Fluctuations of the equatorial currents system connected with the hydroclimatic conditions in the Western Pacific

Jean-René DONGUY (1) and Christian HENIN (2)

ABSTRACT

From the wind field and from the mean curl of wind stress, it is possible to draw in the western tropical Pacific models of meridian thermal profiles for three cases: pre El Nino period, El Nino itself and post El Nino period. These profiles induce also three kinds of zonal equatorial currents system. Such models are compared with experimental thermal structures deduced from data obtained between 150° E and 180°. The agreement is usually good between models and realisations.

RÉSUMÉ

MODIFICATIONS DU SYSTÈME DE COURANTS ÉQUATORIAUX LIÉS AUX CONDITIONS HYDROCLIMATIQUES DANS LE PACIFIQUE OCCIDENTAL

Trois types de conditions hydroclimatiques ont été mis en évidence dans le Pacifique ouest: le premier, appelé pré El Nino, correspond à la préparation du phénomène El Nino et se caractérise sur l'équateur par un fort vent d'est, un upwelling équatorial intense et un niveau moyen élevé de la surface de l'océan. Le second est observé simultanément au phénomène El Nino lui-même et se caractérise sur l'équateur par l'arrêt du vent d'est et de l'upwelling. Le troisième, appelé post El Nino, correspond aux conséquences du phénomène El Nino et se caractérise sur l'équateur par un faible vent d'est ou même un vent d'ouest, la disparition de l'upwelling et un niveau moyen bas de la surface de l'océan. A chacune de ces situations correspond un modèle de profil thermique méridien de 10° N à 10° S établi à partir du champ de vent et du niveau moyen sur l'équateur, du rotationnel moyen de la force d'entraînement du vent en zone tropicale. Ces profils thermiques induisent trois systèmes de courants équatoriaux: en situation de pré El Nino, la circulation générale porte à l'ouest et le Courant Équatorial est renforcé; pendant El Nino même, ce Courant Équatorial disparaît tandis que les Contre Courants équatoriaux sont renforcés, principalement le Contre Courant Équatorial nord; en situation de post El Nino, la circulation générale porte à l'est, les contre courants équatoriaux sont renforcés tandis que le Courant Équatorial reste faible. Ces modèles de profils thermiques et de systèmes de Courants Équatoriaux sont ensuite confrontés avec les données provenant de croisières océanographiques françaises ou étrangères faites dans le Pacifique Ouest ou encore avec les données bathythermiques (XBT) obtenues grâce à la coopération franco-américaine dans le cadre du programme SURTROPAC. L'accord est généralement bon entre les modèles et les résultats expérimentaux.

INTRODUCTION

Two types of hydroclimatic conditions occurring in Western Pacific have been pointed out (DONGUY and HENIN, 1981): one is characteristic of the period preceding El Nino phenomenon, other is characteristic of the period following this phenomenon. Between them, during a short period, the El Nino event itself occurs. In the Western Pacific, west of the date line, the basic atmospheric feature

(1) *Centre O.R.S.T.O.M., B.P. A5, Nouméa Cedex, Nouvelle-Calédonie.*
(2) *Centre de Recherches Océanographiques de Dakar-Thiaroye, B.P. 2241, Dakar, Sénégal.*

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driving the climate seems to be the position of the Intertropical Convergence Zone of the Wind (I.T.C.Z.). PAZAN and MEYERS (1982) have shown that during pre El Nino period, which is the case of high Southern Oscillation Index (S.O.I.), there is a movement of the I.T.C.Z. from 10° S in January-February to 10° N in September-October, the I.T.C.Z. persisting, however, in the Southern Hemisphere under the name of South Pacific Convergence Zone (S.P.C.Z.). El Nino is characterized in the Western Pacific by a complete change of the wind field. I.T.C.Z. and S.P.C.Z. merge on the equator near the date line and westerly winds prevail west of this equatorial convergence. In post El Nino period, which is the case of small S.O.I., the convergence stays in the vicinity of the equator several months and possibly several years. Pre and post El Nino sequences last a variable time and induces two different systems of equatorial currents.

SCENARIO IN THE CHANGES OF THE EQUATORIAL CIRCULATION DUE TO THE DIFFERENT WIND FIELDS

Simple qualitative models of the thermal structure may be suggested by the consideration of the wind field during pre El Nino period, during El Nino itself and during post El Nino period. These models will be compared to the experimental realisations.

Along the equator, due to the absence of Coriolis force, the wind stress itself is important by inducing surface current but also vertical movement of the upper level of the ocean. Within the tropical zone of the Western Pacific (5°-15° latitude), the curl of the wind stress is determining the response of the upper level of ocean to variations of zonal wind stress T_x and T_y. According to the Ekman theory, the divergence of the horizontal mass transport is given by:

$$\text{div } M = \text{curl}\frac{T}{f} = \frac{\partial}{\partial x}\left(\frac{T_y}{f}\right) - \frac{\partial}{\partial y}\left(\frac{T_x}{f}\right) \quad (1)$$

with $f = 2\ \omega \sin\varphi$.

The vertical transport computed is negative or positive and induces consequently convergence or divergence. This effect may be defined as Ekman pumping.

The depth and the slope of the isotherms is connected to the wind stress on the equator and to the curl of the wind stress in tropical area. Using a simple two-layer approximation (WYRTKI and KENDALL, 1967), the meridional slope of the thermocline is an excellent index of the zonal circulation.

According to WYRTKI (1979a), during pre El Nino period, strong easterly winds blowing along the entire equatorial Pacific induce a piling up of the waters in the Western Pacific and consequently high sea level. Due to the baroclinic balance, isotherms deepen. However, at the equator, easterly wind produces equatorial upwelling and isotherms ridge. West of the date line in tropical area, according to PAZAN and MEYERS (1982), two tongues of negative curl of the wind stress occur each side of the equator (fig. 1). The northern one is small and close to the equator, the southern one spreads from 5° S to 15° S. The curl is positive at 10° N, from 5° S to the equator and at 20° S. Consequently thermocline troughs occur at 5° S and 3° N, thermocline ridges south of 10° S and at 10° N. From 5° S and 3° N, thermocline slope is positive equatorward and also positive poleward (fig. 2); so, from the equator to 10° latitude, westward Equatorial Current occurs from 5° S to 3° N and is followed in the north and in the south by eastward Equatorial Countercurrent.

El Nino is connected with a change of the Pacific wind field. During the occurrence of this event which lasts usually several months (RASMUSSON and CARPENTER, 1982), the I.T.C.Z. lies close to the equator and westerly winds are blowing in equatorial area. Equatorial upwelling cannot be sustained and an equatorial trough occurs. During the dramatic phase of El Nino event, strong Ekman pumping induces abrupt thermocline ridge at 10° N, less intense thermocline ridge at 10° S (DONGUY et *al.*, 1982). Consequently from the equator to tropical ridges at 10° latitude, the thermocline slope is positive poleward and induces only eastward circulation. The Equatorial Current, in this case, does not exist or is very weak and is replaced by South and North Equatorial Countercurrents which merge at the equator.

The persistance of such conditions during post El Nino period induces low sea level and, by baroclinic adjustement, thermocline is 50 meters shallower than during pre El Nino period (fig. 2). From the equator to 15° S, negative curl of wind stress occurs with more important values than during pre El Nino period (PAZAN and MEYERS, 1982) (fig. 1). Positive curl of wind stress occurs between the equator and 10° N and south of 15° S with also more important values than during pre El Nino period. Consequently the slope of the thermocline would be equatorward only in the southern hemisphere and would induce westward Equatorial Current from 5° S to the equator. North of the equator and south of 5° S, thermocline slope is positive poleward and induces eastward Equatorial Countercurrent.

EXPERIMENTAL SURFACE CIRCULATION DURING PRE EL NINO PERIOD

According to DONGUY *et al.* (1982), between 1965 and 1980, there were three pre El Nino period:

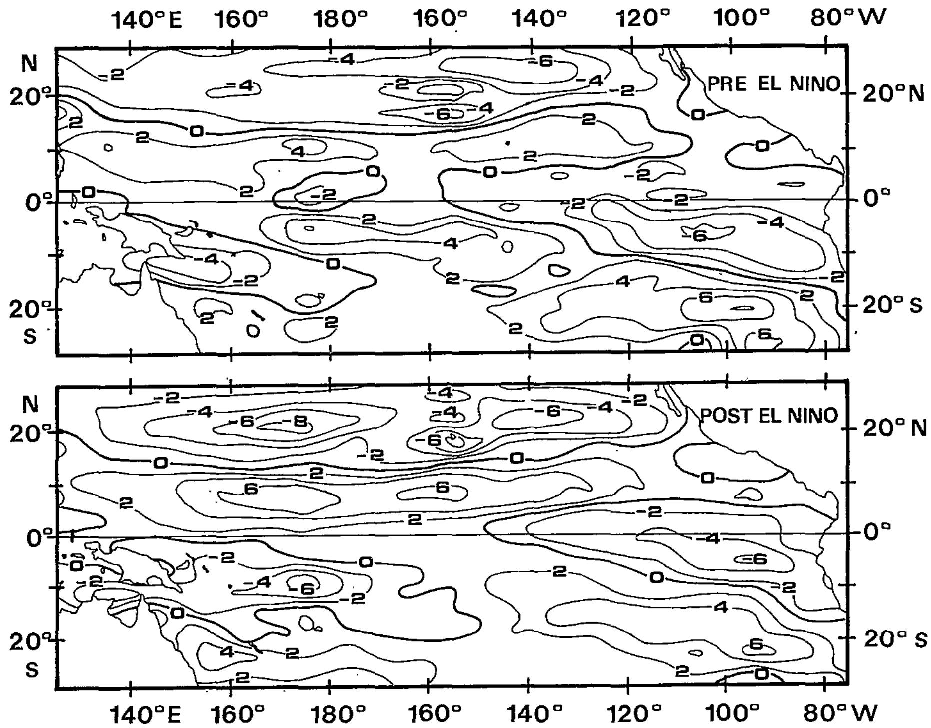

FIG. 1. — Annual mean curl of wind stress (PAZAN and MEYERS, 1982) in the case of pre El Nino (upper part), and post El Nino (lower part).

Moyenne annuelle du rotationnel de la force d'entrainement du vent (PAZAN and MEYERS, 1982): en haut, dans une situation de pré-El Nino; en bas, dans une situation de post-El Nino.

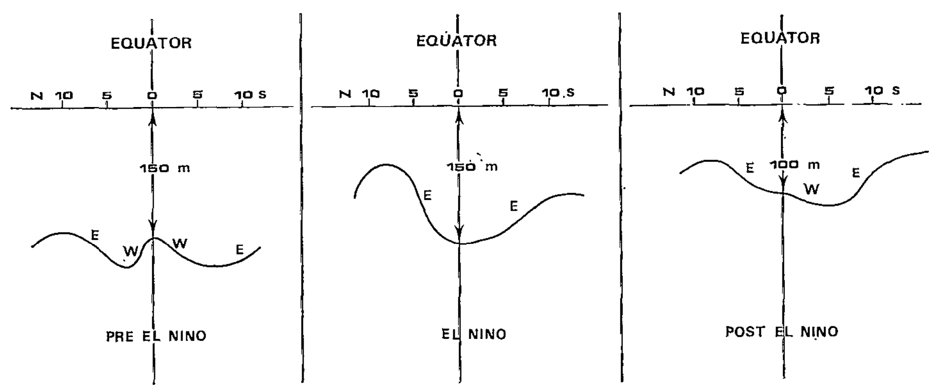

FIG. 2. — Schematic thermal structure and circulation in the Western Pacific from 10° N to 10° S in pre El Nino period, El Nino itself and post El Nino period.

Schéma de la structure thermique et de la circulation dans le Pacifique occidental, entre 10° N et 10° S, à trois périodes différentes: pré-El Nino, El Nino et post-El Nino.

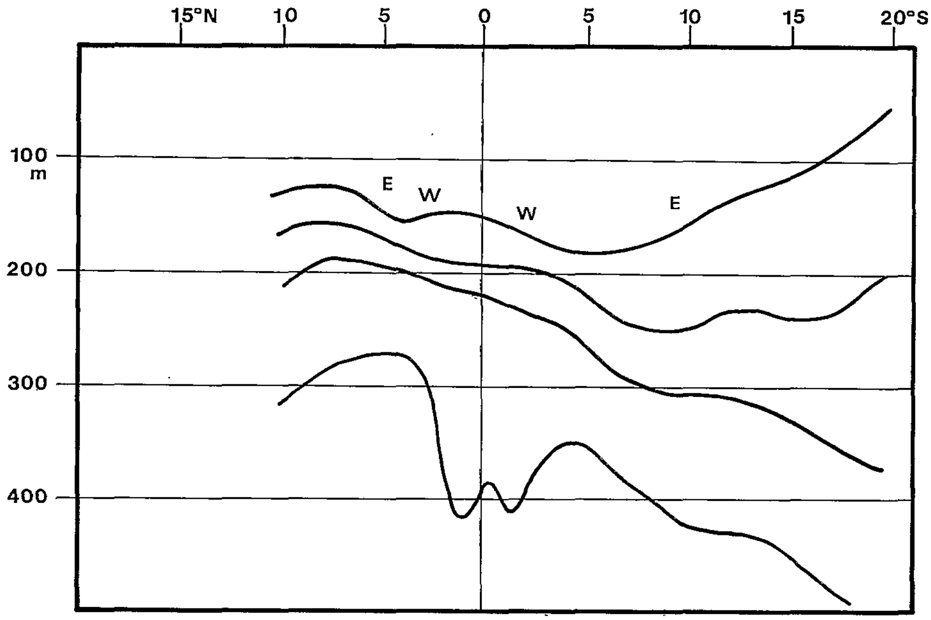

FIG. 3. — Experimental thermal structure and zonal circulation during pre El Nino period.
Structure thermique observée et circulation zonale en période de pré-El Nino.

1967-68 before the weak 1969 El Nino, 1970-1972 before the strong 1972 El Nino, 1974-1975 before the moderate 1976 El Nino. The data available during these homogeneous periods allow to consider mainly two realisations: one with the 6 CYCLONE cruises carried out at 170° E in 1967-68 by the Centre O.R.S.T.O.M. de Nouméa (ROTSCHI *et al.*, 1972) and one including RYOFU MARU cruise at 155° E and SCHOKALSKY cruise at 160° E in 1975. The 25° C, 20° C, 15° C and 10° C isotherms from each realisation have been averaged by eye adjustement. As the both realisations are in good agreement, a composite thermal structure including the whole cruises considered extends from 10° N to 20° S (fig. 3). The 25 °C isotherm is mainly included between 100 and 200 m depth, the 20° C one between 150 and 250 m. As 25 °C and 20 °C isotherms are roughly the top and the center of the thermocline, the consideration of their slope leads to a qualitative description of the superficial zonal currents. There is a contrast between the thermal structure of the northern hemisphere and the one of the southern hemisphere: thermocline is very sharp in the north and splitted in the south. Consequently, the slopes of the 25 °C and 20 °C isotherms are not always in agreement in the southern hemisphere. Each side of the equator, the positive equatorward slope of 20 °C and 25 °C isotherms induces westward Equatorial Current as far as 4° N and 6° S where isotherms trough induces a current change. From 4° N to 8° N, the slope of the isotherms is positive poleward and consequently eastward North Equatorial Counter Current prevails. In the southern hemisphere the slopes of 25 °C and 20 °C isotherms disagree: the slope of the 25 °C one is positive poleward from 6° S to 20° S inducing eastward South Equatorial Countercurrent, whereas the slope of the 20 °C isotherm is positive poleward from 6° S to 10° S inducing South Equatorial Countercurrent but negative from 10° S to 15° S inducing South Equatorial Current and again positive south of 15° S inducing South Tropical Counter Current. This current system is in agreement with MERLE *et al.* (1969).

EXPERIMENTAL SURFACE CIRCULATION DURING EL NINO

Within the last ten years, two major El Nino occurred: the 1972 strong one and the 1976 moderate one. During 1972, a RYOFU MARU cruise at 155° E in July and a SCHOKALSKY cruise in February at 180° are available. During 1976, a RYOFU MARU cruise at 155° E in July and the cruise EPONITE 2 carried out by the Centre O.R.S.T.O.M. de Nouméa in August-September are also available. For each El Nino, a composite thermal profile has been produced. As the 1972 and the 1976 ones are in good agreement, a schematic thermal structure may be considered (fig. 4). The

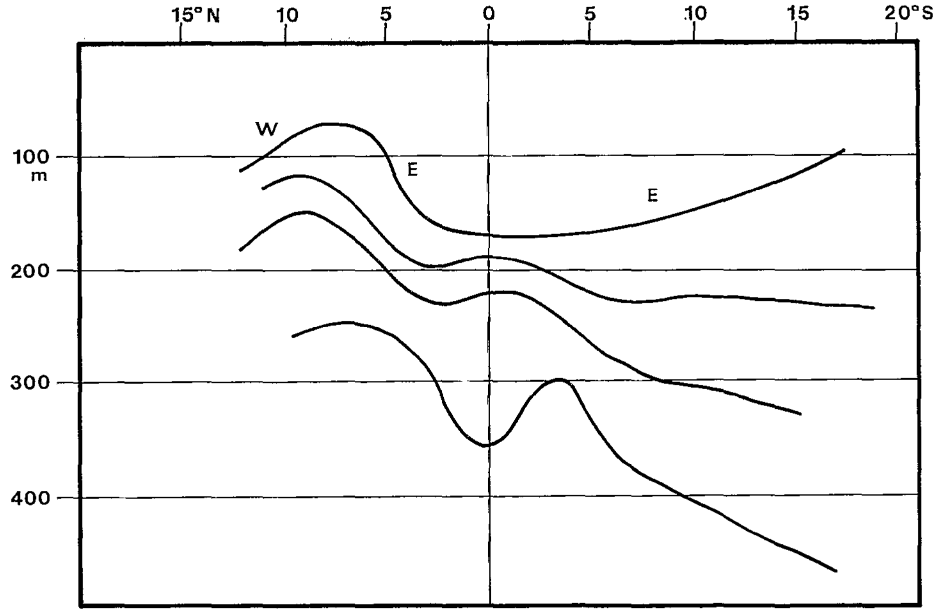

FIG. 4. — Experimental thermal structure and zonal circulation during El Nino itself.
Structure thermique observée et circulation zonale en période d'El Nino.

25 °C isotherm is mostly between 100 and 200 m depth except at the northern tropical ridge, the 20 °C one between 100 and 250 m depth. The most salient feature is the considerable ridge of the isotherms at 8° N: the depth of the 25 °C isotherm changes from 170 m at 2° N to 70 m at 8° N; the depth of the 20 °C changes from 200 m at 2° N to 110 m at 8° N. Consequently, the North Equatorial Counter Current is very strong as noticed by WYRTKI (1979a). The Equatorial Current does not exist or is very weak. South of the equator, the slope of 25 °C isotherm is positive poleward, inducing South Equatorial Counter Current. However, as the slope is weak in southern hemisphere, there is a great dissymetry each side of the equator: North Equatorial Counter Current is strong but South Equatorial Counter Current is weak.

EXPERIMENTAL SURFACE CIRCULATION DURING POST EL NINO PERIOD

According to DONGUY *et al.* (1982), between 1965 and 1980, four post El Nino periods occurred: 1965-66 after the moderate 1965 El Nino, 1969-70 after the weak 1969 El Nino, 1972-73 after the strong 1972 El Nino, and 1976-77 and again 1979-80 after the moderate 1976 El Nino. The data available during these homogeneous periods lead to consider two main realisations: the 4 BORA cruises carried out at 170° E between 20° S and 4° N in 1965-66 by the Centre O.R.S.T.O.M. de Nouméa (ROTSCHI *et al.*, 1972), and the 1979-81 XBT data from the O.R.S.T.O.M.-SIO experiment (SURTROPAC) between Nouméa and Japan.

The 25 °C, 20 °C, 15 °C and 10 °C isotherms have been averaged from these cruises by eye adjustement (fig. 5). The 25 °C isotherm is mainly included between 100 and 150 m, the 20 °C between 150 and 200 m depth. The isotherms depths are roughly 50 m shallower in post El Nino than during pre El Nino cruises. The consideration of the 25 °C isotherm which coincides with the top of the thermocline and of the 20 °C isotherm which coincides with the center of the thermocline leads to a qualitative description of zonal superficial currents. From the equator to 5° latitude, the poleward slope is negative in the south, equal to zero in the north; consequently, a rest of the westward Equatorial Current remains in the southern hemisphere. From 5° to 10° latitude, the poleward slope is positive and consequently the North and the South Equatorial Countercurrent occur. Out of 10° latitude, the poleward slope of 20 °C and 25 °C isotherm is negative in the north, whereas in the south the 25 °C slope is positive poleward and the 20 °C one negative. Consequently, the North Equatorial Current occurs in the northern hemisphere but in the southern one, the South Equatorial Current is only noticed by the 20 °C slope.

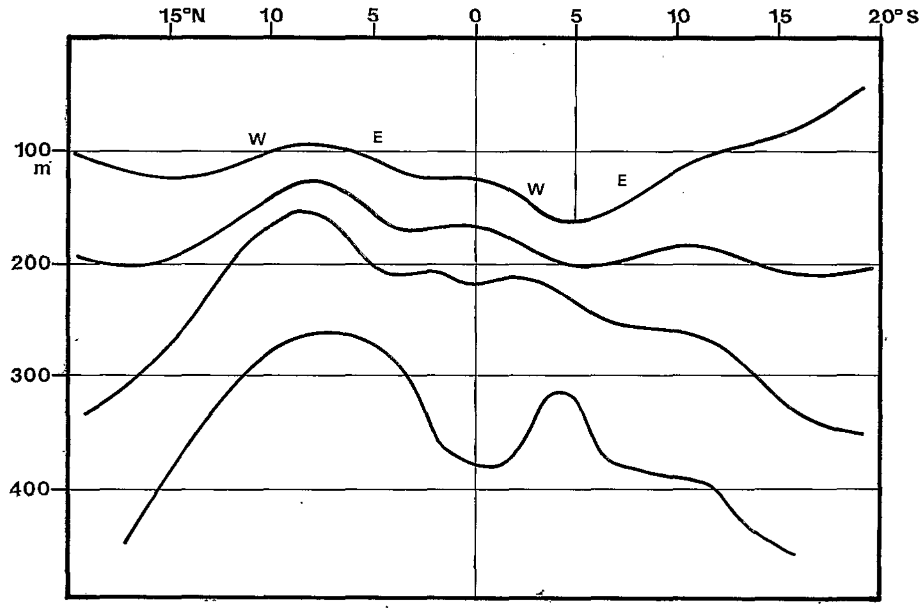

FIG. 5. — Experimental thermal structure and zonal circulation during post El Nino period.
Structure thermique observée et circulation zonale en période de post-El Nino.

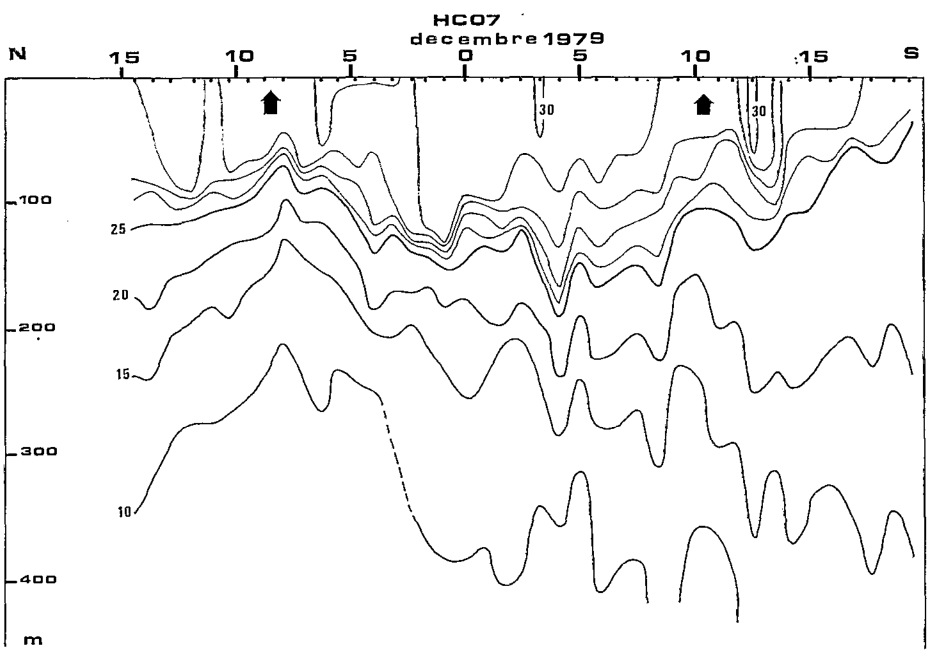

FIG. 6. — Thermal structure between Nouméa and Japan in December 1979. Ekman pumping is marked by vertical arrows.
Structure thermique entre Nouméa et le Japon en décembre 1979. Le pompage d'Ekman est indiqué par des flèches verticales.

DISCUSSION

Several features may be pointed out from this study:

(1) Between 10° N and 20° S, the thermal structure is homogeneous during each phase. For example, during pre El Nino period, the 1967-68 isotherms and the 1975 ones are very close; during El Nino itself, the 1972 and the 1976 thermal structure are similar; during post El Nino period, the same features are observed for the 1965-66 isotherms and the 1979-80 ones.

(2) The isotherms from post El Nino data are 50 meters shallower than the ones from pre El Nino data. WYRTKI (1979b) estimated the change between 50 and 80 m in 1972-73. The influence of the seasonal variations have been eliminated since the averages used include data from opposite seasons. In the other hand, WYRTKI *et al.* (1981) have showed that, according to the SHUTTLE EXPERIMENT data, in low latitude area, the seasonal variations of isotherm depth are usually weaker than the interannual ones.

(3) There is a good agrement between the thermal profile deduced from the wind field (fig. 2) and the experimental realisation (fig. 3, 4 and 5), mostly by consideration of the 25 °C isotherm. DONGUY *et al.* (1982) have found in post El Nino period, some evidence of symmetrical Ekman pumping each side of the equator. This feature does not appear in the thermal profiles considered. However, in some cases as in December 1979, Ekman pumping occurring at 10° N and 10° S induces exceptionnal thermal symmetry (fig. 6).

In the other hand, the influence of the Ekman pumping on the intensity of the tropical ridges may be considered. As already pointed out by MEYERS *et al.* (1981), the strength of the North and South Equatorial Countercurrent is monitored by the meridional slope of the 20 °C isotherm between trough and ridge, or their depth difference ΔD, from 25 Noumea-Japan sections (1979-1980). The vertical displacement due to Ekman pumping (DONGUY *et al.*, 1982) at the northern and southern thermocline ridge (10° N-10° S) is compared to ΔD (fig. 7). No correlation can be found. However,

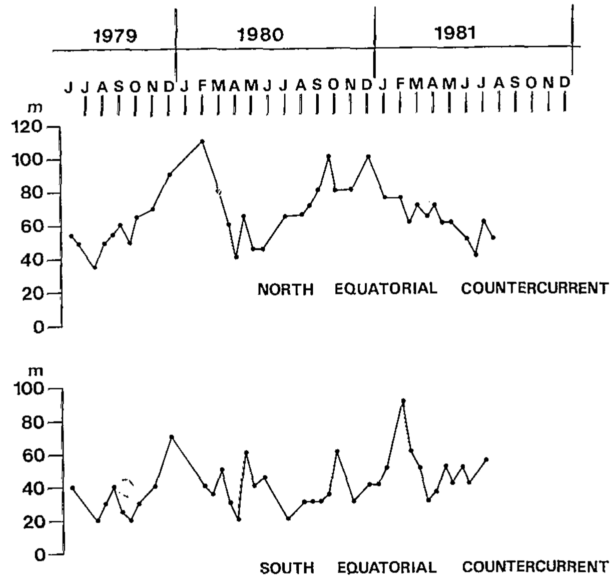

FIG. 7. — Depth difference ΔD between trough and ridge of the 20 °C isotherm for the North Equatorial Countercurrent and for the South Equatorial Countercurrent.

Ecart ΔD entre les profondeurs maximales et minimales de l'isotherme 20 °C; en haut Contre-courant Equatorial nord; en bas, Contre-courant Equatorial sud.

rough seasonal ΔD variations may be suspected with maximum in northern winter, as already stated by WYRTKI (1974) and MEYERS *et al.* (1982).

CONCLUSION

The models of thermal structure and of equatorial circulation induced by wind field are usually in good agreement with the experimental realisations. Consequently, wind field induces not only the heat content state but the way of dispersion of this heat content into Pacific Ocean. The monitoring of the Pacific by ship-of opportunity gives a good idea of the heat content state and of the equatorial current system. However we need more complete and more accurate wind measurement to establish reliable relations between ocean and atmosphere.

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