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In Situ Wind Measurements and the Ocean Response in the Equatorial Atlantic During the Programme Francais Ocean et Climat Dans l'Atlantique Equatorial and Seasonal Response of the Atlantic Ocean Experiment

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In situ wind measurements collected as part of the Programme Français Océan et Climat dans l'Atlantique Equatorial (FOCAL)/Seasonal Response of the Equatorial Atlantic (SEQUAL) experiment (1983–1984) in the western and eastern parts of the equatorial Atlantic basin are described. They were obtained from meteorological stations placed Saint Peter Peter and Saint Paul Rocks (SPP) (1°N, 29°W) and at the top of a surface buoy moored in the Gulf of Guinea (0°N, 4°W). From the wind observations the wind stress was inferred, and results are compared with climatology. The wind stress time series show the abrupt increase of the winds during the spring that, at SPP, reaches a value as high as 0.35 dyn/cm^2 in 2 weeks for both observed years. The 11-day running mean time series shows that the onset of the zonal component of the wind stress occurs at SPP on April 10, 1983, and on May 17, 1984, and in the Gulf of Guinea (GG) on April 5, 1983, and April 10, 1984. The monthly mean observations show an interannual variability both in the time of the onset and in the strength of the trade winds. At SPP and GG the total wind stress increases 1 month earlier than climatology in 1983 but at the same time as climatology in 1984. At SPP the zonal component of the wind stress also intensifies 1 month earlier than climatology in 1983 but 1 month later in 1984. The equatorial temperature records at 28°W and 4°W show that the depth of the 20°C isotherm, on a seasonal time scale, decreases during the relaxation period of the trade winds (boreal winter). In 1983–1984 this occurred in December 1983 at 28°W and in March 1984 at 4°W. After the onset of the local trade winds, the thermocline continues to move upward during 1 month at 28°W and during 3 months at 4°W; thereafter, the thermocline deepens at both locations. At the surface, the temperature decreases when the trade winds intensify and remains low as long as the trade winds are blowing. The seasonal variations of the temperature both at the surface and below the surface at 28°W and 4°W are interpreted in the light of the results of a nonlinear multilevel model in the cases of a sudden increase and a sudden relaxation of the trade winds.

1. INTRODUCTION

The equatorial areas of the oceans, owing to the high sea surface temperatures (SST), are of fundamental importance in the studies of atmosphere-ocean interactions. Moreover, the time of adjustment of the ocean to atmospheric disturbances is faster at low than at high latitudes. The knowledge of the wind field and its variability in the equatorial area is therefore essential for understanding the equatorial ocean response.

The first wind field observations in the open sea were provided by ships of opportunity. They gave, through monthly mean wind values, a description of the seasonal variability over the entire Atlantic intertropical zone [*Bunker*, 1976; *Hastenrath and Lamb*, 1977; *Hellerman*, 1979]. The horizontal surface wind distributions clearly show a band of confluence north of the equator, the Intertropical convergence zone (ITCZ), oriented in a southwest to northeast direction and which is located close to 10°N during August and near the equator in February. On the eastern side of the basin, the annual trade winds intensification in April–May is associated with heavy rainfalls over the northwestern area of the African continent. This corresponds to the west African Monsoon. The importance of this historical data set is undeniable (e.g., modeling studies have contributed to a better understanding of equatorial dynamics); however, these observations are insufficient to resolve space and time scales of dynamic significance. Therefore direct and continuous wind measurements were needed both to validate the wind products for the large space scales and to determine the time variability at both low and high frequencies of the wind field in the vicinity of the moored instrument.

The first in situ measurements, covering a period of time longer than one month, were obtained in 1979 during the First GARP Global Experiment (FGGE) at Saint Peter and Saint Paul rocks (SPP) [*Garzoli et al.*, 1982]. The data described the annual cycle of the wind field in the western equatorial basin. As part of the same program, data were collected during the boreal winter and spring at 0°N, 4°W in the Gulf of Guinea (C. Colin et al., Variabilités saisonnière, annuelle, et interannuelle du vent, de la temperature, et des courants dans le Golfe de Guinée, submitted to *Océanographie Tropicale*, 1987). The data showed the abrupt springtime increase in the trade winds at 29°W, as well as the dominant southeast direction at 0°N, 4°W. Because of the lack of data in summer and autumn 1979 in the Gulf of Guinea, it was not possible to study the adjustment of the ocean simultaneously at both locations and

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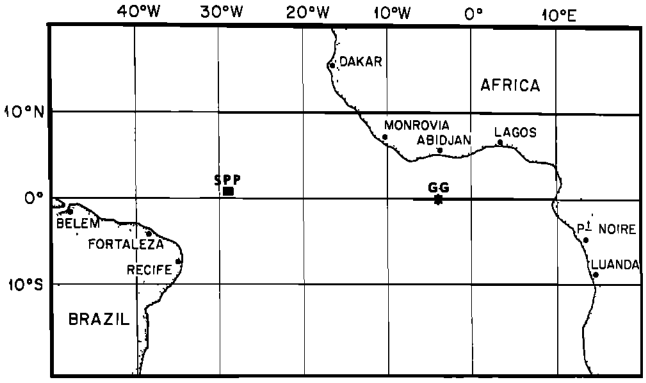

Fig. 1. Location of the two wind recorders deployed during the FOCAL/SEQUAL experiment: the asterisk labeled GG represents the Gulf of Guinea surface mooring (0°N, 4°W); the solid square labeled SPP shows Saint Peter and Saint Paul rocks (1°N, 29°W).

over a complete annual cycle. This was one of the main scientific objectives of the joint French-U.S. Programme Français Océan et Climat dans l'Atlantique Equatorial (FOCAL) and the Seasonal Response of the Equatorial Atlantic (SEQUAL) experiment carried out in the equatorial Atlantic from 1982 through 1984.

The objective of this paper is to describe and analyze the in situ wind and temperature measurements simultaneously recorded in the western (1°N, 29°W; 0°, 28°W) and eastern (0°N, 4°W) equatorial Atlantic from February 1983 through October 1984. The paper is organized as follows: the instruments are described in section 2; section 3 gives a description of the seasonal variability of the wind speed, wind direction, and horizontal wind stress components. In section 4 the seasonal variability of the wind is analyzed in relation with the local sea surface temperature and depth of the 20°C isotherm, representative of the depth of the thermocline obtained from instruments moored nearby the wind recorders; theoretical results from a general circulation model are used to interpret the oceanic response at both locations to an abrupt intensification and relaxation of the wind. Conclusions follow in section 5.

2. INSTRUMENTS

2.1. *Saint Peter and Saint Paul Rocks (1°N, 29°W)*

Saint Peter and Saint Paul rocks are an outcrop of the mid-Atlantic Ridge, an ideal site to measure unobstructed winds in the equatorial Atlantic [*Garzoli et al.*, 1982]. A description of the meteorological unit used to record and transmit the observations during the SEQUAL/FOCAL experiment is given in a previous paper [*Garzoli and Katz*, 1984]. The wind recorder was placed at the top (24 m above mean sea level) of a rock positioned at 0°55.13'N, 29°20.60'W (Figure 1). The vector mean wind velocity is computed every hour and telemetered every 3 hours through the NOAA Geostationary Operational Environmental Satellite (GOES) collection system. The two gaps in the wind records from November 20 through June 21, 1983, and from June 12 through July 25, 1984, are due to a malfunction of the equipment.

2.2. *Gulf of Guinea* (0°N, 4°W)

At 0°, 4°W (GG), in the Gulf of Guinea (Figure 1), the wind observations are obtained from a wind recorder mounted on a surface mooring. The sensors were placed at 2.5-m height above sea level. Two units were used: The first was developed by the Etablissement d'Etudes et de Recherches Météorologiques, Météorologie Nationale Française (EERM) and moored from February 1983 to February 1984. The data were transmitted through the Argos system and sampled every 3 hours. The second was developed by Aanderaa Instruments and has an in situ data recorder which collected data from the end of February 1984 until the end of September 1984. The sampling interval is 1 hour, and the data are averaged every 3 hours. The intercalibration of these two recorders was done both in the laboratory and in the field. Gaps in the wind records are due either to cuts of the mooring line by tuna boats (April 14 through May 30, 1983; October 28 through November 25, 1983; and February 5–23, 1984) or to equipment failures (March 23 through April 14, 1983, for the vane of the wind recorder; June 26 through July 14, 1984, for the entire instrument).

3. WIND DATA

3.1. *Wind Speed and Wind Direction Observed*

The daily mean values of the wind velocity and of the zonal and meridional components of the wind speed at both locations show a large annual signal. At SPP (Figure 2), the wind speed is minimum from February through April 1983 and from January through May 1984. From April through November 1983 and from May to the end of October 1984, the winds are practically constant, with a mean amplitude of about 6.9 m/s in 1983 and 6 m/s in 1984. At GG (Figure 3), the relaxation of the winds occurs at the same period of time as at SPP. Maximum velocities are reached in 1983 from June through the end of December, with a mean value of about 4.8 m/s which corresponds, according to *Wu* [1980], to a wind speed of 6.1 m/s at 24-m height, which is less than that obtained at SPP for the same period of observations. In 1984 the mean wind speed observed from May through August is 4.3

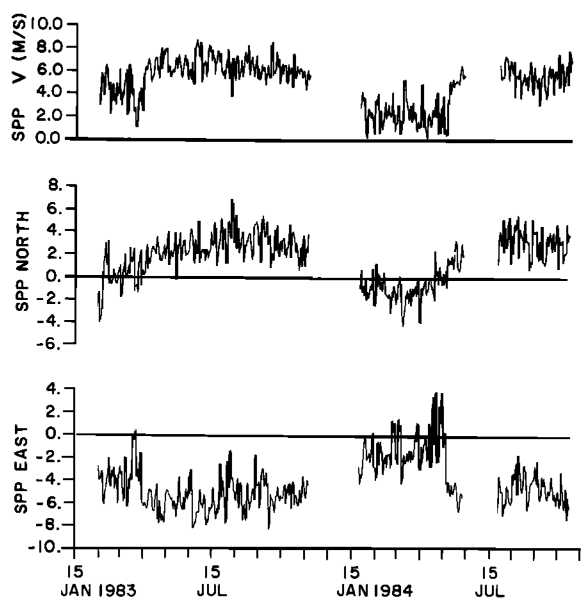

Fig. 2. Daily mean values of the total wind speed and of the meridional and zonal wind velocity components (in meters per second at SPP from February 16, 1983 to September 30, 1984.

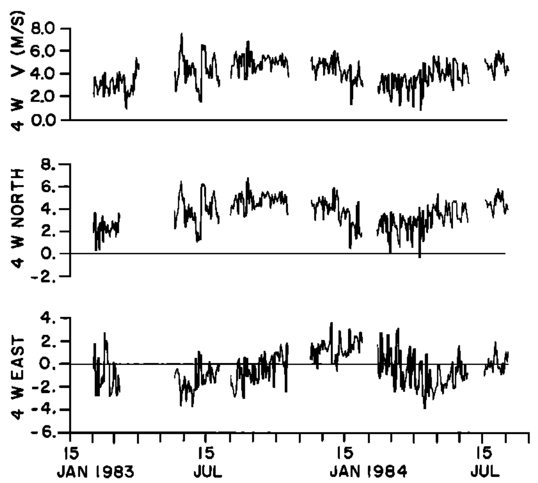

Fig. 3. Daily mean values of the total wind speed and of the meridional and zonal wind velocity components (in meters per second) at GG from February 16, 1983 to August 20, 1984 (the vane of the wind recorder was broken from March 23 through April 14, 1983).

m/s. The onset of the winds occurs at SPP around 5 weeks later in 1984 than in 1983 (Figure 2); at GG (Figure 3), the onset occurs on April 5, 1983; in March–April 1984, the onset is partially masked by the high-frequency variability which appears in the wind speed. A more detailed description of the relation between quantities obtained at different levels of measurement will be given in the next section in the discussion of the inferred wind stress.

A parameter directly related to the migration of the ITCZ and the establishment of the trades is the wind steadiness. This quantity is defined by the relation

$$ST = (\bar{U}^2 + \bar{V}^2)^{1/2}/(\overline{U^2 + V^2})^{1/2}$$

and measured in percentages (the bars indicate time averaged). Winds blowing in the same direction (trades) will have a value for the steadiness of 100% while winds blowing randomly will have near zero values. Values of the 11-day running mean steadiness have been obtained from the wind records (Figure 4) at both locations. Minima in the steadiness appear in March–April–May (Figure 4); they are associated at SPP with the passing of the ITCZ. At GG, the minimum in 1984, reflects the rotation of the wind, from the south-southwest (autumn-winter 1983) to the south-southeast (spring-summer 1984). The steadiness is higher at SPP than at GG from May through November. The reverse is observed during the relaxation period in 1984. This implies a larger latitudinal displacement of the ITCZ on the western side of the basin during 1984. The establishment of the trades (high values of steadiness) at SPP is more pronounced in 1983 than in 1984. This is a consequence of the position of the ITCZ, located north of the equator in 1983 and at the equator in 1984. At GG the direction of the wind depends on two factors which are linked: the position of the ITCZ and the development of the Sahelian low-pressure zone (SLPZ). In spring, when the ITCZ is moving northward, the wind is blowing from the southeast; in summer the direction of the wind veers to the southwest because of the influence of the SLPZ.

3.2. *Wind Stress Inferred*

The wind acts on the upper layers of the ocean through the tension it exerts at surface, the wind stress. This is the quantity used to force theoretical models of equatorial circulation and its knowledge allows a simulation of the observed temperature and current fields. The wind stress and the wind stress components τ_x and τ_y are defined by the relation

$$\tau = \rho_a C_D |V|^2 \qquad (1a)$$

$$\tau_x = \rho_a C_D |V| V_x \qquad (1b)$$

$$\tau_y = \rho_a C_D |V| V_y \qquad (1c)$$

where ρ_a, C_D, $|V|$, V_x, and V_y represent the air density, the drag coefficient, the absolute value, and horizontal components of the wind velocity measured at the height "z" respectively.

The drag coefficient is a function of the wind velocity [*Wu*, 1980]. It can be approximated by simultaneously solving the following equations, assuming the logarithmic nature of the wind profile near but not overly close to the surface:

$$|V|/V_0 = \ln (Z/Z_0)/k \qquad (2a)$$

$$Z_0 = V_0^2 a/g \qquad (2b)$$

$$C_D = V_0^2/|V|^2 \qquad (2c)$$

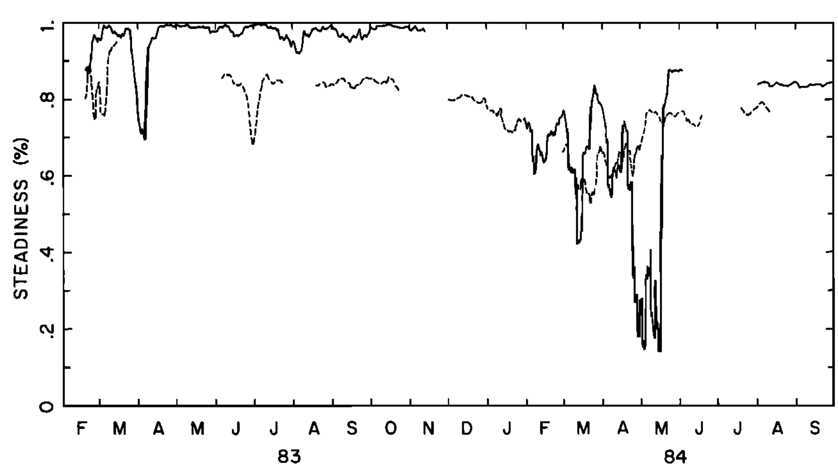

Fig. 4. Eleven-day running mean values of the steadiness for the wind speed and direction recorded at SPP (solid lines) and GG (dashed lines) during the SEQUAL/FOCAL experiment.

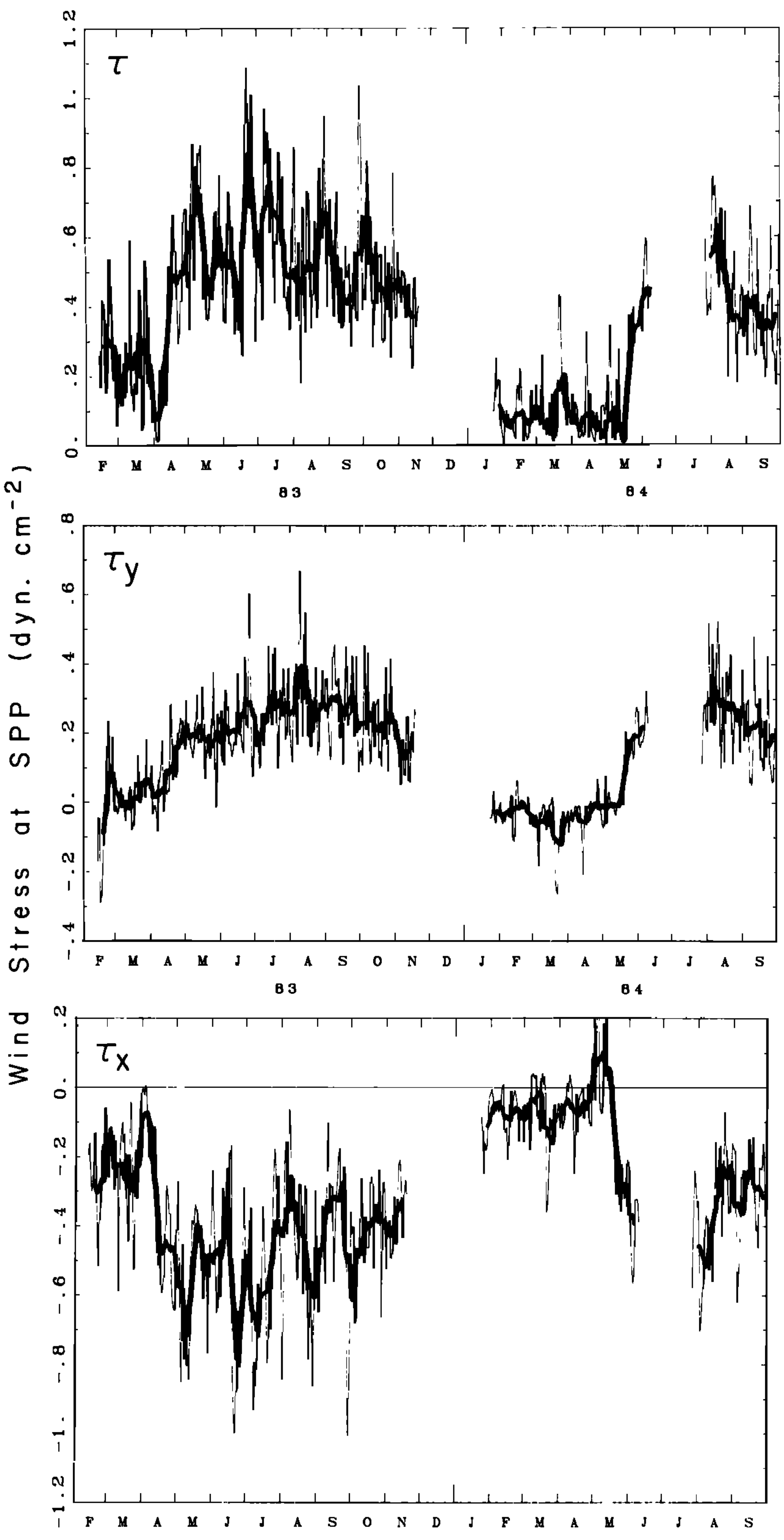

Fig. 5. Daily mean values (light lines) and 11-day running mean (bold lines) of the total wind stress and of the meridional and zonal wind stress components (in dynes per square centimeter) at SPP from February 16, 1983, to September 30, 1984.

where $|V|$ is the wind speed (in meters per second) at the height z (in meters; z is 24 m at SPP and 2.5 m at GG), V_0 is the friction velocity, Z_0 is the roughness length of the sea surface, $k = 0.4$, and $a = 0.0185$ are the Von Kármán and Charnock constants respectively, and g is the gravity acceleration.

The drag coefficient can be approximately expressed as a linear fit of the wind speed for values of $|V| < 20$ m/s. Solu-

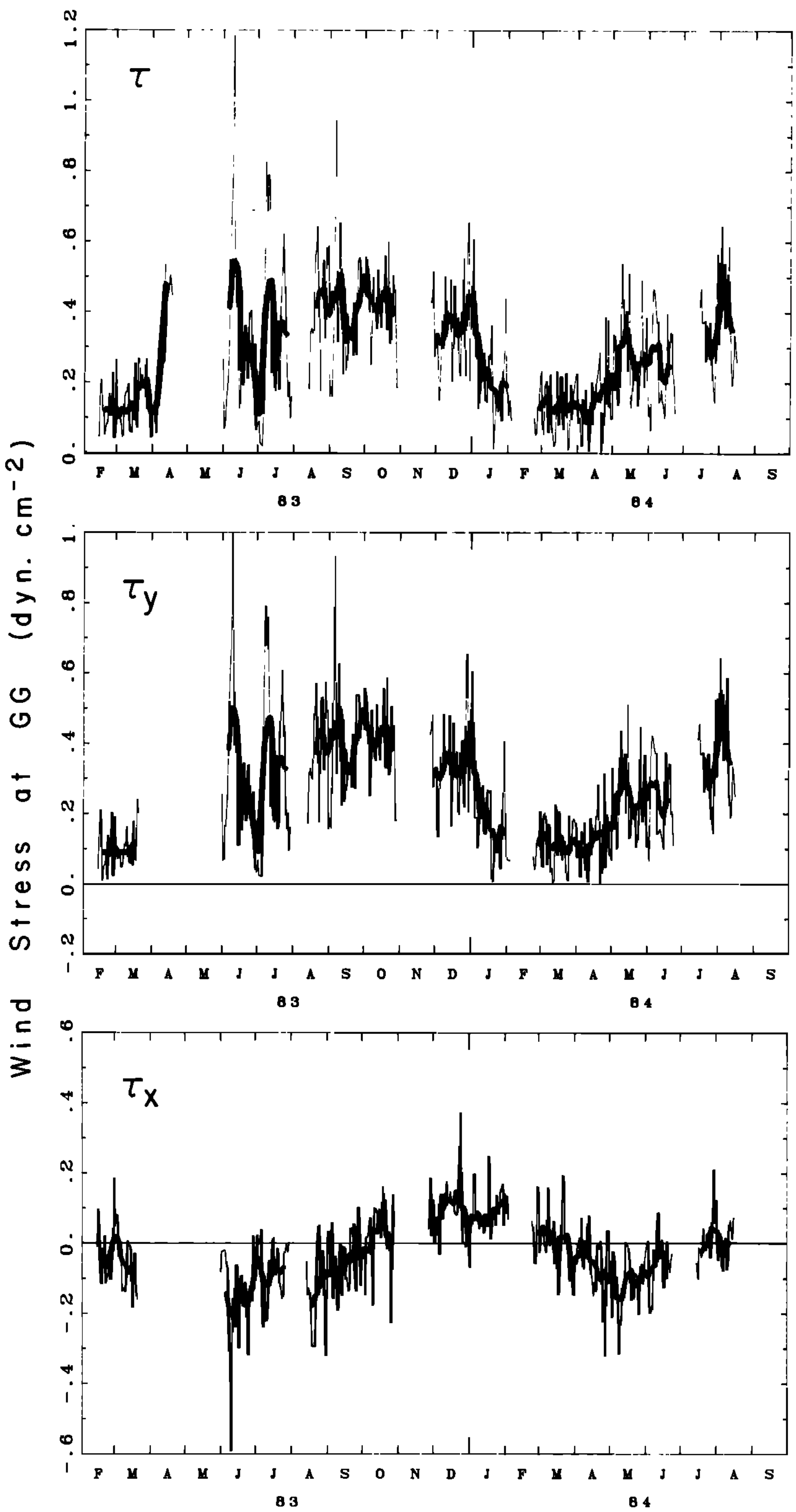

Fig. 6. Daily mean values (light lines) and 11-day running mean (bold lines) of the total wind stress and of the meridional and zonal wind stress components (in dynes per square centimeter) at GG from February 16, 1983, to August 20, 1984.

tion of equations (2) yields the following value of the drag coefficient (C_D) at each location:

At SPP [*Garzoli et al.*, 1982]

$$C_D = (0.743 + 0.0479|V|)0.001$$

At GG

$$C_D = (0.822 + 0.1870|V|)0.001$$

The daily mean values of the total wind stress and the wind stress components are shown, superimposed on the 11-day

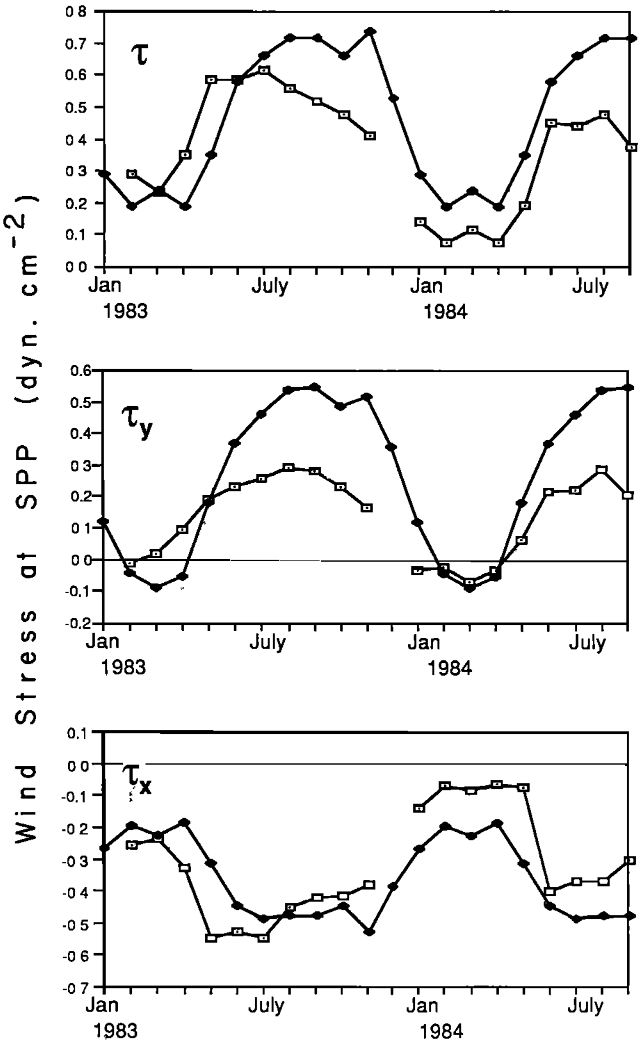

Fig. 7. Monthly mean values of the wind stress and of the wind stress components observed at SPP (open squares) and from climatology (solid diamonds). The ticks on the time axis correspond to the fifteenth day of the month.

running mean, in Figures 5 (SPP) and 6 (GG). The low-frequency variability is obviously similar to that of the wind velocity. However, according to relation (1), the intensification and relaxation periods are enhanced. The better resolution obtained with the continuous time series allows us to observe the rapid intensification of the wind stress. At SPP this occurs (Figure 5, top panel) on April 10, 1983, and on May 17, 1984 (0.35 dyn/cm^2 in a week). At GG (Figure 6, top panel), the wind stress increases on April 5, 1983, and on April 10, 1984 (i.e., almost at the same time in both locations during the first year and about 1 month apart during the second one). After the onset of the trade winds the mean wind stress at both locations is higher in 1983.

At SPP (Figure 5, bottom panel) the relaxation period is more pronounced during the second year of observations owing to a period of weak westerly winds at the beginning of May. At GG (Figure 6, bottom panel) during February the zonal wind stress is negative in 1983 and positive in 1984; moreover, the duration of the southeast trade winds in boreal summer is larger in 1983 than in 1984. From the beginning of October 1983 to the end of February 1984, the zonal component of the wind stress is positive at 4°W while it remains negative at 29°W.

In order to compare the in situ observations with the climatology obtained in the same area, the monthly mean values of the wind stress and of the wind stress components are plotted together (Figures 7 and 8); the climatological data are those calculated by *Hellerman* [1979] over 1° × 1° averaged boxes. (Please note that according to Figures 5 and 6, monthly means do not always correspond to the mean of a full month of observations.)

The monthly mean values of the inferred wind stress at SPP and GG confirm the general behavior of the mean climatic annual cycle. There are, however, three major differences: (1) The climatic total wind stress, as calculated by *Hellerman* [1979], is higher, on average, than the observed values during the 20 months of recorded data (except, however, in March–April 1983) at the two locations. From June to November 1983, for example, the difference between the in situ observations and climatology is of -0.15 dyn/cm^2 at SPP and of -0.08 dyn/cm^2 at GG, (2) The total wind stress during the wind relaxation period is weaker for the in situ observations (except at SPP in 1983) than for climatology. (3) The observations present an interannual variability both in the onset and in the strength of the trade winds. At SPP and GG the in situ total wind stress increases 1 month earlier than climatology in 1983 but at the same time as climatology in 1984; the intensification of the zonal wind stress component at SPP also occurs a month earlier than climatology in 1983 but a month later than climatology in 1984 (Figure 7). At GG (Figure 8), the onset of the zonal component of the wind stress in 1984 is in phase with climatology; in 1983 this comparison is impossible because of the lack of wind direction data. The reversal (westward to eastward) of the zonal wind stress component at GG during the boreal summer occurs a month later than climatology in 1983 but a month earlier in 1984 (Figure 8).

4. OCEAN RESPONSE

In the Atlantic Ocean the equatorial thermal structure rapidly adjusts to the seasonal wind forcing [*Katz et al.*, 1977; *Katz*, 1987]. Based on the climatic mean wind field data set, the oceanic temperature field was found to respond to the wind field both locally [*Philander*, 1979; *Philander and Pacanowski*, 1981*a*] and remotely [*Adamec and O'Brien*, 1978; *Moore et al.*, 1978; *Philander and Pacanowski*, 1980; *Cane and Sarachik*, 1981; *Busalacchi and Picaut*, 1983; *McCreary et al.*, 1984]. In particular, the strong upwelling which occurs in the Gulf of Guinea during the boreal summer depends, for a major part, on the intensification of the wind over the western half of the equatorial basin. The secondary cooling which occurs below the surface in winter at 0°–4°W, is, on the other hand, ascribed to the semiannual signal of the wind stress over the eastern half of the equatorial basin [*Busalacchi and Picaut*, 1983].

A comparison between the sea surface temperature and the depth of the thermocline, observed on the equator at 28°W and at 4°W during the FOCAL/SEQUAL experiment, was done by *Weisberg and Colin* [1986], in relation with the large-scale features of the wind field observed at SPP during the same period of time. The authors showed that instead of a slowly varying response nearly in phase with the observed easterly wind stress component, the thermocline undergoes sequences of deepening and shoaling varying in both duration and magnitude along the equator. These sequeces are related to the rapidly varying nature of the wind stress [*Weisberg and Tang*, 1985] observed in both years (1983 and 1984) at SPP rather than to the slowly varying nature of the climatology at the location. However, as was pointed out by the authors, the depth of the thermocline and the SSP are not related in a simple manner at both sites. The seasonal variability of the local trade winds has to be considered when studying the 1983–1984 oceanic response, at each site. Figure 9, adapted from *Weisberg and Colin* [1986], shows at 0°, 28°W and 0°, 4°W the time series of the 10-day running mean of both the temperature at 10 m (SST) and the depth of the 20°C isotherm (D20), which is representative of the depth of the thermocline at both locations.

4.1. *General Description*

The SST and D20 at 28°W and 4°W reveal, as do the total wind stress at SPP and GG, an annual cycle. The two SST curves are in phase, on a seasonal time scale, with a larger amplitude at 4°W than at 28°W (3°C versus 1.5°C).

Contrary to the SST, the two D20 curves are phase shifted, with 28°W leading 4°W by 2 months. The mean amplitude of the D20 vertical oscillation is also higher at 4°W than at 28°W (30 m versus 20 m). The larger amplitude of the seasonal temperature field variability at 4°W agrees more with the larger amplitude of the zonal wind stress component at SPP than at GG.

The seasonal variability of both the SST and the depth of the 20°C isotherm are now described in relation with the seasonal variability of the wind stress inferred at nearby locations from the wind field. The results are summarized below:

4.1.1. *Relaxation of the wind.* When the wind relaxes in February–March 1983 and from January through May 1984, the SST is 1°C colder at 28°W than at 4°W. This could correspond to the higher negative values observed in the zonal wind stress component at SPP than at GG in both years (Figures 5 and 6). On a seasonal time scale, the D20 begins to shallow in December 1983 at 28°W and in March 1984 at 4°W (Figure 9). From mid-February 1984 to the beginning of April 1984, the D20 are the same and might indicate a complete relaxation of the equatorial thermal structure at that time. In winter 1982–1983, no conclusive statements can be made because data are available only from mid-February 1983. However, in February–March 1983 (1) The D20 at 4°W, on a seasonal time scale, increases as in 1984, and (2) the difference in depth of the D20 at 28°W and 4°W suggests the presence of a zonal temperature gradient which could be explained in 1983 by the persistence of weak southeasterly winds during that period of time, compared with 1984.

4.1.2. *Onset of the wind.* After the onset of the trade winds, the SST decreases at both locations and for both years. The decrease of the sea surface temperature at 4°W occurs before the increase of the winds at SPP. This is particularly obvious in 1984. At 28°W the D20 continues to decrease (the thermocline is moving upward) after the onset of the winds at SPP; this lasts for a period of about 1 month in both years, and then the D20 increases (the thermocline is moving downward), more abruptly in 1984 than in 1983 (Figure 9). At 4°W the shoaling of the thermocline lasts for more than 2 months after the onset of the local trade winds both in 1983 and 1984.

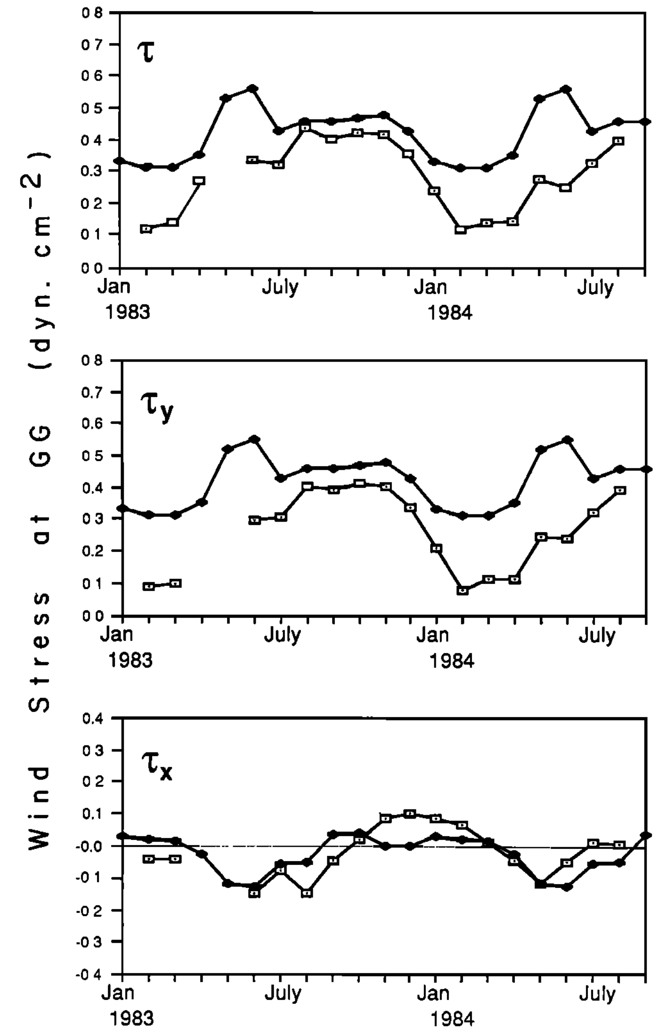

Fig. 8. Monthly mean values of the wind stress and of the wind stress components observed at GG (open squares) and from climatology (solid diamonds). The ticks on the time axis correspond to the fifteenth day of the month.

After that, the thermocline stays close to the surface until the end of July in both years.

4.1.3. *Trade wind period.* During the period of high trade winds, the mean SST at 28°W is higher than that at 4°W (26.5°C versus 23.5°C in 1983 and 26°C versus 25°C in 1984). Theoretical results show that the stronger the winds, the deeper the thermocline is and the higher the SST is in the west. This is in agreement with the magnitude of the wind stress observed at SPP in 1983 and 1984. At 4°W, the SST is lower (higher) when the trade winds are stronger (weaker). The SST remains low at both locations as long as the zonal component of the wind stress is negative. However at 4°W, the SST does not increase while the zonal wind stress is zero in September 1983 and August 1984. This might be due to meridional advection of cold waters upwelled south of the equator, in the divergence band [*Voituriez*, 1983]. At the end of September 1983, the SST linearly increases at 4°W owing to the change in sign (westward to eastward) of the zonal wind stress component, while at 28°W, the SST remains relatively constant (Figure 9). From mid-October 1983 through mid-

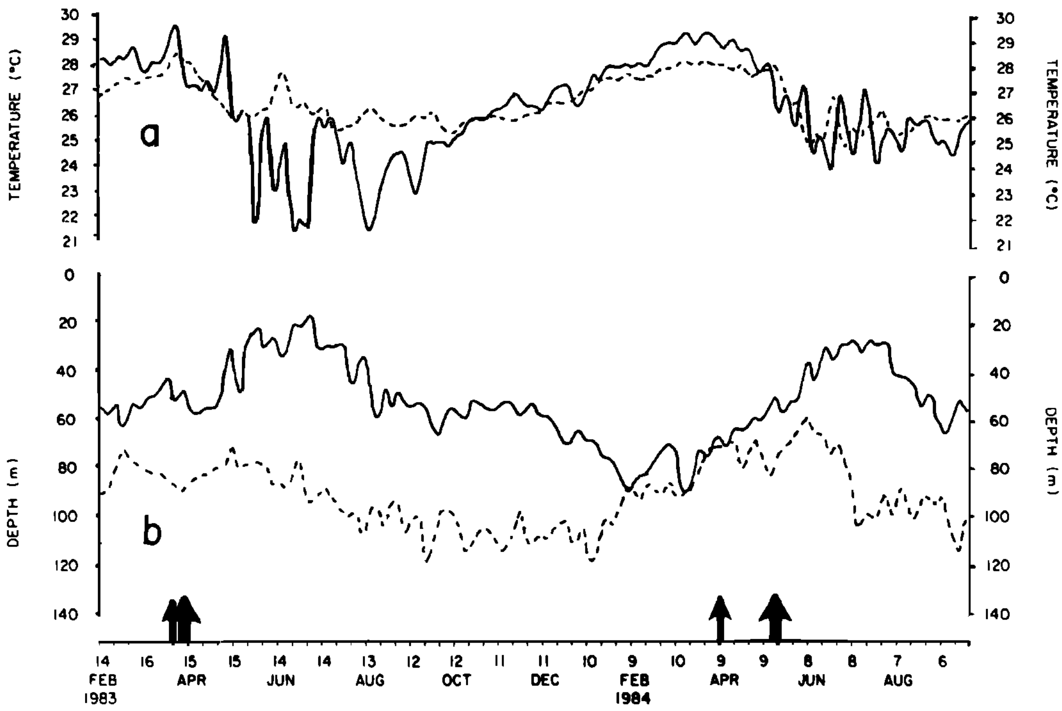

Fig. 9. Daily mean values of (*a*) the temperature at 10-m depth and of (*b*) the depth of the 20°C isotherms at 0°N, 28°W (dashed line) and 0°N, 4°W (solid line) from February 16, 1983 to September 25, 1984. The light and bold arrows indicate the increase of the trade winds at GG and SPP, respectively. (Adapted from *Weisberg and Colin* [1986]).

February 1984, the two mean SST are of the same magnitude and increase at both locations.

The deepening of the thermocline at 4°W occurs at the end of July for both years, although the onset of the trade winds is observed at SPP 5 weeks later in 1984 than in 1983. This deepening coincides with the decrease in the westward zonal wind stress component at GG at that time. From mid-October through mid-December 1983 (Figure 9), the depth of the thermocline at 28°W remains constant; at 4°W, the D20 slightly decreases from the beginning through the end of October and increases again from mid-December to mid-February 1984. The decrease of the temperature appars more clearly when looking at the temperature records at 60- and 85-m depth (Figure 3 of *Colin et al.* [1987]). At that time, the local zonal wind stress component is positive (to the east) and is therefore unable to maintain a locally (Ekman) forced upwlling; it induces, on the contrary, a deepening of the thermocline there. The wind distribution west of 4°W must therefore be taken into account to explain this secondary temperature minimum. *Weisberg and Tang* [1987] showed, from a reduced gravity model, that the abrupt increase of the wind along the equator in spring is sufficient through equatorial wave guide dynamics to produce such a temperature minimum in the Gulf of Guinea.

4.2. *Discussions*

As a first approach, the results obtained from a nonlinear multilevel model are used in the cases of a sudden onset [*Philander and Pacanowski*, 1980] and a sudden relaxation [*Philander and Pacanowski*, 1981*b*] of a uniform easterly wind, to interpret the temperature fluctuations observed both at 28°W and 4°W. This approximation agrees with a schematic description of the observed zonal component of the wind stress at SPP (Figure 7).

When the uniform easterly wind is turned on, the SST on the equator at a point in the center of the basin decreases rapidly for the first 30–35 days. The SST at first drops at the surface from 24°C to 17°–18°C (see Figure 9 of *Philander and Pacanowski* [1980]), then it remains constant for 30 more days, and thereafter slowly increases. In the west (east), the duration and the intensity of the SST cooling are shorter and weaker (longer and stronger) than in the central part of the basin. This is due to the time required for the Kelvin wave front, initially excited at the western boundary, to propagate along the equator. This is in good agreement with the observations obtained both at 28°W and 4°W. Fifty days after the onset of the wind, the zonal SST gradient has already reached its maximum value and remains constant thereafter. Below the surface, at 112.5-m depth, the temperature in the central part of the equatorial basin also decreases after the onset of the winds; this decrease lasts only 20 days and moreover has a smaller rate than the one found at the surface. This result is in agreement with the in situ temperature observations at 28°W; at 4°W, however, the increase in temperature lasts 2 months; this difference can be attributed to the upwelling produced by the meridional component of the wind [*Philander and Pacanowski*, 1981*a*]. Six months after the onset of the uniform wind, a secondary temperature minimum appears in the subsurface thermal field, with an amplitude larger in the east than in the west. The amplitude of this semiannual signal is enhanced in the linear case.

When the uniform easterly wind is turned off, the strong zonal temperature gradient at the surface is reduced 3 months later by a factor of 5. The heat has been redistributed zonally by means of advection in order for the thermocline to reach a horizontal position again. The warming of the upper ocean, which lasts 2 and 3 months at the longitudes of 28°W and 4°W, respectively, is stopped by the Kelvin wave front initially excited at the western boundary. If the relaxation period is of the order of 150 days, which corresponds to the adjustment time of the equatorial Atlantic basin [*Cane*, 1979], the thermocline is in a horizontal position again. This could correspond to the situation observed in February–March 1984 (Figure 9). If the relaxation period of the winds is considerably less than 150 days, the ocean does not have enough time to relax, and a significant difference in the depth of the thermocline at both locations must prevail. This could correspond now to the situation observed in February–March 1983 (Figure 9). In that case however, the model does not reproduce the SST distribution as it appears in the in situ observations: lower SST values at 28°W than at 4°W. When the winds are still easterly in the west but westerly in the east, the response given by the model shows that the SST remains constant in the west but rapidly increases in the east because of the deepening of the thermocline there. This is the situation found in November 1983 at the equator, where the winds were southwesterly at GG and southeasterly at SPP (Figures 5 and 6).

5. CONCLUSIONS

Synoptic and continuous in situ wind measurements obtained at 1°N, 29°W and at 4°W at the equator in the equatorial Atlantic basin during the FOCAL/SEQUAL experiment allowed, for the first time, a precise description and comparison of their seasonal variability.

The time series of the wind velocity show two different situations: (1) a relaxation period which is observed from at least February through April at both sites in 1983 and from January through April in the Gulf of Guinea and from January through May at Saint Peter and Saint Paul rocks in 1984 and (2) an abrupt intensification, particularly in the west, after which the wind speed remains constant until at least mid-November in the west and until the end of December in the east. The inferred total wind stress shows an abrupt increase which occurs at SPP on April 10, 1983, and on May 17, 1984. At GG this happens on April 5, 1983, and April 10, 1984. In both years the increase of the total wind stress appears at the eastern location first. The negative values of the zonal wind stress component observed during the boreal summer are larger in 1983 than in 1984 at both locations. After September 1983, the zonal wind stress component is positive at GG, showing the absence of a semiannual signal in the westward component. The comparison between the climatic and the FOCAL/SEQUAL monthly mean wind stress values show, both at SPP and GG, an increase of the in situ total wind stress 1 month earlier than climatology in 1983 but at the same time as climatology in 1984. This is not true for the in situ zonal wind component at SPP in 1984, which increases 1 month later than the climatic one. At GG the rotation of the wind from the southeast to the southwest in boreal summer occurs 1 month later than climatology in 1983 but 1 month earlier in 1984. Time series of the temperature at 10-m depth and of the depth of the 20°C isotherm obtained at the equator at 28°W and at 4°W show the shoaling of the thermocline at 0°N, 28°W in mid-December 1983, when the winds relax. At 0°N, 4°W, this occurs 3 months later. At the surface, during the same period of time, the temperature reaches maximum values at both locations and for both observed years; the mean SST is higher in 1984 (28.5°C at 28°W and 29.5°C at 4°W) than in 1983 (28°C at 28°W and 28.5°C at 4°W), and it is lower at 28°W than at 4°W both in 1983 and 1984. The 10-m temperature and 20°C isotherm depth time series also show the decrease of the sea surface temperature following the onset of the local trade winds, in both years and at both locations. After that, the SST remains low as long as the zonal wind stress has a negative component (easterly winds), while the depth of the 20°C isotherm continues to decrease at both sites after the onset of the trade winds. The shoaling in both years lasts 1 month at 28°W and until the beginning of July at 4°W. At 28°W the thermocline deepens in 1983 from mid-May through the end of November; in 1984 the deepening starts at the beginning of June, with a faster rate than in 1983. At 4°W, the deepening starts at the end of July, both in 1983 and 1984, with the same rate and stops at the beginning of October in 1983; the SST remains low while the thermocline deepens at both locations. The depth of the 20°C isotherm slightly decreases from the beginning to the end of October 1983, while the zonal component of the in situ wind stress is eastward and increases thereafter from the beginning of December 1983 to February–March 1984.

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