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VARIATIONS OF EQUATORIAL CURRENTS

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From october 1965 to may 1968 the R.V. CORIOLIS of the Centre O.R.S.T.O.M. of Noumea made 10 cruises along 170°E, from 20°S to 4°N. Out of these 10 cruises, 7 included direct measurements of the equatorial currents system. Some of the most significant preliminary results of these cruises will be discussed here.

Current measurements :

Depending on the cruises, the direct current measurements were made with one or two self-recording Hydro-Products current-meters attached to the hydrographic cable. The current measurements took place immediately after a hydrological station during which the ship was manoeuvred in order to find a speed and a bearing allowing the cable to remain vertical.

Comm. 9ème Ass. gen. SCOR, 1968, La Jolla

The first current-meter was attached to the cable after 1,000 m of it had been paid out. The second meter was attached 1,000 m above the first so that the measurements were made with the shallow meter in the layer 0-500 m relative to the deep one located in the layer 1,000-1,500 m.

One continuous measurement during 4 minutes was made every 20 m in the layer 0-300 m and every 50 m from 300 m to 500 m. Measurements were made again while retrieving the cable. During the whole serie of measurements, the speed and the bearing of the ship were kept constant so that the angle of the cable be minimal.

When one current-meter was out of order, the same technique was used with the remaining apparatus which was sent at regular time at 500 m or at 1,000 m in order to give a deep reference. During the first two cruises the reference was 500 m.

With this technique, it is considered that the layer 1,000-1,500 m being motionless, the meter which is in it records the drift of the ship. A vector substraction gives the true current. But, in any case, it must be born in mind that the currents to which it will be refered are currents relative to the layers 1,000-1,500 m, except for the first two cruises.

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Obviously, such a technique does not guarantee that the drift of the ship is constant during the station and that its evaluation is reliable enough. A study of the current measured at 500 m relative to 1,000 m during two prolonged stations at the equator, at 170°E and 169°E respectively (figure 1) shows a slight variation in time of both the east-west and north-south components, but with an average which is the same for both stations ; it is of the order of + 20 cm/sec (positive to the east) for the east-west component, and of - 10 cm/sec (positive to the north) for the north-south component. Similarly, the comparison of the results obtained at five weeks interval, at another prolonged station at the equator and 170°E, shows a current at 500 m relative to 1,000 m with the same east-west component of + 20 cm/sec and north-south component of - 10 cm/sec.

Fig. 1

Thus, at prolonged stations at two different locations of the equator and at five weeks interval, the current at 500 m relative to 1,000 m has been found constant. This indicates that in the hypothesis of a stable deep current, the evaluation of the drift of the ship by the above method is acceptable.

Further, it can be stated that the accuracy of the measurements of the east-west component of the current is of the order of ± 5 cm/sec.

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Five of the main cruises have been made at five weeks intervals in march, april, june, july and august 1967. The eastward flux of the equatorial undercurrent computed between the isotach 8 cm/sec as the upper limit, 4°S limit to the south, 400 m lower limit and a narrowing of the flow to the east which has always been found towards 3°W (Figure 2), shows considerable variations. Fig. 2

Within three months, from april to july, the flux has increased about fourfold and within a month, from march to april or from july to august, it has decreased by about one half (Table 1). Table 1

It must be pointed out that during all the cruises but one, cruise C3, the flow was extending at least between the isanosteric level 500 cl/t and 150 cl/t ; when the flow was minimum at C3, it was extending only between 350 cl/t and 150 cl/t.

Another point which is worth noting is the fact that there is an obvious continuity between the north-equatorial counter-current*,

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* As suggested by TSUCHIYA in this Proceeding, the existence of a pattern of zonal currents more complicated than the three currents system which is actually in use make it necessary to revise the terminology. The term "north-equatorial countercurrent" used here, refers to the so called equatorial countercurrent and introduces the existence of a south-equatorial countercurrent, the permanent presence of which has now been demonstrated.

the equatorial undercurrent and a subsurface flow to the east extending the undercurrent to the south and to greater depth (figure 1). The deeper part of this third flow, below the isanosteric level 150 cl/t shows some stability ; between this isanosteric level and the 600 m depth, a flux of the order of 4 x 10^6 m^3/sec has been measured (Table 2).

Table 2

Besides, on three cruises, C2, C5 and C6, the east flow had two cores, the upper one at the level 450-500 cl/t and the deeper one close to 150-250 cl/t (Table 2). The minimum of flux is close to 350-450 cl/t. It appears also (figure 3) that the salinity maximum of the subtropical lower water of the south Pacific is distinct from the lower core of the undercurrent. Thus, one can consider that the flow of the undercurrent is vertically stratified with, from top to bottom, an upper core in which the thermosteric anomaly is greater than 450 cl/t, a layer of minimum of flux with a thermosteric anomaly between 350 cl/t and 450 cl/t, a salinity maximum with a thermosteric anomaly equal to 250-350 cl/t, a lower core at 150-250 cl/t and the deep flow which has been mentioned earlier. The stablest part of the flux is the deepest one which is formed of water originated at intermediate depth of the southern hemisphere and also the lower core which is a mixture of equatorial water and north-equatorial countercurrent water. The less stable one is the shallowest composed of surface and subsurface water of both the northern and the southern hemisphere (Table 3).

Fig. 3

Table 3

It is interesting to compare these measurements to those which have been made further east, at 150°W, by MONTGOMERY and STROUP (1962) who computed a flux of 34×10^6 m^3/sec relative to 300 db, comparable to that which has been found during the cruise C4 of the R.V. CORIOLIS.

Table 4

It can be seen (Table 4) that the flux above the isanosteric surface 350 cl/t decreased from west to east ; in the layer of the salinity maximum, the flux was the same and in the core layer and below, there was an increase from west to east. The difference of flux below 150 cl/t is probably due to the fact that the flux at cruise C4 has been evaluated to 400 m. Finally, it seems that the undercurrent cools down as it moves to the east.

Equatorial upwelling :

In the western part of the Pacific, the equatorial surface cooling due to an upwelling has seldom been observed, except at 180°E at the begining of the year. Nevertheless, the atlases of surface distribution of the temperature indicate that there could be an extension to 170°E of the equatorial upwelling but at the begining of the year only. Thus it could be considered that the enrichment of the upper layers of this region of the Pacific is an unlikely event in spite of the fact that the average wind has a noticeable east component.

During all the cruises of the R.V. CORIOLIS along 170°E the wind which has been observed in the equatorial region had an east component stronger than 2 m/sec but in december 1965 and in june 1966 when it was blowing for a short period from the west. The Ekman transport as observed from the drift of the ship and from the direct current measurements was in the direction of the wind except in april 1967, cruise C3, when in spite of a rather strong east wind, the surface current was eastward. During june and september 1966, a tendency to a surface divergence at the equator has been noted.

Fig. 4

Thus, in most cases, the conditions were satisfied for a surface divergence to be induced and it is what was observed during most of the cruises (figure 4). The vertical distribution of the temperature in the upper 100 m, between 4°S and 4°N, gives a good picture of the surface circulation ; it indicates that there was an upwelling at all cruises but in december 1965, cruise B1, and in april 1967, cruise C3. During these two cruises, the eastward surface current induced on the contrary a convergence which is responsible for the low flux of the undercurrent measured during cruise C3.

The vertical distribution of the nutrients, phosphate and nitrate, does confirm that there is effectively an upwelling with enrichment of the upper layer at the equator. In the two cases, when there was a convergence, the surface waters were poorer and no enrichment at the equator relative to the adjacent waters was observed.

The minimum of flux of the equatorial undercurrent which has been found during the cruise C3 of april 1967 is directly bound to the particular structure of the currents during this period. At all the other cruises the direct measurements have indicated that the surface eastward flow is very shallow and does not extend, at the equator, deeper than 60 m. Below this depth, there is a continuous flow to the east down to a depth of at least 300 m. Further north and south, the current to the east extends much deeper. During the cruise C3, when the flux of the undercurrent was smallest, the vertical structure at the equator was different. The equatorial undercurrent proper was extending only between 200 m and 300 m. In the upper 100 m there was a flow to the east, between 2°N and 2°S ; in the intermediate layer 100-200 m, the flow was to the west. Thus, in the presence of a surface convergence, the undercurrent was deprived of its shallower part which is composed of warm and less saline water, and this loss, added to the obvious slackening of the speed at the core was responsible for the considerable decrease of the flux.

South-equatorial countercurrent :

JARRIGE (1968), in a preliminary study of the data of all the cruises of the R.V. CORIOLIS from the point of view of the geostrophic circulation has found a permanent eastward component of the surface current relative to 1000 db. This current located near 10°S corresponds to the south-equatorial countercurrent shown in various atlases of the surface circulation and reported by REID (1958).

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The characteristics of this current are highly variable (Table 5). Its depth is nearing 200 m for one cruise, 300 m for two others and it is over 500 m for all the others. Nevertheless, the velocity core with a velocity of 10-30 cm/sec has always been very close to the surface. The average width is of the order of 650 km, varying between 330 km and 820 km ; the southern limit which is bound to a permanent lessening of the eastward component of the wind does not vary much in latitude whereas its northern limit varies much more.

Table 5

Moreover, the upper 100 m of the current are always associated to a salinity minimum whose value is between 34.00°/oo and 34.80°/oo.

The existence of this current has been confirmed by the capture at 10°S, 170°E of <u>Euphausia fallax</u> which originated north of New Guinea and also by the capture at about the same location of stomatopod larvae at a very early stage which can only have had their origin in the northern part of New-Hebrides archipelago. Recent G.E.K. measurements indicate that in may 1960 there was, at the latitude of the geostrophic south-equatorial countercurrent, an eastward drift. Finally the star fixes and the dead reckoning always indicated an eastward drift of the ship at the latitude where the geostrophic eastward current exists.

Remarks on the hydrological structure of the equatorial undercurrent :

KNAUSS (1960) has noted that in the core of the equatorial undercurrent, the oxygen content did not vary and that this homogeneity can be considered as a clue to the existence of a fairly strong vertical mixing process within the core of this undercurrent.

Fig. 5

A close examination of the measurements made along the equator by the R.V. CORIOLIS during its cruise "ALIZE" (ROTSCHI et al 1967) shows that the core layer of the undercurrent is not really homogeneous ; on the contrary, there is a minimum at the upper limit of this layer, and a maximum at its lower limit both differing by about 0,10 ml/l (figure 5). It seems somewhat conspicuous that a mechanism of vertical mixing could create such a distribution. A further detailed study of the hydrological structure of the undercurrent has shown that in the same layer where the oxygen content is apparently constant, the concentrations of the nitrate and of the phosphate are substantially increasing with depth.

Fig. 6

In fact, it has been observed at 170°E (PICKARD and ROTSCHI 1968) in July 1967, that in the core layer, where the speed was higher than 50 cm/sec, there was a chemical two layer system ; in the upper layer, a little less than 100 m thick, between 100 m and 200 m depth, limited by two thermal inversions, the oxygen decreased with depth (figure 6). In the lower layer, between 200 m and 300 m, it increased slightly. In both layers nitrate and phosphate increased, but in the deeper one, the gradient was greater.

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Such a stratification and such different variations with depth of the concentrations of variables which are bound to each other do not militate in favour of a strong vertical mixing. They suggest on the contrary that, at least in the western Pacific, the water of the core of the equatorial undercurrent is stratified ; the stratification is favoured by stable quasi permanent thermal inversions.

Thus, it well could be that the apparent oxygen homogeneity of the water of the undercurrent is more probably due to the formation of this current from different water sources at different depth having purely by chance approximately the same oxygen content. This view is supported by TSUCHIYA (1967) and his analysis of the distributions on the 160 cl/t isanosteric surface. Recent studies undertaken at the Centre ORSTOM of Noumea have shown that the undercurrent can be formed in its upper part by tropical and subtropical water of the south Pacific crossing the equator north of New-Guinea and by water of the north-equatorial countercurrent. As far as the lower part is concerned, the same studies confirm TSUCHIYA hypothesis on the importance of the Coral Sea in its formation.

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Table 1

Variations of the east flux of the equatorial undercurrent observed during five cruises of the R.V. CORIOLIS in 1967

Cruise	Month	Depth of reference	flux 10^6 m^3/sec
C2	march	500	20
C3	april	500	12
C4	june	1,000	34
C5	july	1,000	54
C6	august	1,000	28

Table 2

Variations of the zonal flux in various layers

	10^6 m^3/sec				
cl/t	C2	C3	C4	C5	C6
> 500	0,1	0	2,0	3,9	1,3
450-500	3,3	0	1,0	0,1	2,8
400-450	0,4	0	2,0	6,1	1,7
350-400	0,7	0	3,3	5,1	1,5
300-350	1,5	0,8	4,0	5,9	1,5
250-300	2,1	2,8	4,0	4,9	2,5
200-250	4,0	2,3	5,4	4,6	5,0
150-200	3,0	3,2	6,0	8,7	7,2
< 150	4,4	3,4	4,0	6,1	4,8

Table 3

Variations of the flux in the five main layers of the undercurrent

Layer	Thermosteric anomaly cl/t	Flow 10^6 m^3/sec				
		C_2	C_3	C_4	C_5	C_6
upper core	450	3,4	0	3,0	12,0	4,1
minimum of flux	350-450	1,1	0	5,3	11,1	3,2
salinity maximum	250-350	3,6	2,0	9,7	10,0	4,0
lower core	150-250	7,0	9,5	12,2	13,3	12,2
deep flux	150	4,4	3,4	4,0	6,1	4,0

Table 4

Comparison of the fluxes at 150°W and 170°E (10^6 m^3/sec)

Layer cl/t	150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-550
150°W	1,9	9,4	7,0	4,9	5,0	2,0	1,9	0,7	0,0
170°E	4,0	6,0	5,4	4,0	4,9	3,9	2,0	1,0	2,0
		Increase to the east		unchanged		decrease to the east			

Table 5 : Characteristics of the south-equatorial countercurrent at 170°E (after JARRIGE 1968)

Cruise	Date	Extreme latitude	Depth (m)	Max. Vel. (cm/sec)	Latitude Max. Vel.	Width (km)	Mass. transp. ($10^6 m^3$/sec)	Smin (°/oo)	Drift of the ship
BORA 1	dec. 65	7°00'S-12°15'S	160	12	9°45'S	500	2,2	34,6	-
BORA 2	march 66	4°00'S-10°15'S	500	51	7°50'S	605	19,6	34,3	6°00'S-5°00'S 1knt-ENE
BORA 3	june 66	5°50'S-12°05'S	500	24	6°50'S	605	9,6	34,5	-
BORA 4	sept.- oct. 66	7°30'S-13°25'S	500	20	8°00'S	330	6,5	34,7	9°00'S 0,2knt-E
CYCLONE 2	march 67	8°20'S-12°10'S	500	31	9°40'S	410	10,6	34,8	10°30'S-9°00'S 0,8-1,0knt-E
CYCLONE 3	april 67	5°00'S-12°45'S	500	22	6°00'S	930	14,7	34,2	9°00'S 1,5-2,0knt-SE
CYCLONE 4	june 67	8°45'S-13°05'S	500	28	12°00'S	400	12,4	34,8	-
CYCLONE 5	july 67	9°20'S-13°00'S	200	21	12°00'S	410	6,6	34,8	11°30'S-11°00'S 1,0knt-E
CYCLONE 6	aug. 67	8°25'S-13°10'S	220	15	9°00'S	540	3,4	34,8	-

Captions to figures :

Figure 1 - East-west and north-south component of the current at 500 m relative to 1,000 m at 0° and 170°E and 169°E respectively during cruise C5 and at 0° and 170°E five weeks later during cruise C6.

Figure 2 - Vertical distribution of the east-west component of the currents at 170°E, between 4°S and 4°N, in march 1967, cruise C2.

Figure 3 - Fluxes in the equatorial undercurrent for various classes of salinity and thermosteric anomaly, at 170°E, in march 1967, cruise C2 (10^6 m^3/sec).

Figure 4 - Vertical distribution of temperature, in the upper 150 m, at 170°E, during various cruises of the R.V. CORIOLIS (0°C)

Figure 5 - Vertical distribution of oxygen along the equator.

Figure 6 - Oxygen-temperature, phosphate-temperature and nitrate-temperature diagrams at the equator and 170°E in july 1967.