Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1265-1268.

THE BAROCLINIC STRUCTURE OF THE BRAZIL CURRENT SYSTEM IN THE SÃO PAULO BIGHT

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The Brazil Current system (BCS) is formed by two western boundary currents that flow along the Southeast Brazilian continental margin from the surface to the depth of 1800 m. These two currents are the southward-flowing Brazil Current (BC) and the northward-flowing Intermediate Western Boundary Current (IWBC).

The investigation of the dynamics of the baroclinic structure of the BC system is conducted solely from hydrographic data analysis from two oceanographic mesoscale surveys from the COROAS Project, as part of the World Ocean Circulation Experiment (WOCE), [*Godoi*, 2005]. We selected two, HM1 and HM2, of the three cruises that sampled the central portion of the São Paulo Bight (23.5^{o} - 27^{o}S), for the summer and winter of 1993 (Figure 1). Due to similarities between the results from both cruises emphasis is given to results related to cruise HM2, winter 1993.

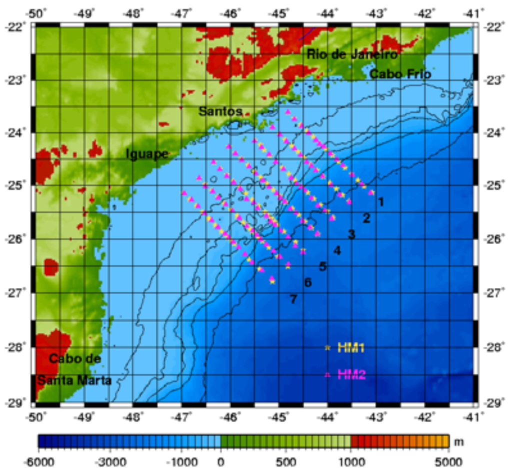

Figure 1: Location of the hydrographic array performed by the HM1 and HM2 cruises on São Paulo Bight, Southwest Atlantic Ocean.

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A quantitative estimation of the reference level to calculated the geostrophic velocity is conducted through the comparison of two different and independent methodologies. This level represents the inversion level of the first baroclinic mode, e.g., the interface between BC and IWBC. This is estimated by the comparison between the classical analysis of the water masses and the numerical calculation of the baroclinic pressure gradient by using the sectional version of the Princeton Ocean Model ($POM_{x\sigma}$).

The first method uses a previous knowledge that, at central region of the São Paulo Bight, the BC transports Tropical Water (TW) and South Atlantic Central Water (SACW) to the south and IWBC transports mainly Antarctic Intermediate Water (AAIW) northward. This method, referred here as the *Thermodynamical Criterion*, applies the Shtokman theorems [*Shtokman*, 1944] to estimate the interface depth between SACW/AAIW and AAIW/NADW. These interfaces are indicated at the mixture triangle (Figure 2 - upper panel) and at the potential conventional density mean vertical profile (Figure 2 - lower panel).

The second method, designated here as the *Dynamical Criterion*, consists of modelling the absolute baroclinic velocities for all 14 hydrographic transects, performed by the HM1 and HM2, using the sectional version of the $POM_{x\sigma}$. The numerical model version is based on *Silveira et al.* [2004] and *Lima* [1997]. The initialization of the model uses potential temperature and salinity sections. Based on the evolution of the mean kinetic energy the numerical simulations runs for three days in the diagnostic mode and for five days in the prognostic mode [*Godoi*, 2005].

The results of these two methods differ only by 7 dbar, that is 478 dbar using *Thermodynamic Criterion* and 485 dbar using *Dynamical Criterion*. Therefore, the optimized reference level of 480 dbar is adopted to represent the average interface isobaric level between BC and IWBC in the geostrophic calculations [*Godoi*, 2005].

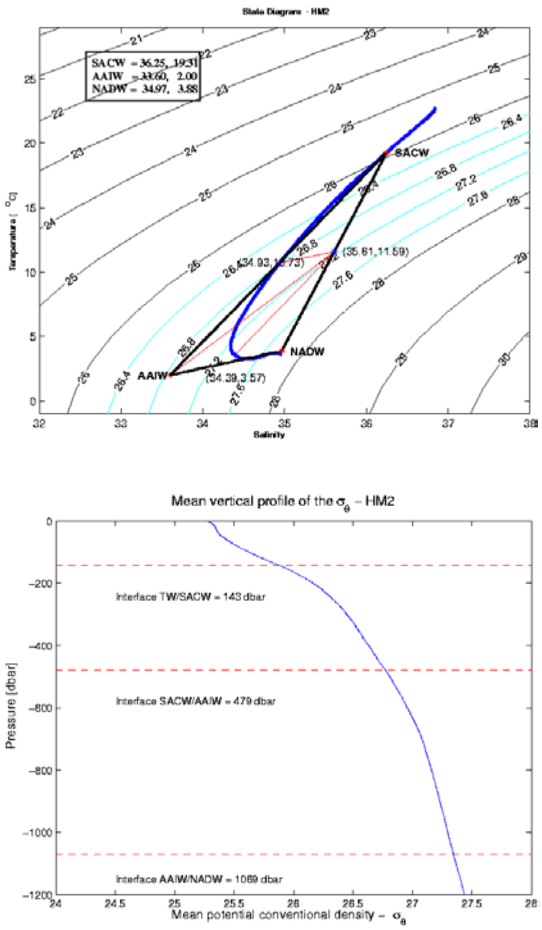

Figure 2: The state diagram [upper panel] shows the mean T-S curve (dark blue) and the mixture triangle (black). The correspondent mean vertical profile [lower panel] of the observed potential conventional density (blue) indicates the water masses interfaces and the correspondent isopycnal surfaces. The thermodynamic criterion is used to estimate the interfaces between AT/SACW, SACW/AAIW and AAIW/NADW, outlined by red broken lines in both panels.These results referred to the HM2 cruise, winter 1993.

An example is showed for the Transect 7, winter 1993, considering the baroclinic velocity obtained by the $POM_{X\sigma}$ (Figure 3 - upper panel) and the relative geostrophic velocity to the 480 dbar from the dynamic method (Figure 3 - lower panel). The inspection of this figure permits the identification for just one inversion of the flow direction along the vertical axis, which is associated with the first baroclinic mode. There is an evidence of the asymmetric and cyclonic vortex in both sections. The largest differences are located over the continental shelf or near the slope, where the numerical model fits baroclinically to the topography.

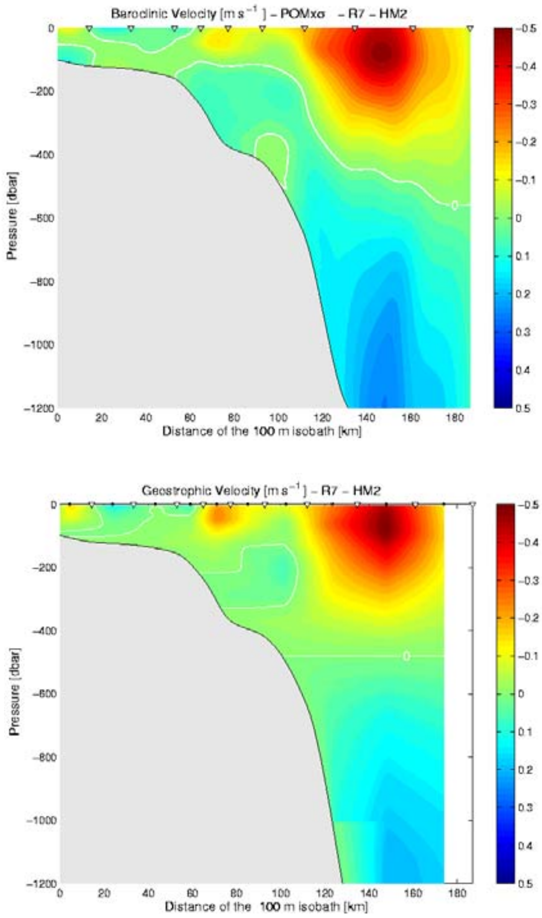

Figure 3: The vertical section (Transect 7) of the modelled baroclinic velocity simulated by $POM_{X\sigma}$ [upper panel] and the corresponding vertical section of the relative geostrophic velocity to 480 dbar estimated by classical dynamic method [lower panel]. The white lines delimit the positions of the BC/IWBC interface. The white triangles located at surface indicate the positions of the hydrographic stations. The asterisks indicate the intermediate positions between stations, used in the geostrophic calculations. These results referred to the HM2 cruise, winter 1993.

Horizontal distributions of the geostrophic stream function from surface to 1200 dbar, for each 10 dbar, are generated using isotropic objective mapping [*Carter and Robinson*, 1987] and Dirichlet boundary conditions, to not permit normal flux at solid contours. The distributions present unequivocal evidences of cyclonic and anticyclonic structures in both summer and winter 1993 cruises [*Godoi*, 2005]. These features are associated to meanders of the BCS. They are depicted in opposing sides of the current core (Figure 4).

In the first 480 dbar the cyclone (L - lower pressure) is seen at the BC coastal side and the anticyclone (H - high pressure) is placed at its oceanic side (Figure 4 - upper and middle panels). The Figure 4 [lower panel] exemplify the IWBC domain, where is evident the inversion of the flow direction. The principal flow characteristic of the IWBC is enclosure by a anticyclonic in the southwest domain.

The compilation of the results show that the IWBC just as the BC exhibit meanders which have opposite signals that observed above the reference level. Such configuration corroborates the affirmation about of the structures of the dynamic first mode. Therefore, geostrophic stream function maps reveal cyclonic and anticyclonic meanders associated with first mode baroclinic vorticity waves.The evidences found in the combination of the stream function surface maps (Figure 4 - upper panel) and sea surface temperature satellite images confirm a wavelength of 200 - 300 km.

To synthetize the results we show the configuration of the baroclinic structure of the BCS obtained by a data-derived two-layer quasi-geostrophic model. This model was built assuming an inviscid flat-bottomed ocean in the beta plane [*Godoi*, 2005]. The mean Rossby number estimated for the geostrophic velocities is 0.13.

A set of geostrophic stream functions horizontal distributions are constructed using the reference level of 480 dbar. In Figure 5 we show, for the same cruise HM2, winter 1993, the stream functions for the first (480 dbar - upper panel), for the second (720 dbar – middle panel) layers and for the baroclinic stream function (lower panel).

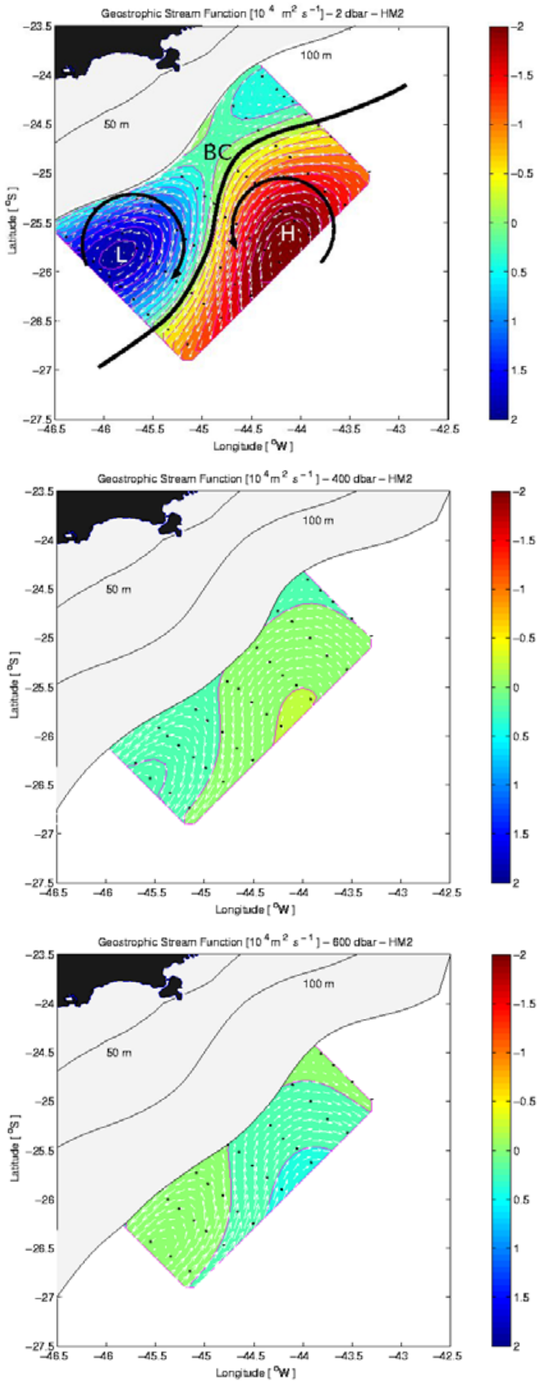

Figure 4: The geostrophic stream function current map at 2 dbar [upper panel], 400 dbar [middle panel], and 600 dbar [lower panel]. For the surface map the thick black lines indicate the mean position of the BC flow and the thick black arrows indicate the cyclone (L) and the anticyclone (H). The dots indicate the location of the stations. These results are referred to the HM2 cruise, winter 1993.

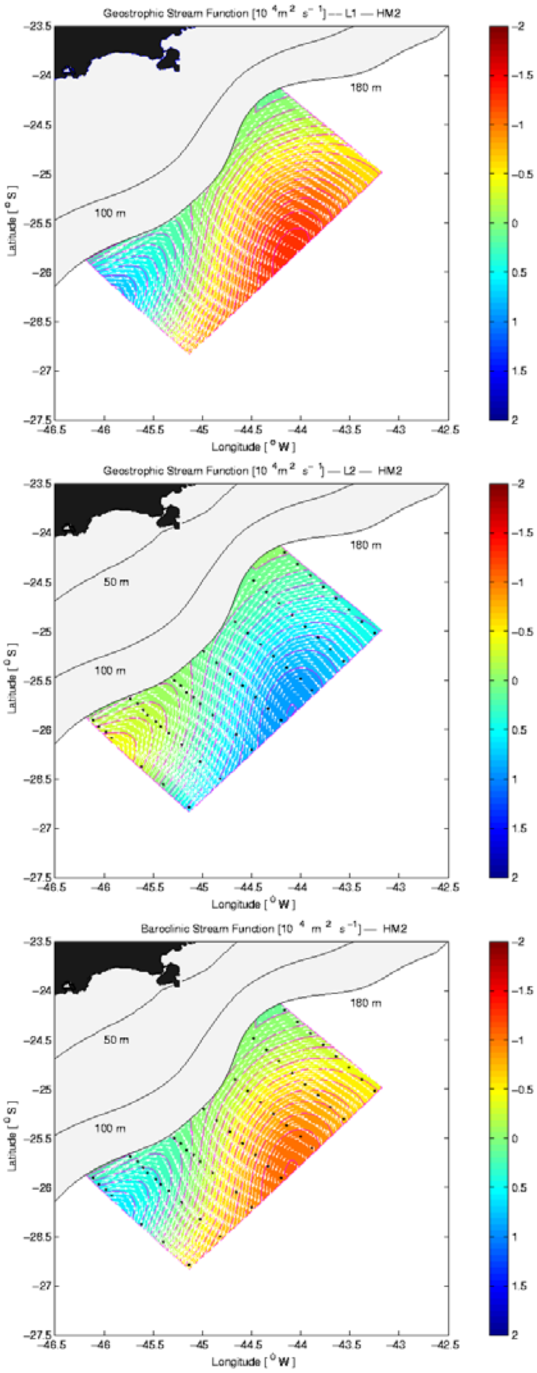

Figure 5: Horizontal distribution of the stream function for the first layer [upper panel], second layer [middle panel] and for the baroclinic stream function [lower panel], for the HM2 cruise, winter 1993.

The stream function field of the first layer, in the BC domain, maintains the structure diagnosed like a baroclinic wave in both summer and winter 1993 conditions. Considering the structure of the second layer, the condition of null barotropic integrated transport impose a baroclinic signature of the vortex with opposite sense in the IWBC domain. This current flows to the north in the similar configuration to the BC, but with the oceanic and coastal sides of the current showing also opposite signals. We observe that the pattern of the baroclinic stream function repeats that in the first layer in the sense of the circulation.

Again, the single vertical inversion of these horizontal flows also confirms that these vortex-like features are part of a first baroclinic mode wave. These aspects also corroborates previous speculations found in the literature [*Silveira et al.*, 2004].

Acknowledgments

This research was developed by “DINBRAS Project at Instituto Oceanográfico da Universidade de São Paulo”. This project was supported by ”Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP”. The authors are grateful for Dra. Olga Sato, Dr. Paulo Polito and MSc. Leandro Calado for the sugestions.

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