GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO. 9, PAGES 1243-1246, MAY 1, 2000

The equatorial West Pacific fresh pool at the end of the La Niña event in October/November 1996

M. Ioualalen

Institut de Recherche pour le Développement, IRD, Nouméa, New-Caledonia.

J. Holfort[1], G. Siedler[2] and W. Zenk

Institut für Meereskunde, Kiel, Germany

C. Hénin and J. Picaut[3]

Institut de Recherche pour le Développement, IRD, Nouméa, New-Caledonia.

Abstract.
The salinity, temperature and current distributions have been measured during the TROPAC cruise (Oct./Nov. 1996) at two sections, i.e. 143°E and 150°E, during the final phase of the 1995/1996 La Niña. The results present evidence that the fresh pool and the salinity front at its eastern boundary had moved far to the west, and that a barrier layer existed in that phase. The observed currents support the idea that advective processes play an essential role in creating the thermohaline structure during this ENSO phase. In relation with this process, it is found that the westward subduction mechanism of relatively dense eastern equatorial waters may apply during that phase.

1. Introduction

The thermohaline structure in the upper western equatorial Pacific is characterized by pools of fresh and of warm water. The Pacific warm pool with near-surface water temperatures higher than 28.5°C usually extends over an area as large as Australia and over the top 100 m depth. The warm pool and its associated area of atmospheric convection induces the so-called fresh pool [*Hénin et al.,* 1998] at the surface layer with salinity < 34.5 psu through a significant input of rainfall. It is separated from high salinity surface waters (> 35 psu) further east by a sharp zonal salinity gradient. This salinity front has been observed by *Eldin et al.* [1997], during the FLUPAC cruise (Oct. 1994 at 172°W), with a typical value of 0.1 psu/1° longitude with a maximum of 0.25 psu/1° and by *Ando and McPhaden* [1994] at 165°E in historical data. *Picaut et al.* [1996] and *Vialard and Delecluse* [1996] found that the salinity front is associated with a convergence of water masses, and oscillates within the equatorial band mainly through zonal advection at interannual time scale in phase with the Southern Oscillation Index. During La Niña, the warm pool is confined to the far western Pacific, with a thick barrier layer (BL) west of 165°E, while during El Niño it extends farther east [*Ando and McPhaden,* 1997].

West of the front, low density waters prevail and are often insulated from below by the BL [*Lukas and Lindström,* 1991] which is the layer between the bottoms of the mixed and isothermal layers. Athough heavy precipitations are sources of fresh water and may generate a thin BL, they do not necessarily induce a persistent and thick BL. To date, the formation and persistance of the BL is attributed to two mechanisms: the first, proposed by *Lukas and Lindström* [1991], is associated with the encounter of different waters and the westward subduction of eastern relatively high salinity waters; the second, proposed by *Roemmich et al.* [1994], is associated to the presence of an eastward wind-anomaly-driven equatorial jet accelerated by a zonal near-surface-only salinity gradient (a zonal pressure gradient not present at the thermocline) at the eastern edge of the fresh pool.

The presence of the BL is expected to play a role in the ENSO mechanism because it influences the heat and momentum budget of the relatively thin mixed layer by inhibiting entrainment cooling and trapping the wind-induced momentum [*Lukas and Lindström,* 1991]. This tends to insulate the low density fresh pool from underlying waters and to amplify equatorial jets generated by westerlies, facilating the eastward shift of the fresh pool during El Niño [*Picaut et al.,* 1996].

We report here on near-surface thermohaline and current fields in the western tropical Pacific observed during the TROPAC (TROpical PACific) cruise of the German F.S. SONNE in Oct./Nov. 1996 [*Siedler and Zenk,* 1997] that happened at the end of the 1995/96 La Niña.

[1]Now at Institut für Meereskunde, Troplowitzstr. 7, D-22529 Hamburg, Germany

[2]also at Instituto Canario de Ciencias Marinas, Aptdo. 56, 35200 Telde, Gran Canaria, Spain

[3]Now at LEGOS, 18 av. E. Belin, 31401 Toulouse, France

Paper number 1999GL002396.
0094-8276/00/1999GL002396$05.00

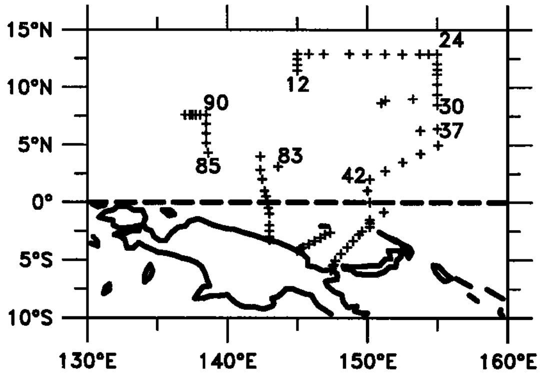

Figure 1. Route of F.S. SONNE, during the TROPAC cruise, 10 Oct. – 19 Nov. 1996, CTD station numeroted.

2. Thermohaline sections and currents during the final La Niña phase

The TROPAC cruise was conducted in the western tropical Pacific from Oct. 10 to Nov. 19, 1996. The route (Fig. 1) was similar to those of the WEPOCS cruises (June-Aug. 1985 and Jan.-Feb. 1986) [*Lukas and Lindström*, 1991]. The observations included two cross-equatorial transects at 143°E and 150°E. Current profiles were continuously recorded with a vessel-mounted 150 kHz-ADCP, and were averaged every 5 minutes in 8 m bins from 21 to 413 m depth. CTD measurements provided 92 temperature/salinity profiles.

During the 1995-1998 period, the tropical Pacific was subject to a complete La Niña/El Niño/La Niña cycle. Figure 2 shows that at the end of the 1995/1996

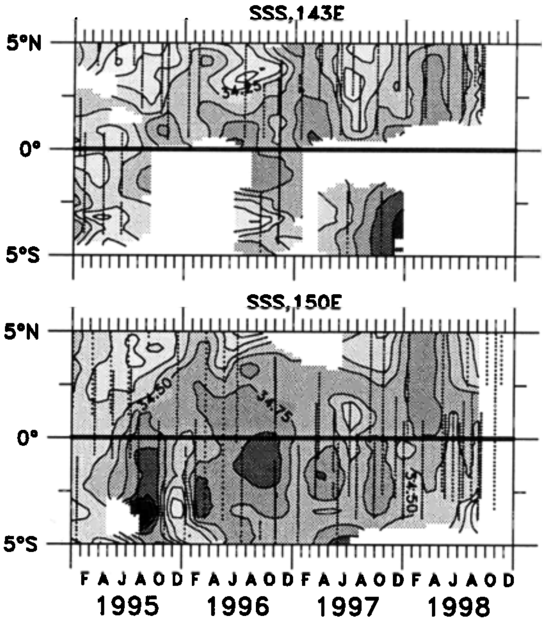

Figure 2. Sea surface salinity contours derived from the thermosalinograph network monitored by IRD/Nouméa. Data are selected along two tracks of 6° width in longitude, centered at 143°E and 150°E (0.25 psu iso-contours, + signs: data points).

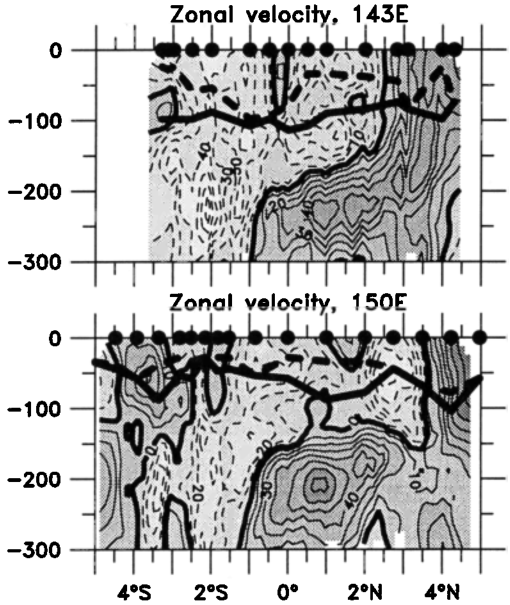

Figure 3. TROPAC transects for the zonal component of the current (depth in m). The two transects cross the equator at 143°E on the 13th Nov. 1996 (top), and at 150°E on the 5th Nov. 1996. Full lines represent eastward direction (10cm/s iso-contours). Dots at the top-axis: CTD stations. The bold dashed line represents the bottom of the mixed layer and the bold line is the isothermal layer (see criteria in the text).

cold event (which happened to be during the TROPAC cruise), the tongue of salty waters (> 35 psu) crossed 150°E transect (in the band Eq.-2°S) but not 143°E just prior to the eastward withdrawal of the salinity front.

Figure 3 shows that the TROPAC cruise was performed when there was still a persistent overall westward near-surface zonal flow. A reversal of zonal winds (to the east) in the TROPAC area occurred only at the end of the cruise [*Ioualalen and Hénin*, 2000], and an accumulation of high salinity waters in the western Pacific, enhancing the frontal gradient, occurred before the wind reverses. During TROPAC a *static* zonal salinity gradient of about 0.06 psu/1° is observed between the two transects in the top 50m layer within the 1°N-1°S band (Fig. 4). Besides, considering the mean westward current of 30 cm/s in the same top layer (Fig. 3), and a time lag of 8-9 days between the two transects, one may add a residual 0.02 psu/1° which corresponds to the westward displacement of the 150°E high salinity waters during this time lag. This leads to a zonal salinity front estimate of order of 0.08 psu/1° in the referred top layer assuming that zonal advection processes dominate the dynamics of the salinity front [*Hénin et al.*, 1998; *Picaut et al.*, 1996]. This value is in the same range given by *Eldin et al.* [1997].

Yet, the intensity of the front varies with atmospheric and oceanic conditions. *Ioualalen and Hénin* [2000] evidenced erosion/reconstitution process of the fresh pool and the salinity front. This is due to effects of westerlies that erode the fresh pool and deepen the mixed layer and the BL below their core, then allow a salin-

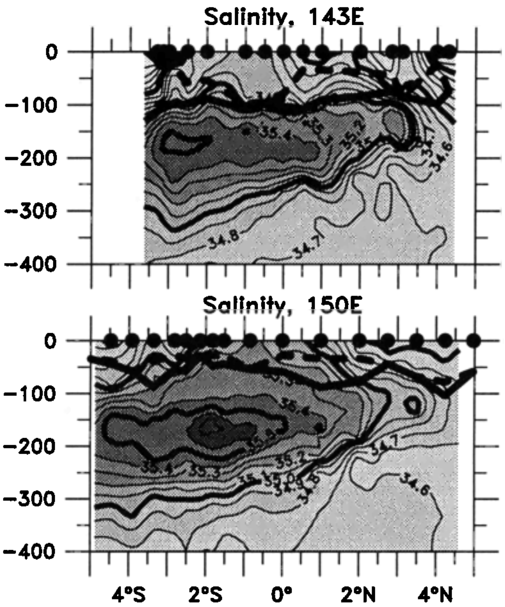

Figure 4. Same as figure 3 for the salinity (0.1 psu iso-contours)

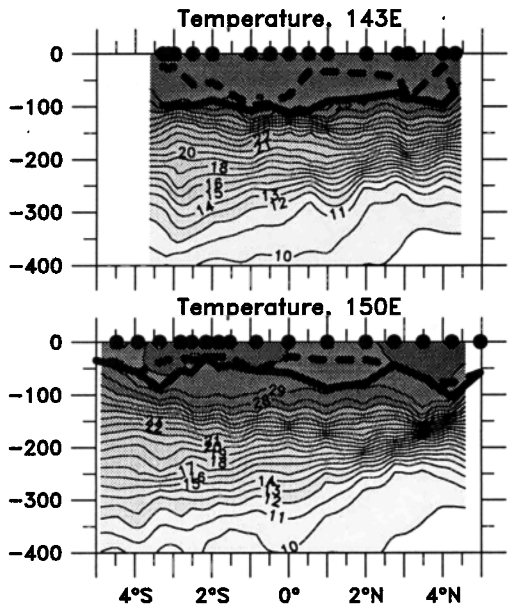

Figure 5. Same as figure 3 for the temperature (1°C iso-contours)

ity front/fresh pool reconstitution east of their core if there is sufficient precipitations to activate a BL formation/maintaining through above-cited mechanisms. The authors questionned possible effects of such process on ENSO dynamics since the thermohaline structure of the equatorial Pacific changes abruptly.

The temperature and meridional velocity sections along the two transects (Figs. 5-6) do not exhibit any equatorial upwelling or divergent flow. Moreover, the thermocline is deeper around the equator. A westward flow is observed (Fig. 3) and the winds are still westward [*Ioualalen and Hénin,* 2000] with overall persistent easterlies until Nov. 1996 in the western Pacific. At least, a trace of upwelling should have been observed in that region. This lack of upwelling strengthens the hypothesis that the dome of salinity at the equator (Fig. 4) is mainly due to horizontal advective processes or possibly indicates a downward vertical flow, i.e; the vertical component of a possible zonal westward subduction process [*Lukas and Lindström,* 1991] equilibrating the equatorial upwelling below the front.

The mixed and isothermal layers depths observed during TROPAC are plotted in Figures 3-6. We have used the same criteria as *Lukas and Lindström* [1991], i.e. a vertical temperature gradient of 0.05°C m^{-1} for the isothermal layer depth and a 0.01 kg m^{-4} density gradient for the mixed layer depth. The mixed layer depth was of order 50 m in the whole 4°S-4°N range for the eastern transect and north of the equator for the western transect (Figs. 3-6). South of the equator, the mixed layer is deeper, 80 m in average, for the western transect. The isothermal layer depth is of order 70 m for the eastern transect and 90 m for the western transect. Consequently, a BL was observed during the TROPAC cruise within the zonal salinity front and was in average deeper and thicker at 143°E than at 150°E. Considering the elevation of the BL and the mixed and isothermal layers around the salinity front while progressing to the east, it is likely that the BL disappears at its eastern edge. At least qualitatively, the subduction process of high salinity waters when reaching the salinity front in their westward displacement is likely to apply.

A particular feature is the presence of an eastward equatorial jet (Fig. 3) at 143°E-eq. of 0.5° of meridional extension, due to a reversal of the easterlies starting at the beginning of Nov. 1996, leading to westerlies propagating eastward and reaching 150°E after the TROPAC

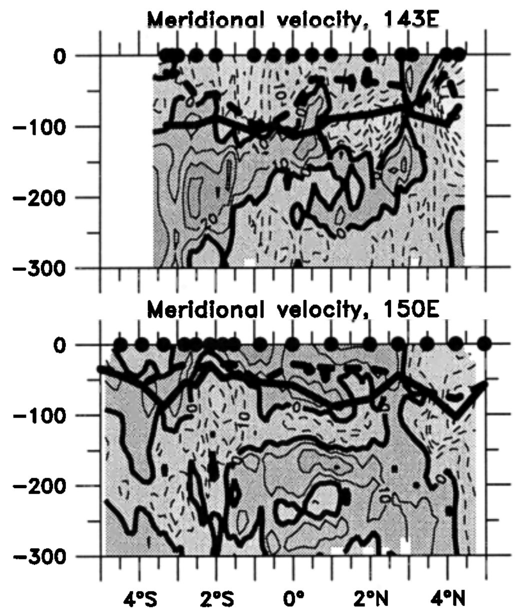

Figure 6. Same as figure 3 for the current meridional component

period [*McPhaden,* 1999]. This start of current reversal confirms that the salinity front is an area of zonal convergence of currents, which in turn explains the formation of the salinity front [*Picaut et al.,* 1996]. It is worth noting that this jet is trapped in the mixed layer. Also this jet is likely to have deepened the mixed layer and the BL. Moreover, at 143°E Figure 6 indicates a southward meridional component of the current in the isothermal layer in the 2°S-2°N band at least: this is likely to be the cause of the deepening of the mixed layer and of the erosion of the BL south of the jet.

The presence of the BL at the end of the 1996-1997 La Niña may have played a role in the triggering of the strong 1997-1998 El Niño, by trapping the westerly wind-induced momentum in the mixed layer and also by input of heat in the mixed layer: most of the CTD profiles presenting a BL exhibit a temperature gradient inversion at the bottom of the pycnocline: this suggests an entrainment heating of the mixed layer from the BL waters where the heat is stored [*Ioualalen and Hénin,* 2000]. Following *Lukas and Lindström* [1991], the conjunction of such probable heating and of the starting of equatorial westerlies immediately after the TROPAC cruise might have been the reasons why the westerly wind event propagated eastward from Nov./Dec. 1996, reached the date line and lasted nearly one year.

Acknowledgments. The assistance of Capt. E. Bruns and his crew and of the staff of the IfM-Kiel Marine Physics Department is gratefully acknowledged. The study was supported by the Ministry of Science and Techn. (BMBF), Bonn, Germany through grants 03G0113A and 03F0176A.

References

Ando, K., and M. J. McPhaden, Variability of surface layer hydrography in the tropical Pacific ocean, *J. Geophys. Res., 102,* 23,063-23,078, 1997.

Eldin, G., M. Rodier and M.-H. Radenac, Physical and nutrient variability in the upper equatorial Pacific associated with westerly wind forcing and wave activity in October 1994, *Deep-sea Res., 44,* 1783-1800, 1997.

Hénin, C., Y. du Penhoat and M. Ioualalen, Observations of sea-surface salinity in the western Pacific fresh pool: Large scale changes during 1992-1995, *J. Geophys. Res., 103,* 7523-7536, 1998.

Ioualalen, M., and C. Hénin, Thermo-haline variability of the western tropical Pacific during 1995-1998: on the erosion/reconstitution of the fresh pool, *J. Geophys. Res.,* submitted, 2000.

Lukas, R., and E. Lindström, The mixed layer of the western equatorial Pacific ocean, *J. Geophys. Res., 96,* 3343-3457, 1991.

McPhaden, M. J., Genesis and evolution of the 1997-98 El Niño, *Science, 283,* 950-954, 1999.

Picaut, J., M. Ioualalen, C. Menkes, T. Delcroix, and M. J. McPhaden, Mechanism of the zonal displacements of the Pacific Warm Pool, implications for ENSO, *Science, 274,* 1486-1489, 1996.

Roemmich, D., M. Morris, W. R. Young and J. R. Donguy, Fresh equatorial jets, *J. Phys. Oceanogr., 24,* 540-558, 1994.

Siedler, G., and W. Zenk, Untersuchungen zu den tiefen Wassermassen und planktologische Beobachtungen im tropischen Westpazifik während der SONNE-Fahrt Nr.113 (TROPAC), *Ber. Inst. Meeresk., 288,* Kiel, Germany, 129pp., 1997.

Vialard, J., and P. Delecluse, An OGCM study for the TOGA decade. Part I: Role of salinity in the physics of the western Pacific fresh pool, *J. Phys. Oceanogr., 28,* 1071-1088, 1998.

M. Ioualalen, C. Hénin and J. Picaut, IRD, BP. A5, 98848 Nouméa Cedex, New-Caledonia.

J. Holfort, G. Siedler and W. Zenk, Institut für Meereskunde an der Universität Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany

(Received September 13, 1999; revised February 07, 2000; accepted February 23, 2000.)