution around 0.083°. For the Level2, temperature and salinity fields were assimilated from the MyOcean model.

An Automatic Running Tool (ART) software was used to manage and to automatize the operational procedures, namely to pre-process the input files needed, execute the model and distribute the model results in several forms. The ART tool allows running models in a cascade scheme, where downstream models wait for a signal from the immediate upstream model indicating the end of the running, and triggers the following model simulation. This procedure reduces the computational time, as the different models can run in separate machines.

3. Lusitania results

The Lusitania is running since January 2013 and is being run to become fully operational. The results of the water levels and 3D fields for currents, salinity and temperature are being produced and published in the portal http://forecast.maretec.org/opmodelcat.

Model results analysis shows that the main water masses present in the domain can be observed in the Lusitania results. The entering of Atlantic water into the Mediterranean through the Strait of Gibraltar as surface water mass can be observed in the surface velocity field results (Fig. 2). In the western basin of the Mediterranean Sea the main circulation patterns are also observed: the inflow of the Atlantic water is first directed north-eastward due to the orientation of the Strait of Gibraltar, then generally describes a clockwise gyre in the east of the Alboran Sea between Spain and Morocco (El-Geziry and Bryden, 2010).

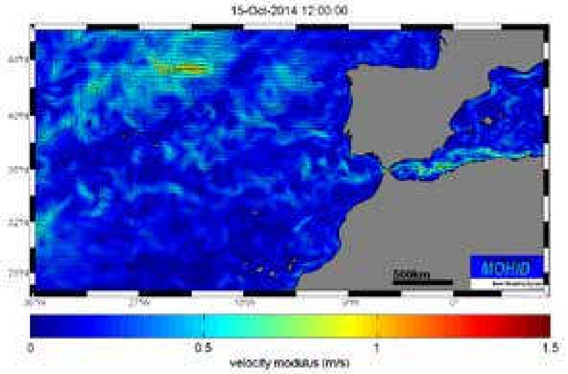

Figure 2 Instantaneous surface velocity field obtained with the Lusitania model for the day 15 of October 2014.

The analysis of one month average surface salinity shows that Lusitania reproduces the salinity gradients between the saltier Mediterranean water and the Atlantic water, and the mixing between these waters (Fig. 3). The one month average water surface temperature results (Fig. 4) display the meridional temperature gradient in the Atlantic side and the more homogeneous temperature distribution in the Mediterranean Sea. Also evident in results is the wind influence on temperature through coastal upwelling along the Western European and African coasts (Fig. 4). In the Mediterranean, near the Straits of Gibraltar lower surface water temperatures can be observed due to the colder Atlantic Waters. Also in the Gulf of Lions, North Western Mediterranean Sea, surface temperature results shows lower water temperature that could be related to the surface cooling due to cold air transported by north-western winds known as mistrals.

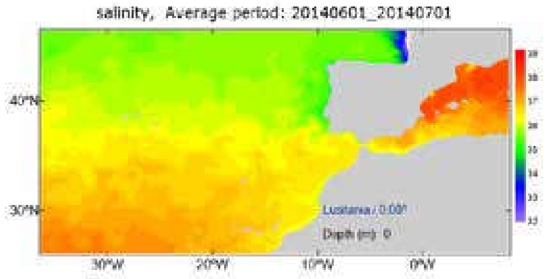

Figure 3 Lusitania average surface salinity. The average corresponds to the model results obtained for the period between 1of June and 1of July 2014.

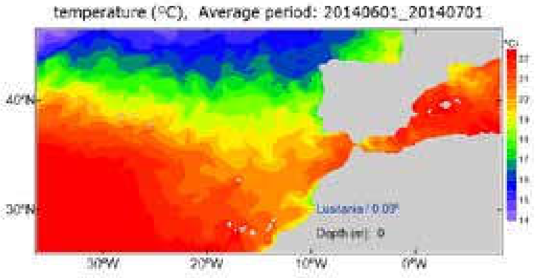

Figure 4 Lusitania average water surface temperature. The average corresponds to the model results obtained for the period between 1of June and 1of July 2014.

3.1 Model validation

Model results validation includes comparisons with data from remote sensing sensors, satellite and ARGO floats, and data from moored sensors, buoys and tidal gauges. Remote sensing allows obtaining observations in remote areas where traditional sampling would be very costly while also covering large areas. Lusitania sea surface temperature (SST) results are being compared with Microwave Optimally Interpolated sea surface temperature data (MW OI SST) produced by the Remote Sensing Systems group. Plots with the difference between model results and remote sensing data are produced and quantitative statistics are calculated to assess model performance. Fig. 5 illustrates an example of this comparison, where the results show good agreement between the model results and the observations.

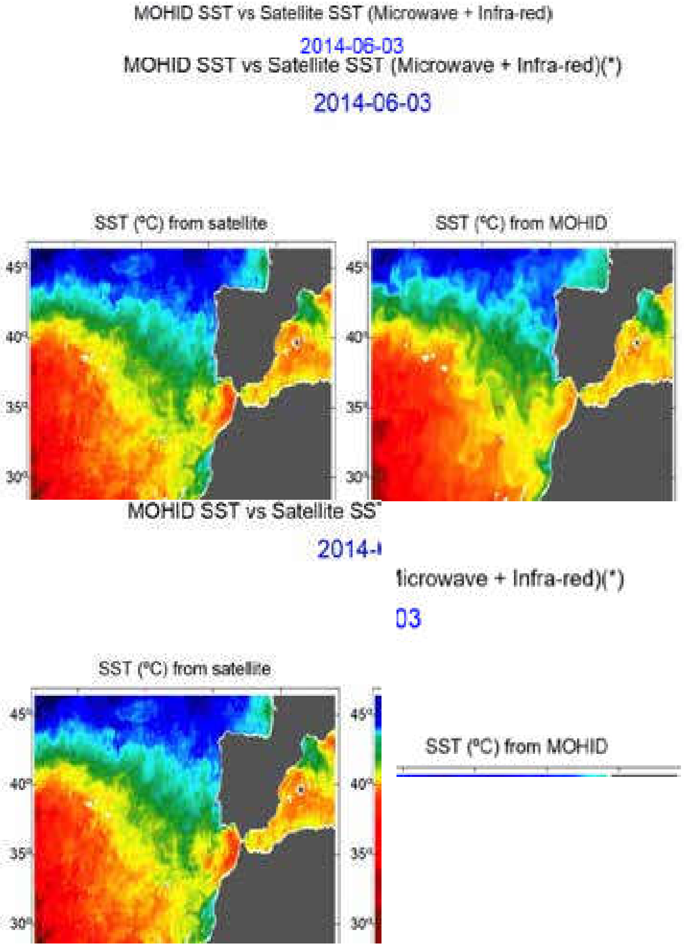

Figure 5 Comparison between Lusitania model (MOHID) and satellite sea surface temperature: SST obtained from the satellite; SST obtained from the Lusitania model results; SST difference between the Lusitania and the satellite; quantitative statistics.

Comparisons between model temperature and salinity profiles and the Argo floats (http://www.argos-system.org/) are also being performed. This comparison shows the correctness of the model water masses vertical distribution, complementing the information provided by satellite imagery. An example of this comparison is shown in Fig. 6, where plots of temperature and salinity profiles from the Lusitania model (red), MyOcean model (green) and Argo floats (blue) are compared. In this case, Lusitania and MyOcean models have similar results and the profiles obtained are similar to the Argo profiles.

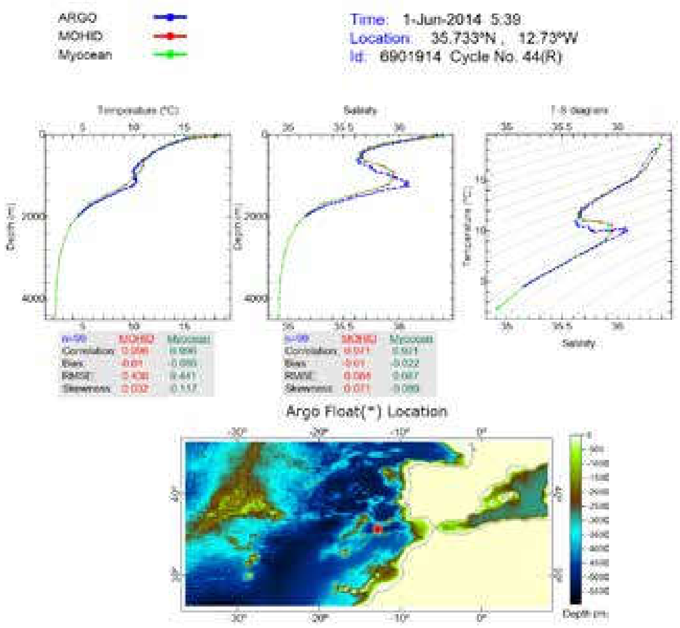

Figure 6 Comparison between the temperature and salinity profiles from the Lusitania model, the MyOcean solution and the Argo float.

3.2 Model downscaling

Downscaling requires the combination of tidal models with the lower frequency solution provided by global circulation models. Normally, this implies the use of simplified approaches at the open boundaries having consequences for the near boundary solution. Thus the model open boundary must be located as far as possible from the end user study area. When nested models are used the open boundary issue has lower consequences because at the boundary between the coarser and the finer models there is only a numerical issue, since both levels simulate the same processes.

A downscaling offline technique will be used in Lusitania model results to provide boundary conditions to the regional models. This approach consists in saving a window of model results from the upstream model (Lusitania model) with a high temporal resolution, able to represent the main processes coming from the open ocean (i.e. the tide signal), and use these results in the local models (Portuguese continental coast, the Madeira and the Azores archipelago models) boundary conditions (Campuzano et al., 2012).

In this cascade downscaling technique the model is waiting for a signal from an upwind model indicating that all the conditions are ready to start running. This synchronization optimizes computing time and reduces operating errors. This technique allows: the local model to run independently; running several downstream models at the same time; and the integration of ecological processes with greater time scales.

4. Conclusion and future work

The Portuguese Exclusive Economic Zone (EEZ) includes a large part of the Atlantic Ocean which resources could be exploited economically in different ways. The EU Marine Strategy Framework Directive (Directive 2008/56/EC) aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend.

Regional models make the link between global circulation models and local coastal and estuarine models that are in fact the most important in terms of socio-economics. At the global scale free surface fluxes are the only relevant forcing, while at the local scale tide is often the most important forcing. Downscaling of global circulation models to force local models needs an intermediate regional model forced at the open boundary by results of a global circulation model and by a global tidal model.

The Lusitania application could be regarded as an important tool for ocean and coastal monitoring, forecast and management of the Portuguese EEZ. Lusitania can provide boundary conditions to more refined regional models, i.e. Portuguese continental coast and the Madeira and Azores archipelagos, and to areas that could be defined of interest following the cascade downscaling technique.

The Lusitania application is able to represent the oceanographic processes as temperature and salinity fronts and gradients, and the general circulation patterns of this area of the Atlantic and the western Mediterranean basin. The validations performed show a good agreement between the model results and the observations.

The described pre-operational model will be continuously simulated until the present to become an operational application. Future version of Lusitania application will include the biogeochemical processes to increase its performance, and also the use of MPI to improve the computational time.

Acknowledgements

This study has been conducted using MyOcean Products. The bathymetric metadata and Digital Terrain Model data products have been derived from the EMODNet Hydrography portal - http://www.emodnet-hydrography.eu. Microwave OI SST data are produced by Remote Sensing Systems and sponsored by National Oceanographic Partnership Program (NOPP), the NASA Earth Science Physical Oceanography Program, and the NASA MEaSUREs DISCOVER Project. Data are available at www.remss.com.

References

Becker, J.J., Sandwell, D.T., Smith, W.H.F., Braud, J., Binder, B., Depner, J., Fabre, D., Factor, J., Ingalls, S., Kim, S-H., Ladner, R., Marks, K., Nelson, S., Pharaoh, A., Trimmer, R., Von Rosenberg, J., Wallace, G., Weatherall, P. (2009). Global bathymetry and elevation data at 30 arc seconds resolution: SRTM30_PLUS, Marine Geodesy, 32:4, 355–371.

Campuzano, F.J., Fernandes, R., Leitão, P.C., Viegas, C., de Pablo, H., Neves, R. (2012) Implementing local operational models based on an offline downscaling technique:

The Tagus estuary case. 2.as Jornadas de Engenharia Hidrográfica, IH, Lisbon, Extended abstracts: 105-108.

El-Geziry, T. M., Bryden, I. G. (2010). The circulation pattern in the Mediterranean Sea: issues for modeller consideration, Journal of Operational Oceanography, 3:2, 39-46.

Lyard, F., Lefevre, F., Letellier, T., Francis, O. (2006). Modelling the global ocean tides: modern insights from FES2004, Ocean Dynamics, 56, 394–415.

Neves, R. (2013). The MOHID concept. In Ocean modelling for coastal management - Case studies with MOHID. Eds. M. Mateus & R. Neves, 1-11.