Deep-Sea Research, Vol. 37, No. 12, pp. 1875–1886, 1990.
Printed in Great Britain.

0198–0149/90 $3.00 + 0.00

Geostrophic transport in the Brazil Current region north of 20°S

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(*Received* 1 *December* 1989; *in revised form* 27 *June* 1990; *accepted* 31 *July* 1990)

Abstract—Geostrophic volume transports in the upper 500 m are computed from historical hydrographic data for the area off the Brazilian coast west of 30°W and between 7° and 20°S. On the basis of water mass distributions, potential density surfaces of $\sigma_\theta = 27.05$ kg m^{-3} (360–670 m) and $\sigma_\theta = 27.6$ kg m^{-3} (~1200 m) are used for referencing the meridional and zonal components of the geostrophic shears, respectively. Near 15°S a northwestward flow of 8 Sv crosses 30°W. This current reaches the shelf near 10°S in February and March, the only two months for which observations are available near that latitude along the coast; of the 8 Sv, about 4 Sv continue towards the northwest into the North Brazil Current while another branch also carrying 4 Sv turns southward as the beginning of the Brazil Current. Between 10° and 20°S the Brazil Current does not appear to strengthen appreciably, but because of the likely existence of flow on the shelf these transport values represent lower limits to the actual ones. At 30°W, another westward flow of approximately 8–10 Sv enters the area near 10°S and serves to strengthen the North Brazil Current. The total transfer of 12 Sv or more from the South Equatorial Current into the North Brazil Current and later to other currents and the northern hemisphere may be an important factor contributing to the well-known weakness of the Brazil Current in its more northerly latitudes.

INTRODUCTION

THE Brazil Current has its origins with the southernmost part of the South Equatorial Current, but just where the southward geostrophic flow along the coast actually begins is not especially clear. Ship drift data have long shown the Brazil Current to originate with the bifurcation of the South Equatorial Current near Cabo de São Roque (5°30′S) (RENNELL, 1832), a feature that also can be seen in the trajectories of satellite-tracked drifting buoys (MOLINARI, 1983; REVERDIN and MCPHADEN, 1986). However, the initial southward drift near Cabo de São Roque is probably realized only in the Ekman layer which has the same southward motion (RICHARDSON and WALSH, 1986; ARNAULT, 1987); there seem to be no southward geostrophic surface currents north of 10°S (ARNAULT, 1987). This might be expected considering that the main westward current of the South Atlantic subtropical gyre remains south of 10°S except near the coast of Brazil (TSUCHIYA, 1986).

The transport of the Brazil Current is generally considered to be small when compared with that of the Gulf Stream, its western boundary counterpart in the North Atlantic. As summarized by PETERSON and STRAMMA (1990), the Brazil Current has been reported to transport only about 5 Sv (1 Sv = 10^6 m^3 s^{-1}) of surface water near 20°S. At about 20.5°S

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the Brazil Current encounters a zonal seamount chain, the Vitoria–Trindade Ridge. EVANS *et al.* (1983) observed the current to flow through the inshore-most passage and not through passages farther to the east. North of the seamount chain, at 19°S, they obtained a transport of 5.3 Sv relative to 500 m in April 1982, which is slightly less than the 6.5 Sv relative to an isanosteric surface near 500 m depth computed by MIRANDA and CASTRO FILHO (1982) for September 1967. The greatest surface speed observed in April 1982 was 50 cm s^{-1}, and in September 1967 it was 72 cm s^{-1}.

From data obtained during the Brazilian participation in the International Geophysical Year (IGY) 1957/58, SILVA (1957) found three anticyclonic cells of recirculation in the dynamic height field relative to 500 dbar; they were located near Cabo São Tomé (22°S), Ilha da Trindade (21°S) and north of Banco da Vitória (18°S). LUEDEMANN (1975) released drift bottles off the east coast of Brazil at 18°30′S to 20°S in July 1972, with the locations of the recovered bottles suggesting the existence of two branches of the Brazil Current flowing south. The coastal branch was traced between 18°30′S and 21°30′S and had a relatively high velocity on the order of 50 cm s^{-1}. The offshore branch had a lower velocity of 13 cm s^{-1} and might have been influenced by eddies and meanders. MAGLIOCCA (1978) studied the oxygen minimum layer near the Brazilian coast between 7° and 22°S, finding the core of the layer to be located in the isopycnal range of σ_t = 26.8–27.2 kg m^{-3}, which lies at depths of 300–400 m at 7°S and 600–800 m at 22°S. This oxygen minimum represents the lower limits of the southward-flowing Brazil Current water just above the Antarctic Intermediate Water (AAIW) moving north.

It is still unclear how much water is transported by the Brazil Current in the region north of 20°S, as well as where the southward geostrophic flow along the coast first appears. There are no estimates of the Brazil Current transport in the general literature for latitudes north of 19°S. In this paper we compute geostrophic transports from historical hydrographic data for the Brazil Current north of 20°S; the transport south of 23°S was the subject of an earlier paper (STRAMMA, 1989). In addition to the new transport values obtained here, we also identify the area where the South Equatorial Current bifurcates into the Brazil Current and North Brazil Current (the latter often being called the North Brazilian Coastal Current) during the austral summer.

DATA AND METHODS

Except for two *Meteor* sections (Table 1), all data used here are archived at the World Oceanographic Data Centre A (WODC, status 1988). Extracted from the WODC data set are 14 hydrographic sections which start near the Brazilian shelf between 7° and 20°S and extend generally eastward. All but four of these sections reach the vicinity of 30°W (Fig. 1). In addition to the zonal sections, six meridional sections along 30°W are extracted from the historical data set which serve to close our region on the eastern side. For clarity only two of these six sections, one made from the *Hudson* in December 1969 and another from the *Prof. Vize* in April 1969, are included in Fig. 1. Two other sections were made by the *Lomonosov* in May 1959 and June 1961, while another came from the *Ak. Shirshov* in April 1970; the remaining section came from the *Oceanus* in February 1983. CTD data were taken only on the *Oceanus* section, whereas all the other stations consist of bottle data.

A quality check has been performed on all the station data and obviously incorrect values have been removed on the basis of T–S diagrams. The scatter in these diagrams is

Table 1. Summary of hydrographic sections and geostrophic computations (positive southward) using the potential density surface of σ_θ = 27.05 kg m^{-3} as reference. Transports are for the layer above 500 m depth. Section transport refers to all the transport west of the easternmost station; coastal transports are obtained by integrating eastward out to where the flow direction reverses. Also shown are maximum geostrophic surface velocities for the coastal current. At coastal station pairs not deep enough to reach the reference isopycnal, the deepest depth available is used. Northward transports in parentheses are inshore of the southward-flowing Brazil Current

Ship	Latitude (S)	Easternmost station (W)	Time	Reference depth (m)	Section Trans. (Sv)	Coastal current Trans. (Sv)	Coastal current Max. vel. (cm s^{-1})
A. Saldanha	7°5′	30°18′	Oct. 1959	410–550	−13.4	−16.5	−56.8
*Crawford**	8°15′	29°38′	Mar. 1957	380–410	−7.3	−4.6	−5.6
Crawford	8–9°	30°6′	Feb. 1963	360–390	−9.2	−4.7	−24.7
A. Saldanha	10°5′	30°1′	Feb. 1975	380–500	−4.7	1.0	19.1
Atlantis	12°15′	30°2′	Mar. 1959	410–500	−4.6	2.2	73.7
Meteor	9–13°	30°	Sep. 1926	390–510	−5.7	4.1	30.8
A. Saldanha	13–14°	33°57′	Apr. 1957	480–520	−1.7	2.1(−4.3)	5.0
A. Saldanha	15°	29°59′	Feb. 1975	470–530	2.1	6.0(−0.9)	16.0
Crawford	15°45′	29°17′	Apr. 1957	470–560	−0.5	3.8(−1.0)	11.0
A. Saldanha	16°6′	32°3′	Jan. 1975	490–580	1.0	5.6(−2.8)	27.2
Meteor	18–16°	30°3′	Jun. 1926	510–580	−3.1	0.8	5.9
Prof. Besnard	19°	30°5′	Sep. 1967	560–670	0.8	3.7	61.2
A. Saldanha	19°25′	31°	Jun. 1970	470–640	4.0	5.7	18.8
*A. Saldanha**	19°30′	34°3′	Mar. 1957	480–560	2.8	1.0	10.8
*A. Saldanha**	20°3′	30°	Jan. 1975	590–630	3.9	1.6	23.9
Atlantis	20°15′	29°18′	Mar. 1959	570–630	4.5	1.9	18.7

*Section shown in Fig. 1 by triangles.

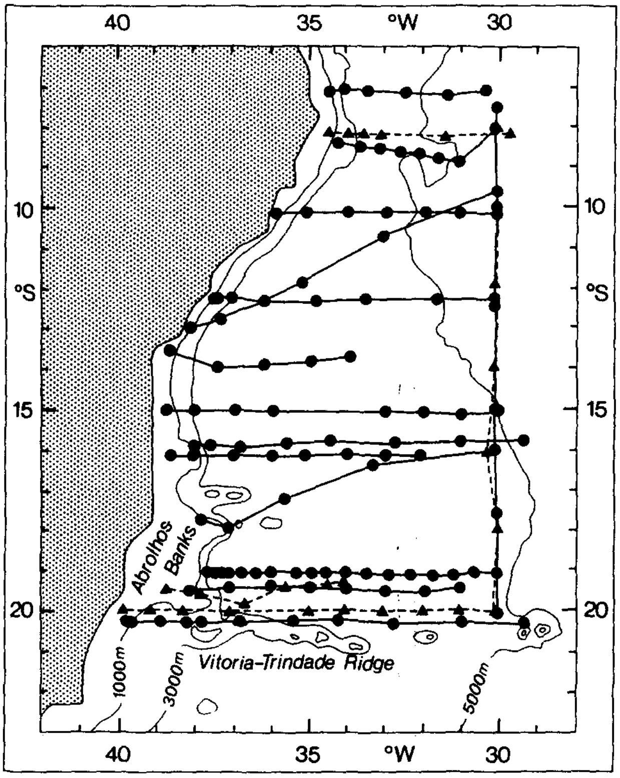

Fig. 1. Positions of hydrographic stations along all the zonal sections used here (Table 1) and two of the six meridional sections described in the text (dots: *Hudson*, December 1969; triangles: *Prof. Vize*, April 1969), together with bottom bathymetry. Dashed lines and triangles on selected zonal sections are used only for clarity.

small in the IGY data (*Crawford*, *Atlantis*) and in the *Oceanus* CTD section, but other sections contain considerably more scatter. The most noise appears in the sections from the *Ak. Shirshov*, the *Prof. Vize*, and in the older sections from the *A. Saldanha*. Nevertheless, these sections still appear to be useful for making geostrophic computations as they yield similar flow fields and transports as do the sections with small scatter.

Assuming the flow to be primarily along isopycnal surfaces, we use vertical distributions of water mass properties to find a potential density surface where the motion might vanish and thereby provide a suitable reference for adjusting geostrophic velocity profiles. These properties have been described by Reid *et al.* (1977) for the western South Atlantic south of about 20°S and have been summarized on a north–south section by Peterson and Whitworth (1989). In our region, the uppermost warm and salty water mass is the Tropical Water that lies above the South Atlantic Central Water (SACW), whose lower limits are indicated by an oxygen minimum near 500 m depth. Directly underneath is the AAIW, which is identified by an oxygen maximum just above a salinity minimum at depths of approximately 700–800 m. The upper branch of Circumpolar Deep Water (CDW) is the next deepest water mass, and is characterized by minima in both temperature and oxygen near 1000–1200 m. The final water mass of concern to us is the upper branch of North

Atlantic Deep Water (NADW), it being characterized by a weak temperature maximum overlying maxima in salinity and oxygen.

The directions of motion in these layers in the southwestern South Atlantic (away from the western boundary) do not appear to change significantly with depth. DEFANT (1941, plate XXVI) showed the 800 dbar velocity field as reflecting the gyre circulation. BUSCAGLIA (1971) explicitly observed the AAIW as circulating in the same direction as the surface water, a finding in agreement with REID *et al.* (1977), who presented additional evidence that the anticyclonic motion extends downward through the NADW. In the tropical South Atlantic there is another circulation regime, a cyclonic gyre, roughly triangular in shape, having greatest latitudinal extent near the African shelf and narrowing toward the west (REID, 1989). The transition between the subtropical anticyclonic and tropical cyclonic gyres is oriented along the zero-line in the annual mean field of wind stress curl over the South Atlantic (GORDON and BOSLEY, 1990; PETERSON and STRAMMA, 1990). In the east, the tropical cyclonic gyre extends to great depth (KIRWAN, 1963; REID, 1989), but the vertical coherence of direction is less apparent in the west where its northern limb approaches the eastern promontory of Brazil (REID, 1989). Finally, at the western boundary at low latitudes, there are sharp changes in the direction of flow between various layers. Using a Pegasus profiler to obtain absolute velocities in the Brazil Current near 23°S, EVANS and SIGNORINI (1985) found the flow to be southward in the upper 400 m, but toward the north in the underlying AAIW. There is another reversal at depth due to the NADW flowing south along the shelf as a western boundary current (DEFANT, 1941).

The AAIW is known to flow northward along the South American continental shelf, and its presence can be seen in the vertical section of oxygen on an east–west line along 15°45′S (Fig. 2). The highest values in this layer exceed 4.4 ml l^{-1} west of 35°W, and gradually erode toward the east. Above the high-oxygen core of AAIW near the shelf is the minimum associated with the lower reaches of SACW. Between these two extrema in the west is the potential isopycnal of $\sigma_\theta = 27.05$ kg m^{-3}, which we choose as a reference

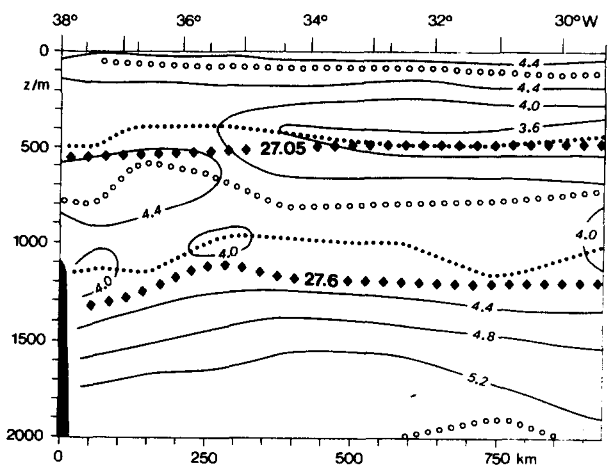

Fig. 2. Vertical distribution of oxygen (ml l^{-1}) in the upper 2000 m along the west (left)–east (right) line of stations occupied by *Crawford* at 15°45′S in April 1957. Relative minima are denoted by dots and maxima by open circles. Also shown are the isopycnals of σ_θ = 27.05 and 27.6 kg m^{-3} (diamonds).

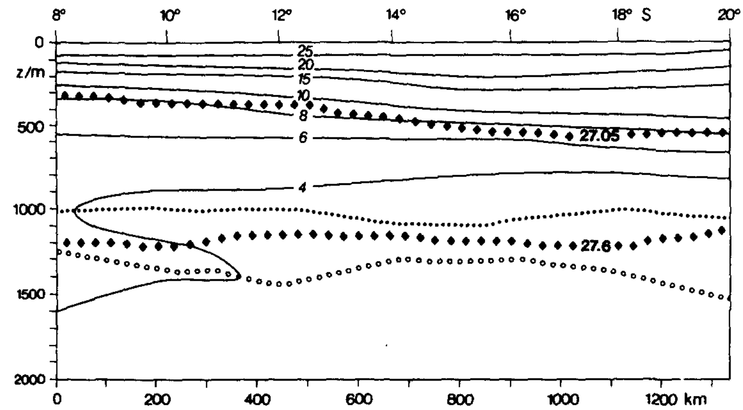

Fig. 3. Vertical distribution of temperature in °C in the upper 2000 m along the north (left)–south (right) line of stations occupied by *Prof. Vize* at 30°W in April 1969. Relative minima are denoted by dots and maxima by open circles. Also shown are the isopycnals of σ_θ = 27.05 and 27.6 kg m^{-3} (diamonds).

for computing the geostrophic transport of the Brazil Current, similar to what was done by STRAMMA and PETERSON (1989) in the Benguela Current region.

The optimal zero-reference for the zonal flow component in regions away from the western boundary in the tropical South Atlantic lies at greater depth than the boundary between SACW and AAIW, and is less easily identified. According to REID (1989) the SACW and AAIW have the same flow direction at about 30°W. As shown in Fig. 1, we have closed our region to the east with north–south lines of hydrographic stations along 30°W. A vertical section of temperature along that meridian is shown in Fig. 3. Although this field has little structure other than the thermocline stratification, a weak minimum associated with the upper branch of CDW and a maximum due to NADW are present and separated in depth by only 200–300 m, providing perhaps the best indication of where the boundary between these two water masses is. As shown in Fig. 3, the potential density surface of σ_θ = 27.6 kg m^{-3} lies between the two extrema, and is used along this section as reference for geostrophic computations.

A mismatch exists between the reference used for the zonal sections and that used for the meridional section, which naturally leads to mass imbalances. These are discussed in the following section. However, our primary objectives, i.e. to determine the spatial patterns of flow in the southern South Equatorial Current as it nears the western boundary and to provide estimates for the volume transport of the newly formed Brazil Current, are met by using this method.

OBSERVATIONS

The geostrophic transports across the zonal sections, computed relative to the potential density σ_θ = 27.05 kg m^{-3} for the upper 500 m (Table 1), show a northward-directed geostrophic flow along the coast at latitudes north of 9°S, flow which is part of the North Brazil Current. We have only three sections within this current, and its largest transport, more than 16 Sv, is observed at 7°S in the month of October. This is nearly 12 Sv more than obtained just a degree farther south during the opposite time of year, which may at first be suggestive of a strong seasonal signal. But from maps in the paper by Cochrane *et al.* (1979), it appears as though the North Brazil Current is stronger in February–April and weaker in July–September. As discussed below, the rapid intensification we observe is likely brought about by the merging of two branches of the South Equatorial Current.

The southward geostrophic flow of the Brazil Current first appears at about 10°S, and just two degrees farther south the surface speeds can exceed 70 cm s^{-1}. Unfortunately, because our four sections between 8°15′S and 12°15′S were all made in February and March it is not possible for us to speculate on any possible seasonality in the formation latitude of the Brazil Current. Between 10° and 20°S the (coastal) Brazil Current is found to transport on the order of 1–6 Sv, and the variations are not systematic with respect to time of year. Because these transport values are so small, any seasonality could be obscured by data noise and by the Brazil Current in its northern reaches being a shallow feature, often residing up on the continental shelf (reviewed by Peterson and Stramma, 1990). However, a systematic pattern does seem to exist in the flow field itself. In all sections south of 10°S a northward flow is observed to the east of the coastal flow with a second southward flow farther offshore (but still west of 30°W). The total transport in the upper 500 m west of 30°W is directed poleward south of 15°S and equatorward north of there.

The velocity distribution along the *A. Saldanha* section at 15°S in February 1975 (Fig. 4) shows two southward current bands, the coastal one having a maximum surface speed of

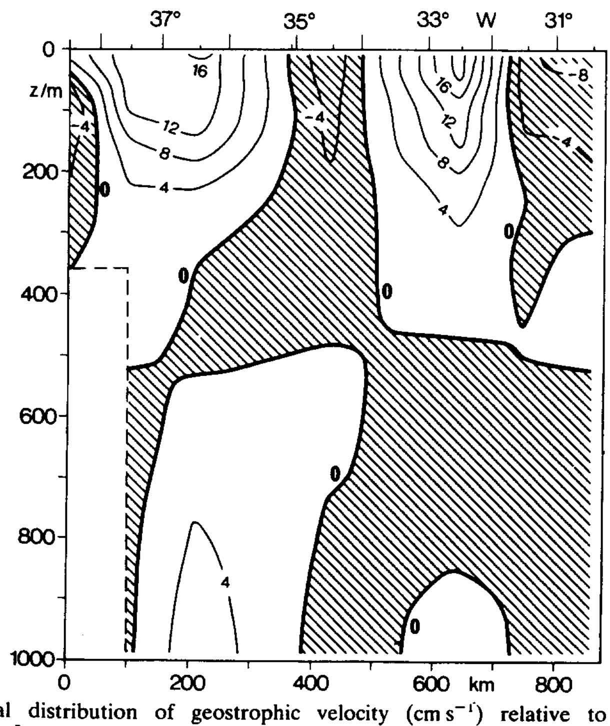

Fig. 4. Vertical distribution of geostrophic velocity (cm s^{-1}) relative to the isopycnal $\sigma_\theta = 27.05$ kg m^{-3} for the *A. Saldanha* section at 15°S in February 1975. Positive velocity is southward, negative velocity is directed northward and indicated by shading. Short tick-marks on top show the mid-points between stations. The broken line on the left side indicates where no velocity estimates exist due to shallow bathymetry.

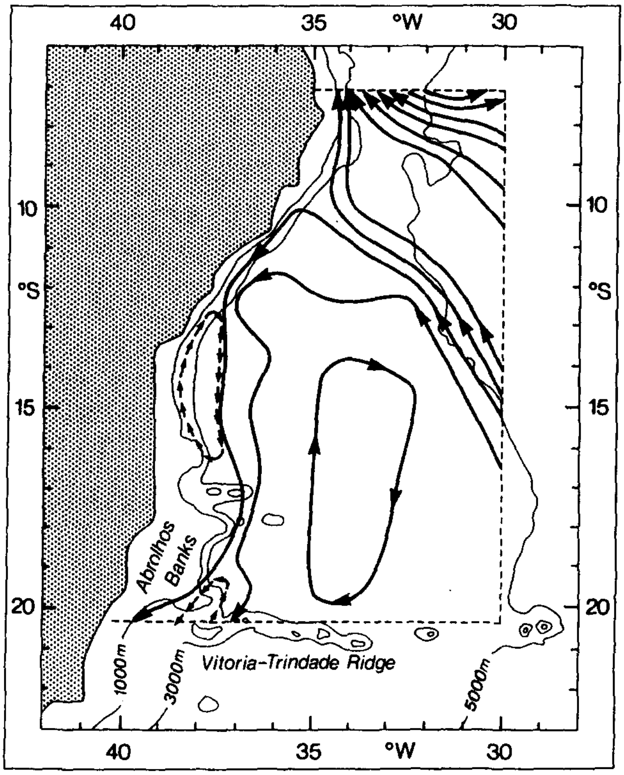

Fig. 5. Schematic representation of the geostrophic flow field in the upper 500 m based on historical hydrographic data within the region defined by the dashed box. Solid flow lines represent a transport of 2 Sv, disconnected arrows a transport of 1 Sv. The location of where the South Equatorial Current bifurcates is based on data obtained in the months of February and March.

16 cm s^{-1} and another farther offshore with 20 cm s^{-1}. Both of these bands are surface features where speeds of 8 cm s^{-1} or more are restricted to the upper 200 m. A similar two-banded structure in the surface layer is also present in the other sections south of 10°S.

A schematic representation of the geostrophic flow field based on our data is constructed to fit the major features observed (Fig. 5). However, because of the mass imbalances resulting from the use of non-synoptic sections and a deeper reference layer along 30°W than along the zonal sections, this field does not closely fit all the transport estimates in Table 1. Most important, though, is that this field shows the essential qualities of the flow. The geostrophic flow of the Brazil Current begins at about 10°S and separates from the coast near 12°S. As noted above, this formation latitude for the Brazil Current is based only on data taken during the months of February and March. Between 12° and 16°S there is a weak cyclonic circulation inshore of the Brazil Current, with the northward flow along the shelf carrying an average of only about 2 Sv. There appears to be another (and larger) cyclonic gyre offshore of the Brazil Current centered near 17°S, 34°W. The manner in which it is contoured here is only one possible interpretation. Another would be a southward meandering of the southernmost part of the South Equatorial Current and a subsequent northward reflection at the Vitoria–Trindade Ridge. The transport of the

Brazil Current itself, roughly 4 Sv, agrees with observations made in the region of the Vitoria–Trindade Ridge during April 1982 by EVANS *et al.* (1983). They estimated a geostrophic transport relative to 500 m of 5.3 Sv at 19°S, 3.8 Sv at 20°28′S, and 4.4 Sv at 21°40′S.

From the six sections along 30°W, no westward current band can be distinctly identified as being a stable feature in all the sections. Instead, the flow is spread broadly with many irregularities (including occasional countercurrents) over most of the section. Typical for the sections at 30°W, however, is a somewhat stronger westward branch at 8°–11°S and another near 15°S, which are included in Fig. 5. Except for an *Oceanus* section (which starts at only 11°50′S) the westward geostrophic transports in the upper 500 m across these meridional sections between 8° and 20°S relative to the potential density surface of $\sigma_\theta = 27.6\ \mathrm{kg\ m^{-3}}$ varies from 18 to 25 Sv. For the *Oceanus* section, there is a total westward transport of 13.3 Sv between 11°50′S and 20°8′S. The westward transport of 16 Sv shown in Fig. 5 is smaller than the 18–25 Sv across the other sections because of the deeper reference level used along the meridional sections ($\sigma_\theta = 27.6\ \mathrm{kg\ m^{-3}}$) than in the zonal sections ($\sigma_\theta = 27.05\ \mathrm{kg\ m^{-3}}$). If the shallower reference is used along 30°W, the westward transport averages about 13 Sv, suggesting that the actual value might be near that contoured in Fig. 5.

Also evident from Fig. 5 is that most of the transport of the two quasi-permanent branches of the South Equatorial Current continue equatorward across 10°S into the North Brazil Current. The beginnings of this current as a near-coastal geostrophic feature appear to be with the southern portions of the South Equatorial Current near 10°S with a transport of about 4 Sv, but with the input of the other branch of the South Equatorial Current, the North Brazil Current strengthens to more than 16 Sv at 7°S (Table 1). However, it should be noted that these estimates of the North Brazil current transport are likely to be lower than the actual values because the underlying AAIW is probably moving in the same direction, and we have not adjusted our reference level accordingly. Also not well resolved in the northeastern corner of our region is the eastward-flowing South Equatorial Countercurrent, which MOLINARI (1982) observed as being located between 7° and 9°S at 25°–28°W.

Referring again to Fig. 5, the continental shelf is relatively narrow north of about 15°S. Because of this, and because of the small cyclonic circulation near the coast, it is doubtful that very much of the Brazil Current escaped measurement in this region. However, for regions south of 15°S it is likely that we have underestimated the transport of the Brazil Current. The WODC data we have used came only from stations which are at least 200 m deep. At 23°S, EVANS and SIGNORINI (1985) found that part of the Brazil Current exists inshore of the 200-m isobath, with the inshore transport amounting to about 5 Sv. Such a flow is also possible on the broad shelf at the Abrolhos Banks between 16° and 20°S, which we are not able to resolve.

That we have probably underestimated the Brazil Current transport near the Abrolhos Banks is attested to by the results obtained by MIRANDA and CASTRO FILHO (1982). They used the same section made from the *Prof. Besnard* at 19°S as we have, but they had two additional station pairs on the shelf with which to work. They estimated the net flux of the Brazil Current as being 6.5 Sv, whereas we find only 3.7 Sv. But part of the difference is also due to using different reference depths. They used the 130 cl ton^{-1} isanosteric surface (near 520 m depth) versus our reference of $\sigma_\theta = 27.05\ \mathrm{kg\ m^{-3}}$ (at about 670 m depth beneath the Brazil Current). Using a fixed reference depth of 520 m, we obtain a transport of 5.0 Sv for the coastal Brazil Current. In their conclusions, MIRANDA and CASTRO FILHO (1982) stated that the Brazil Current near the continental slope transports about 5.5 Sv, which is similar to our 5.0 Sv using a reference of 520 m. The 1 Sv difference between their two values of 5.5 and 6.5 Sv might be their estimate of the shelf transport, but they were not explicit about this.

A large difference also exists between our transport of 0.8 Sv for the Brazil Current across the *Meteor* section at 18°–16°S and a transport of 6.2 Sv in the upper 600 m which can be extracted from Table IX in WÜST (1957). The reasons for the difference are again because of reference depth (Wüst used 1000–1200 m), and because Wüst extrapolated *Meteor* Sta. 161, which was made on the shelf in only 60 m depth, down to 1200 m, whereas we have made no such extrapolation.

Because the station spacing in our sections is not uniform, and often quite large (Fig. 1), the large scatter in our coastal current velocities (Table 1) is not surprising. However, the highest velocity, nearly 75 cm s^{-1}, comes from an unexpectedly far north latitude of 12°15′S. This leads to the question as to whether or not there might be southward geostrophic flow on the shelf north of 10°S, where we have found the bifurcation of the South Equatorial Current (in February–March). Because all our data come from stations in water depths of 200 m and more, we are unable to provide an answer. There also might be some seasonality or interannual variability involved, which we are again unable to adequately resolve. DEFANT (1941, plate XXII), showed a coastal flow towards the south beginning near 5°S, but his field was likely based on ship drifts in this region: his 100-dbar velocity field (DEFANT 1941, Fig. 51) has a poleward component along the coast only from 11°S and southward.

DISCUSSION

As it has long been known, the newly formed Brazil Current is very weak as far as western boundary currents go. Part of the reason might be surmised by the patterns shown in Fig. 5. Although we are not sampling the entire South Equatorial Current as it reaches the vicinity of the western boundary, it seems clear that most of its water is transported into the North Brazil Current, after which it would be lost to other currents and the northern hemisphere (helping to intensify the Gulf Stream). Only about 4 Sv get into the Brazil Current. Farther upstream in the circulation of the subtropical gyre, the Benguela Current supplies more than 20 Sv to the South Equatorial Current (STRAMMA and PETERSON, 1989), of which less than 10 Sv is thermocline water from the Indian Ocean (GORDON *et al.* 1987; STRAMMA and PETERSON, 1990). On our northernmost zonal section, made by the *A. Saldanha* near 7°S, we obtain a transport for the North Brazil Current of 16.5 Sv (Table 1), roughly twice that which comes from the Indian Ocean into the southern Benguela Current. Our other zonal sections lie farther south and sample less or none of the North Brazil Current. As pointed out by GORDON and BOSLEY (1990) and PETERSON and STRAMMA (1990), the zero-line of the annual mean curl of wind stress in the lower latitudes of the South Atlantic is oriented diagonally across the basin from near Cape Town to equatorial latitudes north of the northern coast of Brazil. It does not intersect the South American coast south of the equator, in which case one might expect from Sverdrup dynamics that the subtropical gyre does not completely recirculate, thus leading to a loss of water from the gyre to the North Brazil Current. This loss of water appears to be real, and could be largely compensated by flux in the Ekman layer, which ROEMMICH (1983) estimated in the

South Atlantic as being 13.7 Sv southward across 8°S (in the annual mean). But regardless of how the compensation takes place, the geostrophic transfer of subtropical gyre water into the North Brazil Current may be one of the mechanisms leading to the overall weakness of the early Brazil Current.

Here we have used the available historical data to map (for the first time we believe) the general geostrophic flow field in the surface layer near the Brazilian coast north of the Vitoria–Trindade Ridge. Although some of our data are not of the highest quality, the patterns we have obtained should be fairly accurate. Unfortunately, our data from the region near the coast where the southernmost portion of the South Equatorial Current splits into the Brazil and North Brazil currents come only from February and March, so we are unable to resolve any possible seasonality in the bifurcation. Many more high-quality measurements from all seasons, including shallow stations on the shelf, are needed for this.

Acknowledgements—This work has been supported by the Bundesminister für Forschung und Technologie grant 07K2128-12a (L.S.), the Deutsche Forschungsgemeinschaft grant Si 111/34-1 (R.G.P.), both at Bonn, F.R.G., and Banco Interamericano de Desenvolvimento (BID) as well as Universidade de São Paulo, Brazil (Y.I.).

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