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Penetration of Waters from the Brazil-Malvinas Confluence Region Along the South American Continental Shelf up to 23°S

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ABSTRACT

A variety of moored, surface layer drifters, ship and satellite-based measurements have been collected since the Fall of 1992 as part of the COROAS (Circulação Oceânica na Região Oeste do Atlântico Sul) project. Analysis of hydrographic, drifter and satellite data for the austral winter of 1993 has revealed the presence of a tongue of relatively cold (14-17°C) and low salinity (33.0-34.0) water between the coast and the Brazil Current, extending from south of the Rio de La Plata estuary (35°S) to latitudes as low as 23°S, with a typical average northbound velocity of 10.7 cm s^{-1}. These three data sets rule out the possibility that the origin of this water is river runoff or from deeper water upwelled near the coast, due to Ekman dynamics.

Key words: Brazil current, Malvinas waters, Santos bight.

INTRODUCTION

The great majority of the historical oceanographic cruises in the area known as South Brazil Bight (SBB) has been limited mainly to regions on the shelf, leaving the shelf break and slope, and therefore the Brazil Current (BC) itself, largely unstudied. Due to this substantial lack of knowledge in that region, a comprehensive oceanographic survey in the SBB and the nearby Brazil Basin (Fig. 1) has been set forth by a group of Brazilian oceanographers: the COROAS Project.

In this article we report the observation, in the winter of 1993, of a continuous layer of relatively cold and low salinity surface water between the BC and the shoreline extending from the Brazil-Malvinas confluence region to almost the latitude of Rio de Janeiro (23°S). This event was observed *in situ* during the realization of a COROAS oceanographic cruise on board the N/Oc. Prof. W. Besnard. While there is a lack of reference about this phenomenon in the scientific literature, the wintertime northward intrusion of waters from the Uruguayan-Argentine shelf regions along the Brazilian southern continental shelf is relatively well known by the oceanographic community in Brazil. As a matter of fact, one of the anonymous reviewers of this paper points out that in Schumacher's atlas, published in 1940, there is a first attempt to elucidate the seasonal variations of the South Atlantic Ocean mean circulation. This atlas indicates, for the transition autumn-winter season, that coastal currents generated in the Brazil-Malvinas conver-

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gence region may flow along the Brazilian coast as far north as Rio de Janeiro state. However, the typical northernmost latitude reached by the intrusion in around 28°S, in contrast to the one reported in this paper, which reached latitudes north of 23°S.

EXPERIMENTAL PROCEDURE

Project COROAS (Circulação Oceânica na Região Oeste do Atlântico Sul, or Oceanic Circulation in the Western Region of the South Atlantic) is a major contribution of the Brazilian oceanographic community to the international WOCE (World Ocean Circulation Experiment) program Campos *et al.* (1996). Its primary objective is the determination of seasonal mean fields of velocity, heat and mass transports by the Brazil Current and the Antarctic Intermediate Water flowing into the coastal region of southeastern Brazil. These are the first *in situ* observations of mesoscale phenomena in this area to be collected synoptically and with modern WOCE-quality instrumentation.

The hydrographic portion of the COROAS project includes a "mesoscale" survey in a set of transects more or less perpendicular to the shelf break. As indicated in Figure 1, where the dots represent the location of the stations, each of these hydrographic legs extends from the 50m isobath to

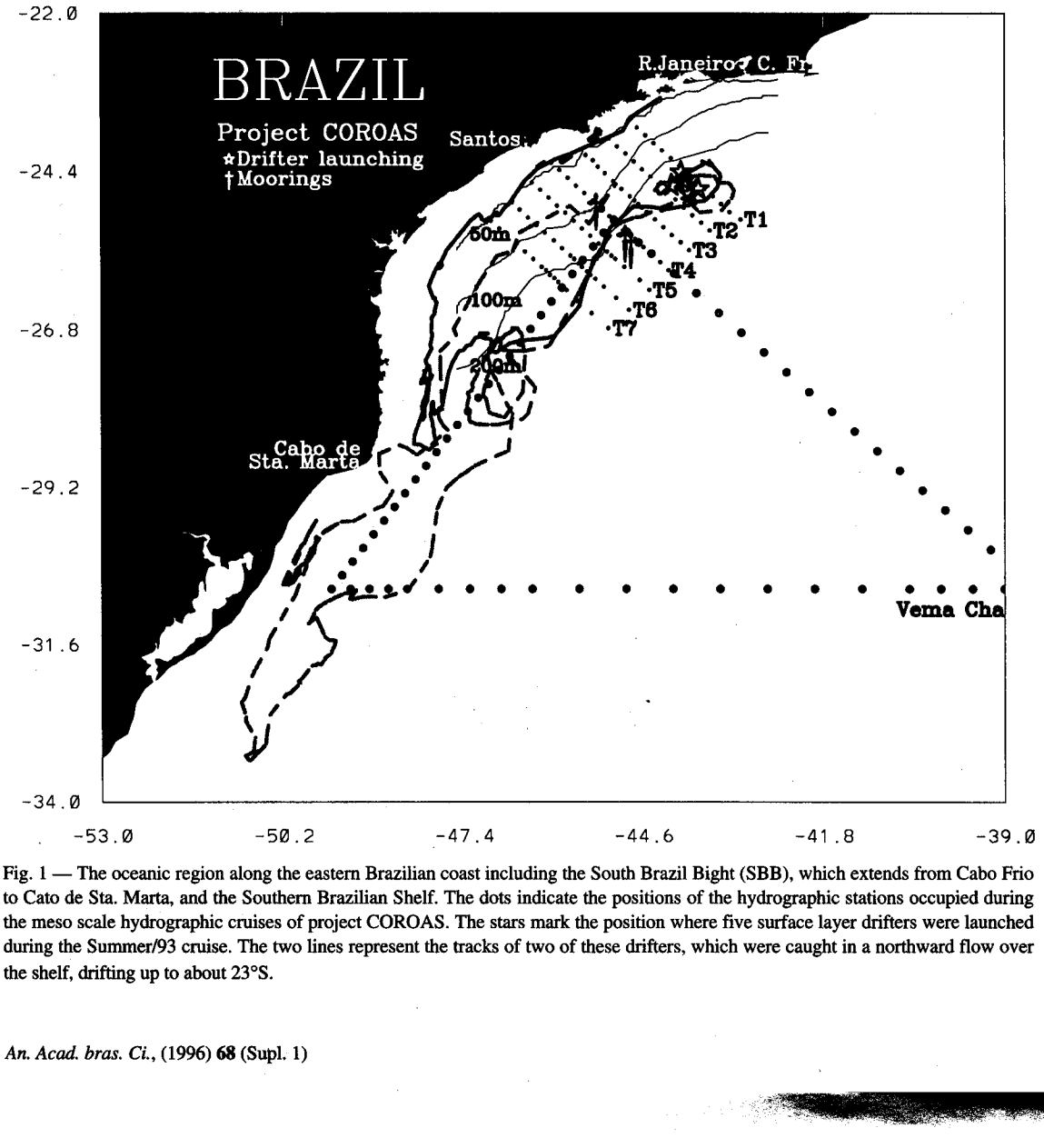


Fig. 1 — The oceanic region along the eastern Brazilian coast including the South Brazil Bight (SBB), which extends from Cabo Frio to Cato de Sta. Marta, and the Southern Brazilian Shelf. The dots indicate the positions of the hydrographic stations occupied during the meso scale hydrographic cruises of project COROAS. The stars mark the position where five surface layer drifters were launched during the Summer/93 cruise. The two lines represent the tracks of two of these drifters, which were caught in a northward flow over the shelf, drifting up to about 23°S.

oceanic regions having depths greater than 2000 meters. Along-isobath structure is resolved by 50 kilometer station spacing, while a much smaller variable spacing (in the range of 10 to 17 km) was used to resolve cross-isobath frontal variability. One of the objectives of this data collection was an attempt to resolve the seasonal water mass structure and to obtain the associated geostrophic flow and transports over the continental shelf and shelf break regions. This includes a study of the dynamics of the BC in the surveyed area. To this end three seasonal cruises on board the University of São Paulo's RV Prof. W. Besnard have been completed. In each of these cruises, about 100 hydrographic stations have been occupied using a SeaBird CTD for collection of temperature and salinity profiles.

During the same experimental period, a set of daily AVHRR/NOAA digital images were recorded and processed using the NOAA level-1B format, at the Instituto Nacional de Pesquisas Espaciais (INPE), the Brazilian institute for space research. The resulting SST maps were obtained using NOAA's MCSST algorithms for atmospheric corrections.

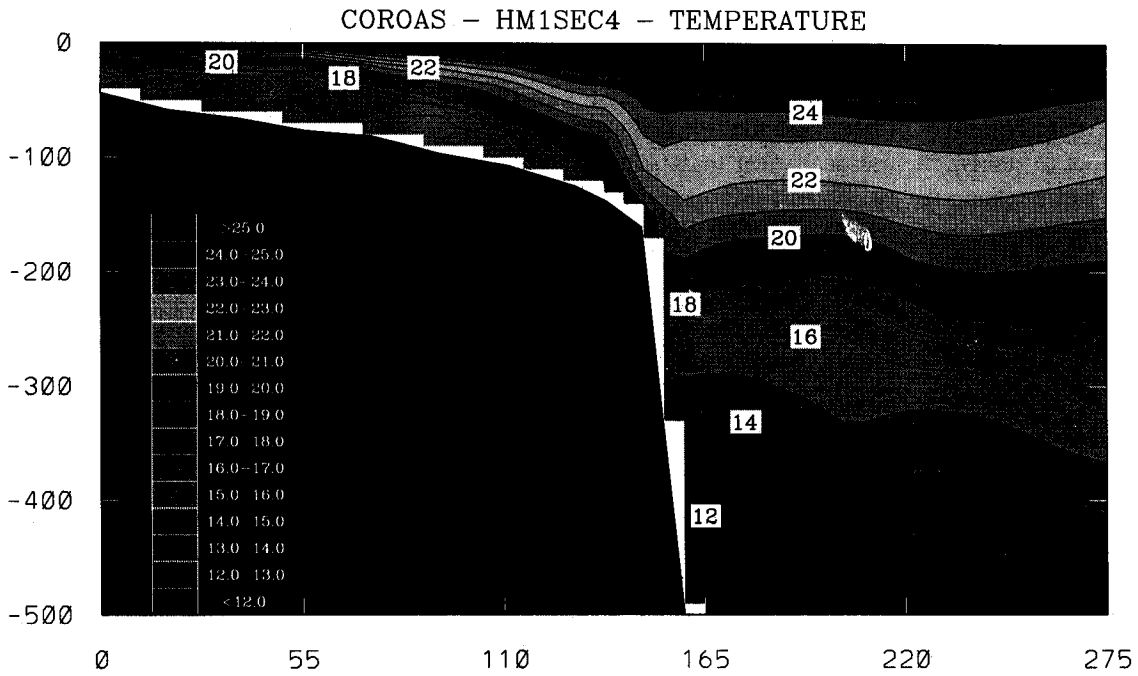
To obtain information on the spatial variability and on the dynamics of eddies in the BC, several (five in each cruise) WOCE standard, satellite-tracked, surface layer drifters were launched on the inshore side of the BC, at the locations indicated by the stars in Fig. 1. The tracks of two of these drifters, launched in January of 1993 and recovered in July of 1993, are shown in Fig. 1. Note that both were recovered practically in the same region they were deployed.

RESULTS

Along each of its transects, the COROAS hydrographic survey encompassed most of the continental shelf and extended through the BC into the subtropical gyre. Summertime T-S characteristics of the water observed on the shelf indicate that South Atlantic Central Water (SACW), that is water with salinity varying from 34.5 to 36.4 and temperatures from 6.0°C to 20°C (Miranda, 1982), is upwelled at the BC front, near the shelf break, and deposited on the shelf. This is indicated by the orientation of the isotherms isohalines in Fig. 2a,b The upwelled water spreads out as the bottom layer, reaching the shallower regions near the coast. This intrusion of the SACW is possibly a result of a combined effect of large-scale (100-300 kilometer) BC cyclonic meanders, and of coastal upwelling forced by the prevailing NE wind during the summer and other forcing mechanisms, such as baroclinic adjustment of the density field associated with an increase of the geostrophic flow of the Brazil Current. During winter, the prevailing SW direction of the wind inhibits coastal upwelling. This results in little interaction between shelf and deeper waters, as observed in the temperature and salinity profiles of Figs. 2c,d. The COROAS hydrographic data as well as previous surveys of the region (e.g.: Castro Filho *et al.*, 1987; Stech & Lorenzzetti, 1992; Campos, Ikeda & Gonçalves, 1995) show that in normal conditions, the shelf water is vertically stratified during the summer and mostly homogeneous during the winter.

During the winter of 1993, waters with relatively low temperature and salinity were found in the surface layers between the BC and the coast. Figure 3 presents the surface temperature (Fig. 3a) and salinity (Fig. 3b) maps derived from the hydrographic data for the July/1993 cruise. In that picture, the presence of a tongue of cool (T≈18°C) and low salinity (S≈34) water intruding into the area surveyed from its southwestern corner is clear. This is certainly not water of coastal origin, due to the absence of any major river or others sources of fresh water along the coast. In fact, satellite SST maps taken in July, 16 (Fig. 4) and July 20, 1993 (Fig. 5) confirms the presence of this water, and clearly show that it is originated farther to the south. These figures suggest, from continuity, that the origin of this tongue of water is located in the inshore side of the Brazil-Malvinas confluence, near the Argentine coast. Figure 4 was processed at the Rosenstiel School of Marine and Atmospheric Science of the University of Miami and kindly ceded by O. Brown and G. Podesta.

The trajectories of two of the drifters launched during the Summer/93 cruise are shown



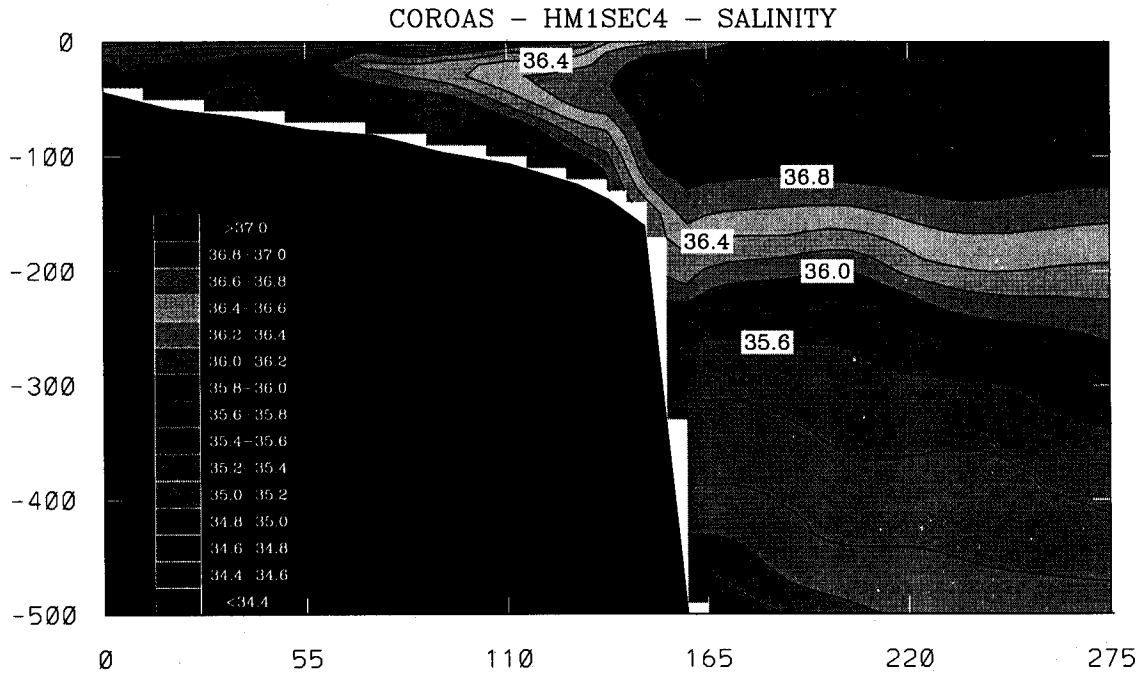
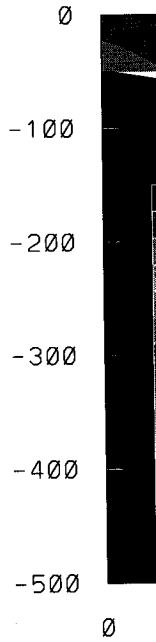
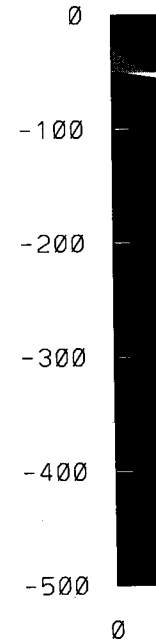


Fig. 2 — Vertical sections of temperature and salinity along the central transect of Fig. 1: (a,b) Summer of 1993 (Jan 21-Feb 5/1993).





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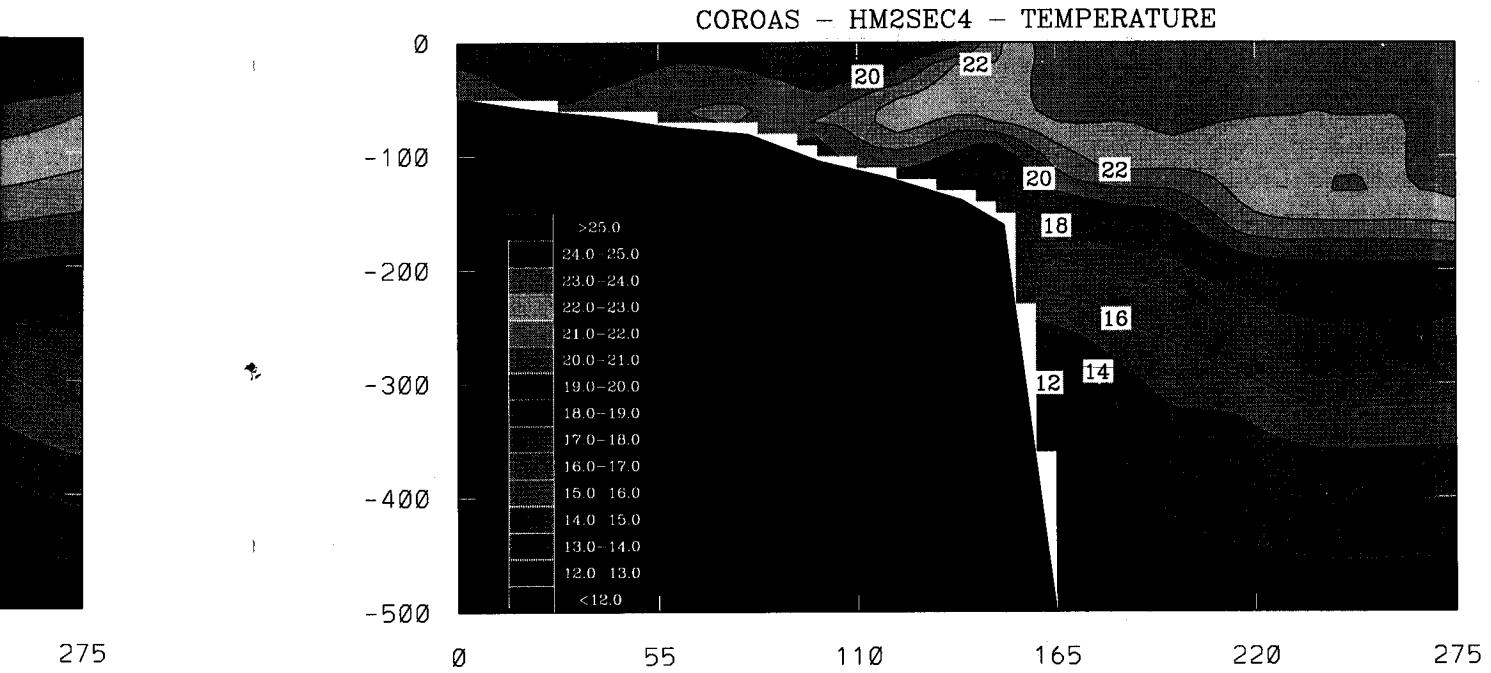

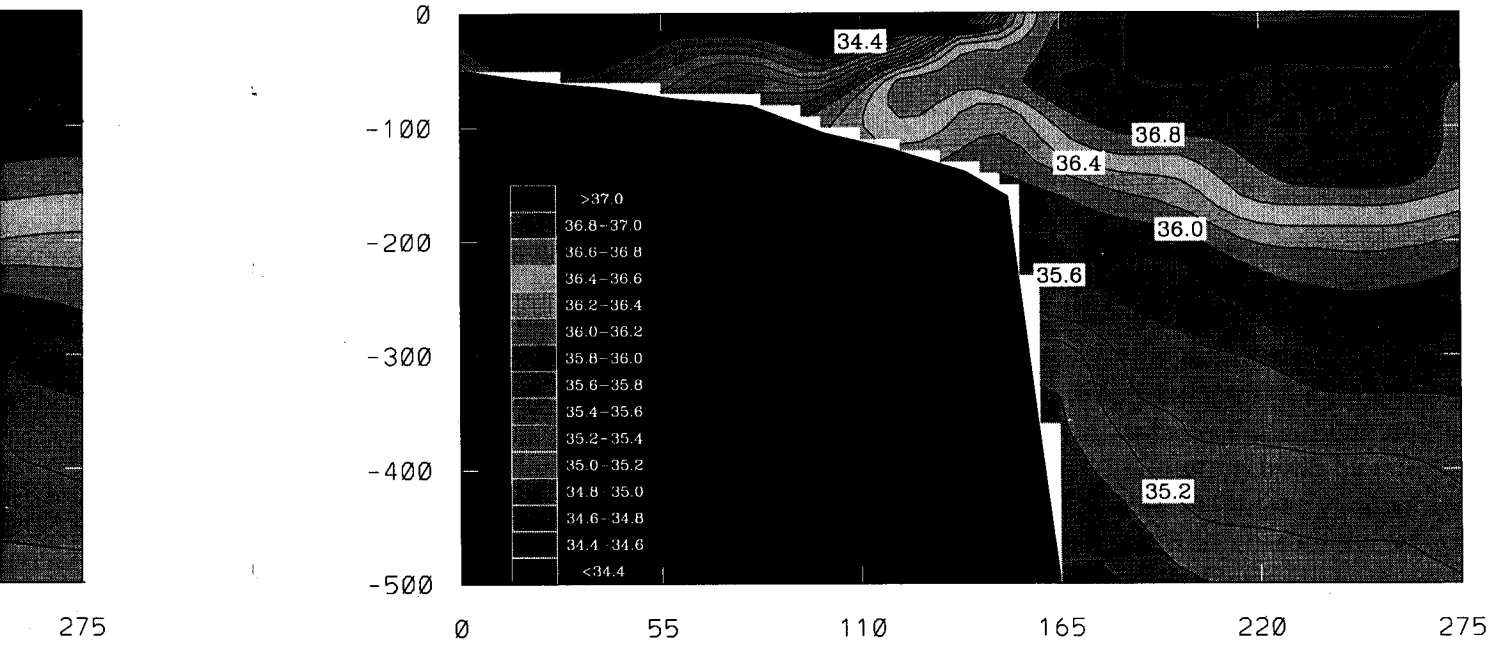

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Fig. 2 — Vertical sections of temperature and salinity along the central transect of Fig. 1: (c,d) Winter of 1993 cruise (Jul 17-Jul 29/1993).

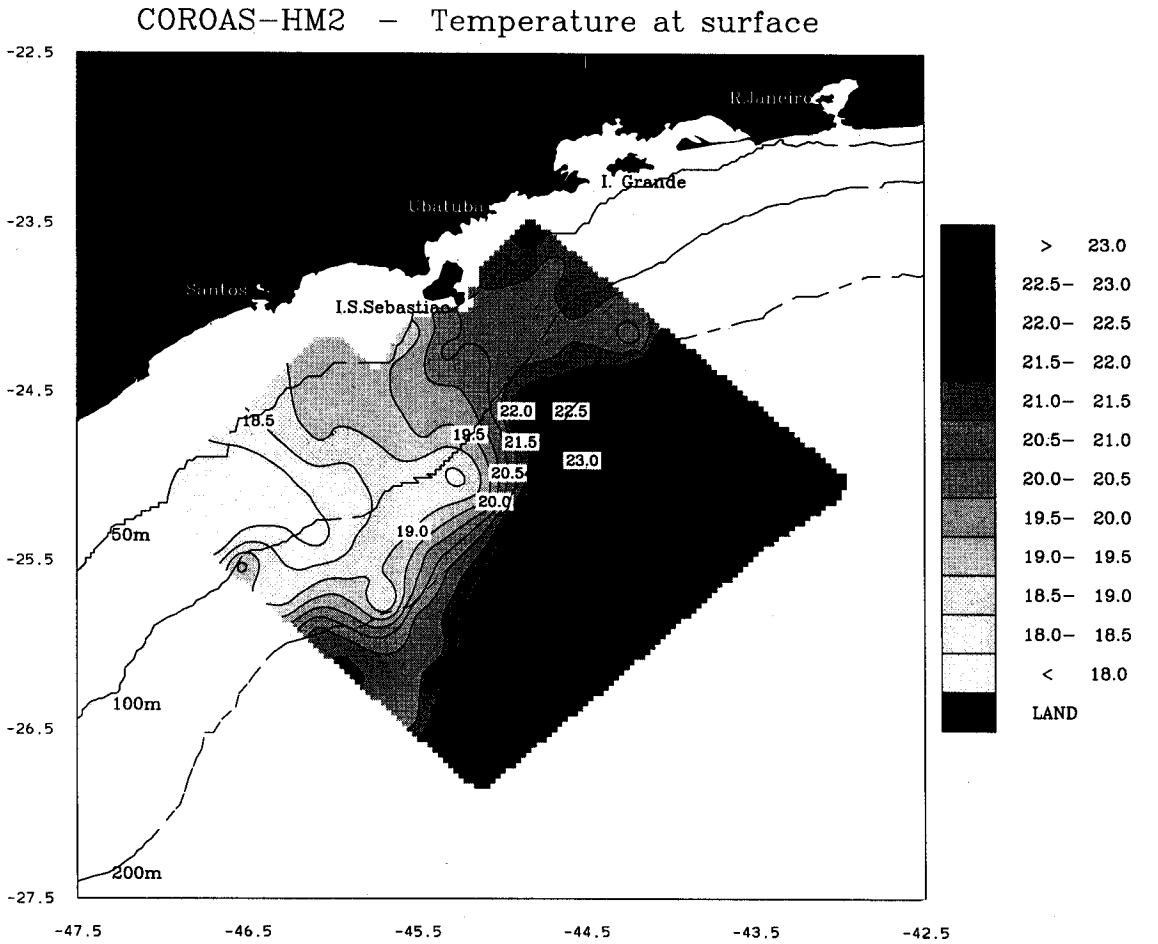

Fig. 3 — Sea Surface Temperature (a) and salinity (b) as measured during the COROAS hydrographic cruise in the winter of 1993.

in Fig. 1. The solid line shows the path of a drifter that, after going south to about 29°S, returned and reached a point to the north of the region of deployment. The dashed line shows the track of another drifter, which continued farther south to about 33°S where it also turned back and drifted in a northeastward direction. The meanders and loops in this trajectory suggest the presence of eddies during the southbound excursion of the drifter, what can be clearly seen in the satellite SST images (Figs. 4 and 5).

Calculation for the first drifter (the one whose trajectory is indicated by the solid line) shows that the mean southward velocity was of 17.1 cm s^{-1} toward 29°S. During that time, the mean surface water temperature was of 25.40°C (±0.6°C; 1 std.dev.). As the drifter approximated 29°S, it moved onshore and then proceeded along a northward course over the shelf, parallel to the shore with a mean speed of 10.7 cm s^{-1} towards 23°S. The mean surface water temperature during the northward part of the track was of 20.31°C (± 2.9°C; 1 std.dev.).

While the surface hydrographic temperature and satellite SST images denote the cooler water along the coast, these data only cover a time interval of a couple of weeks at the most. On the other hand, the mean water temperature obtained from the drifters was surprisingly consistent and the drifter data were obtained over a much longer period (they where launched in January of 1993 and reached their final positions, indicated in Fig. 1,

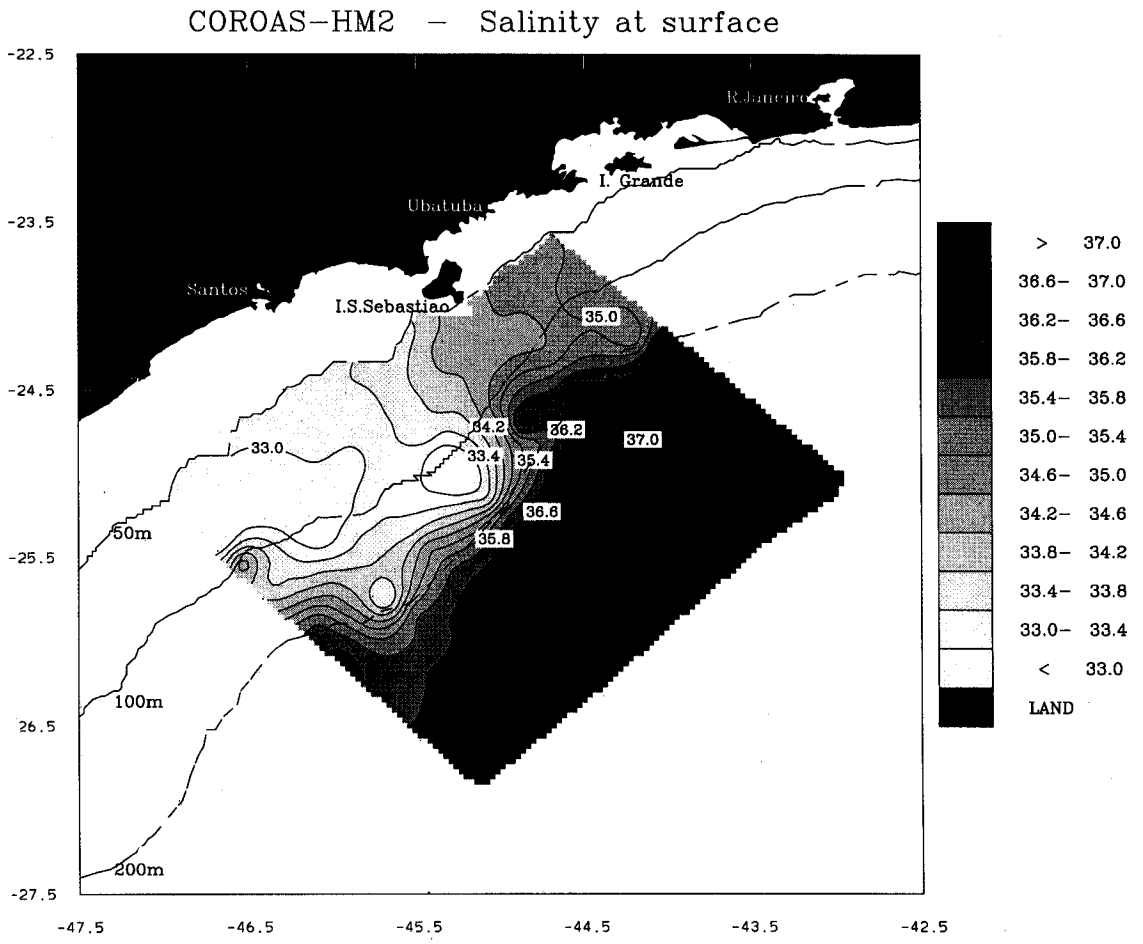

Fig. 3 — Sea Surface Temperature (a) and salinity (b) as measured during the COROAS hydrographic cruise in the winter of 1993.

approximately six months later). The combination of these data shows the intrusion of the cool, low salinity water to be a persistent phenomenon extending over hundreds of kilometers and several months time.

DISCUSSION

Usual T-S characteristics of the water observed on the shelf in the Santos Bight indicate that in this region the South Atlantic Central Water (SACW) is upwelled near the shelf break by the meandering of the Brazil Current and deposited on the shelf (Campos, Gonçalves & Ikeda, 1995; Campos, 1995). The upwelled water spreads out as the bottom layer, reaching the shallower regions near the coast. This mechanism is very efficient during the Summer, when there is a positive combination of the effects of large-scale (100-300 kilometer) BC cyclonic meanders, and of coastal upwelling forced by the prevailing NE wind. During the winter when the wind direction changes frequently to southwesterly, owing to the passage of cold fronts, this mechanism is weakened but not completely eliminated. That is, intrusion of SACW into the inner shelf regions could still occur. During the winter of 1993, however, the SACW was found only in regions deeper than 100m, even though an upwelling-favorably cyclonic meander was observed in the nearby Brazil Current and the wind blowed constantly from the NE during the cruise (about 12 days). Based on these observations one can easily conclude that the low-density

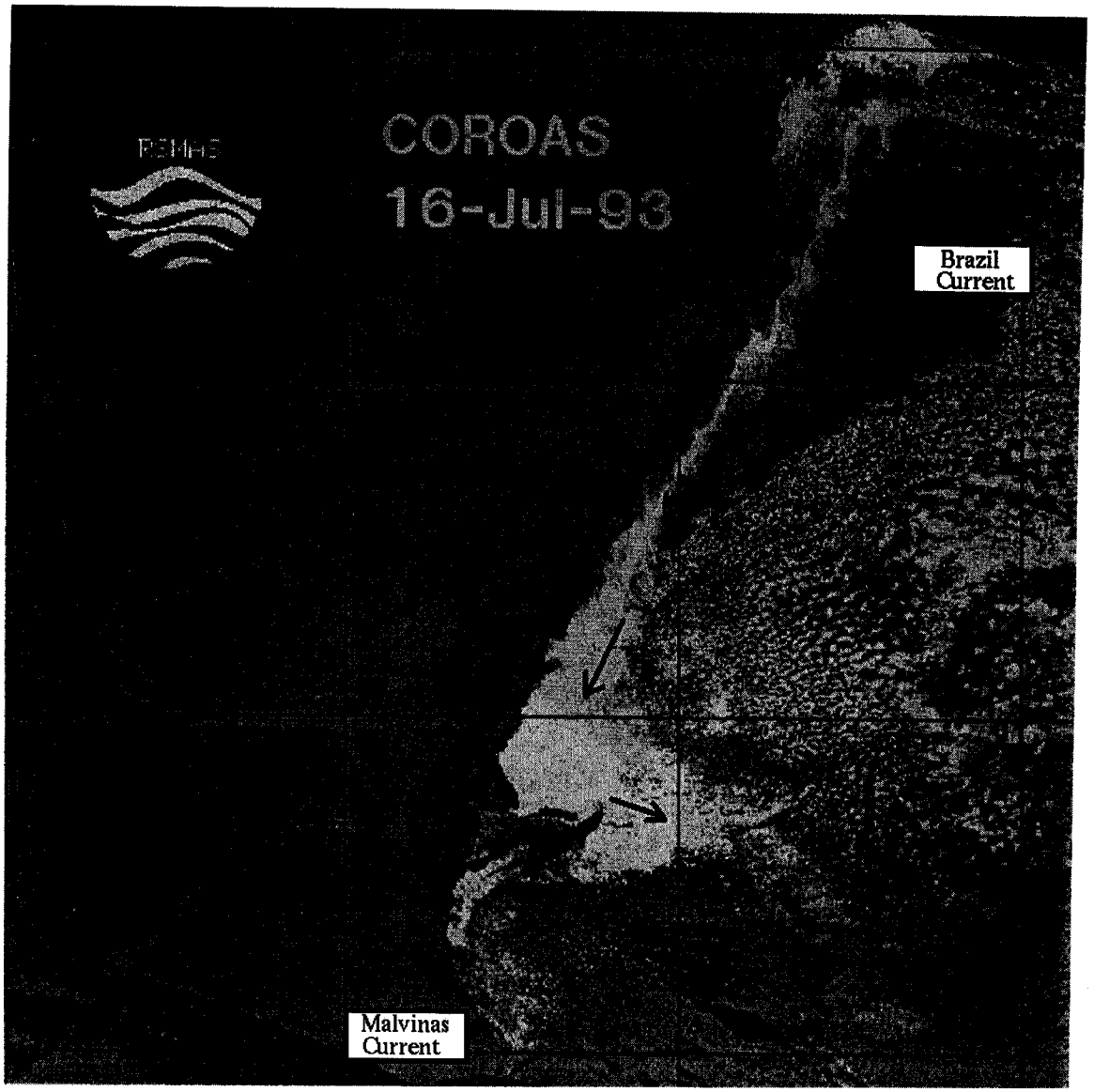

Fig. 4 — Sea Surface Temperature map processed at RSMAS (Univ. of Miami) showing waters from the Brazil/Malvinas confluence penetrating northward along the South American continental shelf up to the South Brazil Bight. The arrows indicate the direction of the flow. The direction of the flow over the continental shelf was inferred with basis on the drifter trajectories of Fig. 1.

Fig. 5 — Sea S
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extraneous water coming from the south, on the continental shelf, impeded the further penetration of the SACW to shallower regions. Thus, one of the immediate consequences of the presence of the water from the Brazil/Malvinas confluence region in such low latitudes was the observed blocking of the nutrient-rich SACW to the outer regions of the continental shelf.

CONCLUSIONS

A conclusive answer about the origins and composition of this cool and low salinity water reaching the SBB is not yet available. While satellite imagery suggest that it comes from the Brazil/Malvinas confluence, or even more to the south, analyses of hydrographic and other *in situ* data need to be carried out in order to obtain more in-

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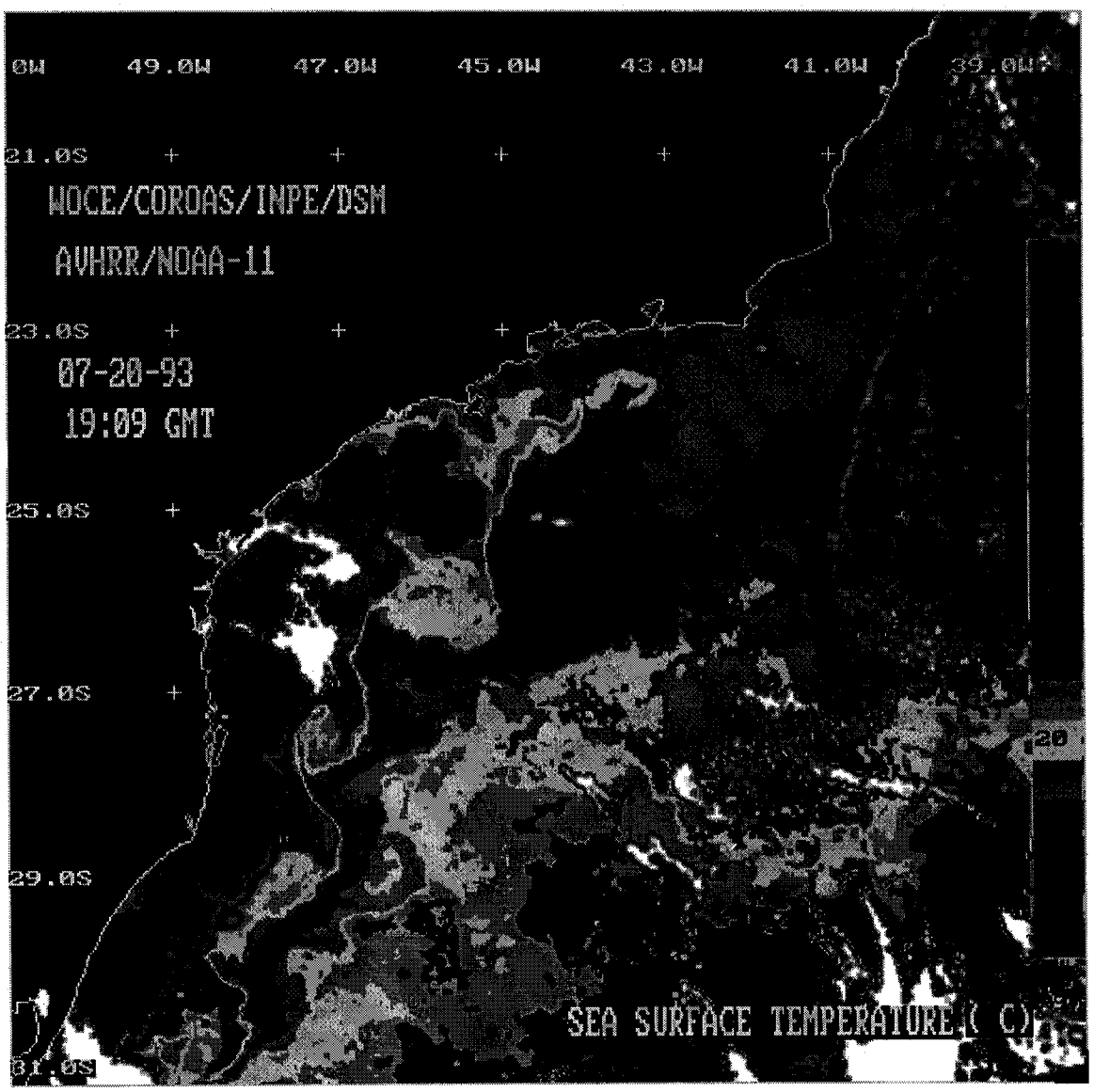

Fig. 5 — Sea Surface Temperature map obtained from AVHRR/NOAA-11 satellite for July 20, 1993, processed at INPE as part of the COROAS Project. This picture shows with greater detail the region surveyed by COROAS mesoscale hydrographic cruise from July 15 to July 29, 1993.

formation on several aspects; such as: the exact origins; the physical and chemical properties; and the impact of the presence of this water in the ecology of regions such as the South Brazil Bight. However, in spite of the lack of more data, the present analyses carried with the present COROAS data strongly suggest that the origins of the low-temperature, low-salinity waters observed in the SBB originates far to the south, confirming earlier suggestions of the penetration of waters from the Brazil-Malvinas confluence region in such relatively higher latitudes. The presence of this water in the Santos Bight has strong impact on the local ecosystem. For that reason this phenomenon has to be better understood, specially with respect to its long term time-variability, in order to infere if it has any correlation with climate or other global change processes.

Presently an extensive study aiming at the physics and time-variability of this phenomenon is being carried on as a cooperative effort between the Oceanographic Institute of the University of São Paulo (IOUSP) and the Rosenstiel School of the University of Miami (RSMAS), under the sponsorship of the Inter-American Institute for Global Change Research (IAI).

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