An operational system for the forecasting of oceanographic conditions in the Nazare Canyon area (W Portugal)

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***Abstract*-We describe the development of an operational forecast system for the NAzare Canyon area (W Portugal) which is presently being conducted at Instituto Hidrografico (IHPT). The system integrates a number of numerical models aimed to simulate and forecasts the wave conditions, the circulation promoted in the canyon area by wind forcing, interactions with the deep sea circulation or tides, and the littoral processes. The forecast system is planned to make an extensive use of the real-time observations collected by multi-parametric platforms maintained by IH in the Nazare Canyon area as part being developed sic guidelines for preparing papers for conference proceedings.**

I. Introduction

The Nazare Canyon is the largest submarine canyon indenting the European continental margin. With a length of more than 270km, it cuts the complete western Portuguese margin at about 39º 30’ N, extending from abyssal depths of 5000m to just a few hundred of meters from shore, where the canyon head attains 150m depth.

Since 2002 the Nazare Canyon is being monitored by the Portuguese hydrographic office, Instituto Hidrográfico (IHPT). A program of long-term mooring observations at three locations along the canyon axis, complemented with regular (once per year) multidisciplinary surveys of the complete area of influence of this submarine canyon was developed with the co-funding of major European projects such as EUROSTRATAFORM (FP5), HERMES (FP6) and HERMIONE (FP7, ongoing). In 2009 this effort was extended, with the implementation of capacities for the real-time monitoring of the Nazare Canyon. An array of two multi-parametric platforms was deployed and is being operated by IHT in the framework of project MONICAN (EEA Grants). These platforms have two tide gauge stations installed at two points along the coast in the coast and one coastal meteorological station, from the network maintained by IH are being operated by IHPT in the framework of project were canyon and operational forecasting of the canyon conditions, which are being conducted in the framework of project MONICAN (EEA Grants).

In parallel with the reinforcement of monitoring capacities for the Nazare Canyon area, IHPT is also presently developing, under project MONICAN, an operational system aimed to provide forecasts of the evolution of the oceanographic conditions in the area of influence of this canyon. The system is designed to cover the broad range of processes that previous studies showed to be active in this area. It is also intended to extensively use the data collected by the different observing platforms and other real-time monitoring systems operated by IHPT in this area.

In this contribution we provide a brief overview of the main areas of development of this system, presently conducted at IHPT.

II. OPERATIONAL WAVE FORECASTING

The forecasting of wave conditions affecting the Nazare Canyon area is done as part of the wave forecasting system implemented at Instituto Hidrográfico. This system was started in 2002 and developed within the framework of the national funded project MOCASSIM (PARLE/POCTI-QCA III). At the present stage the system provides detailed wave forecast of the Atlantic Ocean area and the Portuguese Coast.

The Atlantic Ocean forecast is performed using the WW3 model ([1], [2]), forced by wind forecasts provided by FNMOC and with a temporal extension of six days (Fig. 1a). The coastal forecasts for the different areas of Iberian Portuguese Coast (as well as Madeira’s Archipelago) are performed using the SWAN model [3], with a temporal extension of three days, using the WW3 results as boundary conditions and including local wind generation fir which high resolution meteorological forecasts obtained with the ALADIN model and provided by the Portuguese Meteorological Office (Instituto de Meteorologia) are used.

For the Nazare Canyon area, other higher resolution SWAN domains were implemented to provide detailed wave forecasts in areas of specific interest. These include in particular, particularly well known surf spots.

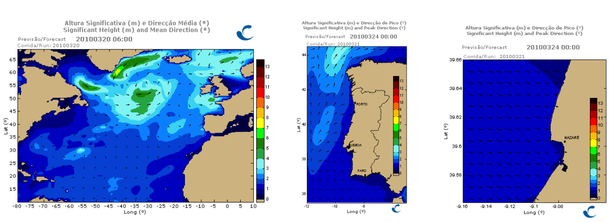

Figure 1. Wave models used in the IH-PT operational wave forecast system. From left to right: North Atlantic domain, Portuguese continental margin and Narazé area.

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Model performance is presently being evaluated using the real-time monitoring information provided by the MONICAN buoys. Fig 2 shows the time evolution for the significant wave height, peak period and peak direction (for the period May 2009 – February 2010), compared with the observations of the coastal buoy of the MONICAN project (located near Nazaré). The statistical results obtained reveal that the accuracy of the system is similar to the results presented in other works ([4], [5], [6]) with a RMSE of 0.58 meters for the significant height. These results reveal that the forecast system presents a fairly reasonable accuracy, taking into account that the area is totally exposed to severe wave conditions a large part of the year.

Currently, new system architecture is under preparation, with a large increase in the computation capacity. This new system will allow us to increase the number of high resolution areas, apart from increase the models resolutions and time-scales.

A more extensive validation and calibration study for coastal areas is under preparation, with the objective of improving the current forecast system. A correct calibration of the models and an increase in spatial and temporal resolution, complemented with a better wind forcing, can improve significantly the system results.

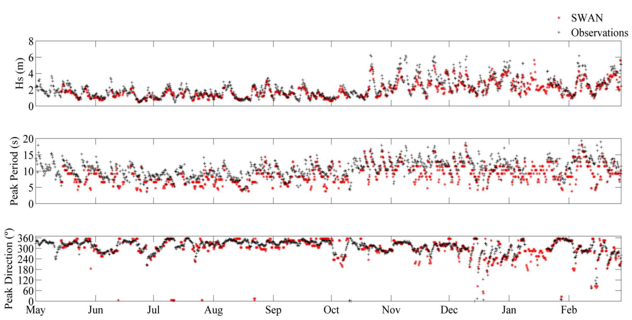

Figure 2 - time evolution for the significant wave height, peak period and peak direction (May 2009 – February 2010), compared with the observations of the coastal buoy.

Other wave models are also under evaluation to simulate the wave propagation over the canyon head, where strong refraction effects are observed. Both the daily forecasts of wave conditions as well as model performance evaluation and other associated products are being disseminated to the general public through the IHPT web page (http://www.hidrografico.pt).

III. CIRCULATION MODELS

A number of circulation models are presently being implemented and tested to forecast the shelf-slope circulation driven, in the canyon area, by atmospheric forcing, interactions with the deep-ocean dynamics or tides. The models are being adapted to use boundary conditions from large scale circulation models (MERCATOR, NRL-Hycom).

At the present the HOPS model ([7], [8]) was implemented in the Nazare Canyon area of influence. HOPS is a rigid lid PE model with includes an Optimal Interpolation module to assimilate hydrographic profiles. Hindcast simulations are being used to extend the understanding of canyon processes, complementing the observational effort conducted in the framework of projects EUROSTRATAFORM, HERMES and HERMIONE. Tests to evaluate model performance in operational mode were conducted using the data collected during a survey conducted in July 2007. The observations included an initialization survey that covered the complete area of interested and were followed by an updated survey. HOPS runs were conducted using meteorological forecasts provided by FNMOC.

Ongoing developments include the implementation of ROMS and HYCOM models to the Nazare Canyon area.

IV. MODELING THE NEARSHORE DYNAMICS

The supply of sediment from the coastal zone through the head of the Nazare Canyon is considered one of the major mechanisms that drive large amounts of down-canyon sediment transport [9]. Wave-induced alongshore currents, predominately southward directed, dominate the littoral dynamics along the Portuguese West Coast. The proximity of the canyon to the shore allows the converging of longshore currents towards the canyon head, located in the nearshore zone. Storm episodes strongly increase the magnitudes of these flows which trigger the capture of large amounts of sediments from the surrounding nearshore zone and subsequent transport through the upper canyon. A fraction of the suspended load bypasses the canyon head towards the south and eventually end-up nourishing beaches south of the canyon.

Up to now no extensive 3D coupled sediment transport-ocean circulation-surface wave modeling system has been applied to simulate the inner shelf dynamics including the littoral processes occurring at the Nazaré coastal area. Regional Ocean Modeling System (ROMS) is presently being implemented in a set of nested grids to provide more insight into these physical processes and describe the circulation and sediment transport patterns over the entire nearshore zone surrounding the Nazaré Canyon. ROMS is a member of a general class of tree-dimensional, fee-surface, terrain-following numerical model that solves finite Reynolds-average Navier-Stokes (RANS) equations using the hydrostatic and Boussinesq assumptions [10]. It uses a horizontal curvilinear Arakawa C grid and vertical stretched terrain-following coordinates. The grid can be rectilinear with constant or varying grid spacing, or curvilinear to allow focusing of the mesh to specific areas.

Recently the model has evolved to include new features allowing effective application of ROMS across a variety of geographical and dynamical environments accounting coastal and surfzone hydro/morphdynamics. Wave-current interaction on ocean circulation with three-dimensional radiation-stress terms have been inserted into the momentum equations, along with a surface roller module. Two-way coupling to the surface wave model Simulating WAves Nearshore (SWAN) allows efficient transfer of data fields between the two models. Sediment transport model algorithms have been revised and improved to allow an unlimited number of user-defined non-cohesive sediment classes. Suspended-sediment transport in the water column is computed by solving the advection-diffusion equation with a source/sink term to account for vertical settling and exchange with the bed. Bottom wave boundary layer submodels parameterize wave-current interactions over a movable bed. A multi-level bed framework tracks the distribution of every size class in each layer and the evolving properties of the seabed, including bulk properties of the surface layer such as active-layer thickness, mean grain diameter, mean density, mean settling velocity, mean critical shear stress for erosion and description of the subgrid-scale morphology and bed roughness. Suspended-load mass is exchange vertically between the water column and top bed layer and bedload mass is exchange horizontally between the top layers. A morphological model tracks the change in sea floor elevation by equating the bottom-boundary condition of the vertical velocity to the rate of change of the sea floor. ([10], [11]).

ROMS will operate on a nested-grid framework intended to resolve the broad spectrum of space and time scales acting in the inner shelf off Nazare. The characteristics of the grids and model setups will be selected considering the rather complex bathymetric configurations of the area and the range of scales of the first-order processes responsible for the circulation patterns over the Narazé Canyon head and adjacent nearshore areas. ROMS and SWAN will run uncoupled on matching outer model domains and provide accurate boundary conditions for the high-resolution implementation. Fully-coupled ocean-wave system is implemented in the inner model domains, allowing for a dynamic information exchange between the ROMS and SWAN models at synchronization intervals. SWAN sends to ROMS arrays of wave height, wavelength, average wave periods at the surface and near bottom, wave-propagation direction, near-bottom orbital velocity and wave-energy dissipation rate. ROMS provide to SWAN arrays of water depth, sea-surface elevation and current velocity [8]. Such coupling of models allows incorporating self interacting processes such has the effects of waves on the currents and mutual response of currents on the waves that are crucial to effectively resolve the wave-driven circulation patterns of the predominantly alongshore currents.

This model setup aims to better understand the role of nearshore currents circulation on the overall sediment exchange between the littoral zone and the Nazaré Canyon and to identify the time and spatial scales of major episodes of resuspension, transport and deposition in the area. The high-resolution implementation is also intended to resolve wave-driven circulation currents, sediment transport and beach morphology evolution in the surfzone. Besides ROMS also XBEACH (eXtreme Beach behavior) and NearCoM (Nearshore Community Model), which include REF/DIF1 as the wave driver and SHORECIRC (nearSHORE CIRCulation) as the nearshore circulation module, were implemented at the highest resolution bathymetric grid.

SHORECIRC is a quasi-3D depth integrated wave-averaged model that includes the effect of the vertical variation of the currents for both the current-current and wave-current interactions within a depth integrated model [12]. XBEACH is a 2-DH short-wave averaged but wave-group resolving model of surf zone and swash zone processes of wave propagation, transformation and run-up, nearshore circulations, sediment transport and bottom changes and developed to simulate the response of coast and dunes to individual storms events [13].

Preliminary applications and comparisons of two model systems, NearCoM and XBEACH, have been performed on each beach surrounding Nazaré Canyon head. Both models were forced at the offshore domain boundary with a monochromatic wave propagating approximately perpendicular to the coastline general orientation. Lateral boundary conditions were set assuming quasi-stationary conditions corresponding to an alongshore uniform coast at the boundaries and outside the model domain. SHORECIRC was set-up with a periodic boundary conditions implying that the instantaneous flow at each point of one of the lateral boundaries is mirrored at the equivalent point of the other lateral boundary and XBEACH was implemented with a so-called Neumann boundaries. The main issue was to evaluate the relative behavior of the models when running with theirs default parameter values without, for the time being, giving much concern about setting accurate and realistic boundary conditions. SHORECIRC runs were performed in a smoothed topography to avoid the model from crashing. In contrast, XBEACH was able to run in the original bathymetry without any constrains. The main parameters for each circulation model run are listed in Table 1. The depth integrated instantaneous nearshore circulation (at the end of each run) from both models at the Nazaré Beach, South Beach and North Beach located respectively in front, south and North of the Nazaré Canyon head are shown in Fig 3. Although SHORECIRC outputs are slightly more regular, in general the overall circulation patters from both models are similar and the main circulation cells are located approximately at the same positions. Differences in the circulation are more obvious near the cross-shore boundaries and they could be related with the dissimilar treatment in both models of the cross-shore boundaries conditions. From the three coastal sectors, Nazaré Beach is the one that have the most complex bathymetry, characterized by pronounced bed slopes directed to the Nazaré Canyon head. In both models outputs, particularly in SORECIRC, one can observe a cross-shore directed current connecting the surf zone with one of the canyon entrances. This particular result seams to support the concept that there is a strong hydrodynamic interaction between the nearshore zone and the canyon.

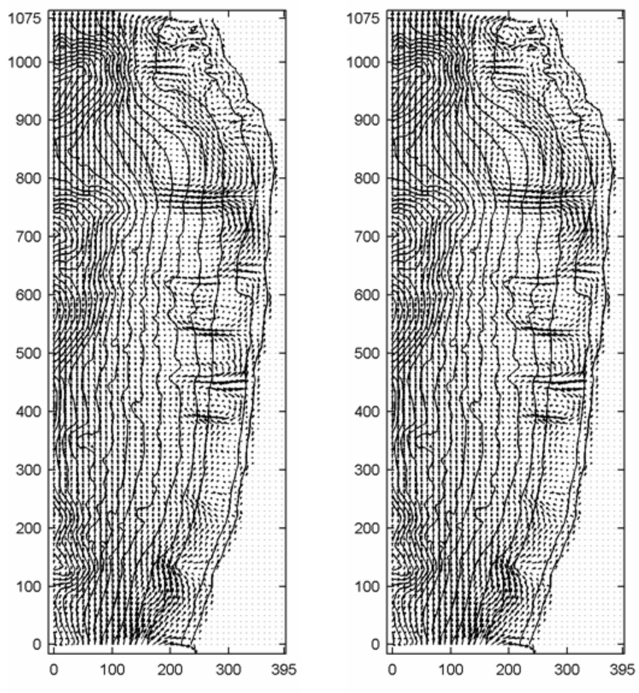

Figure 3. Predicted circulation pattern at Nazaré Beach: a) SHORECIRC model b) XBEACH model. The axis become in meters.

TABLE I

Model parameters for three beaches cases

	South Beach		**Nazaré Beach**		**North Beach**	
Model parameter	**SHORECIRC**	**XBeach**	**SHORECIRC**	**XBeach**	**SHORECIRC**	**XBeach**
Grid width (cross-shore)	275	275	400	400	455	455
Grid length (longshore)	860	860	1080	1080	1090	1090
Grid size in x	5	5	5	5	5	5
Grid size in y	5	5	5	5	5	5
Depth range (XB)	10.8	-12.6	39.9	-8.8	10.2	-5.8
Depth range (SC)	10.8	0.01	39.9	0.01	10.2	0.01
offshore wave amplitude	1	1	1	1	1	1
Offshore wave period	10	10	10	10	10	10
Offshore wave direction	0º	0º	0º	0º	0º	0º
Wave-current interaction	*Off*	*off*	*Off*	*Off*	*Off*	*off*
Roller contribution	*On*	*On*	*On*	*On*	*On*	*On*
Lateral boundary conditions	Circular	Neumann	Circular	Neumann	Circular	Neumann
Friction factor	0.012	0.024	0.012	0.024	0.012	0.024
Roller turbulence coefficient M	0.05	0	0.05	0	0.05	0
Eddy viscosity coefficients (SC)	0.08	–	0.08	–	0.08	–
3D dispersion coefficient (SC)	*On*	–	*Off*	–	*On*	–
Smagorinksy coefficient (SC)	0.2	–	0.2	–	0.2	–
Turbulent viscosity (XB)	–	0.5	–	0.5	–	0.5
shear dispersion factor (XB)	–	1	–	1	–	1
Wetting and drying (XB)	–	yes	–	yes	–	yes
Simulation time (s)	3600	3600	3600	3600	3600	3600

V. FUTURE DEVELOPMENTS

In the very near future, these developments are aimed to lead to the building of operational forecasting capacities for the Nazaré Canyon area. This implies that the implementation of modeling capacities at IHPT is also being followed by the evaluation and test of different strategies of observation, in search of the best solutions to monitor this complex environment and feed the data assimilation models. Multidisciplinary surveys were conducted in the global canyon area of influence to test model capacities and data assimilation strategies. The use of low cost sensors installed in ships of opportunity or operated during non-dedicated surveys conducted by IHPT are being presently evaluated. And the models data assimilation modules are being adapted to used the new data collected by the real-time monitoring systems. This includes the real-time ADCP and temperatures data measured by the already installed MONICAN multiparametric platforms or the surface current data to be collected by an HF radar system planned to be installed in the Nazare Canyon area in 2011, in the framework of a national funded project (SIMOC).

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