Western boundary current variability off French Guiana as observed from moored current measurements

Currents
Western boundary
Equatorial Atlantic Ocean
Variability

Courants
Bord Ouest
Océan Atlantique Equatorial
Variabilité

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ABSTRACT

Moored current measurements carried out from 31 March 1990 to 15 September 1991 in two stages at a point (near 6°N) located over the mid-continental slope off French Guiana are presented. Six current meters were positioned between 200 and 2700 m depth. Upper level mean current data showed a northwestward flowing North Brazil Current (NBC) with mean velocity values decreasing from 10 cm/s in the range 200-250 m to almost zero at 800 m depth, the level of the Antarctic Intermediate Waters. In the range 500-800 m, the current reversed in spring in the presence of the southeastward Western Boundary Under Current (WBUC); the mean velocity from February to June 1991 is around 2 cm/s. Deep currents over the continental rise show a strong southeastward Deep Western Boundary Current extending from around 1000 m depth to the bottom (3000 m depth in this case) with mean core speeds of 20 cm/s at 2000-2070 m depth. Transport estimates based on these data and a few *Pegasus* sections for the mean vertical and lateral extensions of the DWBC yield a value of 21 × 10^6 m^3/s at that location. Low-frequency current fluctuations were dominated by a well-defined 50- to 70-day period oscillation with peak-to-peak northwestward velocity amplitude of around 90 cm/s at the upper level. The mean vertical eddy kinetic energy distribution showed an abrupt decrease of the energy down to 800 m depth and a slight decrease below and down to the bottom.

RÉSUMÉ

Variabilité des courants de Bord Ouest au large de la Guyane Française observée à partir des mesures d'une ligne de mouillage de subsurface instrumentée.

Dans cet article sont présentés les résultats de mesures courantométriques effectuées le long d'une ligne de mouillage, disposée du 31 mars 1990 au 15 septembre 1991 en deux fois, en un point situé vers 6°N et à mi-pente du plateau continental de la Guyane Française. Six courantomètres étaient placés entre 200 m et 2700 m de profondeur. Dans les couches de surface, les observations montrent la présence du Courant Nord Brésilien (CNB) orienté vers le nord-ouest, avec des vitesses moyennes décroissant de 10 cm/s dans la couche 200-250 m à des valeurs presque nulles vers 800 m de profondeur, niveau de l'Eau Antarctique Intermédiaire. Au printemps, dans la couche 500-800 m, le courant s'inverse : apparaît alors le Sous-Courant de Bord Ouest (SCBO), de vitesse moyenne d'environ 2 cm/s entre février et juin 1991. Les mesures en profondeur effectuées le long de la pente du plateau continental indiquent la présence d'un Courant Profond de Bord Ouest (CPBO) intense, orienté vers le sud-est et s'étendant d'environ 1000 m de profondeur jusqu'au fond (3000 m dans le cas de notre mouillage) avec des vitesses maximales moyennes de 20 cm/s vers 2000-2070 m de profondeur. A partir de ces données, et en utilisant les sections de courants perpendiculaires à la côte obtenues à l'aide d'un profileur de courant *Pegasus*, le transport associé au CPBO est de 21×10^6 m³/s. Les fluctuations basse fréquence des courants sont dominées par une oscillation de période 50 à 70 jours, d'une amplitude d'environ 90 cm/s dans les couches supérieures. Ces tourbillons très énergétiques se déplacent vers le nord-ouest et peuvent affecter les courants moyens jusqu'à une profondeur de 2700 m. La comparaison des spectres des courants et du vent indiquent que ces oscillations ne sont pas forcées par l'atmosphère. La distribution verticale de l'énergie cinétique turbulente moyenne montre une décroissance très rapide de cette énergie à partir de 800 m de profondeur.

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INTRODUCTION

The oceanic western boundary currents play an important role in the meridional redistribution of both the mass and heat transports from the equator to higher latitudes (Vonder Haar and Oort, 1973) and in the recirculation associated with the equatorial current system. The presence of these boundary currents in the northwestern part of the equatorial Atlantic was established : at the surface, on the basis of monthly mean ship drift maps (Richardson and McKee, 1984), drifter trajectories (Richardson and Reverdin, 1987) and Geosat Altimetry coupled with WOCE model results (Didden and Schott, 1992); subsurface, on the basis both of salinity and oxygen horizontal distributions (Metcalf and Stalcup, 1967; Cochrane *et al.*, 1979) and direct current measurements (Flagg *et al.*, 1986); and at greater depths, mainly on the basis of moored current measurements (Johns W.E. *et al.*, 1990; Schott *et al.*, 1993). These observations allowed the description : at the surface, of the northwestward North Brazil Current (NBC), continuous in boreal winter from the equator to the Carribean Sea but retroflected in summer near 8°N; subsurface of the retroflection of the lower part of the NBC particularly in summer-autumn; and deeper, of a southeastward flow extending from 2500 m depth to the bottom with mean core speeds of nearly 30 cm/s at 4300 m depth ; this bottom intensified current appears as the deeper part of the Deep Western Boundary Current (DWBC), whose main core has been observed around 2000 m depth at 26.5°N (Lee *et al.*, 1990). Recent *Pegasus* current measurements carried out for the first time off French Guiana during the joint French-US NOE (région Nord-Ouest Equatoriale) / STACS (SubTropical Atlantic Climate Studies) programme from September 1989 to June 1991 (Colin and Bourlès, 1993), contributed to a more precise description of the seasonal time and space variability of the velocity field in the area. In summary, the observations showed : at the surface, a NBC, strong (100-120 cm/s), coastally trapped (250 km wide) and confined in the first 250 m in boreal winter veering offshore in boreal summer at the latitude of Cayenne following the northward displacement of the InterTropical Convergence Zone (ITCZ) in June ; at that time the NBC velocity and lower current limit both increase (respectively 120-150 cm/s and down to 1000 m depth) ; subsurface and only during the period of late winter, spring and beginning of summer of the Western Boundary UnderCurrent (WBUC), trapped at the upper part of the slope and flowing southeastward (25 cm/s core speed) in the depth

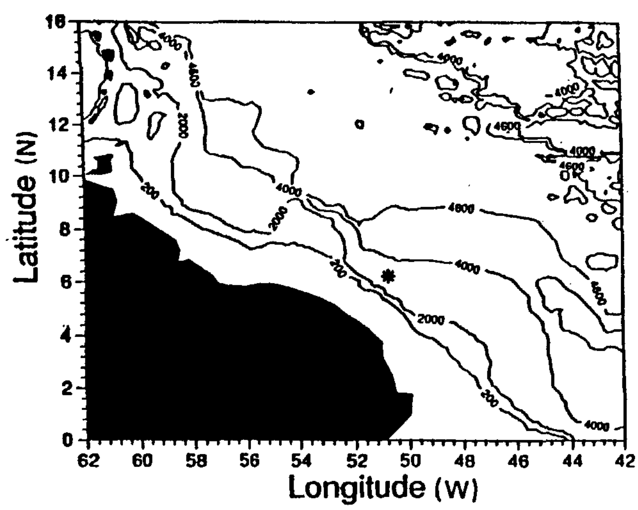

Figure 1

Geographical position of the subsurface mooring off French Guiana.

Position géographique de la ligne de mouillage de subsurface déployée en face de la Guyane française.

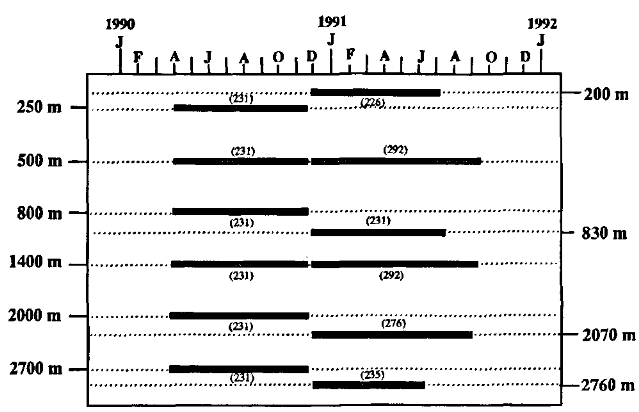

Table 1

Duration (in days) and depths (in m) for the two parts (31 March to 18 November 1990 and from 27 November 1990 to 15 September 1991) of the moored current measurements respectively at the locations 6°12N-51°01W (bottom depth 3000 m) and 6°11N-51°01W (bottom depth 3040 m).

Durée (jours) et profondeurs (mètres) des enregistrements de courant obtenus du 31 mars 1990 au 18 novembre 1990 et du 27 novembre 1990 au 15 septembre 1991 respectivement aux points 6°12N-51°01W (fond 3000 m) et 6°11N-51°01W (fond 3040 m).

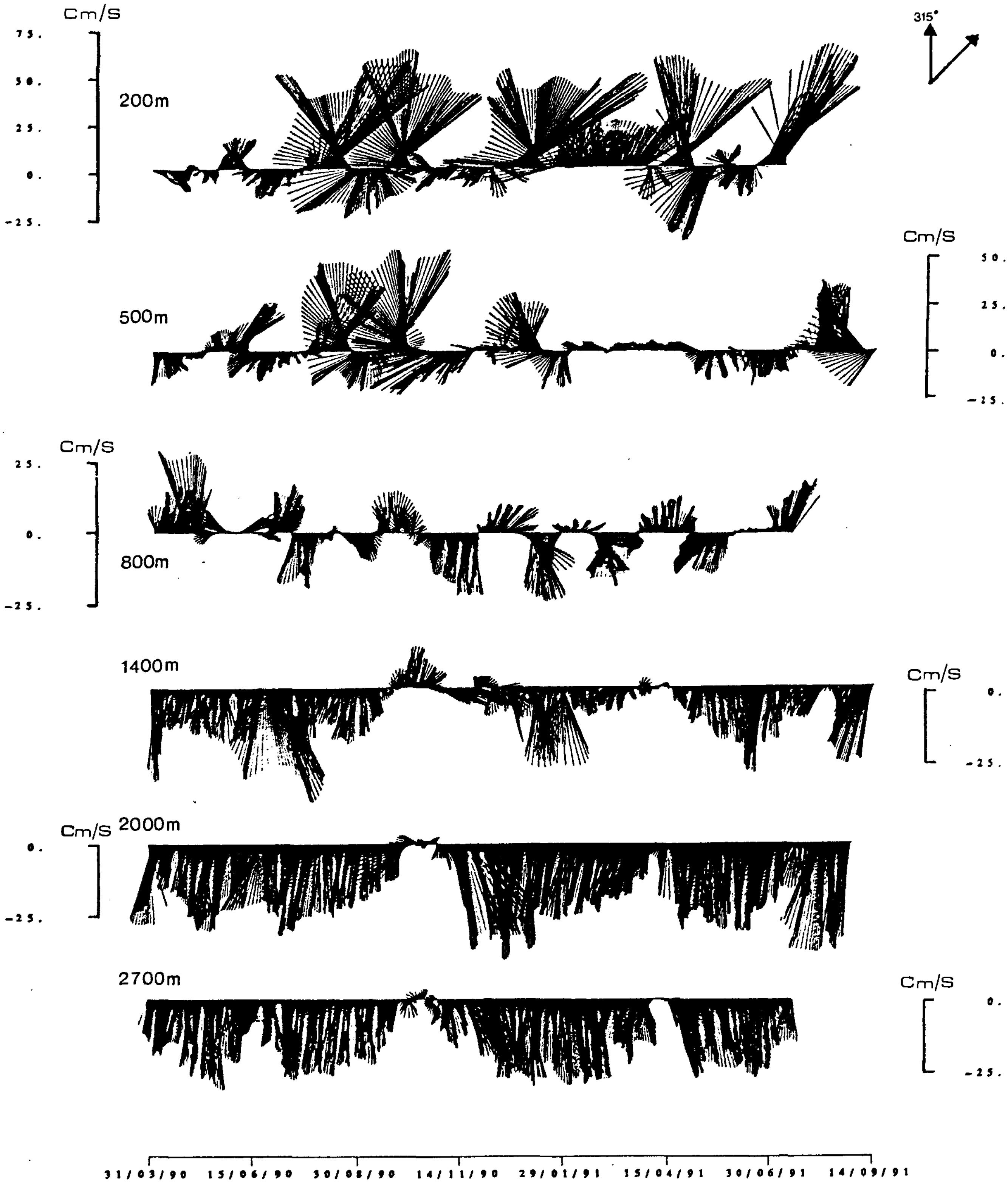

Figure 2

Vector plots (315° True) of the current records at 200, 500, 800, 1400, 2000 and 2700 m depths from 31 March 1990 to 15 September 1991 (see text and table 1 for more details).

Tracés des vecteurs courant (par rapport au 315°) aux immersions 200, 500, 800, 1400, 2000 et 2700 mètres de profondeur du 31 mars 1990 au 15 septembre 1991 (cf. le texte et le tableau 1 pour des informations complémentaires).

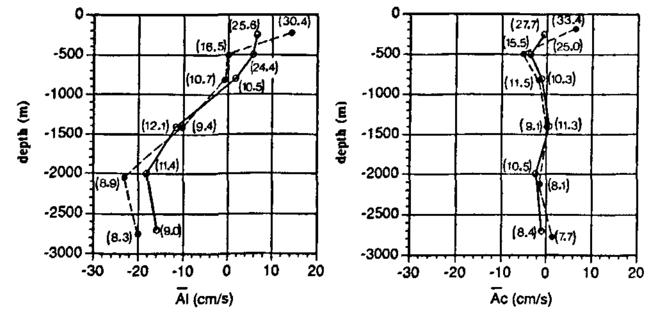

Figure 3

Vertical profiles of the mean alongshore (Al, left side) and across-shore (Ac, right side) components (cm/s) of the velocity of the currents for the two periods of observations (full lines for 31 March-18 November 1990 and dashed lines for 27 November 1990 to 15 September 1991) at the depths of measurements, with the associated standard deviations (in parenthesis).

Profils verticaux des valeurs moyennes des composantes (cm/s) de la vitesse du courant parallèle (Al, côté gauche) et perpendiculaire (Ac, côté droit) à la côte pour les deux périodes d'observations (ligne continue pour la période 31 mars au 18 novembre 1990 et ligne en tiretés pour la période 27 novembre 1990 au 15 septembre 1991) et aux profondeurs de mesures. Les valeurs des écarts-type sont indiquées entre parenthèses.

range 250-800 m ; deeper, the Deep Western Boundary Current (DWBC) located in the depth band 1000-3000 m, trapped less than 100 km off the slope, flowing southeastward with mean core speeds of 50 cm/s in spring-summer and 23 cm/s in autumn-winter. Some interannual variability appears at these depth and location : the DWBC is strong (weak) in January 1991 and September 1989 (February 1990 and September 1990).

To attend the seasonal variability of the *Pegasus* velocity field in the area, current measurements were carried out off French Guiana at one moored station in 1990 and 1991 (Fig. 1). We present here the time-dependent variability of the currents observed at the 3000 m bottom depth site. This subsurface mooring was part of the STACS mooring array (5 from the University of Miami on both sides of French Guiana and 3 from the University of Kiel along 44°W between the equator and 2°N). A comparison with the moored observations obtained north (Johns *et al.*, 1993) and south (Schott *et al.*, 1993) of the domain is made. A global description of the spatial and time-dependent variabilities of the upper ocean, deep circulation, transports and water masses structure will be treated in more detail after further synthesis of the STACS programme data. The paper is organized as follows : data are first presented, then the results are described and discussed, followed by a summary and conclusions.

DATA

The subsurface mooring experiment was carried out in two stages (Tab. 1) : from 31 March 1990 to 18 November 1990, at 6°12'N and 51°01'W (bottom depth 3000 m) with the current meters positioned at 275 m, 500 m, 800 m, 1400 m, 2000 m and 2700 m depths (Colin *et al.*, 1991) and from 27 November 1990 to 15 September 1991, at 6°11'N and 51°01'W (bottom depth 3040 m) with the current meters at 200 m, 500 m, 830 m, 1400 m, 2070 m and 2760 m depths (Colin *et al.*, 1992). In this paper the 200 and 275 m, 800 and 830 m, 2000 and 2070 m, 2700 and 2760 m records are processed together and are respectively referred to the following depths : 200, 500, 800, 1400, 2000 and 2700 m. The deployments and recovery were achieved in 1990 by the ORSTOM R.V. *André Nizery* and the final recovery in September 1991 by the NOAA (National Oceanographic and Atmospheric Administration) ship *Malcolm Baldridge* during the STACS cruise 39.

RESULTS

The vector plots at the depths of measurements (toward the 315° true direction which is roughly parallel to the coast) are presented (Fig. 2). Schematically the vectors are directed to the northwest (southeast) above (below) 800 m depth. The intra-seasonal variability on the records is large and of the same order of magnitude as the one observed near 8°N (Johns *et al.*, 1990). The peak-to-peak amplitude at the upper level is of around 90 cm/s and decreases downward.

Mean distributions

The vertical profiles of the mean alongshore and offshore (45° true) velocity components of the currents (Fig. 3) indicate the permanence of the NBC (lower part) at 200 m depth ; the component then linearly decreases from +10 cm/s to -20 cm/s at 2000 m depth which corresponds to the maximum DWBC core speed as observed from *Pegasus* current measurements in the area (Colin and Bourlès, 1993). At 500 m and 800 m depths, the values are very weak, particularly during the first part of the measurements. At 2700 m depth, the mean component is slightly less (– 18 cm/s) than the one observed in the core speed. The Al standard deviation values are very high at all levels but particularly in the upper layer ; this aspect will be discussed hereinafter. The mean Ac velocity components are weak at all depths and rarely exceed + 5 cm/s (figure not shown). The associated standard deviations are of the same order of magnitude as the Al ones. From one mooring, it is difficult to make a very accurate estimate of the DWBC transport. However, assuming a minimal width of 60 km (which corresponds in mean to the distance of the 10 cm/s line to the slope) and a vertical extension of 2500 m (Fig. 4, drawn from Colin and Bourlès, 1993), and considering the mean Al standard deviations for the error estimation, the mean value of the DWBC transport is approximately 21 + 15 Sv, which is of the same order of magnitude as those found : by Johns *et al.*, (1990) near 8°N (20 Sv) and Schott *et al.*, (1993) at the equator (19-22 Sv), in both cases from moored current measurements. This value is : larger than the one observed by Richardson and Schmitz (1993) from SOFAR float displacements (15 Sv) between

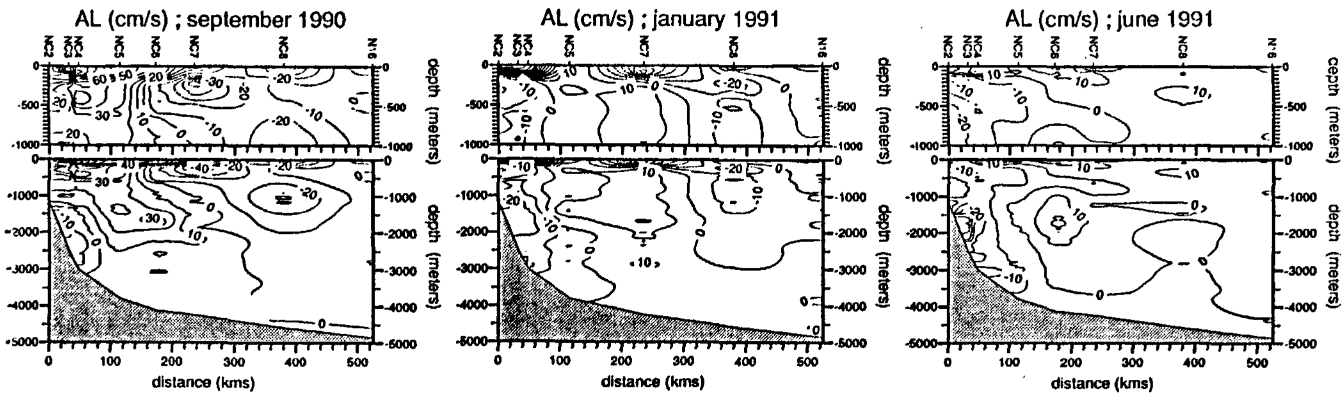

Figure 4

Vertical sections of the Pegasus alongshore (Al) component of the velocity of the current (cm/s) at eight stations (NC2 to N16) along a line located off Cayenne in: (a) September 1990, (b) January 1991 and (c) June 1991. These periods are included in the subsurface mooring duration. The position of the mooring line is indicated by the vertical dashed line.

Sections verticales de la composante parallèle (Al) à la côte de la vitesse du courant (cm/s) déduites des profils *Pegasus* effectués en: (a) septembre 1990, (b) janvier 1991 et (c) juin 1991 à huit stations (NC2 à N16) situées le long d'une radiale en face de Cayenne. Ces périodes de temps sont incluses dans la durée totale des enregistrements du mouillage de subsurface. La position de la ligne de mouillage est indiquée par la ligne verticale en pointillés.

7°N and the equator; slightly less than the mean one (25 + 7 Sv) deduced from the three *Pegasus* sections covering the same period of time (September 90, January 91 and June 91 *Pegasus* sections shown in Fig. 4) of the moored current measurements (Colin and Bourlès, 1993); but small compared to the one deduced also from moored current measurements (33 Sv) at 26.5°N (Lee *et al.*, 1990). All these values obtained in the area lead to a mean 22 Sv DWBC transport.

According to the temperature and current vertical structures observed off French Guiana, the currents have been split into the barotropic and baroclinic components. The barotropic current has been calculated by averaging the velocity vectors over depth for the common periods of all the measurements (31 March 1990 to 9 July 1991). The baroclinic currents are then obtained by subtracting the barotropic current from the observed current at each level.

The barotropic current plots indicate mean southeastward flows of respectively 5.8 cm/s and 6.5 cm/s for the first and second parts of the records, pointing to the importance of the DWBC in the northwestern boundary circulation (Fig. 5). The corresponding standard deviations are respectively 9.3 cm/s and 6.2 cm/s. The current is southeastward except in August and September 1990, during which the barotropic flow is northwestward, due – as will be shown later – to the propagation of eddies. The mean vertical profiles and values of the baroclinic Al components (Fig. 6) resemble both the mean ones (with in that case a zero speed around 1200 m depth) and the first baroclinic dynamical mode structure (zero crossing around 1500 m depth) calculated near 8°N by Johns *et al.*, (1990) from CTD casts.

The vertical distributions of the mean kinetic energy of the two parts of the records (Fig. 7*a*) reflect the vertical mean current ones : maximum at the 200-275 m level (150 cm^2/s^2), minimum at 800-830 m (5 cm^2/s^2) depth and maximum again at 2000-2070 m depth (420 cm^2/s^2). The difference between the two pieces appears more clearly

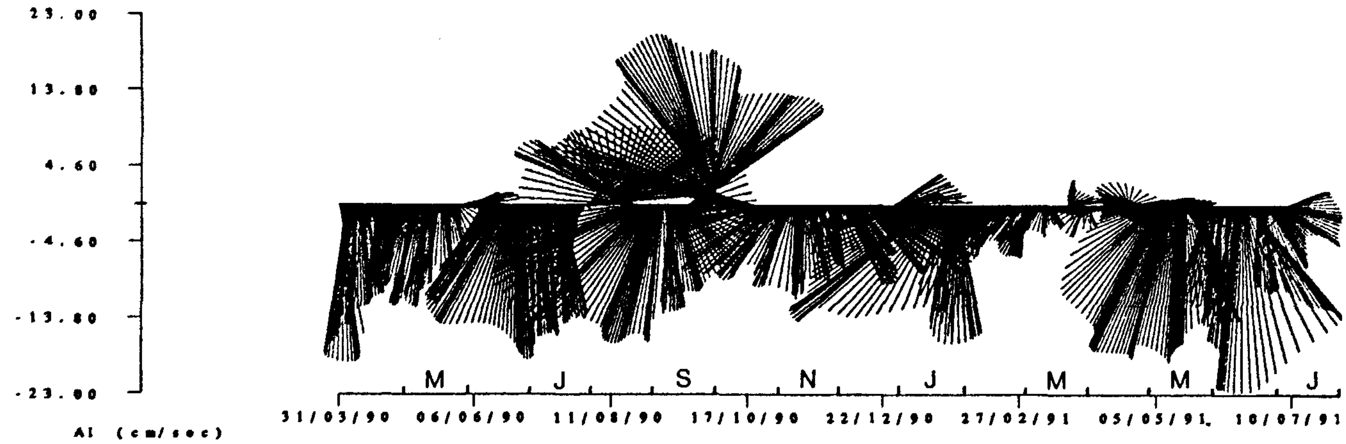

Figure 5

Vector plot (315° True) of the barotropic current from 31 March 1990 to 9 July 1991, common date of all the records.

Tracé du vecteur courant barotrope (par rapport au 315°) du 31 mars 1990 au 9 juillet 1991, durée commune à tous les enregistrements.

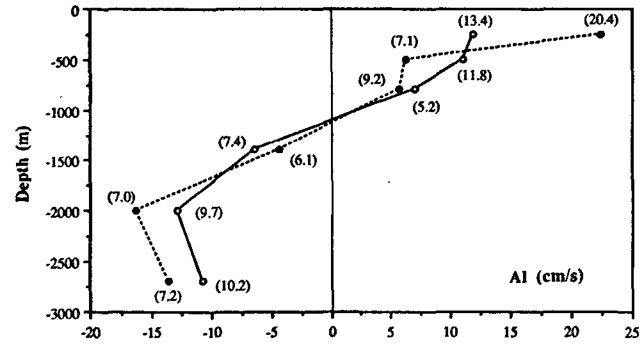

Figure 6

Vertical profiles of the mean baroclinic currents for the two periods of observations (31 March to 18 November 1990 in full line and from 27 November 1990 to 9 July 1991 in dashed line) at the depths of measurements with the associated standard deviations (in parenthesis).

Profils verticaux des valeurs moyennes des courants baroclines pour les deux périodes d'observations (en trait plein du 31 mars au 18 novembre 1990 et en pointillés du 27 novembre 1990 au 9 juillet 1991) aux profondeurs de mesures. Les écarts-types correspondant sont entre parenthèses.

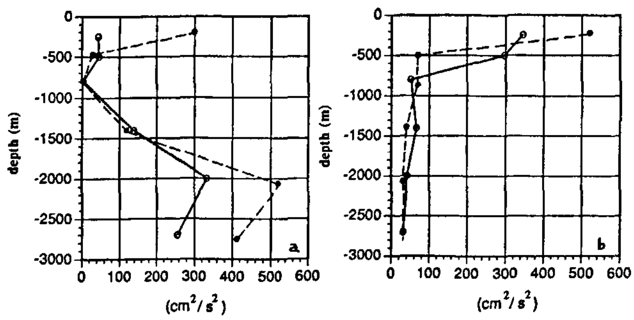

Figure 7

Vertical profiles of the mean (left side) and eddy (right side) kinetic energy values (cm^2/s^2) for the two periods of observations (31 March to 18 November 1990 in full line and from 27 November 1990 to the end of the record in dashed line) at the depths of measurements.

Profils verticaux de l'énergie cinétique (cm^2/s^2) moyenne (à gauche) et turbulente (à droite) pour les deux périodes d'observations (en trait plein du 31 mars au 18 novembre 1990 et en pointillés du 27 novembre 1990 à la fin des enregistrements) aux profondeurs de mesures.

than on the vertical distribution of the mean velocity values : 260 cm^2/s^2 around 200 m depth and 200 cm^2/s^2 around 2000 m depth. The eddy kinetic energy vertical profile (Fig. 7*b*) is also maximum in the upper level (430 cm^2/s^2 in mean), indicating there the presence of eddies at shorter time scales than the total period of measurements. Then the eddy kinetic energy monotically decreases downward (from 60 cm^2/s^2 at 800 m depth to 30 cm^2/s^2 at 2700 m depth). Whereas eddy motions dominate over mean flow over most of the water column, eddy kinetic energy in the DWBC is a factor 4-5 lower than mean kinetic energy. These mean profiles are consistent with those obtained northward by Johns *et al.*, (1990).

Annual variability

Previous studies (Richardson and Reverdin, 1987) have clearly shown a well-defined current seasonal variability in the upper layer : the northwestward NBC trapped along the coast in winter-spring (February to June), veering offshore in summer-autumn (September to January) with a transition period in June-July, as illustrated in Figure 4 (drawn from Colin and Bourlès, 1993).

The mean current values computed for the two periods, September 1990 to January 1991 (NBC retroflection period) and February 1991 to June 1991 (NBC coastally trapped), also exhibit an annual variability in the subsurface and deep layers (Fig. 8), with smaller amplitude than in the surface layers. The lower limit of the NBC is located between the 200 and 500 m depths in winter and spring, while it is below the 800 m depth in summer and autumn ; in winter and spring, the flow below the NBC (down to 800 m depth) is weak (2 cm/s) and southeastward. This is a consequence of the presence at that time of the WBUC as it clearly appeared on the *Pegasus* current vertical profiles at and shoreward of the mooring site (Fig. 4, drawn from Colin and Bourlès, 1993). At the DWBC level, differences also are observed : the mean Al components at 1400, 2000 and 2700 m depths are larger by around 2 to 5 cm/s in winter and spring 1991 than in summer and autumn 1990, suggesting an annual reinforcement of the DWBC. This velocity difference yields a DWBC seasonal transport variability of approximately 4.5 Sv. The mean Ac values are weak but differences nevertheless exist, the most important of which concerns the 500 m depth, where the southwestward values are larger in summer-autumn (9 cm/s) than in winter-spring (4 cm/s) as globally do the standard deviations values.

Intra-annual variability

Figure 2 exhibits sequences of intense and weak flows *versus* time at all depths in agreement with the standard devia-

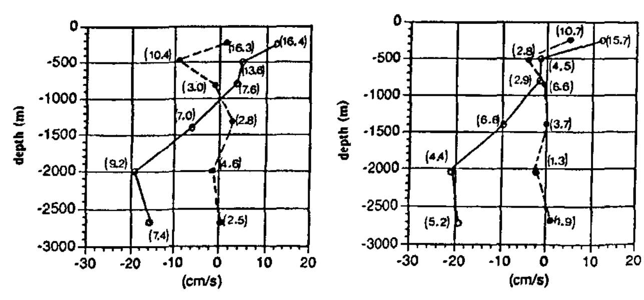

Figure 8

Vertical profiles of the mean alongshore (full line) and across-shore (dashed line) velocity values (cm/s) for the two seasons : September 1990 to January 1991 (left side) and from February 1991 to June 1991 (right side) at the depth of measurements. The associated standard deviations are in parenthesis.

Profils verticaux des composantes (cm/s) parallèle (trait plein) et perpendiculaire (en pointillés) à la côte de la vitesse du courant pour les deux saisons : septembre 1990 à janvier 1991 (à gauche) et de février 1991 à juin 1991 (à droite) aux profondeurs de mesure. Les écarts-types correspondants sont entre parenthèses.

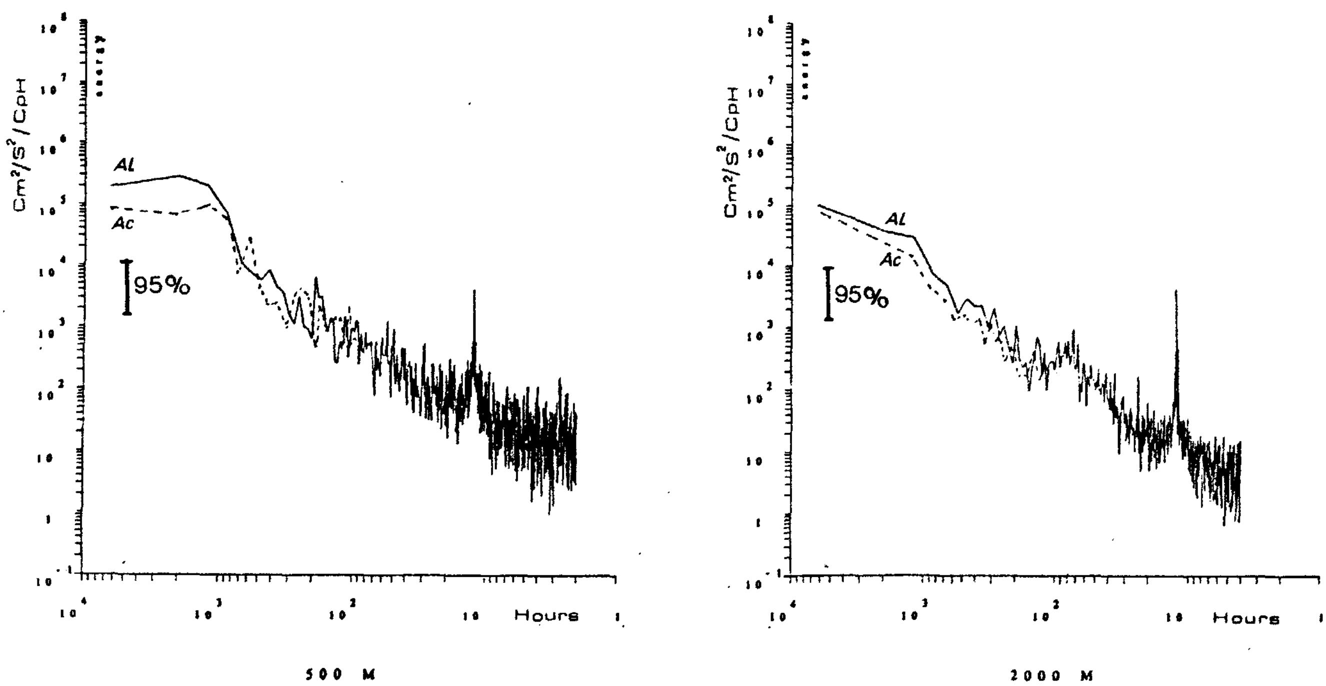

Figure 9

Energy spectra of the alongshore (Al, in full line) and across-shore (Ac, in dashed line) components of the velocity of the currents at 500 m (left side) and 2000 m (right side) depths, with the 95% corresponding confidence interval.

Spectres d'énergie des composantes de la vitesse du courant parallèle (Al, en trait plein) et perpendiculaire (Ac, en pointillés) à la côte aux immersions 500 m (à gauche) et 2000 m (à droite), avec l'intervalle de confiance correspondant au seuil de probabilité de 95%.

tion and eddy kinetic energy vertical profiles. If periodicity is quite well marked at 200 m depth, at greater depths (2000 m and 2700 m) the amplitude (period) of these fluctuations are much smaller (higher). A spectral analysis of all the records exhibits interesting features :

– for periods exceeding 720 hours (30 days), the energy density abruptly increases on all spectra with, however, more energy in the alongshore component than in the across-shore one; as an example, the spectrum at 500 m depth clearly shows a peak, centred in the period band 1200-1920 hours (50-80 days) ; at 2000 m depth the energy associated with this peak is smaller (Fig. 9) ; this aspect will be discussed in greater detail in the following paragraph;

– in the 48-720 hour (2-30 day) period band, all the spectra present no individual peaks except around the 72-hour (3-day) period at 2000-2070 m depth ; the inertial period (5.19 days at the site) does not appear significantly at all depths as in Johns *et al.*, (1990);

– for periods less than 48 hours (2 days), the spectra exhibit a peak centred at 12.43 hour period (semi-diurnal M_2 tide oscillation) with roughly the same energy density at all depths ; the other tide waves (K_2, S_2, N_2, K_1, P_1 and O_1) are also present with the same energy density.

DISCUSSION

The current vector plots clearly indicate at the upper level anticlockwise movements of the arrows *versus* time (Fig. 2). These movements are associated with the propagation of eddies, five from July 1990 to July 1991, without any apparent seasonality either in time or in amplitude. The current vector spectra exhibit above (below) 1000 m depth, more energy in the anticlockwise (clockwise) direction (Fig. 10) ; this is consistent, as in Johns *et al.*, (1990), with a northwestward clockwise eddy propagation (with the center located to the right of the mooring position) in the presence of a northwestward current. This oscillation also appears in a drifter trajectory off the coast of French Guiana (P.L. Richardson, personal communication), obtained from the end of 1990 (Julian day 304) to the beginning of 1991 (Julian day 45), which exhibits the presence of clockwise loops moving northwestward in autumn during the maximum NBC retroflection period and the disappearance of these loops in winter when the NBC is trapped along the coast.

This fluctuation also appears in the 21-month tide gauge coastal pressure record at Kourou, seven nautical miles offshore. The spectrum exhibits, as do the offshore current spectra, an increase of the energy density in the 1200-1920 hour (50-80 day) period band (Figure 11*a*). This is not the case, however, for the spectra of the zonal and meridional velocity components of a five consecutive yearlong (1987-1991) wind record at the same location prior to and including the moored current observations (Figure 11*b*) where no energetic peaks appear in that particular period band. Not do coherency spectra between the wind and both the pressure gauge and the current records during the same periods of observations present a significant peak in this band (figures not shown). Therefore the oscillation observed, particularly well defined in the upper layer, is not related to the global 40 to 60 day variability found in the tropical atmosphere

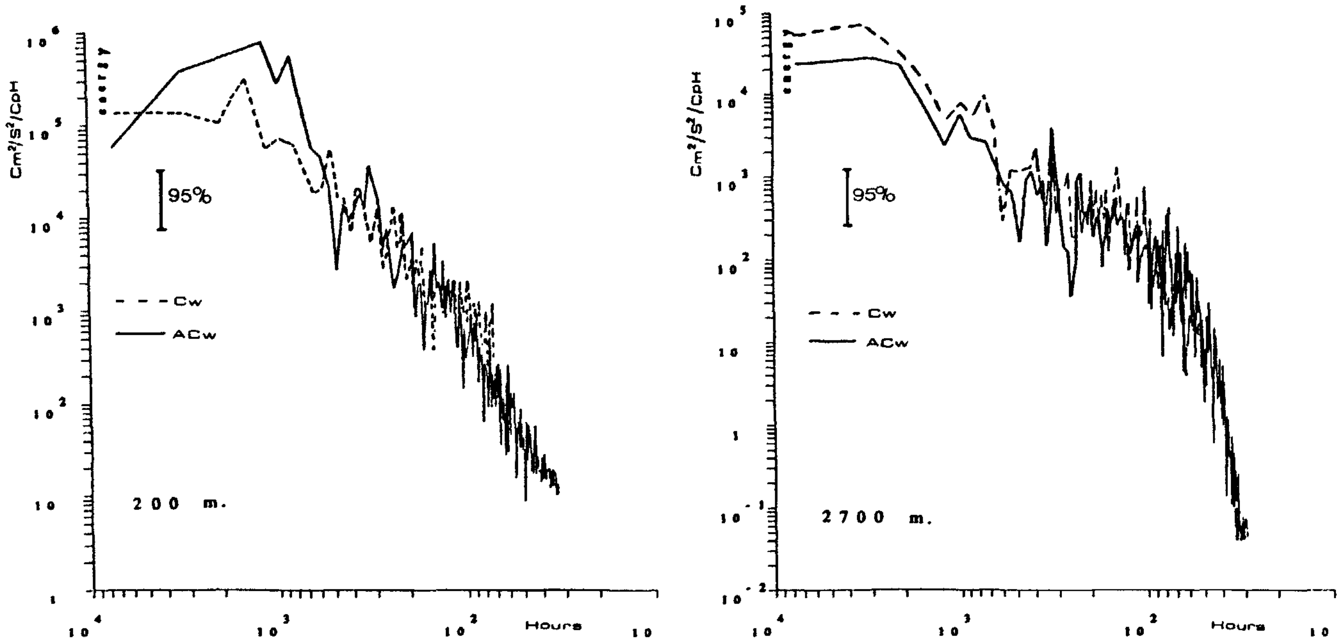

Figure 10

Anticlockwise (full lines) and clockwise (dashed lines) spectra of the current vectors at 200 m (left side) and 2700 m (right side) depths, with the corresponding 95% confidence interval.

Spectres d'énergie dans les sens cyclonique (en traits pleins) et anticyclonique (en pointillés) des vecteurs courant aux immersions 500 m (à gauche) et 2700 m (à droite), avec l'intervalle de confiance correspondant au seuil de probabilité de 95%.

(Madden and Julian, 1972) and in particular in the Atlantic equatorial area (Colin and Garzoli, 1988). Johns *et al.*, (1990) and Richardson *et al.*, (1993) linked this oscillation to the time-dependent behaviour of the NBC retroflection front located between 6°N and 10°N and associated with eddy formation typically following the advancement of this front. The current records off Cayenne present 1200 hour (50-day) period oscillations which, however, persist throu-

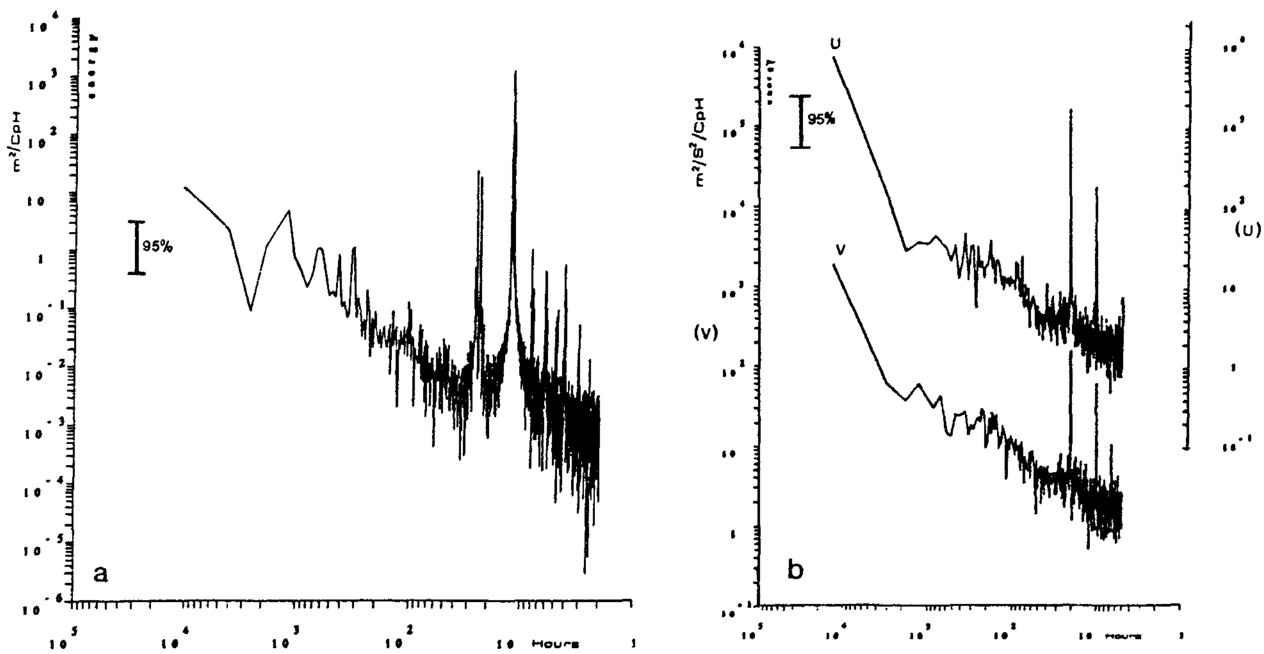

Figure 11

Spectra of a 21 month tide gauge record (a) and of the zonal (u) and meridional (v) components of a 5-year wind speed record (b) at Kourou (7 n.m. offshore), with the 95% corresponding confidence interval.

Spectres d'énergie d'un enregistrement de niveau moyen de la mer (d'une durée de 21 mois) et des composantes zonale (u) et méridienne (v) de la vitesse du vent (durée 5 ans) à Kourou (7 milles nautiques au large), avec l'intervalle de confiance correspondant au seuil de probabilité de 95%.

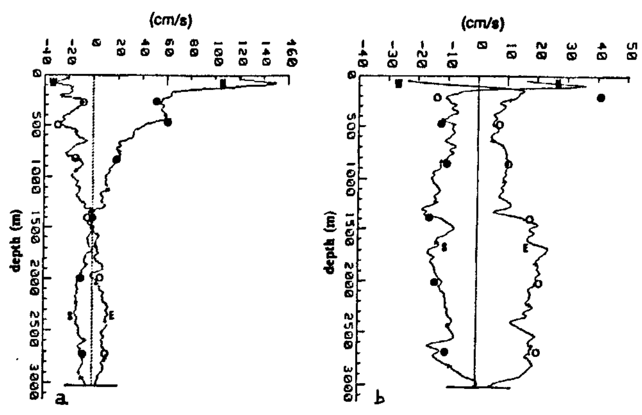

Figure 12

Vertical profiles of the zonal (E/W) and meridional (N/S) components of the current velocity obtained on 23 September 1990 at 10.00 T.U. (left side) and on 9 June 1991 at 09.55 T.U. (right side) with a Pegasus profiler at station NC4 situated closet the subsurface mooring location. The circles (open for the E/W components and full for the N/S components) indicate the corresponding velocity components drawn from the mooring current records at the same time and same depths.

Profils verticaux des composantes zonale (E/W) et méridienne (N/S) de la vitesse du courant obtenues par le profileur *Pegasus* le 23 septembre 1990 à 10.00 T.U. (côté gauche) et le 09 Juin 1991 à 09.55 T.U. (côté droit) à la station NC4 située près de la ligne de mouillage. Les cercles (vides pour les composantes E/W et pleins pour les composantes N/S) indiquent les valeurs des composantes de la vitesse du courant données par les courantomètres du mouillage au même instant et aux mêmes profondeurs.

ghout the two consecutive years, even in winter when the NBC retroflection is absent ; these eddies moreover carry South Atlantic waters at the upper level; they are thus to be related to a westward propagating wave field whose energy source lies in the ocean interior rather than in the western boundary current system (Johns *et al.*, 1990).

The consequences of the propagation of the eddies on the mean current are dramatic at all depths, particularly in the upper layer where the amplitude of the oscillation is maximum, and there is a consequent tendency to overestimate the mean amplitude of the seasonal variability at each depth. As an example, the moored current measurements obtained in the vicinity of the NC4 *Pegasus* vertical profiles, respectively on 23 September 1990 at 10.00 T.U. (Fig. 12*a*) and 26 June 1991 at 09.55 T.U. (Fig. 12*b*), show that the strong (weak) NBC and the weak (strong) DWBC vertical extensions in September 1990 (June 1991) are the consequence of a northwestward eddy displacement (Fig. 2). The *Pegasus* profiles obtained one month sooner or later would have led to different alongshore velocity component distributions and therefore to a different seasonal amplitude estimation of the current system. Moored and *Pegasus* current observations are therefore complementary, and have to be carried out together.

SUMMARY AND CONCLUSIONS

The moored current measurements carried out in two stages off French Guiana during the NOE programme from March 1990 to September 1991 have made it possible to determine the mean currents and their variability at five depths ranging between 200 m and 2700 m. The mean currents are northwestward in the upper level in agreement with the presence of the North Brazil Current ; in winter the vertical extension of the NBC is mainly limited to the upper 300 metres; in summer the NBC velocity weakly increases as the lower limit (down at least to 800 m depth). These results are consistent with other recent observations. Below, the Western Boundary UnderCurrent is present only in winter at 500 m and 800 m depths ; the corresponding mean velocity values are weak due to the offshore position of the mooring line relative to the WBUC core based on *Pegasus* velocity profiles obtained nearby. At greater depths and over the continental rise, the mean flows are southeastward at and below 1400 m depth due to the presence of the Deep Western Boundary Current ; mean core speeds of 18-23 cm/s are observed in the 2000-2700 m depth range ; the velocity maximum is found at 2000 m depth. A rough estimate of the DWBC transport from the mooring yields a mean value of approximately 21 + 15 Sv, which is of the same order of magnitude as other estimations obtained in the same area. The presence of the 50-80 day period eddies can, however, greatly affect the mean currents at depths as great as 2700 m when these eddies move in the northwest direction. The peak-to-peak alongshore velocity amplitudes of around 90 cm/s are observed at the upper level. The coherency spectrum between the wind and the currents show that this oscillation is not atmospherically forced. Water masses analysis carried out by other authors indicate for these motions a remotely ocean interior origin.

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