M_2 TIDAL DYNAMICS IN ALGECIRAS BAY AND ITS RELATION TO THE HYDRODYNAMICAL REGIME OF THE STRAIT OF GIBRALTAR: NUMERICAL 3D MODEL RESULTS

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Abstract
A simulation of the M_2 tidal dynamics in Algeciras Bay (South of Spain) was conducted by use of a 3D hydrodynamical model and complemented with experimental data, focusing on the influence of the general hydrodynamical regime of the Strait of Gibraltar over the bay dynamics. The semidiurnal, mesotidal regime present in the strait, together with the strong density-stratification of the water column, was found to have important consequences for the particular tidal dynamics of Algeciras Bay. Firstly, model results showed the occurrence of a cross-current system between the Atlantic and Mediterranean water layers inside the bay. Secondly, the 3D hydrodynamical model was able to simulate accurately the so-called baroclinic internal wave, generated by hydraulic jump over Camarinal Sill, as well as its propagation into Algeciras Bay.
Keywords: Tides, Models, Strait Of Gibraltar

Study site
Algeciras Bay (South coast of Spain) constitutes a physical environment of special characteristics, due to its morpho-bathymetric configuration and geographical location, close to the eastern boundary of the Strait of Gibraltar. The interaction between the mesotidal, predominantly semidiurnal tidal regime of the Strait of Gibraltar with the water stratification, due to the presence of Atlantic water at the upper layer and Mediterranean water (more salty and cold) at the lower one, has important hydrodynamical consequences, as the generation of the so-called baroclinic internal wave over Camarinal Sill and effects on the vertical profiles of the velocity of currents. Because of its wide connection to the Strait, the tidal hydrodynamics of Algeciras Bay is expected to be submitted to this peculiar processes, so the aim of this study was to conduct a detailed research in that respect by analyzing both empirical and numerical 3D model data, comparing them and setting the main characteristics of the tidal dynamics in this environment.

The Model
The three-dimensional, nonlinear, high-resolution, finite-difference, sigma-coordinated UCA 3D hydrodynamical model is based on the numerical solving of 3D equations of motion (assuming the hydrostatic simplification). The system is coupled to a two-dimensional, depth-averaged scheme [1] by the splitting technique [2]. For the modeling of the M_2 tidal hydrodynamics in the Strait of Gibraltar and Algeciras Bay, a calculation domain was chosen extending from the western Strait boundary to the Alboran Sea. The model Arakawa-C staggered grid had a horizontal resolution of 500 m and 50 vertical sigma-levels. The system was forced by a single M_2 tidal wave and the zero-frequency constituent Z_0; initial conditions of free-surface elevation and current velocity (amplitudes and phases), as well as those of salinity and temperature, were obtained from the Experiment "Strait 94-96" and previous works by [3] and [4].

Results
Modeled time-spatial fields of the M_2 harmonic parameters, obtained by conventional harmonic analysis [5], were compared with available experimental values at 40 different locations. The root mean squares of errors were 4.0 cm and 4.4º for the amplitude and phase of elevation and 18.2 cm s^{-1} and 18.3º for those of depth-averaged current velocity. Focusing on the Algeciras Bay area, model results show a little spatial variation of M_2 elevation harmonic parameters, with amplitudes and phases around 31 cm 47º Greenwich. Modeled depth-averaged M_2 current ellipses present highest semimajor axes by the coastal margins (until 40 cm s^{-1}), while they do not overcome 10 cm s^{-1} through the deeper central canyon of the Bay. A more detailed analysis of vertical velocity profiles revealed that the latter is due to a system of tidal cross-currents between the Atlantic and Mediterranean water layers inside Algeciras Bay, being a phase-lag of near 180º between the current ellipses of both layers. Comparisons with experimental ADCP data through ship transects in the Bay area show a remarkable qualitative and quantitative correlation in that respect.

In relation to the time-spatial propagation of the baroclinic internal wave, Fig. 1 (top) shows an example of model spatial field of free-surface elevation together with remote-sensing satellite image at the corresponding tidal stage. It can be appreciated a significant correspondence between them, as well as the penetration of the eastwards internal wave front into Algeciras Bay. The wave parameters, estimated from model and satellite fields, are: period: 22 minutes; wavelength: 1.8 km; wave celerity: 4.9 km/h; the amplitudes of oscillations are of the order of 1 cm. The spectral density distribution of free-surface elevation from a CTD cast on the inner Bay (Fig. 1, bottom) shows a marked peak by period values close to the calculated from model results.

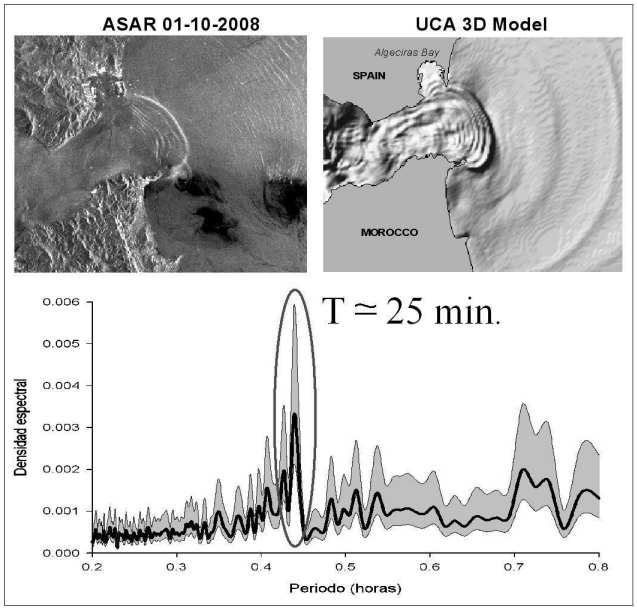

Fig. 1. Top: an example of ASAR image (left) and modeled field of free-surface elevation at analogue tidal stage (right). Bottom: spectral density distribution of free-surface elevation from a CTD cast inside Algeciras Bay, with periods up to 2 hours removed.

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