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Equatorial currents at 1000 m in the Atlantic Ocean

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Abstract. Twenty-seven Profiling ALACE (PALACE) floats were deployed in the equatorial Atlantic during July-August 1997. The floats were ballasted to drift at 1000 m for 10 to 14 days, return to the surface while obtaining a temperature profile, transmit data via satellite, and then after one day return to 1000 m. One-year float paths are now available. Floats deployed on the equator were launched into a deep westward jet. The jet extends some 1°-2° north of the equator, with eastward motion observed in floats to the north of 2°N. The equatorial current reverses in the central basin to the east in mid-October and then back to the west in mid-February. Flow to the north also reverses. The short space and time scales contrast with earlier work based on fewer floats that inferred space scales of some 5°-10° in latitude and time scales greater than one year. The new results are consistent with models that indicate that equatorial Rossby waves are the cause of the reversing currents.

Introduction

Twenty-seven Profiling ALACE (PALACE) floats were deployed in the equatorial Atlantic as part of the Atlantic Circulation and Climate Experiment, the last field phase of the World Ocean Circulation Experiment. These floats were ballasted to drift at 1000 m. Herein, we use the first year of trajectory data to describe the circulation at 1000 m between 6°S and 6°N from July 1997 through July 1998. We begin with a description of the data followed by a discussion of results and a summary placing these results in the context of earlier studies.

Data

Twenty-seven PALACE floats were deployed along 6°S, the equator, and 6°N during a July-August 1997 R/V *Seward Johnson* cruise. Float technology is described in *Davis et al.* [1992]. Floats are ballasted to drift at a desired depth (1000 m for this experiment) for a fixed period of time (10-14 days). When returning to the surface, they collect profiles of temperature. The floats remain at the surface for approximately one day (i.e., the 1000 m trajectories are not continuous), transmitting position and profile data through the ARGOS system. Positions are accurate to better than 0.5 km. The resting depths of the floats have shallowed during the year (order 100 m), possibly because of peeling of paint, corrosion, and/or incomplete transfers of ballasting oil [D. Webb, personal communication, 1998].

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Lowered acoustic Doppler current profiler (LADCP) stations were taken just prior to a float launch. The LADCP collects vertical profiles of horizontal velocity. LADCP velocity components are accurate to about .02 m/s [*Hacker et al*, 1996].

Results

At the time of deployment, westward flow was observed along almost the entire length of the equatorial transect between about 500 m and 1100 m (Figure 1). A velocity core was embedded within this flow at 1000 m. The alternating patterns of velocity cores below 1000 m are suggestive of equatorial jets observed previously in the basin [*Ponte et al.*, 1990, for example]. Except for the profile at 26°W, maximum westward speeds within the 1000 m core were greater than .05 m/s and were greater than .20 m/s at 19°W, 32.6°W, and 35°W. Except for the 40°W observation, maximum speeds occurred between 925 m and 1125 m with some suggestion of deepening in the eastern basin (Figure 1). Similar basinwide features were not observed at either 6°S or 6°N (not shown).

Trajectories comprised of 10- to 14-day segments nominally at a depth of 1000 m and one-day segments at the sea surface for the entire July 1997 through August 1998 time period are given in Figure 2. The flows in the near-equatorial band are strongly zonal except near the boundaries where largest northward components are observed (e.g., these floats became entrained in the North Brazil Current). The meridional current scales near the equator are very small (order several degrees). However, this second perception may be more a function of buoy placement than actual current structure (i.e., the buoys are typically limited to a narrow meridional strip during any time period). Finally, a general northward trend in the float tracks (beyond the surface one-day drifts) is observed.

Three-month long trajectories are presented in Figure 3. We concentrate on the trajectories resulting from floats deployed on the equator and those deployed along 6°N. We will address the following questions: what are the zonal scales of the currents; is there a series of opposing currents, each of the order two degrees wide, existing concurrently; is the entire band from the equator to 6°N reversing direction at the same time; and is some combination of these two last structures occurring?

The issue of the zonal scales of the equatorial currents is complicated by the relatively sparse array of the floats. However, the basinwide character of the westward equatorial jet is supported by the LADCP section (Figure 1) and the float trajectories from launch through late September 1997 (Figure 3a). Basinwide eastward flow between 1°N and 3°N is also supported by the trajectories between early September and mid-December 1997 (Figure 3b).

North of 3°N, it becomes more problematic to discern basin-wide current structures. For instance, from mid-January 1998

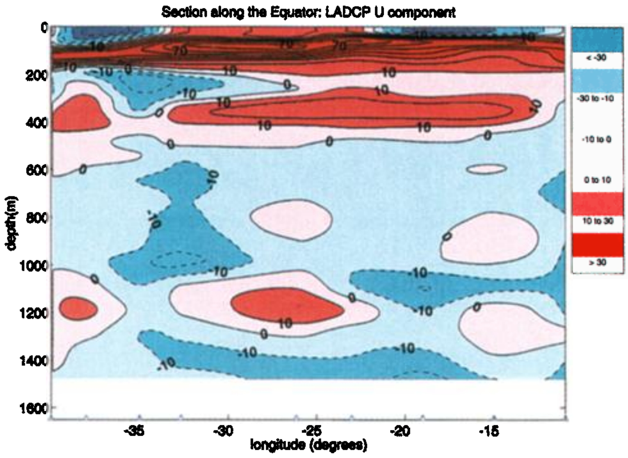

Figure 1. Vertical section of the zonal component of velocity (cm/s) along the equator obtained during a July 1997 cruise. Positive (negative) values correspond to eastward (westward) currents.

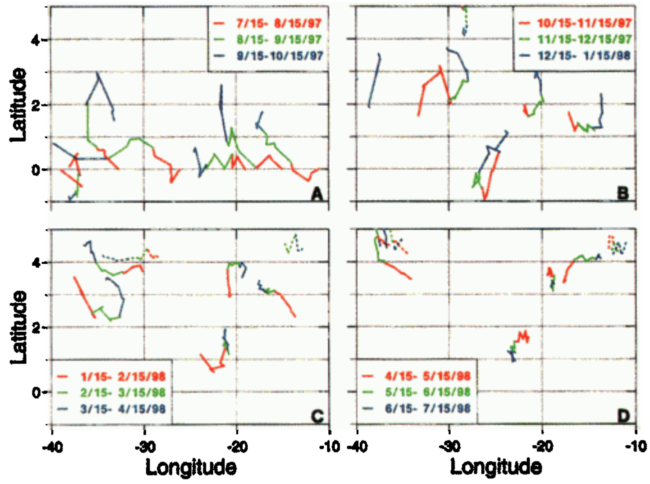

Figure 3. Three-month trajectories with dates given in the inset. The zonal axis is distorted relative to the meridional axis to provide a clearer representation of the trajectories. Colors represent month-long trajectories, with time increasing from red to blue (see inset).

through late-April 1998 the flow west of 28°W between 3° and 5°N is to the west (Figures 3c and 3d). One float at 20°W and 4°N is advected eastward at this time, while between 14°W and 18°W transport is again westward (Figure 3c).

Because of the float dispersion, the zonal scales of other features can only be inferred for limited subregions. For instance, the concurrent nature of the westward equatorial jet and eastward flow just to the north is evident in the mid-September through mid-October trajectories between 32°W and 3°W (Figure 3a), and the mid-October through late November 1998 equatorial trajectory between 24°W and 28°W (Figure 3b).

The coexistence of westward flow between 1°N and 3°N and eastward flow between 3°N and 5°N from mid-March through mid-April is shown by the trajectories between 28°W and 36°W (Figure 3c). Between 12°W and 18°W, we observe eastward flow north of 4°N and westward flow to the south (Figures 3c and 3d). This evidence argues for narrow meridional scales (order 2 degrees) of alternating flows across the basin.

Time series of float longitude are given in Figure 4. Two events can be tracked through the records. A September 1997 current reversal at about 19°W can be traced westward to 29°W (event A, Figure 4). At this westernmost latitude, trajectories show opposed flows north and south of 2.5°N that reverse direction at the same time. A similar event (B, Figure 4) begins during December 1997 at about 14°W and propagates eastward to at least to 21°W. Here, as observed with the earlier event, the oppositely directed currents north and south of 2.5°N reverse at the same time. A current reversal at 37°W during May-June 1998 may represent the westward propagation of this event. These events propagate at about .15 m/s.

Discussion

Zonal jets on the equator at subsurface depths have been observed in all three oceans [*Luyten and Swallow,* 1976; *Eriksen,* 1981; and *Ponte et al.,* 1990]. The subsurface velocity core shown in Figure 1 has similar properties to the point measurements taken in the Atlantic at the equator and 30°W during January 1989 [*Ponte et al.,* 1990] and June 1991 [*Böning and Schott,* 1993]. Maximum speed was greater than .25 m/s to the east during January 1989 and about .10 m/s to the west

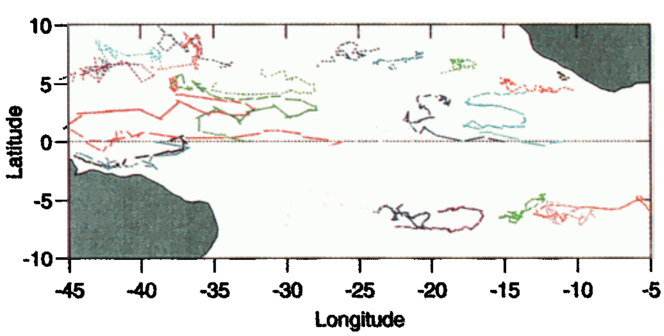

Figure 2. Composite 1000 m float trajectories, solid lines represent 10-day paths for floats deployed on the equator and 6°S and dotted lines, 14-day paths for floats deployed on 6°N . The breaks in the paths represent one-day trajectories at the sea surface.

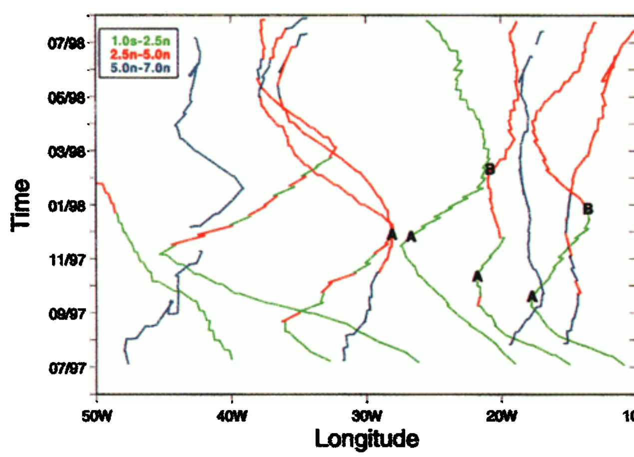

Figure 4. Time-series of float longitudes. Solid lines represent floats deployed on the equator and dotted lines, floats deployed at 6°. Latitudinal ranges are given by the colors defined in the inset. Events discussed in the text are indicated by letters.

during June 1991. The deep currents observed in the central equatorial Atlantic during January and June 1998 (Figure 3) are consistent with these earlier current directions.

Although an individual float ranges over resting depths of some 100 m to 150 m, the LADCP section suggests that at least at the time of deployment a float would still remain close to the velocity core of the equatorial jet. We have no additional direct velocity observations to determine if the vertical current structure has changed over the course of the experiment, so we implicitly assume that vertical scales remain similar to those at deployment (i.e., changes in direction represent changes in horizontal space rather than the float sampling different portions of the vertical velocity profile).

In the central basin between about 10°W and 35°W, the floats portray a circulation pattern characterized by short scales in the north-south direction. The equatorial jet extends north of the equator some two degrees of latitude (Figure 3a). Concurrently, flow in the opposite direction is observed north of this jet, also some two degrees wide. The westward equatorial flow reverses between September and November (Figure 3b) and the eastward equatorial flow reverses in the January-March 1998 timeframe. The flows between 2°N and 4°N are essentially out of phase with the deep equatorial currents.

The temporal evolution of the near-equatorial currents is very different from the time dependence of equatorial currents inferred from the SOFAR float trajectories of *Richardson and Schmitz* [1993], hereinafter RS. SOFAR floats are acoustically tracked at a prescribed depth. The RS floats were ballasted to float at 800 m. However, because of a deformation of the pressure housing, these floats probably sank some 230 m over the February 1989 to October 1990 experimental interval.

RS report that six floats "drifted eastward along the equator between 5°S and 6°N at a mean velocity of 11 cm/s; one reached 5°W in the Gulf of Guinea, suggesting that the equatorial currents at this depth extended at least 35°-40° along the equator. Three of these floats reversed direction near the end of the tracking period." One float in particular drifted eastward some 16 months along the equator, with only one 30-day period of westward drift, RS. Thus, these few floats do not portray the short meridional scales given by the PALACE floats nor the temporal variability shown during the 1997-1998 period.

In the Pacific, *Muench et al.* [1994] describe a 16-month record of directly observed, near equatorial currents obtained between 3°S and 3°N. They decompose the total velocity field into a low-vertical mode component and a residual component that includes the equatorial jets. The vertical structure of the residual component remains relatively constant over the 16-month interval, with jets moving little vertically. However, the low mode structure reverses direction after one year. Thus, a float on the equator, although still in a jet, would change direction. The structure of the jets is described in terms of Rossby waves.

In contrast, in the Atlantic, *Böning and Schott* [1993] present evidence from an eddy-resolving, primitive equation model that suggests that jet structure as well as the low mode structure varies with time. The model simulates both the wind-driven and thermohaline components of the circulation, forced in part by a seasonally varying surface wind stress distribution. The current structure below about 900 m in the model is characterized by a relatively intense equatorial current extending 2° poleward of 0°. Counter-flowing currents, some 2° wide, bound the equatorial flow. All these currents reverse seasonally. *Böning and Schott* [1993] state that the reversals "are induced by the seasonal cycle of the wind stress in the equatorial Atlantic and show characteristics of long equatorial Rossby waves with westward phase propagation of about 15 cm/s."

The float trajectories presented in this note are consistent with the Atlantic model results of *Böning and Schott* [1993]. Currents on and north of the equator reverse once during the one-year period. Also, two events propagate westward at about .15 m/s (Figure 4). However, in contrast, the period of eastward flow in the central basin is only three months. Thus, it is concluded that the analysis of the float trajectories presented provide evidence to support the model finding of deep current reversals forced by Rossby waves.

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