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South-Eastern Bay of Biscay eddy-induced anomalies and their effect on chlorophyll distribution

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ABSTRACT

The analysis of deep-water glider hydrographic and fluorescence data, together with satellite measurements provides a new insight into eddy-induced anomalies within the South-Eastern Bay of Biscay, during summer. Two cyclonic eddies and a SWODDY have been observed in different glider transects and by means of different sources of satellite data. Vertical profiles reveal complex structures (characteristic of the second baroclinic mode): upward/downward displacement of the seasonal/permanent thermocline in the case of X13 and the opposite thermocline displacements in the case of the cyclones. This is a typical behaviour of mode-water and "cyclonic thinny" eddies. A qualitative analysis of the vertical velocities in the anticyclone indicates that though geostrophy dominates the main water column, depressing the isopycnals, near the sea-surface the eddy-wind interaction affects the vertical currents, favouring Ekman pumping and upwelling. The analysis of the Θ-S properties corroborates that inside cyclones and between the 26 and 27 isopycnals, net downwelling occurs. These two types of intra-thermocline lenses appear to deeply impact the Chl-a fluorescence profiles, since the maximum Chl-a fluorescence is located just below the seasonal thermocline. The mean Chl-a fluorescence was higher in the anticyclone than within the cyclones and the mean for the entire study period; the highest values were observed in the centre of the anticyclone. These results are in agreement with previous findings concerning the SWODDY F90 and surrounding cyclones, located in the South-Western Bay of Biscay. Significant differences in the Θ-S properties of the two cyclonic mesoscale structures have been observed: higher temperatures and lower salinity in the easternmost cyclone. Finally, time variation of the salinity content of the shallowest water masses of the anticyclone (salinity decreasing over time), probably indicates advective mixing processes occurred during the mission.

1. Introduction

1.1. Hydrography of the South-Eastern Bay of Biscay

The geographical area covered in this study is located in the South-Eastern Bay of Biscay (SE-BoB) between the Cantabrian coast and 45°N and from 2.5°W to 4.5°W (Fig. 1). Upper and intermediate water masses of the SE-BoB (from surface to 1000 m depth) are the Eastern North Atlantic Central Water (ENACW) and the Mediterranean Water (MW) (van Aken, 2000; Lavín et al., 2006). ENACW is originated by winter mixing over a region from North-East of Azores to the European margin, bounded by the North Atlantic and the Azores currents (Pollard and Pu, 1985; Pollard et al., 1996), and it delimits the upper permanent thermocline (Prieto et al., 2013). The core of ENACW has a potential density (σ_Θ) between 27.1 and 27.2 (Somavilla et al., 2009) and is located in the Bay of Biscay at about 350 dbar. The bottom of ENACW is characterized by a salinity minimum layer (at about 500 dbar and $\sigma_\Theta = 27.2$–27.3). Below the ENACW, the Mediterranean Water (MW) begins to influence the intermediate waters (Somavilla et al., 2009). The core of the MW is mixed with less saline waters along the Cantabrian slope and, consequently, the maximum salinity of MW in the SE-BoB is lower than the values observed in other areas. The mixed layer in this temperate sea describes a seasonal cycle, in tune with the net solar flux. The analysis of two years of hydrographical data concludes that the temperature of the water in the SE-BoB starts to rise from late April, with maximum values (20–22 °C) in July–August, and begins to decrease in October–November (Rubio et al., 2013). During summer, the Mixed Layer Depth (MLD) is located between 30 m (Somavilla et al., 2011) and 50 m depth (Rubio et al., 2013).

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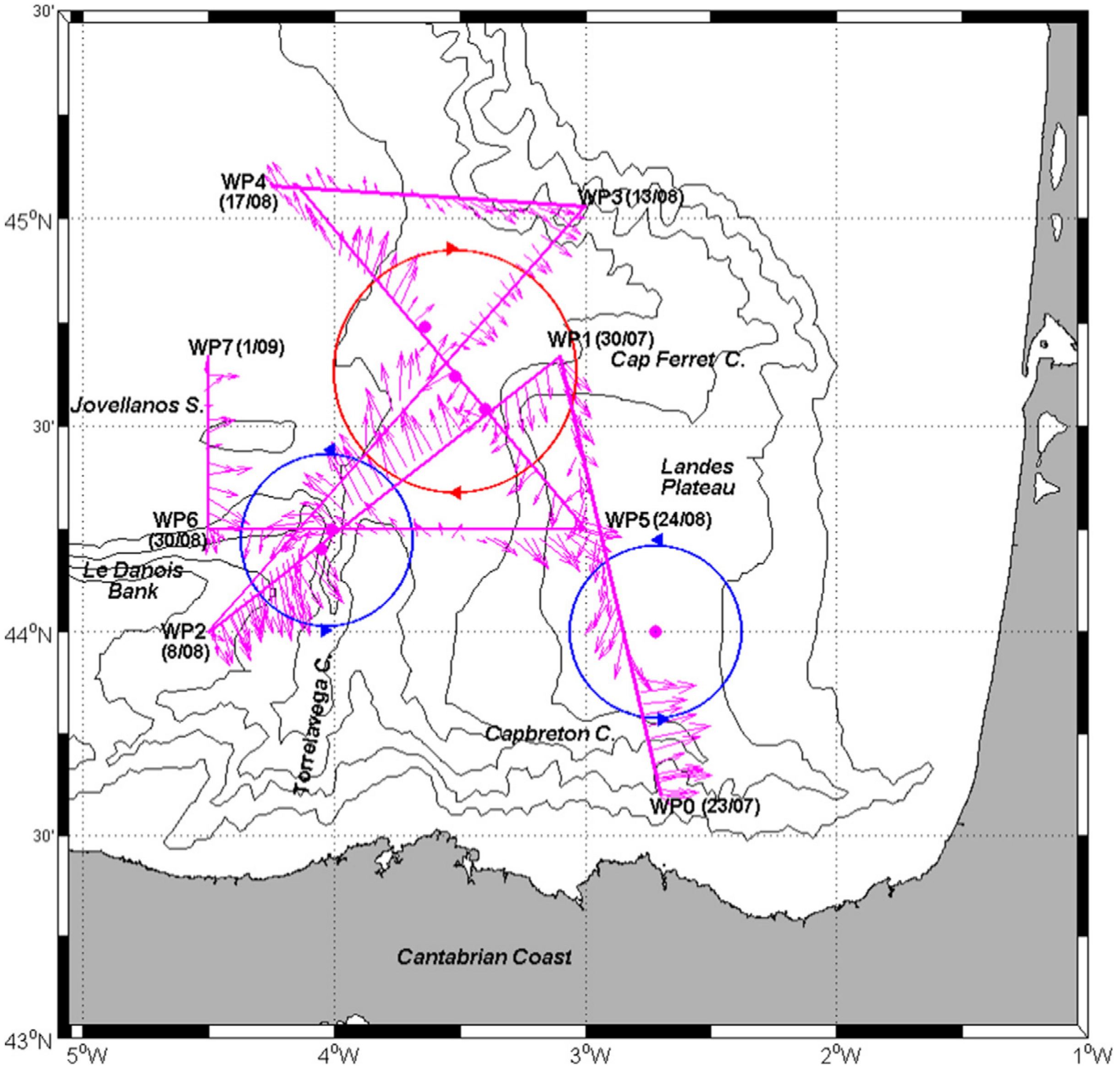

Fig. 1. Study area. Pink lines show the tracks followed by the glider from the initial (WP0) to the last (WP7) waypoints considered in this work. Pink vectors and points represent the vertical integrated currents and the centre of eddies, respectively. A sketch of the position and the area occupied by the observed anticyclone (red circle) and cyclones (blue circles). Pink points indicate COEs (Centre Of Eddies) using the method described in Section 2.2. Isobaths (m): 200, 1000, 2000, 3000 and 4000. *Note: the trajectories of the glider have been smoothed in order to simplify the sketch; the real trajectories can be consulted in the following link: http://glider83a.dt.insu.cnrs.fr/EGO_groundstation/html/campe/GESEBB/deployment_summary.txt.kml.

These are the average characteristics of the water masses in the study area, but it should be taken into account that these mean properties are affected by high and low frequency variations. A recent description of the water masses, mean circulation patterns and their variability in the Bay of Biscay is provided by Pingree and Garcia-Soto (2014). One source of variability is the seasonal arrival of the salty and warm subtropical waters by the Navidad slope current (Pingree and Le Cann, 1990) in the SE-BoB. Evidences of the variability linked to the slope current in the SE-BoB have been recently addressed by Garcia-Soto and Pingree (2012), Rubio et al. (2013), Esnaola et al. (2013), Pingree and Garcia-Soto (2014) and Solabarrieta et al. (2014). Another process that modifies the hydrography of the SE-BoB is the coastal upwelling, forced by seasonal winds along the Cantabrian coast. Easterly winds induce a transport of colder and fresher waters offshore (Lavín et al., 2006). Usually, from May to September wind patterns favour coastal upwelling, reversing the cyclonic circulation over the near-surface slope (Le Cann and Pingree, 1995). Input of fresh water from the river outflow also induces a hydrographic variability; it occurs from late winter to early spring, significantly modifying the salinity of the surface adjacent shelf. During certain years, depending on the wind regime, this fresh water reaches the shelf break in low salinity lenses (Puillat et al., 2004). The migration of this type of water in 2009 was investigated by Reverdin et al. (2013), concluding that fresh water masses from river outflows (winter–spring) were spread to the shelf break (early May), observing two months after (mid-July) that freshwater spread from west of the Landes Plateau to 4°W. Internal waves induce high frequency variability, during summer stratification, to the mean hydrographic distribution of the near-surface waters. These waves that may have two possible origin places, the shelf break (Pingree et al., 1986) and the central Bay of Biscay (New and Pingree, 1990, 1992) have amplitudes of up to 50–60 m periods of 20–30 min. And finally, eddies, which are described in detail in the following Section, generate mesoscale variability on the mean hydrographic conditions of the SE-BoB.