Hydrographic monitoring of El Niño 97-98 off the coast of southwest Mexico

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RESUMEN

Se analiza la información de campo colectada durante muestreos hidrográficos mensuales frente a la costa occidental de México en el periodo 1996-1998. Los perfiles de temperatura y salinidad para los periodos verano-otoño 1997 e invierno 1998 son muy diferentes a los perfiles obtenidos en los mismos meses para el año de 1996. Estas diferencias podrían ser explicadas por la entrada de grandes volúmenes de agua templada y menos salina, cuyas características TS sugieren un origen del Pacífico Tropical. En enero de 1998, estas masas de agua ocuparon completamente la capa superficial en sus primeros 90 m. El almacenamiento de energía en los 150 m superiores aumentó a 15.3 GJ/m^2 en comparación con el valor de 10.1 GJ/m^2 en enero de 1996. El proceso responsable de las anomalías en la temperatura superficial en la región EN B del Pacífico ecuatorial ocurrió un mes antes del aumento en temperatura y descenso de la salinidad observada en el lugar.

PALABRAS CLAVE: El Niño, hidrografía, calor almacenado, sudoeste de México.

ABSTRACT

Hydrographic data from monthly surveys off the West Coast of Mexico for the period 1996-98 are analyzed. Temperature and salinity profiles of the 1997 summer-fall and the 1998 winter periods differ strongly from similar profiles obtained in 1996. The differences might be due to the input of large volumes of relatively warm and less saline water, with TS features suggesting a Tropical Pacific origin. By January 1998, those water masses had filled the entire upper 90-m layer. The heat storage of the upper 150-m increased to 15.3 GJ/m^2, as compared with a January 1996 value of 10.1 GJ/m^2. The process which caused sea surface temperature anomalies in El Niño Pacific Equatorial region B occurred one month before the rise in temperature and fall in salinity at our site.

KEY WORDS: El Niño, hydrography, stored heat, SW Mexico.

INTRODUCTION

El Niño, a natural oscillating process that occurs in the ocean-atmosphere system has long been documented in various publications (Philander, 1990; Díaz and Markgraf, 1992; Trenberg, 1997). The event consists of a substantial upwelling suppression and the replacement of cold water by equatorial warm water. In a typical El Niño year, the surface temperature can increase some 3 °C, and sometimes up to 5-6 °C. Trade winds are weakened causing warm Equatorial water to move poleward from the Equator along a 1500 to 2000 km stretch of the South American coastline. This, in turn, leads to changes in migration patterns of fisheries or even the death of cold-water fishes (Díaz and Markgraf, 1992).

According to current concepts (LeBond and Mysak, 1978), during El Niño years, the Equatorial Trapped Kelvin Waves (ETKW) drive off the relatively warm and fresh Pacific Equatorial Surface Water towards the east along the equator. Upon reaching the American coast, ETKW force the Coastal Trapped Kelvin Waves (CTKW). The latter propagate into the narrow coastal area and drive the warm water along the coast of the North and South America. This mechanism is described in a number of theoretical papers (Anderson and Rowlands, 1976, Clarke, 1983). The Kelvin waves tend to increase sea level. Their periods vary from a few to 30-50 days, and their phase speed ranges from 1 to 2 m/s (LeBond and Mysak, 1978).

El Niño is noticed by changes in surface ocean water temperature and sea-level rises along the Mexican coast, as well as by climatic variations over the entire country. During one of the strongest El Niño events in this century (1982-83), the level of the Pacific ocean rose by 15-20 cm between Puerto Madero and Ensenada, and 25-30 cm in Manzanillo (González *et al.*, 1996). This particular event had a dramatic impact on the normal air circulation process, resulting in severe drought in Central Mexico but heavy rains in the northern parts of the country (Philander, 1990; Diaz and Markgraf, 1992; Filonov and Tereshchenko, 2000). El Niño (1997-98) also increased the air temperature in the western parts of Central Mexico, which in turn caused severe drought and numerous forest fires, which covered the entire country with a thick layer of smoke that extended to the adjacent areas of the United States (Informe Meteorológico, 1996-98).

The Department of Physics and the Center of Coastal Ecology of the University of Guadalajara (UdeG, Mexico) conducted field work in the period 1996-1998 to measure temperature and salinity changes caused by El Niño in the 150-m surface layer of the Western coast of Mexico.

MEASUREMENTS

The surveys covered a polygonal area off southwestern Mexico (Figure 1). A small-sized boat, the Bip-V owned by UdeG, equipped with an undulating CTD (SBE-19), was used continuously for nearly 16-18 hours at an average speed of 6 knots, following the approach of Filonov *et al.* (1996). Internal tides are known to cause significant vertical variations in all the hydrographic parameters over the continental shelf, so TS-characteristics were measured over a finely resolved grid during different phases of the internal tides, and then averaged to minimize their influence (Filonov, 2000). Previous measurements in the area had shown that seasonal cycles occur only in the upper 120 m layer (Filonov *et al.*, 1998), whereby surveys were made to 150 m depth. Each survey consisted of 10 sections 1.5 km appart and perpendicular to the coastline (Figure 1). A typical survey covered 50x15 km (Figure 1a), yielding about 100 vertical profiles of temperature and salinity. In January 1998, the survey was changed to a cross-shaped (80x30 km) track (Figure 1b). Normally, the surveys were done on the 15th of each month. A total of 29 surveys were conducted between January 1996 and June 1998, yielding 2374 temperature and salinity profiles from the site.

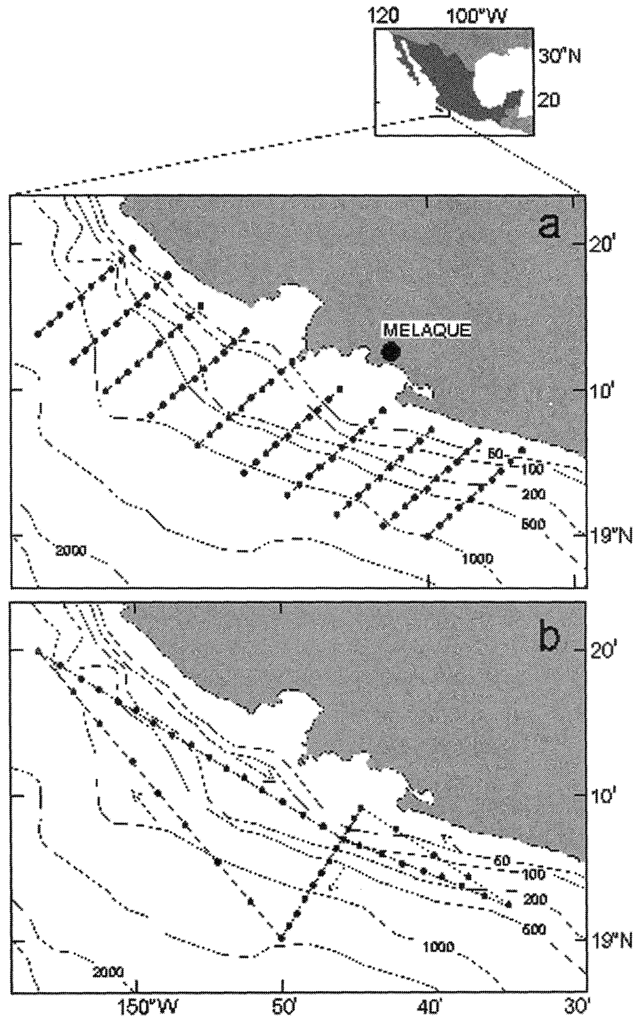

Fig. 1. The schematic of the Polygon, where the monitoring of El Niño 1997-98 was conducted. a) The legs made in the 1996-97 surveys, b) The legs made in the 1998 surveys. Dots show the locations of the temperature and salinity vertical profiles made with the use of the SBE-19 CTD-instrument.

RESULTS AND DISCUSSION

The water mass in the area belongs to the Eastern Tropical type of the Pacific ocean. In the winter, some portions of the California Current and a surface current out of the Gulf of California can reach the area. In the summer, the currents that contribute to the North Equatorial Countercurrent dominate the region (Wirtky, 1965).

A distinct change in the hydrological pattern of the area, most probably caused by El Niño, became clear in July 1997. A weakening of the trade winds had resulted in a displacement of the Subsurface Equatorial Water toward the Mexican coast. This water mass has relatively high temperature and low salinity, with TS characteristics identical to those of the Pacific Tropical Surface Water (PTSW). Eventually, this water mass drove the local water out of the upper layer. In Figures 2 and 3 the vertical distributions of temperature and salinity in the upper 150-m layer are presented. It is seen from the figures that the largest change in the distribution occurred in June-December 1997. It was this change that made the major contribution to the total difference between the 1996 and 1997 distributions. During July-August 1997, the lowering of the thermocline was distinctly smoother, and the increase in salinity from 34 psu (practical salinity units, (UNESCO, 1981)) at the surface to 34.7 psu at a 150 m level, was almost linear.

In September 1997, the vertical temperature profile became noticeably concave downward, which suggests the formation of a homogenous layer of PTSW, which grew steadily throughout the entire fall, reaching a thickness of

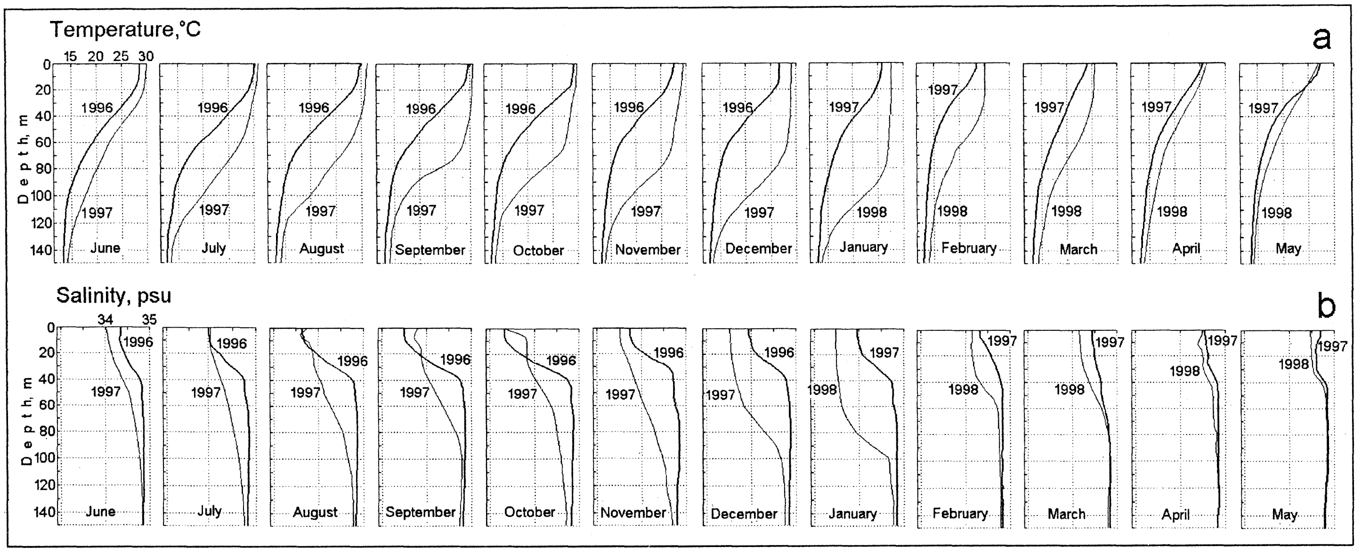

Fig. 2. Mean vertical (a) temperature and (b) salinity profiles in the Polygon area, based on monthly oceanographic surveys conducted in June 1996 - June 1998.

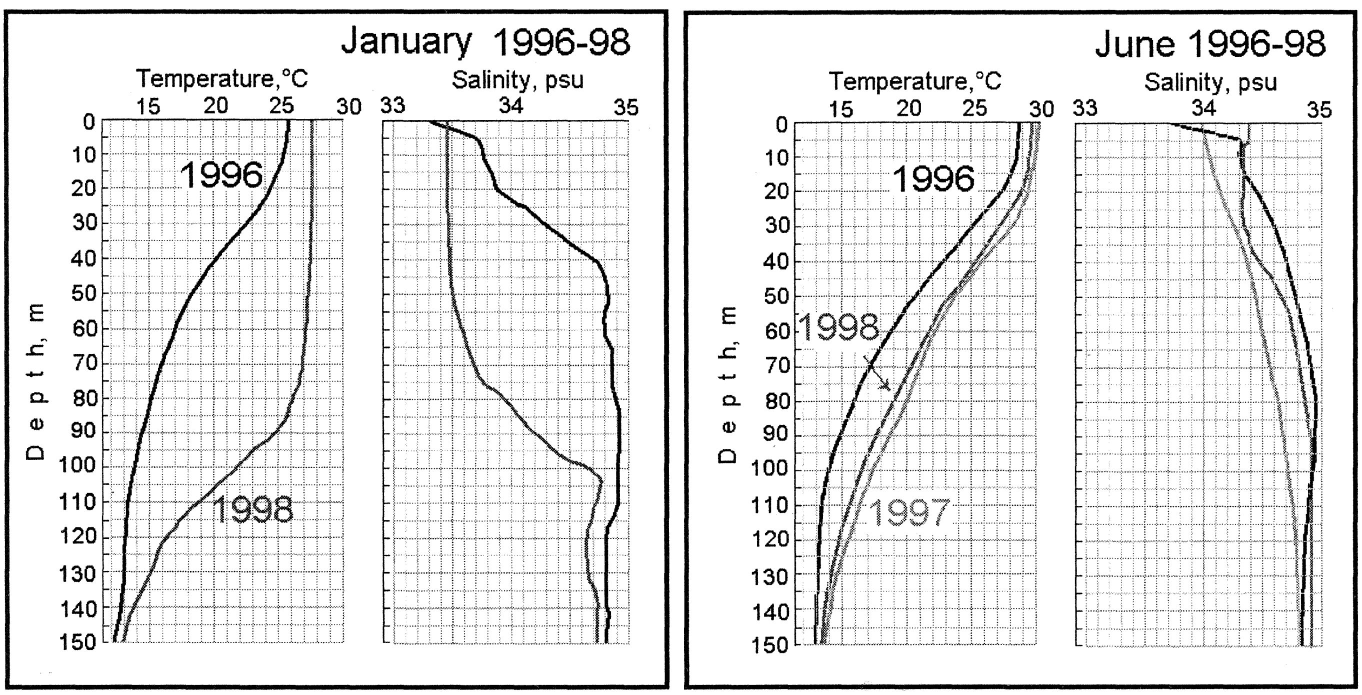

Fig. 3. Mean temperature and salinity profiles in the Polygon area for the 0-150 m layer, based on monthly oceanographic surveys conducted in January and June 1996-1998.

70 m by December 1997. The corresponding water temperature was 28.5 °C. At the same time, salinity fell to 33.5 psu at the surface, while in the homogeneous layer it increased to 34 psu.

The strongest impact of El Niño occurred in January 1998. At that time, PTSW filled the entire upper 80-m layer at 27.5 °C and a salinity less than 34 psu. For comparison, in January 1996, the surface temperature was 25.5 °C and the top of the thermocline was at a depth of 25 m (Figure 3). Even at 90-m depth, the temperature was 15 °C and salinity was 35 psu. This is clearly seen on Figure 4, where the mean TS curves for January 1996 and January 1998 are presented. During the El Niño year, an 80-m subsurface layer contained

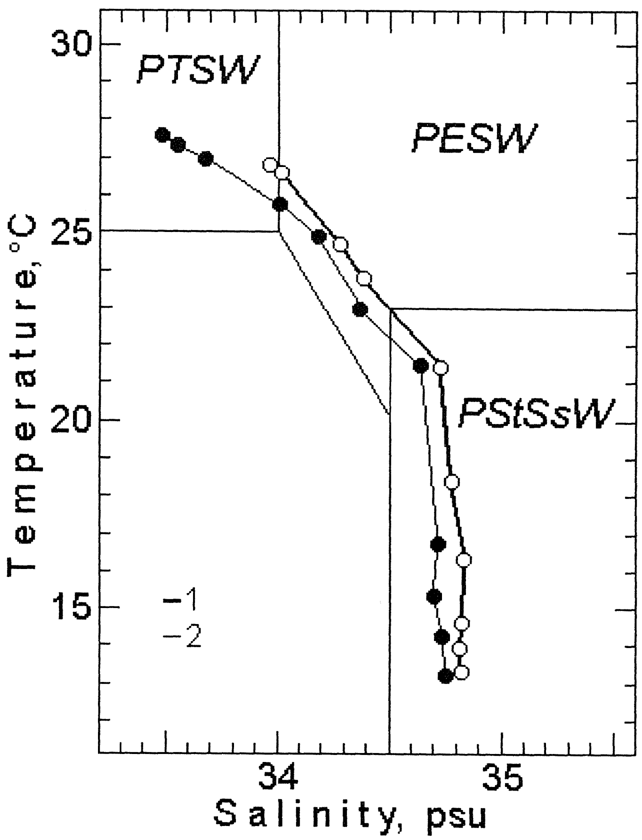

Fig. 4. Mean TS curves for (1) January 1996 and (2) January 1998. Thin lines indicate the boundaries between the Pacific Tropical Surface Water (PTSW), Pacific Equatorial Superficial Water (PESW) and Pacific Subtropical Subsuperficial Water (PStSsW).

PTSW, the 80-96 m layer was occupied with Pacific Equatorial Surface Water (PESW), and all the water beneath was Pacific Subtropical Subsurface Water (PStSsW).

In February 1998, the homogeneous layer was less than 40 m thick, its temperature was 25 °C and its salinity was higher than 34 psu. Significant departures (up to 4-5 °C) from the baseline temperature profile were still observed in March 1998, but in general, the temperature was closer to that in March 1996. The vertical distribution of salinity during that month was similar to that of the year before. In May 1998, the evolution of El Niño slowed down even more, making the TS characteristics barely different from those in May 1996. Only in the upper 60-m, was the salinity 0.2-0.3 psu less than during the previous year. The results clearly demonstrate that in May 1998, the thermodynamic event caused by the 1997 98 El Niño was over.

The temperature and salinity variations caused by this El Niño event were compared against the monthly sea surface temperature anomalies (SST) in the equatorial part of the Pacific, region B (4°N-4°S, 90°W-150°W) (Monthly Ocean Report, 1998). For this purpose, vertical integrals for T and S, from 0 to 150 m depth, were taken for each month from January 1996 - June 1998, and the active layer heat storage per unit surface area was calculated following Mamayev [1975],

$$Q = \frac{1}{M}\sum_{i=1}^{N}\sum_{j=1}^{M}\rho_{ij}C_{p_{ij}}T_{ij}\Delta z, \qquad (1)$$

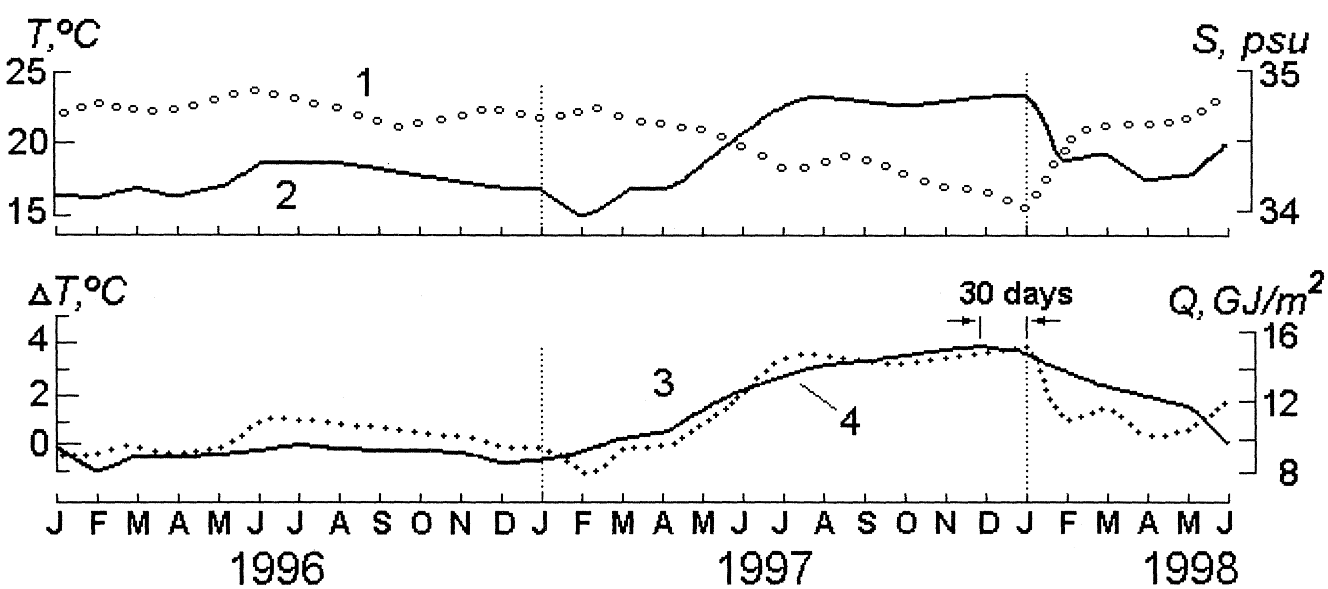

Fig. 5. (1) Temperature, (2) salinity and (3) heat storage Q variations in the 0-150m layer and (4) monthly sea surface temperature anomalies (SST) in the equatorial region B (4°N-4°S; 90°W-150°W) of the Pacific ocean in 1996-98.

where M is the number of vertical soundings in a survey, N is the number of 1-m depth increments, ρ is water density, Cp is specific heat content, T is water temperature. The results are shown in Figure 5. During the 1997-98 El Niño event, the rate of change heat storage, the rise in temperature and the drop in salinity within the upper layer agree well with SST anomalies time series in region B. In January 1998, the temperature was 7.6 °C higher and salinity was 0.5 psu lower than in January 1996. Over the same period, the heat storage of the oceanic active layer had increased from 10.1 to 15.3 GJ/m^2. During the entire year of 1996, the sea surface temperature anomalies in region B were close to zero (Figure 5). Beginning in 1997, their values became positive and continued to increase until December, when they peaked at +4.5 °C. Starting in January 1998, they decreased rapidly and decayed to almost zero in June (Monthly Ocean Report, 1998). El Niño had the strongest impact on the Mexican coast within a month after the El Niño Index reached its peak in region B.

CONCLUSIONS

Our findings show that during the fall of 1997 and in early winter of 1998, the upper 90-m layer off the Western Mexican coast was filled with PTSW and PESW. The latter might have been transported poleward from the equator by Kelvin waves. There are many experimental studies of the low-frequency oscillations off the North American coast caused by El Niño (Christensen *et al.*, 1983; Baumgartner and Christensen, 1985). Shaffer (1997) presents the results of a special-purpose experiment conducted off the Chilean coast, which revealed the presence of low-frequency signals in the time series of sea level and currents. The fluctuations were caused by CTKW during the 1992-93 El Niño; their typical periods were of 5-10 days and 50 days. A one-month sampling interval of our experiment does not allow us to estimate the periods of CTKW caused by the 1997-98 El Niño. We now intend to conduct a study of the daily mean time series of sea level in some western Mexican ports, with an analysis of sea surface temperature satellite images. Such a study will allow estimates to be made of the periods, amplitude and phase of CTKW off the Mexican coast, caused by the last El Niño of the previous century.

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