Sea Observatory and operational modelling system for the south-eastern Brazilian shelf

THE OPERATIONAL MODELLING SYSTEM
Members of the grouping

<table>
<thead>
<tr>
<th>Institution</th>
<th>Web Address</th>
<th>Contact Details</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fax: +351 218 417 365</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:ramiro.neves@tecnico.ulisboa.pt">ramiro.neves@tecnico.ulisboa.pt</a></td>
</tr>
<tr>
<td>Universidade Federal do Paraná – UFPR</td>
<td><a href="http://www.ufpr.br">http://www.ufpr.br</a></td>
<td>Telephone: +55 41 3360 5064</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fax: +55 41 3360 5064</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:m.noernberg@ufpr.br">m.noernberg@ufpr.br</a></td>
</tr>
<tr>
<td>EnvEx – Engenharia e Consultoria</td>
<td><a href="http://www.envexengenharia.com.br">http://www.envexengenharia.com.br</a></td>
<td>Telephone: +55 41 3053.3487</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:envex@envexengenharia.com.br">envex@envexengenharia.com.br</a></td>
</tr>
<tr>
<td>FUNPAR - Fundação da Universidade Federal do Paraná para o Desenvolvimento da Ciência Tecnologia e da Cultura</td>
<td><a href="http://www.funpar.ufpr.br/">http://www.funpar.ufpr.br/</a></td>
<td>Telephone: +55 41 3360 7415</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fax: +55 41 3323 1630</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:funpar@funpar.ufpr.br">funpar@funpar.ufpr.br</a></td>
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1 OPERATIONAL MODELLING SYSTEM

Herein is described the operational modelling system implemented by the Centre for Marine Studies (CEM), a research centre of the Federal University of Parana (UFPR) - Brazil, supported by the MARETEC group, a research centre of the Instituto Superior Técnico (IST – University of Lisbon – Portugal). The aim is to provide forecast results of oceanic parameters daily to the Brazilian Sea Observatory at coastal scale. The numerical tool adopted is the MOHID modelling system, which has been applied in numerous projects in different countries (www.mohid.com).

A regional scale model for the South-Eastern Brazilian shelf is the first domain of the operational modelling system, covering the coasts of the states of Santa Catarina, Paraná, São Paulo and Rio de Janeiro (Figure 1) with a horizontal resolution of approximately 3 km x 3 km and 50 vertical layers, with less than 1 m of thickness near the surface. The generic vertical discretization of the MOHID modeling system allows adopting different types of vertical coordinates for a better representation of the mechanisms that force hydrodynamics. In this case, Cartesian coordinates were used for the deeper layers and Sigma coordinates for the layers closest to the surface. The bathymetry of the regional scale model was defined based on the GEBCO online database (https://www.gebco.net/).

Atmospheric boundary conditions are obtained from the Global Forecast System (GFS) with a resolution of 0.25° (forecast) to 0.5° (analysis) and frequency of 1 to 3 hours. The analysis results from GFS were used for the hindcast simulations (https://nomads.ncdc.noaa.gov/data/gfsanl/), whereas the forecast results are used for operational purposes (https://www.ftp.ncep.noaa.gov/data/nccf/com/gfs/prod). Results from GFS interpolated for the grid of the regional scale model are presented in Figure 2.

Figure 1 – Domain of the regional scale model for the south-eastern Brazilian shelf
Figure 2 – Atmospheric pressure and wind velocity (vectors) from GFS interpolated for the grid of the regional scale model

The oceanic boundary conditions for the regional scale model are defined from daily-mean values of salinity, temperature, water level, and currents obtained from the Copernicus Marine Environment Monitoring Service (CMEMS) product: GLOBAL_ANALYSIS_FORECAST_PHY_001_024 (GLOBAL OCEAN 1/12° PHYSICS ANALYSIS AND FORECAST UPDATED DAILY).

The CMEMS products are available for download free of charge from the online database: http://marine.copernicus.eu/services-portfolio/access-to-products/. The downscaling from the CMEMS products allows to obtain higher resolution results of ocean circulation, temperature, and salinity for the south-eastern Brazilian shelf (Figure 3).

Figure 3 – Ocean currents computed by the regional model for the south-eastern Brazilian shelf
The coastal model for the Brazilian states of Santa Catarina and Paraná was developed with a horizontal grid resolution of 600 m x 600 m (Figure 4). The oceanic boundary conditions (salinity, temperature, water level and currents) are provided by the regional model and the tidal level is imposed considering amplitudes and phases of the tidal constituents from FES2014 (Finite Element Solution). By its turn, the coastal model provides oceanic boundary conditions for local models for the Paranaguá estuarine system (Figure 5) and for the Babitonga bay (Figure 6), with a horizontal grid resolution of 200 m x 200 m and 120 m x 120 m, respectively. The bathymetries for the coastal and estuarine models were defined based on nautical charts form the Brazilian Navy and data from local institutions and companies (e.g., CEM and Envex). Cartesian coordinates were used for the deeper layers and sigma coordinates for the layers closest to the surface, with few tens of centimeters of thickness near the surface. The atmospheric boundary conditions are also obtained from the Global Forecast System (GFS).

Figure 4 – Surface currents computed by the coastal model for Santa Catarina and Paraná
The discharges of 24 affluent rivers are considered through monthly averages calculated by using data from the National Water Resources Information System (https://www.snirh.gov.br/hidroweb/) or from published papers and thesis. The outlet of some rivers is considered in the same grid point of the models (Figure 7).
Figure 7 – River outlets for the models

Figure 8 – Total flow rate of the affluent rivers to the Paranaguá estuarine system
Different tools in Python programming language were developed to automate downloading and processing of data to be used in the boundary conditions, execution of the models and storage of results, in order to provide forecast results for the Brazilian Sea Observatory on a daily basis. A dedicated server was acquired for the daily simulations of the operational forecast modelling system, which is located in the UFPR informatic centre. The forecast results are sent to an FTP server from the Envex company, which make them available in the Brazilian Sea Observatory.

Firstly, the regional model was validated with satellites and in-situ measurements. The comparison between sea surface temperature from satellite images and from the regional model is presented for
a day in the summer (Figure 11) and in the winter (Figure 12). During the winter season, colder water enters from the Southern boundary, whereas in the summer the wind pattern change, and colder water are observed at the North boundary due to the upwelling process on the coast of Rio de Janeiro. Water with less salinity in the winter also comes from the South due to the Rio de la Plata flow. However, the satellite images have a low resolution for sea surface salinity for proper validation of model results (Figure 13 and Figure 14).

Figure 11 – Sea surface temperature from satellite images (left) and from the regional scale model (right) on 15 January 2014.

Figure 12 – Sea surface temperature from satellite images (left) and from the regional scale model (right) on 15 July 2014.
In-situ measurements of temperature and salinity from drifting profiling floats give more information about model results precision inside the water column (Figure 15 and Figure 16). However, these floats normally collect data on open ocean and marginal seas are not well covered. For calibration and validation purposes, the year of 2014 was simulated due to the existence of local in-situ measurements in the mouth of the Paranaguá estuarine system from the Brazilian Coast Monitoring System (SiMCosta), which is an integrated network of floating or fixed platforms, equipped with instruments and sensors, with autonomous operation and the ability to regularly collect oceanographic and meteorological variables (Figure 17). The tendency of water temperature over
the year is well represented by the model (Figure 18). The differences in salinity between data and model results (Figure 19) in the summer months reveal the uncertainty from the definition of monthly averages of affluent rivers flow rates due to the lack of data for the simulated period. In the winter months, the decrease in salinity observed in the data cannot be explained by the flow rates, which are lower in these period of the year (Figure 8), as also verified by the precipitation rates for 2014 (Figure 20). A possible explanation is an interference from the plume of the Rio de la Plata that goes to the North due to the action of Southerly winds in the winter. The plume of the Rio de la Plata is considered in the oceanic boundary of the regional from the CMEMS global model results. Thus, errors in the CMEMS global model for the calculation of the plume affect the results of the operational modelling system for the South-Eastern Brazilian Shelf.

Figure 15 – Temperature and salinity profiles from modeling results (red) and from in-situ measurements (blue) on 7 January 2014.

Figure 16 – Temperature and salinity profiles from modeling results (red) and from in-situ measurements (blue) on 26 July 2014.
Figure 17 - Brazilian Coast Monitoring System (SiMCosta)

Figure 18 – Surface water temperature in 2014 in the mouth of the Paranaguá estuarine system from SiMCosta float (gray dots) and model results (black line).
Figure 19 – Surface water salinity in 2014 in the mouth of the Paranaguá estuarine system from SiMCosta float (gray dots), model results (black line), and CMEMS global model (red dotted line).

Figure 20 – Monthly accumulated precipitation in 2014 for a station located in a watershed of a river that is affluent to the Paranaguá estuarine system.

Sea surface temperatures were also verified inside the estuarine systems by using satellite observations with a good correlation, as presented in Figure 21. The tide propagation inside the Paranaguá estuarine system and Babitonga bay operational models was verified through tidal gauges data provided by Paranaguá Pilots Pilotage Services Ltda and Epagri, a public company from Santa Catarina State. The forecast results of water level for the estuaries entrance and port locations agree with the measurements from tidal gauges (Figure 22 and Figure 23). The operational modelling system represents the meteorological effects in the water level, which are of great importance to navigation and port activities, and cannot be predicted just by harmonic analysis.
Figure 21 – Comparison between satellite observations and model results of sea water temperature during 2014 in the Paranaguá estuarine system.
Figure 22 – Water level predicted by harmonic analysis from T_Tide package (gray line), computed by the operational model (blue dotted line) and measured by the tidal gauge in the entrance of the Paranaguá estuarine system and in the ports of Paranaguá and Antonina.
Although water quality modelling was initially considered for the operational forecast system, the lack of regular data series for the rivers (e.g., nutrients and phytoplankton) is a great source of uncertainty. Thus, forecast results of water quality parameters will not be provided at this stage to the Brazilian Sea Observatory, as previously planned. The few in-situ data available for validation purposes is another constraint. The development of watershed models, as well as meteorological models with higher horizontal grid resolution, seems mandatory to decrease these uncertainties in the future.

An oil spill drift model was implemented through the MOHID modelling system to allow the prediction of oil trajectory in few minutes by users of the Brazilian Sea Observatory. The forecast results of the Copernicus Marine Service (GLOBAL_ANALYSIS_FORECAST_PHY_001_024) are used to provide the currents for the entire Brazilian coast (Figure 24), whereas the forecast results of the operational modelling system increase the detail along the South-Eastern Brazilian shelf and allow the simulation of oil trajectory inside the Paranaguá estuarine system and Babitonga bay (Figure 25 and Figure 26). The future perspective is the expansion of the operational modelling system to cover the main estuarine systems along the Brazilian coast.
Figure 24 – Simulation of the trajectory of an oil spill by a vessel based on the disaster that happened in the Northeast Brazilian coast in 2019
Figure 25 – Simulation of the trajectory of an oil spill by a vessel near the coast of the Paraná State

Figure 26 – Simulation of the trajectory of an oil spill in the Port of Paranguá