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Near-equatorial eddies off South America

Abstract A considerable amount of the Amazon River water that is discharged into the equatorial Atlantic is then advected northward along the shelf by the strong North Brazil Current (NBC). Being relatively fresh, this water remains in the near-surface layer and can serve as an excellent tracer for the complex and variable flow of the offshore mesoscale eddies. Both surface salinity observations and CZCS (Coastal Zone Color Scanner) imagery can be mapped to estimate the circulation patterns of the eddies. Presented here are two sets of XBT ( expendable bathythermograph) sections that give the thermal structure of eddies off the Demerara Rise (6-9°N). They were occupied nearly contemporaneously with CZCS imagery obtained during October 1980 and November 1981. Several studies have shown from ship drift data, from CZCS observations, and from Geosat altimetry that, particularly during late summer and fall, the NBC is found to retroreflect offshore to the east, supplying the North Equatorial Counter Current (NECC) and is associated with eddies along the coast. Good agreement is shown between the CZCS and a NAVOCEANO AXBT (airborne bathythermograph) survey during this period as well as observations of surface phytoplankton and geopotential anomaly from an earlier 1964 survey. Estimates of volume transport within the eddy structure indicate that at times the offshore retroflection during spring as well as autumn can amount to $10 \times 10^6$ m$^3$ s$^{-1}$. The pronounced eddy variability off South America is shown by comparing a number of past hydrographic surveys. These suggest that considerable spatial variability can occur as can seasonal changes in volume transport of the NBC and the associated eddy circulation.

Introduction

Conservation of vorticity (Csanady 1985) in the water column of the North Brazil Current (NBC) as it flows to the northwest from the equator appears to produce a complex and variable eddy field in which the coastal current in part turns offshore (Bruce and Kerling 1984). It is associated with pronounced mesoscale eddies, most often anticyclonic, generally between approximately 4° and 12°N. Observations, however, by drifter drogues (Richardson 1993) and by satellite altimetry (Didden and Schott 1993) have indicated that eddy advection to the northwest along the coast can occur, particularly during August to December.

In addition to drifters and satellite altimetry, the Coastal Zone Color Scanner (CZCS) imagery (scanning radiometer) can be useful for indicating surface flows and variability. Gordon et al. (1983) have shown that the imagery can be used to delineate warm-core rings from the Gulf Stream. Color contrasts caused by surface chlorophyll variability in different waters (especially near-coastal) can be observed with CZCS by measuring the spectral radiance back-scattering out of the ocean. Estimates can be made (within about 30%) of the phytoplankton pigment concentration (sum of the concentrations of chlorophyll $a$ and the associated phaeopigments), which might range from roughly 12.0 down to 0.10 mg m$^{-3}$ for near-coastal waters or offshore waters influenced by coastal circulation patterns.

As suggested by Muller-Karger et al. (1988), it also appears possible from satellite CZCS imagery to monitor, on occasion, the patterns of the looping or retroflection of the coastal current. The inshore portion of the NBC can advect Amazon River outflow water, which is relatively fresh, near surface, and phytoplankton-rich, to the northwest. Some of this water can be looped offshore in the eddy-like features that are formed. A map of temperature at 100 m depth from a near-synoptic airborne bathythermographic (AXBT) survey (13–20 September 1983) clearly indicates the general circulation pattern of the retroreflecting upper layer (Fig. 1) during this period near 10°N. Because of the relatively closely spaced stations, the mapping
suggests that a considerable amount of smaller scale variability can also occur in the form of eddy-like structures.

**CZCS imagery and XBT sections**

We have been fortunate to have obtained two sections of XBT stations passing through the central portion of the offshore eddies at the time relatively clear satellite images of the CZCS were recorded in the same general location (Figs. 2 and 3). In these figures, the CZCS imagery clearly shows the eddy structure in patterns somewhat similar to the observations of the Gulf Stream warm-core rings (Gordon et al. 1983). In Fig. 2a the imagery shows the autumn 1980 coastal flow in part turning offshore near 8°-10°N, while the inshore portion continues northward. The offshore flow, initially orange and red (≈2-7 mg m⁻³) in the color coding, turns to light blue (≈0.2-0.3 mg m⁻³) in the retroflected loop around the eddy boundary. To the south (5°-6°N), there is a boundary region where a more southerly offshore flow occurs. These eddy-like features and their boundaries where pronounced upwelling occurs (6°-7°N, 9°-10°N) are clearly seen in the temperature structure (Fig. 2b) obtained almost contemporaneously (5-6 days earlier) along a section of XBT stations (every ≈45 km) (Bruce 1984) on 28-29 September 1980.

The following year, in late autumn 1981, a relatively cloud-free CZCS image was obtained, indicating a strong retroflection plume near 9°-10°N (Fig. 3a) with the color code showing mean pigment values of about 0.2-2.0 mg m⁻³. A single fairly distinct eddy is shown in the CZCS imagery. Approximately one day later (21-22 November 1981), the XBT section of Fig. 3b was occupied, passing nearly across the middle of the eddy. As was the case in Fig. 2b, the temperature contours show strong upwelled regions near 6°-7°N and 8°30'-10°N. The mixed layer in the central region of the eddy appears to extend down to about 150 m depth. Both Figs. 2b and 3b indicate that the horizontal gradients in the upper thermocline region were relatively intense (up to 13°C over 50 km) near the eddy boundaries.