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Effects of Stratification and Vertical Velocity on Tidal Dynamics Over a Continental Slope

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ABSTRACT

This paper describes a two-dimensional linear model developed on a cross-shelf transect used to define the structure of semi-diurnal tidal current over a continental shelf margin in a continuously stratified ocean. It details the method applied to develop the equations classically employed in internal tide generation models (Baines, 1982). This development was aimed at solving a propagation equation for the semi-diurnal tide forced by the astronomical tide-generating force. A simple numerical method was applied to first solve this propagation equation in a homogeneous ocean. It allowed the characterization of the barotropic tidal velocity field over the slope. After that, the propagation equation was solved in the case of a stratified ocean to determine the surface velocity field. From an assumption made on the form of the vertical velocity induced by the slope and suggested by observations (Holloway, 1996), the vertical distribution of the tidal velocity field was investigated. This part of the study highlighted an important feature: stratification induces a shearing of tidal current which is maximal in the thermocline. The internal structure of the tidal current was then compared with two sets of *in situ* measurements carried out in Spring in the Bay of Biscay. Based on these Doppler currentmeter data determined from two moorings located on the upper part of the Celtic slope, the comparison exhibited a good agreement between theory and *in situ* data. This semi-analytical linear model by its contribution to state the initial and boundary conditions is a significant contribution to a further more complete numerical model, which will include the nonlinear effects due to the spatial variability of the tidal current over the slope.

INTRODUCTION

To develop the equations classically employed in internal tide generation models (Baines, 1982) the following assumptions are made. An incompressible stratified fluid whose equilibrium density is given by $\bar{\rho}$ whereas ρ_0 stands for $\bar{\rho}(z=0)$ is considered. The system of Cartesian co-ordinates is defined as follows: *x* cross-slope, *y* longslope and *z* vertical upward direction. Motion is assumed to be hydrostatic and equations are supposed linear and frictionless. The acceleration due to gravity and the Coriolis parameter are denoted *g* and *f* respectively.

The astronomical tide-generating force is introduced in equations by means of the equilibrium tide, $\bar{\eta} = V/g$, where V denotes the potential from which derives the tide-generating force. Its form is specified later for the semi-diurnal tide. In addition to the barotropic pressure gradient induced by the free-surface slope, η_0, due to the astronomical forcing, an internal pressure gradient is introduced. Being the consequence of the vertical motion induced by the slope, it is responsible for the strong temporal and spatial variations of isopycnal displacements η. These ones are equivalent to vertical displacements if we assume $\frac{\partial\bar{\rho}}{\partial x}=\frac{\partial\bar{\rho}}{\partial y}=0$. The buoyancy frequency is then $N^2=-\frac{g}{\rho_0}\frac{d\bar{\rho}}{dz}$ and the sea-bed depth *H*.

Under these assumptions, with *u*,*v* and *w* being the *x*,*y* and *z* velocity components respectively, the considered equations are written:

$$(1)\quad \frac{\partial u}{\partial t} - fv = -g\frac{\partial}{\partial x}(\eta_o - \bar{\eta}) - \frac{\partial}{\partial x}\int_{-z}^{o} N^2(\eta - \eta_o)dz'$$

$$(2)\quad \frac{\partial v}{\partial t} + fu = -g\frac{\partial}{\partial y}(\eta_o - \bar{\eta}) - \frac{\partial}{\partial y}\int_{-z}^{o} N^2(\eta - \eta_o)dz'$$

$$(3)\quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$(4)\quad \frac{\partial}{\partial x}\left(\int_{-H}^{o} u\,dz\right) + \frac{\partial}{\partial y}\left(\int_{-H}^{o} v\,dz\right) = -\frac{\partial \eta_o}{\partial t}$$

A particular cross-shelf section is considered assuming that it is uniform in the longshelf direction. Then, *H(x)* is independent upon the long-slope direction, *y*, and is chosen in a hyperbolic tangent form to easily simulate any topography configuration by changing the parameters presented on Fig. 1. These parameters are *H0* for the depth on the abyssal plain, *H1* for the depth on the shelf. The origin of *x*-axis is taken at the slope bottom. The offshore end of the cross-shelf section and the coastline end are denoted x_0 and x_1 respectively.

The configuration presented in Fig. 1 corresponds to the Portuguese slope characterized by a very narrow shelf. However, in the mathematical model used, the shelf width can be extended to match the topographies encountered in the North of the Bay of Biscay.