The Seasonal Circulatin of the Eastern Brazilian Shelf between 10^{o}S and 16^{o}S: a modeling approach

Amorim F. N.[1,2]*; Cirano M.*[1,2,3]*; Marta-Almeida M.*[1,2]*; Middleton J. F.*[3]*; Campos E. J. D.*[1,4]

Introduction

The region of study (Fig. 1) encompasses an important dynamic part of the Eastern Brazilian Shelf (EBS), which hosts the bifurcation of the South Equatorial Current (SEC) into the two major Brazilian Western Boundary Currents (WBC): the southward Brazil Current (BC) and the northward North Brazil Current/Undercurrent (NBC/NBUC). The SEC bifurcation, in the top 400 m, undergoes a strong meridional seasonal cycle due to the north-south displacement of the marine Inter-Tropical Convergence Zone (ITCZ), reaching a southernmost (northernmost) position at 17^{o}S (13^{o}S) latitude in July (November) (*Rodrigues et al., 2007*). The bifurcation also undergoes a latitudinal excursion with depth, reaching $\sim$22^{o}S at $\sim$400 m depth. As a result, in the region of study, the BC is a shallow and weak flow associated with the Tropical Water (TW) and the upper thermocline, underneath the surface layer, always flows northward carried by the NBUC.

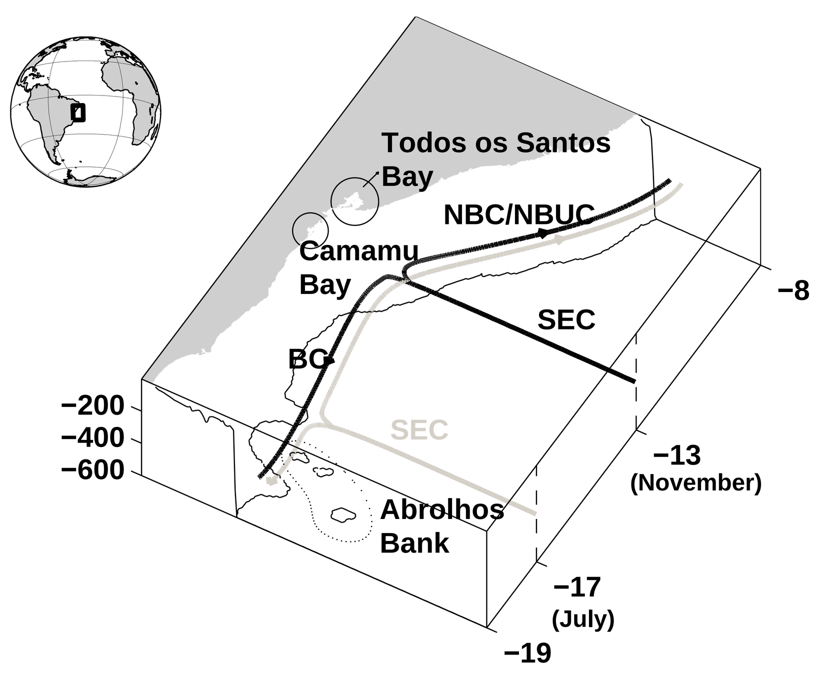

FIGURE 1: Schematic seasonal variation of the Western Boundary Currents (WBC) at the upper levels along the EBS shelf/slope region. The grey (black) line shows the southernmost (northernmost) position of the SEC bifurcation, according to *Rodrigues et al. (2007)*

Following the large scale seasonality of the trade winds, the shelf currents along the EBS are mainly wind driven, experiencing a complete reversal of the mean flow between seasons due to a similar change in the wind field (*Amorim et al., 2011, 2012*). The arrival of cold-frontal systems during the spring season is able to cause periodical reversals of the depth-integrated flow (*Amorim et al., 2012*). These authors have also shown that the shelf currents are influenced by topographic changes, which can enhance the upwelling system during the spring/summer seasons.

Based on a long term regional model simulation, this work aims to describe the seasonal circulation along the EBS shelf/slope region, as well as its interaction with the large scale meteorological and oceanic processes.

Methodology

The simulations were performed with the Regional Ocean Modeling System (ROMS) with embedded nesting capabilities based on AGRIF, configured with a refined grid (1/36^o) and realistic forcings: i) daily initial and boundary conditions from the 1/12^o HYCOM Global Circulation Model (GCM) coupled on the NCODA system analysis. The model temperature, salinity and velocity (2D and 3D) were also nudged towards the GCM daily values with a variable relaxation time scale; ii) surface boundary fluxes based on the 6-hourly NCEP Reanalysis2; iii) 6-hourly surface wind stress and intensity from the QuickSCAT scatterometer and SMM/I radiometer provided by *CERSAT/IFREMER*; iv) sea surface elevation and barotropic currents from TPXO tidal model. The bottom topography was interpolated from ETOPO1 with a smooth to fit the bathymetric gradients with a maximum slope factor of 0.2.

The integration period was 6 years (January 1st/2004 to December 31st/2009). The first two years were used as the model spin-up and, with the exception of tides, include all forcings described above. The period for the seasonal analysis encompasses the last four years of simulation.

Results

The monthly mean surface currents derived from the Regional Circulation Model (RCM) are investigated and compared with the surface gestrophic currents derived from AVISO as a modeling validation approach (Fig. 2). For these analysis and those discussed in Fig. 3, we have adopted the months that represent the austral seasons: October (spring), January (summer), April (autumn) and July (winter). The modeled surface currents for spring and summer clearly show the southward BC as a flow composed by the coastal borders of anticyclones, which is in agreement with *Soutelino et al. (2011)* and resembles the geostrophic currents from AVISO south of 12^{o}S (Fig. 2a-d).

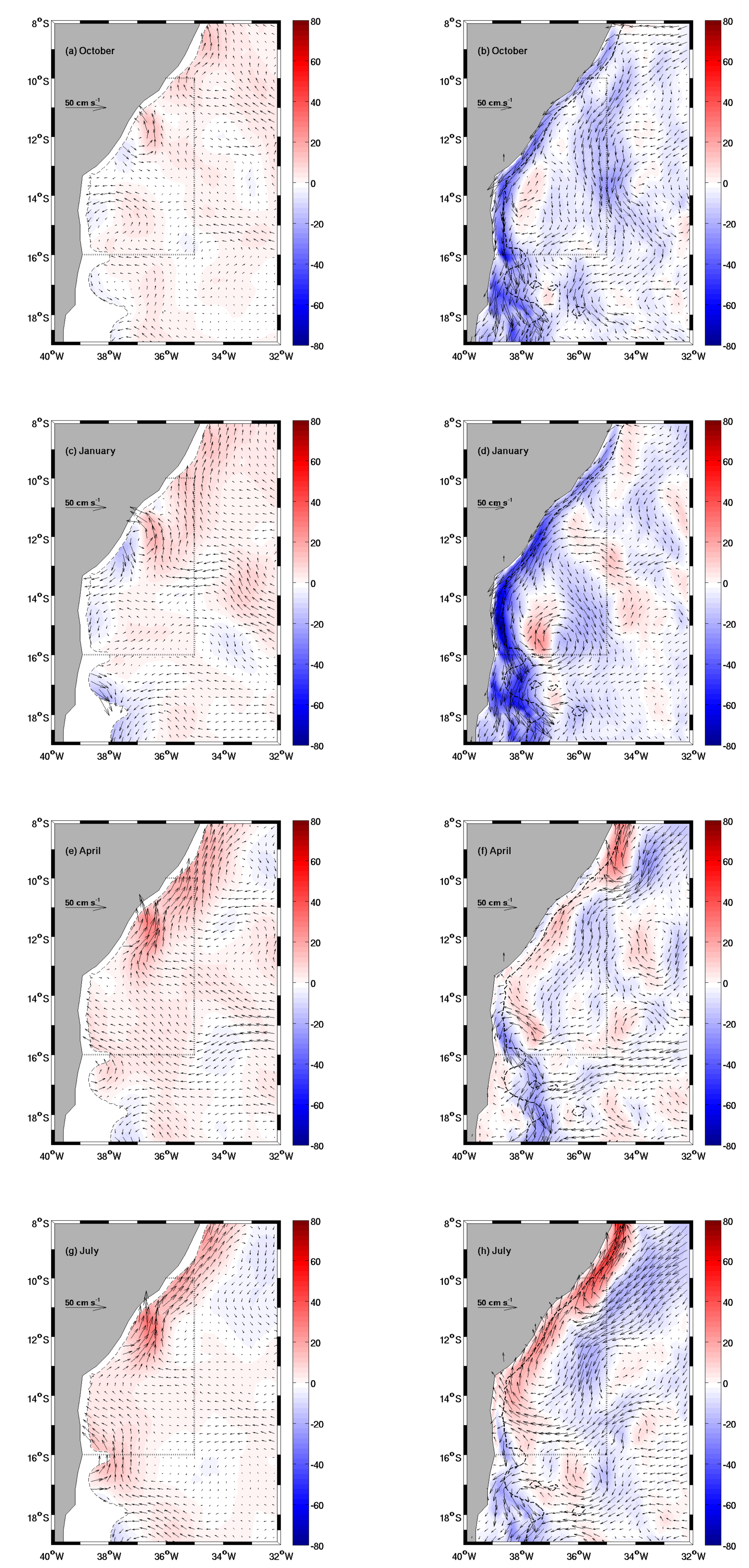

FIGURE 2: Monthly mean (2006-2009) geostrophic currents (vectors) derived from AVISO (left panels) and horizontal surface currents (vectors) derived from the RCM. The shaded area represents the intensity (cm s^{-1}) of the meridional velocity component, where positive values are equatorward. The area inside the dotted lines represents the region of study.

The reversal of the WBC during the autumn and winter seasons, where the modeled northward NBC/NBUC are present north of 15^{o}S, is also in agreement with the geostrophic currents (Fig. 2e-h). In addition, and with no sign of seasonality, both modeled and geostrophic currents show a continuous BC south of 17^{o}S.

At sub-surface (100 m depth) the circulation is dominated by the seasonal flows of the BC/NBUC, following the excursion of SEC bifurcation (Fig. 3). As a response, for the months of October and January, the beginning of the southward BC occurs at $\sim$15^{o}S and $\sim$13^{o}S, respectively. To the south of these latitudes, the coastal borders of three robust anticyclones could represent the beginning of the southward BC flow (Fig. 3a,b).

Following the summer season, the SEC bifurcation starts to migrate southward. In April, the beginning of the northward NBUC flow is observed at $\sim$16^{o}S, reaching its southernmost position in July, when the origin of the NBUC flow is observed at $\sim$17^{o}S (Fig. 3c,d). For these months, the presence of anticyclone eddies confined at the Royal Charlotte (RCB, 18^{o}S) and Abrolhos (AB, 16^{o}S) Banks imposes a weak southward flow, which could be associated with the beginning of a weak southward BC.

As a result of the meridional displacement of the SEC bifurcation along depth, reaching 22^{o}S between 200 m-400 m, the South Atlantic Central Water (SACW) is transported northwards by the NBUC flow over the domain and during the whole year, with a strong intensification toward the equator (Fig. 4). A similar pattern occurs for the Antarctic Intermediate Water (AAIW), since at this level the bifurcation occurs at about 25^{o}S (*Stramma & England, 1999*).

The cross-shore radials show that at 10^{o}S, and for the TW layer, the northward NBC/NUBC system is the dominant pattern and the southward flow appears as a thin flow confined to the top 50 m depth during the spring/summer seasons (Fig. 4 left). At 14^{o}S and 16^{o}S (Fig. 4 middle and right) there is an alternate dominance of the BC/NBC flow at the first 150 m depth, with the dominance of the BC (NBC) flow between September-February (April-July) at 14^{o}S. At 16^{o}S a permanent surface southward flow and a marked mesoscale activity is captured throughout the year (Fig. 4 right), probably ascribed to the flow constrain due to the RCB topography, which alters the circulation pattern between seasons

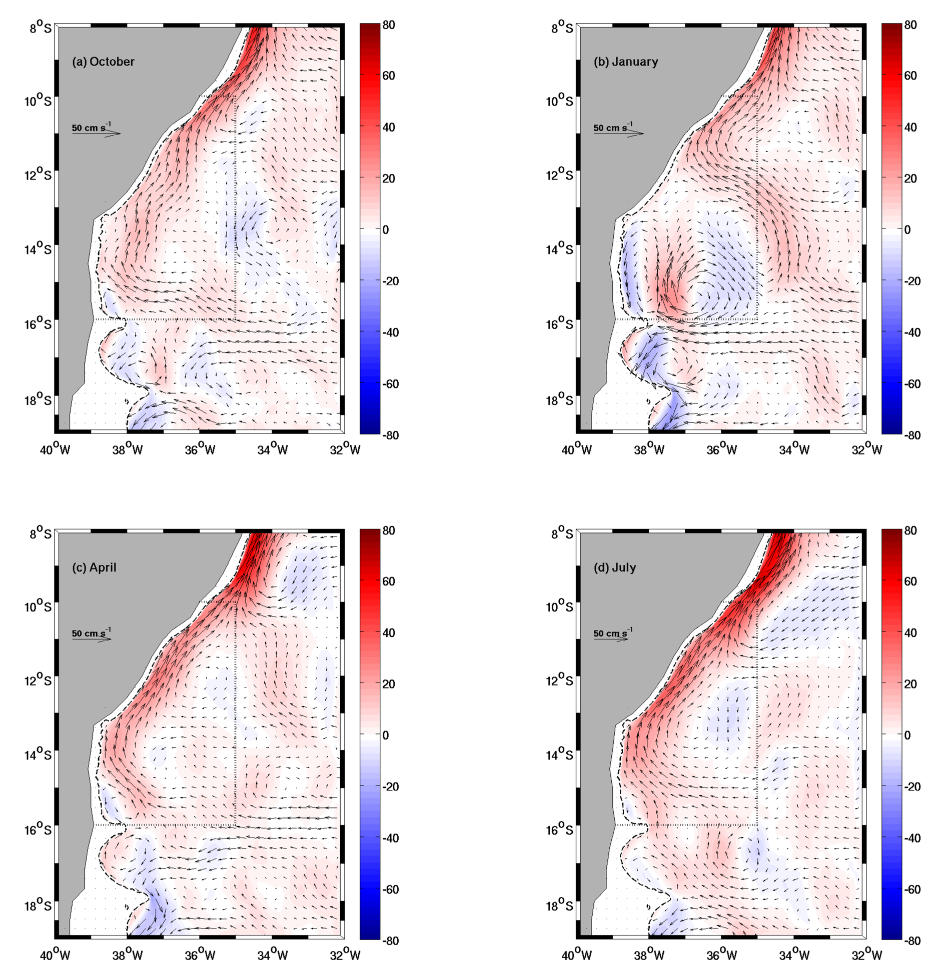

FIGURE 3: Monthly mean (2006-2009) 100 m depth currents (vectors) derived from the RCM. The shaded area represents the intensity (cm s^{-1}) of the meridional velocity component, where positive values are equatorward. The area inside the dotted lines represents the region of study.

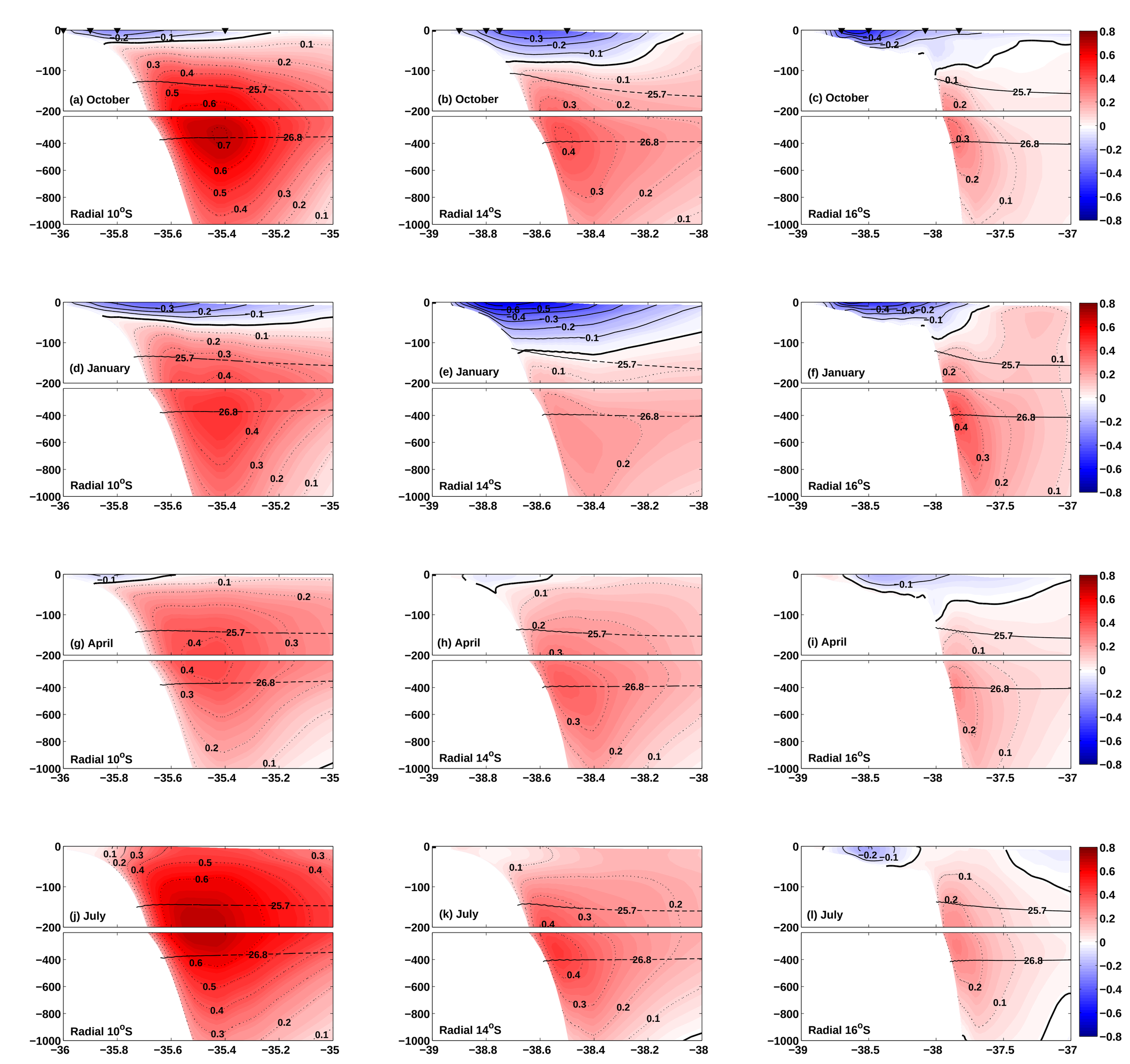

FIGURE 4: Mean vertical sections (2006-2009) of the alongshore velocity at 10^{0}S (left), 14^0 (middle) and 16^{0}S (right). The dashed lines indicate the isopicnal limits between the TW (σ_θ < 25.7 kg m^{-3}) and SACW (25.7 kg m^{-3} < σ_θ < 26.8 kg m^{-3}). Red (blue) shades represent positive (negative) northward (southward) flow.

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1 *Rede de Modelagem e Observação Oceanográfica - REMO*
2 *Grupo de Oceanografia Tropical, Instituto de Física, Universidade Federal da Bahia, Brazil*
3 *Aquatic Sciences, South Australia Research and Development Institute, Australia*
4 *Instituto Oceanográfico da Universidade de São Paulo, Brazil*