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NOTE

The Brazil Current transport south of 23°S

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Abstract—Geostrophic computations from historical data across the Brazil Current at 23° and 24°S lead to transports of 10.2 and 9.6 Sv, respectively. Data exist from all four seasons at about 24°S, but no seasonal signal can be seen in the baroclinic transport of the Brazil Current there. At 33°S the Brazil Current transport is estimated to be 17.5 Sv. A recirculation cell of 7.5 Sv is found in the western South Atlantic south of 28°S. The major problem in computing transport of the Brazil Current is not with determining the correct reference depth, but with the Brazil Current flowing partially over the shelf and therefore not being sampled completely by deep-water hydrographic stations. As long as the vertical distribution of water masses is taken into account for choosing a reference depth, geostrophic computations lead to results consistent with previous estimates.

INTRODUCTION

THE Brazil Current has long been known to transport substantially less water than the Gulf Stream (STOMMEL, 1957), its counterpart in the North Atlantic, and, compared to the Gulf Stream, the Brazil Current has been sampled to a much lesser extent. Most transport estimates for the Brazil Current have been in two regions: near Rio de Janeiro and in the Brazil–Falkland Confluence Zone. At 19°S MIRANDA and FILHO (1981) obtained a southward geostrophic volume transport of 5.5 Sv (1 Sv = 10^6 m^3 s^{-1}) and a maximum surface velocity of 72 cm s^{-1}, all relative to a layer near 500 m depth. Adjacent to Capo Frio at 24°S, SIGNORINI (1978) estimated the transport relative to 600 m as 9.4 Sv, that being contained in two branches, with the peak surface geostrophic velocity as being 55 cm s^{-1}. Within 60 km of that section, two other hydrographic sections yielded volume transports of 6.8 and 7.5 Sv by using the same reference of 600 m (SIGNORINI, 1978). Two other investigations in the area of 19° to 24°S (EVANS *et al.*, 1983; EVANS and SIGNORINI, 1985) agree with these estimates of transport and maximum surface velocity, using both direct current measurements and hydrographic data.

GORDON and GREENGROVE (1986) investigated the Brazil–Falkland Confluence Zone, finding that at 38°S the Brazil Current transports 19 Sv southward relative to 1400 m. Near that latitude, the Brazil Current encounters the northward-flowing Falkland (Malvinas) Current, and there both currents separate from the continental margin. The transport of 19 Sv toward the south at 38°S represents an increase of approximately 12 Sv over the transport at about 20°S. The increase is less than that found for the Gulf Stream, but the 5% growth rate per 100 km is similar (GORDON and GREENGROVE, 1986). This

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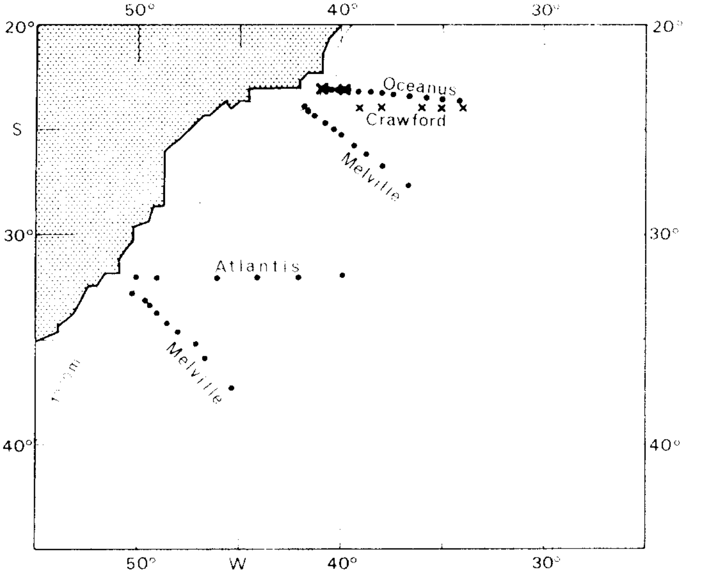

Fig. 1. Hydrographic stations (dots or crosses) used for computing Brazil Current transports, together with ship names and the 1000 m isobath.

increase may be associated with a recirculation cell in the South Atlantic. For latitudes between 24° and 38°S there are apparently no direct transport estimates for the Brazil Current from hydrographic sections. FU (1981), applying inverse methods to the trans-Atlantic IGY (International Geophysical Year) and R.V. *Meteor* hydrographic sections, obtained no clear Brazil Current north of 25°S, but estimated it to have a transport of 20–27 Sv at 28°S, which is large compared to other estimates.

In this study, geostrophic transports of the Brazil Current, relative to different reference depths, are estimated from the sections shown in Fig. 1. All data used here are archived at the World Oceanographic Data Center A (WODC, status 1988). Data near 24°S are used for comparisons with existing estimates while the other sections are presented to reduce the gap of transport estimates between 24° and 38°S. Finally, the upper geostrophic flow field of the western South Atlantic is constructed for November 1972, which again contributes to the transport estimates of the Brazil Current.

TRANSPORT COMPUTATIONS

The dynamic method for computing geostrophic velocities is burdened with the problem of finding an integration reference, commonly called the "level of no motion", a problem that is strongly dependent on the data available. DEFANT (1941) established reference depths on the basis of zero or low vertical gradients in geopotential anomaly. With the complete data set of the *Meteor* expedition of 1925–1927, as well as with other data, DEFANT (1941) estimated the best choice of a layer of no motion for the entire Atlantic Ocean. His reference depth for the South Atlantic ranges from 400 m at the equator to 2500 m in the central Atlantic near 50°S. In the area of the Brazil Current he obtained a reference depth of 1300 m at about 23°S, which descends to 1500 m at 28°S and 1800 m at 38°S. Dynamic topography of the South Atlantic derived from his "surface-of-no-motion" clearly shows the gyre circulation, including the Brazil Current off the coast of Brazil (DEFANT, 1941).

More recently, investigations of the Brazil Current at 19° to 24°S (MIRANDA and FILHO, 1981; SIGNORINI, 1978) have used reference depths between 500 and 600 m, which are much shallower than Defant's. The 600 m depth lies between the surface layer, which flows to the south, and the Antarctic Intermediate Water, which flows to the north. The different flow directions can be seen in direct current velocity measurements made with a Pegasus profiler (EVANS and SIGNORINI, 1985). Therefore, a reference depth within the Antarctic Intermediate Water near 1000 m would lead to wrong transport estimates.

Transport estimates of the Brazil Current for the sections shown in Fig. 1, at various reference depths, are presented in Table 1. These transports are obtained by integrating velocities from the station nearest the coast out to where the upper ocean velocity vanishes or becomes northward. At station pairs not deep enough to reach the selected reference depth, the deepest depths available are used instead. At 23° and 24°S, using Defant's reference depth of 1300 m, the Brazil Current transports increase by less than 1 Sv over those using a reference of 600 m. The reason is that a 1300 m reference depth is located beneath the Antarctic Intermediate Water and within the Upper Circumpolar Deep Water (REID *et al.*, 1977), a layer probably having weak absolute motion. Therefore, using either Defant's reference depth or a 600 m depth leads to similar transports in the region 24°S. The slightly smaller transports when using the lower transport integration depths at 800 m instead of 600 m is due to the influence of the northward-flowing Antarctic Intermediate Water below 600 m. The Brazil Current is thus restricted to the upper 600 m near 24°S.

In a survey of the Brazil Current between 19 and 24°S, EVANS and SIGNORINI (1985) found it to be closely confined to the region near the continental slope. It flowed through the inshore-most passage of a seamount chain at 20°30′S and onto the continental shelf. From Pegasus profiler measurements at 24°S they estimated a Brazil Current transport of 11 Sv, composed of 6 Sv offshore from the 200 m isobath and 5 Sv inshore. Their value of 11 Sv compares well with the transport estimates at 23° and 24°S given in Table 1, estimates made only with profiles in water depths of more than 500 m.

The temperature section made by *Oceanus* at 23°S (Fig. 2a) shows strong horizontal gradients over the upper 600 m in the westernmost portions, those being related to the Brazil Current. The geostrophic velocity distribution for the western side of Fig. 2a is

Table 1. *Offshore transport estimates for the Brazil Current from historic profiles*

Ship	°S	Date	Reference depth (m)	Integration interval (m)	Southward transport (Sv)
Oceanus	23	Feb. 1983	600	0–600	10.2
			600	0–800	10.1
			950*/1300	0–600	11.0
			950*/1300	0–800	10.9
Melville	24	Nov. 1972	600	0–600	9.6
			600	0–800	9.2
			800*/1300	0–600	10.2
			800*/1300	0–800	9.9
Atlantis	32	Apr. 1959	800*/1600	0–800	19.2 (13.3)
Melville	33	Nov. 1972	800*/1600	0–800	12.2

* At coastal station pairs not deep enough to reach the selected reference depth, the deepest depth available, as indicated, was used instead.

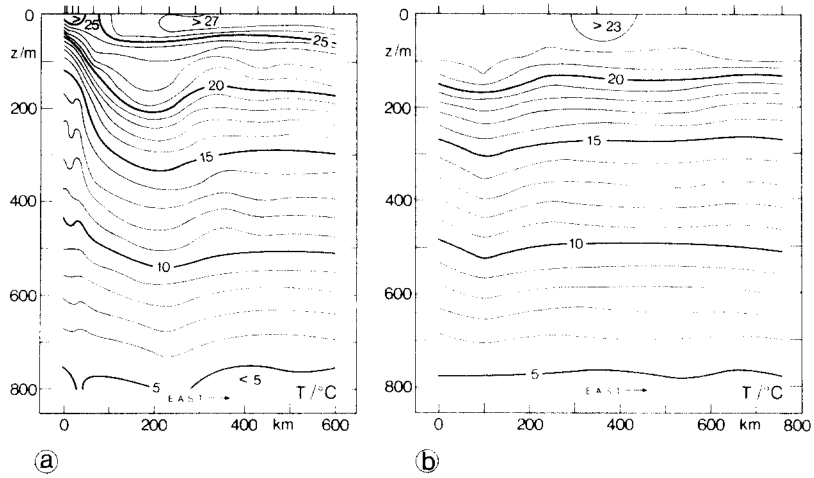

Fig. 2. Vertical sections of temperature as observed by (a) R.V. *Oceanus* in February 1983 between 23°2.3'S, 40°48.4'W (left) and 23°32.9'S, 35°1.0'W (right) and (b) R.V. *Crawford* in October 1958 between 23°5.4'S, 41°0.8'W (left) and 24°1.6'S, 34°W (right). Tick-marks on top indicate station positions.

presented in Fig. 3. The main core of the Brazil Current is found to have velocities of up to 58 cm s^{-1} at 50 m depth and velocities of more than 10 cm s^{-1} above 450 m depth. Another core to the west also has strong southward velocities, but they are limited only to the upper 100 m. The inshoremost velocity profile has a surface speed of about 65 cm s^{-1}, but because of the small cross-sectional area of this current band, it accounts for less than half Sverdrup out of the total southward Brazil Current transport of 10.2 Sv (Table 1).

The maximum speed of this *Oceanus* section compares well with that given by SIGNORINI (1978), with the 10.2 Sv transport obtained here being between the 9.4 Sv estimate of Signorini and the 11 Sv estimate of EVANS and SIGNORINI (1985), the latter having included the transport inshore of the 200 m isobath. Although no shelf transport is included in the computations made here at 23°S (*Oceanus*) and 24°S (*Melville*), indications are that the largest part of the Brazil Current transport was measured with these two sections.

FU (1981) found the northernmost part of the Brazil Current to be at 16° to 24°S, further south than what is normally expected. A reason for this might be that Fu used the *Crawford* IGY section at 23° to 24°S (Fig. 1). In contrast to the *Oceanus* section at 23°S (Fig. 2a), there is no strong signal of the Brazil Current in the *Crawford* temperature section (Fig. 2b). Geostrophic computations using the *Crawford* data lead to a southward transport of 2.5 Sv (0–600 m depth) between the two stations nearest the Brazilian coast, but this is compensated by a northward transport of 2.5 Sv (0–600 m depth) just to the east between Stas 2 and 3 counted from the west. The maximum velocity in the *Crawford* section, 8.4 cm s^{-1}, is small compared to typical Brazil Current velocities of 50 cm s^{-1}. The westernmost velocity profile of the *Crawford* section is located at the shelf edge, 21 km west of, and 6 km south of the westernmost profile of the *Oceanus* section at 23°S. Therefore, the Brazil Current did not exist seaward of the

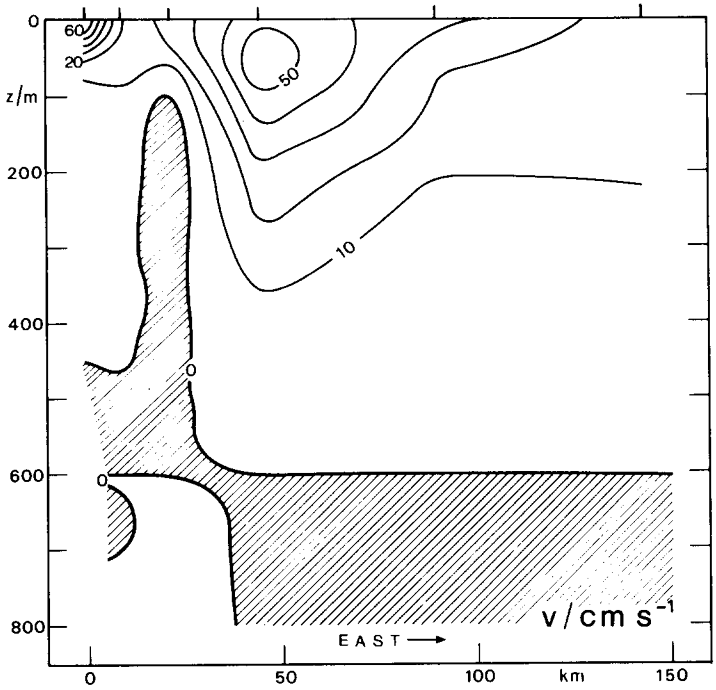

Fig. 3. Geostrophic velocity distribution relative to 600 m in cm s^{-1} (positive southward, negative values are shaded and directed northward) for the *Oceanus* section in February 1983 between the stations at 23°2.3′S, 40°48.4′W (left) and at 23°11.7′S, 39°9.6′W (right). Tick-marks on top indicate the center between two stations.

1000 m isobath in October 1958. Compared to the other sections presented here and in the literature near 23°S, the *Crawford* section is the only one without a clear Brazil Current signal. From EVANS and SIGNORINI (1985) we know that a transport of at least 5 Sv can be found inshore of the 200 m isobath. Therefore it is not clear whether there was no Brazil Current at 23°S in October 1958, or if the Brazil Current had shifted to the west of the 1000 m isobath and onto the shelf.

The Brazil Current flowing along the shelf edge, or on the shelf itself, might also be a problem in the transport estimates at 32° and 33°S (Table 1). For these sections Defant's reference depth of 1600 m is used, which lies near the core of the Upper Circumpolar Deep Water (REID *et al.*, 1977).

For the *Atlantis* IGY section at 32°S in April 1959, the two station pairs closest to the Brazilian coast show a transport of 19.2 Sv in the layer 0–800 m depth, but a strong reversal with a transport of 5.9 Sv to the north is found just to the east of those stations, which could reduce the transport to 13.3 Sv (Table 1). EVANS *et al.* (1983) obtained a transport of 13 Sv at this *Atlantis* IGY section above 1000 m, but did not explain how they derived it.

The *Melville* section at 33°S, from the CATO expedition, gives a southward Brazil Current transport of 12.2 Sv. The greatest velocity is 27 cm s^{-1} at the surface, and there are speeds of 10 cm s^{-1} or more above 620 m depth at the westernmost station pair. The western station is at the continental rise in about 850 m of water, so there is a strong possibility of significant transport west of this station.

The CATO expedition by the *Melville* covered an area larger than just the Brazil Current region. Its quasi-synoptic survey extended out east of the Rio Grande Rise, and south of 40°S. The transport field of the upper 800 m is computed here for that region of the western South Atlantic in November and December 1972. Defant's reference depths of 1300–1600 m are used. It is assumed that the transport of 9.9 Sv at 24°S (Table 1) represents the major transport of the Brazil Current, and that no significant transport occurred on the shelf. With this assumption the transports are computed along the sections and between stations of different sections. The resulting transport field (Fig. 4) shows a Brazil Current of 10 Sv close to the 1000 m isobath at 24°S. South of 28°S a recirculation cell of 7.5 Sv is found which increases the Brazil Current transport to 17.5 Sv at 33°S. There is a southward transport of 5 Sv west of the westernmost station at 33°S, which is plausible from the velocity distribution described above. The Brazil Current transport of 17.5 Sv at 33°S agrees well with the slightly larger value of 19 Sv at 38°S given by GORDON and GREENGROVE (1986). The extension of the Brazil Current east of the Brazil–Falkland Confluence Zone can be seen in the lower portion of Fig. 4. GORDON and GREENGROVE (1986) noted that the Brazil Current becomes more diffuse in its extension to the east. PIOLA *et al.* (1987) computed the surface circulation of the southern world oceans from drifting buoys. While their surface velocity stream function for the South Atlantic shows an ocean-wide gyre with the center more to the South African side, the contours of large eddy kinetic energy in the western South Atlantic are very similar to the recirculation cell from the CATO expedition in Fig. 4.

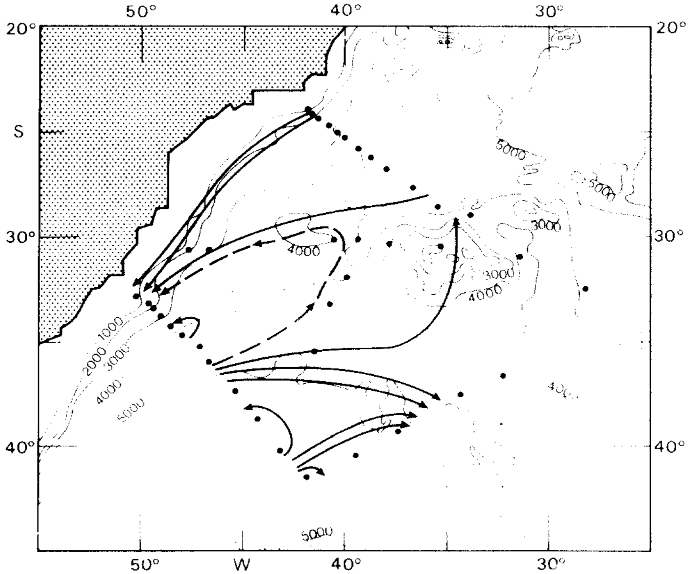

Fig. 4. Transport field of the CATO expedition profiles (dots) in November and December 1972 for the layer 0–800 m. Each flow line indicates 5 Sv, the broken line 2.5 Sv. Bathymetry is in meters (thin lines).

DISCUSSION

A major problem in investigating the Brazil Current from particular hydrographic station data is that the current may at times be along the shelf edge, or even up on the shelf, whereas often the first station on hydrographic surveys is taken in deep water, therefore excluding the landward part of the transport. This is illustrated by the transport field of the CATO expedition (Fig. 4), where the computed balances lead to transports inshore of the 1000 m isobath. Transports of 10 Sv west of the section at 30°30′S and of 5 Sv west of the diagonal section in the south are found.

Among the water masses in the southwestern Atlantic is the Upper Circumpolar Deep Water (Reid *et al.*, 1977), which is where Defant's (1941) reference depth is located. This layer lies between the northward-flowing Antarctic Intermediate Water and the southward-flowing North Atlantic Deep Water, and should thus have weak absolute motion. Consequently, the choice of Defant's reference depth appears to lead to useful estimates of the Brazil Current transport. Near 24°S, a reference depth at about 600 m, which also lies between water masses moving in opposite directions, leads to transport values comparable to those obtained with Defant's reference. As long as the water mass distribution is taken into account in the choice of a reference depth, the offshore computations of the geostrophic transport of the Brazil Current lead to good results.

Still unclear is the reason for the absence of the Brazil Current in the *Crawford* IGY section at 23°S in October 1958. If there indeed was no current, it must be regarded as a rare occurrence of possible interannual variability, as several other investigations clearly showed a Brazil Current at this latitude. Evans and Signorini's (1985) observations suggest that it might have shifted onto the shelf. Whatever the reason, it probably is not due to a seasonal signal. The CATO expedition took place in the same season as the *Crawford* section, but the CATO data give a strong Brazil Current at 24°S. Furthermore, hydrographic sections taken at 23° to 24°S in February (*Oceanus*, Table 1) , in April (Evans and Signorini, 1985), in July (Signorini, 1978) and November (*Melville*, Table 1) of different years all lead to geostrophic transport values for the Brazil Current of 9–11 Sv, strongly suggesting that no large seasonal signal in the baroclinic transport of the Brazil Current at this latitude exists.

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