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CROSS-SHELF EXCHANGES IN THE BAY OF BISCAY

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Abstract

Cross-shelf exchanges in the Bay of Biscay are investigated utilizing various tools including in situ temperature and salinity profiles, satellite derived sea surface temperature and chlorophyll-a concentration and numerical simulations. Various eddy-induced cross-shelf transport events were detected following in situ and remotely sensed data. Identified eddy-induced transport events were further investigated using high resolution (1km) simulations. Important role of shelf-break (sub)mesoscale eddies and associated filaments on cross-shelf exchanges in the Bay of Biscay is documented. An example case is presented. This study constitutes a basis for the ongoing study, where the overall goal is to quantify these eddy-induced cross-shelf exchanges.

Keywords: Cross-shelf exchanges, Bay of Biscay, (sub)mesoscale, eddies, filaments

1. Introduction

Cross-shelf exchange is a crucially important pathway for nutrients, biota and materials determining their delivery and removal rates on the continental shelf (Brink, 2016). These exchanges are important for the carbon and nutrient budgets of the ocean (Huthnance *et al.*, 2002).

The Bay of Biscay is one of the key constituents of the Western European Continental Shelf in the North Atlantic, playing an important role in the interactions between the continental shelf and the open ocean waters. Narrow continental shelf in the southern part (~30km), extends to a wider continental shelf (~180km) off Brittany (Charria *et al.*, 2013). Together with internal tides and Ekman flow, this complex topography (and the canyons in it) strongly influences the continental slope current (Pingree and Garcia-Soto, 2014). This complex topography and the instability of the slope current may lead to a generation of coherent mesoscale structures (Charria *et al.*, 2017), such as the Slope Water Oceanic eDDIES (SWODDIES) (Pingree and Le Cann 1992a; Pingree and Le Cann 1992b; Garcia-Soto *et al.*,2002; Caballero *et al.*, 2014). Despite the fact that the eddy generation and properties have been well documented in the southern part of the Bay of Biscay, eddy activity in the north remains yet unclear with limited studies based on drifter data (Van Aken, 2002; Charria *et al.,* 2013). Despite the eddy generation mechanism in the north (similar to the south), related with the influence of topographic features and the instability of the slope current, another mechanism might be contributing to the eddy generation. Northern (north of 45oN) part of Bay of Biscay displays a fully developed frontal activity (Yelekçi *et al.,* 2017). The baroclinic instability of these fronts (particularly tidal fronts) might be an additional mechanism leading to eddy generation in the north (Badin *et al.,* 2009).

Albeit the circulation and hydrography in the Bay of Biscay has been well presented, there is limited knowledge on the cross-shelf exchanges in the region. Available knowledge is limited to suggestions of cross-shelf flows following drifter trajectories (Porter *et al.,* 2016) and modelling studies documenting cross-shelf flows of fresh shelf waters (Reverdin *et al.,* 2013). Quantification of the ocean-margin exchange has been limited to rough estimates (Huthnance *et al.,* 2002, 2009).

Cross-shelf exchange is a rather difficult problem to address, considering it is weak, not easy to observe and often ageostrophic (Brink, 2016). Despite the different processes (Ekman transport, bottom boundary-layer flows etc.) that might lead to cross-shelf exchanges (through violation of the Taylor-Proudman assumptions, Brink, 2016), in this study we are mainly interested in the (sub)mesoscale structures; eddies and associated filaments contributing to these cross-shelf exchanges.

Therefore, the main purpose of this study is to determine the eddy activity in the Bay of Biscay, its contribution to cross-shelf exchanges and in the end, quantification of the heat, salt and volume transports at the ocean margin.

2. Data and methodology

In situ vertical profiles of temperature and salinity used in this study are acquired from the Coriolis Ocean Dataset for Reanalysis for the Ireland-Biscay-Iberia region (CORA-IBI, Szekely *et al.,* 2017). CORA-IBI dataset contains observations from a variety of platforms including research/opportunity vessels (CTD, XBT, Ferrybox) and autonomous platforms (Argo floats, moorings, gliders, drifters and fishery observing system - RECOPESCA program). CORA-IBI product supplies quality flags, which are assigned through statistical tests and visual quality controls (Szekely *et al.,* 2017).

Remotely sensed sea surface temperature (SST) data are night time Level 2 ungridded products with ~1km resolution available from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on Aqua and Terra satellites. Remotely sensed chlorophyll-a concentration with ~1km resolution for the North Atlantic Ocean are acquired through E.U Copernicus Marine Service Information (marine.copernicus.eu). Chlorophyll concentration is estimated using the OC5ci algorithm, a combination of

OCI (Hu *et al.*, 2012) and OC5 (Gohin *et al.*,2008), using OCI for open/case-1 waters and OC5 for coastal/case-2 waters.

Outputs from two different configurations of the MARS3D model (Lazure *et al.*,2009) have been used for this study. The first configuration is the configuration developed in the frame of the coastal operational oceanography project PREVIMER (Dumas *et al.*,2014, http://www.previmer.org), running operationally (2006-ongoing), with 2.5km horizontal resolution, 40 sigma levels with hourly outputs. For details of the PREVIMER configuration, see Yelekçi et al. (2017) and references within. Second configuration of the MARS3D model used in this study is the outputs of BACH1000 simulations (Theetten *et al.*, 2017). This configuration is a hindcast (2001-2010) with 1km horizontal resolution, 40 sigma levels and daily outputs. For details of the BACH1000 configuration, see Charria et al. (2017) and Theetten et al. (2017). Outputs of these two configurations were compared with the remotely sensed products. Despite both configurations were able to simulate features with a resolution >20km, the PREVIMER configuration was not able to simulate smaller scale features, which constituted a considerable amount of the observed (sub)mesoscale activity on the shelf break. Therefore, in this abstract, results from the PREVIMER configuration are not shown.

In this study, we focus on the northern part of Bay of Biscay, particularly in two rectangular areas (first area bounded by 46oN-48oN and 4oW-8oW and second area by 45oN-47oN and 3oW-7oW). Selection of these areas were done considering the lack of knowledge in literature for this region (north of 45oN), the availability of *in situ* measurements and the observed (sub)mesoscale features (with possible role in cross-shelf exchanges) observed along the shelf-break in the region (from satellite images).
The area was further divided into 3 regions (Fig. 1), following a simple bathymetry criterion, as shelf waters (R3: water depth<150m), shelf-break region (R2: 150<water depth< 2500m) and open waters (R1: water depth >2500m). *In situ* data were used to construct the monthly distribution of temperature and salinity in these 3 sub-regions. After obtaining these background states of temperature/salinity for the sub-regions, anomalies (not shown here) were obtained by simply subtracting the climatological means of each month (average of 2007-2014 for each month) from the corresponding month (e.g: Anomaly of March 2008= March 2008- March mean (2007-2014)).

In situ measurements were also used to detect possible imprints of cross-shelf exchanges, simply by investigating data clusters over the shelf-break region, and through individual Argo float transects which cross the shelf break. However, no clear sign of cross-shelf exchange was found. Therefore, satellite images of SST and CHL were carefully investigated for eddies and filaments over the shelf-break. Numerous features were detected. Model results (both configurations) were investigated and compared with the features observed through remote sensing. BACH1000 simulations were able to successfully simulate different types of shelf-break eddies and filaments. Observed features were further investigated using the model outputs, in order to obtain the mechanism behind the formation/dissipation of the features and their impact on the cross-shelf exchanges.

3. Results

In order to understand the general thermohaline characteristics in the region of interest, *in situ* temperature and salinity profiles were used to construct the background state. Fig. 1 represents the distribution of profiles in the domain of investigation. Here, temporal distribution of temperature (Fig. 2) is presented only for the first region (R1-open ocean) as an example. For all the regions, temperature fields represent the seasonal cycle and interannual variations clearly, whereas for salinity it was rather unclear due to high variability. Some of the observed temperature anomalies were associated with eddy activity (as seen by satellite images), whereas for salinity anomalies no direct link was found. Despite the high uncertainty (due to alternating number of observations over time), *in situ* profiles of temperature/salinity provided the climatological state of the region fairly well, constructing background knowledge for the numerical simulations.

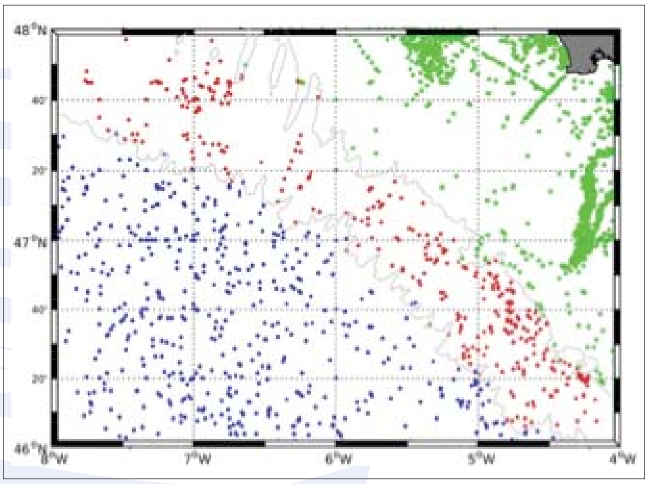

Fig. 1. Distribution of temperature/salinity profiles in the first rectangular area (2007-2014). Blue, red and green dots represent profiles in the open-ocean(R1) , shelf-break (R2) and coastal (R3) regions respectively.

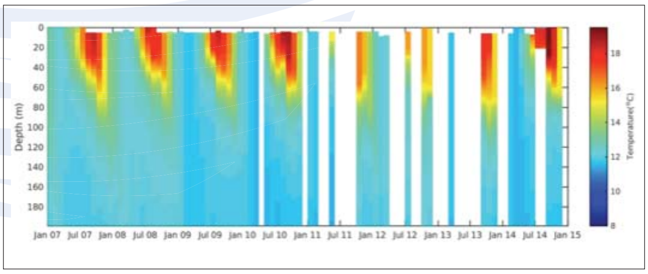

Fig. 2. Temporal evolution of temperature in region R1.

Satellite SST and chl-a concentration images were investigated carefully for eddies and filaments (leading to offshore transport) along the shelf break. We focused on 15 features in area-1, which were categorized in four groups as: cyclonic eddy, anticyclonic eddy, dipole of eddies and large-scale intrusion of cold water from the north. Observed features were further investigated with the outputs of numerical simulations.

Here we illustrate one example for the cross-shelf transport events: a cyclonic eddy and associated filament on the shelf break. On 20 May 2008, satellite chlorophyll concentration map (Fig. 3) suggests transport of high-chlorophyll offshore. Satellite SST (Fig. 4) for the same date also shows a cold filament exactly on the same location as the high-chlorophyll patch. BACH1000 model successfully simulated this feature (on 24 May 2008). The model was able to simulate the filament and associated eddy (Fig. 5). Gray and red lines in (Fig. 5 and Fig. 7) both represent the 46.1oN line, along which the sections were illustrated. The model also simulated the low salinity protrusion offshore (Fig. 6). Simulations suggested the total time for the formation, propagation and dissipation of this eddy took ~one month. Frequent generation of eddies were observed at this location, both in the satellite data and numerical simulations, which seems to be generated due to instabilities occurring around Sables d'Olonne Canyon (located at 46oN-4oW). The periphery of these eddies and the associated filaments displayed the strongest velocities (Fig. 7, Fig. 8) in the cross-shelf direction. For this particular day (Fig. 8), meridional velocity was ~0.15m/s along the filament. However, this filament reached ~0.4 m/s during its lifetime. These results highlight the important role of eddies in the shelf break. Their impact on the cross-shelf transports will be estimated.

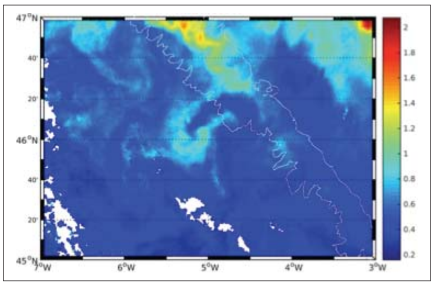

Fig. 3. Observed remotely sensed Chlorophyll concentration (in mg m^3) on 20 May 2008.

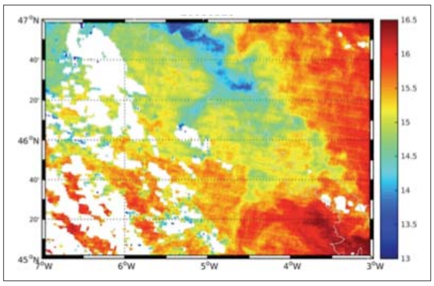

Fig. 4. Observed Sea Surface Temperature (in oC) from MODIS-Aqua on 20 May 2008.

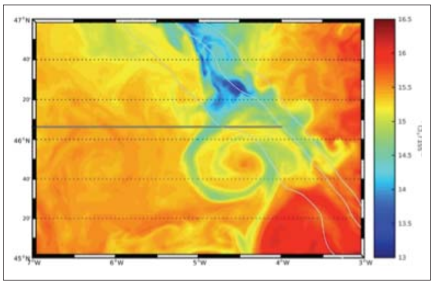

Fig. 5. Simulated Sea Surface Temperature on 24 May 2008.

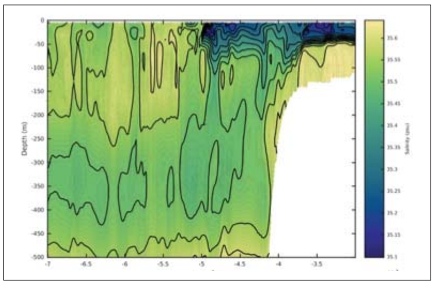

Fig. 6. Simulated salinity section along 46.1°N on 24 May 2008.

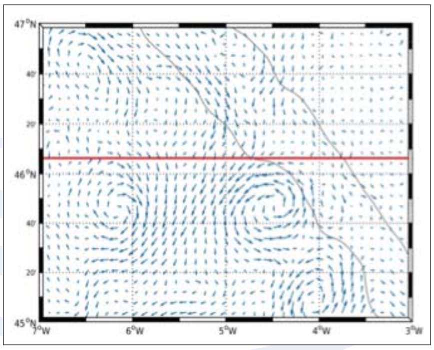

Fig. 7. Simulated surface circulation on 24 May 2008.

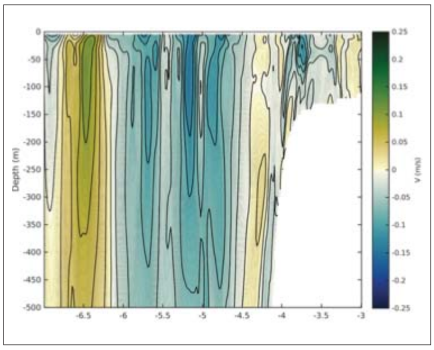

Fig. 8. Simulated meridional geostrophic velocity section along 46.1°N.

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