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On Austral Summer Surface Eastward Flows at the Equator in the Western Pacific

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I. INTRODUCTION

There are a few references in the literature of observations of an eastward surface current at the equator in the western Pacific (150°E–180°), whereas following general equatorial circulation schemes, one would expect to find there the South Equatorial Current (SEC) flowing westward. Most of these observations take place in austral summer, during periods of low easterlies or calm weather.

Probably the oldest report is found in a Soviet paper (Istoshin and Kalashnikov, 1965), relating measurements from buoys at 180°E and 1°N, 0°, 1°S, in December 1963–January 1964. They find an eastward flow of about 30 cm s^{-1} from 0–75 m during the 6 days of measurements in "calm weather" at the 3 buoys. Below it lies a weak remnant of the SEC, and the core of the Equatorial Undercurrent (EUC) is at 200 m. They note that such surface flows are not uncommon at this season, as being already described in a Soviet Mariners Chart of 1958. These observations are attributed to a southward displacement of the North Equatorial Counter Current (NECC).

In April 1967 at 170°E, a similar situation was found during the ORSTOM CYCLONE-3 cruise (Hisard *et al.*, 1970). An eastward flow extended from 2°S-2°N, 100 m deep, with maximum velocity of more than 50 cm s^{-1}. Below it, the SEC was strong (more than 50 cm s^{-1}), and the EUC core stayed at a depth of 200m. Hydrological and meridional velocity data show a convergence of the eastward surface flow towards the equator, which is characterized by a temperature maximum (>29.0°C) and a salinity minimum (<34.70 ‰). At the time of these measurements, winds were weak easterlies or southeasterlies. The observed flow is not a response to local wind forcing, and the authors assumed that it was caused by weak northwesterly winds which had been blowing in the region, but at least 12 days before. Also, they point out that hydrological characteristics of this water mass are close to those of waters found to the north of New Guinea (140°E-150°E), suggesting that it may originate there.

II. OBSERVATIONS FROM THE SURTROPAC CRUISES

The SURTROPAC Group at ORSTOM-Noumea has been carrying out semiannual cruises along the 165°E meridian, from 20°S-10°N, usually in January and July of each year since 1984. Hydrology and velocity structures are measured along the transect; details on data processing and analysis can be found in Delcroix *et al.*, 1987. During these cruises, surface eastward equatorial flows were found twice, in January 1985 and 1987. A strong eastward flow is also measured in July 1987, extending from 5°S to the NECC, during strong westerly winds and highly anomalous climatic conditions linked to the currently occuring ENSO event. This observation will not be discussed here.

Zonal velocity sections, focusing on the region of interest, 5°S-5°N, 0-200 m, for each January cruise are shown in Figure 1. In January 1984 and 1986, no eastward surface flow is present, but there are some important differences in velocity structures: In January 1984, the SEC and EUC form a symmetric pattern around the equator, and the NECC boundary is at 2-3°N. Vertical velocity shear is progressive from SEC to EUC, and the EUC core lies at 150 m, which is shallower than its annual average depth of 200 m (Toole *et al.*, 1987).

In January 1986, the SEC presents two separate maxima, one at the surface, the other at 100 m. The EUC core is stronger and deeper (190 m). (The sharp edge of isolines between130-170 m at the equator is accentuated by the contouring process.)

In January 1985, an eastward flow straddles the equator from 1°S-3°N and to 100 m depth; it is joined at 3°N to the NECC, but somewhat differs from it by its hydrology. Its velocity passes 50 cm s^{-1}, for a transport of 7 Sv (1 Sv = 10^6 m^3s^{-1}). Below it, a strong SEC is present and the EUC velocity core is around 180 m deep.

In January 1987, the eastward flow extends from 2°S-2°N and reaches 80 m deep, but is weaker, with a maximum velocity close to 40 cm s^{-1} and a transport of 5 Sv. It is completely embedded in westward flows of the SEC, the southernmost boundary of the NECC staying at 5°N. Below, the SEC is weak, under 30 cm s^{-1}, but the EUC transport is stronger than in January 1985 (Delcroix *et al*,. 1987).

Winds measured during stations in 1985 and 1987 are weak easterlies to northeasterlies, less than 5 m s^{-1}.

For these two cruises, temperature and salinity sections show some indication of convergence in the eastward surface flow, from the shape of isolines; maximum temperature and minimum salinity are reached just on the equator. Although

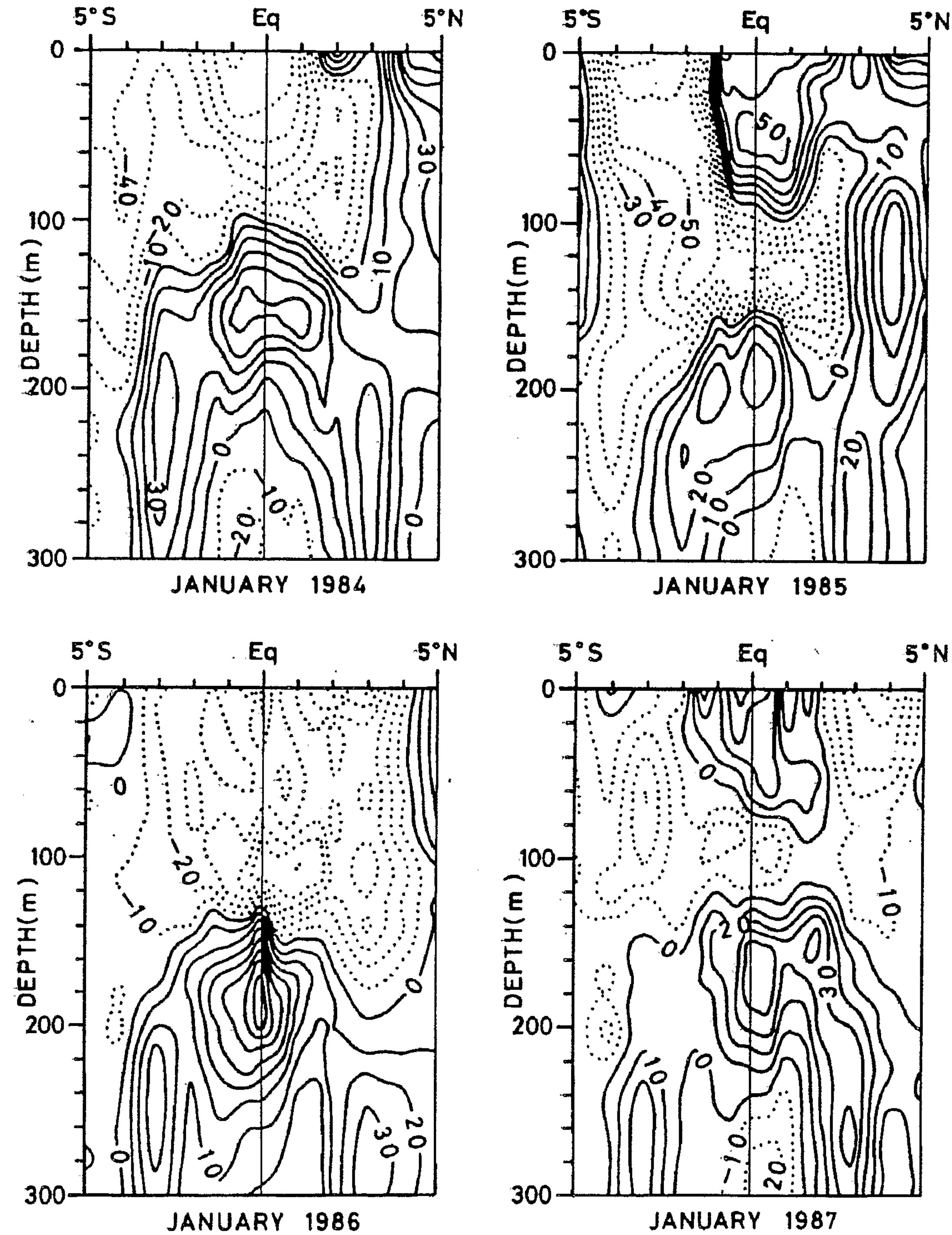

Figure 1. Sections of measured zonal velocity during SURTROPAC cruises 1,3,5,7, from January 1984 to 1987. Velocities in cm s^{-1}, depths in m. Contouring interval is 10 cm s^{-1}. Eastward flows: solid lines; westward flows: dotted lines.

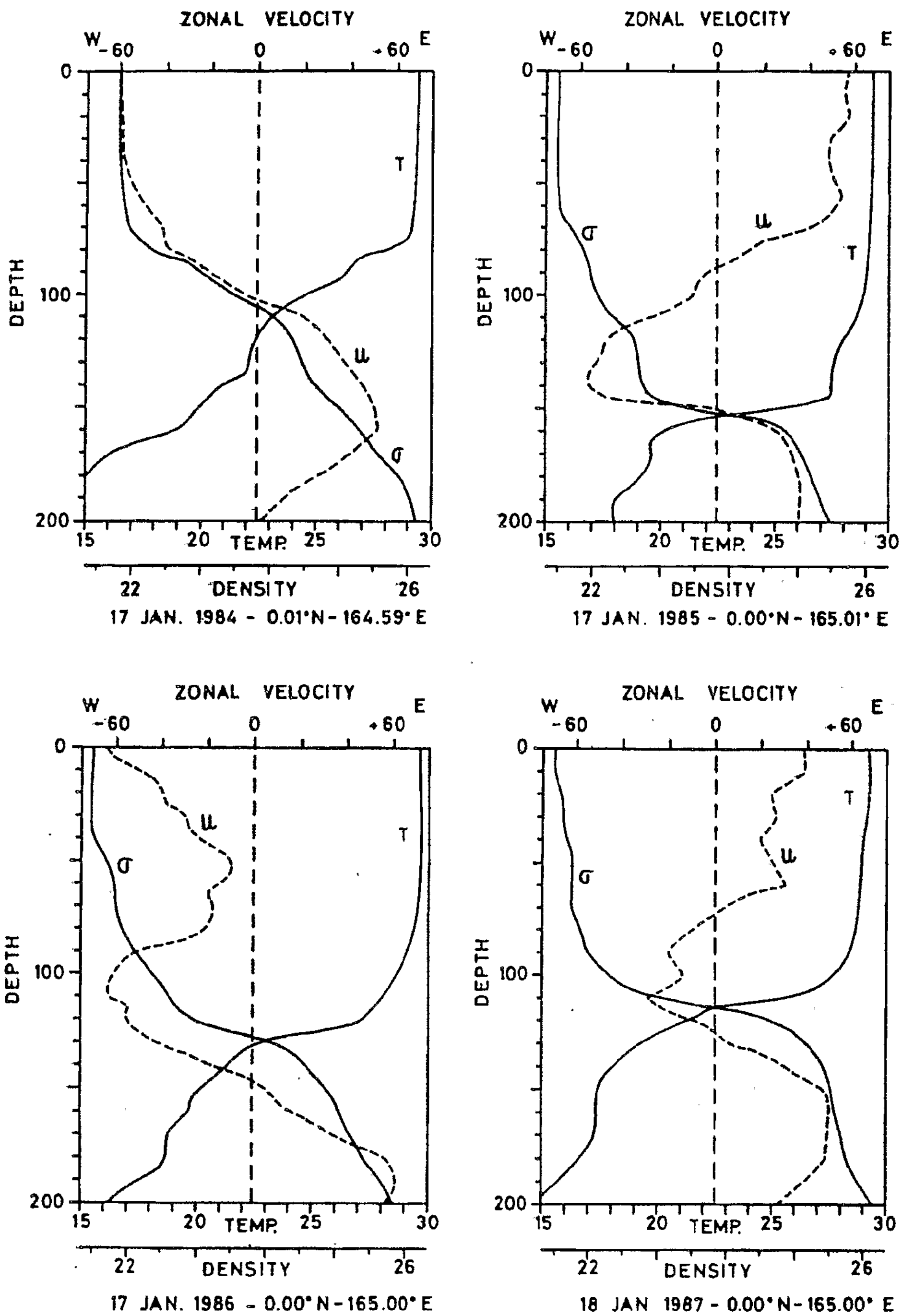

Figure 2. Equatorial profiles of temperature (T), σ_T, and zonal velocity (u), for the four SURTROPAC January cruises. Units are °C for temperature, kg m^{-3} for σ_T, and cm s^{-1} for velocity; eastward velocities positive, westward negative. Depths in m.

geostrophic calculations would not give reliable quantitative results there, dynamic height profiles indicate that these flows are at least partially in geostrophic balance.

Figure 2 shows the equatorial profiles of temperature, density and zonal velocity for the 4 cruises, which are representative of the region 2°S-2°N. For the sake of clarity, salinity is not presented, but its influence is reflected in density profiles.

In January 1984, the thermocline and pycnocline are similar, without sharp gradients, and the main flow of the SEC is contained in the nearly homogeneous layer 0-80 m. This layer is of relatively high density (21.85 stu; stu = σ_T unit = 1 kg m^{-3}) probably because some upwelling associated with the westward flow brings higher salinity waters towards the surface.

In January 1985, a more complicated layered structure appears; the bulk of the surface eastward flow corresponds to a well-mixed layer of density 21.49 stu and temperature 29.30°C. From 50-120 m a transition zone of velocity shear and density gradient is present. At 120-145 m a second layer of density around 22.70 stu and temperature 27.70 is linked to the maximum SEC flow. At 145-155 m, maxima in temperature and velocity gradients are tied, with values reaching 0.8°C m^{-1} and 0.1 s^{-1} respectively. Below with values reaching 0.8°C m^{-1} and 0.1 s^{-1} respectively. Below this very sharp transition the EUC appears broader and weaker than usual.

In January 1986, a surface mixed layer is found again (0-40 m), but associated with the upper core of westward flow of the SEC. Temperature and salinity values are slightly higher there than in January 1985, but result in about the same density of 21.50 stu. The constant temperature layer reaches somewhat deeper, to 70m, where a weak inversion is present (0.05°C in 10 m). The SEC flow below is not associated with a distinct layer in density or temperature, and at its deep boundary shear values are "normal", of the order found in January 1984.

In January 1987, despite the presence of the surface eastward flow, there is no mixed layer at all, except in the first meters. There is a continuous stratification above the thermocline, from the surface to 90 m, caused mostly by a regular increase in salinity and some decrease in temperature.

Summarizing these results, it is noteworthy that all available observations of surface equatorial eastward flows at 165°E-180°, not locally driven by wind forcing, present some common features; flows have the same spatial extension, 3-4° of latitude, 80-100 m deep, are of lower density that surrounding waters, present indications of meridional convergence, and are consistent with geostrophic balance.

III. DISCUSSION AND CONCLUSIONS

Although it is difficult at this time to separate effects of short term variability and to give quantitative estimates, observations from the SURTROPAC cruises may support the following hypotheses on the origin and evolution of equatorial surface eastward flows.

During austral summer, frequency of westerly wind bursts increase in the extreme western Pacific, Low density surface waters from the region thus gains eastward momentum. To the east of the wind patch, this eastward surface flow still propagates along the equator as a well-mixed layer (e.g. January 1985) and converges under the effect of the Coriolis force; it then increases its velocity, thereby also increasing its loss of energy by turbulent exchange with the strong westward flows of the SEC; surface easterly wind stress also acts to dissipate this flow, and these two effects lead eventually to a reversal of the surface flow (e.g. January 1986). After a while, resumption of upwelling would mix waters of the two westward flows and lead to a homogeneous layer of relatively high density, as in January 1984. However, measurements of January 1987 do not fit well in this scheme, because of the density stratification found through the eastward flow. Large vertical migrations of the EUC are not explained either, but their origin should be more likely be found in variations of the large scale zonal pressure gradient along the equator.

Future studies could lead to a more complete explanation of surface eastward flows by including other data from the region, particularly those from the US-PRC program of cruises and equatorial current meter mooring. A modelling effort is also necessary to understand the dynamics of these flows, their interaction with the SEC, and the effect of the easterly wind stress upon them.

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