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Circulation patterns at Le Danois Bank, an elongated shelf-adjacent seamount in the Bay of Biscay

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ABSTRACT

Le Danois Bank is a seamount-like topographical feature located at the continental shelf in the central Cantabrian Sea (Bay of Biscay), recently declared Marine Protected Area. The bank is partially connected to the shelf by a saddle, topographically bounding an inner valley. Hydrographical cruises and direct current measurements from current meters, vessel-mounted ADCP and subsurface floats are analysed to describe the main circulation patterns in the area. Records are consistent with the presence of anticyclonic flow at the seamount summit. The inner valley seems to support the development of retentive flow structures and the whole system is affected by strong and variable along-slope currents, thus complicating the overall picture.

Scaling arguments, based on non-dimensional parameters accounting for the surrounding flow characteristics and the geometry of the seamount, allow an estimate of the dynamical processes that may be active at the bank. Temporary Taylor cap formation by weak impinging flow may occur, although a clear signature of this feature does not emerge from the observed density fields. The strong local amplification of the diurnal tide suggests the presence of resonant seamount trapped waves. The strength of the semidiurnal tide M_2 in the region, in combination with the steepness of the flanks of the bank, points to a significant contribution of tidally rectified flow to the observed residual anticyclonic flow. An observation of an isopycnal vertically repositioned by 50 m within one downcast/upcast period of a CTD profile indicates the importance of high frequency internal wave dynamics.

1. Introduction

Submarine banks and seamounts are areas of special interest for a wide range of marine science fields. Recently conducted reviews (e.g. Pitcher et al., 2007; Staudigel et al., 2010) have provided a broad perspective on the complex relationships between different disciplines. Seamounts are biodiversity hotspots and support species rich ecosystems targeted by the fisheries industry. This ecological richness is partly controlled by local enhancement of primary productivity affecting lower-trophic level biota, caused by intensified hydrodynamical activity that emerges from the disturbance of the surrounding flow (e.g. Genin, 2004). Interdisciplinary studies of seamounts are at the forefront of marine ecosystem research.

In the year 2002 an integrated study of Le Danois Bank, a seamount-like topographical structure located at the southern Bay of Biscay close to the north Spanish coast, was launched within the framework of the ECOMARG project (www.ecomarg.net). The main aim of the project was to describe the benthic ecosystem of the bank, to characterise its habitats and to evaluate the impact of fisheries (Cartes et al., 2007; Sanchez et al., 2008; Rodriguez-Cabello et al., 2009). ECOMARG results and subsequent observations served as the basis for an agreement of the Council of Ministers of Spain to declare the site as the *El Cachucho Bank*[1] *Marine Protected Area* (MPA) on March 14, 2008, thus establishing the first Spanish offshore MPA (Spanish Government, 2009).

The scope of the ECOMARG project was to advance the understanding of the ecosystem functioning as a whole. Within this multidisciplinary framework, most cruises in the area incorporated

[1] Le Danois Bank was named after Edouard Le Danois, who carried out pioneering research in 1940s to be the first to describe the marine fauna in the Celtic Sea and Bay of Biscay paying detailed attention to the aforementioned bank (Le Danois, 1948). However, decades before, the bank was known by local fishermen as the productive fishing ground of "El Cachucho", the vernacular term of the commercial fish species *Beryx decadactylus* (Sanchez et al., 2008). This name is widespread today in the non-scientific community.

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hydrographical sampling and specific current meter moorings were deployed. The results allowed to describe key features of the circulation in a place where previous studies are almost nonexistent. The present work describes and discusses the main findings within the context of the hydrography and circulation in the southern Bay of Biscay and the particular location and geometry of the bank. In Section 2 the main characteristics of Le Danois Bank and known hydrographical properties and circulation patterns are presented. Section 3 introduces the data set, while Section 4 presents the results. Section 5 provides a discussion of the findings and the main conclusions are summarised in Section 6.

2. The physical setting of Le Danois Bank

2.1. Location and topography

Le Danois Bank is a marginal shelf bank (a seamount-like topographical feature nearby and partially connected to the continental shelf) located in the central Cantabrian Sea (Bay of Biscay, NE Atlantic) at a distance of $\sim$60 km of the northern Spanish coast. Geologically the structure is a "horst", elongated zonally and presenting great dissymmetry between its northern and southern flanks (Gómez-Ballesteros et al., 2009; van Rooij et al., 2010). Fig. 1 shows the high-resolution bathymetry of the bank embedded within a GEBCO1 Chart of the area (www.gebco.net). The centre of the bank is located at $\sim$44°05′N, 004°50′W. The summit of the bank is a $\sim 65 \times 12$ km east-west oriented plateau of $\sim$550−600 m depth. At the western side there is a dome with a minimum depth of 424 m that emerges as a rocky outcrop. The outer flank is very steep, sharply dropping to $\sim$4000 m into the Bay of Biscay abyssal plain. The inner flank of the bank is much smoother and connected to the continental shelf by a saddle shaped structure $\sim$30 km wide and $\sim$900 m deep at its crest. This saddle together with the bank and the continental shelf bounds an inner basin that is oriented towards the southwest.

2.2. Water masses and background dynamics

During the past decades a number of studies have improved our knowledge on water mass properties and large scale circulation patterns in the Bay of Biscay (see Lavín et al., 2006 for a review). We introduce a short summary of local water masses and dynamics to facilitate subsequent references to the observed conditions.

Upper waters in the region are subject to seasonality and confined by the maximum extent of the mixed layer depth in wintertime, normally limited to $\sim$250 m (Gonzalez-Pola et al., 2007). The layer below is composed of Eastern North Atlantic Central Water (ENACW), a modal water mass formed by winter mixing in a wide region from northeast of the Azores to the European margin (Pollard et al., 1996). Its core is found at $\sim$350 m. The lower boundary of ENACW is characterised by a salinity minimum located at a depth of $\sim$500 m in the Bay of Biscay, which corresponds to the summit depth of Le Danois Bank. Mediterranean Water (MW) dominates the layer below the ENACW level, spreading northward along the western European margin from its source region in the Gulf of Cadiz (Iorga and Lozier, 1999). The core of MW is locally placed at $\sim$1000 m. Below MW, Labrador Sea Water (LSW) is centred at $\sim$1800 m, followed by deep water masses.

The general circulation in the Bay of Biscay is weak compared with the main NE Atlantic basin. Currents roughly follow an anticyclonic loop with a southward component of $\sim$1 cm/s at surface and thermocline levels (Paillet and Arhan, 1996; van Aken, 2002). The circulation at MW and LSW levels is less established, but studies based on Lagrangian float experiments indicate that these waters roughly follow an anticyclonic loop in the outer Bay while MW at the northern Spanish slopes seems to circulate eastwards (Bower et al., 2002; Colas, 2003). Below this level the circulation is very weak. As in other eastern boundary systems, there exists a meridional density gradient driven poleward flow along the Iberian coast, known as the Iberian Poleward Current (IPC) (see Peliz et al., 2003 for a recent review). The IPC progresses eastward along the Cantabrian Sea while decaying by friction as the coastline changes to a zonal orientation (Pingree and Le Cann, 1990). Seasonality in wind patterns also affects shelf-slope dynamics. South-westerly winds in autumn and winter favour downwelling and enhance the IPC signal (Haynes and Barton, 1990), while northerly winds in summer cause upwelling (Wooster et al., 1976). Much of the variability derived from atmospheric forcing is, however, concentrated at scales shorter than seasonal, so that sustained wind pulses can cause notable and quick responses in the shelf-slope dynamics (e.g. Gonzalez-Pola et al., 2005).

3. Data set

In the framework of the multidisciplinary studies of Le Danois Bank different data sets were collected. Fig. 2a, b, e, and f shows

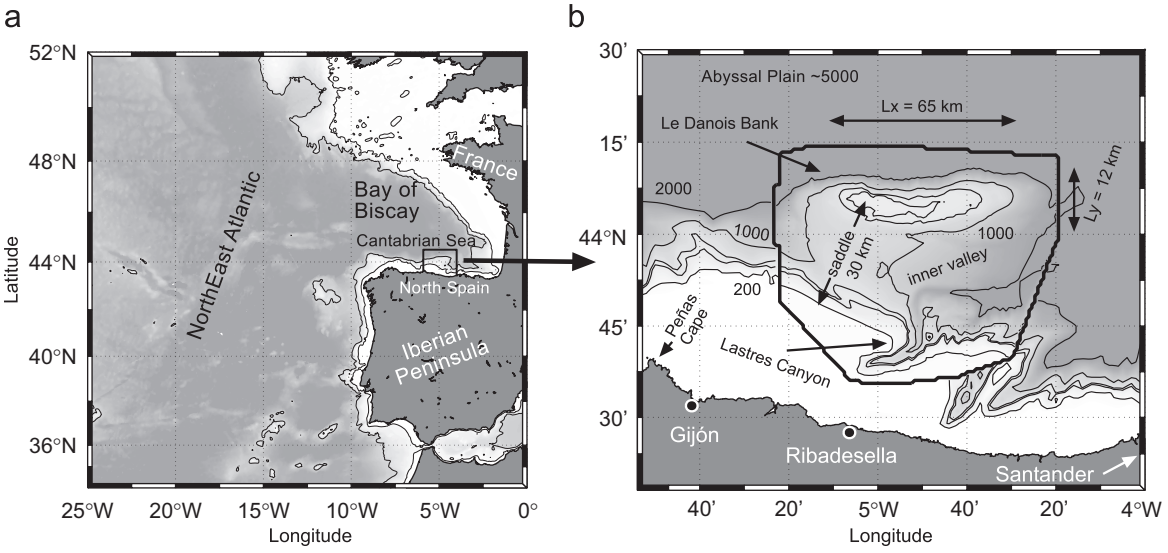

Fig. 1. (a) Location of Le Danois Bank in the NE Atlantic. Isobaths of 200 m and 2000 m are included. (b) Le Danois Bank high resolution bathymetry (bounded by a black line) embedded in the large-scale GEBCO1 Chart. Isobaths of 200, 500, 600, 1000 and 2000 m are shown.