Implementation and validation of an operational model for 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: Abstract: The Lusitania model is a 3D baroclinic regional model for the Portuguese Exclusive Economic Zone (EEZ) based on the MOHID Modelling System. The Lusitania application covers a wide area of the eastern Atlantic Ocean, including the Portuguese EEZ, and the Western Mediterranean Sea and 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 domain's limits were set to provide modelling results to the Portuguese EEZ and to supply boundary conditions to the existing operational models that run on a daily basis for the continental region, Madeira and Azores archipelagos. A general description of the Lusitania application will be provided and model results will be shown.

Key words: Portuguese EEZ model, Operational model, MOHID modelling system

1. INTRODUCTION

Ocean and coastal modeling have reached the scientific and technological development to be used on a forecast mode by operational models. The information provided by an operational model is used mainly by local users and consequently the local service has to be the result of a downscaling process that must be financially and technically sustainable. To be scientifically sustainable it must be built on regional scientific developments in order to be part of the regional scientific agenda. To be financially sustainable it must be consistent with the administrative structure. In Europe the national level appears immediately after the Union level and consequently downscaling must pass by a national level.

The Portuguese EEZ is one of the largest in the Europe and downscaling from ocean models can be done directly to the regional seas (Madeira, Azores and Iberian zone). However, the account of an intermediate level has scientific and socio-economic advantages. Lusitania model for the entire Portuguese EEZ aims to get advantage of both.

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

The Lusitania model covers the current Portuguese EEZ providing results to the Portuguese EEZ and to supply boundary conditions to the existing operational models that run on a daily basis for the continental region, Madeira and Azores archipelagos. The second level models, in addition, provide boundary conditions to even more refined local applications that require higher resolution results to answer management issues as bathing water quality, outfall monitoring, in a downscaling process.

2. MODELLING TOOLS

The Lusitania application is a system based on the MOHID model (Neves, 2013). MOHID is an open-source numerical model (www.mohid.com) programmed in ANSI FORTRAN 95 using an object orientated philosophy. The MOHID modelling system includes three main parts: MOHID Water for generic free surface flow, MOHID Land for catchments and MOHID River Network for the catchment drainage system. Each component manages the specificities of the equations to be solved and the main system manages common issues (e.g. solvers, atmospheric forcing, IO, Geometry handling tools). The core of the model is a fully 3D hydrodynamic model which is coupled to different modules including water quality, atmosphere processes, discharges, oil dispersion, jet mixing zone model for point source discharges. The MOHID Water model has been applied to several coastal and estuarine areas and has shown its ability to simulate successfully different spatial scales from large coastal areas (i.e. Santos *et al*., 2002; Bernardes, 2007) to estuaries (i.e. Saraiva *et al*., 2007, Campuzano *et al*., 2013) and coastal structures (i.e.

Silva *et al.,* 2000), including the interaction between waves and currents.

Downscaling within MOHID can be done online or offline. Online nesting obliges all model levels to run simultaneously, the boundary conditions being provided in sequence, from the coarser level to the finer level, at all time steps. This implies that the all system must be run on the same local network and preferentially on the same computer. In offline, downscaling boundary conditions are provided to each modelling level using the upper level output files written with a high frequency in order to be used to simulate the tidal flow (Campuzano *et al*., 2012). This operational modelling philosophy allows producing local realistic forecasts that integrate the large ocean processes to more detailed bathymetry descriptions and more reliable local forcing (e.g. meteorological and rivers discharges). These modelling techniques and tools are generic, thus it can be applied in any location within the study area. This downscaling philosophy will be applied to Lusitania model results in order to provide boundary conditions to the Portuguese continental coast, the Madeira archipelago and the Azores archipelago regional models.

In order to manage and to automatize the operational procedures Maretec-IST developed the Automatic Running Tool (ART) software that 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 indicating that the immediate upstream model have finished running, and triggers the following model simulation. Thus reducing the computational time, as the different models can run in separate machines.

3. LUSITANIA MODEL

The Lusitania 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 to simulate accurately the Strait of Gibraltar water fluxes that influence the southern coasts of continental Portugal.

The Lusitania application is composed of two nested model domains with 0.08º resolution. The Level1 (L1) consists on a 2D barotropic model covering the geographic area 24.63ºN-47.91ºN and 37.83ºW-9.45ºE. This level is forced along its open boundaries by tidal components obtained from the FES2004 global tide solution (Lyard et al., 2006).

The Level2 (L2) 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, where the top 8 meters correspond to 7 sigma coordinate layers being followed by 43 Cartesian layers with increasing depth thickness.

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

The Level2 domain was forced using the tidal levels computed by Level1 along with atmospheric forcing provided by the NCEP Global Forecasting System (GFS) and the MyOcean general circulation model (MyOcean catalogue product ID: GLOBAL-ANALYSIS-FORECAST-PHYS-001-002). The GFS model provides information about air temperature, atmospheric pressure, wind and solar radiation with a horizontal resolution of 0.5º. The initial and boundary conditions for currents, sea temperature and salinity were obtained from the MyOcean product with a horizontal resolution around 0.083º.

Figure 1 shows (a) the contours of the three regions forming the Portuguese EEZ, the domain of the Lusitania model (larger rectangle) and the limits of the operational models being run for the Azores, Madeira and Iberian regional seas. These three models will be forced with boundary conditions provided by the Lusitania application using the MOHID model nesting capability. The Lusitania simulation started in January 2013 and is being run to become fully operational.

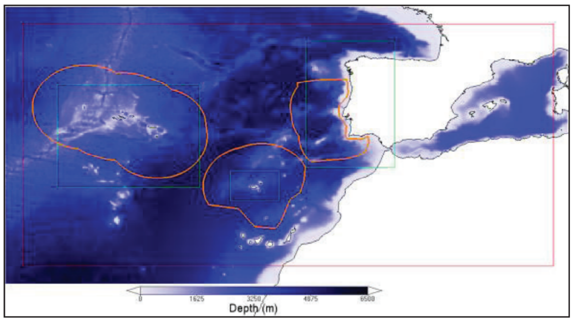

Fig. 1. Map displaying the current Portuguese EZZ (orange polygons), regional models (green squares) and the bathymetries for the Lusitania Level1 grid (whole domain), Level2 grid (area within the red lined square).

3.1. Model results

The Lusitania Level2 is producing water levels and 3D fields for currents, salinity and temperature. The model reproduce the abrupt differences in water levels that could take place between the Atlantic Ocean and the Mediterranean Sea (Fig. 2).

Model results showed the different water masses present in the domain. The model reproduces (Fig. 3) the sharp salinity gradients in the Mediterranean created by the surface fresher Atlantic water flow and shows the mixing between this water and the saltier Mediterranean water consequence of the negative water balance between evaporation and fresh water inputs. The surface temperature results

(Fig. 4) display the meridional gradient in the Atlantic side that contrasts with the more homogeneous Mediterranean Sea distribution. The figure also puts into evidence the wind influence on temperature through coastal upwelling along the Western European and African coasts. In the Mediterranean, lower surface temperatures can be observed near the Strait of Gibraltar due to colder Atlantic Waters and in the Gulf of Lions (North Western Mediterranean Sea) that could be related to major surface cooling due to cold air transported by north-western winds known as mistrals. The combination of high salinities and cold water in this region produce dense water that submerges creating the Western Mediterranean Deep Water (WMDW).

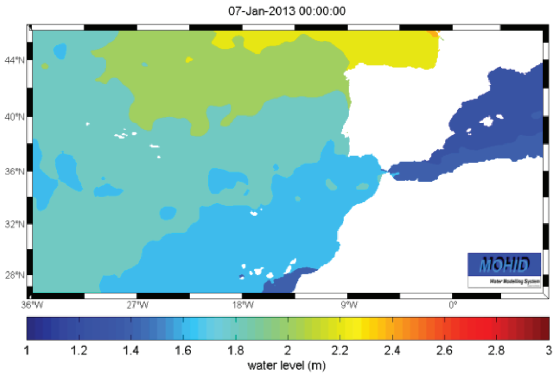

Fig .2. Example of instantaneous water levels generated by the Lusitania Level2 application.

The Lusitania model results were verified using remote sensing sensors, i.e. satellite and Argo floats and moored sensors as tidal gauges and buoys.

Moored stations are commonly used to confirm model performance along the coast; in recent times with the implementation of operational procedures data is nearly available in real time. For verifying the Lusitania model, tidal gauge and buoys data from the MyOcean project belonging to three different countries (France, Spain and Portugal) are being used. Remote sensing permits to obtain observations in remote areas where traditional sampling would be very costly. Satellite imagery allows covering spatially large regions of the globe and can be used to validate the values and general distributions of variables. In this case, model results are being compared with MicroWave Optimally Interpolated sea surface temperature data (MW OI SST) produced by the Remote Sensing Systems group. Also comparisons with the Argo floats (http://www.argos-system.org/) are being performed.

The Argo floats consists of a large collection of small, drifting oceanic robotic probes deployed worldwide that each 10 days submerge up to 2000 m and register conductivity and temperature profiles. This comparison is crucial for determining the correctness of the water masses vertical distribution in the model, complementing the information provided by satellite imagery.

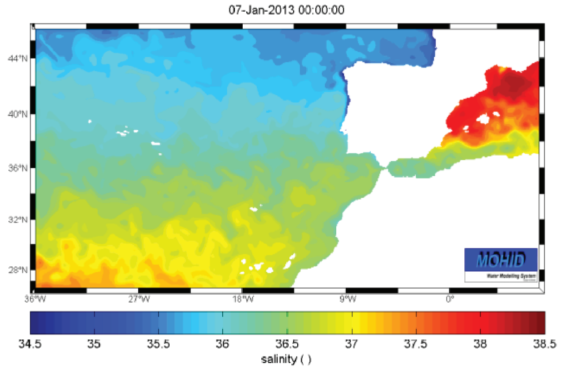

Fig .3. Example of instantaneous surface salinity for the Lusitania Level 2 application.. The gradient between the Atlantic Ocean and the Mediterranean Sea in the Alboran Sea is clearly visible.

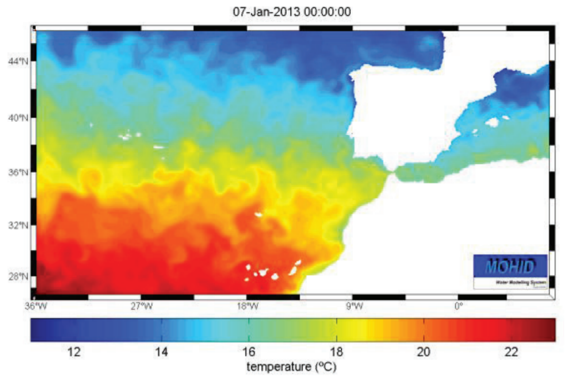

Fig. 4. . Example of instantaneous surface temperature for the Lusitania Level 2 application.

4. CONCLUSION AND FUTURE WORK

Regional models make the bridge 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 for consequence 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 is able to represent the oceanographic processes as temperature and salinity fronts and gradients, and the general circulation patterns of this part of the Atlantic and the western Mediterranean basin. This model would 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 described pre-operational model will be continuously simulated until the present to become an operational application. Under the Mohid modelling philosophy, the application would be able to increase its performance including rivers and biogeochemical processes that would be included in the following versions.

Acknowledgements

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