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# Mesoscale dynamics of the Balearic Front, integrating glider, ship and satellite data

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ABSTRACT

An intensive observational programme of the Balearic Front, in the Western Mediterranean Sea, was carried out using conventional (CTDs from a ship) and new technologies (gliders). The strategy consisted of repeated sampling of a section almost perpendicular to the Balearic Current situated to the north of Mallorca Island. This section is coincident with track 773 of the ENVISAT satellite. In this work we present results of missions undertaken in July and September 2007. In July the sampling was designed to collect in-situ data from a ship and a coastal glider, almost simultaneously with the passage of the radar altimeter on board the ENVISAT satellite. In September the sampling was done only by the glider platform, and also simultaneously with the passage of the satellite. The Balearic Front was clearly detected by salinity (not temperature), with lower values (37.4 PSU) near the coast that are likely to be related to the input of recent Atlantic Water through the Mallorca Channel. The observed width of the front was about 35–40 km, with a vertical extension of 200 m. It had a significantly different pattern between the July and September samplings, which confirms the high mesoscale variability of this frontal area. Using a reference depth level of 180 m we have obtained maximum geostrophic velocities of 40–45 cm/s, flowing northeastwards along the north Mallorca coast. These velocity estimates are not sensitive to the test reference level (600 m), indicating that the layer between 200 and 600 m does not play a key role in the dynamics of the upper layer (200 m). A dynamic height rise from July to September (in 70 days) of about 3–7 cm reflects the seasonal cycle of sea level due mainly to thermosteric expansion of the water column. This gives a rise rate in the range of 1.3–3 cm/month, which is in agreement with previous estimates in the Mediterranean Sea. Absolute dynamic topography from altimetry data reveals good coherence with the dynamic height from the glider data in the area where there are common observations. In September, ENVISAT captured the sharp gradient observed with in-situ data, with mean velocities of about 24 cm/s, but with a smaller variance than the glider due to the larger wavelength of the filter applied to the altimeter data. From the technological point of view the observational experiment has confirmed the feasibility of using a coastal glider to monitor the spatial and low-frequency variability of the coastal ocean. The coastal glider was appropriate in this particular case since the vertical extension of the front only reaches up to 200 m. The autonomous platform was shown to be strongly robust, and able to monitor the area even under adverse meteorological conditions. This represents an important achievement, since under the same conditions the CTD sampling from a traditional research vessel would normally have been cancelled. Moreover, this type of platform allows autonomous collection of CTD casts and biogeochemical measurements at high spatial resolutions and at very low costs compared to conventional methods.



## 1. Introduction

The Balearic Sub-basin is located in the Western Mediterranean between the Iberian Peninsula and the Balearic Islands (Fig. 1). On the continental side the bottom topography is characterised in the north by a narrow continental shelf, commonly defined as the 200 m isobath, that widens considerably south of the Ebro River Delta. On the island side the shelf is narrow, with sills of different depths. Between Mallorca and Ibiza (Mallorca Channel) the depth is 600 m, whereas between Mallorca and Menorca it is just 100 m. For the channel between Ibiza and the mainland the maximum depth is 800 m, and in the northern part the maximum depth between Menorca and Barcelona is 2000 m.

The general surface circulation was well established in the late 1980s: it is controlled by the presence of two quasi-permanent fronts and their associated currents. The Catalan Front is a shelf/slope front that separates old Atlantic Water (AW), in the centre of the Balearic Sub-basin, from the less dense water transported by the Northern Current, which is also old AW but fed into the Gulf of Lions and the Catalan shelves by fresh continental water (Fig. 1). The Northern Current flows southwards along the continental slope until it either exits the basin through the Ibiza Channel, or re-circulates cyclonically over the island's

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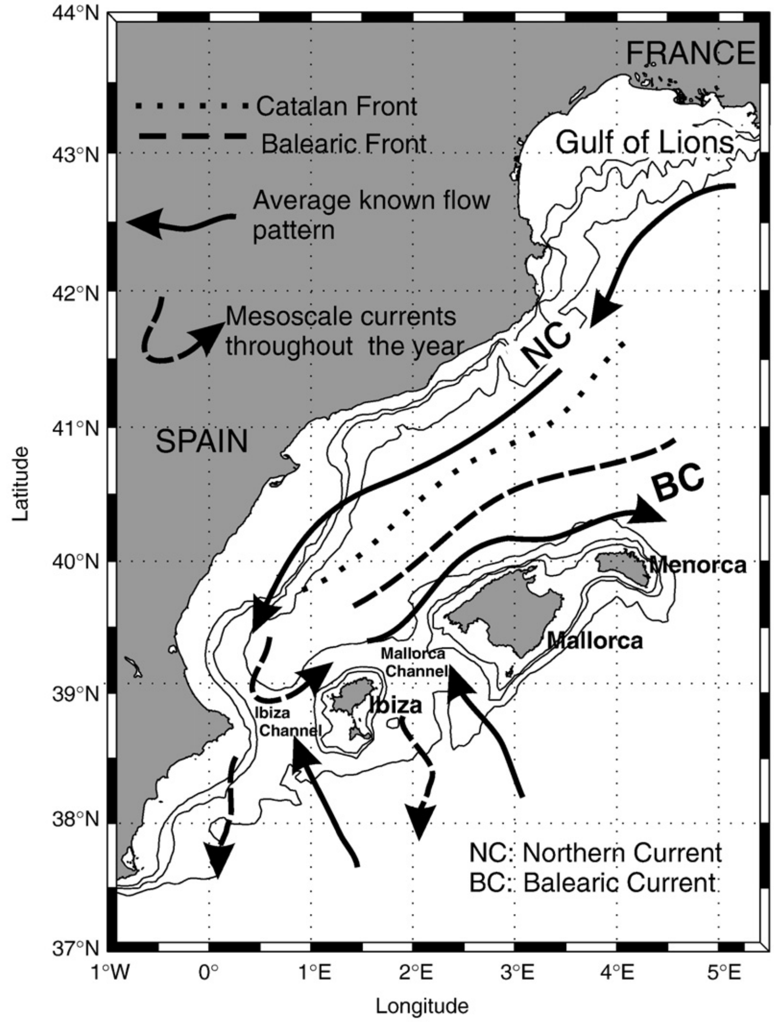


**Fig. 1.** Map of the main circulation in the Balearic Sub-basin (Western Mediterranean). Isobaths are 100, 200 and 1000 m. Figure modified from Pascual et al. (2002).

slope forming the Balearic Current. This latter current is also fed by recent warm and fresh AW waters coming from the Algerian Basin through the Mallorca and Ibiza Channels. The Balearic Front thus separates old AW, present in the middle of the basin, from the lighter water transported by the Balearic Current. Both currents (Northern and Balearic) are of the order of 50 km wide and represent the major force causing the circulation, since winds have been shown to produce only transient perturbations (Font, 1990).

On seasonal time scales, observations of the Northern Current (Béthoux, 1980; Font et al., 1988) provide evidence of higher transports in winter than in summer (of about 1.5–2 Sv and 1 Sv, respectively), while the opposite is found in the Balearic Current (about 0.3 Sv in winter compared with 0.6 Sv in summer).

In terms of the mesoscale variability La Violette et al. (1990) confirmed the frequent occurrence of instabilities associated with both fronts, the Catalan and Balearic, noting that this second front appeared to be more stable and better identified during the summer. However, López García et al. (1994) later demonstrated that the variability of the Balearic Front was more intense than previously described.

Tintoré et al. (1990) showed that the intrusion of low-salinity anticyclonic eddies in the Balearic Sub-basin could be generated by the vorticity adjustment of the buoyant gravity current, or be the result of the interactions between the southward coastal flow (the Northern Current) and bottom topography. Pascual et al. (2004) and Jordi et al. (2005) have recently explored the influence of deep topographic canyons on the modifications of the Northern Current.

Focusing on the area of the islands, Pinot et al. (1995) showed that the Balearic Current is in good geostrophic balance, and found maximum surface velocities of about 30 cm/s. It is also well known that in this area the tidal currents are weak (a few cm/s), and inertial oscillations only occur after strong storms, mainly in autumn and winter (Pinot et al., 1995). Pinot and Ganachaud (1999) used quasi-synoptic hydrographic data collected in the whole Balearic Sub-basin, during spring–summer 1993, to estimate the absolute geostrophic flow, and to build transport maps for the different water masses. They noticed that the presence of winter intermediate water (WIW) can play an active role in the Balearic Sub-basin dynamics. In particular, a major anticyclonic WIW eddy located to the South of the basin was observed to obstruct the water exchange through the Ibiza Channel, and to deflect the Northern Current back to the northeast. Pinot et al. (2002) found a marked interannual variability in the water exchanges through the Ibiza and Mallorca Channels, but they also discovered some permanent features: the flow regime in the Ibiza Channel is dominated by the Northern Current, which carries northern waters southward but also systematically bifurcates northeastward, to a lesser or greater extent, forming the Balearic Current. As far as the Mallorca Channel is concerned, part of the Balearic Current crosses the channel southward and part of the flow avoids the sill and proceeds northeastward along the Mallorca slope. Moreover, their results indicate that the Mallorca Channel is the preferential path of southern waters to the north, while the Ibiza Channel is dominated by southward advection of northern waters. Using estimates given by an inverse model, and from hydrographic and