

## ACOUSTIC PROPAGATION IN THE BRAZIL CURRENT SYSTEM OFF THE SOUTHEASTERN COAST

Leandro Ponsoni<sup>a</sup>, Olivier Carrière<sup>a</sup>, Qun-yan Ren<sup>a</sup>, Ilson Carlos Almeida da Silveira<sup>b</sup>,  
Jean-Pierre Hermand<sup>a</sup>

<sup>a</sup>Environmental hydroacoustics lab, Université libre de Bruxelles (U.L.B.), Belgium.

<sup>b</sup>Laboratório de Dinâmica Oceânica, Universidade de São Paulo (USP), Brasil.

Leandro Ponsoni, Av. Fr. Roosevelt 50, CP 194/05, 1050 Brussels, Belgium [email:  
lponsoni@ulb.ac.be, <http://ehl.ulb.ac.be>]

***Abstract:** The Brazil Current (BC) is perhaps the less studied subtropical boundary current of the world ocean. Within this region, the BC develops vigorous meanders and rings. A combination of numerical simulations and observational studies are important tools to unravel these phenomena. Direct current measurements are rare and usually too short to depict the mean, long term circulation patterns. Similarly, quasi-synoptic hydrographic data in the region is sparse. Acoustic waves are an efficient tool for covering large regions of the water column in a synoptic way. Acoustic tomography can be therefore useful to better predict through inversion for the effective sound speed field and its assimilation to a circulation model the oceanographic fields of interest (temperature, salinity, density). Such information is particularly important for initialization and data assimilation to regional models for which small and meso-scale processes are of fundamental interest. In this paper, a preliminary study of acoustic propagation modeling through two vertical sections off the Brazilian southeastern coast is presented. Actual hydrographic data from DEPROAS 2003 sea trial serve to construct the physical parameters that characterize these sections.*

***Keywords:** Brazil Current, Acoustic Tomography, Feature Models*

## 1. INTRODUCTION

The region off coast of southeastern Brazil (between 20°S and 28°S) is subject to a complex pattern of meso-scale currents. Prediction and monitoring of this geostrophic currents system are topics of interest for the scientific community, given its importance, for instance, on climate, on fishing and for oil industry [*Sunyé & Servain, 1998; Lima et al., 2009*].

However, for a integrated program of observational oceanography and numerical ocean modeling it is essential to develop an efficient system of synoptic data sampling. In this context, acoustics may provide additional source of data that supplements the other conventional methods (e.g., moorings, buoys, gliders, hydrographic cruises) to infer the physical state of the oceans, with the interesting advantage that acoustical methods are able to sample the water column over large distances on an effectively synoptic scale [*Stéphan et al., 2010*]. In addition, the operational feasibility of meso-scale currents monitoring (including fronts and meanders) may be enhanced by acoustics due to real-time access to data, including time series, given the possibility of installing acoustic moorings close to shore.

Thus acoustic tomography can be very useful in providing estimates for numerical model initialization and data assimilation as well as providing important information about the structure of mass (density), which is ultimately what determines the baroclinic geostrophic currents.

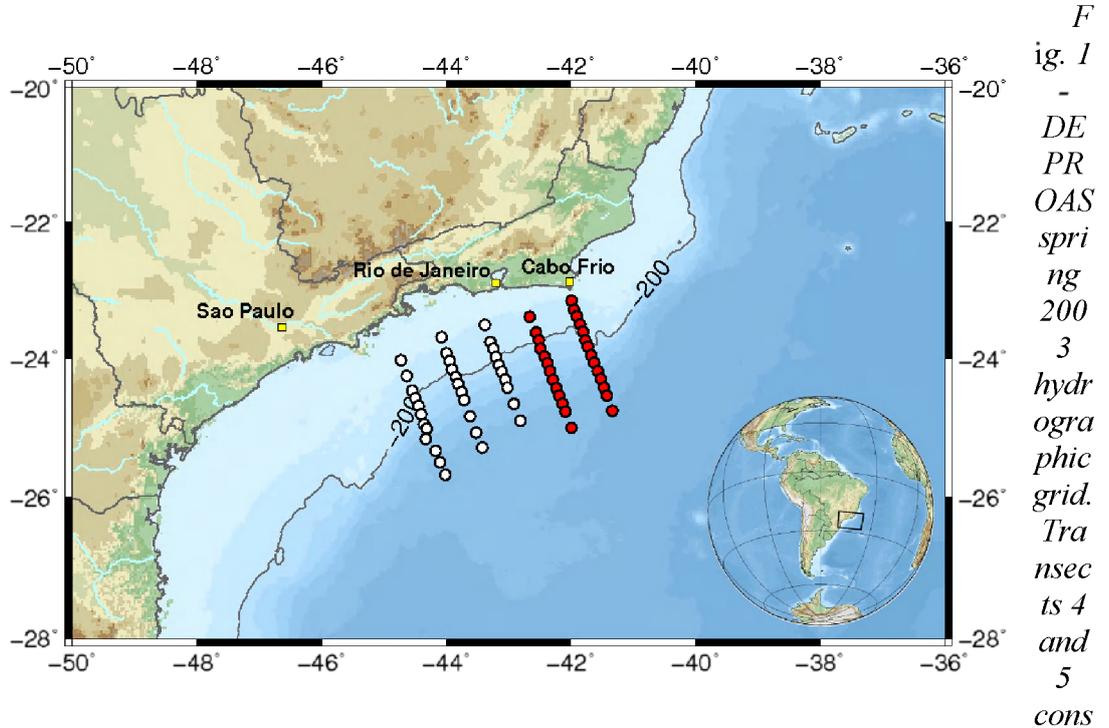
Off the coast of southeastern Brazil, the Brazil Current (BC) takes place typically in the first 500 meters of the water column, flowing towards the south/southwest [*Evans & Signorini, 1985*]. The BC denotes the western boundary current responsible for closing the South Atlantic subtropical gyre. At intermediate levels, between 500 m and 1300 m, approximately, a reversal in the flow occurs, and the water mass is carried by the Intermediate Western Boundary Current (IWBC) in the opposite direction (north/northeast) [*Boebel et al., 1999*]. Coupled with the complex currents reversal mechanism, this current system presents strong meso-scale activity associated with the meandering and eddy formation [*Silveira et al., 2004; Calado et al., 2006*].

Aiming to understand acoustic propagation in this current system this paper presents some preliminary results on low-frequency (80 Hz) sound propagation modeling through two vertical sections off the Brazilian southeastern coast, each with a different bathymetry and isopycnic structure, based on real oceanographic data collected *in situ*.

## 2. DEPROAS 2003 DATA SET

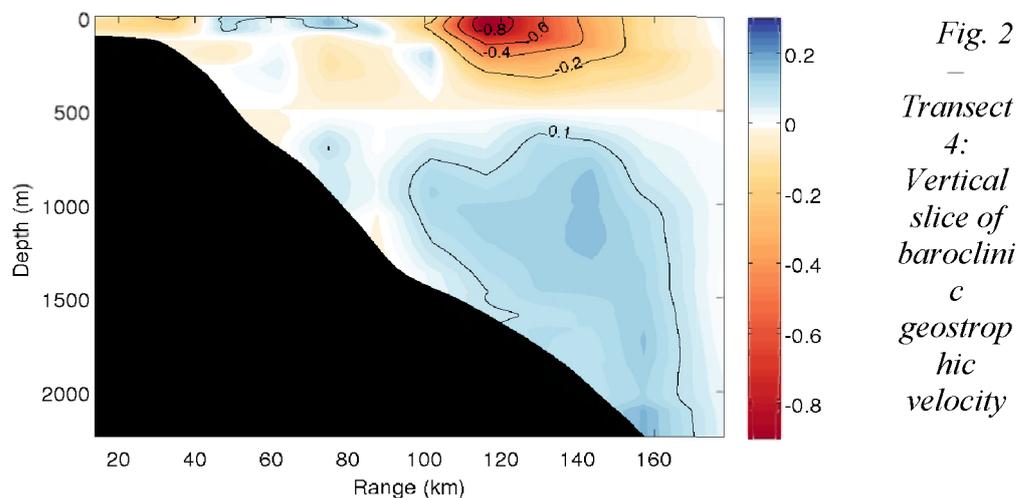
This work involves a subset of the DEPROAS (“Dinâmica do Ecosistema de Plataforma da Região Oeste do Atlântico Sul”, Ecosystem Dynamics of the Continental Shelf Region of the western South Atlantic) experiment conducted in the Austral Spring of 2003. Hydrographic profiling was done with a Fallmouth CTD. The data were collected by the University of São Paulo aboard the R/V Prof. W. Besnard.

The cruise consisted of five transects sampled between 22 and 29 September, 2003. These five transects are distributed on 60 stations in a region bounded on the north by Cabo Frio (23°S) and on the south by São Sebastião Island (25°S), as showed in Fig. 1. In this paper, only the two north transects are considered, referred as Transects 4 and 5 in the remaining of the paper.

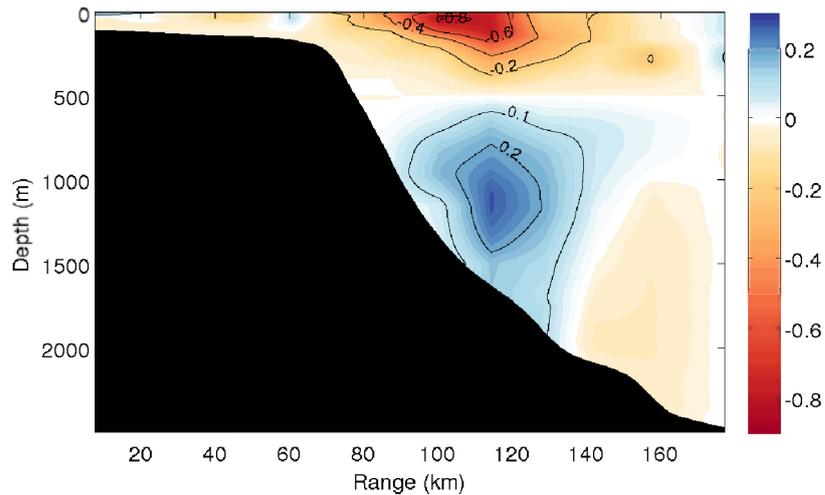


*idered in this paper are highlighted in red. Each circle corresponds to a station where hydrographic data were collected.*

Figures 2 and 3 show the vertical slices of the baroclinic geostrophic velocity for the Transects 4 and 5, respectively. Spatial variations in density were used to calculate the baroclinic geostrophic velocity through the Dynamic Method [Sandström & Helland-Hansen, 1903]. A level of zero motion at 500 m was established, since this is the characteristic thickness of the BC off southeastern Brazil [Evans & Signorini, 1985]. Maximum speeds of approximately  $0.8 \text{ m s}^{-1}$  were found for the BC in the two transects, while the IWBC is slightly more strong in Transect 5 (maximum speed of approximately  $0.2 \text{ m s}^{-1}$ ) compared to Transect 4 (maximum speed of approximately  $0.1 \text{ m s}^{-1}$ ).



calculated with a level of zero motion set at a pressure of 500 dbar.



*Fig. 3*  
 —  
*Transect*  
*5:*  
*Vertical*  
*slice of*  
*baroclinic*  
*geostrophic*  
*velocity*  
*calculated with a*  
*level of*

*zero motion set at a pressure of 500 dbar.*

### 3. ACOUSTIC PROPAGATION THROUGH THE BRAZIL CURRENT

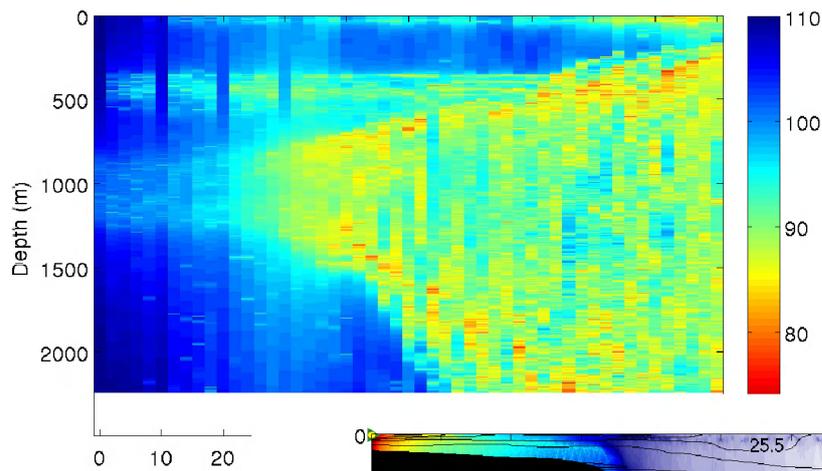
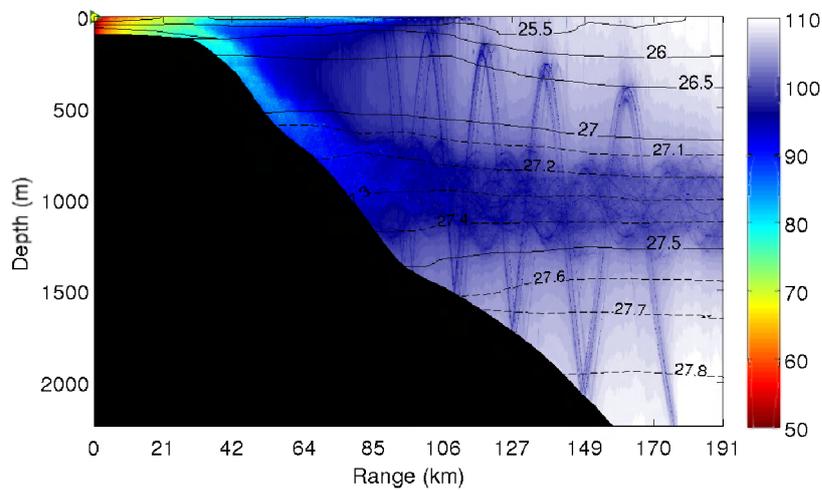
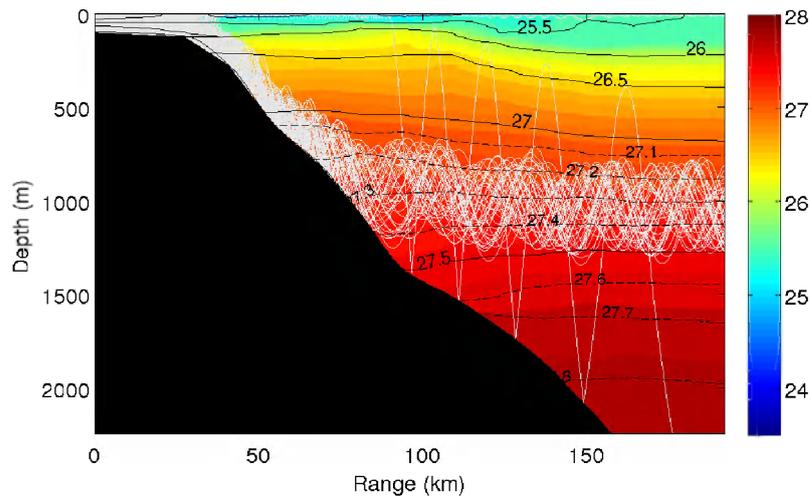
This first paper aims to study the characteristics of acoustic propagation through realistic BC sections constructed from the DEPROAS 2003 data. The acoustic propagation is modelled with BELLHOP ray model [Porter & Bucker, 1987] with a source frequency of 80 Hz. The source is placed at the same position as the hydrographic station closest to the coast at a depth of 5 m (0-km range, Figs. 4 and 5). The investigated range of propagation corresponds to the maximum distance between the hydrographic stations.

Figure 4 illustrates the acoustic propagation for Transect 4. The figure shows the density field overlaid by the acoustic propagation rays, the incoherent transmission loss overlaid by isopycnals, and the variations of transmission loss on the extremal vertical profile when the acoustic source position varies in the range from 0 km to 100 km. In the region of the continental shelf, rays propagate throughout the whole water column because of the cumulated effects of refraction and surface/bottom interaction. At the shelf break (about 40 km from the first station) the rays move away from the surface to follow the bathymetry. However, when the rays reach the minimum sound-speed region, part of the acoustical energy is trapped and propagates in the so-created channel. This channel is here located between 760-m and 1270-m depths, corresponding here to a range of density bounded by  $27.1 \text{ kg m}^{-3}$  and  $27.5 \text{ kg m}^{-3}$  approximately.

When the source is placed near the shelf break the transmission loss values are reduced, and the rays do not propagate exclusively in the channel (Fig. 4, bottom panel).

Figure 5 shows the same three panels for Transect 5. The channel is basically limited by the same isopycnals. Compared to Transect 4, the only major difference is that the range between the first station (inshore) and the shelf break is larger (about 70 km from the first station). Therefore, the acoustic rays propagate longer in relatively shallow waters, increasing consequently the number of surface and bottom interactions, resulting in higher transmission loss values compared to Transect 4. A surface duct also traps an important

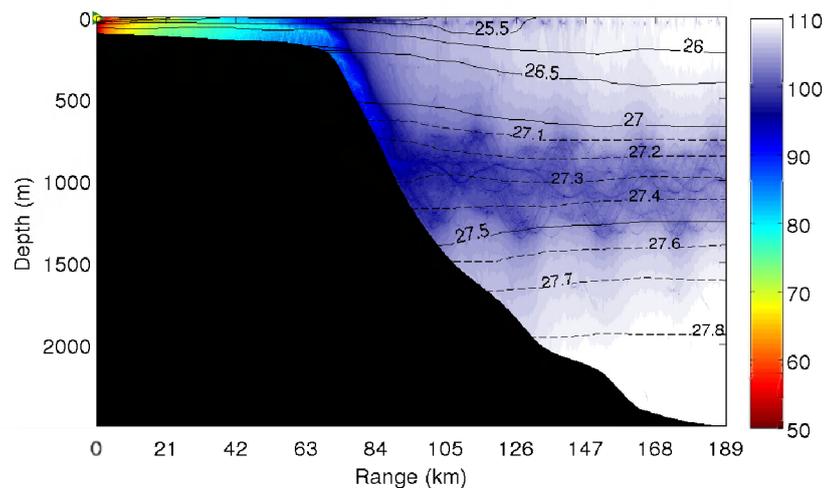
part of the energy when the acoustic source is located between 45 km and 80 km, for  
Transect  
5.



*Fig. 4 –  
Transect  
4:  
Potential  
density overlapp  
ed by the rays (top  
panel),  
the  
transmiss  
ion loss  
field  
superimp  
osed by  
isolines  
of  
potential  
density  
(central  
panel),  
and the  
transmiss  
ion loss  
when the  
acoustic  
source  
position  
varies in  
the range  
from 0  
km to  
100 km  
(bottom*

*panel).*

*Fig. 5 – Transect 5: Potential  
density overlapped by the rays  
(top panel), the transmission*



*loss field superimposed by isolines of potential density (central panel), and the transmission loss when the acoustic source position varies in the range from 0 km to 100 km (bottom panel).*

#### **4. CONCLUSION**

This paper presents some preliminary results about the acoustic propagation modeling through two vertical sections off the Brazilian southeastern coast constructed from real oceanographic data measured during the DEPROAS 2003 sea trial. The simulations illustrate the interaction of the acoustic rays with the boundaries (surface and bottom) in the continental shelf region, occupying whole the water column. In the continental slope region, in the same portion of the water column occupied by IWBC, rays propagate through the duct of minimum sound speed and they do not interact anymore with the surface and bottom.

In combination with other sources of oceanographic data, acoustics can have a significant role in determining mass fields for initialization of numerical models and data assimilation as needed by an operational oceanography program. These topics will be investigated in the next phase of this work.

#### **5. ACKNOWLEDGMENT**

The authors acknowledge PETROBRAS for providing the DEPROAS 2003 data and CAPES for providing the PhD fellowship to the first author at the Université libre de Bruxelles.

#### **REFERENCES**

- [1] **Sunyé, P. S. and Servain, J.**, Effects of seasonal variations in meteorology and oceanography on the Brazilian sardine fishery, *Fisheries Oceanography*, 7, 89–100, 1998.
- [2] **Lima, J. A. M., Ribeiro, E. O., Ceccopieri, W. and Matheson, G. G.**, Directional extreme current profiles based on complex empirical orthogonal functions (C-EOF) for offshore design, In *ASME 28th International Conference on Ocean, Offshore and Arctic Engineering - OMAE2009*, University of Hawaii, Honolulu, 79.467, 2009.
- [3] **Stéphan, Y., Hermand, J-P. and Gervaise, C.**, La tomographie acoustique océanique : technique du passé ou de l'avenir ?, *Annales Hydrographiques*, 7 (776), 3.1–3.9, 2010.

- [4] **Evans, D. and Signorini, S. R.**, Vertical structure of the Brazil Current, *Nature*, 315, 48–50, 1985.
- [5] **Boebel, O., Davis, R. E., Ollitrault, M., Peterson, R. G., Richardson, P. L., Schmid, C. and Zenk, W.**, The intermediate depth circulation of the Western South Atlantic, *Geophysical Research Letters*, 26 (21), 3329–3332, 1999.
- [6] **Silveira, I. C. A., Calado, L., Castro, B. M., Cirano, M., Lima, J. A. M. and Mascarenhas, A. S.**, On the baroclinic structure of the Brazil Current-Intermediate Western Boundary Current system at 22° – 23°S, *Geophysical Research Letters*, 31, L14308, 5 pp., 2004.
- [7] **Calado, L., Gangopadhyay, A. and Silveira, I. C. A.**, A parametric model for the Brazil Current meanders and eddies off southeastern Brazil, *Geophysical Research Letters*, 33, L12602, 5 pp., 2006.
- [8] **Sandström, J. W. and Helland-Hansen, B.**, Über die Berechnung von meerestromungen, *Report on Norwegian fishery and marine investigations* 2, 4, 43 pp., 1903.
- [9] **Porter, M. B. and Bucker, H. P.**, Gaussian beam tracing for computing ocean acoustic fields, *J. Acoust. Soc. America*, 82(4), 1349-1359, 1987.

