A Thermal Interpretation of a Change in Equatorial Western Pacific Circulation

Equatorial current measurements are very rare in the western Pacific Ocean, and nearly all the existing data were recorded by the Centre ORSTOM de Nouméa in 1967-68 (Magnier *et al.*, 1973), 1971, and 1979. On most occasions, the cross-equatorial meridional section of zonal current showed the Equatorial Undercurrent (EUC) to consist of two superimposed cells. Three times, an unexpected current distribution was found. During the April 1967 CYCLONE 3 cruise (Hisard *et al.*, 1970) along 170°E, eastward flow from the surface to 100 m appeared above a westward current after eight days of westerly wind; the EUC occurred below 200 m (Figure 1). During the January 1971 FOC I cruise, which occurred ten days after an approximately 35-day period of westerly winds typical of this time of year (Colin *et al.*, 1973), eastward surface flow was measured above a westward current at 100 m and an EUC between 150 and 300 m. Again in February 1979, a similar current structure was observed at 166°E during the monsoon westerly wind season (Jarrige and Rual, 1981).

The system of equatorial, upper ocean, zonal currents in the western Pacific is typically associated with a characteristic vertical distribution of the isotherms above 15°C. Surface westward drift produces upwelling of the upper isotherms, while a spreading of the 15-25°C isotherms occurs within the eastward EUC (Figure 2A). When the surface current is eastward (as shown in Figure 1), the vertical pattern of the isotherms is suggested in Figure 2B. The surface eastward current caused by the westerly wind is strongly convergent at the equator, inducing a downwelling of the upper isotherms. The subsurface divergent westward flow is associated with upwelling of the lower isotherms. On each side of the equator at 3-5° latitude, the lifting of the upper isotherms generated by Ekman pumping (Donguy *et al.*, 1982) causes a reversal of the north-south slope of the isotherms and, consequently, a westward flowing surface geostrophic current. At the equator, the speading of the lower isotherms between 15 and 20°C corresponds to the core region of the EUC.

While the equatorial current pattern shown in Figure 1 has been observed several times during the westerly monsoon wind season in the western Pacific, the associated thermal patterns recorded in April 1967 (Figure 3), January 1971, and February 1979 each differed slightly from the schematic description of Figure 2B. This is probably due to the lack of a permanent westerly wind regime. In April 1967 the westerly wind had been blowing for only eight days. In January 1971 the westerlies prevailed for about one month, but disappeared two weeks before the measurements were made, and in Feburary 1979 northerly winds blew during the measurement period. After the westerly wind speed drops, or the prevailing wind direction is no longer toward

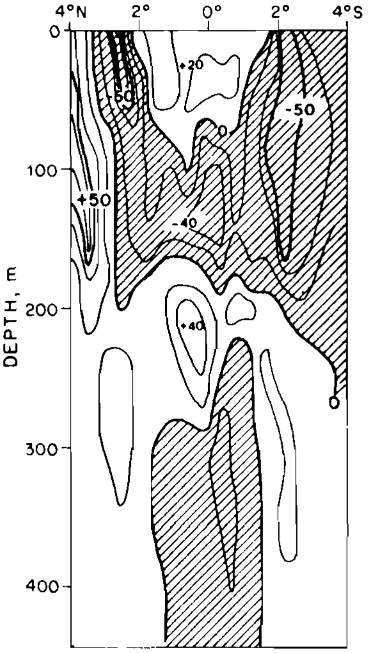

FIGURE 1 (*Donguy et al.*)
Vertical distribution of zonal (positive direction eastward) currents (cm s⁻¹) relative to 500 m depth along 170°E in April 1967. Shaded region corresponds to westward currents.

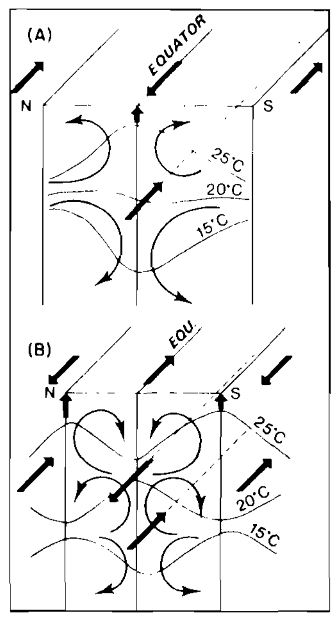

FIGURE 2 (*Donguy et al.*)
Schematic pattern of isotherms and currents along an equatorial meridional section for (A) surface westward current and (B) surface eastward current.

the east, the current pattern on the equator may persist, but in the absence of Ekman pumping the meridional structure of the thermal field will change.

Since the 1979 beginning of the France-United States XBT ship-of-opportunity program, the thermal pattern illustrated by Figure 2B has been observed near the equator around 160°E in two unusual circumstances. A shrinking, or contraction, of the depth interval between the 15 and 20°C isotherms and a spreading of the 20-25°C isotherms occurred in September 1980 and from September to December 1982 (Figure 4). Westerly winds prevailed during both times; from September to December 1982 the zonal slope of the isotherms along the equator was reduced west of 160°W (Meyers and Donguy, 1983) and was connected with the severe changes in the equatorial circulation in the central (Firing and Lukas, 1983) and eastern Pacific (Halpern, 1983). From September to December 1982 westerlies and associated low surface salinities due to the equatorial convergence occurred on the equator as far east as 160°W; also, the wind field possibly generated Ekman pumping. Consequently, one may speculate that between September and December 1982 a current pattern such as the one shown in Figure 1 occurred in the western Pacific.

Of the thirteen current measurement sections made between 150 and 170°E since 1967 by the Centre ORSTOM de Nouméa, only three sections provide data showing the response of the western equatorial Pacific thermal and flow fields to a relaxation of the trade winds. At the equator the vertical distribution of the zonal current of these three sections exhibits a westward subsurface current between two eastward currents. The typical isotherm distribution produced by the westerly wind suggests a three-layered system, particularly during the recent 1982-83 warm event. Whether this isotherm pattern is connected to the observed current system is not clear. In fact, for the three cases studied, the westward current occurred mainly in the quasi-homogeneous surface layer (Figures 1 and 3), suggesting that the westward flow is a remnant of the surface circulation previously set up by the normal trade winds.

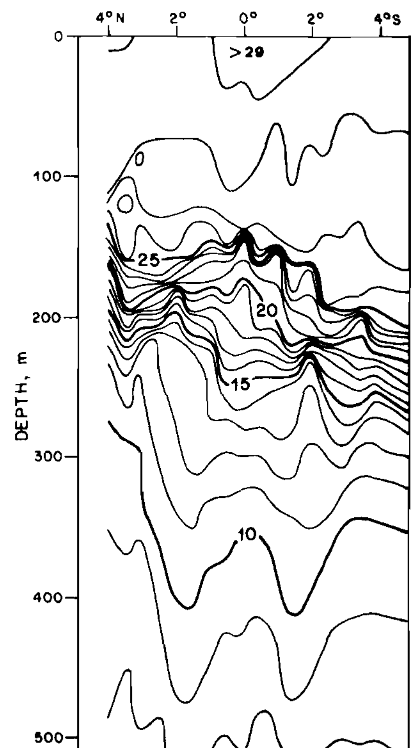

FIGURE 3 (*Donguy et al.*)
Equatorial temperature (°C) structure along 170°E

The reversal of the zonal slope of the sea surface (or thermocline) along the equator, which is associated with eastward winds, might be favorable to the development of a divergent westward undercurrent, although this response has not been simulated by several models (Cane, 1980). However, the dynamics of the deeper eastward undercurrent becomes questionable if the zonal pressure gradient produced by the sea surface slope is considered to be the main driving force. An inconsistent feature of this hypothesis is that during the three periods when the wind pattern was anomalous,

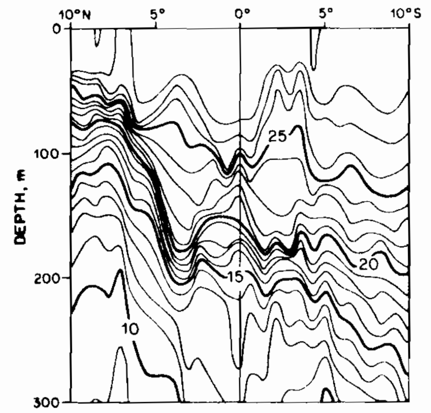

FIGURE 4 (*Donguy et al.*)
Equatorial temperature (°C) structure along 160°E in October-November 1982.

the eastward undercurrent core had the same velocity (40-70 cm s^{-1}) as during normal conditions. The central Pacific flow field observed by Firing and Lukas (1983) in October 1982 was very different because of the large decrease of the undercurrent velocity.

A reversal or relaxation of the trade winds could be connected with the development of an eastward inertial current, which is consistent with the north-south narrowness of the observed current. However, then the questions arise, why the eastward current does not occupy the whole surface layer and how a westward current can be driven in the upper thermocline. A westward current could be maintained by lateral transfer of momentum if the winds were westward in the equatorial area except for a narrow strip of eastward winds on the equator; but the observed wind pattern did not resemble this situation.

The water moving westward at the bottom of the surface layer in the western Pacific could have originated from upwelling in the central equatorial Pacific. This slightly cooler and more saline water would be heavier than the surface water in the western Pacific, and consequently, could sink slowly along the top of the thermocline. In this case, the westward motion would be maintained by the conservation of potential and kinetic energy. This explanation is also not quite satisfactory because, unless such a water mass is maintained along the equator by meridional pressure gradients, a westward inertial current at the equator is definitely unstable.

In summary, the relationship between thermal structure and current pattern is not yet obvious. Continuous measurements of moored currents in the western equatorial Pacific would provide significant support for the solution of this problem.

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