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Fortnightly and monthly variability of the exchange through the Strait of Gibraltar

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Abstract

The fortnightly and monthly variability of the exchange through the Strait of Gibraltar has been studied from two simultaneous five-month long moored datasets, at Camarinal Sill and the East Section. The study focuses on the M_{sf} and M_m tidal components and their role for the subinertial exchange. A significant monthly signal is observed in the upper layer transport. Also, a significant fortnightly signal is observed in the lower layer transport, which minimum (maximum flow toward the Atlantic) takes place approximately on spring tides. In consequence the net transport has both signals, with maximum taking place during neap tides and a small monthly inequality. Fortnightly and monthly variability in the interface depth is also observed at Camarinal Sill, the interface being deeper on neap and shallower on spring tides. At the East Section the interface depth signals are not significant.

The subinertial variability of the transports is separated in two contributions. The first one is called quasistatic transport and arises from the subinertial fluctuations of currents. The second contribution, called tidally rectified transports, arise from the non-linear correlation of currents and interface depth at tidal frequencies. The tidally rectified transports are important at Camarinal but not at the East Section. An apparent contradiction between the fortnightly signals of the subinertial currents and subinertial transports is resolved when the fortnightly signal of the tidally rectified transports are considered. The fortnightly signal of the quasistatic and tidally rectified transports mutually cancel in the upper layer, but not in the lower layer where the rectified transports dominate. A simple model for the spring-tide mixing forcing accounts for the fortnightly variability of the lower layer quasistatic transports but underestimates it for the upper layer. Finally, the observed lower layer transport is compatible with the hydraulic control condition at Camarinal Sill except for certain periods during intense spring tides.

Keywords: Strait of Gibraltar; Baroclinic motion; Spring tides; Neap tides; Tidal rectification; Hydraulics

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1. Introduction

1.1. The mean exchange

The Strait of Gibraltar is the only dynamically relevant connection of the Mediterranean Sea with the World Ocean. It is a narrow and shallow channel, with a sill depth of less than 300 m (Camarinal Sill, CS hereinafter) to the west of a narrow region (Tarifa Narrows, TN) of about 15 km of minimum width (Fig. 1a). A small net inflow of fresh water through the Strait is necessary to balance the excess of evaporation minus precipitation over the Mediterranean. Mass and salt conservation force this net inflow to be achieved as a density driven baroclinic flow: fresh ($S_1 \simeq 36.2$) and warm North Atlantic Water flows in at the surface (the upper layer transport, Q_1); saltier ($S_2 \simeq 38.4$) and colder Mediterranean Water flows out at depth (the lower layer transport, Q_2). Mixing and water entrainment originate an interfacial layer where water properties change gradually. The interfacial layer has a significant thickness and contributes appreciably to the exchanged flows (Bray et al., 1995). However, the inverse-estuarine exchange can still be approximated as a two-layer system of reduced gravity $g' \simeq 0.02\ \mathrm{m/s^2}$, mean layer transports $\overline{Q}_1 \simeq -\overline{Q}_2 \simeq 1$ Sv, and mean net transport $\overline{Q}_0 = \overline{Q}_1 + \overline{Q}_2 < 0.1$ Sv. We will make use of this two-layer system and, in this framework, subindexes 1 and 2 will be used to designate upper and lower layers quantities, respectively.

The amplitude of the transport fluctuations in either layer can be of the same order of magnitude, or higher, than the mean value (Candela et al., 1990; Bryden et al., 1994). Traditionally the fluctuations have been divided into three main frequency bands (Lacombe and Richez, 1982; García-Lafuente and Vargas, 2003):

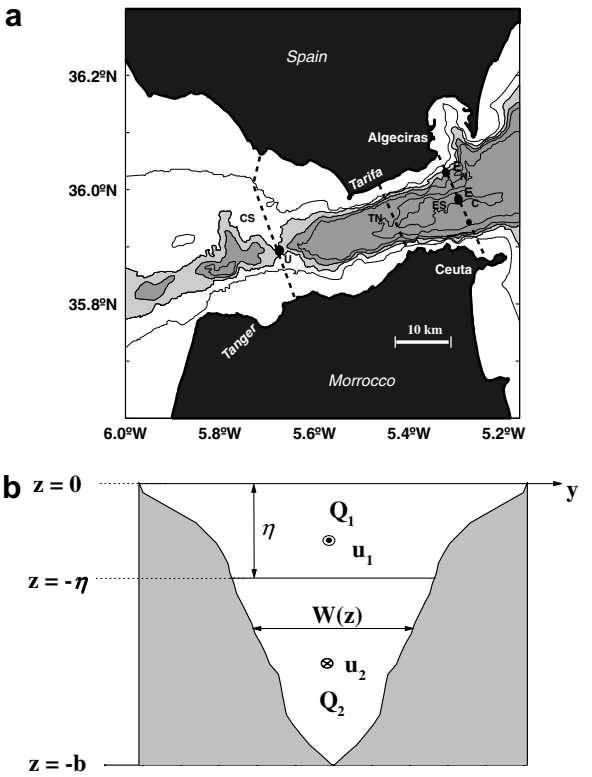

Fig. 1. (a) Bathymetry of the Strait of Gibraltar. Notable sections have been labeled: the main sill (Camarinal Sill, CS), the narrower section (Tarifa Narrows, TN), and the eastern exit (East Section, ES, also called Algeciras–Ceuta section). The mooring sites U, E_N and E_C are also shown. Isobaths have not been labeled for clarity. Isobaths depths are 100 m, 290 m (to illustrate the depth of Camarinal Sill), 400 m, 500 m, 700 m, and 900 m. Depths grater than 290 m are in light gray, and those grater than 400 m in dark gray. (b) Sketch of a traverse section of arbitrary shape, viewed from the Mediterranean.