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Benthic-pelagic uncoupling between the Northern Patagonian Frontal System and Patagonian scallop beds

Bárbara C. Franco [a, *], Elbio D. Palma [b], Mariano H. Tonini [b]

[a] Centro de Investigaciones del Mar y la Atmósfera (CIMA/CONICET-UBA), Intendente Guiraldes 2160 – Ciudad Universitaria. Pabellón II – 2do. Piso, C1428EGA Buenos Aires, Argentina
[b] Departamento de Física, Universidad Nacional del Sur and Instituto Argentino de Oceanografía (IADO/CONICET), Bahía Blanca, Argentina

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A B S T R A C T

Availability of planktonic food in the bottom is the most important factor to explain the persistence and recurrent localization of Patagonian scallop (*Zygochlamys patagonica*) populations. The establishment of the scallop Sea Bay bed (SBB) has been related with food supply from the Northern Patagonian Frontal System (NPFS). In this article outputs from high resolution numerical models combined with particle tracking methods were used to identify for the first time potential physical mechanisms of food transfer. The model results showed no evidence of benthic-pelagic coupling between the NPFS and the SBB. They also revealed that the dominant instantaneous semidiurnal tidal currents and the mean N–NE flow on the inner-middle Patagonian shelf are the main dynamical mechanisms preventing particles released at the surface of the NPFS to reach the SBB area. Sensitivity studies changing the stochastic numerical method for solving the particle trajectories, the release month and location of the particles, the magnitude of the horizontal turbulent diffusion coefficient and the frequency of the wind forcing did not alter this conclusion significantly.

1. Introduction

The Patagonian continental shelf has high rates of tidal energy dissipation locally induced by large tidal amplitudes, constituting one of the most energetic tidal regimes in the world (Simpson and Bowers, 1981; Glorioso and Flather, 1997; Egbert and Ray, 2001; Palma et al., 2004). Current meter observations indicate that the tidal forcing accounts for more than 90% of the kinetic energy variance in the inner portion of the Patagonian continental shelf ($z < 50$ m) and at least half of the variance in the outer shelf (Rivas, 1997). Strong currents driven by the dominant semidiurnal tide (M_2) inhibit the formation of the seasonal thermocline in some coastal areas of the Patagonian shelf, inducing homogenization of the whole water column even during the spring and summer when the surface heat flux increases (Glorioso, 1987; Rivas et al., 2006).

The Northern Patagonian Frontal System (NPFS, *e.g.*, Sabatini and Martos, 2002; and references therein) presents a NE–SW alignment following the bathymetry between ~42° and 45°S (Fig. 1). Historical hydrographic records indicate a significant interannual variability of the NPFS location (Ehrlich et al., 2000; Sabatini and Martos, 2002). In particular, during 1996 and 1998 an anomalous increase of the water temperature was reported in the region and the NPFS emerged separated in two main fronts, with the spacing between them located near the mouth of the Nuevo Gulf (see Ehrlich et al., 2000). Both branches of the NPFS were located significantly nearest to the coast as compared with the mean position defined by Sabatini and Martos (2002).

The highest rates of tidal energy dissipation occur in the northernmost part of the NPFS (Palma et al., 2004; Tonini et al., 2013). This area is located in the southeastern tip of the Valdés Peninsula extending to the northeast (~42°S) and it has a highlighted importance as one of the most important frontal areas of the shelf. Along this sector of the NPFS is located the Valdés Front which is associated with high concentrations of chlorophyll-*a*, zooplankton, and fishes (Carreto et al., 1998; Sabatini and Martos, 2002; Acha et al., 2004). In the southernmost part of the NPFS (~43°–45°S) rates of tidal energy dissipation are not so high. This area is related with spawning and nursery areas of the anchovy (*Engraulis anchoita*) and hake (*Merluccius hubbsi*), two important commercial fish species of Argentina (Ehrlich and Ciechomski,

* Corresponding author.
E-mail addresses: barbara.franco@cima.fcen.uba.ar (B.C. Franco), uspalma@criba.edu.ar (E.D. Palma), mtonini@criba.edu.ar (M.H. Tonini).

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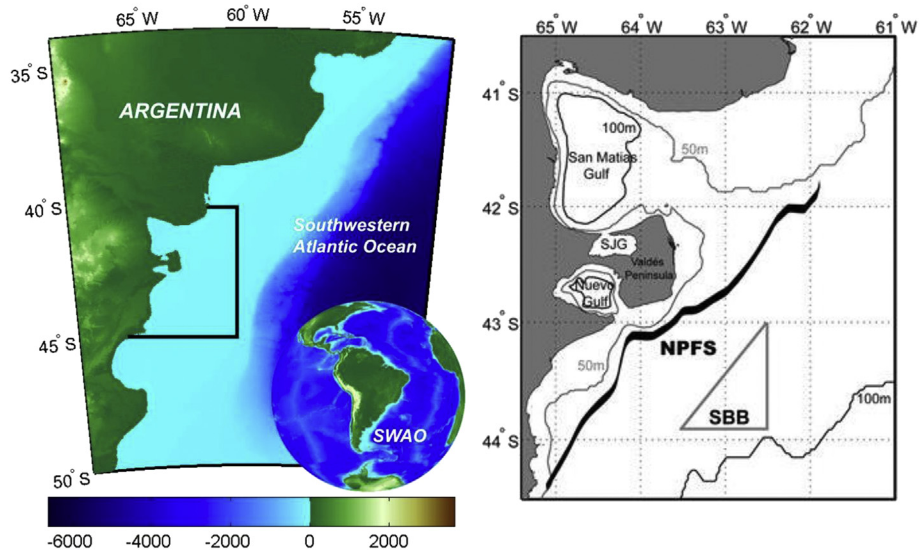

Fig. 1. Study area located in the Southwestern Atlantic Ocean (SWAO, left panel); Schematic illustration of the NPFS mean position (*e.g.*, Sabatini and Martos, 2002) and the Sea Bay bed area (SBB, dark gray polygon) (right panel). The North Patagonian Gulfs (Nuevo Gulf -NG-, San Matías Gulf -SMG-, and San Jose Gulf -SJG-) and the 50 and 100 m isobaths are shown.

1994). Other authors also indicated that the main spawning period of adult hake occurs during spring and summer in the stratified side of the frontal area (NPFS) along 43°–45.5°S (Pájaro et al., 2005).

Previous studies have suggested that the establishment of the Patagonian scallop Sea Bay bed (SBB, ~43.9°S and ~62.5°–63.5°W) (Fig. 1), occurs matching the NPFS location (see Bogazzi et al., 2005; Ciocco et al., 2006). Availability of planktonic food in the bottom is the most important factor to explain the persistence and recurrent localization of Patagonian scallop populations (Orensanz et al., 2006). The NPFS has been suggested to be able to supply planktonic food towards the SBB through benthic-pelagic coupling processes; however, the physical processes which could induce such coupling between the NPFS and SBB are not known. A high interannual variability in the recruitment of the species in the SBB is reported by Ciocco et al. (2006). Therefore, improving our knowledge about the dynamics and variability of the NPFS is crucial to improve fisheries management and overfishing prevention strategies, and to provide a better understanding about fluctuations in the recruitment of a wide group of marine species.

The primary aim of this study is to investigate the physical processes which could induce benthic-pelagic coupling between the NPFS and SBB. To address this investigation we will employ results from idealized and realistic numerical models combined with stochastic Lagrangian particle tracking methods. In Section 2, the numerical models and the calculations are described. Section 3 characterizes the dynamics and variability of the NPFS at semi-diurnal and intra-seasonal scales, and analyzes how the dynamics of this frontal system and its variability affect particles transport. Some conclusions follow in Section 4.

2. Material and methods

2.1. Hydrodynamic numerical models

To analyze the dynamics and variability of the NPFS we employed idealized and realistic numerical simulations based on the Regional Ocean Modeling System (ROMS, Shchepetkin and McWilliams, 2005).

2.1.1. Idealized numerical model of a tidal frontal system

The study of Bogazzi et al. (2005) suggests that the NPFS would maintain the existence of the SBB by supplying planktonic food from the surface. However, Simpson (1998) argued that in a tidally-controlled environment horizontal particle movements of more than ~10–15 km from the average frontal position are unlikely. The purpose of the idealized model is precisely to show the strength of this argument in a controlled experiment resembling the Patagonian shelf environment using a quasi two-dimensional version of ROMS.

The model has a periodic domain open in the north-south direction and an idealized continental shelf with 400 km (W–E). The parameterization of vertical mixing is calculated using the Large–McWilliams–Doney (LMD) turbulent closure scheme, with higher vertical resolution at the top and bottom layers (Large and Gent, 1999). The spatial resolution of the horizontal grid is of about 6 km. The semidiurnal tidal component (M_2) was imposed at the lateral open side (E) of the model domain with an amplitude of 0.75 m. This tidal amplitude generates a mean sea level rise of 1.5 m in the coast during the high tide according observations reported previously near the Valdés Peninsula. At the same lateral open side (E) of the model domain a combination of radiation and advection conditions is used (Marchesiello et al., 2001). Seasonal surface heat fluxes for the Patagonian region are calculated as recommended by Rivas (1994) and incorporated in the model through a parameterization following the formulation of Barnier (1998). A wind stress of 0.1 Pa with uniform westward direction (*i.e.*, simulating the predominant offshore wind) is imposed at the surface. The model was run during 3 years were a statistical steady state of energy balance was achieved. The outputs of the model for the last year of simulation were analyzed.

2.1.2. Realistic numerical model of the NPFS

For our realistic experiments outputs (three dimensional currents and vertical diffusivity fields) from a high resolution hydrodynamic model (ROMS, 3-D) of the North Patagonian region were used (Tonini et al., 2013). The resulting flow patterns and tracer fields (temperature and salinity) obtained with this model were analyzed and validated against the available observations in Tonini et al. (2013); here only a brief summary is given. The spatial resolution of the grid is variable, with maximum resolution (~1 km) into the gulfs. In the vertical the model equations were discretized in 20 sigma levels, with higher vertical resolution at the top and bottom layers. The bathymetry is based on digitized nautical charts. At the lateral open boundaries of the model they impose tidal amplitudes