Aspects of circulation over submarine canyons: A numerical study

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1. INTRODUCTION

During several years circulation over submarine canyons were ignored due to the small size of these features. However in the last twenty years some observations (Freeland and Denman, 1982; Hickey et al., 1986) have shown that canyons should play an important role both on sediment transfer between and in maintaining high levels of primary production over the continental shelf.

In this paper we describe a few results obtained with a 3D ocean model. The model was used to perform specific process studies such as internal tide propagation and wind driven flows over the Nazaré Canyon. The Nazaré Canyon is located on the western Iberian margin near 40ºN. It is the largest European Canyon extending for about 230 Km from the mouth (at 5000 m depth) to the head (located close the coast). The area is characterized by a permanent poleward subsurface slope current driven by the meridional pressure gradient. The poleward slope current extends from the bottom of the surface mixed layer to the bottom of the Mediterranean Water (characterized by high values of temperature and salinity) at about 1500 m. Occasionally the subsurface current reaches the surface – mainly during winter, when the winds are from the west/southwest. During the spring and summer the winds are from the north/northwest inducing coastal upwelling and an associated equatorward jet in the surface layers.

2. MATERIAL AND METHODS

2.1 – Model Description

A 3D Ocean Circulation Model (*MOHID)* was applied to study some processes occurring over the Nazaré Canyon. *MOHID* was developed at IST, Lisbon and is actually a system of coupled modules. Successful studies concerning ocean circulation in the Iberian Margin were carried out in the past (e.g., Coelho, et al., 2002; Santos et al., 2002).
The hydrodynamic module of *MOHID* solves the three-dimensional primitive equations in Cartesian coordinates for incompressible flows. Hydrostatic equilibrium is assumed, as is as Boussinesq approximation. Density is calculated as a function of temperature and salinity by the equation of state published by Millero e Poisson (1981). The computed flow field transports salinity, temperature and other tracers using an advection-diffusion equation.

2.2 – Experimental Design

The model domain is shown in Figure 1. Horizontal grid spacing is 1.6 km in both directions. Bottom topography was derived from ETOPO5 by means of an interpolation for the model grid followed by smoothing with a five-point Laplacian filter. The model uses 24 vertical layers (20 sigma layers above 1000 m – minimum resolution near the bottom is 2 m). Biharmonic heat, salt and momentum diffusion coefficients are set to $2x10^9$ m^4s^{-1}, a value equal to the one used by Batteen *et al* (2000) with a similar horizontal resolution.
For both process studies (internal tides and wind-driven flows) the model is initialized with from the rest with vertical profiles of temperature and salinity representative of the area. At open boundaries we use a radiation condition described in Coelho *et al.* (2002). For the internal tide study M2 tidal components are also imposed at the open boundaries.

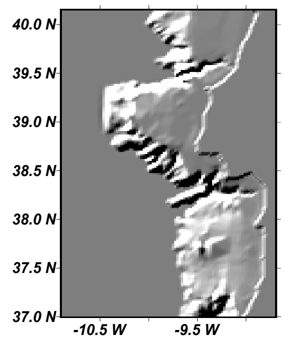

Figure 1- Model domain and bathymetry used.

3. RESULTS AND DISCUSSION

3.1 – Wind Driven Experiment

For this particular experiment a time variable northerly wind stress with a period of 10 days and amplitude of 0.1 Pa was applied. The model response is an alongshore equatorward jet typical from upwelling systems. In the upper water column (100 m) the presence of the canyon has relatively less importance than in lower layers. On the other hand the presence of Cabo Carvoeiro leads to the formation of an offshore filament of cold and nutrient rich water (See Figure 2).

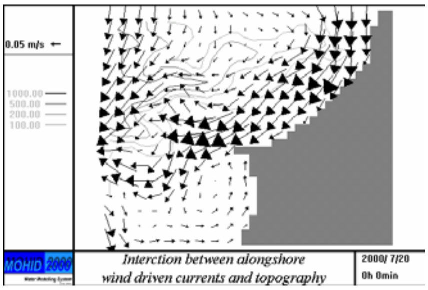

Figure 2 – Velocity field at 55 m depth.

At 130 m the presence of the canyon becomes more important for the circulation. The equatorward jet "feels" the topography and is deflected onshore where it accelerates causing divergence and enhanced upwelling at the head of the canyon. As a result a pool of cold and nutrient rich water is found downstream (see Figure 3).

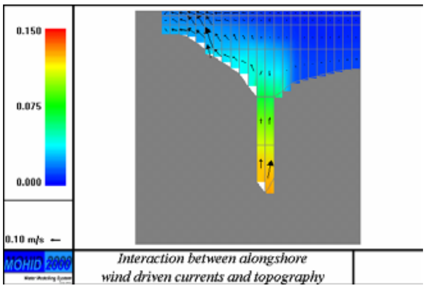

Figure 3 – Meridional cross section at the head of the Canyon. Vectors represent the N-S and vertical (x100) velocity components. Colors represent nitrate concentrations (in mg N/l). South is to the left in the figure.

Further deep, at (330 m) the geostrophic equilibrium is kept in the deeper part of the canyon. However in the upper narrow canyon that equilibrium is disrupted and a strong upcanyon flow develops feeding the upwelling previously referred (see Figure 4).

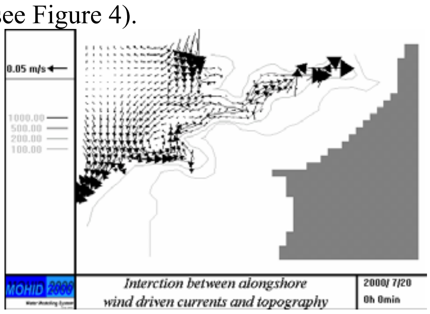

Figure 4 – Velocity field at 330 m depth.

3.2 – Internal Tide Experiment

To study the effect of the canyon in the propagation of tides we have performed a simple experiment where the semidiurnal tide (M2 component) is imposed at open boundary). More than describing the process of generation of internal tides or their propagation in locations like canyons (this was previously done by other authors, e.g. Petruncio et al., 2002) we are interested in the effect of internal tide propagation within the canyon in terms of sediment ressuspension and deposition. In Figure 5 we put in evidence the existence of strong baroclinic velocities (up to 15 cm/s) along the canyon, axis indicating the presence of strong internal tide within the canyon. At Figure 6 we show a cross section along the canyon axis (near the head) where it is possible to observe high sediment concentrations close to the bottom. Observations made in a cruise during September 2002 also show a similar pattern (see a companion paper by Garcia et al.)

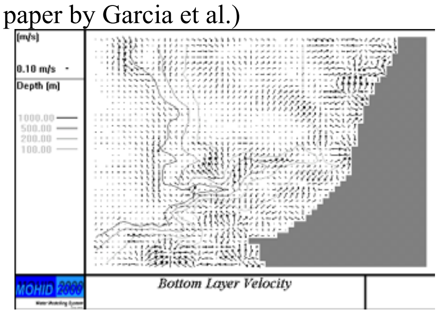

Figure 5 – Velocity field during the flood tide at the deepest sigma layer which is for the purpose the bottom following layer.

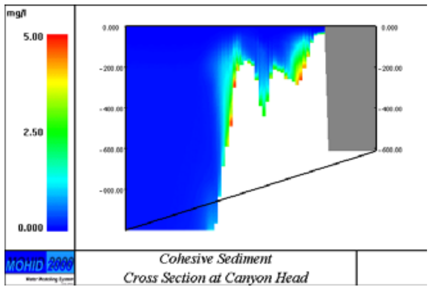

Figure 6 – Cross section along the canyon axis showing the sediment concentration near the bottom.

4. CONCLUSIONS

Two numerical experiments were performed to study aspects of the circulation over the Nazaré Canyon. Results are in agreement with previous studies and with observations. A more general model is being applied to integrate all the aspects described together with the large scale circulation and give a better description of sediment transport along the shelf and canyon.

REFERENCES

Batteen, M. L., J. R. Martinez, D. W. Bryan and E. J. Buch, 2000: A modeling study of the coastal eastern boundary current system off Iberia and Morocco*, J. Geophys. Res*., **105**, 14173-14195.

Coelho, H., R. Neves, M. White, P. Leitão and A. Santos, 2002: A Model for Ocean Circulation on the Iberian Coast. *Journal of Marine Systems*, **32**(1-3): 153-179.

Petruncio, E., J. Paduan and L. Rosenfeld, 2002: Numerical Simulations of the Internal Tide in a Submarine Canyon. *Ocean Modelling*, **4**, 221-248.

Santos, A., H. Martins, H. Coelho, P. Leitão and R. Neves, 2002:A circulation model for the European ocean margin *Applied Mathematical Modelling*, **26** (5), 563-582.