Mechanisms of Subsurface Thermal Structure and Sea Surface Thermo-Haline Variabilities in the South Western Tropical Pacific during 1979-85 - A Preliminary Report

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ABSTRACT

Major features of the South Western Tropical Pacific, defined between 160°E-140°W and 24°S-10°S, are brought to light through analysis of surface water samples (23000) and temperature profiles (8500) gathered during the 1979-85 period.

Mean vertical thermal structure, sea surface temperature (SST) and salinity (SSS) are first portrayed, to further quantify their 1979-85 respective variability. It is demonstrated that the observed seasonal and interannual variabilities, the latter being associated with the strong 1982-83 El Nino, are mostly governed by specific mechanisms involving varying wind field and rainfall regime.

During the non ENSO period (1979-81+1984-85), SST annual cycle and 0-100m thermal structure changes are tied to the seasonal variations of the sun position (minimum SST in August). Below the mean position of the SPCZ is a marked seasonal SSS cycle (minimum SSS in March). This minimum occurs 2-3 months after minimum E-P whose variations suffice to explain SSS changes, assuming a 28±7m mixed layer depth, in agreement with sporadic density profile observations. It suggests that SSS annual cycle is mostly driven by the E-P regime associated with the SPCZ intensity and meridional migration. Noteworthy, the seasonal meridional migration of the SPCZ also causes alternation of cyclonic and anticyclonic wind stress curls west of 175°W and between 13°S-17°S. Such migration governs the seasonal thermocline depth variations through the Ekman pumping mechanism.

During the ENSO period (1982-83), notable changes in the vertical temperature distribution were perceivable between 10°S-15°S, in the upper 100m. These changes occured in response to the anomalous wind stress field that strongly uplifted the thermocline through local Ekman pumping (as much as 70m in May 1983). In the northern part of the studied region (i.e., in the warm pool area) , the thermocline shoaling modified the whole water column all the way to the surface, and was thus responsible for the observed SST cooling anomaly (-0.5°C to -1°C). In the southern part, similar SST cooling anomaly were concomitant with positive latent heat flux anomaly (>20Wm^{-2}) related to an increase in the northward wind component. At the mean SPCZ position, the drastic +1 SSS increase mainly resulted from a rainfall deficit associated with the equatorward shift of the SPCZ.

1. Introduction

In the frame of the international TOGA and COARE programmes, the poorly documented South Western Tropical Pacific ocean (Fig.1) is of main interest to study. Indeed,

- it is situated below the mean position of the South Pacific Convergence Zone (SPCZ), i.e., under the influence of its related wind stress, rainfall regime and convective activity,
- its northern part belongs to the warm pool area (SST > 28°C), and it is located in the rainiest part of the tropical Pacific ocean,
- it lies in between Tahiti and Darwin where the sea level pressure records define the usual Southern Oscillation Index (SOI).

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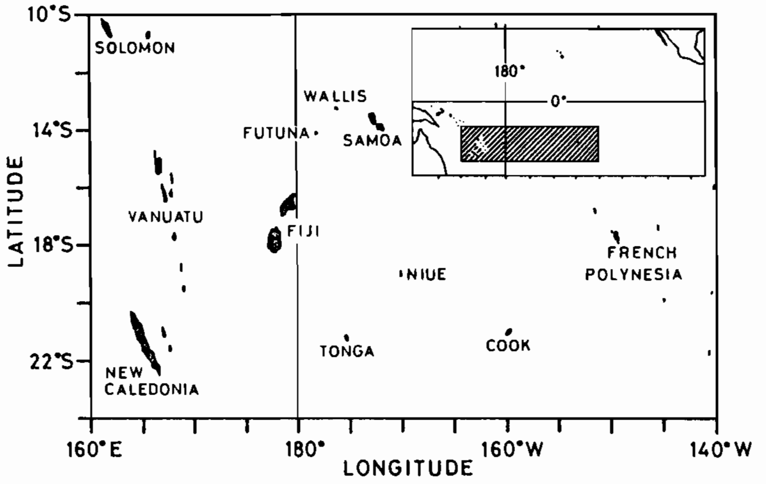

FIG.1. Location of the south western tropical Pacific in relation to the Pacific ocean.

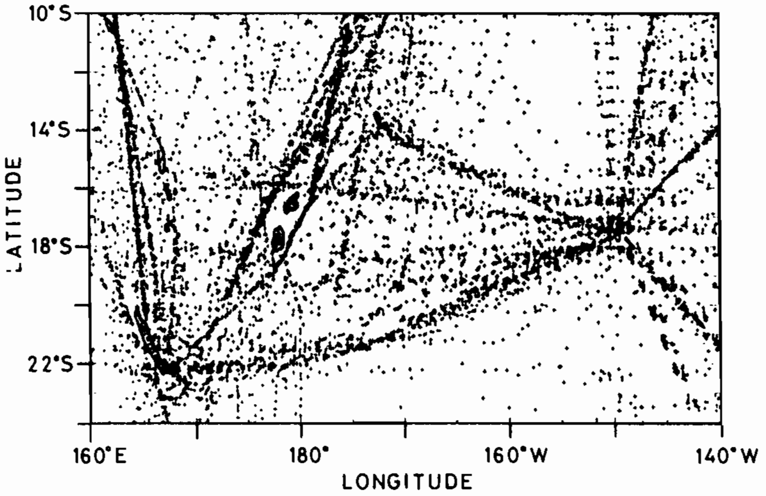

FIG.2. Spatial distribution of temperature/depth observations deployed during 1979-85 in the south western tropical Pacific.

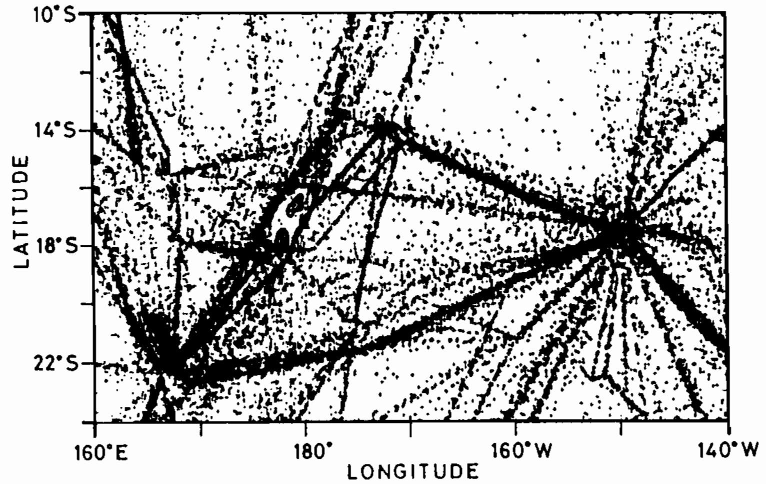

FIG.3. Spatial distribution of SSS observations deployed during 1979-85 in the south western tropical Pacific.

Thanks to a subsurface and surface monitoring, a basic description of the mean hydrological structures and of the 1979-85 variability was undertaken. Specific mechanisms responsible for this variability were identified and tested.

2. The data

Subsurface data (Fig.2) are mainly issued from an ORSTOM-SIO ship of opportunity network, and are complemented with data collected in different data banks. They consist of 8500 XBT temperature profiles (0-400m) during the 1979-85 period, i.e., about 125 XBT month^{-1}. The entire set of sea surface samples (T and S) comes from a ship of opportunity programme operated jointly by the ORSTOM centres in Nouméa and Papeete. The Sea Surface Salinity (SSS) data set (Fig.3) is composed of about 23000 observations (1979-85), i.e., about 240 SSS month^{-1}.

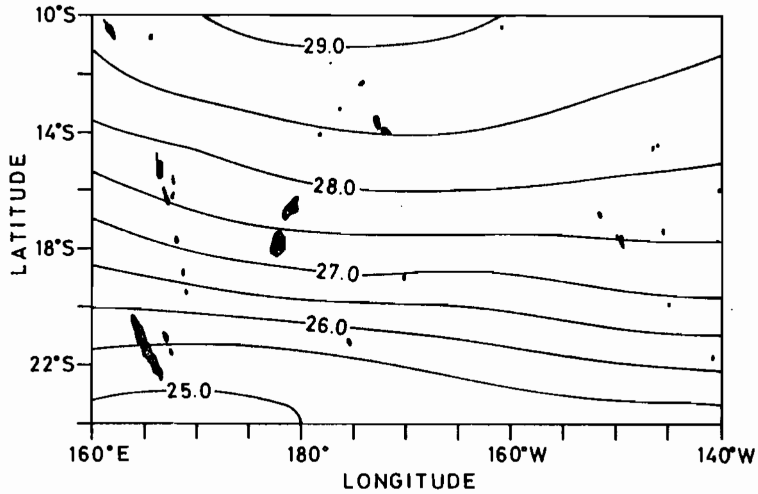

FIG.4. Mean sea surface temperature with contours at 0.5°C intervals.

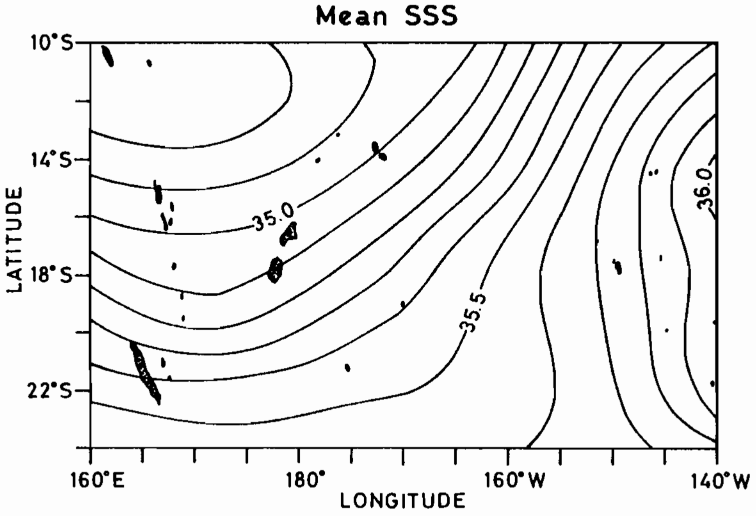

FIG.5. Mean sea surface salinity with contours at 0.1 intervals.

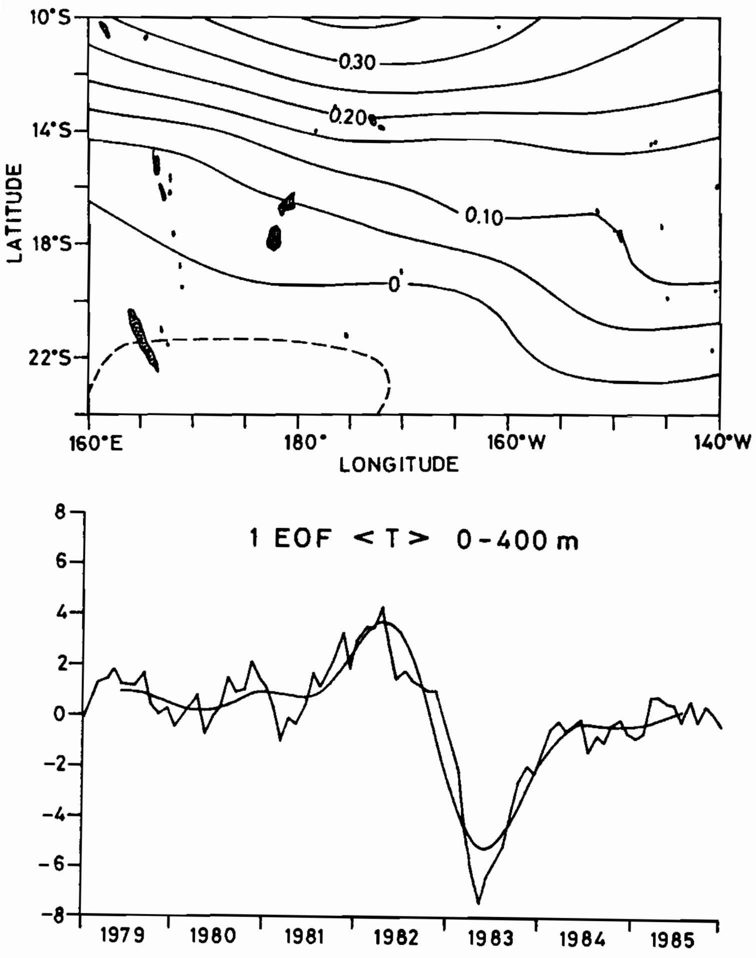

FIG.6. First empirical orthogonal function of the 0-400m average temperature with spatial pattern and time function. The broken line in the top panel denotes negative values. The low-frequency curve in the bottom panel is a result of a Fourier low pass filter removing period < 14 months.

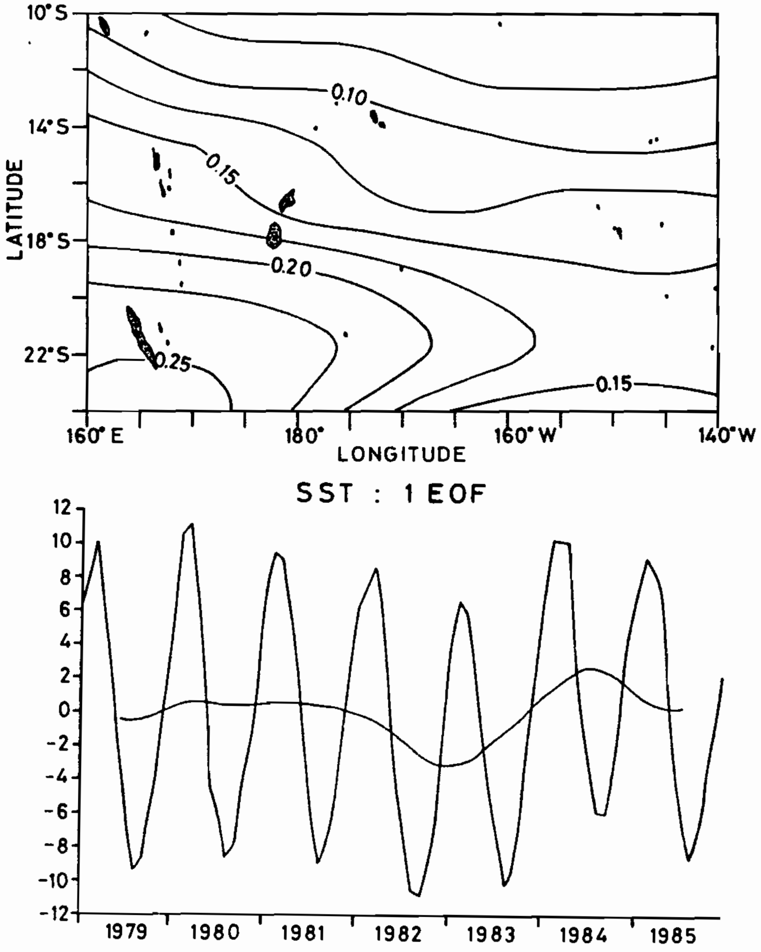

FIG.7. First empirical orthogonal function of the sea surface temperature with spatial pattern and time function. The low-frequency curve as in Fig.6.

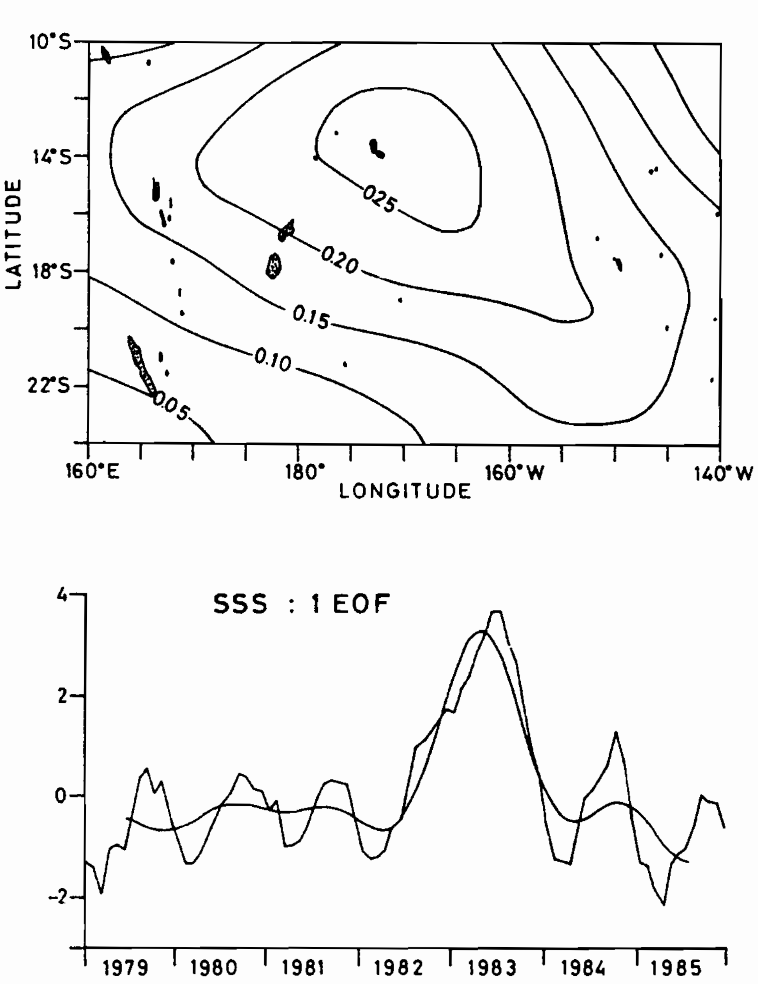

FIG.8. First empirical orthogonal function of the sea surface salinity with spatial pattern and time function. The low-frequency curve as in Fig.6.

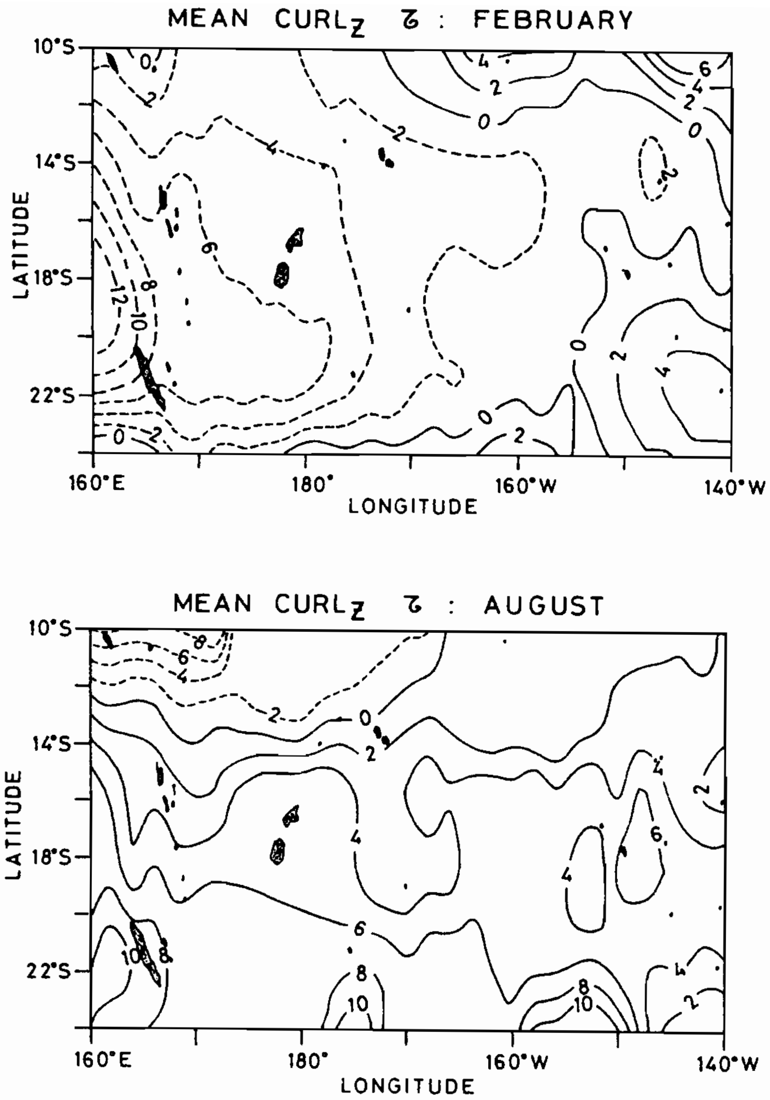

FIG.9. Mean (1979-81+1984-85) February and August wind stress curl. Contours are at $2.10^{-8}N.m^{-3}$ intervals and the broken lines denote negative values.

3. The mean structures

The mean meridional temperature-depth structure, and the mean SST and SSS distributions were computed over the 1979-81+1984-85 years, in order to exclude the 1982-83 El Nino period.

The mean meridional temperature section (not shown here; cf Delcroix and Hénin, 1989) evidences the gradual southward disappearance of the thermocline, with spreading of the isotherms south of 15°S. Schematically, the region is in the transition zone between the vertical temperature distribution of the equatorial band and the one of the extra-tropical region.

The mean SST map (Fig.4) shows zonally oriented isotherms ranging from 25°C to 29°C. North of 15°S is the southern part of the equatorial Pacific warm pool (SST > 28°C), which migrates to about 12°S and 20°S during the austral winter and summer, respectively.

The mean SSS map (Fig.5) exibits an almost SE/NW gradient between the high salinity waters (S > 35.9) of central south tropical Pacific and the low salinity ones (S < 34.8) south of the Solomon Islands. Minimum SSS coincides with evaporation minus precipitation (E-P) minimum (cf Weare et al., 1981) where rainfall can reach as much as 5 m year^{-1} (Taylor, 1973).

4. The 1979-85 variability

The 1979-85 variability is described here through EOF analysis of the average temperature of the upper 400m and, SST and SSS. The presentation is restricted to only the first EOF.

The first EOF on heat content (Fig.6) accounts for 43% of the variance. The corresponding time function may be decomposed into: a) an accumulation of warm water from mid-1981 to March 1982, b) a net release of heat between April 1982 and May 1983, which constitutes the strong ENSO signal, and c) a return to a "normal" situation only reached in 1984. The space function points out that the ENSO signal is mostly restricted north of 15°S.

The first EOF on SST (Fig.7) accounts for 82% of the variance and primarily represents the seasonal cycle with minimum SST in August (austral winter). The interannual variability is depicted by the low frequency curve, evidencing that SST reaches maximum cooling anomaly at the end of 1982 and early 1983. Note the preponderance of the SST annual signal versus the interannual change related to the 1982-83 El Nino.

The first EOF on SSS (Fig.8) accounts for 46% of the variance. The pattern of the eigenvector is maximum along a SE/NW axis representative of the mean SPCZ location. The time function depicts both the seasonal cycle during the "normal" 1979-81+1984-85 period (minimum SSS in March) and the interannual variability associated with the 1982-83 ENSO phenomenon. It shows that maximum SSS annual amplitude is +0.25 below the SPCZ, as compared with the large + 1 SSS increase during the El Nino period.

5. The mechanisms

Mechanisms involving varying wind field and rainfall regimes accounts for the observed sub-surface and surface changes. In the South Western Tropical Pacific, Ekman pumping, evaporation and precipitation are the main processes that all contribute to the normal seasonal cycle and/or are related to the strong ENSO effects. The role of water advection and vertical mixing will not be examined here.

a. The Ekman pumping

In off-equatorial region, the simplest dynamical mechanism that can affect the vertical thermal structure is Ekman pumping. The Ekman pumping balance is written as:

$$-\partial h/\partial t = \mathrm{curl}_z(\tau/\rho.f)) \qquad (1)$$

or

$$-\partial h/\partial t = (\mathrm{curl}_z(\tau) + (\beta/f).\tau^x) / (\rho.f) \qquad (2)$$

where h is the depth of the thermocline (>0 down) and the other variables state for their usual meaning. The equation evidences that the relative magnitude of the two right-hand side terms of Eq.(2) determines the sign of Ekman pumping. A qualitative description of these two terms is therefore presented first.

During a "normal" year, the zonal component of the wind stress is always negative (westward), whereas the seasonal meridional migration of the SPCZ induces alternation of negative (cyclonic) and positive wind stress curl, in the course of the year (Fig.9). Hence, the two terms of the equation add or balance , so the South Western Tropical Pacific may be sliced into regions: a) weakly affected by Ekman pumping, b) favourable to upwelling, c) favourable to downwelling, and d) propitious to alternation of upwelling and downwelling depending on the period of the year.

During the "abnormal" 1982-83 period, drastic wind field changes were observed. Of main interest is the reversal of the zonal component of the wind stress in early 1983 between about 13°S and 2°N, as reported in atlases (Leetmaa and Witte, 1984), papers (Kessler and Taft, 1987), and deduced here from the FSU wind field analysis. At this time, both τ^x and $\mathrm{curl}_z\tau$ act in the same way, leading to a strong positive (upward) Ekman pumping velocity in the northern part of the studied region. The effect upon the vertical thermal structure distribution is exemplified in Fig.10.

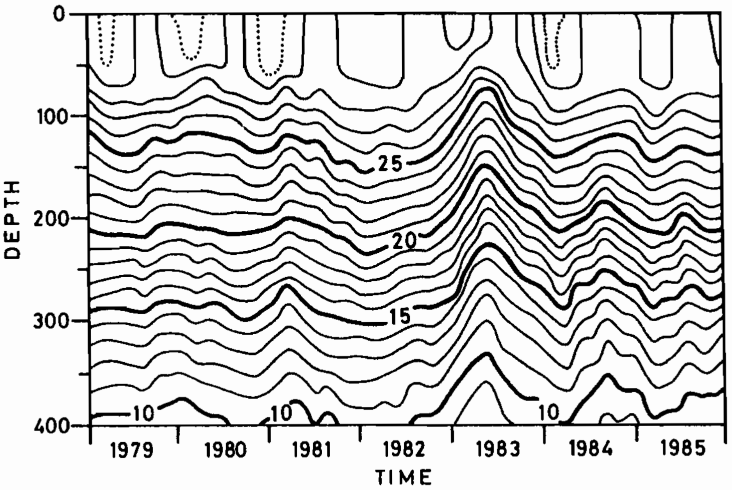

FIG.10. 1979-85 time series of isotherm depth distribution in the (10°S-12°S; 180°-170°W) box. Contours are at 1°C intervals, except for the dotted line which is the 29.5°C isotherm.

Besides the previous qualitative approach, a quantitative comparison between the two terms of the Ekman pumping equation has been performed. It is presented in Fig.11 for selected locations, and it confirms the preceding qualitative discussion.

b. Evaporation and precipitation

Evaporation and/or precipitation are related to the SPCZ which overspreads the studied region, and contributes to SST and SSS changes.

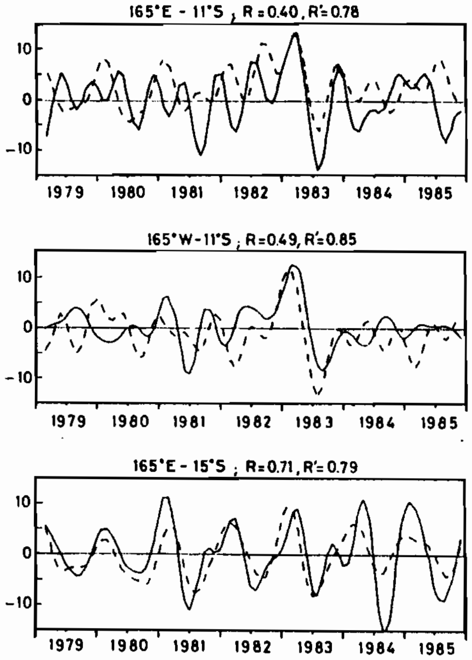

FIG.11. 1979-85 time series of the two terms of the Ekman pumping balance (see Eq. 1), at different reported locations. Solid line is $-\partial h/\partial t$, broken line is $\mathrm{curl}_z(\tau/\rho.f)$ in m.month^{-1} (the upward motion is positive). R and R' are, respectively, the correlation coefficients between the two terms during the 1979-81+1984-85 and 1982-83 periods.

During a normal year, mean monthly values of SSS were compared with mean monthly values of E-P (Fig.12). Evaporation was calculated from Weare et al.(1981)'s formulae, and precipitation data derived from the maps of Taylor (1973). Significant correlations (R > .7) are best obtained below the mean SPCZ position, for 2-3 month lag between the twelve month series (i.e., minimum SSS 2-3 months after minimum E-P). Note that similar result is obtained when comparing SSS with only P (i.e., minimum SSS 2-3 months after maximum P). Since E-P may be reasonably written as:

$$E\text{-}P = (E\text{-}P)_0.\cos(\omega.t-\theta) \qquad (3)$$

where $(E\text{-}P)_0$ is the annual mean amplitude, ω the annual frequency and θ is one month (January), the necessary condition for only E-P governs SSS is satisfied (Hires and Montgomery, 1972). In fact, SSS minimum occurs a quarter cycle (3-months) after minimum E-P. The thickness of the mixed layer (in density) that would be required to explain that only E-P variations account for annual SSS variations was thus computed over the R>.7 area. The results show that it is 28±7 m, i.e., in agreement with sparse density measurements. This suggests that, during a normal year, mostly E-P governs SSS below the mean SPCZ position.

The drastic SSS change associated with the 1982-83 El Nino was shown in Fig.8. An estimate of the possible responsible mechanisms was performed. Although horizontal advection and vertical mixing are consistent with the 1982-83 SSS change, we found that such SSS change was mainly governed by the equatorward shift of the SPCZ (Ardanuy et al., 1987), leading to a rainfall deficit below its usual position. For example, at 12°S-170°W, assuming that rainfall linearly decreased from 0.2 m month^{-1} in mid-1982 (the mean June value) to 0 in mid-1983 (Ardanuy et al., 1987), we obtain a -1.2 m fresh water deficit over a one year period. Alone, such deficit would induce a 0.8 SSS rise over

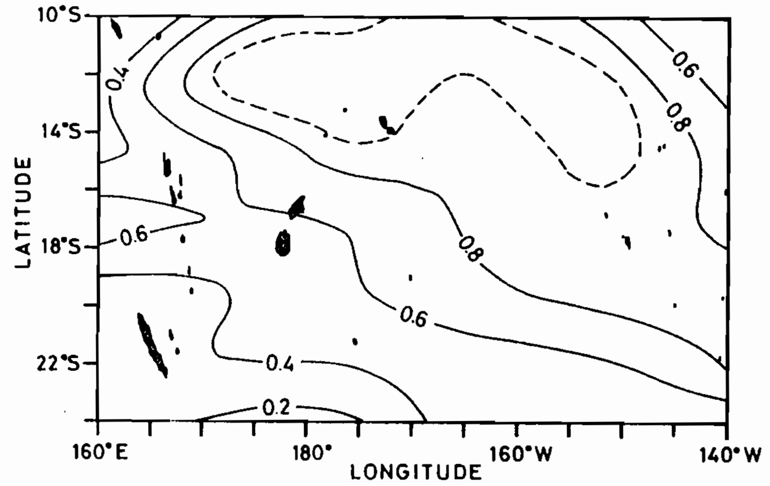

FIG.12. Correlation coefficients between sea surface salinity and evaporation minus precipitation mean years for a 2-month lag. Contour intervals at 0.2 except for the broken line which denotes the 0.9 value.

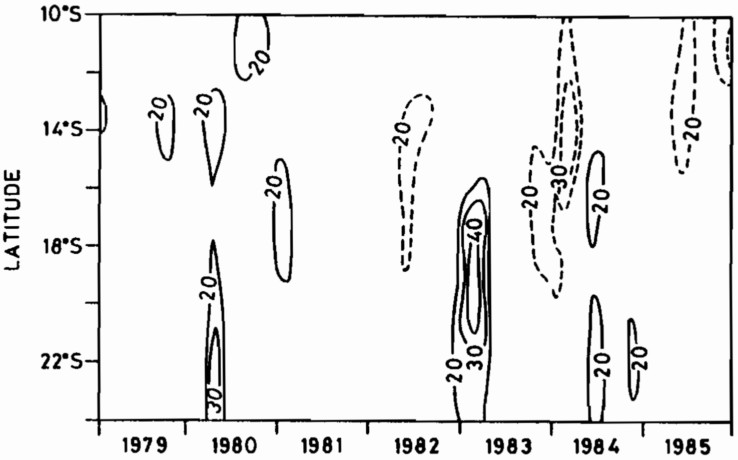

FIG.13. Zonal mean (160°E-140°W) latent heat flux anomalies (W m^{-2}) with reference to the (1979-81+1984-85) mean year, as a function of time and latitude.

a 50 m mixed layer, i.e., the same order of magnitude as observed in mid-1983. Rainfall deficit thus appears to be the dominant factor influencing SSS during the 1982-83 period.

As reported before (cf. Fig.10), Ekman pumping strongly uplift the thermocline in the northern part of the studied region. It modifies the whole water column all the way to the surface, perturbating the normal SST cycle. Figure 13 evidences that the latent heat flux anomalies which occured in early 1983, may also contribute to the abnormal SST cooling observed south of about 16°S.

6. Conclusions

The above findings suggest that most of the oceanic variability observed in the South Western Tropical Pacific is related to the SPCZ which, in turn, is affected by the surface oceanic conditions (Kiladis and Van Loon, 1988). Quantifying the role of such air-sea interactions over the whole warm pool is therefore of great interest. This is the challenge of the future COARE programme.

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