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Response of the Equatorial Atlantic Ocean to the 1983–1984 Wind From the Programme Français Océan et Climat Dans l'Atlantique Equatorial Cruise Data Set

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Variations of the zonal pressure gradient (ZPG) and the Equatorial Undercurrent (EUC) are described in the equatorial Atlantic Ocean (between 34°30′W and 6°30′E) as observed during eight pairs of Programme Français Océan et Climate dans l'Atlantique Equatorial cruises between October 1982 and August 1984. In 1982 and 1983 the annual cycle of weak trades early in the year, followed by comparatively strong and sustained trades, were relatively normal. In the boreal winter of 1984, the extent of the collapse of the trade winds was exceptional, and consequences were observed in the upper layers of the ocean along the equator. The 20°C isotherm depth, representative of the thermocline depth, was unusually deep along the equator in the Gulf of Guinea. A near-zero value of the ZPG was observed from the Greenwich meridian westward. An eastward surface current, separated from the EUC by a layer of reduced velocity, was observed over much the same fetch. West of 10°W the maximum velocity of the EUC showed very little seasonal variation, usually between 70 and 80 cm s^{-1}, except in the boreal fall of 1983 when it exceeded 100 cm s^{-1}. During this period (in both 1983 and 1984) the EUC transport at 23°W reached 25×10^6 m^3 s^{-1}, or twice its annual average, which derived not only from the increase in speed but also for a deepening of the current to below 100 m. It was also the season when the ZPG was strongest and has a similar amplitude at both the surface and 50 dbar relative to 500 dbar. The seasonal variations of the EUC in the Gulf of Guinea were even more pronounced. During the boreal summer and fall, the current weakened, while the local ZPG reversed direction compared to the west. The stronger penetration of the EUC into the gulf occurred in the alternate seasons when there was no local reversal in the eastward acting ZPG force. The large changes in the oceanic and atmospheric circulation during the 1983–1984 period are hypothesized to be related to the suppression of the coastal period are hypothesized to be related to the suppression of the coastal Benguela upwelling along the Namibia coast. This Atlantic equivalent to El Niño occurred 1 year after the exceptionally strong event in the Pacific.

1. INTRODUCTION

In response to the mean annual westward wind stress, the equatorial thermocline slopes downward to the west. The resultant negative (westward) zonal pressure gradient (ZPG) in the upper layers relative to a deeper reference level is important in the dynamics of the Equatorial Undercurrent (EUC). In the equatorial Atlantic Ocean, which has a pronounced annual cycle, the annual ZPG cycle is characterized by a trend of low values in the boreal spring and high values in midsummer through fall [*Katz et al.*, 1977]. The zonal wind stress on the equator also attains a minimum value in spring coincident with the southernmost displacement of the intertropical convergence zone (ITCZ). The Equatorial Undercurrent, however, does not exhibit a clear annual cycle. For example, the EUC transport was not coherently altered during a period (between July and August 1974) when the ZPG doubled. The EUC was very much in evidence during the 1963 winter when a near-zero pressure gradient occurred [*Katz et al.*, 1977]. During May–June 1979 at 28°W, in spite of a nearly constant ZPG value, the EUC transport decreased from 26 to 14 Sv during a period of intensifying trade winds. Then during July–August 1979, the zonal wind stress was nearly constant, the ZPG value increased by a factor of 2, and the EUC transport increased from its minimum (about 10 Sv) to 21 Sv within approximately 1 month [*Lass et al.*, 1980]. During March 1980 the EUC transport reached a maximum value of about 44 Sv at 28°W compared with an average of 16 Sv in the summer months when the wind stress is the strongest [*Katz et al.*, 1981]. In contrast *Lass and Hagen* [1980] deduced from various data collected at 30°W during different years that the EUC maximum velocity is reduced by two thirds in February relative to its summer and fall values. Katz and Garzoli used the continuously recorded wind at Saint Peter and Paul rocks (SPPR) (1°N, 29°W) in 1979 to compare the available quasi-synoptic First GARP Global Experiment (FGGE) data set to the theoretical results of an equatorial circulation model [*Cane*, 1979, 1980; *Philander and Pacanowski*, 1980]. Two significant periods were identified from the wind record: the month of May, when the wind stress abruptly changed from near zero to its full value (around -0.5 dyn cm^{-2}), and January or December, when the wind slowly began to relax. They deduced in accordance with the model results that when the wind weakened, the thermocline shallowed and an eastward surface current developed. It is at this time that a rapid increase in the EUC transport was observed. The EUC transport reached a maximum value in the spring, then it weakened

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toward its summer minimum 2 months after the minimum value of the wind stress was observed. The minimum value occurred, as predicted by the model, during the period when the reintensified trade wind was reestablishing the ZPG.

2. THE DATA

From October 1982 to August 1984, eight pairs of French cruises were conducted in the equatorial Atlantic Ocean as part of the joint Programme Français Océan et Climat dans l'Atlantique Equatorial (FOCAL) and Seasonal Response of the Equatorial Atlantic (SEQUAL) experiments. The principal objective was to obtain a synoptic data base for the study of the response of the seasonal equatorial thermocline to the observed wind field. Two annual cycles were observed in order to mitigate the consequences of observing an unusual year due to an exceptional forcing, such as occurred during the Equatorial Atlantic Survey (EQUALANT) in 1963. Equatorial moorings equipped with current meters and temperature sensors were deployed [*Weisberg and Weingartner*, 1986] together with inverted echo sounders (IES) and tide gauges on SPPR and São Tome island [*Katz et al.*, 1986]. Seven equatorial transects between 35°W (NE Brazil) and 6°30'E (near São Tome island and the Gabon coast) were seasonally sampled, by the R/V *Capricorne* and *A. Nizery*. The wind field was nearly continuously recorded at SPPR and at the equator and 4°W.

The data set for each FOCAL cruise consists of nearly 100 Neil Brown conductivity-temperature-depth-oxygen ($CTDO_2$) casts (0–500 m). These were spaced 30 nautical miles (~55 km) apart between 5°N and 5°S along 35°W, 23°W, 4°W, 1°E, and 6°30'E, and between 2°N and 2°S along 29°W and 10°W. Dynamic height values were averaged between 1°N and 1°S to reduce high-frequency aliasing due to equatorially trapped waves. During CTD casts, direct measurements of the flow field to 500 m were made by a profiling current meter suspended from a free-drifting, heavily loaded surface buoy. Whenever possible, the current data were checked by comparison with data from the SEQUAL and FOCAL moorings (data kindly provided by R. Weisberg and C. Colin). The two agreed well. The 500-m measurement was used to correct the drift of the surface buoy and suspension wire. The correction rarely exceeded 10 cm s^{-1}. The surface current between stations was estimated from ship drift by a Magnavox satellite navigation system. A mechanical system delayed the descent of the profiler until the buoy reached an equilibrium position. This new way to operate *Duing and Johnson*'s [1972] profiler method significantly improved our results. Preliminary results have been discussed by *Hisard and Hénin* [1984] and by *Hisard et al.* [1986]. A general comparison has been reported [*Katz et al.*, 1986] of the equatorial ZPG values provided by the $CTDO_2$ data, the thermocline depth variations as deduced from the IES, and the sea level variations from the tide gauges. Estimates of the ZPG soley on the basis of the temperature data from the equatorial moorings are reported by *Weisberg and Weingartner* [1986].

3. THE WIND FORCING

In the equatorial Atlantic Ocean west of 10°W, the annual cycle of the trade winds is related to the meridional migration of the ITCZ. This moves from a nearly equatorial position during the northern hemisphere winter to beyond 10°N during the southern hemisphere winter [*Hastenrath and Lamb*, 1977]. Barometric pressure centers over the African and South American continents regulate this annual cycle (in contrast, the ITCZ undergoes a very weak annual north-south migration in the Pacific Ocean). In the Gulf of Guinea east of 10°W, the winds are predominantly northward. North of the equator, the south-SE trades shift to form the so-called southwest African monsoon during summer and fall. The years 1982 and 1983 were characterized by strong, persistent southeast trade winds and were reported as a "buildup phase" by analogy with the Pacific Ocean prior to the onset of an El Niño [*Horel et al.*, 1986]. Then, after a final intensification of the trade winds during fall of 1983, a rapid and large scale relaxation of the trade winds occured between November 1983 and January 1984. The relaxation at that time of the year is normal, but its magnitude was exceptional. During May 1984, positive (eastward) wind stress was observed on the SPPR record [*Katz et al.*, 1986]. Such an eastward wind stress along the equator, although unusual, also occurred in 1968 [*Hisard*, 1980]. Sustained weak trades were previously noted during the 1963 boreal winter.

The wind range and consequences of this change in wind field between the 2 years tell an interesting story. North of the equator, coastal upwelling off Senegal and Mauritania, which had been weak for several years, strengthened during the 1984 boreal winter owing to strong northeast trade winds. This replaced a dusty, sandy continental wind (the so-called Harmattan) from the Libya anticyclone. At the equator a large band of doldrums was observed. It was characterized by two bands of maximum cloudiness roughly along 5°N and 5°S clearly seen from Meteosat imagery. South of the equator a severe, persistent drought condition in 1983 on the island of Fernando de Noronha (4°S, 32°30'W) was replaced by extensive rainfall. Local Brazilian newspapers at Recife and Natal which had been reporting drought (the so-called "Secas" of the NE Brazil "Sertão") during 1983, now deplored the casualties from flooding and its epidemic consequences. Rainfall conditions also changed along the Angola coast. The Benguela upwelling was sharply weakened along the Namibia coast during February–March 1984 [*Boyd and Thomas*, 1984; *Shannon et al.*, 1986]. Intrusions of warm waters (29°C) southward from Recife along the Brazil coast were also reported by the FOCAL expendable bathythermograph (XBT) program (P. Rual, personal communication, 1985). All these features were confirmed by the National Oceanic and Atmospheric Administration (NOAA) Climate Diagnostic Analysis monthly bulletin. Since that time most conditions have returned to normal [*Wagner*, 1986].

An estimate of how rapid and intense was the relaxation of the southeast trade winds during 1984 in the western equatorial Atlantic can be obtained from the wind analysis provided by the European Meteorological Centre of Reading (the European Centre for Medium-Range Weather Forecasts, or ECMWF). Figure 1 shows the wind stress at the equator and 40°W from 1982 to 1984 (S. Arnault, Y. Gouriou, and Y. Du Penhoat, personal communication). As was noted earlier, the zonal wind stress was stronger in 1982–1983 than in 1984. The main interannual difference occurred during winter and spring. The FOCAL 6 cruise in January–February 1984 thus happened to be during the most energetic wind signal of the 3 years: the relaxation from the maximum to the minimum wind stress of that period.

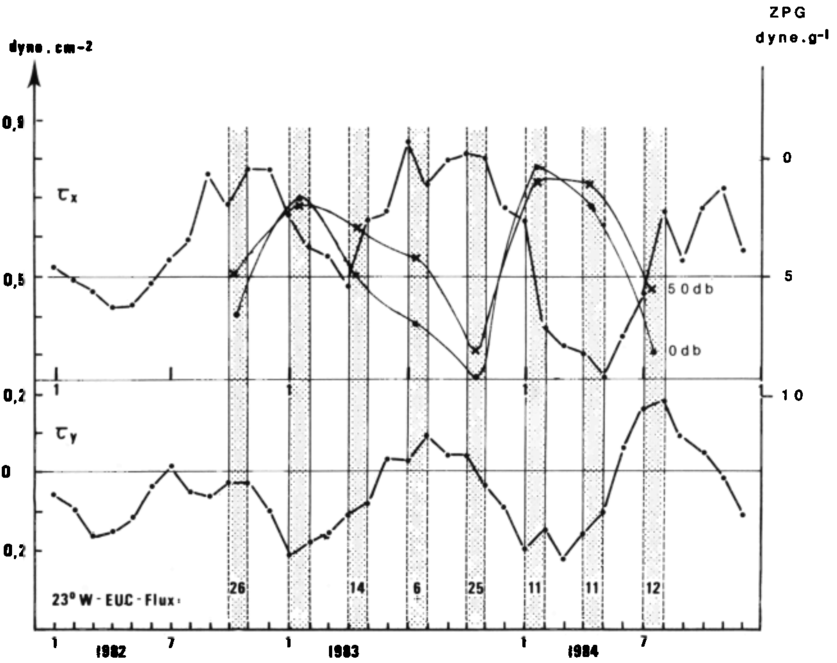

Fig. 1. Monthly averaged (top) τ_x and (bottom) τ_y zonal wind stress components (in dynes per square centimeter) at the equator and 40°W during the 1982–1984 period from ECMWF data. Superimposed are the 0-dbar and 50-dbar ZPG curves relative to 500 dbar from estimated values (see Figure 7). The EUC transport in sverdrups (1 Sv = 10^6 m^3 s^{-1}) at 23°W for the eight FOCAL cruises has been noted at the vertical of each cruise period.

4. THE RESPONSE OF THE OCEAN

The Thermocline

In Figure 2 the annual march of the 20°C isotherm (the upper part of the thermocline) is shown across the basin along the equator. The shallowest 20°C isotherm in the western Atlantic was found to occur in April during both years (FOCAL 3 and 7) despite the interannual difference in wind field. The season of the deepest expression of the thermocline, however, varied across the basin. In the western Atlantic, CTD stations between January 17 and 27, 1984 (FOCAL 6), show that the 20°C isotherm in the western Atlantic at 23°W, 29°W and 35°W was nearly as deep as that during most other cruises, including the previous year's. From the temperature observation at the SEQUAL mooring at 0°, 28°W [*Weisberg and Weingartner*, 1986], we note that shoaling begins soon afterwards (Figure 3). However, east of 20°W and in the inner part of the Gulf of Guinea during February 1984, the thermocline was unusually deep. The 20°C depth leveled out around 100-m depth from 28°W and deepened sharply between 1°E and 6°30′E (February 22 and 14, respectively). This is an exceptional deepening in the eastern sector between the 2 years. At 1°E and 6°30′E, the thermocline at the beginning of 1984 was more than 50 m deeper than it was during the comparable season of 1983. By the April 1984 cruise (FOCAL 7), with the trade wind still weak to the west, the 20°C isotherm in the Gulf of Guinea had returned to a shallower position which was somewhat deeper than its position during the April 1983 cruise (FOCAL 3). The situation returned to normal by the FOCAL 8 cruise in July 1984, when the 20°C isotherm depth was the same as that during July 1983 (FOCAL 4). The deepening of the thermocline during February 1984 in the Gulf of Guinea was confirmed by the São Tome tide gauge but, sur-

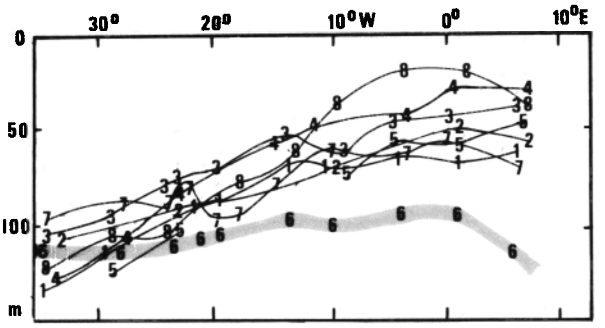

Fig. 2. Averaged values between 1°N and 1°S of the 20°C isotherm depth along the equator between 35°W and 6°30′E during the FOCAL cruises (as identified by their cruise number). Cruises 1 and 5 refer to the October–November 1982 and 1983 October–November cruises; 2 and 6 are the January–February 1983 and 1984 cruises; 3 and 7 are the April 1983 and 1984 cruises; and 4 and 8 are the July–August 1983 and 1984 cruises.

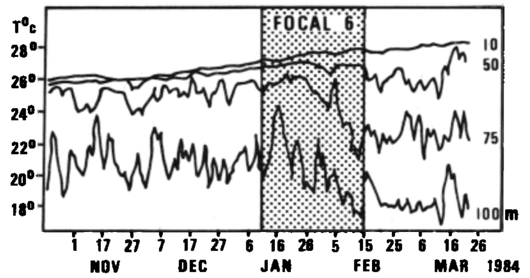

Fig. 3. Position of the January–February 1984 FOCAL 6 cruise in the temperature field variation of the equatorial SEQUAL mooring (0°, 28°W) at 10-, 50-, 75-, and 100-m depth, between November 1, 1983, and March 31, 1984, during the relaxation phase of the trade winds as seen from Figure 1. Data kindly provided by R. Weisberg.

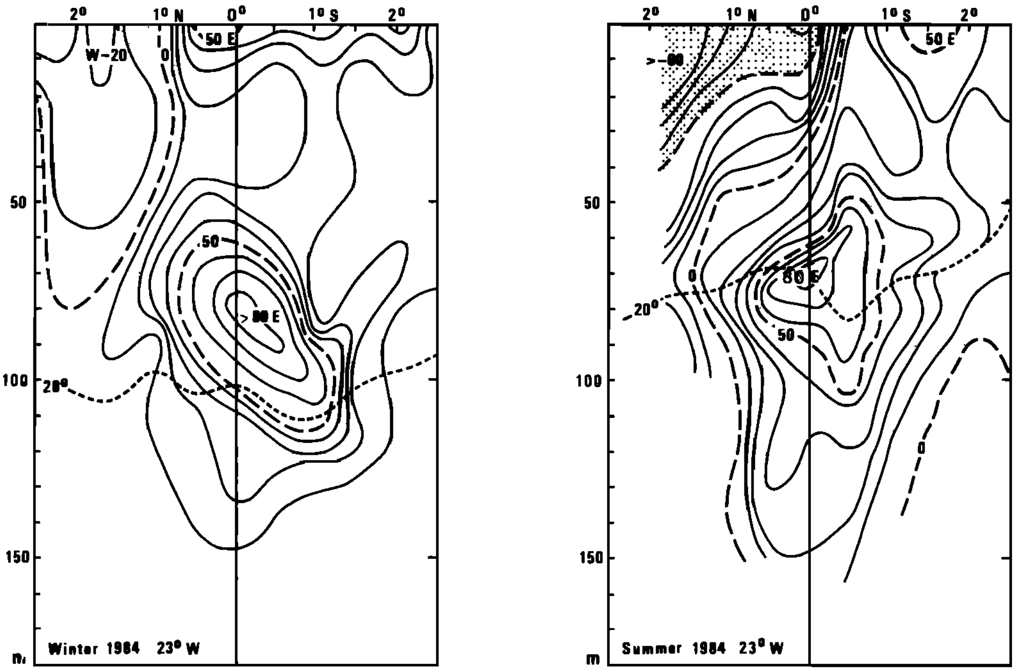

Fig. 4. Vertical distribution of the zonal component of the current at 23°W, between 2°N and 2°S, from 0- to 180-m depth during (left) the January–February 1984 cruise and (right) the July–August 1984 cruise. The position of the 20°C isotherm is indicated. Westward speeds are negative, and values above −50 cm s^{-1} are shaded. The dates of the equatorial stations are January 17 and July 10, respectively.

prisingly, not by the IES record [*Katz et al.*, 1986]. A possible explanation for this is that the higher mean temperature of the upper layer had been compensated by a lower mean temperature in the deeper layers; but there is no independent confirmation that this had indeed occurred.

The depth of the 20°C isotherm (still representing thermocline depth) is shown on the meridional sections of zonal current along 23°W during the 1984 winter and summer (Figure 4) and 25°W during April (Figure 5). A local deepening of the 20°C isotherm at the meridian of the EUC core is evident.

The basin wide thermal structure along the equator is illustrated for several seasons in Figure 6*a*. An eastward deepening of the subsurface layer isotherms, in the Gulf of Guinea, is seen for all seasons. This eastward deepening of the isotherms

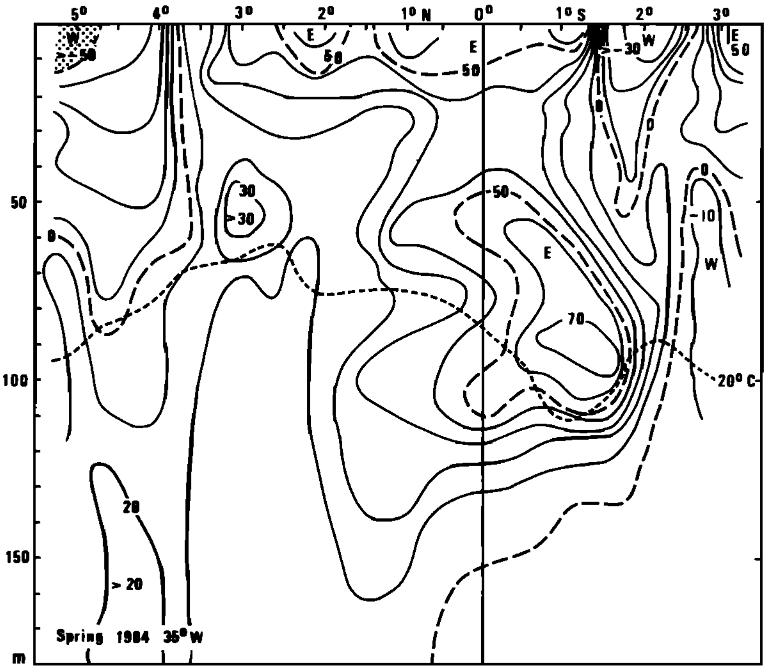

Fig. 5. Vertical distribution of the zonal component of the current at 35°W, between 5°N and 3°S, from 0- to 180-m depth during the April 1984 cruise (FOCAL 7). The position of the 20°C isotherm is indicated. Westward speeds are negative, and values above −50 cm s^{-1} are shaded. The date of the equatorial station is April 8, 1984.

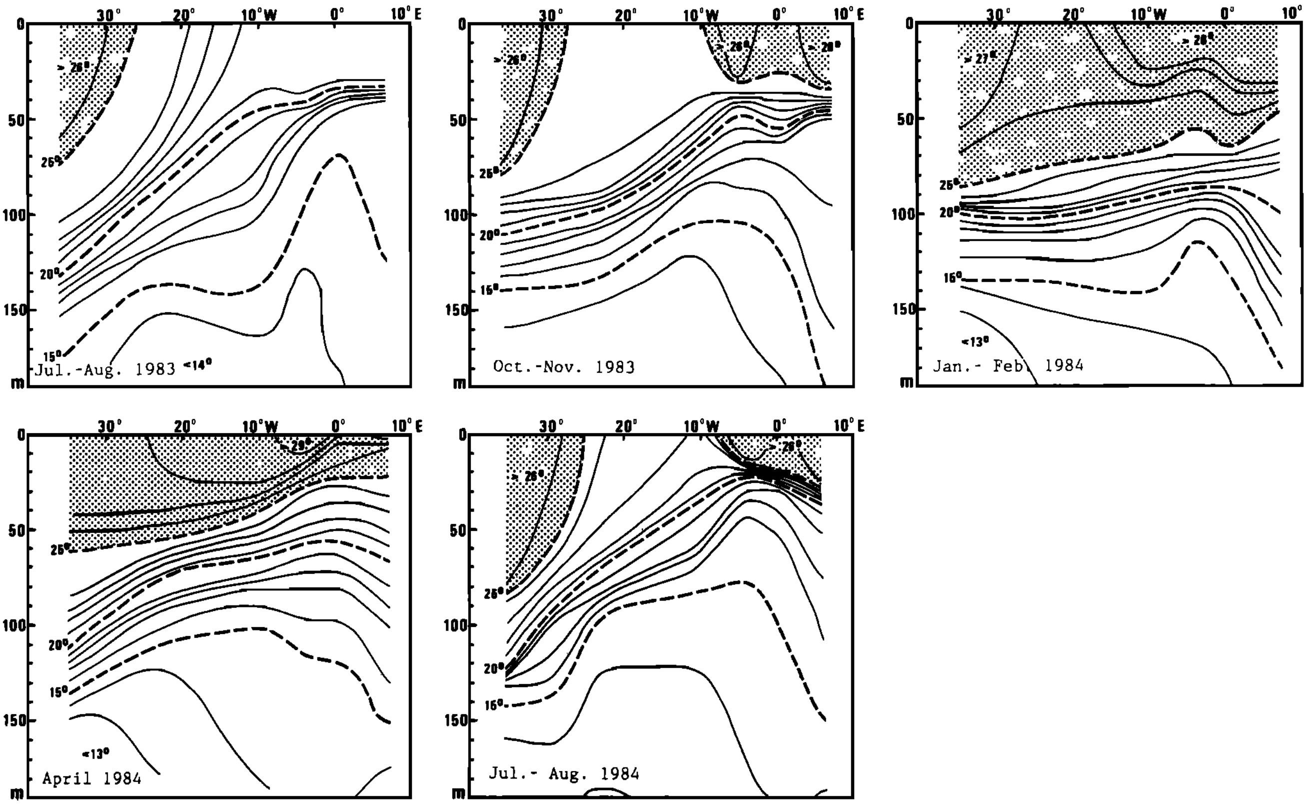

Fig. 6*a*. Vertical distribution of the temperature (in degrees Celsius) along the equator in the Atlantic Ocean from 35°W to 6°30′E from October–November 1983 to July–August 1984. Shaded areas denote temperatures above 28°C.

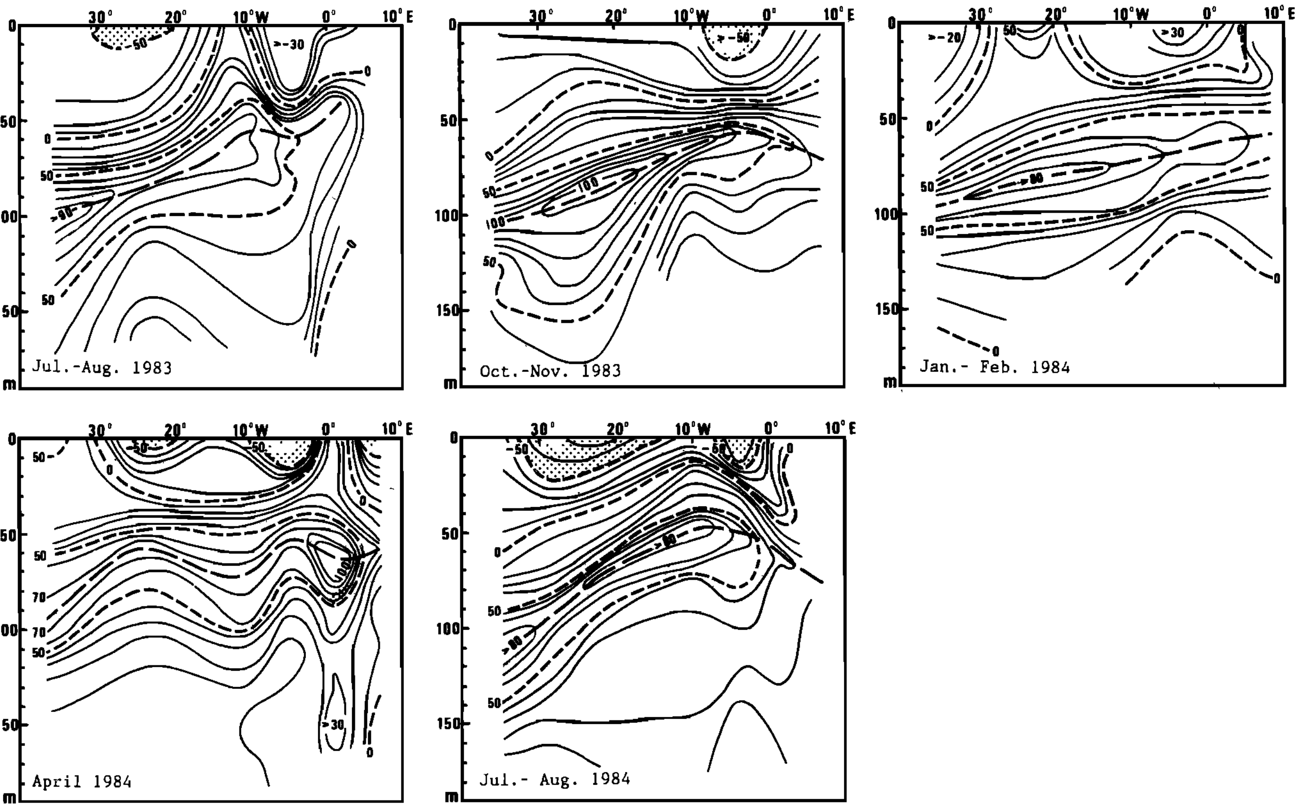

Fig. 6*b*. Vertical distribution of the zonal components (in centimeters per second) of the current along the equator in the Atlantic Ocean from 35°W to 6°30′E from October–November 1983 to July–August 1984. Shaded areas denote westward flow.

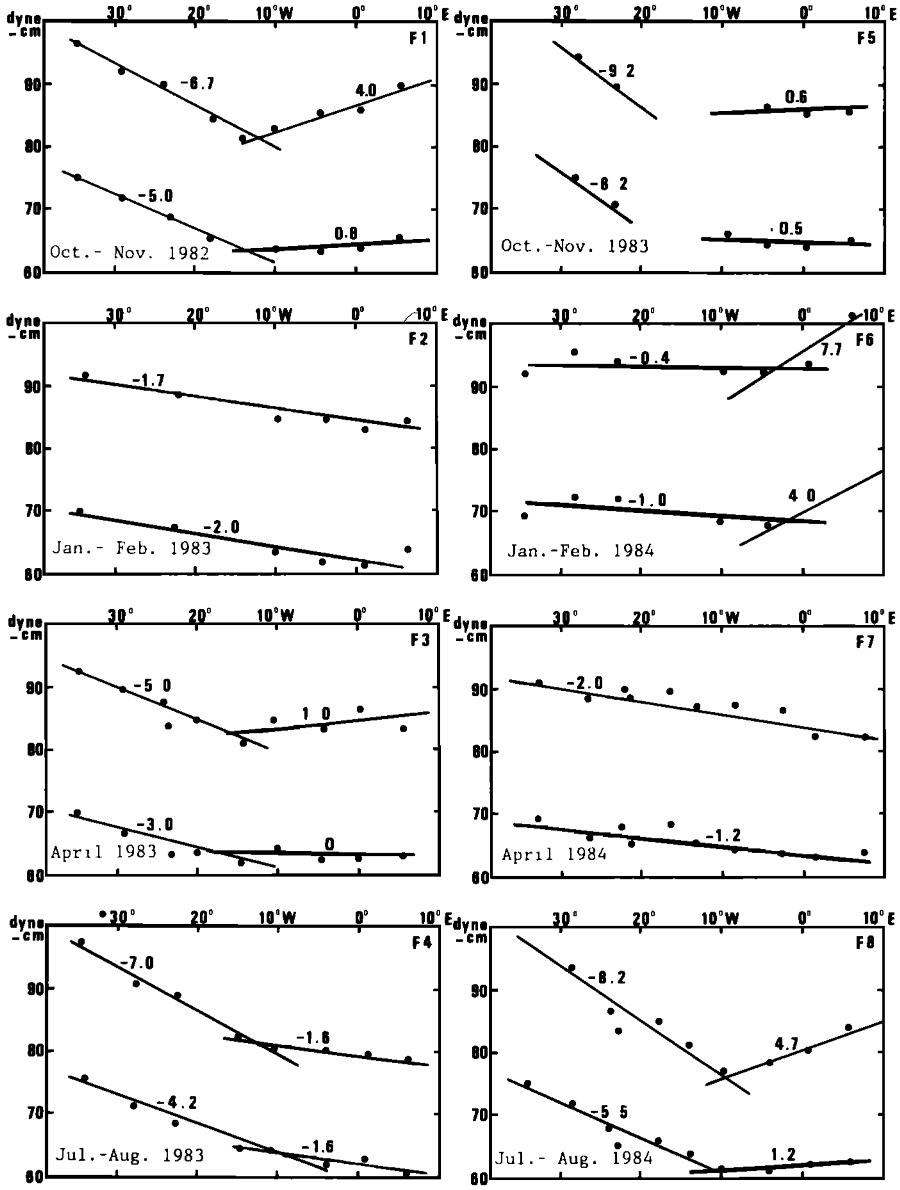

Fig. 7. The 0-dbar and 50-dbar dynamic height variation relative to the 500-dbar reference level along the equator during the eight FOCAL cruises. Dynamic height values are averaged between 1°N and 1°S. The ZPG values have been estimated from the hand-drawn lines.

(also observed in the eastern Pacific by *Meyers* [1979]) produced a ZPG reversal in the eastern Atlantic (Figure 7). The longitude where this reversal occurred can sometimes be as far west as 12°W (fall 1982). The reversal of the ZPG was first hypothesized to be a consequence of the SW African monsoon, and *Neumann* [1960] even incorrectly suggested that a westward undercurrent might result from the reversed ZPG. *Lukas* [1981] came to the conclusion that the ZPG reversal in the Pacific Ocean results from the EUC's impinging upon the coast of Ecuador. The proximity of an eastern boundary as well as a northern boundary (latitude 5°N) suggest that the dynamics controlling the EUC in the Gulf of Guinea may be very complex relative to upstream in mid-ocean.

The Zonal Pressure Gradient and the Undercurrent

The eastward weakening of the EUC around 4°W was much more rapid during summer and fall, when the ZPG reversal was most pronounced, than during winter and spring (compare Figure 6*b*). (The 1°E velocity maximum value during spring 1984 is probably overestimated, since profiler measurements along the 1°E and 6°30′E transects were made from the drifting R/V *A. Nizery*.) During the latter two seasons the EUC penetrated farther into the Gulf of Guinea, despite no systematic trend in the ZPG (Figure 7). It is well known that the velocity maximum of the EUC is correlated with a subsurface salinity maximum (though the latter is sometimes observed to lie shallower and to the south). A space and time diagram of the horizontal distribution of the subsurface salinity maximum (Figure 8) also suggests deeper penetration of the EUC into the Gulf of Guinea during winter and spring. A sharp difference between spring 1983 and spring 1984 is obvious. It can be related to (if not explained by) the absence of any ZPG reversal during spring 1984. The highest salinity maximum value (36.86 parts per thousand, or ppt) at 35°W in July 1984 decreased to less than 35.75 ppt at 4°W, a time of a large (but not the largest) ZPG reversal.

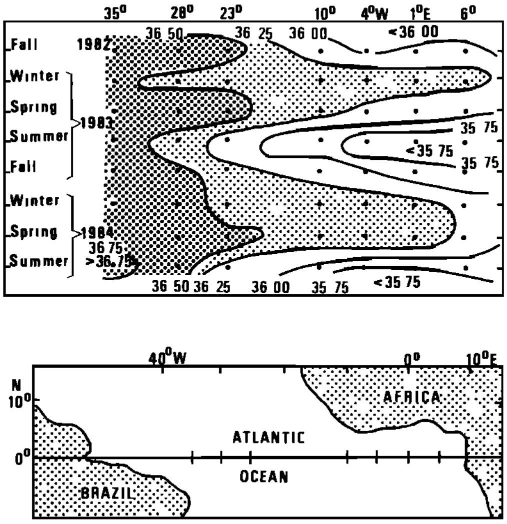

Fig. 8. Horizontal distribution of the salinity maximum value (in parts per thousand) associated with the Equatorial Undercurrent during the eight FOCAL cruises from October–November 1982 to July–August 1984 along the equator in the Atlantic Ocean.

The estimate ZPG values between 35°W and 10°W for the 0-dbar and 50-dbar level relative to 500 dbar are noted in Figure 1 for the eight FOCAL cruises. The estimated EUC transport (between 0 and 500 m; $U > 20$ cm s^{-1}) at 23°W is noted at the bottom of Figure 1. The highest ZPG values at both depths occurred during the 1983 fall cruise. The EUC transport was at its annual maximum (25 Sv) at that time. Similar conditions prevailed in fall 1982 with a similar transport and high, but smaller, values of the ZPG. Higher values of the ZPG also characterize the 2 summer months observed, but the differences between the 0-dbar and 50-dbar values are larger. This suggests that baroclinic adjustment of the isotherms was not achieved in the summer. The two summer EUC transport values were weak, with 1983's being the lowest observed (6 Sv). Low ZPG values occurred during both winters. However, the winter EUC transport was not clearly different than during the summer. The lowest ZPG value was observed during the January 1984 cruise. It coincides with the rapid deceleration of the trade wind. By April the thermocline in the east has substantially shoaled (Figure 3) and the ZPG may have begun to be restored in the west, though the zonally averaged wind stress is now at its weakest. The April 1984 ZPG value shown in Figures 1 and 7 is a fit to the data between 35°W and 10°E. If the fit is limited to 10°W, the slope is -1.0, and the difference between January and April 1984, is hardly significant.) Later, in July 1984, the ZPG value is higher than during the 1983 summer in spite of the stronger and more sustained westward wind in 1983.

At 10°W the range of variance of the EUC transport was sharply reduced. The fall 1983 transport was the weakest (6 Sv), while the summer 1984 was transport the highest (15 Sv), in contrast with the 23°W variations. The possible influence of wind stress pulses of short periods on the EUC transport [*Knox and Halpern*, 1982; *Lass and Hagen*, 1980] is a major obstacle to a more successful analysis.

Four velocity profiles from the equator and 28°W, near a SEQUAL mooring, from October 1983 to August 1984 are shown in Figure 9. The August 1984 station gave the least

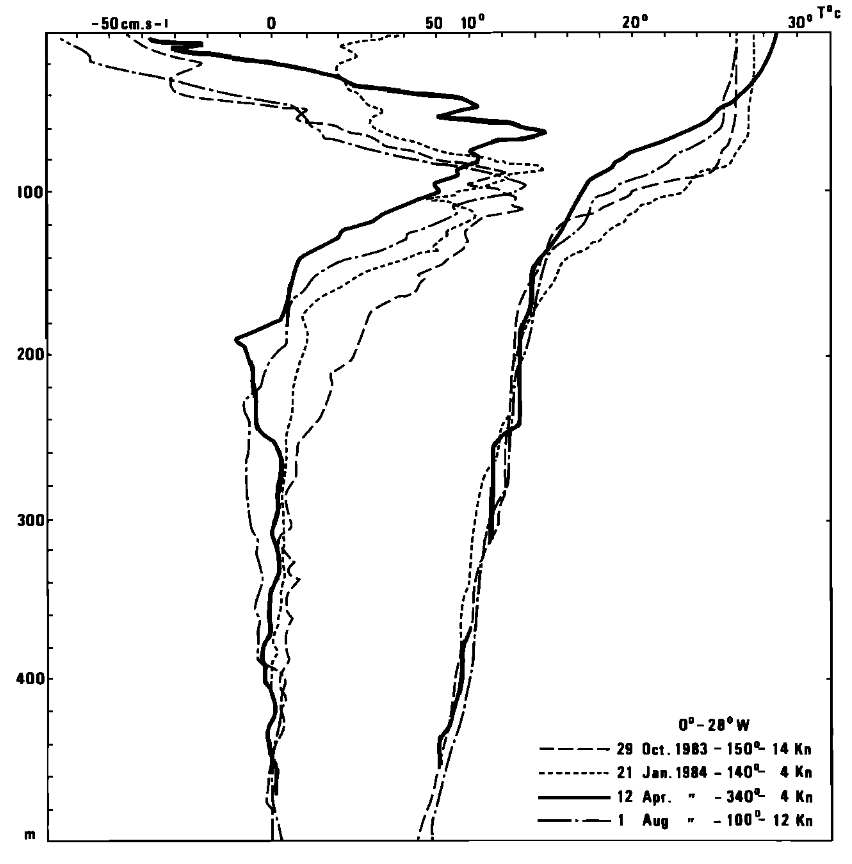

Fig. 9. Zonal component of the current and temperature variation between 0- and 500-m depth at 0°, 28°W at four periods: October 1983, January 1984, April 1984, and August 1984.

transport per unit width value (34 $cm^2 s^{-1}$ versus 70 to 80). It occurred at the same time that the local South Equatorial Current is strongest, and the interaction between the two presumably weakened the EUC. The velocity maximum was constant during the year, but its depth varied, being shallowest in April 1984. In summary, the ZPG value at 50 dbar increased from a boreal winter and spring minimum to a maximum in fall. The range scale of the values was from $1\text{–}8 \times 10^{-5}$ dyn g^{-1}. The EUC transport at 23°W was clearly highest in fall. The range of variation was from 10 Sv to 25 Sv. The quantitative correlation between the ZPG variation at the surface and the wind stress is far from perfect, but the ZPG was low when the winds were decreasing or weak and higher during periods of increasing or sustained trade winds. The values of the EUC velocity maxima at 28°W and 23°W showed little annual variation. There was, however, a possible increase from 80 to 100 cm s^{-1} during the fall. The depth of the velocity maximum at 28°W changed from 65 m in April to 110 m in the fall, in parallel with the thermocline depth variation. The depth of the reversal, from eastward to westward current above the EUC, was as deep as 50 m. When an eastward surface current developed in January, it was separated from the EUC by a layer of reduced velocity. Thus its transport should be estimated separately to avoid biasing the EUC transport value. A significant thickening of the EUC was observed during fall. The depth of the lower 20 cm s^{-1} isotach changed from 125 m in April to 205 m in fall.

The Eastward Surface Currents

Reports of eastward surface currents at the equator in the western Atlantic are not rare during the boreal winter and spring. It might be anticipated to appear when the southeast trade wind is relaxed. The oldest report was from the *Keppler* during March 1894 [*Puls*, 1895]. Such a surface eastward flux, plus the EUC below it, could be a factor in explaining the deepest 20°C depth in January 1984. The heat content at 28°W from 0 to 150 m is greatest in January 1984 (Figure 9). From Figure 4, this layer at 23°W is being transported eastward between 0°30′S and 2°30′S. During the same month, the North Equatorial Countercurrent (NECC) was anomalously strong at 23°W around 5°N [see *Hénin and Hisard*, 1987]. A little further downstream, these waters will flow into the Gulf of Guinea unless diverted northward. One might therefore suspect a link between these waters flowing into the Gulf of Guinea and a southeastward coastal current observed along the Angola and Namibia coasts. This hypothesis is supported by the observations there of equatorial species of sea fauna and by the high salinity of the observed waters [*Boyd and Thomas*, 1984; *Shannon et al.*, 1986]. On April 14, 1984 (Figure 5), a strong eastward surface flow was present between 3°N and 1°S at 35°W, but it was not observed on April 12 at 28°W (Figure 9). Presumably, the unusual events of the boreal winter of 1984 were coming to a close.

A broad eastward surface flow with speeds of up to 50 cm s^{-1} was also observed to the south of the equator at 23°W on July 10, 1984 (Figure 4), despite a westward wind. The wind along that meridian was less than that in July 1983 (zonal stress equal to -0.3 compared with -1.1 dyn cm^{-2}, as observed from the ship and averaged between 2°N and 2°S). At 10°W, the wind during the July 1984 survey blew from 190° to 210° at a speed from 1 to 7.5 m s^{-1} but from 130° to 140° at 5 to 9 m s^{-1} on August 4, 1983. During nearly all the FOCAL cruises, whatever the wind and the season, a clear but narrow eastward surface current was observed around 2°S. It linked, at the surface, the EUC flow and the subsurface South Equatorial Countercurrent around 3°–4°S [*Hénin and Hisard*, 1984]. During the summer months this eastward surface flow intensified as a geostrophic response to the uplifting of the thermocline along the equator. This uplifting is shifted south of the equator because of the persistent northward component of the trade winds. Such an eastward surface current has also been observed in the eastern equatorial Pacific [*Leetmaa*, 1982] and in the Gulf of Guinea [*Voituriez*, 1983*a*, *b*]. During the July 1984 cruise this eastward near-surface flow was unusually strong (Figure 4).

5. CONCLUSION

During 1983 and 1984 the equatorial Atlantic Ocean was forced by two different wind fields. During 1983, the trade winds were present the entire year, particularly in the western equatorial area. This situation also prevailed during 1982. By contrast, the equatorial Pacific Ocean experienced an intense El Niño event in 1982–1983. After this "buildup phase," the trade winds sharply weakened in the western equatorial Atlantic during the northern 1984 winter, while the ITCZ crossed the equator. This relaxation of the wind was very rapid during January–February 1984. The weakening of the trade winds along the equator lasted until mid-May. Eastward wind stress was occasionally observed.

The response of the equatorial oceanic structures was as follows: during fall 1983 the ZPG at both the 0-dbar and 50-dbar levels reached its greatest value. The similarity of the gradient at both levels suggests a baroclinic adjustment to the wind forcing. During January 1984, as the trades relaxed, the ZPG rapidly weakened to near zero, well before the wind stress reached its minimum. When the latter occurred, during April (at least as averaged around 0° and 40°W), the ZPG had started to develop. During July 1984, the surface ZPG was stronger than it was during July 1983 in spite of a much shorter duration of westward wind forcing.

The largest current variations were in the surface layer. As the trades relaxed, an eastward surface flow developed along the equator during January 1984. This created the conditions for a vertical circulation which deepened the thermocline layer. One month later, warm, saline waters of equatorial origin were observed along the Namibia coast. The Benguela upwelling was weakened. For the first time, an Atlantic equivalent to the Pacific El Niño was clearly depicted. It has been tentatively hypothesized that events, both on the equator and alongside Namibia, were closely related.

The data analyzed in this paper are from four pairs of 1-month-long cruises in each of 2 years. This raises questions about the statistical significance of some of the results because there is considerable spatial variability and considerable variability on time scales shorter than the interval between cruises. There are, fortunately, other data sets, including continuous time series, that were collected during the same period as part of the FOCAL and SEQUAL programs. The matter of statistical significance will be addressed once these data sets have been merged. In the meantime we draw the following conclusions from our analysis.

We claim that the so-called EUC surfacing during periods of well-weakened trades is an erroneous conclusion. When an eastward surface current occurred it was nearly always clearly separated from the EUC by a layer of reduced velocity. It is our opinion that this return flow must be separated from the calculation of the EUC transport to avoid overestimating the latter. Surface eastward velocity can reach 50 cm s^{-1} and even more. The higher-speed surface layer appears to be rather thin and would be difficult to observe with current meters below a surface mooring (the first meter is usually at least 10 m below the surface). A second potential problem with current meter moorings is that we have seen that the EUC can deepen considerably without a change in core depth. The moorings must therefore give good coverage well below the core, which is not always the case.

The sea surface slope induced by the trade winds reverses in the eastern equatorial Atlantic. To understand the EUC variations in the Gulf of Guinea, it is important to be aware of both the magnitude and westward extent of the ZPG reversal. The slope reversal can occur as far west as 12°W. The importance of the reversal at depth is revealed by the eastward deepening of the isotherms around 200-m depth. The cause of the deepening is believed to lie with the geometry of the gulf and the effect of the EUC impinging on the coast.

Knowledge of the wind stress variation in the western Atlantic, between 35°W and 40°W, is important in order to analyze the equatorial variation in the central Atlantic. Relaxation of the trade wind in the central Atlantic can lead by 1 month the relaxation further west. The wind relaxation in the central area can even coincide with a second peak of trade wind intensification in the western Atlantic. This allows for high ZPG values to the west of 30°W but a near-zero value in the central Atlantic, as was observed during 1979 [*Lass et al.*, 1983].

Relaxation of the trade wind during the boreal winter in the far west can induce a very energetic ocean response because of the larger magnitude of wind stress which is found there. This can give rise to a more rapid El Niño-like phenomenon in the Atlantic, as compared with the Pacific, since the former is a much narrower basin. The equatorial variability can be augmented by unusual large values of the NECC transport during the boreal winter. In this season the NECC flow is further south and can contribute more directly to the Guinea Current bringing new water into the Gulf of Guinea. To the south of the equator, a permanent narrow eastward surface current exists around 2°S at 23°W. This current widens during summer as a geostrophic response to the uplifted near-equatorial thermocline's being slightly shifted to the south of the equator. In some years, as during 1984, the extent of this flow is increased. Analysis of this phenomenon in terms of a south equatorial surface countercurrent would require a more detailed analysis of the wind stress curl field during the FOCAL-SEQUAL experiment.

The unusual relaxation of the trade winds along the equator during the 1984 boreal winter occurred 1 year after an intense Pacific El Niño. That this occurred following an intense Pacific El Niño is probably not a coincidence. The relaxation was associated with a large modification of the rainfall regime in areas south of the equator (NE Brazil, Angola, Namibia) where drought conditions of the last years were ended. The equatorial currents (the EUC and also a probable south equatorial surface countercurrent) cause a rapid, oceanwide transport of heat and create a new pattern for air-sea exchange. Further investigation is needed to understand the interaction between these currents and the climate variability of the region. This is an important task for the ongoing Tropical Ocean and Global Atmosphere (TOGA) experiment.

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