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NOTE ON THE SHELF BREAK UPWELLING OFF THE SOUTHEAST COAST OF BRAZIL (LAT. 26°30'S)

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Synopsis

A western margin frontal zone is described, from measurements of temperature, salinity and currents, in a section taken with R/V "Prof. W. Besnard" in December 1980, crossing the shelf break border at latitude 26°30'S. The analyses of the sections showed consistently the occurrence of an ascension of the T and S isolines over the shelf break. Simultaneous current measurements showed a surface eddy structure with clockwise circulation and anti-clockwise circulation having a common stem over the break characterizing a shelf break upwelling.

Descriptors: Water temperature, Salinity, Current measurement, Coastal upwelling, Oceanic eddies, Frontal zones, Oceanic fronts, Advection, Southeast coast-Brazil, R/V "Prof. W. Besnard", Paranaguá-PR, Continental shelf break.
Descritores: Temperatura da água, Salinidade, Medição de correntes, Ressurgência costeira, Vórtices oceânicos, Zonas frontais, Frentes oceânicas, Advecção, Costa sudeste-Brasil, N/Oc. "Prof. W. Besnard", Paranaguá-PR, Borda da plataforma.

This work is based on temperature, salinity and current measurements conducted during the November-December 1980 cruise of the R/V "Prof. W. Besnard" of the Universidade de São Paulo. Measurements were taken on stations along a vertical section across the shelf break (S.B.) off the coast of Paranaguá (26°30'S), Paraná, Brazil. Continuous temperature and salinity profiles were obtained with a Plessey STD 9040 unit. The current measurements at several depths were taken over-the-side with a Hydrocean time-averaging (20 sec), Savonius type currentmeter. Conventional Nansen casts were also made in all stations and in additional stations prolonging the section oceanward from the S.B. and shoreward until the coastline (Fig. 1).

Figures 2-3 show, respectively, the temperature and salinity distributions. It can be seen, in an area of limited horizontal extension above the S.B., an upwelling of the cooler ($T < 20°C$) and less haline ($S < 36 \times 10^{-3}$) Sub-Tropical Water (Emílsson, 1961). This water mass was found at depths of less than 30 m on the S.B. area, whereas, in stations outside the area, it was only found at depths greater than 70 m, over the shelf, or greater than 100 m on the ocean side of the S.B.

A separation of the more haline Tropical Water mass ($S > 36 \times 10^{-3}$), Emílsson (*op. cit.*), in two distinct bodies is shown in Figure 3. In particular, the profiles obtained in stations 4049 and 4050 exhibited an almost constant (lower) value of salinity between the surface and a depth around 70 m. This feature is in sharp contrast with the well defined halocline found in the profiles obtained in stations located outside the S.B. area.

Two weeks earlier, it was also observed (Mesquita *et al.*, in prep.) in a similar section, using only Nansen casts, that the main body of the southward flowing Brazil Current (with salinities over 37×10^{-3}) was located in a position corresponding to St. 4052 and thus, from the present measurements, it seems to have moved to a new position more than 50 km oceanward of its first place leaving behind, at mid-depth, an apparent intrusion of Tropical Water which penetrated over the shelf for a distance of more than 100 km. A similar intrusion was also observed by Mesquita *et al.* (1979) in two vertical sections, with a 13-day interval between them, in the northernmost area of Rio de Janeiro (Lat. 23°30'S).

As it can also be seen, there were inversions in the T and S profiles seeming to indicate the breaking of internal waves and/or an interleaving

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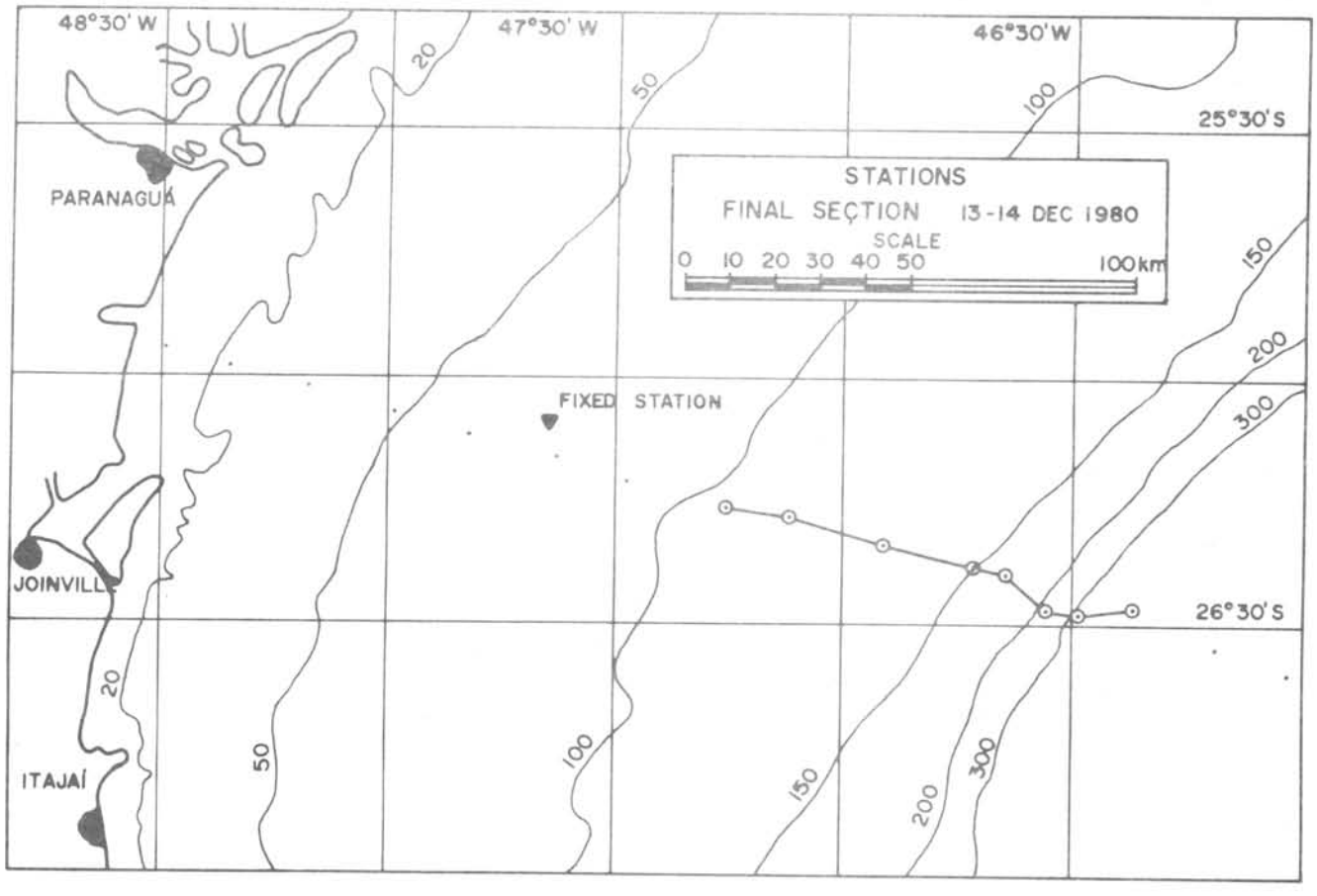

Fig. 1. The area of study.

of the layers, possibly as a result of the composition of the horizontal motion with the strong vertical advection in the area.

It was also observed that, in the area above the S.B., the T and S horizontal gradients are smaller at the surface than at mid-depth, which may indicate that the upwelling is more intense below the surface layer. On the other way, low salinity water ($S < 35.5 \times 10^{-3}$) was found at the surface on the ocean side the S.B. area (Sts 4053 and 4054) suggesting, additionally, an offshore transport of the Shelf Water through the upwelling area as indicated by the surface currents measured at the fixed station (see below). From the measurements one can not expect that the low salinity waters are a result of an offshore advection of upwelled water, but there is no full evidence to refuse this possibility, since upwelling areas are known to be zones of divergence.

Summing up the above features, the vertical and horizontal circulation as induced from the T and S distributions seem to adjust well to the S.B. upwelling models so far proposed in the litterature and a clearer picture may be obtained by examining the currentmeter data.

In each station the deepest current measurements were taken as near as possible to the bottom, so that it could be assumed that the measured currents at these depths were representative of the ship's drift. It was also implicitly assumed that the near-bottom currents were much smaller (~ 5 cm/s) than the real currents in the layers above (found to be as large as 30 cm/s in the surface layers). This hypothesis is supported by the fact that at the fixed station, the maximum observed values of the bottom currents (60 m) were of about 10 cm/s and it is reasonable to assume that at greater depths they would be even smaller. The corrected currents at each depth were calculated and Figure 4 shows the resulting current vector distribution at several depths.

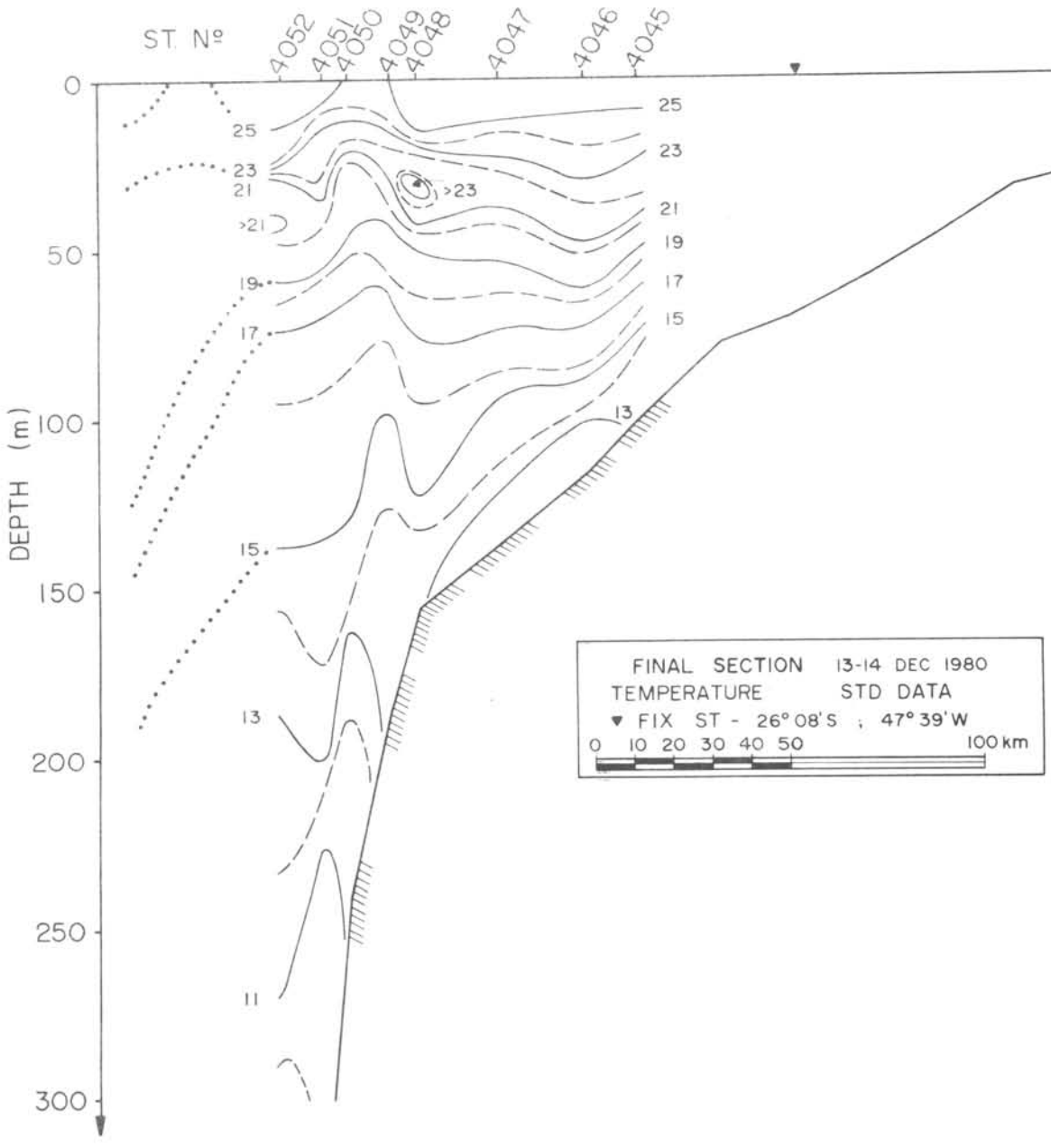

Fig. 2. Temperature distribution across the shelf break off the southern coast of Brazil, latitude 26°30'S - December 1980.

As it can be seen in the Figure 4, the layer between 25 and 60 m outside the S.B. area (both offshore and inshore) underwent and inward flow as required for a S.B. upwelling according to Johnson & Killworth's model (1975). These inward current vectors correspond to the mid-depth intrusion of Tropical Water seen in Figure 3. It seems then that an out-ward meandering of the main body of the Brazil Current forces a return flow pushing shoreward, at mid-depth, in a type of response resembling the mid-depth flow observed by Boicourt & Hacker off the coast of Delaware and referred by Mooers *et al.* (1978).

The resulting currents obtained in the section do not show an offshore transport in the surface layer as required by the known S.B. upwelling models, but such an out-going flow was indeed observed in (anchored) current measurements carried out at a fixed station half-way between the S.B. and the coastline. In the preceeding 4 days before the section was taken, the upper 20-25 m (of the 66 m column of water at the fixed station) showed a very definite eastward flow (Mesquita *et al.*, in prep.) which, however, did not seem to be related to the local wind (almost absent in the 4-day period).

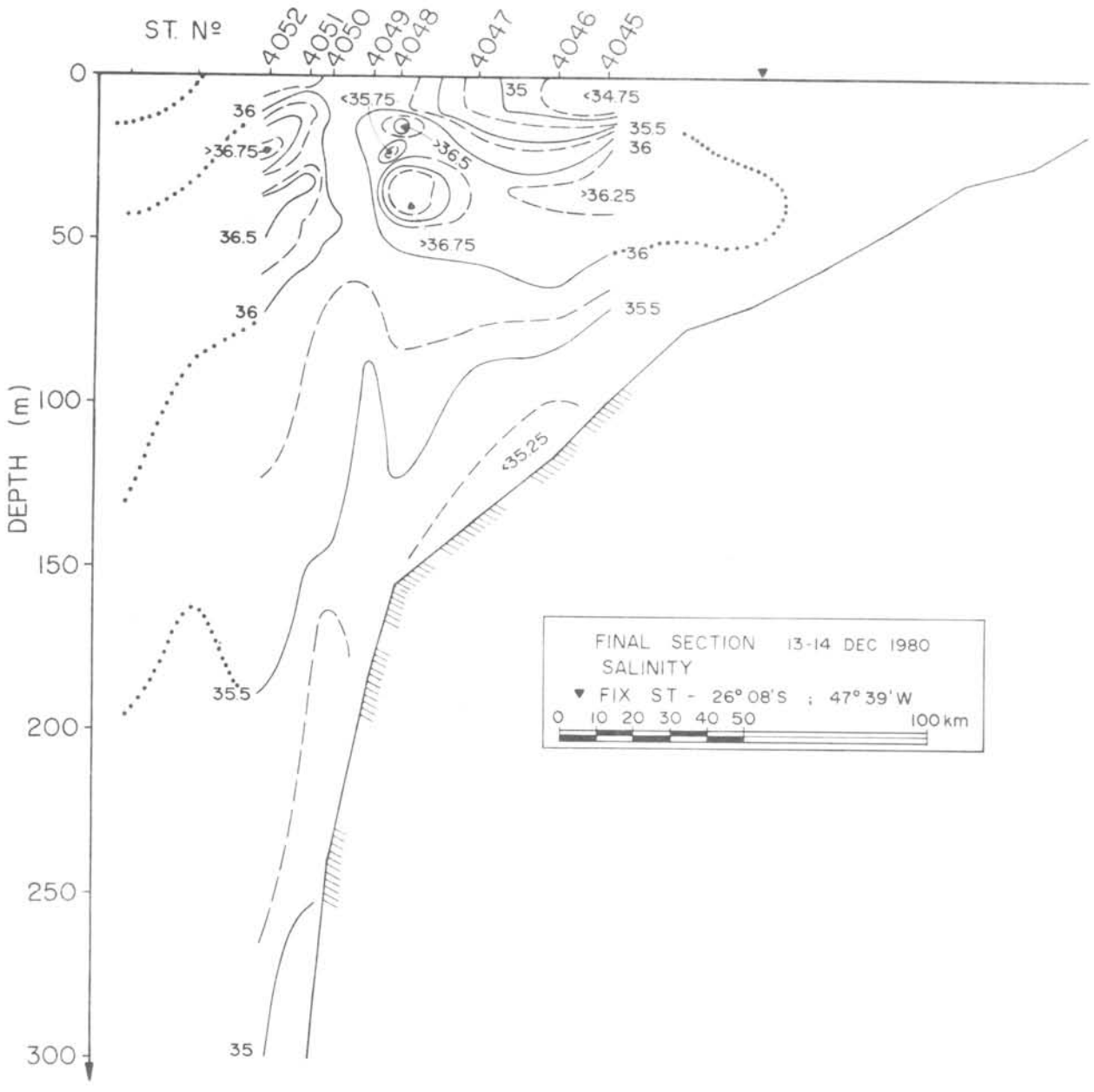

Fig. 3. Salinity distribution across the shelf break off the southern coast of Brazil, latitude 26°30'S - December 1980.

Although the direction of the flow of the Sub-Tropical Water (below the Brazil Current) is, in general, northward along the shelf-slope, the current measurements indicate a stronger northward flow (~ 10 cm/s) in the layer between 130-200 m for the stations on the ocean side of the S.B. (Sts 4051 and 4052). This intensification of the bottom current in the vicinity of the S.B. seems to correspond to the bottom countercurrent known to occur in the S.B. upwelling models.

At the surface, in the area above the S.B., the current vectors suggest an irregular eddy structure as depicted in Figure 4. Similar irregular eddies (cyclonic and anti-cyclonic) over a S.B. have been reported by Pingree (1978) from infra-red satellite imagery information of the S.B. area between France, Ireland and England.

From the analogies above and the evidences gathered from the T and S field, the continental shelf border off the southeast coast of Brazil may be

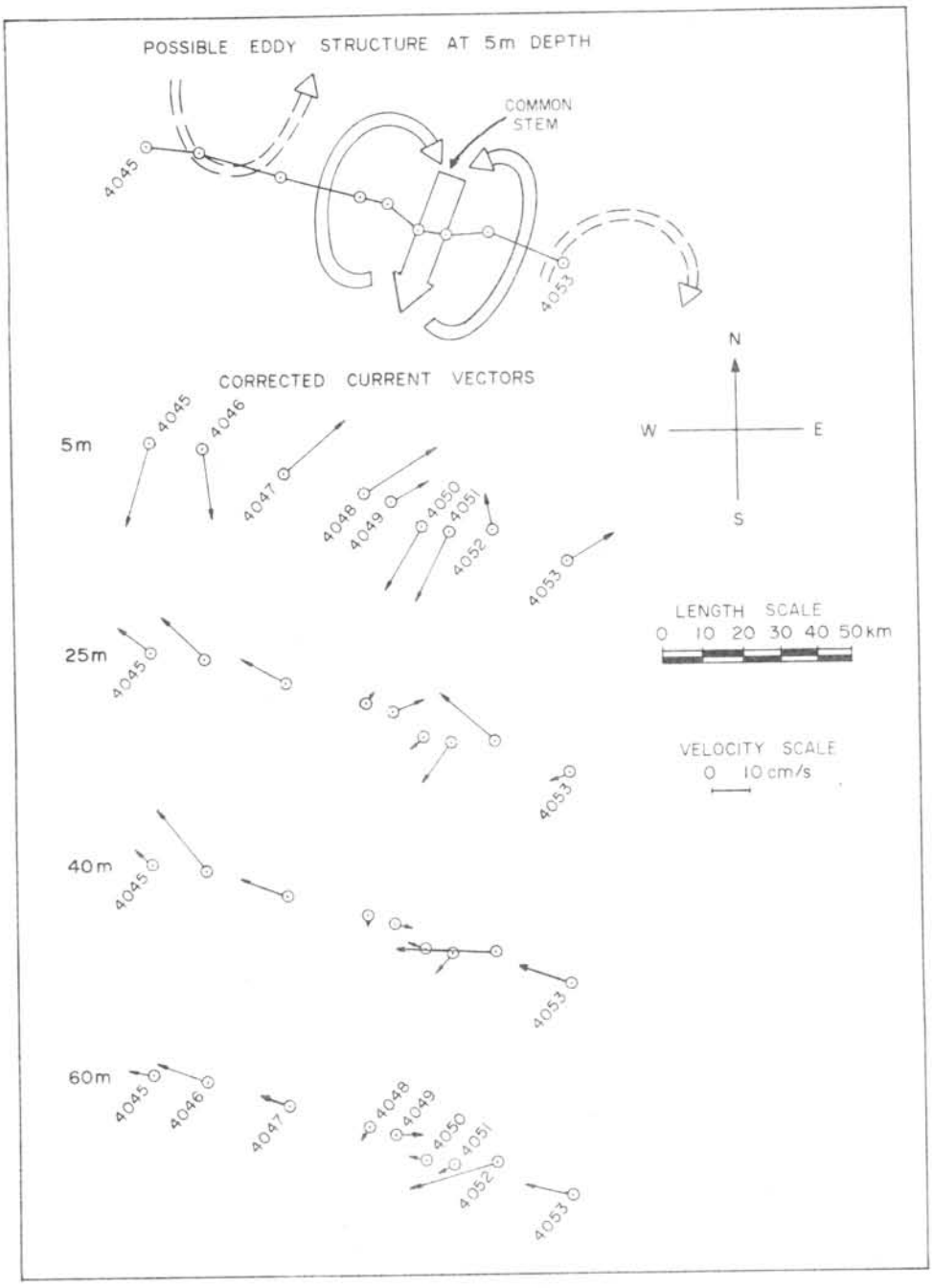

Fig. 4. Current vectors distribution for the depths of 5, 25, 40 and 60 m across the shelf break off the southern coast of Brazil, latitude 26°30'S - December 1980. The upper part of the Figure indicates a probable configuration of vortices at the 5 m depth layer.

identified as an area of (shelf break) upwelling, which presumably extends from 23°S to 40°S. The picture of this (western) S.B. upwelling seems to be different from the wind-induced S.B. upwelling observed along east margins of the oceans. It also differs from the already known strongly seasonal, locally wind-driven coastal upwelling described in Mesquita (1974), which apparently reaches the maximum strength during the summer, due to the onset of a coastal thermohaline circulation from December to March. These and the tempo-

ral and space extension of the phenomenon are obviously interesting points for further works.

Acknowledgements

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