TIME FLOW VARIABILITY IN THE BALEARIC CHANNELS AND ITS RELEVANCE TO THE WESTERN MEDITERRANEAN CIRCULATION

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Abstract

The "CANALES 96" field experiment was carried out during March-July, 1996, to investigate the time variability of the water exchanges through the Balearic channels (Western Mediterranean). Four instrumented moorings were deployed and monthly hydrographic surveys were carried out. The main result is that ocean properties are characterized by energetic mesoscale events due to cold eddies of Winter Intermediate Water (WIW, T<13ºC). Eddies aggregation can even lead to the sporadic appearance of a large anticyclonic WIW gyre to the north of the Ibiza channel which drastically modifies the water exchange dynamics through the channels, therefore affecting the northward spreading of Modified Atlantic Waters and the southward flow of Mediterranean Waters. Simulations with a numerical model are also carried out to help understanding *in situ* observations.

Key-words: Balear Sea, Straits and Channels, Hydrography, Monitoring

Introduction

For several years now, the Balearic Sea has been considered as a key transition basin between the northern Gulf of Lions and the southern Algerian basin in the Western Mediterranean. The Balearic Sea communicates with the Algerian basin through the Balearic channels: the Ibiza channel between Ibiza and the Spanish peninsula, and the Mallorca channel between Mallorca and Ibiza. The idea that the Balearic channels concentrate the meridional fluxes between the (thermo)dynamically well contrasted northern and southern Mediterranean leading to an energetic seasonal adjustement between the southward spreading of Mediterranean Water (MW) cooled in the north and the northward spreading of lighter Modified Atlantic Water (MAW) from the south was reinforced by recent satellite [1] and large scale modelling [2] studies. *In situ* high resolution surveys also highlighted that the circulation in this basin is characterized by a high mesoscale activity that substantially distorts the mean circulation pattern of along-slope currents [3]. More recent studies emphasized the role played by the Balearic channels in controlling the meridional mass transport and fluxes of heat, salt and other properties, hence showing its relevance to the general circulation of the Western Mediterranean [4, 5]. Satellite and *in situ* observations in the Balearic channels also suggested complex interactions between surface and subsurface mesoscale eddies and channel topography, with strong effects on the mean seasonal exchange dynamics through the Ibiza channel [6]. All these previous studies were extremely useful for defining the spatial characteristics of the circulation in the Balearic Sea but missed the time evolution of the flow.

The INTERMESO group, composed by oceanographers from the Institut Mediterrani d'Estudis Avancats, Centro Oceanografico de Baleares and Institut de Ciencies del Mar, carried out a unique field experiment during 1996-97 to investigate the annual cycle of the ocean circulation in the Balearic channels. The experiment was mostly oriented towards determining the nature and the time scales of circulation variability. The data presented here were collected during the "CANALES 96" field experiment, March-July, 1996, and relied on two major efforts: 1) The deployment of 4 instrumented mooring lines to continuously monitor currents and water properties and resolve the time variability at subinertial frequencies and 2) Repeated hydrographic surveys every month to sample the water mass structure and help assess flux seasonal variability. All CTD casts reached the bottom and moorings were designed to record the current and water properties for each layer of the water column. Additional data of sea surface temperature from NOAA satellite imagery were obtained and used to interpret *in situ* measurements. Also numerical modelling experiments were carried out to help in the understanding of observed phenomena. Crucial data were thus obtained for the first time, for a broad range of ocean processes in the Balearic Sea which appear to be fully relevant for the general circulation of the Western Mediterranean.

Design of the experiment and instruments used

The typical pattern of the mean circulation in the Balearic Sea is shown in Figure 1 which also highlights the question of the flow interaction in the channels. Triangular shape hydrographic surveys to be repeated every month were designed for each channel (Figure 1). Four days were needed every month to sample both channels (37 stations in total).

Four sub-surface moorings were also deployed to continuously monitor the fluxes and physical properties of ocean waters flowing through the channels at particular locations, over the 900 m isobath (Figure 1). The four moorings included a total of 12 mechanical current meters (vector average) and 2 thermistor strings (10 thermistors each).

During all cruises a SBE-25 CTD probe was used for hydrographic measurements. A critical point in this kind of study dealing with hydrographic climatology is the correct calibration of the sensors which should allow sensible comparison between all cruise data sets. The SBE-25 probe was calibrated in situ during the May cruise, half way between March and July using another SBE-25 probe which had been calibrated a few days prior to the cruise in OSI laboratory (Southampton, UK). Temperature and salinity data were obtained for all cruises on the basis of this particular calibration. Temperature and conductivity sensors of moored instruments were also calibrated using the closest CTD profiles performed in their vicinity at the time of the cruises.

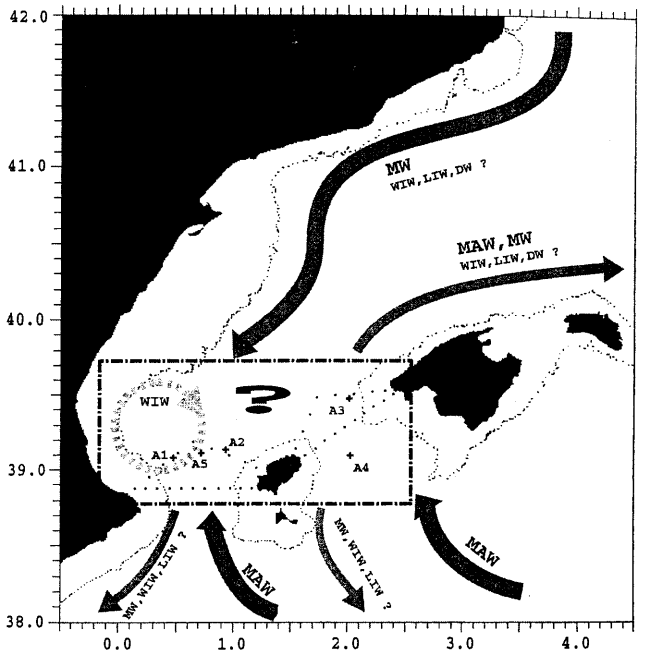

Figure 1: Classical picture of the main inflow patterns into the Balearic Sea (dark grey solid arrows). Surface Mediterranean Water (MW), Winter Intermediate Water (WIW), Levantine Intermediate Water (LIW) and Western Mediterranean Deep Water (DW) are assumed to enter the basin along the continental slope from the northern Gulf of Lions. Modified Atlantic Water (MAW) flows into the Balearic Sea from the southern Algerian basin. Light grey solid arrows sketch likely outflows resulting from water exchange dynamics through the channels where complex high frequency subinertial flow interactions are expected to occur. The WIW eddy recurrent in spring-summer to the north of the Ibiza channel is represented by a dotted arrow. Crosses indicate A1 to A5 mooring locations for long-term monitoring of the water fluxes and dots represent hydrographic stations repeated every month from March to July, 1996.

Overview of hydrographic data analyses

The hydrographic data set obtained from the March (late winter) to July (early summer) surveys, 1996, give snapshots of the circulation occurring in the Balearic Channels during the transition period from winter to summer with information on the structure, dynamics and transport of the water masses. The analyses were based on plotting distributions of temperature, salinity, density, dynamic height and geostrophic velocity. Dynamic height was computed with a reference at 600 m. For shallow profiles located over the slope, the closest offshore station was extrapolated. A general result that can be derived from the analysis of properties distributions is that two signals are superimposed: a mean, smooth seasonal month-to-month variability at climatological scale which modulates an energetic signal due to mesoscale eddies transiting through the channels.

The March survey evidences thermal homogeneity of the water column resulting from winter convective processes. The circulation in the different

layers follows the known mean circulation pattern: a southward MW flow along the Spanish peninsula slope and northward MAW flow along the Balearic islands slope. Also, Levantine Intermediate Water (LIW) is detected to the north and flows southward through the Ibiza channel. No Winter Intermediate Water (WIW) was observed yet.

This pattern was maintained during the April survey except that, this time at a large amount of WIW was sampled within and to the north of the channels. During the cruise, WIW was practically occupying the whole width of Ibiza channel, in a layer 300 m thick. Similar conditions were occurring in the Mallorca channel. LIW was flowing through the Ibiza channel.

The first MAW was sampled in May. A remarkable northward inflow entered the Balearic Sea over the Ibiza slope, but veered offhore to the north of the channel. This motion seemed to be forced by the interaction with the periphery of an anticyclonic eddy of WIW (clearly seen in satellite imagery) lying to the north of the channel in the intermediate layer, with a thickness of 300 m (Figure 2). Additionally, this eddyseemed to be responsible for an eastward shift of the continental current and LIW core. For this reason, the LIW outflow was displaced to the Mallorca channel where smaller amount of WIW was present (Figure 3a).

No MAW inflow was observed during the June survey. At this time, the main LIW flow was re-established through the Ibiza channel, with a secondary outflow through the Mallorca channel. Small amounts of WIW were flowing through both channels (Figure 3b).

Finally, during July, in typical summer stratified conditions, important inflows of MAW were found, mainly in the Ibiza channel. As in May, the outflow of LIW through this channel was reduced, its main core flowing through the Mallorca channel, while important outflows of WIW were observed through both channels. This observation evidences the important role played by the accumulation of WIW to the north of this channel for the meridional water exchange. Large amounts of WIW appear to have consequences for the surface circulation, such as favouring the inflow of MAW, and for the intermediate layer where it distorts the mean path of LIW along the continental slope.

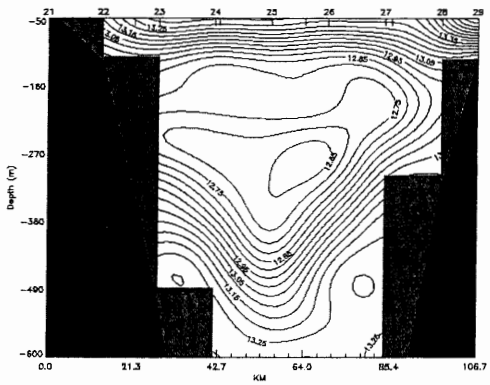

Figure 2: Vertical structure (looking north) of the temperature field in May 1996 along the triangular hydrographic transect to the north of the Ibiza channel.

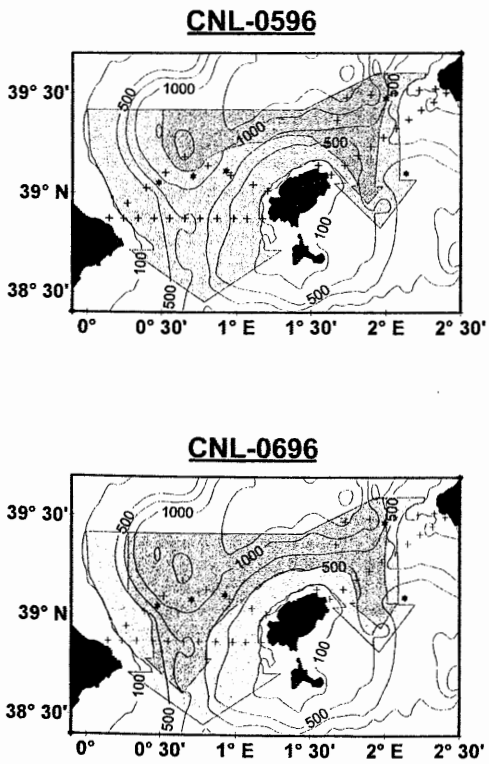

Figure 3: Schematic circulation patterns in the Balearic channels derived from the analysis of hydrographic data for the (a) May and (b) June, 1996, cruises. WIW circulation is represented by light grey arrows and LIW by dark grey arrows.

Main results from mooring data time series

Results obtained from mooring data analyses show that, in spring, a large volume of WIW (T<13°C) permanently fills the western part of the Ibiza channel between 100 and 300 m flowing in the northwestward direction which is opposite to the expected mean along-slope circulation. During summer, thermistor strings data recorded to the north of the Ibiza channel show that the temperature field exhibits strong variations due to WIW eddies. At the same time, the flow regime in this channel exhibits energetic mesoscale fluctuations leading to flow reversals. These WIW eddies strongly interact with the LIW layer which appears to be strongly distorted.

In the Mallorca channel, the circulation is less energetic. The observed mean circulation is northward in both the surface and intermediate layers, with sporadic WIW events to the north of the channel. The flow in the intermediate layer is weakest in summer.

Model results and discussion

All these observational results outline the importance of the WIW for the flow dynamics in the Balearic channels and its relevance to the general circulation of the Western Mediterranean. In order to help understanding the different circulation patterns observed in the data and get insight into the role played by the accumulation of WIW eddies to the north of the Ibiza channel, we carried out a numerical study using the Modular Ocean Model (MOM). On the basis of the *in situ* observations, numerical simulations systematically included the southward continental current flowing along the continental slope, and used different initial and boundary conditions including or not WIW to the north of the Ibiza channel and MAW inflows through the channels.

The results obtained from the different numerical experiments evidence the sensitivity of the circulation in the Balearic Sea to the successive configurations. We found that large WIW eddies are able to deflect the southward continental current away from the slope at intermediate depths, reducing the southward transport through the Ibiza channel during a few months. The WIW recirculates to the north of the channel and lead to a blocking of the southward LIW transport with drastic flow reversals over the slope. As a consequence, the LIW is deflected northeastwards towards the Mallorca channel and meridional mass, heat and salt fluxes are profoundly modified. The veering of the continental current is also observed in the surface layer in presence of a northward MAW inflow through the Ibiza channel.

Concluding, both observational and numerical experiments indicate that WIW is relevant to adequately describe the circulation of the Balearic Sea, with a likely major impact on the ecosystems of the Balearic and continental shelves, and on the general circulation of the Western Mediterranean. All results suggest the importance of accurately taking into account this type of water in numerical models of the Western Mediterranean.

Acknowledgments

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