Estuarine, Coastal and Shelf Science 189 (2017) 115–130

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Tidal dynamics on the North Patagonian Argentinean Gulfs

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ARTICLE INFO

Article history:
Received 8 August 2016
Received in revised form
16 February 2017
Accepted 21 February 2017
Available online 27 February 2017

Keywords:
North Patagonian gulfs
Tidal dynamics
Tidal residual currents
Topographic eddies
Vorticity analysis

ABSTRACT

Semidiurnal (M_2, S_2, N_2 and K_2), diurnal (K_1,O_1 and P_1) and quarter-diurnal (M_4, MN_4 and MS_4) barotropic tides over the North Patagonian Gulfs of Argentina: San Matías, (SMG), Nuevo (NG) and San José (SJG) are examined using a regional numerical model. Detailed comparison of computed elevations and currents with those obtained from harmonic analysis of few long-term observational records showed good agreement. A large amplification of all semidiurnal waves is recorded when they cross SMG mouth. Most of the tidal energy coming from the south at this frequency dissipates to the northeast of Valdés Península, where the largest tidal currents are located. While M_2 currents (up to 2–2.5 m/s) are dominant, there are large S_2 and N_2 currents and locally intensified diurnal currents (5–10 cm/s) in some outer shelf locations. At difference with the semidiurnal and diurnal tides the higher harmonics M_4, MS_4 and MN_4 develop a large amplification inside the NG. The model revealed a complex field of tidal residual currents. The intensity of such currents in some locations are of the same order of magnitude as those generated by winds or offshore forcing. We have identified three main patterns of residual circulation: regional coastal currents and gulf-wide gyres; inlet eddies and, topographic eddies. Vorticity balances and sensitivity experiments indicate that non-linear advection and bottom topography are the key mechanisms involved in the generation of these residual structures.

1. Introduction

The North Patagonian Gulfs (NPGs) region comprises three semi-enclosed gulfs: the San Matias (SMG), Nuevo (NG) and San Jose (SJG) and is considered one of the most productive areas of the Patagonian Shelf ecosystem (Acha et al., 2004, Fig. 1). Two notable physical features of this region are the large amplification of the tidal wave and the localized high tidal energy dissipation rate near the SMG entrance (Glorioso and Flather, 1997; Palma et al., 2004; Simionato et al., 2004; Moreira et al., 2011). The dynamical interplay of the tidal forcing with geomorphological features like headlands, promontories, semi-enclosed areas, deep basins and narrow gulf's entrances leads to the generation of strong fronts and re-circulating patterns (gyres) that have been observed in hydrographic data and remote observations (Piola and Scasso, 1988; Gagliardini and Rivas, 2004) and crudely modeled with low resolution models (Glorioso and Simpson, 1994). Many physical and bio-geochemical processes in the area are also affected by the details of tidal dynamics. For instance, tides influence the extent of vertical mixing, and thus partially determine the location of temperature fronts that are often observable from satellite imagery (Pisoni et al., 2014; Tonini et al., 2013) with potential large impacts on fisheries (Romero et al., 2006) and CO2 fluxes (Bianchi et al., 2005).

Albeit important, knowledge of the details of the tidal dynamics and tidal residual currents in this area is still unsatisfactory and largely based on low-resolution (coarser than 10 km) regional models of the Patagonian Shelf (Glorioso and Flather, 1997; Palma et al., 2004; Simionato et al., 2004) and the analysis of a limited number of in situ current measurements (e.g., Rivas, 1997; Moreira et al., 2009). Two exceptions are the recent high resolution models (~1 km) of Moreira et al. (2011) and Tonini et al. (2013). Moreira et al. (2011) studied the propagation of the M_2 tidal wave in the NPGs applying a set of three nested high resolution models based on a z-coordinate model. The work of Tonini et al. (2013) indicates that tidal forcing plays an important role in shaping not only the barotropic but also the baroclinic ocean response. Tidal forcing significantly contribute to delineate the frontal structures, and the seasonal circulation patterns in the NPGs, mainly in the summer season when the increased stratification interacts with the tides

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http://dx.doi.org/10.1016/j.ecss.2017.02.026

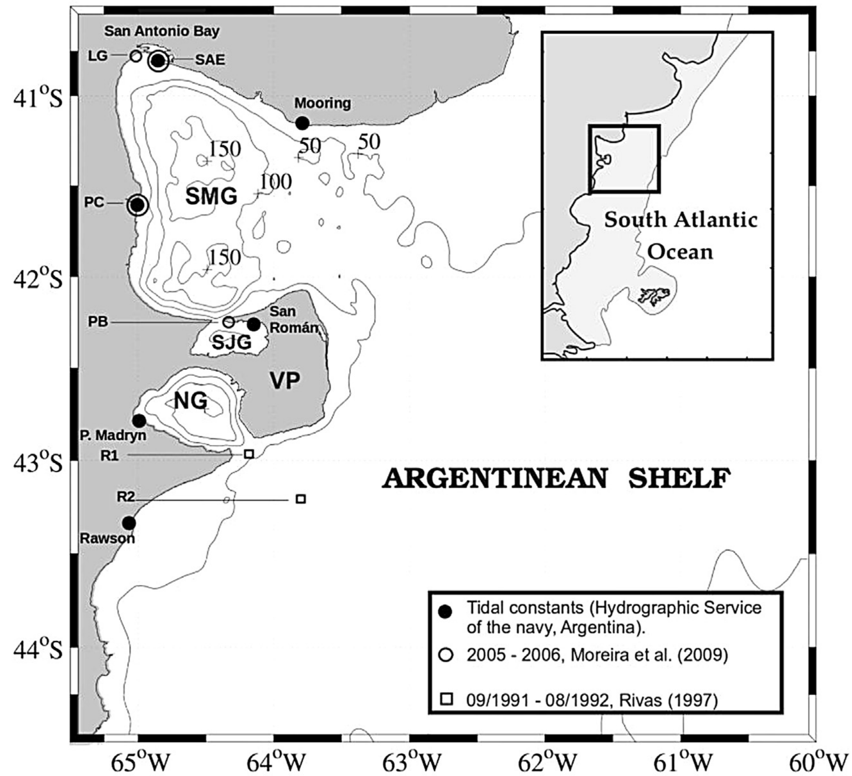

Fig. 1. Study area and computational domain. The thin lines indicate the 50, 100 and 150 m isobaths. The black dots indicate stations where tidal harmonic constants are available. The black circles and black squares show the location of available current time-series. NG: Nuevo Gulf; SJG: San José Gulf; SMG: San Matías Gulf; VP: Valdés Península.

intensifing a cyclonic circulation inside SMG and NG.

Although much have been learned about this region with the previous work, there is still room to be learned in terms of the dynamical role played by the different tidal constituents, the tidal energy fluxes and dissipation mechanisms and the detailed analysis of the residual patterns and the physical mechanisms responsible for its shape and structure. In this article we propose to further explore the barotropic tidal dynamics in this region using a suite of high resolution numerical experiments encompassing the NPGs region based on the earlier model of Tonini et al. (2013).

2. Data and methods

2.1. Model set-up

The numerical model used in this study is the Regional Ocean Modelling System (ROMS, Shchepetkin and McWilliams, 2005). In the vertical, the primitive equations are discretized over variable topography using stretched terrain-following coordinates. In the horizontal, the primitive equations are evaluated using orthogonal curvilinear coordinates on a staggered Arakawa C-grid. For the vertical mixing parameterization we selected the scheme developed by Mellor and Yamada (1982).

The model computational grid has 271 nodes in alongshore (N-S) and 241 nodes in a cross-shore (W-E) direction and extends from 40° to 44° S and from 60° to 65° W (Fig. 1). The spatial resolution of the grid is variable, with maximum resolution (~1 km) in the gulfs. In the vertical the model equations are discretized in 20 s-levels, with higher vertical resolution at the top and bottom layers. The bathymetry is based on digitized nautical charts. The model has three open boundaries (Fig. 1) where a combination of the Flather scheme for the barotropic mode and the Orlanski radiation condition for the internal velocities is used (Marchesiello et al., 2001). At these lateral open boundaries we imposed tidal amplitudes and phases of 8 principal constituents (4 semidiurnal, M_2, S_2, N_2, K_2, and four diurnal K_1, O_1, P_1 and Q_1), 2 long-term constituents (M_f and M_m) and 3 higher harmonics (M_4, MS_4 and MN_4) interpolated from a global tidal model (TPXO6, Egbert et al., 1994).

2.2. Observational data

For validating the model results we employ tidal amplitudes and phases from 5 coastal stations of the National Navy Hydrographic Service with record-length larger than 30 days, one recently deployed tidal gauge with record-length larger than a year (Lago et. al, 2017, under review, Mooring in Table 1) and the scarce available in-situ current observations (Fig. 1). The in situ observations consist in six current meter data from two different sources: the two stations south of domain (R1 and R2) were collected in a cross-shelf section near 43°S between September 1991 and August 1992, (Rivas, 1997). The other four stations are located inside SJG (Playa Bengoa, PB) and SMG (from south to north, Punta Colorada, PC, Las Grutas, LG and San Antonio Este, SAE), and the data were collected between July 2005 and December 2006 (Moreira et al., 2009). The timespan of the time series is of approximately 1 month each (see Table 2).

3. Tidal characteristics

We will focus here on the description, mapping and analysis of the seven major tidal constituents M_2, S_2, N_2, K_2, K_1, O_1 and P_1 and the overtides M_4 and MS_4 and their validation with available data. Although the model has been forced by 13 tidal components only those components with maximum amplitudes larger than 2 cm