MONITORING OF THE FLOW OF ATLANTIC WATER AND ITS PROPERTIES IN THE EASTERN SECTION OF THE STRAIT OF GIBRALTAR. SUBINERTIAL VARIABILITY.

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Abstract

Data acquired in the northern part of the Strait of Gibraltar during a pilot study previous to CANIGO-MAST Project have been analysed in order to provide estimates of some local properties of the inflow and their time variability in the subinertial (meteorological) frequency band. Local exchange, which is not represented by a simple two-layer model, is modulated by zonal winds in the Strait. An interesting result is that local inflow and outflow have a tendency to oscillate in-phase, thus smoothing out the oscilations of the net local flow. Another result is that this net local flow is not always directed toward the Mediterranean.

Key-words : Sea level, water transport, wind, air-sea interactions

Introduction

The importance that the Strait of Gibraltar has with regard to the general circulation and ventilation of the Mediterranean Sea is quite obvious: it represents the only connection with the open ocean. Around $3 \cdot 10^{13}$ m^3 of "fresh" Atlantic water come through it into the Mediterranean every year (somewhat less than 1% of its total volume). This water is transformed into "salty" Mediterranean water that flows out as an undercurrent. The overall exchange results in a net inflow to compensate for the net evaporation that takes place in the Mediterranean basin.

While this general point of view is of interest for climatic and/or other long term studies of the properties of the Mediterranean (residence time of the water, interannual variability), it is not sufficient for more detailed studies of its circulation on shorter time-scales. This is particularly true for surface circulation in its westernmost basin, the Alboran Sea. The knowledge of other properties of the Atlantic inflow like the relative vorticity, the incoming angle or the current intensity (in addition to water transport) and their time variability are of the greatest interest to this kind of studies.

One objective of CANIGO MAST Project is the monitoring of the exchange through the Strait at the eastern section to provide estimations of these properties. From October 95 to May 96 and previously to the start of the Project, a pilot study was carried out to check new acoustic methods of estimating the horizontally integrated transport. As a part of the experiment, a mooring line with five conventional currentmeters was deployed at site "N" (see figure 1). The results obtained from the processing of this information are presented below.

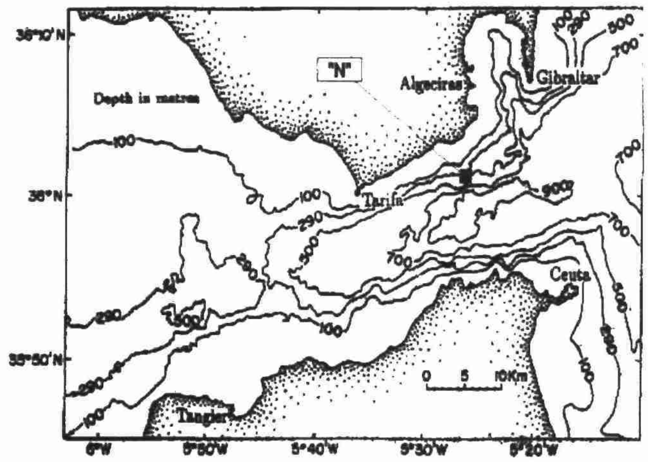

Figure 1 : Map of the Strait showing the mooring's location.

Data and data processing

The mooring line was deployed on the 24th of October 1995 and recovered on the 8th of May 1996 with a short servicing on the 23rd-24th of February. Site "N" was at 36° 02.3N, 5° 23.8W and nominal depths of the instruments were 30, 60, 110, 240 and 400m in 450 m water depth. All instruments were equipped with conductivity and pressure cells so that time series of salinity and depth in addition to velocity and temperature are available. Sea level data from Ceuta (Instituto Español de Oceanografia Data Base) Gibraltar (British Oceanographic Data Centre) and local atmospheric pressure and wind velocity (Instituto Meteorológico Nacional, Spain) were also gathered to investigate cross-strait geostrophy and atmospheric forcing.

Sea level and meteorological variables were filtered out with a gaussian filter with cut-off frequency of 4 cpd to remove tidal variability. Oceanographic data were harder to process: salinity series had trends due to biological contamination of conductivity cells and were corrected. Another problem occuring in this area is the periodic sinking of instruments due to tidal currents. As a result, data collected by a given instrument are not taken at a given depth (this is why instruments were equipped with pressure sensors). Standard filtering techniques are inadvisable and some kind of daily average has been performed instead. Daily means have been filtered with a gaussian filter of the same cut-off frequency as the series above mentioned to compare both types of observations. Further details can be seen in Garcia Lafuente *et al.* [1].

Results and discussion

Vertical structure of the flow. Figure 2 shows time variability and depth structure of the along-strait component of velocity (labelled contours) and salinity (shadowed areas). The local depth of zero along-strait velocity, which separates inflow and outflow, is around 100 - 125 m except for a ten-days period at the beginning when it was considerably deeper. Salinity at this depth is higher than 37.5 (in Practical Salinity Scale Units). This isohaline is sometimes taken as the interface between Atlantic and Mediterranean waters. If so, we must conclude that Mediterranean water recirculates toward the Mediterranean by the northern part of the Strait. However, salinity distribution shows that a two-layer description of the flow at this location is not adequate. A three layer model with an "Atlantic" layer of S<37, a "mixed" layer of 37<S<38 and a deep "Mediterranean" layer of S>38 as that put forward by Bryden *et al.* [2] provides a better picture. In this three-layer structure, the mixed layer flows mainly toward the Mediterranean, in agreement with the description of Bray *et al.* [3] who presented a more elaborated three-layer model.

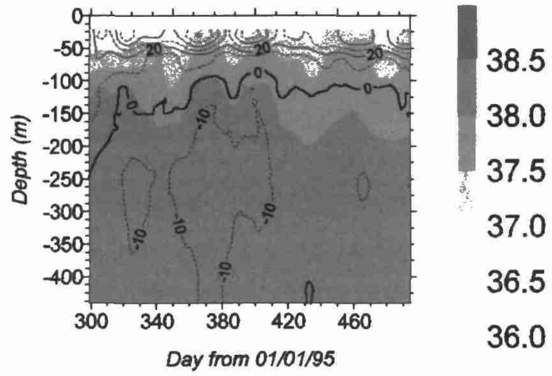

Figure 2 : Depth structure and time variability of along-strait velocity and salinity.

Cross-strait geostrophy. An issue of importance is to check to what extent cross-strait geostrophy keeps validity. The solid thick line of figure 3A represents the along-strait velocity measured by the uppermost instrument (a velocity representative of the ten-meter thick bin from 30 to 40 m). Dashed line is the velocity predicted by the formulae $u=(g/f)(\Delta\xi/\Delta y)$ (1) which is a horizontally averaged version of the actual cross-strait geostrophic relationship with $\Delta\xi$ the sea level difference (Ceuta minus Gibraltar) of two sites separated a distance Δy (21 km). The prediction is shifted toward high values due to the lack of accurate levelling between both shores. This is better shown in the lineal fit of figure 3B which gives a non-zero independent term, contrary to what equation (1) states (it can be written as $\Delta\xi= (f\Delta y/g)u = 0.183u$ for $\Delta y = 21$km). It provides however a very good estimation of the coefficient of u. Taking into account the independent term of the fitting in the prediction, the thin solid line of figure 3A is obtained, which compares well with observations, despite of equation (1) is a horizontally averaged estimate of u while the observations are local values. The lagged correlation of figure 3C gives a highvalue for the correlation coefficient, slightly shifted toward positive lags, what means that u leads sea level slope.

Local transport

The vertical structure of velocities of figure 2 has been used to estimate flows per unit length perpendicular to the strait at site "N", what we call local flows and transports. Their units are m^2/s and are defined as $\int u\,dz$, where u is the low-passed along-strait velocity. Limits of the integral are the depth of u = 0 and the surface for inflow and the sea floor and the depth of u = 0 for outflow. Thin solid, dashed and thick solid lines of figure 4 represent local inflow, outflow and net flow respectively. There are two noteworthy features: first, that net transport is not always directed toward the Mediterranean and secondly, that inflow and outflow behave symmetrically, that is, both increase and decrease simultaneously.