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# Physical processes controlling passive larval transport at the Patagonian Shelf Break Front

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ABSTRACT

The largest beds of the Patagonian scallop (*Zygochlamys patagonica*) have been associated with high chlorophyll-*a* concentration observed along the Patagonian Shelf Break Front but there is no supported hypothesis about how this benthic-pelagic connection is maintained. In this work we address the main physical processes driving the benthic-pelagic linkages through oriented numerical experiments derived from a realistic, high-resolution numerical model, and Lagrangian stochastic simulations. The results support the hypothesis of an important dynamical control of the slope current on the fate of surface released passive particles and their subsequent bottom settlement. A high percentage of the particles released at the surface settled over the scallop beds. The particles remaining at the surface layer followed a prevailing NE flow direction with low cross-shelf dispersion. Additional experiments show that the secondary cross-shelf circulation forced by the slope current promotes downwelling and hence the settlement of particles on the westward side (onshore) of the shelf break. The percent of particles settling over the scallop beds exceeded 80% by the addition of vertical stochastic turbulence and tidal forcing. These results highlight the importance of including the vertical diffusivity in particle tracking experiments to better estimate benthic-pelagic interaction processes.

## 1. Introduction

An important task in marine ecosystems is to identify, characterize and quantify the flux of energy between organisms from different marine habitats. A relevant example is the potential dynamical connection (coupling) between the pelagic (surface) and benthic (bottom) layer communities. The structure of several benthic communities have been associated with the phytoplankton production in the overlying water column (Grebmeier and Barry, 1991; Hily, 1991; Graf, 1992), however relatively little is known about the physical factors involved in the interaction between the pelagic and benthic productivity. These physical mechanisms are necessary for communities located at greater depths because they allow the phytoplankton produced in the euphotic zone and associated organic matter to reach such depths (Graf, 1992). Once near or on the seafloor, the organic matter is often initially consumed by suspension feeders (Josefson and Conley, 1997).

Physical processes influencing frontal productivity mediating the benthic-pelagic connection include wind-forced upwelling events, tidal mixing and shelf-break dynamics. Cycles of upwelling and relaxation generated by the wind can induce areas of higher chlorophyll-*a* (Chl-*a*), where filter-feeders are more abundant and had higher growth rates than in neighboring areas where Chl-*a* is lower (Menge et al., 1997). The downward motion and subsequent establishment of some benthic species has been significantly correlated with these wind events in the US west coast (Wing et al., 1995). The interaction between tidal currents and sloping bottom topography can also generate nutrient flux from the deep region onto shallower areas (i.e. Georges Bank; Tian et al., 2015). Once on the shelf or at the bank edges, tidal mixing redistributes nutrients upward reaching phytoplankton in the near-surface layer and carries particulate matter downward to the benthic communities (Loder et al., 1992). Shelf break fronts separate continental shelf water from slope water and often show high levels of biological productivity. Model results for the Mid Atlantic Bight have suggested that the transverse shelf circulation may be effective in advecting regenerated near-bottom nutrients along frontal isopycnals, potentially reaching the euphotic zone (Gawarkiewicz and Chapman, 1992) and supporting the Chl-*a* maximum found at the surface (Marra et al., 1990). The upward nutrients' flux towards the euphotic zone

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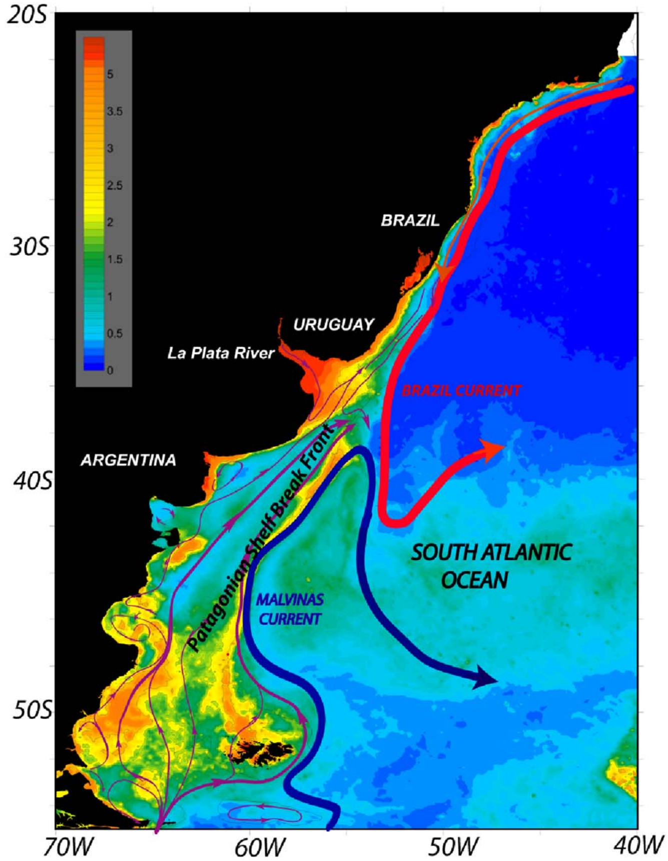


**Fig. 1.** Schematic of the circulation in the SW Atlantic Ocean. The concentration of surface Chlorophyll-*a* (mg m$^{-3}$) obtained with the SeaWIFs radiometer (summer average) is shown in color. Magenta lines indicate the schematic shelf circulation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

might explain the decrease in some species of benthic suspension feeders at the shelf break (Gaston, 1987). In the Celtic Sea the breaking of internal waves at the shelf edge is thought to play an important role on the observed nutrient and Chl-*a* distributions (Sharples et al., 2009) and possibly the high abundance of benthic communities at the bottom (Heip et al., 2001).

The Patagonian Shelf Break Front (SBF), one of the most productive areas of the world ocean (Acha et al., 2004; Lutz et al., 2010), is located near the edge of the extensive Patagonian shelf and marks the transition between waters of the continental shelf and the cold, nutrient-rich subpolar waters of the Malvinas Current (MC, Fig. 1). The sharpest surface temperature gradients that characterize the front are located along the 200 m isobath (Franco et al., 2008), suggesting a strong topographic control of the frontal system. Shelf break upwelling induced by the interaction of the MC with the bottom topography has been suggested to bring nutrients from the slope current to the euphotic zone sustaining the phytoplankton blooms in the SBF (Matano and Palma, 2008; Combes and Matano, 2014; Valla and Piola, 2015). In-situ (Carreto et al., 1995), and remote sensing measurements (Saraceno et al., 2005; Romero et al., 2006) showed that the SBF is associated with a band of high Chl-*a* (see Fig. 1), which is a frequently used proxy for phytoplankton abundance. The region of high Chl-*a* forms a quasi-continuous band located close to the shelf break mainly during austral spring and early summer (Acha et al., 2004; Romero et al., 2006, Fig. 1).

The Patagonian scallop (*Zygochlamys patagonica*) is a suspension feeder bivalve mainly of sedimented phytoplankton and organic matter (Schejter et al., 2002; Mauna et al., 2011) that inhabits soft substrata. The largest beds are located in the bottom of the outer shelf and shelf

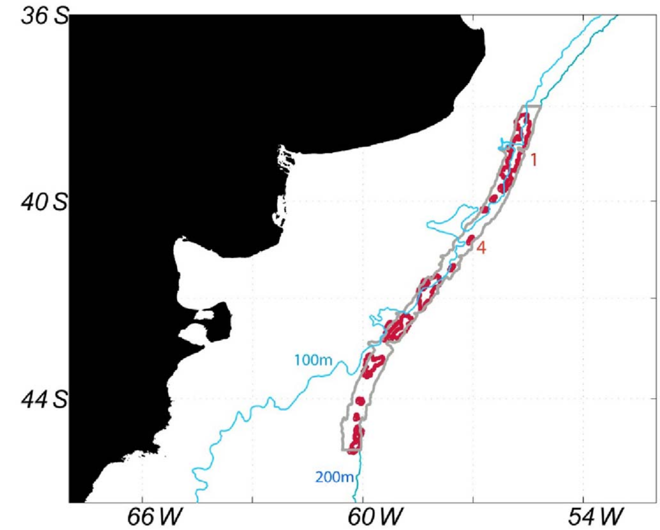


**Fig. 2.** Location of the largest Patagonian scallop beds (red polygons) (e.g., Bogazzi et al., 2005). Scallop beds 1 and 4 are numbered. The gray heavy line indicates a polygon which extends 50 km western from the location of the particles releases in the SBF. The 100 and 200 m isobaths are shown in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

break between 38°S–45°S at depths of ~80–200 m (Fig. 2) nearly matching the surface location of the SBF (Bogazzi et al., 2005; Ciocco et al., 2006). A high concentration of diatoms was reported in gut contents of Patagonian scallops located in the largest bed (number 1, see Fig. 2) (Schejter et al., 2002). The Patagonian scallop is an important economic resource in Argentina, yearly catches of ~50,000 t rank this fishery among the most important scallop fisheries in the world (Soria et al., 2016). The fishery, certified as sustainable by the Marine Stewardship Council (www.msc.org) in 2006 and 2012, has been carried out since 1996 (Ciocco et al., 2006; Soria et al., 2016).

As the largest Patagonian scallop beds are co-located with the zone of highest primary productivity, it has been suggested that the SBF supplies the planktonic food towards these beds (e.g. Bogazzi et al., 2005; Ciocco et al., 2006; Soria et al., 2016). However, while the latter is in the surface layer the former are found at approximately 150/200 m depth. There is at present no supported hypothesis about how these pelagic-benthic connection (or coupling) is accomplished or what are the main physical processes relating the surface expression of the SBF with the scallop beds at the outer shelf and shelf break. In this study we analyze the dynamical linkages between the surface and bottom layer of the SBF employing a suite of Lagrangian particle tracking simulations built on the results of a three dimensional hydrodynamical model.

## 2. Material and methods

### 2.1. Hydrodynamic numerical model

The Lagrangian particle tracking approach, explained in the following section, uses the outputs of a high-resolution ocean hydrodynamical model developed by Combes and Matano (2014). To summarize, the ocean model is the Regional Ocean Modeling System (ROMS_AGRIF version; Debreu et al., 2012), which is a three dimensional, free surface, hydrostatic, eddy-resolving primitive equation ocean model. The model uses a high-resolution "child" grid embedded into a coarser-resolution "parent" grid. The parent grid encompasses the entire southern hemisphere. It has a spatial resolution of 1/4° with 40 terrain-following vertical levels. The child domain extends from 82°W to 41°W and from 64°S to 20°S, with a spatial resolution of 1/12° and 40 vertical levels. The bottom bathymetry is derived from ETOPO1 (Amante and Eakins, 2009). At the northern boundary, the parent grid is nudged towards the monthly mean climatology from the Simple Ocean Data Assimilation