DOWNSCALLING FROM THE DEEP OCEAN TO THE ESTUARINE INTERTIDAL AREAS: AN OPERATIONAL FRAMEWORK FOR THE PORTUGUESE EXCLUSIVE ECONOMIC ZONE.

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Abstract

This paper describes a regional model for the Portuguese Exclusive Economic Zone (EEZ),- Lusitania - based on MOHID forced by MyOcean model and by FES2004 global tide solution. This model aims to generate solutions to be used by smaller scale models that in case of the Portuguese EEZ are still regional models for the Portuguese Seas (Azores, Madeira and Iberia).

The Lusitania application was 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. In this paper, the implementation techniques, the model performance and the verification procedures for a period of six months are discussed. The approach for providing open boundary conditions to the current regional models for the Portuguese continental coasts and the Madeira and Azores archipelagos are also examined.

1. Introduction

Ocean and coastal modeling have reached the scientific and technological development to be used on a forecast mode using operational models. Global models are part of broader data service systems and aim to simulate large spatial and temporal scales assimilating data on a global scale. Being part of global data services, they have necessarily to be run by large consortiums as is the case of HYCOM and MyOcean. Funding for these initiatives must be decided at a very high level, in case of MyOcean Funding has been provided by the EU research programs.

The final user of operational models is usually local 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 build 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.

Portugal has a very large EEZ (the 3rd in Europe and the 10th in the world) and downscaling of ocean models can be done directly to the regional seas (Madeira, Azores and Iberian zone). The consideration of an intermediate level has however scientific and socio-economic advantages. Lusitania model for the whole 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 simplifying approaches at the open boundaries that can have consequences for the solution close to the boundary and thus the boundary must be as far as possible from the local region where the end user is. 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 the same processes are simulated by both levels.

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, all forced directly by MyOcean results and by FES2004. These three models will be forced with boundary conditions provided by the Lusitania

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application using the MOHID model nesting capability.

2. Modelling Tools

The Lusitania application ran using the Mohid Water which is part of the Mohid Modelling System[3] (Neves, 2013). The MOHID is an open source numerical model programmed in ANSI FORTRAN 95 using an object orientated philosophy including three main parts, MOHID Water for generic free surface flows, 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). This system is being developed since 1985 mainly by the Maretec group at the Instituto Superior Técnico (IST) which is part of the Technical University of Lisbon. The model adopted an object oriented philosophy integrating different scales and processes. The core of the model is a fully 3D hydrodynamic model which is coupled to different modules comprising 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 very 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 using ordinary nesting methods or offline. Online nesting obliges all model levels to run simultaneously, boundary conditions being provided at every time step sequentially between levels from the coarser level up to the finer level. 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 upper level output files written describing high frequency evolution 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 so they 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 the operational procedures, software for models automation, the Automatic Running Tool (ART) that pre-process the input files, executes the model and distributes the model results in several forms was developed. 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. The Lusitania model

The Lusitania model covers the current Portuguese EEZ 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. 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 where the finer resolution model - for bathing waters - has 30 m spatial step.

The Lusitania application covers a wide area of the eastern Atlantic Ocean and the Western

[3] http://www.mohid.com

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 0.12º 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.

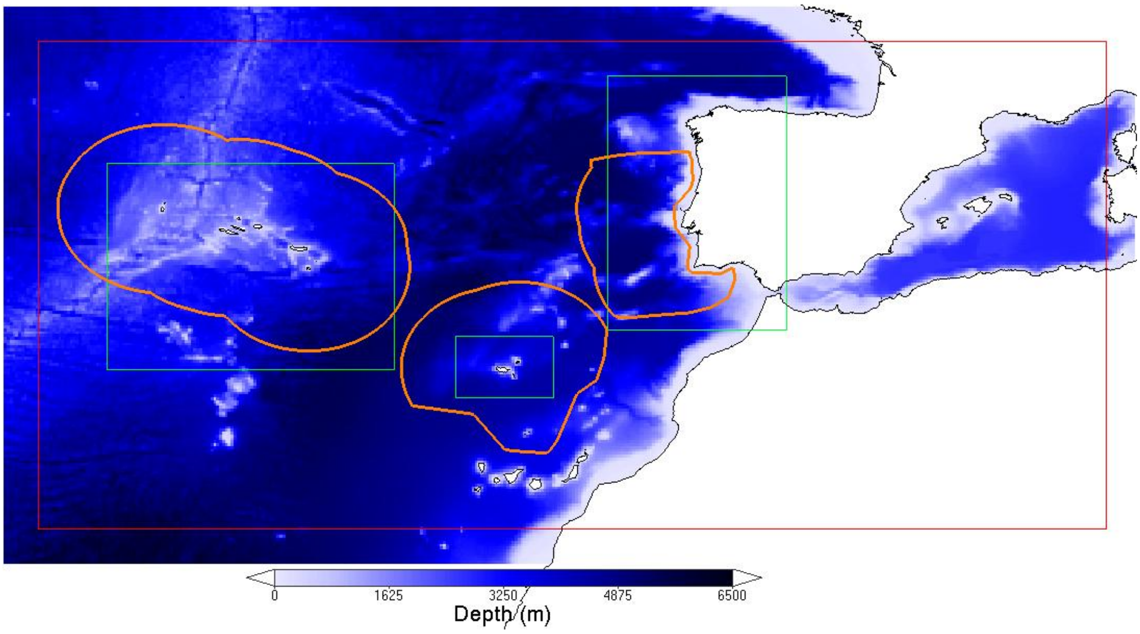

Fig. 1. Map displaying the current Portuguese EZZ (orange polygons), regional models (green squares) and the bathymetries for the Lusitania Level1 grid (whole domain), Level2 grid (area within the red lined square).

Two bathymetric sources of data were combined to populate both levels grids: 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_001_c). The GFS model provides 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 0.125º. The Lusitania simulation started in November 2011 and is being run to become fully operational running on a forecast mode. Results are presented for May 2012.

4. Model results.

The Lusitania Level2 is producing water levels and 3D fields for currents, salinity and temperature. The model was initiated for November 2011 and since then only used MyOcean results to specify the boundary conditions. The model reproduce the abrupt differences in water levels that could take place between the Atlantic Ocean and the Mediterranean Sea and also the presence mesoscale atmospheric structures, i.e. the high pressure in front of Portugal typical of the spring-summer periods (Figure 2).

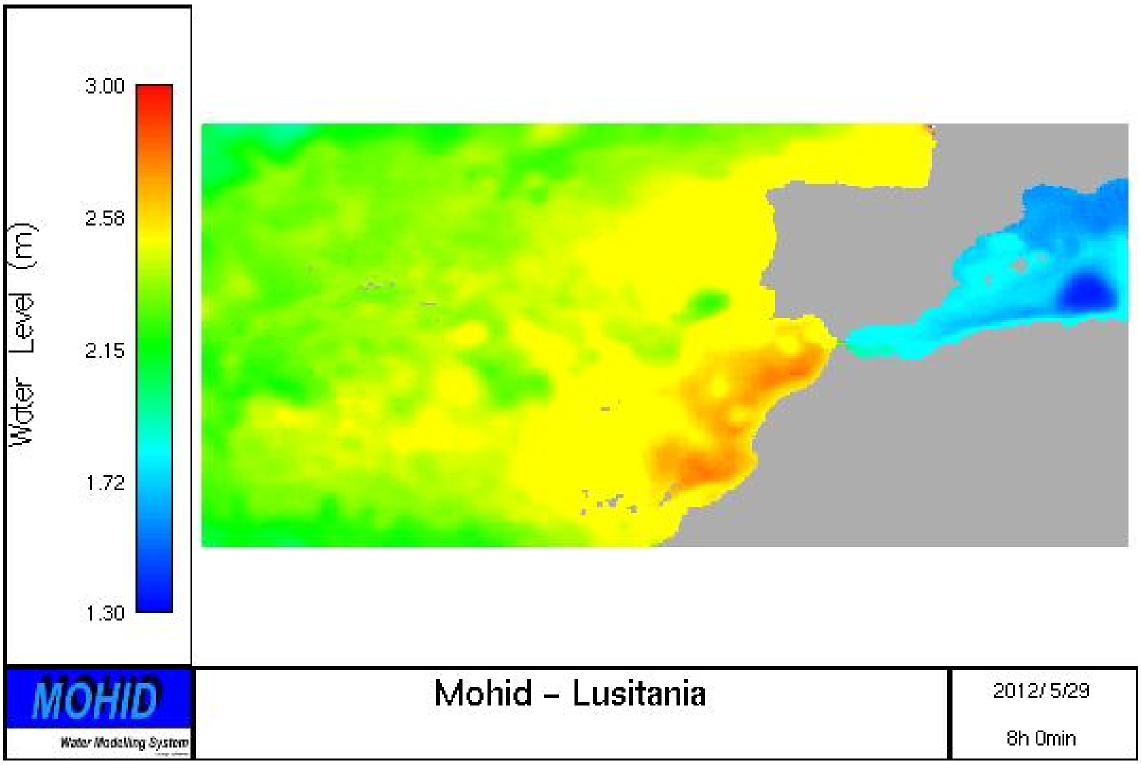

Figure 2. Example of instantaneous water levels generated by the Lusitania Level2 application, putting into evidence the gradient between the Atlantic Ocean and the Mediterranean Sea.

Model results showed the different water masses present in the domain. The model reproduces (Figure 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 salter Mediterranean water consequence the negative water balance between evaporation and fresh water inputs. The surface temperature results (Figure 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, where a filament of cold water reaches the Canary Islands. 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).

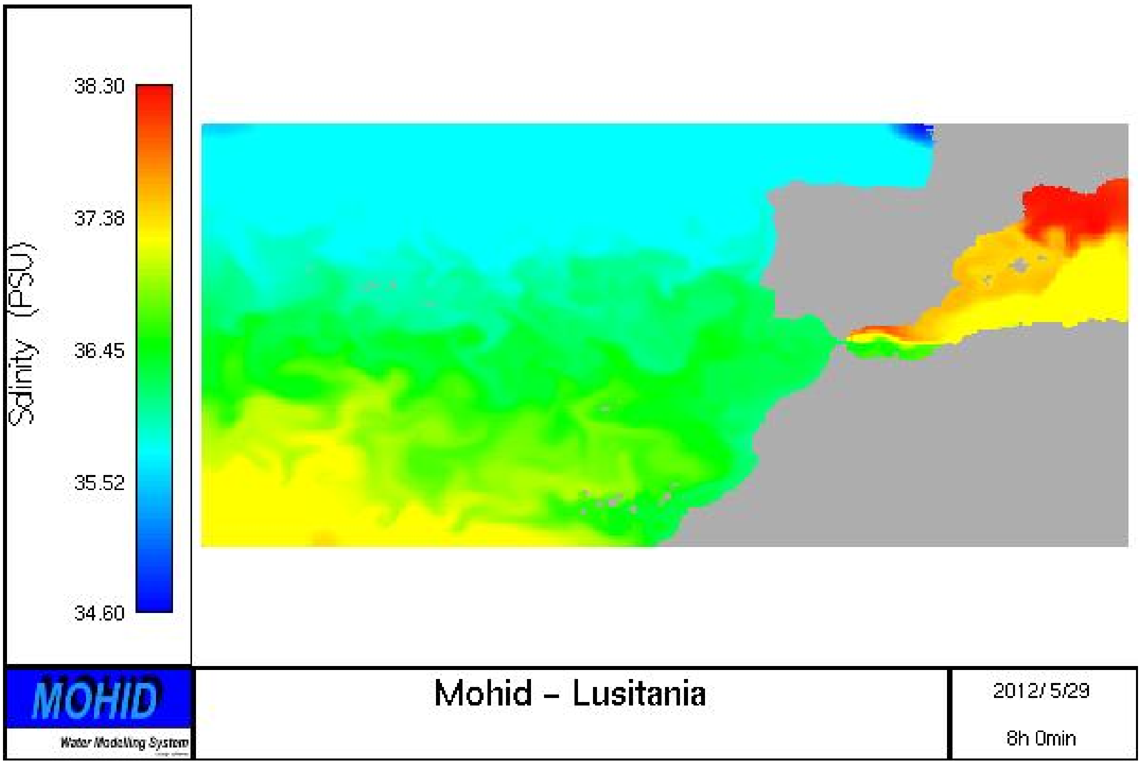

Figure 3. Example of instantaneous surface salinity for the Lusitania Level 2 application after 6 months running. The gradient between the Atlantic Ocean and the Mediterranean Sea in the Alboran Sea is clearly visible.

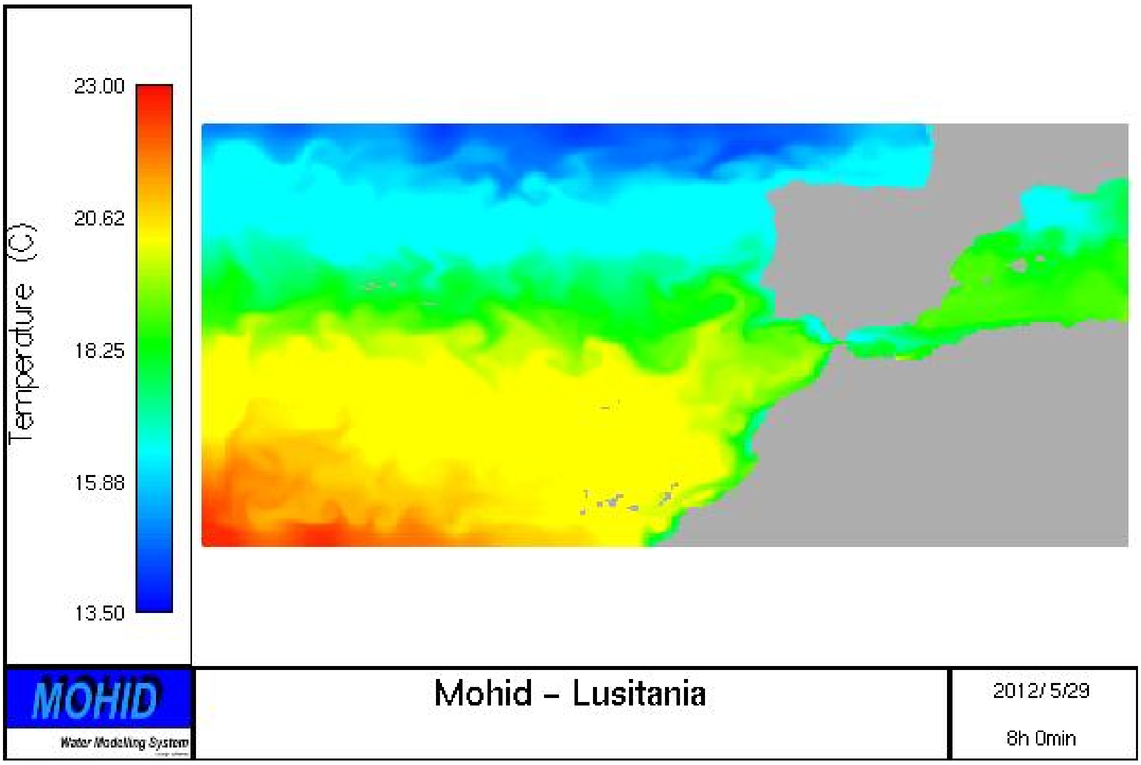

Figure 4. Example of instantaneous surface temperature for the Lusitania Level 2 application after 6 months running. It can be clearly identified the gradient between the Atlantic Ocean and the Mediterranean Sea.

Figure 5 shows instantaneous currents for the 29th of May 2012 after six months of simulation. This figure shows the passage of surface Atlantic water through the Strait of Gibraltar. In the Atlantic Ocean, it can be observed some of the general currents as the Azores current flowing east and the Canary currents to the south, while in front of the Iberian Peninsula can be seen the general current flowing north.

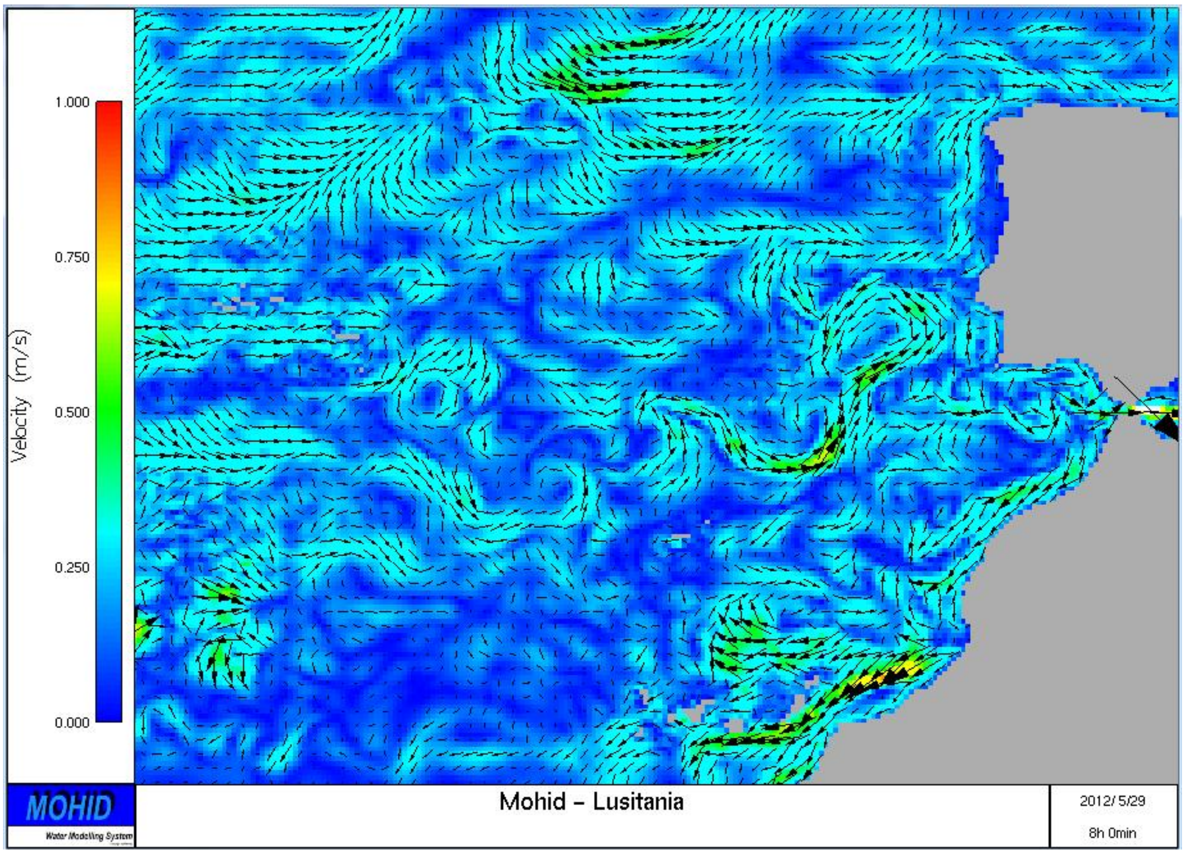

Figure 5. Example of instantaneous surface currents from the Lusitania Level2 domain for the Portuguese EEZ in the 29th of May 2012. To avoid clutter, the velocity vectors are plotted every third grid point in both directions.

5. Results verification

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 almost 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. Figure 6 shows an example of figures created with these observations and model results. The difference between the model results and the observations values could be related to the resolution of the model, as the comparisons are performed between a single point observation and a model cell with a horizontal resolution around 12 km.

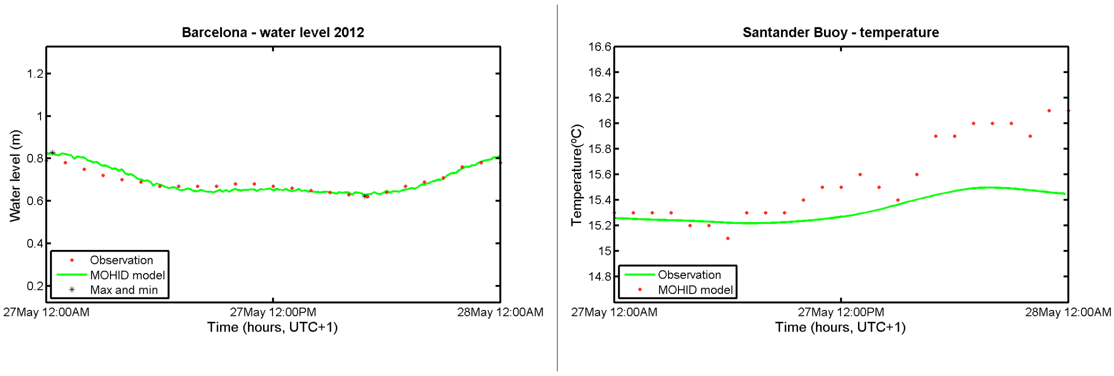

Figure 6. Model results (green lines) and observations (red dots) corresponding to the water level in Barcelona tidal gauge (left) and Santander buoy (right).

Remote sensing allows to obtain observations in remote areas where traditional sampling would be very costly, allowing us to compare results in these areas. The Argo floats (http://www.argos-system.org/) 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 which are send by satellite to the data centres. This comparison is crucial for determining the correctness of the vertical distribution of water masses in the model complementing the information provided by satellite imagery. Figure 7 shows the vertical profiles collected by a Argo float in the NW of the Iberian Peninsula and the Lusitania L2 and MyOcean results where saltier water from the Mediterranean Sea could be identified at a depth of around 1000 m.

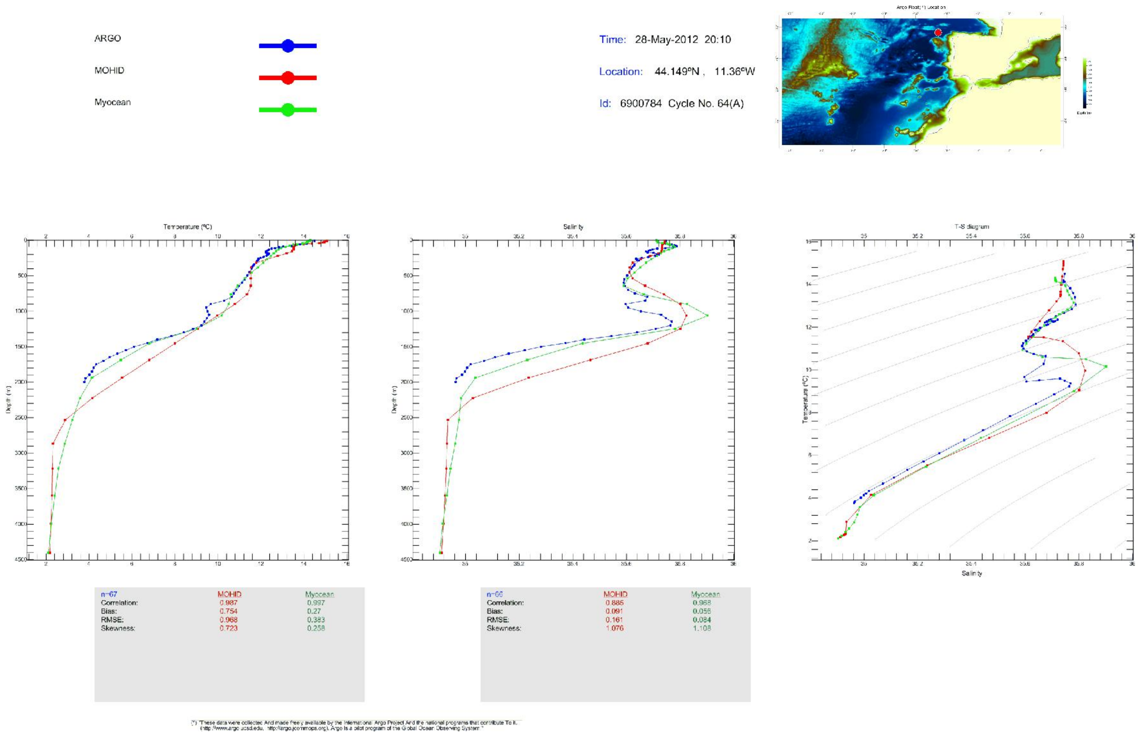

Figure 7. From left to right, temperature, salinity and T-S diagram vertical profile from the Lusitania Level 2 (red line), the MyOcean solution (green line) and the Argo float (blue line) located northwest to the Iberian Peninsula (red dot on the map).

Satellite imagery allows covering spatially large regions of the globe in order to validate the values and general distributions of variables. In this case, model results are compared with MicroWave Optimally Interpolated sea surface temperature data (MW OI SST) produced by the Remote Sensing Systems group. This comparison allowed evaluating the values and the distribution for the sea surface temperature (Figure 8) with the Lusitania L2 results and with the original MyOcean solution. Some of the features described above as the cold temperatures in the Gulf of Lions and the latitudinal gradient of temperatures can be observed in all the three figures.

The consistency between Lusitania solution and MyOcean solution after 6 months simulation is because (a) the tide is irrelevant for the global solution and (b) Mohid simulation is consistent with the MyOcean simulation. The agreement between Mohid solution and the remote sensing data shows that results are realistic.

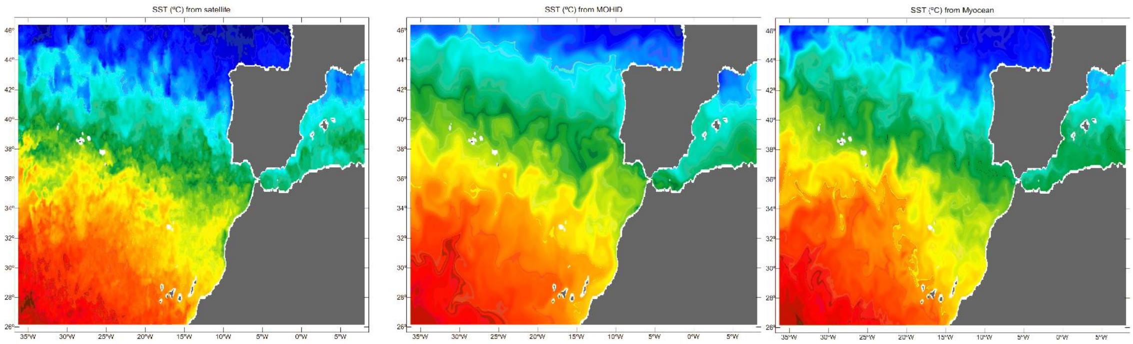

Figure 8. Surface temperature comparison between the remote sensing microwave OI SST (NASA) (left), the Lusitania model results (centre) and the MyOcean solution (right) for the 13nd of Abril 2012.

6. Conclusions and future work

The Portuguese Exclusive Economic Zone (EZZ) includes a large part of the Atlantic Ocean which resources could be exploited economically through different formulas. On the other hand, 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. Bearing in mind the need of detailed hydrodynamics to support both, the economic activities and the monitoring of such a vast area, a model covering the current EEZ was developed.

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 described above.

This procedure is consistent with the strategy foreseen by GMES for Europe and contributes to improve the open boundary conditions - that for free surface level - requires the addition of the tide level and levels computed by the general circulation model. This is done at Lusitania but not at the interface between this model and models forced by its solution.

The implementation of this set of models is a scientific issue, but also a socio-economic issue. MyOcean and HYCOM models are the most credible for the North Atlantic and they operation involve costs that are beyond the financial capacity of a State. On the same way, regional models must be maintained at State level and should produce results for local models which can be maintained by local authorities.

The described pre-operational model would be continuously simulated until present and becoming 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. This way, the Lusitania application could be regarded as an important tool for ocean and costal monitoring, forecast and management of the Portuguese EEZ.

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