THE REVERSAL OF THE WIND-DRIVEN EQUATORIAL UNDERCURRENT

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The Equatorial Undercurrent in the Pacific Ocean, at 170°E, has been described as a double-cell structure (Hisard et al., 1970). The upper cell is located at the bottom of the homogeneous surface layer (120 m thick), surrounded by the Equatorial Current; the lower cell is in the thermocline layer (V max. at 220 m depth) and is connected to the eastward flow of the North Equatorial Countercurrent. The flow of the lower cell is in geostrophic balance (Colin et Rotschi, 1970), and permanent, unaltered by changes in the wind pattern; the upper cell flow does not appear to be in geostrophic equilibrium and, moreover, it reverses westward when there is an eastward current, driven by a west wind, at the surface. So, it can be assumed that the upper cell of the Equatorial Undercurrent belongs to the wind-driven circulation, and that the lower cell belongs to the thermo-haline circulation. In the central Pacific, as the thermocline layer rises towards the east, these two mechanisms drive at about the same depth a one-cell equatorial undercurrent; however, it is possible through chemical considerations such as nutrient salts and oxygen contents, to outline the influence of each cell as far east as 140°W (Colin et al., 1971).

The reversal of the eastward-flowing upper cell of the equatorial undercurrent at 170°E, when an eastward surface current (driven by a west wind) substitutes for the Equatorial Current at the equator, leads us to question the generality of such a structure; from the theoretical point of view, most of the described models agree with the possibility of a reversal of the undercurrent under positive (eastward) wind-stress; moreover, most of these models take into consideration an homogeneous ocean and are consistent with the observation of an undercurrent in the homogeneous surface layer. Gill (1971) pointed out, that the transport of the equatorial undercurrent is proportional to wind stress at the surface, but in opposite direction; in his hypothesis neither the direction of the stress (east or west) nor the direction of the undercurrent (west or east) is given a priori.

The observation of west wind at the equator is not as frequent as the observation of trade wind; however, a west wind is present in the western equatorial Pacific Ocean in northern winter and, in the Indian Ocean, the whole equatorial area is influenced during northern summer by a southwest monsoon. In a lesser degree, west components of the wind can be observed in the easternmost part of the equatorial area, in the Pacific Ocean, east of the Galapagos islands and in the Atlantic Ocean, near the African coast.

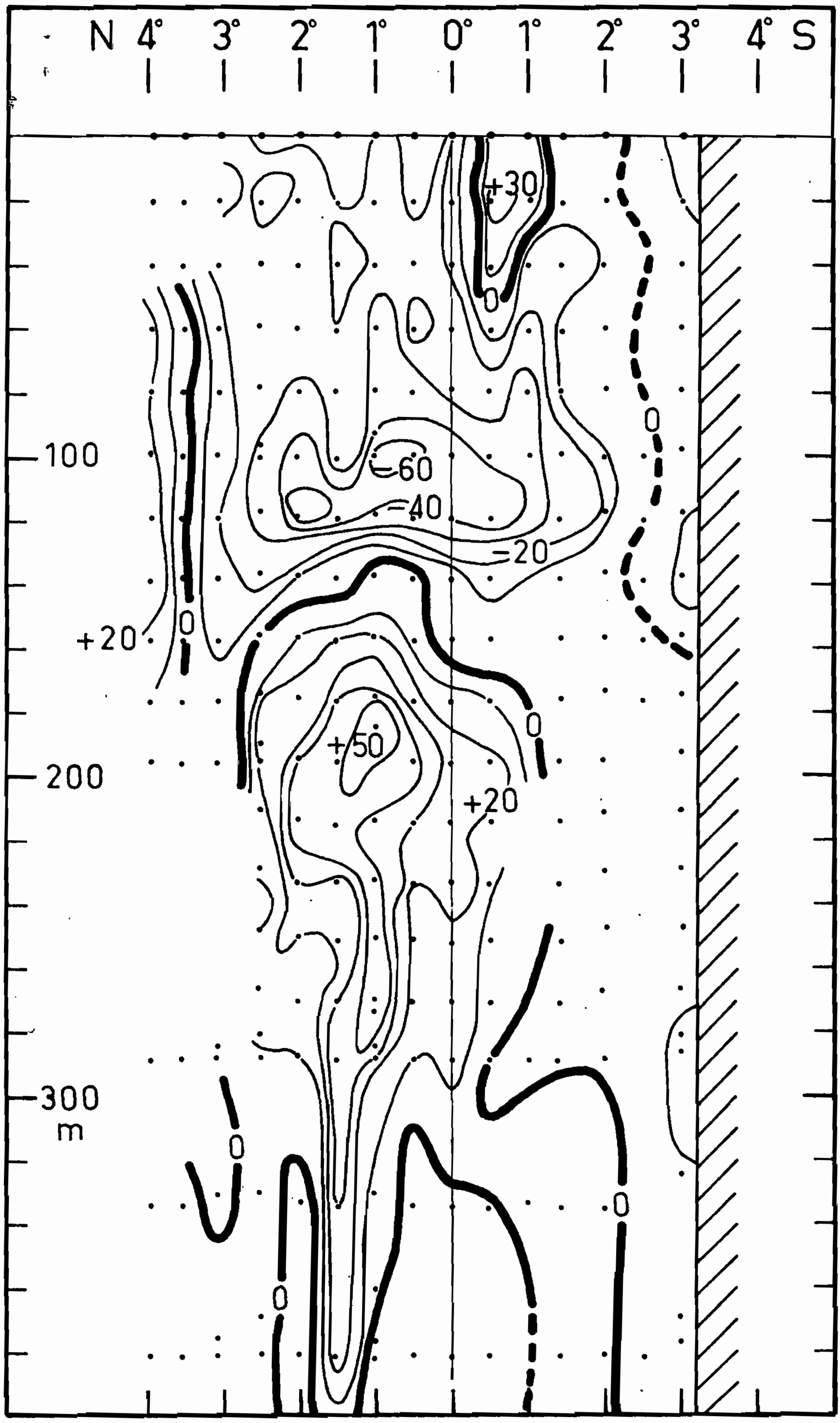
The purpose of this note is to investigate further evidence of a westward subsurface equatorial undercurrent when west wind substitutes for trade wind.

1. - The Equatorial Undercurrent in the western Pacific Ocean, in northern winter.

In northern winter, the high-pressure area over the Asiatic continent, induces a north west wind, north of New Guinea; moreover, as the intertropical zone of convergence is located in northern winter, south of the equator, the southeast trade wind does not reach the equator and an eastward surface current substitutes for the Equatorial Current at the equator, sometimes as far east as 180°. Most of the data reviewed in this area showed very evidently a subsurface westward undercurrent flowing under an eastward surface current; in a deeper layer, an eastward flow, the lower cell of the Undercurrent, is observed permanently (Table 1; Fig. 1).

2. - The Equatorial Undercurrent in the easternmost part of the oceans.

The easternmost equatorial area of the oceans is not influenced by pure trade wind; most of the time, the wind blows from the south, but the presence of the continental mass deviates the wind pattern and west components can be observed; as a consequence, the sign of the zonal pressure gradient reverses and becomes positive (eastward). The reversal of the equatorial undercurrent in these areas was first suggested by Neumann (1960) in the Atlantic Ocean : " It is even possible that close to the African coast a short undercurrent exists that flows to the west". The only observation of such an event was



Meridional distribution of zonal velocity component at 142° 30'E, in February 1971, in the western equatorial Pacific Ocean. Cruise FOC 1 of the R. V. Coriolis. (Velocity in cm/sec; east components are positive) found in the fall of 1961, east of the Galapagos islands, in the Pacific Ocean. As Knauss (1966) planned to track the Cromwell Current to the east of these islands, a weak eastward undercurrent was only observed at 200 m depth (20 cm/sec), but the westward surface current evidenced markedly a subsurface core at a depth of 40 m (30 cm/sec), just at the equator (see Fig. 7, p. 220, in Knauss, 1966). This subsurface core can be accounted to confirm evidence for the reversal of the equatorial undercurrent as Knauss (op. cit. underlines that the negative zonal pressure gradient went to zero west of the Galapagos islands, and to the east of these islands, the sign was reversed; moreover, during the observations the wind blew from 200-240°, force 3-4, at 0°-87°W (Anonymous, 1965).

3. - The Equatorial Undercurrent in the Indian Ocean in northern summer, during the southwest monsoon.

When change in wind-driven equatorial circulation is considered, the Indian Ocean focuses interest due to monsoon balance. The first indication of a westward equatorial subsurface flow was found in the Lusiad report (Taft and Knauss, 1967). During the southwest monsoon, a thin layer of very strong west current was observed at the bottom of the surface layer, with a maximum component of 95 cm/sec at 1°N-79°E; beneath this westward flow, the current was eastward in the thermocline; this structure was permanent as it was observed two months earlier at 0°-79°E, and also a week later. In contrast, during the northeast monsoon (northern spring), the equatorial undercurrent was, in some instances, observed as a very markedly double-cell eastward flow (see Fig. 4, p. 8, in Taft, 1967).

The observations reviewed in the Indian Ocean do not agree always with such characteristical structures. For instance, at 89°E, in September 1962, the east component of current increased from surface with depth in the thermocline to a second maximum; however, this structure did not seem to be in equilibrium, as, five days later, striking changes in the zonal velocity component occured; the maximum east current was reduced from 51 to 34 cm/sec. Also, Swallow (personal communication) drew our attention to the observations he made, at 67°30'E, in April 1964, at which time the wind blew from the west, but there seemed to be eastward flow at all depths to nearly 200 m. However, as Swallow (1967) pointed out, most of his wind observations did not seem to be consistent with the observed strong undercurrent; he suggests that perhaps the undercurrent does not respond to rapid changes of wind and that mean wind stresses over long period should be considered.

4. - The Equatorial Undercurrent in a laboratory ocean model.

In a laboratory β-plane ocean model, Baker and Robinson (1966) and Baker (1970) have produced a circulation predominantly frictional, in which the western boundary current and the equatorial undercurrent are well delineated. As the rotation of the block ocean-model was reversed, an equatorial undercurrent was still observed but in the direction opposite to the velocity of the block, that is the undercurrent can flow either east or west. As the forcing velocity increased, the inertial efforts become more important and the undercurrent that flows westward breaks up and disappears; however it was not clear whether the current was flowing too fast to be clearly visualized by the technique or whether it became unstable.

5. - Conclusion

The most that can be said is that, (i) the hypothesis of a reversed equatorial undercurrent under positive wind stress is not inconsistent with theory, (ii) further, the review of the observations put in light frequent occurences of a westward subsurface equatorial undercurrent when an eastward surface current, driven by a west wind, is present at the equator; perhaps, this structure, if real, may throw some light on the equatorial undercurrent problem and could help the hydrodynamists in their research to build up a model of the equatorial current system.

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TABLE 1

LONGITUDE	DATE	Eastward Surface Current	Westward Upper Undercurrent		Eastward Lower Undercurrent	
			U	Z	U	Z
140° to 150°E	April 1966(a)	+ 40	- 60	125	+ 40	225
140°E	Febr. 1964(b)	+ 30	- 50	80	+ 50	200
142°30'E	Febr. 1971(c)	+ 10	- 60	100	+ 50	200
153°E	Jan . 1958(d)	+ 40	- 30	100	+ 60	200
155°E	Jan . 1928(e)	+ 35	- 35	100	+ 50	200
170°E	April 1967(f)	+ 20	- 40	130	+ 40	210
180°	Jan . 1964(b)	+ 20	- 40	110	+ 50	220

Table 1 : Zonal components of the currents at the equator (positive eastward), in the western Pacific Ocean, during northern winter. Velocity in cm/sec (U); Z : depth in meters of velocity maximum.

a : Vityaz 38 (Kort et al., 1966); b : Shokalskiy 4 (Istoshin and Kalashnikov, 1965); c : Coriolis, cruise FOC 1, see fig. 1; d : Takuyo and Satuma, I.G.Y. (Yosida et al., 1959) see note 1; e : Mansyu Maru (Tsuchiya, 1961) see note 2; f : Coriolis, cruise Cyclone 3 (Hisard et al., 1970).

Note 1 : In January 1958, marked change occured during the observations; an eastward surface current was first present at the equator at 151° and 153°E, but to weeks later, the Equatorial Current reinforced and substituted for the eastward current at the equator; as a consequence, when the observations were reiterated at 153° and 155°E, the subsurface westward flowing core had disappeared and was replaced by an upper cell of eastward flow, linked with the lower eastward undercurrent (see Fig. 4-5, p. 5, in Yosida et al., 1959).

Note 2 : In June 1926, during the northern summer, the observations made by the R.V. "Mansyu", showed markedly an eastward undercurrent beneath the Equatorial Current at 0°-155°E; moreover, at 1°N, this eastward undercurrent had a double-cell structure. (see Fig. 34-39 and 41-48, p. 22-23 in Tsuchiya, 1961).

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