Variability of dynamic topography and equatorial currents in relation to hydroclimatic conditions of the Western Pacific

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ABSTRACT

From hydrographical data obtained between 1956 and 1977 in the Western Pacific, composite transequatorial cruises have been assembled with special references to the hydroclimatic conditions. Geostrophic calculations show interannual variability of the equatorial current system from 10° N to 20° S connected to the appearance of El Nino. Dynamic heights, large before El Nino, become small during post El Nino conditions. The stronger Ninos show a larger decrease. North of 3° N, the dynamic slope is much stronger in post El Nino than in pre El Nino and this feature corresponds to a larger eastward transport of the North Equatorial Counter Current.

KEY WORDS : Dynamic topography — Equatorial currents — Hydroclimatic conditions — Western Pacific.

RÉSUMÉ

VARIABILITÉ DE LA TOPOGRAPHIE DYNAMIQUE ET DES COURANTS ÉQUATORIAUX, EN RELATION AVEC LES CONDITIONS HYDROCLIMATIQUES DU PACIFIQUE OUEST

A partir des données hydrologiques recueillies entre 1956 et 1977 dans le Pacifique Ouest, des croisières composites transéquatoriales ont été établies en tenant compte des conditions hydroclimatiques. Les calculs géostrophiques montrent une variabilité interannuelle des courants équatoriaux de 10° N à 20° S, variabilité en relation avec El Nino. On observe une diminution des hauteurs dynamiques qui de maximum avant un fort El Nino, deviennent minimum après un fort El Nino. Elles sont intermédiaires avant et après un El Nino modéré. Ce changement est du même ordre que les variations saisonnières. Au nord de 3° N, la pente dynamique est plus grande en post El Nino qu'en pré El Nino, ce qui correspond à un transport vers l'Est plus important du Contre Courant Equatorial Nord.

MOTS-CLÉS : Topographie dynamique — Courants équatoriaux — Conditions hydroclimatiques — Pacifique Ouest.

INTRODUCTION

Some authors have pointed out cases of bimodal conditions existing in the tropical Pacific Ocean: according to MEYERS (1982), bimodal climatic states exist in the tropical Pacific Ocean and two different wind regimes are obvious (PAZAN, MEYERS, 1982). DONGUY and HENIN (1980) also found in the south-western Pacific two types of hydroclimatic conditions, pre El Nino and post El Nino, each of them corresponding to a climatic scenario (DONGUY, 1982). A component of this climatic scenario is the equatorial circulation. From the wind field and the associated thermal structure, fluctuations of the equatorial

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TABLE I

Informations on the cruises used. References from Noumea indicate between brackets the month of the cruises

Données sur les croisières utilisées. Pour les références relatives à Nouméa, le mois concerné est indiqué entre parenthèses

Period	SHIP and CRUISE	References NOUMEA	References NODC
1956 - 1957 Pre El Nino	ORSOM EQUAPAC HORIZON	HOS56A (9), HHZ56A (8) HOS56B (10),HOS57A (4)	310724, 590752, 590807
1958 Post El Nino	VITYAZ ORSOM IGY	HVI58A (2),HOS58A(5),HOS58B(11)	900862, 590778, 590924
1960 - 1962 Pre El Nino	GASCOYNE G1/60, G2/60 ORSOM III cruises GASCOYNE G3/61	HGS60A (2),HOS60B(5),HOS60C(9) HTI60A(8),HGS61A(8),HVI61A(11) HDK62A (12)	090005, 090039 590929, 590922, 900065 590001
1965 - 1966 Post El Nino	CORIOLIS BORA	HC065B(12),HC066A(3),HC066B(6) HC066C(9)	350033, 350054, 350051, 350052
1967 - 1968 Pre El Nino	CORIOLIS CYCLONE	HC067A(3),HC067C(4),HC067E(6) HC067G(7),HC067I(8),HC068A(4)	350034, 350035, 350036, 350037, 350038, 350055
1969 Post El Nino	KOYO MARU	HKY69A(11)	Data Report CSK 261
1970 - 1971 Pre El Nino	RADUGU CORIOLIS FOC 1, FOC 2 BOUSSOLE	HRU70A(12) HC071A (2), HC071B(6) HB071A(2,8)	350058 350074 350080
1972 - 1973 Post El Nino	CORIOLIS GORGONE NOROIT MINEPO 1	HC072A(12), HN073B(7)	350077 350078
1973 - 1975 Pre El Nino	CORIOLIS MINEPO 2 GORGONE 2 BOUSSOLE VATE SCHOKALSKY	HC074A(7), HC075A(4) HB073A(11) HSC74A(12)	350086
1977 Post El Nino	CORIOLIS DANAIDES 2 ECOTON	HC077B(7) HC077C(10)	

currents may be pointed out in the western Pacific (DONGUY, HENIN, 1983). However, the qualitative results obtained must be ascertained by quantitative calculations of dynamic heights and geostrophic flows. Such calculations have already been performed in an early paper (DONGUY *et al.*, 1976) but without special reference to El Nino occurrence.

DATA AND METHOD

The area considered extends from 20° S to 10° N and from 160° E to 180°. The data used are stored at the Centre ORSTOM de Nouméa. Roughly meridional cruises have been grouped in order to build cruises characteristic of pre and post El Nino situations.

Table 1 gives detailed information on the cruises used. The dynamic heights relative to 500 decibars have been averaged by degree of latitude, between 160° E and 180°, for each period shown in Table I. Composite sections from 20° S to 10° N are drawn from this calculation. The total variability in this region is rather low: according to WYRTKI (1974), the standard deviation of dynamic height of the sea surface relative to 500 db lies between 5 and 10 dynamic centimeters, while it is more than 30 in the Kuroshio area.

Pre El Nino period is also called non El Nino period and post El Nino period is also called El Nino period. The latter, in the Western Pacific, starts in August-September after El Nino which usually has the peak phase in February-March (DONGUY, HENIN, 1978) and lasts part of the following year. A good index of the post El Nino period is the presence, west of 180°, of low surface salinity (less than 35.0 ‰) in the equatorial area (DONGUY, MORLIÈRE, 1983). The cruises used for the post El Nino composite cruise were carried out at different times of the year, partly eliminating seasonal variations. Usually, pre El Nino periods last longer than post El Nino periods. However, between 1970 and 1980, in the western Pacific, two complete El Nino events occurred and, after 1976, the post El Nino period lasted 2 years. In addition, El Nino like phenomena were found in the western Pacific in 1979 (DONGUY *et al.*, 1982) and these effects remained obvious for one year. Consequently, from 1970 to 1980, post El Nino periods occurred almost during the same time as pre El Nino periods.

The following periods have been selected taking into account the available data:

(1) Pre El Nino periods: 1956-1957, 1960-1962, 1967-1968, 1970-1971, 1973-1974.

(2) Post El Nino periods: 1958, 1965-1966, 1969, 1972-1973, 1977.

DYNAMIC TOPOGRAPHIES

Dynamic heights from pre and post El Nino composite cruises are shown in Figure 1. The two profiles differ in several ways.

Pre El Nino dynamic heights are larger than post El Nino. From 20° S to 10° N, in pre El Nino, the mean dynamic height relative to 500 decibars is 146 cm.dyn. and only 136 cm.dyn. in post El Nino. The mean annual dynamic topography presented by WYRTKI (1974) is closer to the pre El Nino than the post El Nino situation: in pre El Nino (Fig. 1), as in WYRTKI (1974), two maximum of more than 150 cm.dyn. occur at 8° S and 14° S; the agreement is due to the predominance of the pre El Nino situations into the historical data. On the other hand, the post El Nino dynamic profile (Fig. 1) is close to that presented by WYRTKI (1974) for January-February: during these periods, trade winds are weak in the western equatorial Pacific and, as during post El Nino period, the North Equatorial Counter Current is strong.

The main difference between dynamic topographies (Fig. 1) during pre and post El Nino concerns the northernmost part, north of 5° N, where the North Equatorial Counter Current flows. The dynamic slope is much larger in post El Nino than in pre El Nino. Otherwise, the general pattern of equatorial currents (MERLE *et al.*, 1969) exists in both cases: North Equatorial Counter Current (10° N-3° N), Equatorial Current (3° N-5° S), South Equatorial Counter Current (5° S-9° S), South Equatorial Current (9° S-14° S) and South Tropical Counter Current.

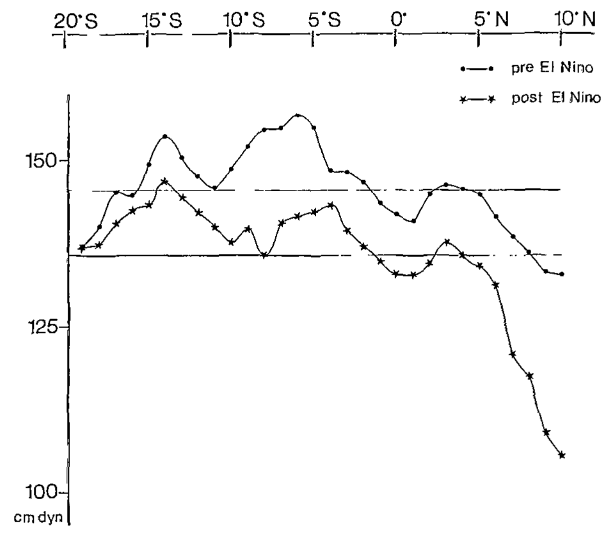

FIG. 1. — Composite dynamic topographies in cm.dyn. relative to 500 decibars in pre and post El Nino conditions

Topographies dynamiques composites, en cm.dyn., par rapport à 500 décibars, en situation de pré et post El Nino

The dynamic heights *before a strong El Nino* (Fig. 2) are considered under the form of a composite cruise including 1956-57 data before the 1957 El Nino and 1970-71 data before the 1972 El Nino. In this case, dynamic heights are large and, from 15° S to the equator, the slope is mostly equatorward, indicating a westward current.

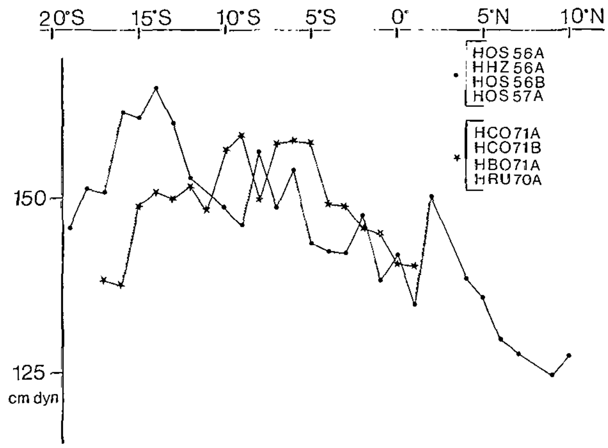

FIG. 2. — Dynamic topography in cm.dyn. relative to 500 decibars before a strong El Nino

Topographie dynamique, en cm.dyn., par rapport à 500 décibars, avant un fort El Nino

The dynamic heights *before a weak or moderate El Nino* (Fig. 3) are determined from 1960-62 data before the weak 1963 El Nino, from 1967-68 data before the weak 1969 El Nino and from 1973-1975 data before the moderate 1976 one. The dynamic heights are more rugged than before a strong El Nino and the apparition of a trough at 12° S and a ridge at 8° S can be interpreted as the traces of the South Equatorial Counter Current between them.

The dynamic heights *after a weak or moderate El Nino* (Fig. 4) are computed from 1965-66 data after the moderate 1965 El Nino, from 1969 data after the weak 1969 El Nino and from 1977 data after the moderate 1976 El Nino. The dynamic profile has almost the same shape as before a moderate El Nino but the dynamic heights are smaller.

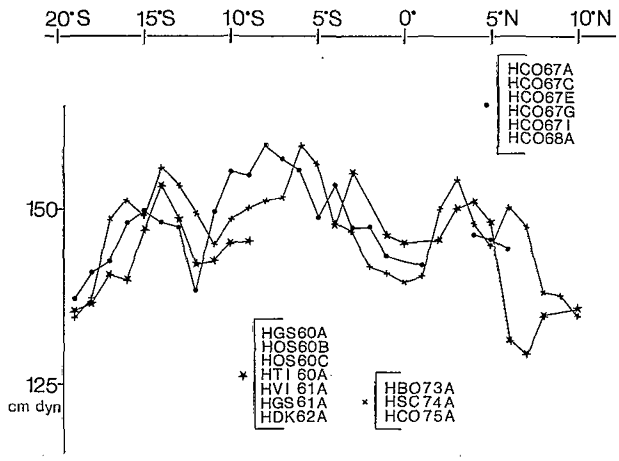

Fig. 3. — Dynamic topography in cm.dyn. relative to 500 decibars before a weak or moderate El Nino

Topographie dynamique, en cm.dyn., par rapport à 500 décibars, avant un El Nino faible ou modéré

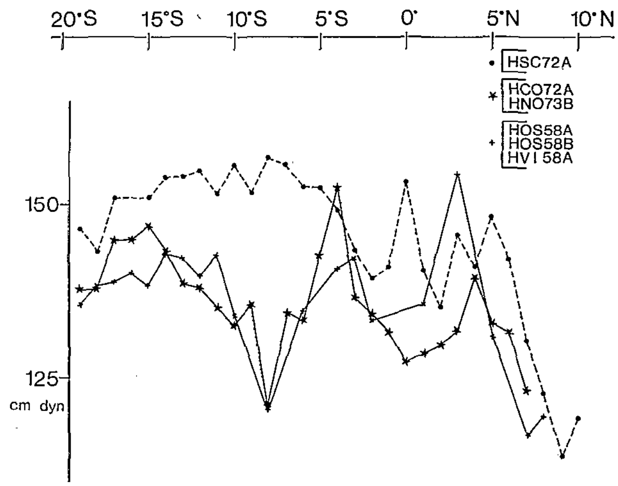

Fig. 5. — Dynamic topography in cm.dyn. relative to 500 decibars after a strong El Nino

Topographie dynamique, en cm. dyn., par rapport à 500 décibars, après un fort El Nino

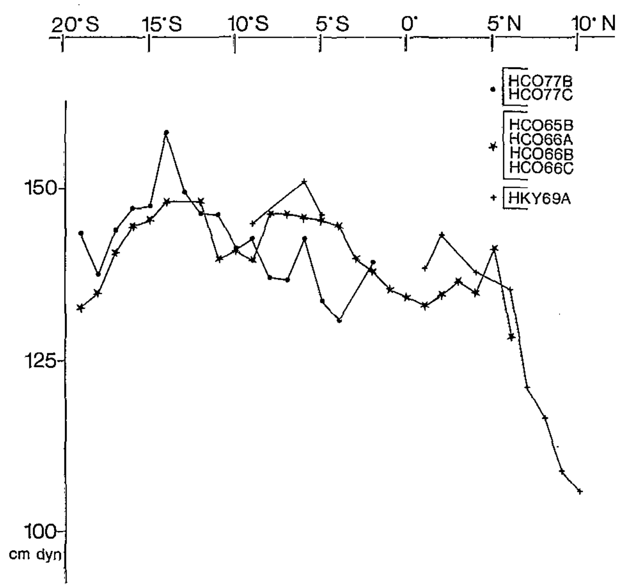

Fig. 4. — Dynamic topography in cm.dyn. relative to 500 decibars after a weak or moderate El Nino

Topographie dynamique, en cm.dyn., par rapport à 500 décibars, après un El Nino faible ou modéré

The dynamic heights *after a strong El Nino* (Fig. 5) come from 1957-58 data after the strong 1957 El Nino and from 1972-73 data after the strong 1972 El Nino. The profiles are very close, at least in the southern hemisphere with a deep minimum at 8° S separating the South Equatorial Current from the South Equatorial Counter Current: consequently, these currents are particularly strong. The dynamic profile of the 1972 Schokalsky cruise carried out during an El Nino peak (February-April 1972) is closer to a pre El Nino than a post El Nino profile, excepted north of 5° N. This cruise occurs during the first part of the year simultaneously to El Nino itself: the North Equatorial Counter Current is already involved into El Nino phenomenon, although Wyrtki (1977) notices an abnormally strong North Equatorial Counter Current only in the second half of 1972. It is probably too early to affect the southern hemisphere, which is still in pre El Nino conditions.

In fact, dynamic heights decrease from pre strong El Nino to post strong El Nino conditions while pre moderate El Nino and post moderate El Nino conditions present intermediate values (Fig. 6). From 20° S to 10° N, the mean dynamic heights are 147 cm.dyn. in pre strong El Nino, 145 cm.dyn. in pre moderate El Nino, 137 cm.dyn. in post moderate El Nino and 135 cm.dyn. in post strong El Nino.

TRANSPORT CALCULATION

Transport is calculated relatively to 500 decibars (Table II). The positions and transports of the equatorial currents are shown in relation to hydroclimatic conditions, in the general cases of pre El Nino and post El Nino and then in the specific cases of pre strong, pre moderate, post moderate and post strong El Nino.

The southern limit (3° N) of the North Equatorial Counter Current does not change, but the location of the currents in the southern hemisphere is very

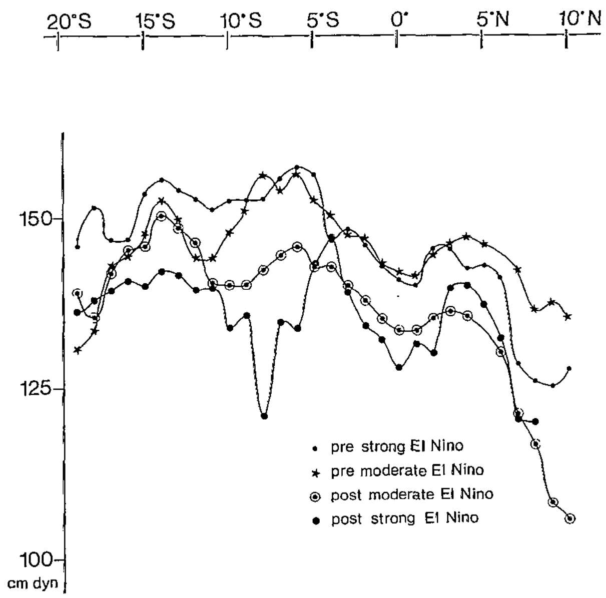

FIG. 6. — Composite dynamic topographies in cm.dyn. relative to 500 decibars before a strong El Nino, before a weak or moderate El Nino, after a weak or moderate El Nino and after a strong El Nino

Topographies dynamiques composites, en cm.dyn., par rapport à 500 décibars, avant un fort El Nino, avant un El Nino faible ou modéré, après un El Nino faible ou modéré et après un fort El Nino

variable. The Equatorial Current is more extended in pre El Nino (reaching as far south as 8° S in pre moderate El Nino) than in post El Nino conditions (4° S). Consequently, the South Equatorial Counter Current is shifted toward the equator from pre El Nino to post El Nino. The South Equatorial Current is more extended in post El Nino than in pre El Nino. These features are in agreement with DONGUY and HENIN (1983). It is more difficult to discuss about transport as the dynamic method does not work well in the vicinity of the equator and consequently the uncertainty on the Equatorial Current flow is large. In the southern hemisphere where the data are numerous, it seems that during post El Nino, the South Equatorial Current located around 10° S is much stronger than during pre El Nino. The distribution of eastward currents is also dependant on the strength of the El Nino event considered: the South Equatorial Counter Current becomes important only in post strong El Nino while the South Tropical Counter Current almost disappears as already noticed by DONGUY *et al.* (1970). For example, in February 1958 during a VITYAZ cruise at 172° E, the transport of the South Equatorial Counter Current was 33 Sverdrups and the South Tropical Counter Current one was 1,9 Sverdrups. However, data from JARRIGE (1968) suggest also seasonal variations of the South Equatorial Counter Current transport.

In the northern hemisphere, the sparcity of data does not allow to point out reliable conclusions for each of the 4 categories of climatic conditions. So, only two categories (pre and post) must be considered. The transport of the North Equatorial Counter Current is much stronger (Table II) during post El Nino than during pre El Nino as already pointed out by WYRTKI (1977).

The balance of the equatorial currents (10° S-

TABLE II

Transport 0-500 db in sverdrups. The approximate location of the equatorial currents has been indicated (+ : eastward)

Transport 0-500 db en sverdrups. La position approximative des courants équatoriaux est indiquée (+ : vers l'Est)

	20°S – 0 (STCC, SEC, SECC; south to north)	EC (0)	0 – 10N (NECC)	TOTAL	TOTAL Equatorial 10°S-10°N	Equatorial balance
Pre El Nino	+ 4,4 / - 6,9 / + 7,3 / - 17,3	no calculations	-2,4 / + 28,3	+ 40,0 - 26,6	+ 35,6 - 19,7	+ 15,9
Post El Nino	+ 1,9 / - 14,0 / +4,2 / -13,8	no calculations	-4,2 / + 39,1	+ 45,2 - 32,0	+ 43,3 - 18,0	+ 25,3
Pre Strong	+2,0 / -4,2 / +4,7 / -6,2 / +4,6 / -19,8	no Calculations	- 8,0 / +45,4	+56,7 -38,2	+50,0 -27,8	+22,2
Pre Moderate	+3,6 / -7,9 / +6,6 / -16,5	no Calculations	- 3,0 / +23,3	+33,5 -27,4	+29,9 -19,5	+10,4
Post Moderate	+4,8 / -12,6 / +2,6 / -15,9	no Calculations	+38,4	+45,8 -28,5	+41,0 -15,9	+25,1
Post Strong	-17,9 / +24,1 / -29,5	no Calculations	-17,0 / +30,3	+54,4 -64,4	+54,4 -46,5	+7,9

10° N) (Table II) shows also that there is a tendancy to an increase of eastward transport during post El Nino (25,3 Sverdrups instead of 15,9 Sverdrups). Moreover, the dynamic method does not provide informations about the equatorial area where a special current pattern could be observed after El Nino: an equatorial jet is flowing eastward from 2° N to 2° S (DONGUY *et al.*, 1984) and can contribute to increase the total eastward flow.

CONCLUSIONS

Composite transequatorial cruises have been built from hydrographical data obtained between 1956 and 1977 in the western Pacific. Geostrophic calculations show the interannual variability of the equatorial current system from 10° N to 20° S, connected to the appearance of El Nino conditions.

The main feature is a general decrease of dynamic heights during an El Nino event, at least of the order of magnitude of the seasonal variations (WYRTKI, 1974). Stronger is El Nino, larger is the decrease. This is consistent with sea level variations in the west Pacific.

North of 3° N, the strong dynamic slope corresponds to a global increase in eastward transport. The distribution of eastward currents is also dependent on the strength of the El Nino event considered: the South Equatorial Counter Current becomes important only in post strong El Nino conditions.

In conclusion, the circulation in the Western Pacific has a bimodal aspect in connection with the occurrence of El Nino but the circulation is also affected by the strength of this event.

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