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Shelf-slope exchanges and particle dispersion in Blanes submarine canyon (NW Mediterranean Sea): A numerical study

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ABSTRACT

A climatological simulation performed with a fine-resolution (~1.2 km) 3D circulation model nested in one-way to a coarse-resolution (~4 km) 3D regional model is used to examine the cross-shelf break water exchange in the Blanes submarine canyon (~41°00′–41°46′N; ~02°24′–03°24′E). A Lagrangian particle-tracking model coupled to the fine-resolution 3D circulation model is used to investigate the role of the incident regional flow (i.e. the Northern Current, NC) and its seasonal variability on the dispersion and residence time of passive particles inside Blanes Canyon. The NC flows southwestward, along the slope, with the coastline to the right. Water is advected offshore/onshore at the upstream/downstream canyon walls, with a net water transport toward the slope (i.e. offshore). The amount of water moved across the shelf break of the upstream wall is approximately three times larger than the amount moved across the shelf break of the downstream wall. This preferential zone for cross-shelf break water exchange is explained by the asymmetric geometry of the canyon and the orientation of the incident current with respect to the canyon bathymetry. Passive particles released upstream Blanes Canyon between the mid-shelf and the upper-slope drift within the NC and accumulate over the shelf edge of the canyon. About half of the particles released at depths above the shelf break move towards shallower areas inside the canyon. In contrast, about two-thirds of particles released below the shelf break move to deeper areas. Particle dispersion is higher under weakly (e.g. winter) than strongly (e.g. summer) stratified conditions. The residence time of passive particles inside the canyon (~4–6 days) is double than the residence time downstream of the canyon, indicating that the canyon acts as an efficient retention zone for passive particles.

1. Introduction

Many submarine canyons are hotspots of biological productivity and biodiversity (e.g. Vetter et al., 2010; Canals et al., 2013; Moors-Murphy, 2014). In the northern hemisphere, left/right-bounded currents (i.e. with the coastline to the left/right, looking downstream) flowing over submarine canyons generally induce favorable conditions for net cross-shelf break transport toward the shelf/slope (see Allen and Durrieu de Madron, 2009 and references therein). Left-bounded currents bring nutrient-rich deep-water onto the continental shelf contributing to enhance local biological productivity (e.g. Freeland and Denman, 1982; Skliris and Djenidi, 2006; Connolly and Hickey, 2014). Right-bounded currents, on the other hand, enhance particle and upper-slope water export from the adjacent shelf to the deep basin, subsidizing the generation of special habitat conditions suitable for recruitment and maintenance of corals, sponges, demersal fishes, crustaceans and other deep-sea organisms (e.g. Gili et al., 2000; Sardà et al., 2009; De Leo et al., 2010).

The NW Mediterranean Sea is a region where numerous submarine canyons cut the continental margin. In particular, the northern Catalan Sea has three large submarine canyons (from North to South: Cap de Creus Canyon, Palamós or La Fonera Canyon and Blanes Canyon) that deeply incise the continental shelf and slope (Amblas et al., 2006). The regional circulation is dominated by the Northern Current (NC), which originates in the

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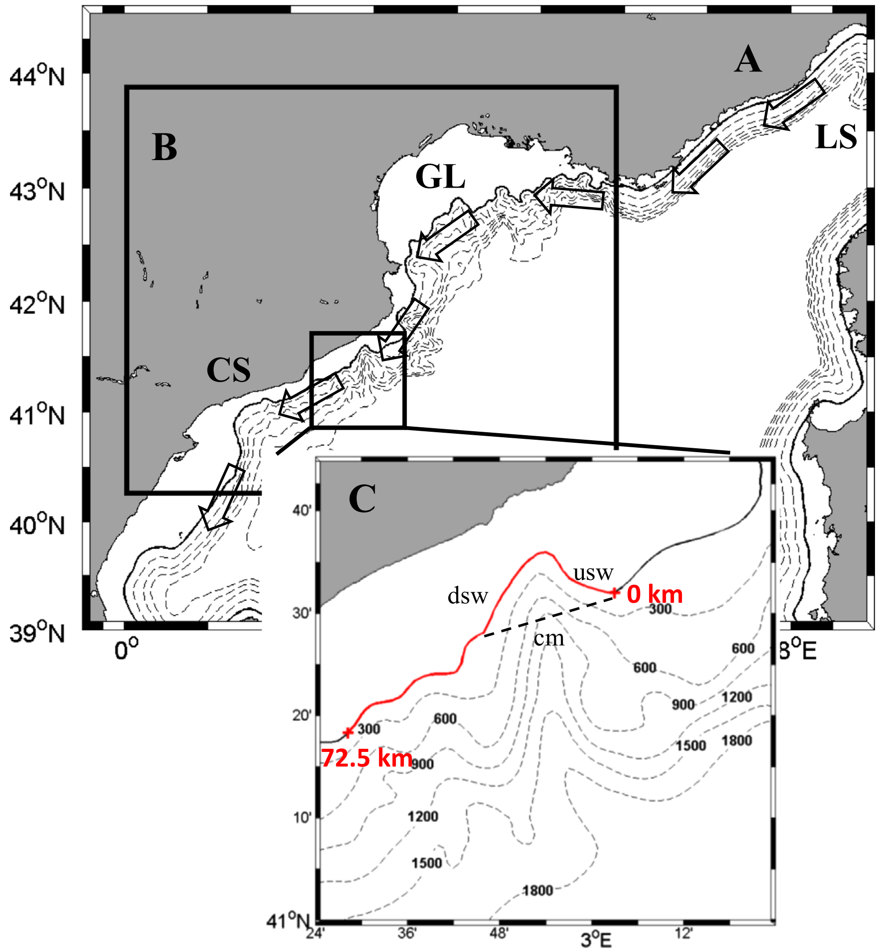

Fig. 1. (A) Coarse-resolution (~4 km) 3D regional circulation model domain. Acronyms stand for: LS=Ligurian Sea, GL=Gulf of Lions and CS=Catalan Sea. White arrows represent the Northern Current pathway. (B) High-resolution (~1.2 km) 3D circulation model domain. (C) Zoom of B over Blanes Canyon. The canyon mouth is defined as the imaginary line that joins the eastern and the western canyon walls at the depth of the shelf break (dashed line; cm). The upstream (usw) and downstream (dsw) canyon walls are indicated. The red line along the shelf break indicates the part of the shelf break that is used to calculate cross-shelf break transports in Figs. 2 and 3: km 0 is at 41°31′N, 3°03′W; km 72.5 is at 41°18.3′N, 2°28.2′W. Isobaths are plotted every 300 m; the shelf break (150 m) is indicated as a bold line. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Ligurian Sea from the merging of the Eastern and Western Corsican Currents (e.g. Birol et al., 2010). From the Ligurian Sea, the NC flows along the slope as far as the southern Catalan Sea (Fig. 1). It is an energetic flow in quasi-geostrophic balance, with a shelf/slope density front maintained by the salinity contrast between relatively fresh coastal waters and more saline offshore waters (e.g. Font et al., 1988; Cruzado and Velasquez, 1990). The NC is a right-bounded flow of about 30–50 km wide with mean surface velocity of 20–30 cm/s decreasing to ~5 cm/s at 300–400 m depth (Flexas et al., 2002). From mid-autumn to early spring, the NC is narrow, fast, and deep (cf. Millot, 1999). Mesoscale structures such as meanders and eddies associated with flow instabilities develop and propagate along the current pathway modifying the local circulation (e.g. Sammari et al., 1995; Flexas et al., 2002; Rubio et al., 2005; Casella et al., 2011; Ahumada-Sempoal et al., 2013).

The interaction of the NC with submarine canyons induces substantial water exchange across the shelf break (Jordi et al., 2005, 2006). Observations also reveal significant differences in the amount of settling particles between canyon and slope environments. Particle fluxes within Blanes Canyon (BC) are higher (almost one order of magnitude) than the fluxes recorded over the neighboring open slope at similar depths (Zuñiga et al., 2009; Sanchez-Vidal et al., 2012; Lopez-Fernandez et al., 2013). Particle fluxes to the deep continental margin and basin of the NW Mediterranean Sea are directly determined by margin's physiography, atmospheric conditions, the NC and event-driven oceanographic processes (i.e. dense shelf water cascading, offshore convection and eastern storms) (Canals et al., 2013). Water exchange across the shelf break and particle fluxes are essential for understanding biogeochemical and ecological processes taking place in the continental shelf and the deep sea (Fennel, 2010).

Quantitative field observations in submarine canyons can be difficult and expensive. Instrumentation maintenance and fishing activities may prevent safe deployments of moored arrays for long periods of time. Numerical modeling is a powerful tool that provides oceanographic estimates at relatively high resolutions for both scientific and operational purposes, thus contributing to fill gaps from field observations.

The aim of this study is twofold. First, we examine the role played by the interaction of the Northern Current with the Blanes Canyon topography on the cross-shelf break water exchange. Second, we examine its role on the dispersion and residence time of passive particles inside the canyon. For this purpose, we use a fine-resolution (~1.2 km), three-dimensional circulation model nested in one-way to a coarse-resolution (~4 km) regional model and a Lagrangian particle-tracking model.

The paper is structured as follows. First, we describe the main characteristics of the model along with the procedure followed to calculate the cross-shelf break water exchange and the particle-tracking experiments (Section 2). In Section 3 we present our