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Assessment of Santa Catarina shelf currents through the analysis of indirect measurements

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ABSTRACT

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Preliminary analyses on the use of drift measurements of a *Waverider* buoy in the study of shelf currents are presented. The equipment was moored at Santa Catarina Shelf in Southern Brazil. The drift was measured by means of a GPS which provided buoy's geographical coordinates on an hourly basis. The data was decomposed in meridional and zonal position components and along with wind and sea level data, covered a period of 203 days from late summer (March 21th) to late spring (October 11th) of 2002. Statistical comparison between mean sea level (msl) and the meridional buoy positioning displayed very high correlation (R_{xy}=0.83) with a 3 h delay in relation to msl. The best correlation between meridional wind and buoy's drift was attained at 10 h time lag (R_{xy}=0.63). Sea level analysis characterizes the tide as mixed, mainly semidiurnal. Diurnal and Semi-Diurnal bands accounted for 63.6% of energy spectra in comparison to 36.4% on the Meteorological-forcing band. Low frequency signal in Meteorological band were clearly dominant in the buoy's meridional series, accounting for 90% of energy spectra. The buoy mooring system seems to work as a very useful indicator of the sense of geostrophic currents over the shelf, which seems to respond to both regional as well remote wind forcing.

ADITIONAL INDEX WORDS: *indirect current measurements, waverider, atmospheric forcing, South Brazilian Shelf, Global Positioning System (GPS).*

INTRODUCTION

Santa Catarina Shelf (SCS) is a 350 km stretch of shelf located around 27° of latitude that links the South Brazilian Shelf (SBS) to the South Brazilian Bight (SBB) (Figure 1, upper map). The shelf is widely used for fisheries, navigation (there are 3 important ports in SC) and, more recently, for oil explotation. Two oceanic boundary currents are believed to influence SCS' s dynamics: the relatively warm and salty Brazil Current and the relatively cold and fresh Malvinas Current further south. Waters from the La Plata estuary are expected to play an important role in the process through the dilution of surface coastal waters. These different water masses are subjected to the direct forcing caused by the wind, which is expected to provide the main driving mechanism that moves and mixes the water over Santa Catarina Shelf.

A number of investigators have addressed the dynamics of SBS and SBB shelf processes. Some studies relied on historical and hydrographic data sets (ZAVIALOV *et al.,*1998; PIOLA *et al*; 2000), others on numerical modeling (PIMENTA *et al.,* 2001), remote sensing (CAMPOS *et al,*.1999; LENTINI *et al.,* 2001), drifters (CAMPOS *et al.,* 1996) or a combination of these methods. Regarding direct mooring measurements, the South Brazilian Bight has received greater attention, through systematic field campaigns performed by the Oceanographic Institute of São Paulo. The South Brazilian Shelf had its first current meter campaign conducted recently by ZAVIALOV *et al.* (2002) offshore Rio Grande. None of these studies, however, has focused specifically on the Santa Catarina Shelf and, to this date, no currents measurements have been performed at SCS.

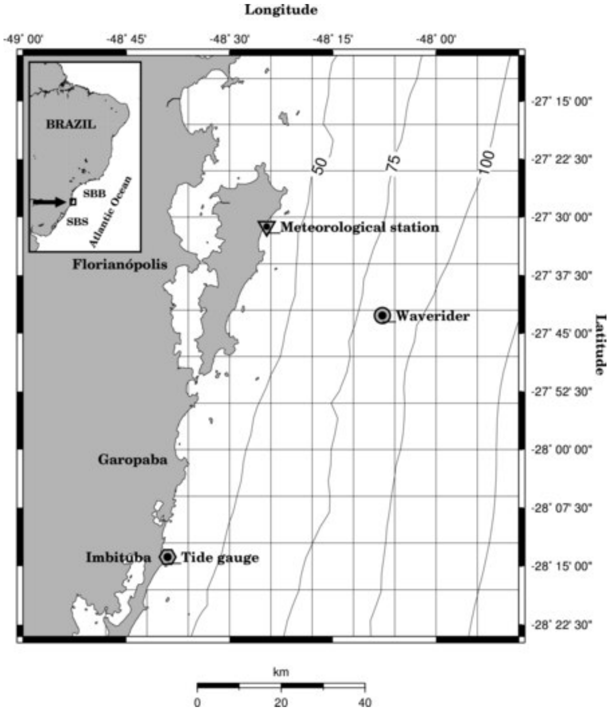

Figure 1. Map of study area. The insert map shows the location of Santa Catarina Shelf, between SBS and SBB. The main map shows the sites of the Waverider buoy, the Meteorological station and the Tide gauge (isobaths are depicted in meters).

The Maritime Hydraulics Lab. of UFSC[1] has been conducting an extensive wave monitoring program on Santa Catarina Shelf for the past year (MELO *et. al.*, 2003). Wave measurements have been performed by a Directional Waverider buoy deployed 35 km off Santa Catarina Island (Figure 1). The data is received by a radio station and retransmitted to the laboratory at the university campus on an hourly basis. Besides wave parameters, the waverider buoy delivers also hourly information about the water temperature and *buoy's position* given by a GPS. The later has been used to monitor the buoy' s relative position to the mooring anchor throughout the year. The waverider mooring we use has twice the local depth lenght, is very flexible and gives considerable freedom for the buoy to move around a circle of ~300 m of diameter.

A simple evaluation about the importance of winds and waves over the buoy's drift was discussed by MELO *et al.* (2002), who demonstrated that these forcings are expected to have secondary importance as compared to the action of currents over the buoy. In this article we present an analysis of the variability of this indirect measurements and look at its correlation with wind and sea level data. Based on these results, we believe that this kind of data might be used as a good indicator of shelf current direction for SCS.

METHODOLOGY

The drifting measurements have been acquired by means of a GPS installed on a Waverider buoy (model Mark II, Datawell) moored at Santa Catarina's inner shelf at 78 meters depth. The equipment consists of a stainless steel sphere of 0.9 m diameter, which remains partially submerged in the water (Figure 2, right panel). The mooring line allows free movements to the buoy and consists of more than 160 m of different ropes, shackles and special connections that are expected to play an important role to the system's drag. The equipment is in operation since its first deployment in December 2001.

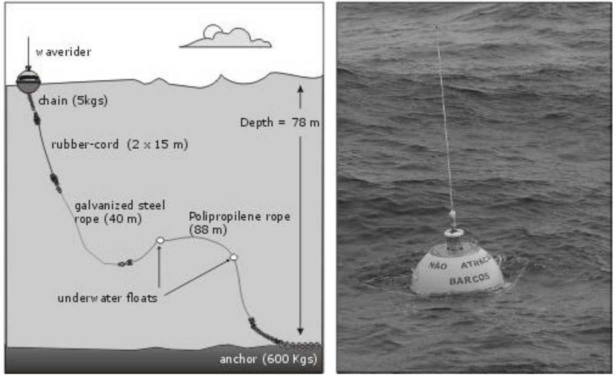

Figure 2. Waverider mooring line scheme (left) and waverider in operation (right). The mooring length adds to almost twice the local depth.

We have selected a 203 days measurement window with minimum gaps. The time series cover a period with for which simultaneous wind and tidal data were available: from the late summer (March 21th) to late spring (October 11th) of 2002. Sea level measurements were obtained from a coastal tide gauge located at Imbituba city, approximately 80 km south of the Waverider site. A Meteorological station, located at Moçambique beach in Florianópolis Island, acquired wind data (wind speed and direction at 50 m height). The positions of these stations are also indicated in Figure 1.

Harmonic analysis was initially performed using the procedure of FRANCO (1988) to get tidal constituents, and an astronomical tidal prediction was done for this period. The mean sea level was then calculated by subtracting the astronomical component from the original record. Buoy's geographical positions were converted to metric positions in relation to the mooring anchor coordinates (Figure 3). Next, both wind and relative buoy positions were separated in meridional and zonal components. The wind components were then converted to 10 meters height wind stress (τ_{sx} and τ_{sy} [N.m^{-2}]) using the procedure of LARGE and POND (1981). By convention, the positive sign of meridional and zonal wind stress (or buoy position) indicates respectively northward and eastward flows. In certain cases, a low pass filter was also applied to the time series.

RESULTS

Hourly buoy positions around the mooring anchor for the 203 days can be visualized in Figure 3. The distribution occurs around a circle with asymmetrical radius. In terms of maximum displacement, the buoy achieved 297.51 m in the northern direction, 202.68 in the southern, 197.72 in east and 176.58 m west. The average meridional position for the period was 33.939 m (std: 128.8), while the zonal mean was 11.273 m (std: 65.40).

The greater density of points in the first and third quadrants observed result from an along-shore positioning preference, as demonstrated by the polar histogram in Figure 3 (right). In this histogram, the northern (southern) distribution accounts for 53.63% (46.38%) of the total record. The orientation of this distribution was near 015°–195° which is very consistent with local isobaths orientation (Figure 1).

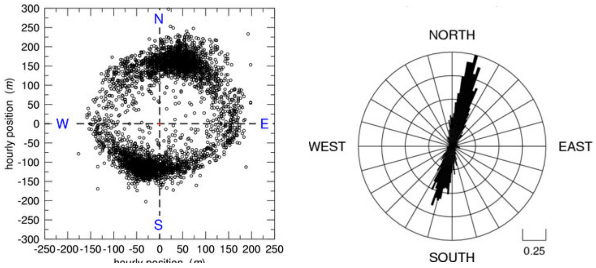

Figure 3. Waverider relative position to its mooring anchor (left) and the polar histogram of these positions (right).

Rather than exploring the aspects of the buoy drift variability, we sought to understand its basic dynamics by comparing it to the other data. For simplification we focused only on its meridional component of drift. An inspection of this variable time series reveals a high frequency response (with very small amplitude) superimposed over a lower frequency signal (Figure 4).

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[1] For more information about the *Coastal Information Program of UFSC*, please visit http://www.lahimar.ufsc.br/pic/

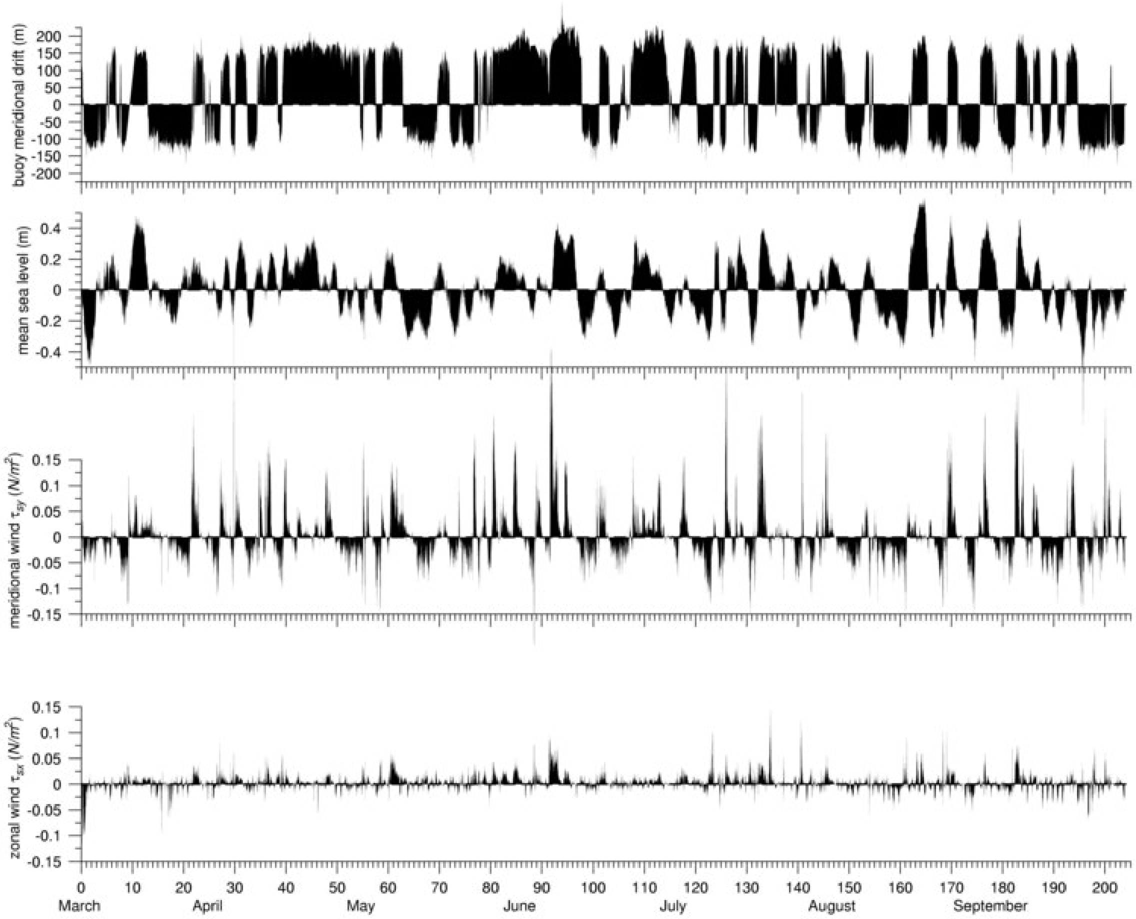

Figure 4. Time series of meridional waverider position, mean sea level, meridional wind stress and zonal wind stress for the period between March 21th and October 11th 2002. Time is depicted in days.

Lower frequency displacements occurs on the time scale of the order of days. Drifting to the North (N) may last for 10 to 20 days (e.g. early May and June), whereas drifting to the South (S) last as long as 8 days at the most. Reversals get more frequent in late July to September, occurring approximately every 2 to 6 days. It is also observed from Figure 4 that the actual displacements tend to be larger to the N than to the S. Now, to verify a possible correlation between the meridional buoy's position and sea level at the coast we compared the later time series with the Imbituba sea level record (Figure 4, second panel). By simple visual observation one realizes that these two variables seem to be quite well correlated: whenever the buoy is drifting to the N, sea level tend to be "high" (i.e. above the average) and, likewise, whenever it drifts to the S sea level tends to be "low" (i.e. below the average). In fact, a correlation between the buoy drift and sea level resulted in a squared correlation coefficient (R^2) of 0.506. For low pass filtered series, this correlation grows to R^2=0.680. The highest cross-correlation (R_{xy}=0.83) between buoy meridional displacements and mean sea level (msl) was obtained with 3 hours delay in relation to msl (Figure 5). The correlation with wind stress time series for meridional (τ_{sy}) and zonal (τ_{sX}) winds were also investigated. Overall, meridional wind stress components were more intense than the zonal component. The mean absolute value of the meridional component was 0.027 $N.m^{-2}$, near 3 times greater than the absolute mean value for zonal component (0.008 $N.m^{-2}$). The relationship between wind stress and buoy position is much less straightforward to observe visually. In fact, meridional buoy's drift series did not show good correlation with the wind stress (R^2=0.19 for τ_{sy} and R^2=0.07 for τ_{sx}) in the original series (non-filtered) and showed only a modest correlation for the low-passed filtered wind stress series (R^2=0.28 for τ_{sy} and R^2=0.14 for τ_{sx}). Reasonable correlations were obtained at 10 hs time lag for meridional wind stress (R_{xy}=0.63) and at 16 hs for zonal wind (R_{xy}=0.56) (Figure 5).

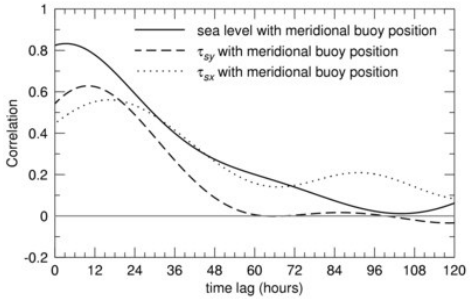

Figure 5. Cross-correlation between meridional buoy position, sea level and meridional wind stress. All series were low-pass filtered.

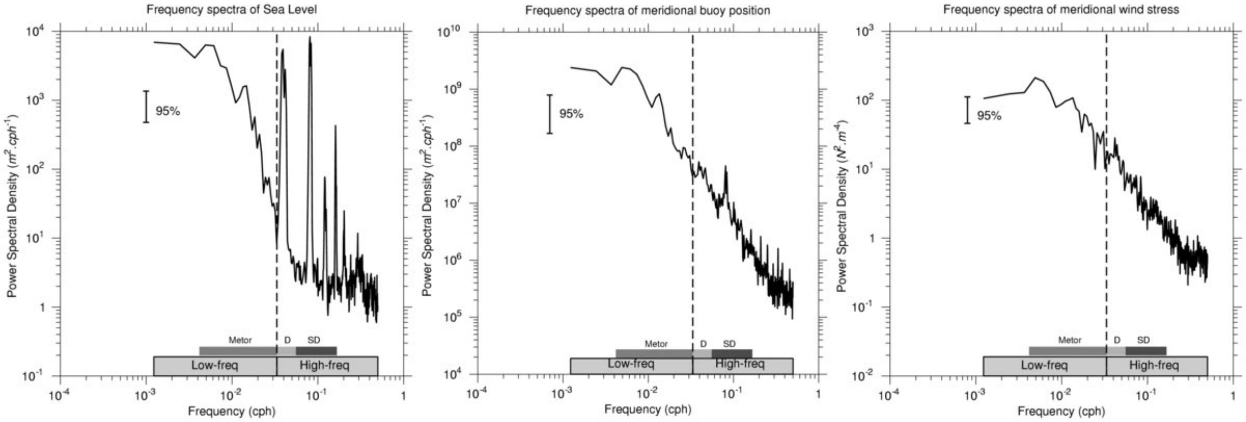

Figure 6: Spectra of buoy meridional displacement (left panel), sea level (at middle) and meridional wind stress (right panel). Low frequency bands and high frequency bands as well as Meteorological forcing (Meteor), diurnal (D), and semidiurnal (SD) sub-bands are indicated.

The frequency spectra for original (i.e. unfiltered) sea level, meridional buoy position, and meridional wind stress variability are shown in Figure 6. Sea level has energetic semi-diurnal and diurnal components, with a form factor of 0.718, characterizing it as mixed, mainly semidiurnal tide (Pugh, 1987). Despite of the peaks in the higher frequency part of sea level spectrum, two peaks at lower frequency were identified, the first between 16 and 33 days, and the second between 6 and 8 days. Following a procedure by Rivas (1997) and Zavialov *et al.* (2002), we computed the fractions of energy residing at semi-diurnal (SD, periods from 6 to 18 h); diurnal (D, 18-30h) and the meteorological forcing bands (Meteo, 30-240 h). (Figure 6 and Table 1). Diurnal and semi-diurnal frequency bands accounted for 22.5 and 41.1 % energy, compared with 36.4 % associated to meteorological band in sea level variability. Quite interestingly, although, SD and D components were much less representative in the buoy signal, where only a small peak may be observed at SD band (Figure 6, middle panel). SD and D bands accounted for 4.9 and 4.3 % respectively, while the meteorological band dominate 90.8 % of its variability. Energy peaks at the meteorological band are located at 8.5 and 3.1 days, in good agreement with sea level peaks. The origin of this low frequency signal in meteorological forcing band is corroborated by the meridional wind signal itself, with clear peaks at 8.5 and 3.1 days. There, the meteorological band accounted for 74.4 % of the calculated energy.

Table1: Distribution of spectra energy in different frequency sub-bands (in percentage)

	Sea Level	Meridional Buoy Drift	Meridional Wind Stress
Semi-diurnal	41.1	4.9	13.9
Diurnal	22.5	4.3	11.7
Meteorological	36.4	90.8	74.4

DISCUSSION

Our observations indicate that the buoy drift show very good correlation with sea level variations in lower frequency domain. The observed relation between these two variables seem to follow quite closely dynamical constrains found in barotropic geostrophic flows. In fact, if one assumes that the meridional buoy's drift responds to the overall water transport (Q_y) over the shelf, one can make the use of Stech and Lorenzetti (1992)'s findings to relate Q_y with sea level at the coast: $f\,Q_y = gH\,\partial\zeta/\partial x$ (where f [s^{-1}] is the Coriolis parameter, g is gravity [m.s^{-2}], H [m] is the local depth, ζ [m] is the sea level, and x is the cross-shore axis). This fact may also explain why the buoy's drift is better correlated with sea level than with local wind stress, which is expected to be the driving force of shelf currents. The reason may lie in the fact that in many situations, shelf currents are the result of remotely generated shelf waves which are uncorrelated with *local* winds. Sea level, on the other hand, may reflect the effect of both local and remote wind forcing. Castro and Lee (1995) pointed out free forced waves propagating equatorward from south of SBB as a source of low frequency energy in the SBB and Melo *et al.* (*2003*) described an continental shelf wave generated by an extra-tropical cyclone along the Uruguayan coast as the responsible for the sea level raise of about 1m in Santa Catarina coast. Local wind conditions were very mild and the buoy escape were apparently motivaded by the strong barotropical currents generated on the shelf ($v=1.6$ m.s^{-1}, estimated by the buoy track). The experience achieved with three Waverider mooring failures provided useful indication on the drift veracity. There were very good agreement between the buoy drift tendency to the circle positioning for all cases (Melo *et al.* 2003). Besides, the buoy drift as in barotropical flows where constrained by depth, following approximately the 80 m isobath. Despite of the less D and SD bands energy in the mooring site, we expect a very small possibility that the buoy-mooring system may be acting as a "filter" of higher frequency movements. Actually we suspect that most of the differences in sea level energy of tidal components (~60% energy of considered spectra bands) to the buoy drift signal (~9%) are highly due to tidal amplification in shallower waters. At the buoy site, this data may be thus representing good evidences of *wind-dominated* type of shelf circulation.

An indication of currents intensity probably may be obtained by the mooring stretching. As verified, greater displacements towards equator were verified in the measurements, indicating stronger south currents over the observed autumn and winter. A development of a reliable method to extract this information would be quite useful, since both direction and velocity must be taken in account for the investigation of water mass transport between SBB and SCS. A definite proof of the reliability of this method would be nicely provided by direct current measurements.

From the point achieved so far there is useful information that may be extracted from the considered waverider series. The inferred current variability demonstrated an unexpected dominance of northward currents in late autumn and winter. The stability on these events (that can achieve more than 10 days) may give support to the explanation of cold and fresh water intrusions occasionally observed to SBB (CAMPOS *et al.* 1996, 1999). The barotropical shelf response to local and remote wind forcing may be an additional factor on the *advection* on the low salinity band established by Rio de La Plata outflow. As emphazized by PIMENTA (2001), the persistence of northward barotropical currents seems to be an important requisite for the cold water intrusions to SBB. From the point achieved so far, we will drive this research toward the examination of the total Waverider's drift measurement time series. Along with temperature measurements made by the buoy, these data may possibly allow us to look at the shelf currents climate in a very interesting way.

CONCLUSIONS

This article presents preliminary results concerning to the use of Waverider geographical positions measured by a GPS as an indicator indirect indicator of shelf currents in Santa Catarina Shelf (SCS), Brazil. By the analysis of the buoy drift together with wind and sea level, the buoy-mooring system seemed to work as a very useful indicator of the sense of currents in the region. Accordingly to this data 90% of meridional drift energy spectrum concentrates in the Meteorological forcing band, giving indication that low frequency movements controls SCS currents. The source of these movements was associated to regional as well remote wind forcing.

LITERATURE CITED

CAMPOS, E. J. D.; LENTINI, C. A. D.; MILLER, J. and PIOLA, A. R., 1999. Interannual variability of the sea surface temperature on the eastern South American continental shelf. *Geophysical Research Letters*, 26, 2061-2064.

CAMPOS, E. J.; IKEDA, Y., CASTRO, B. M.; GAETA, S. A.; LORENZETTI, J. A. and STEVENSON, M. R., 1996. *EOS, Transactions, American Geophysical Union,* 77(27), 253-259.

CASTRO, B. M, and LEE, T. N., Wind-forced sea level variability on the southeast Brazilian Shelf, 1995. *Journal of Geophysical Research,* 100 (C8), 16045-16056.

LARGE, W. G. and POND, S., 1981. Open Ocean Momentum Flux Measurements in Moderate to Strong Winds. *Journal of Physical Oceanography*, 11(3), 324-336.

LENTINI, C. A. D., PODESTÁ, G. G., CAMPOS, E. J. D. and OLSON, D. B., 2001. Sea surface temperature anomalies on the western South Atlantic from 1982 to 1994. *Continental Shelf Research,* 21, 89-112.

STECH, J. L. and LORENZETTI, J. A., 1992. The response of the south brazil bight to the passage of wintertime cold fronts. *Journal of Geophysical Research,* 97 (C6) 9507-9520.

MELO, E.; ALVES, J. H.; BARLETTA, R.; BRANCO, F.; FRANCO, D.; HAMMES, G.; PIMENTA, F. M.; MENDES, D.; PRIDO, E.; ARAÚJO, C. E., and SOUTO, A., 2002. Implementação do programa de informação costeira – on-line. *Proceedings of the IBAMA Workshop. "Diretrizes técnicas para modelagem do derramamento de óleo no mar".* Rio de Janeiro, 24 pp.

MELO, E.; PIMENTA, F. M.; MENDES, D. A.; HAMMES, G. R., ARAÚJO, C. E.; FRANCO, D.; ALVES, J. H. G. M.; BARLETTA, R. C.; SOUTO, A. M.; CASTELÃO, G.; PEREIRA, N. C. and BRANCO, F. V., 2003. *Proceedings of the Sixth International Conference on Coastal and Port Engineering in Developing Countries, COPEDEC VI*, Colombo, Sri Lanka, 14 pp.

PIMENTA, F. M., 2001. Estudo numérico da influência da descarga fluvial e dos ventos sobre a dinâmica da pluma do Rio da Prata. São Paulo, Brazil: Instituto Oceanográfico da Universidade de São Paulo. Master' s thesis, 127 p.

PIOLA, A. R., CAMPOS, E. J. D.; MOLLER, O., CHARO, M. and MARTINEZ, C., 2000. The subtropical shelf front off eastern south America. *Journal of Geophysical Research*, 22, 1975-1986.

PUGH, D. T., 1987. *Tides, surges and Mean Sea-Level.* John Wiley &Sons. Bath Typesetting Limited, Great Britain, 472 p.

RIVAS, A. L., 1997. Current-meter observations in the Argentine Continental Shelf. *Continental Shelf Research,* 17(4), 391-406.

ZAVIALOV, P. O.; MOLLER, O. and CAMPOS, E. J. D., 2002. First direct measurements of currents on the continental shelf of southern brazil. *Continental Shelf Research,* 22, 1975-1986.

ZAVIALOV, P. O.; GHISOLFI, R. D. and GARCIA, C. A., 1998. An inverse model for seasonal circulation over the southern brazilian shelf: Near-surface velocity from the heat budget. *Journal of Physical Oceanography,* 28, 545-561.

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