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Observations of the Equatorial Intermediate Current in the Western Pacific Ocean (165°E)

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ABSTRACT

Direct current measurements (0–600 m; re. 600 m) were carried out every six months from January 1984 to June 1986 in the western tropical Pacific Ocean (165°E) from 20°S to 10°N. The Equatorial Intermediate Current (EIC) occurred beneath the Equatorial Undercurrent (EUC) in the 300–500 m depth range between 2°S and 2°N.

At 165°E, the mean (i.e., the average of six cruises) EIC flow has a characteristic reversed-U shape centered at the equator. Its associated hydrological features are (i) the EIC transports water of salinity 34.6–34.9‰; (ii) its upper and lower limits correspond to the 26.4 and 27.0 sigma-*t* surfaces; and (iii) its velocity core is located in the 11°–14°C water. The average transport of the EIC is -7.0 ± 4.8 (10^6 m^3 s^{-1}), i.e., 35% of the mean EUC transport computed for the same cruises.

Individual cruises exhibit little variability in the vertical (250–550 m) and meridional (2°S–2°N) EIC structure. The EIC velocity core during these cruises is thinnest at the equator and ranges in magnitude from −5 to −20 cm s^{-1}. A notable exception is the 3–8 July 1985 EIC measurements, which show a disappearance of the EIC velocity core at the equator ($U = +20$ cm s^{-1}).

Our EIC observations show good agreement with EIC simulated from models forced by easterly winds.

1. Introduction

As part of the SURTROPAC (SURveillance TRansOcéanique du PACifique) program, which is a French element of the international TOGA (Tropical Ocean and Global Atmosphere) program, the ORSTOM Center in Nouméa (New Caledonia) initiated in January 1984 a series of semiannual cruises along the 165°E meridian, from 20°S to 10°N. Delcroix et al. (1987) describe and analyze some of the results evidenced by the first six cruises, with special emphasis upon the upper 400 meters. The goal of this note is to focus our attention on the 4°S–4°N, 200–600 m region where systematic direct measurements of a westward-flowing current have been noticed. This current will be called the Equatorial Intermediate Current (EIC), following the nomenclature proposed by Hisard and Rual (1970).

The 17 January 1984 current profile at the equator superimposed on the temperature profile exemplifies a well-developed EIC (Fig. 1). The EIC is situated between the main and second thermocline, in the 200–400 m layer, with the maximum velocity ($U_{max} = -20$ cm s^{-1}) located in the 11°–14°C water. Above the EIC are the Equatorial Undercurrent (EUC) in the layer of maximum vertical temperature gradient (0.15°C m^{-1}), and the westward-flowing South Equatorial Current (SEC) in the isothermal layer (0–100 m).

Compared with other equatorial currents, the EIC is rather poorly documented in oceanographic literature. In the Pacific Ocean, interested readers can refer to Taft et al. (1974; Table 4) and to the references in Eriksen (1981) for a bibliography dealing with previous observations. Recent EIC observations in the Atlantic Ocean, are provided by the FOCAL cruises along the 35°, 29°, 23°, 10° and 4°W meridians (Hénin et al., 1986). During these cruises, the EIC is associated with a minimum of oxygenated waters, which cogently suggests zonal continuity of the flow.

This note is organized as follows. Section 2 presents the data and the technical aspects of data acquisition. Section 3 describes the mean EIC flow and its associated hydrological features, presents some characteristics of its variability as given by each cruise and then compares our observations with simulations of the EIC [Philander and Pacanowski, 1980, 1981 (linear case); McCreary, 1981].

2. The data

Dates of EIC measurements are reported in Table 1. Stations which encompassed the EIC were designated at every degree between 4°–2°S and 2°–4°N, and every half degree between 2°S and 2°N. Hydrographic measurements (T, S) were made at each station with a STD or CTD (June 1986 cruise) probe from the surface down to 1000 m. Velocity profiles (0–600 m) were obtained simultaneously with an Aanderaa profiler freely falling along a cable (see Duing and Johnson, 1972) under a drifting buoy. The raw current data are cor-

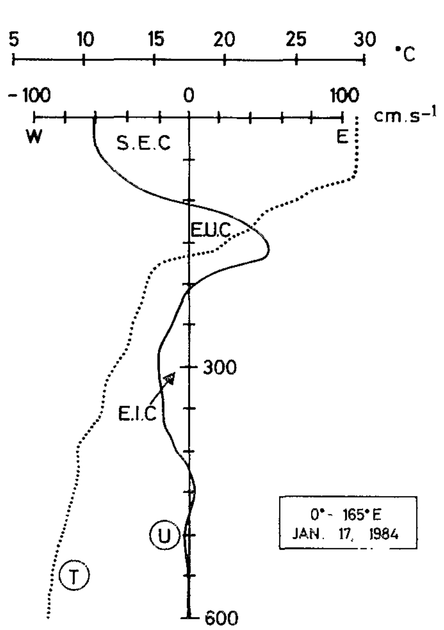

FIG. 1. Velocity (solid line) and temperature (dotted line) profiles at the equator (165°E) on 17 January 1984. The South Equatorial Current (SEC), the Equatorial Undercurrent (EUC) and the Equatorial Intermediate Current (EIC) are indicated.

rected for drift with the help of a current meter placed at the lower end of the cable (600 m): currents are thus relative to 600 m. Whether the EIC reaches deeper levels cannot be determined from the observations, but currents between 500–600 m are generally found to be very weak (0–2 cm s^{-1}). Due to technical problems, current data were not obtained at the following locations: 3°S in January 1985 (no data between 0–600 m); 1°30′S (375–600 m), 1°S (100–600 m) and 0° (115–600 m) in January 1986. Data were thus linearly interpolated from adjacent stations to fill the data gaps. Note that the low EIC transport during the January 1986 cruise (section 3.b) may be due to interpolation. Additional information about cruises can be found in Delcroix et al. (1987).

3. The results

a. The mean EIC flow

The mean zonal velocity component between 4°S and 4°N, 200 and 600 m, i.e., the average over the six cruises, is presented in Fig. 2. Its standard deviation is 2.5 cm s^{-1} at 500 m, increasing almost linearly to 5 cm s^{-1} at 280 m and then to 10 cm s^{-1} at 200 m. In Fig. 2, the westward component ($U < 0$) denotes the mean EIC flow. It is not thought to be representative of the long-term mean because of the twice per year sampling and our lack of knowledge of possible annual EIC variations. However, we believe that this mean EIC flow is still pertinent for (i) a comparison with its mean hydrological features; (ii) a quantitative comparison with other mean current transports calculated during the same cruises; and (iii) a qualitative comparison with theory.

The mean EIC is beneath the EUC (Fig. 2) and is bounded meridionally by the north and south subsurface countercurrents (NSCC, SSCC); these last three currents are discussed in Delcroix et al. (1987). It lies in the 280–500 m layer between 2°S and 2°N, and has a characteristic reversed-U shape centered at the equator. Its maximum velocity core (-7.5 ± 3.0 cm s^{-1}) is slightly displaced to the north between 30′ and 1°30′. This displacement is mainly due to the strong velocity core measured at 1°30′N, 400 m during 16–19 January 1985. If this measurement is excluded, the mean velocity is located right on the equator.

The mean EIC carries waters of 34.6–34.9‰ salinity (not shown here) which are located beneath the band of strong vertical salinity gradient extending from about 20°S—350 m to 2°N—150 m (see Figs. 3a–f in Delcroix et al., 1987). The upper and lower limits of the mean EIC flow correspond to the 26.4 and 27.0 sigma-t surfaces (isanosteres 163 and 105 10^{-8} kg m^{-3}), in agreement with Hisard and Rual's (1970) results at 170°E.

The EIC transports are calculated for each cruise by integrating with depth the westward component in excess of 2.5 cm s^{-1} which is the sensitivity threshold of the current meter used (transports calculated with a

TABLE 1. Characteristics of the Equatorial Intermediate Current for six cruises. U'_{max} (cm s^{-1}) is the maximum zonal velocity, and $Z(U'_{max})$ and Lat (U'_{max}) are the depth (m) and latitude of this maximum. Transport is in Sv.

	Date					
	16–19 Jan 1984	12–14 Aug 1984	16–19 Jan 1985	03–08 Jul 1985	15–19 Jan 1986	22–26 Jun 1986
Vertical extension	250–420 m	320–480 m	260–520 m	400–550 340–500	280–420 m	280–500 m
Meridional extension	1°30′S–2°N	2°S–2°N	1°S–2°30′N	2 cells 2°S, 2°N	2°S–1°30′N	2°S–2°N
U'_{max}	−20	−10	−20	−5, −7.5	−5	−15
$Z(U'_{max})$	320	370	400	460, 400	360	360
Lat (U'_{max})	30′S	0°	1°30′N	2°S, 2°N	0°	30′N
Transport	14.9	4.1	10.7	2.4	4.1	5.6

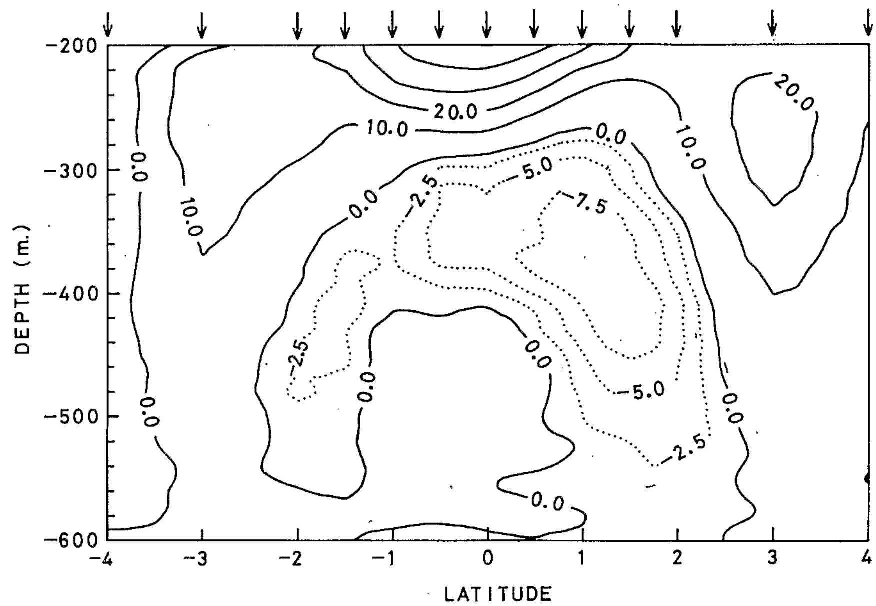

FIG. 2. Mean zonal velocity section at 165°E. Contour intervals of negative (positive) isotachs are 2.5 cm s^{-1} (10 cm s^{-1}). Arrows indicate station positions.

cutoff speed of 0 cm s^{-1} differ only by a maximum of 8%). The mean EIC transport, i.e., the average of transport computed for each cruise, is -7.0 ± 4.8 Sv (Sv $\equiv 10^6$ m^3 s^{-1}) (the second number is the standard deviation). It is 35% of the mean EUC transport computed for the same cruise; its contribution should thus not be neglected in upper-ocean water mass budget studies.

b. The EIC variability

Some characteristics of the EIC variability are reported in Table 1 for each cruise. Except for the 3–8 July 1985 measurements subsequently addressed, they show the following: (i) the vertical extension ranges from extremes of 250 to 520 m over thicknesses of 140 to 260 m; (ii) the meridional extension is relatively stable between 2°S and 2°N; and (iii) the depth of the maximum zonal velocity (U_{max}) is situated between 320 and 400 m. In addition, the densities (sigma-t), the salinities and the temperatures associated with U_{max} are quite constant, with respective values of 26.7, 34.8‰, and 11°–14°C. Note that U_{max} and $Z(U_{max})$ values (Table 1) reinforce Delcroix et al.'s (1987) conclusion that 400 db may not be a good reference level for computing geostrophic velocity from XBT data in the western Pacific Ocean.

The 3–8 July 1985 EIC measurements are quite different from other EIC observations reported in Table 1. Continuous eastward flow is present between 1°S–1°N from the surface down to 600 m (Fig. 3 and Delcroix et al., 1987—Fig. 4d). No EIC is observed at the equator beneath the EUC. Rather, an eastward velocity core ($U_{max} = +20$ cm s^{-1}) centered at the equator appears between 400 and 440 m surrounded by two cores of westward flows (-5 cm s^{-1}) at 2°S and 2°N (Fig. 3).

c. The EIC from numerical models

Presence of a westward flow (EIC) beneath the EUC has already emerged from model results run with linear sets of equations. In these models, Philander and Pacanowski (1980) have used constant zonal wind stress and a rectangular ocean box model with a 4800 km longitudinal extent (i.e., about the size of the Atlantic Ocean basin), while McCreary (1981) has used a 10 000 km east–west ocean model forced by a wind field representative of the steady trades in the Pacific Ocean. Although they use different basin sizes and wind forcing, Philander and Pacanowski (1980; 1981, Fig. 12—linear case) and McCreary (1981, Fig. 4), both show the EIC centered at the equator, with a -10 to -20 cm s^{-1} velocity core between 250–550 and 200–300 m depth, respectively. The latter author even simulates the characteristic reversed-U shape evidenced in our measurements and, interestingly, tests the EIC dependence on model parameters, e.g., the deeper the pycnocline, the deeper the EIC (McCreary, 1981, Fig. 6). The EIC probably owes its existence to Rossby waves radiated away from the eastern boundary, since the EIC exists only when McCreary's (1981) model has an eastern boundary (see his Fig. 8). Hence, these models possess a realistic EIC structure with width, thickness and magnitude that compare quite favorably with our 165°E observations.

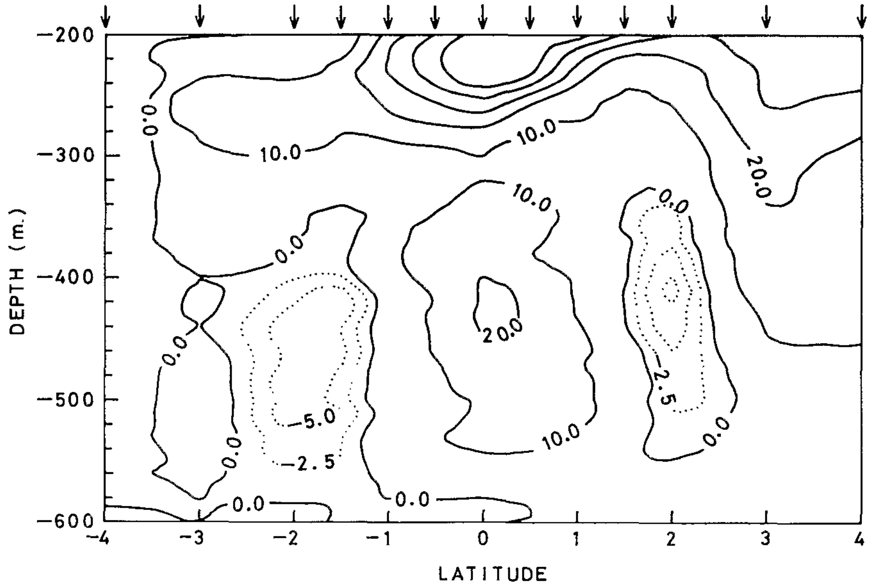

FIG. 3. Zonal velocity section at 165°E during the 3–8 July 1985 period. Contour intervals and arrows as in Fig. 2.

In conclusion, despite these reported similarities between observed and modeled EICs, we believe it would be desirable to run models with special emphasis on the EIC dynamics. For example, questions remain to explain the "unusual" 3–8 July 1985 measurements and the fact that the EIC almost disappears in the nonlinear calculations of Philander and Pacanowski (1980). It is thus hoped that our observations will whet the curiosity of modelers who are studying subsurface current circulation.

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