Atmósfera (1989), **2**, pp. 17-30

ENSO 1986-87 at Mexican subtropical Pacific offshore waters

G. DE LA LANZA

Instituto de Biología, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510, México, D. F., MEXICO

I. GALINDO E.

Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510, México, D. F., MEXICO

(Manuscript received July 25, 1988; accepted in final form October 18, 1988)

RESUMEN

En septiembre de 1987 se determinó la estructura termo-oxi-halina hasta los 100 m de profundidad mediante la selección de ocho secciones obtenidas de un transecto de 340 km de longitud en aguas cercanas a Manzanillo, entre los 104 W y 108 W a los 19 N. Las aguas se encontraron relativamente calientes en los primeros 20 m de profundidad, de 26.4 C a 33.1 C; el promedio a 5 m de profundidad fue 30 C. Lo cual significa una anomalía positiva de la temperatura de la superficie del mar de 1.5 C. La salinidad se encontró en la superficie 0.1-0.4 o/oo por arriba de la normal, este incremento se observó en toda la columna de agua. El oxígeno se encontró dentro de valores normales, entre 4 y 5 ml/l.

En la profundidad de 20 a 100 m se encontró un calentamiento subsuperficial. Las desviaciones más altas de la temperatura ($> 2\sigma$) con respecto a Eastropac 1967, se observaron a la profundidad de 75 m. La termoclina de 15 C se encontró desplazada por abajo de los 100 m. En las mismas profundidades y a unos 150 km de la costa, la salinidad presentó sus niveles mayores entre 35.1 o/oo a 35.2 o/oo. La concentración mínima de oxígeno fue de 0.7 ml/l cerca de la costa, mientras que a 200 km mar adentro fue de 0.4 ml/l. La Capa de Mínimo Oxígeno (1.07 ml/l) se encontró desplazada a 100 m de profundidad cerca de la costa. Estos resultados indican probablemente advección de aguas cálidas subsuperficiales fluyendo hacia el Norte, tal vez debido a un reforzamiento de la Contracorriente Ecuatorial.

El inicio de ENSO 1986-87 fue en octubre y en noviembre de 1986, en Tumaco (1.8 N) y Acapulco (15.9 N), respectivamente. Mientras que en Ensenada (31.9 N) las mayores anomalías de SST y nivel del mar aparecieron hasta diciembre de 1986. A pesar de que se observó calentamiento de la superficie en las Islas Galápagos durante noviembre de 1986, sin embargo la iniciación del evento ocurrió en Chicama (7.9 S) en las costas de América del Sur hasta el mes de abril de 1987, es decir cinco meses después.

Las anomalías positivas de SST y del nivel del mar permanecían en diciembre de 1987 sobre la costa oeste de América Central y México, pero con tendencias a la normalidad.

ABSTRACT

The thermo-oxy-haline structure down to 100 m depth was determined in September 1987 through eight selected stations obtained from a transect of 340 km long across offshore waters near Manzanillo, between 104 W and 108 W at 19 N. The waters in the first 20 m were relatively warm, from 26.4 C to 33.1 C. The average at 5 m depth was 30 C. That means a positive surface anomaly of 1.5 C. Salinity was between 0.1-0.4 o/oo higher than normal at the surface and it showed to be increased in the whole water column. Oxygen was considered normal at the surface.

From 20 m to 100 m depth it was found a subsurface warming. The largest temperature deviations from Eastropac 1967 is at 75 m depth ($> 2\sigma$). The 15 C thermocline was found depressed at depths as down to 100 m. At the same depths, and about 150 km from the coast, salinity attained its largest values, between 35.1 o/oo to 35.2 o/oo. Near the coast the oxygen minimum concentration was 0.7 ml/l whereas 200 km seaward it was 0.4 ml/l. The Oxygen Minimun Layer (1.07 ml/l) was found near the coast depressed to 100 m depth. These results indicate advection of subsurface warmer waters northwards, perhaps due to an strengthening or northward displacement of the Equatorial Countercurrent.

The onset of ENSO 1986-87 episode was between October and November 1986 at Tumaco (1.8 N) and Acapulco (16.8 N), respectively. While at Ensenada (31.9 N) the largest anomalies of SST and sea level did not appear until December 1986. In spite that surface warming was observed in the Galapagos Islands in November 1986, however the onset of ENSO 1986-1987 at Chicama (7.9 S) on the South American coast occurred five months later, in April 1987.

Positive anomalies of SST and sea level remained in December 1987 along the west coast of Central America and Mexico. However there is a decaying trend toward normal.

Introduction

El Niño is an anomalous warming of the eastern equatorial Pacific that takes place at irregular intervals of 2-7 years and lasts for 1-2 years. The Southern Oscillation is a global-scale seesaw in surface pressure with centers of action around Indonesia-North Australia and the Southeast Pacific. Bjerknes (1969) showed that the two phenomena are parts of a global system of climate fluctuations. The El Niño/Southern Oscillation (ENSO) phenomenon is the most notable and pronounced example of year-to-year climate variability.

Several oceanographic and atmospheric indices have been developed in order to characterize and monitor the evolution of ENSO events. Sea surface temperature (SST) and sea level (MSL) positive anomalies are good indicators of El Niño, whereas the Tahiti-Darwin Southern Oscillation Index (SOI) for sea level pressure (SLP) and the outgoing longwave radiation (OLR) as a measure of convective cloudiness and rainfall in the central equatorial Pacific monitor the state of the Southern Oscillation (U. S. Climate Analysis Center). When ENSO is in progress, the SOI is below normal, and SST and MSL are above normal over the equatorial central and eastern Pacific.

At the end of the winter 1985/86 it appeared possible that an ENSO episode might be beginning. In spite of the real-time monitoring of most of the Pacific Ocean and the availability of more data on a global scale, however there was no positive answer at the end of February, as to whether the onset of a warm event was taking place (U. S. Climate Analysis Center, 1986). The different indices: SOI, OLR, and the 200 and 850 mb zonal wind were not conclusive (Arkin and Janowiak, 1986). The uncertainty continued during the next trimester (March-May): positive anomalies of SST were observed near the date line and also along the eastern equatorial Pacific, however the SOI remained near zero (Barnston, 1987). At the same time sea level was below normal along the west coast of Central and South America. From May to July, near normal conditions for SST returned to the eastern equatorial Pacific with sea level also near normal, the SOI was positive in June while in July was near zero (CDB, July 1986). Along the Mexican west coast, positive anomalies of SST were present but MSL remained below or near normal.

It was during August that for the first time since the extraordinary ENSO event of 1982-83, the low-level easterlies were weaker than normal in the equatorial central Pacific as evidenced by the three Pacific 850 mb zonal wind and the SOI indices which were negative (CDB, August, 1986). SST slight positive anomalies had returned to the eastern equatorial Pacific. MSL was positive along Central American coast and between 160 E-140 W in the equatorial Pacific. By September the equatorial Pacific oceanic and atmospheric indices showed that a mid-Pacific warming was under way.

The contradictory signals obtained during the boreal spring serve to illustrate that the so-called precursor phase of ENSO (Philander, 1983) is one of the most difficult stages for simulating in oceanic and coupled ocean-atmosphere models (Arkin and Janowiak, 1987). In fact the analysis of the ENSO events that have occurred since 1950, recorded along the Mexican coast (Galindo, 1987) shows that in most of the cases the onset of ENSO is during the boreal spring (March to May). However the intense event of 1982-83 was also out of phase by six months at the South American coast, where the current and temperature responses were not seen until October 1982 (Rasmusson and Wallace, 1983) near Callao, several days after sea level rose at Galapagos Islands (Smith, 1983). However positive anomalies of SST and MSL were seen along the west coast of Mexico early in March 1982 (Galindo, 1987).

In this paper the evolution of the 1986-87 warm event is documented along the Mexican west coast.

A transect of 340 km long across offshore waters near Manzanillo was performed on board the R/V A. v. Humboldt, operated by the Dirección General de Oceanografía of the Mexican Navy Ministry during September 1987. The hydrographic data are used to determine the perturbed thermo-oxy-haline structure during this warm event. The results are consistent with the positive anomalies of SST and sea level observed along the west coast of Central America and Mexico since November 1986.

Study area

The study area embraces a 340 km long westward transect from the 1,000 m isobate offshore Manzanillo to Isla Socorro. Eight sampling stations were choosen along 19 N distributed between 104 02 W and 108 20 W (Fig. 1).

Under normal conditions, i.e., in non-El Niño years at this time of the year, the area receives water masses from the North Equatorial Current which flows offshore northwestwards. The North Equatorial Current is formed at the Costa Rica Dome by the North Equatorial Countercurrent, which at this time of the year attains its largest velocities and a minor portion of cooler waters supplied form the California Current which leaves the coast at about 25 N (Wyrtki, 1965). The atmosphere of the area is influenced by the Intertropical Convergence Zone (ITCZ) which also attains its northernest position (about 15 degrees North). Mean monthly SST is between 28-29 C (Love, 1975; Sadler *et al.*, 1987). Salinity at the surface is 34.4 o/oo and at 100 m depth is 34.8 o/oo (Love, 1975). The upper limit of the Oxygen Minimum Layer (OML) is between 50 to 70 m depth (Wyrtki, 1962; Gallegos *et al.*, 1984).

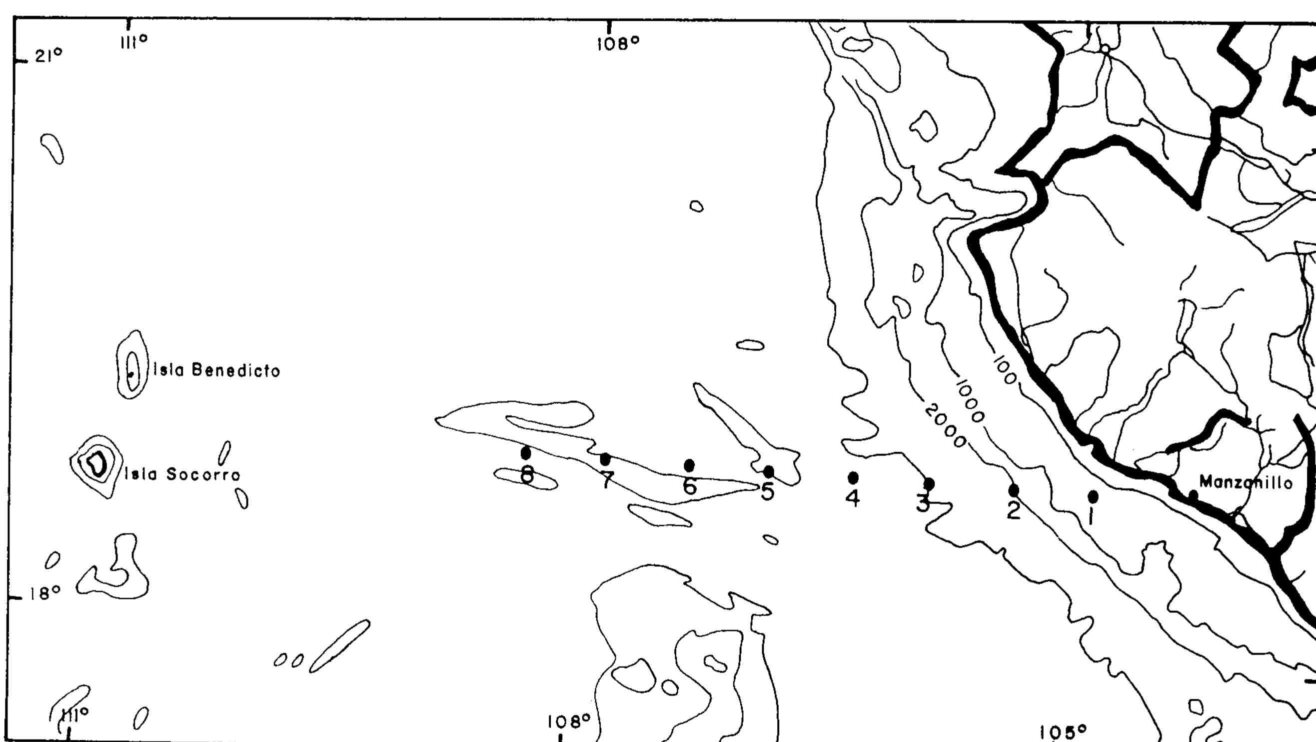

Fig. 1. Area of study. Transect Manzanillo-Isla Socorro, Mexico and Sampling stations.

Data and methods

Stations

At each sampling station Niskin bottles with attached reversible thermometers were used at five depth levels: 5, 10, 20, 75, and 100 m. Temperatures were corrected in accordance with the Manual of the Argentine Navy (1972). Water samples were inmediately analyzed for dissolved oxygen by the method of Winkler (Strickland and Parsons, 1968). Salinity was determined using an induction salinometer. All the profiles were compared with those recorded during Eastropac in 1967 (Love, 1975) for the same place and month, i.e., the data are compared with those obtained during the non-El Niño year 1967. The differences found between Eastropac data and the actual observations are regarded as anomalies if they are statistically significant at the 95 percent confidence level.

Sea level heights and sea surface temperatures

Monthly means of sea level and sea surface temperature data have been recorded since 1952 at the hydrographic stations of Tumaco (1.8 N, 78.8 W), Acapulco (16.8 N, 104.3 W) and Ensenada (31.8 N, 116.6 W). For Puerto Chicama (7.9 S, 79.1 W) only sea surface temperature data (1925-1987) were used.

Sea level anomalies (SLA) have been determined in accordance with Wyrtki (1984) by the relation:

$$SLA = SLH - MSL - MAC \tag{1}$$

where:

SLH denotes individual values of monthly mean sea level heights.

MSL denotes mean sea level during the non-El Niño years.

MAC denotes the mean annual cycle. MAC has been determined by the non-integer technique of power spectrum analysis (Schickedanz and Bowen, 1977). The estimated values of MAC are very near to those documented by Wyrtki and Leslie (1980).

The anomalies SLA are considered statistically significant at 95 per cent confidence level if

$$SLA > \mid 2\sigma \mid \tag{2}$$

where σ denotes the standard deviation for each individual month.

Sea surface temperature anomalies SSTA have been estimated using the simple relation

$$SSTA = SST - LSST \tag{3}$$

where SST denotes the monthly mean sea surface temperature and LSST is the long term monthly average of sea surface temperature for each station during the non-El Niño years.

The anomalies SSTA are considered statistically significant at the 95 percent confidence level if

$$SSTA > \mid 2\sigma \mid \tag{4}$$

Results

Temperature profiles

In the first 20 m depth, temperature was relatively high, between 26.4 C and 33.1 C. The average at 5 m depth was 30 C particularly near the coast. Between 75 m and 100 m depth, the recorded temperatures were lower than 20 C: between the coast line and 280 km seaward, temperatures were between 18.5 C and 20.9 C: from there to Isla Socorro, temperatures were between 16.8 and 15.5 C. The 15 C isotherm was depressed to depths below 100 m (Fig. 2). A comparison of the mean temperature distribution obtained from all the actual temperature profiles with that obtained during Eastropac for the same month in 1967 (Love, 1975) is presented in Fig. 3 which shows that, below 20 m depth, the temperature anomalies are larger than at the surface, with the largest anomalies being attained relative to Eastropac down at 75 m depth. Temperature differences at depths 75 to 100 m are significant at the 95 per cent confidence level (Fig. 4e). Although the actual temperature profiles are cooler than those observed during the extraordinary ENSO event of 1982-83 in nearby offshore waters (Gallegos *et al.*, 1984). It seems, that the actual temperature distributions may be related with the presence of warmer equatorial waters.

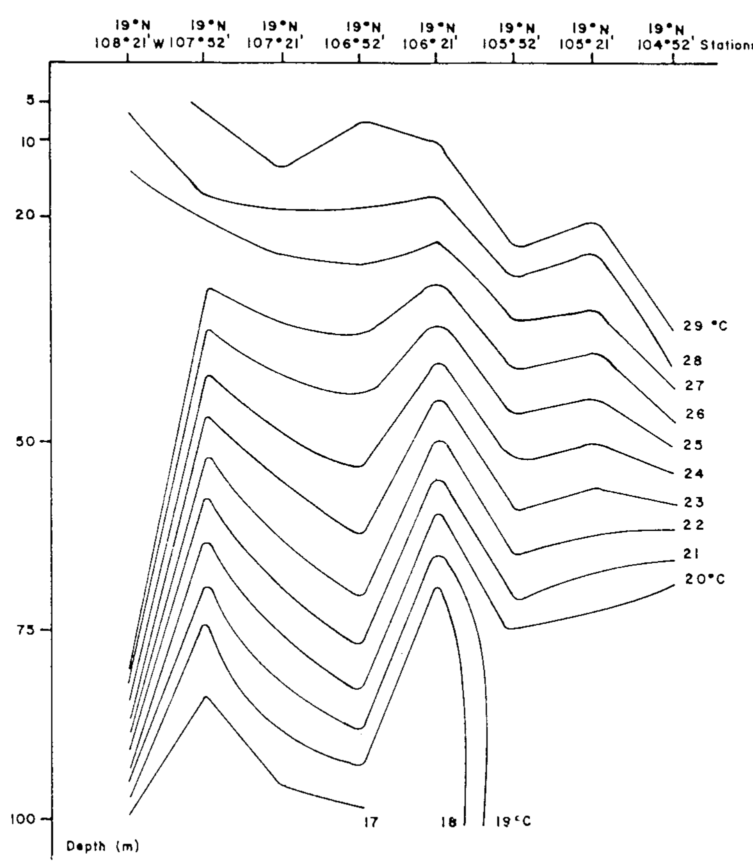

Fig. 2. Temperature profiles obtained for each station during September 1987.

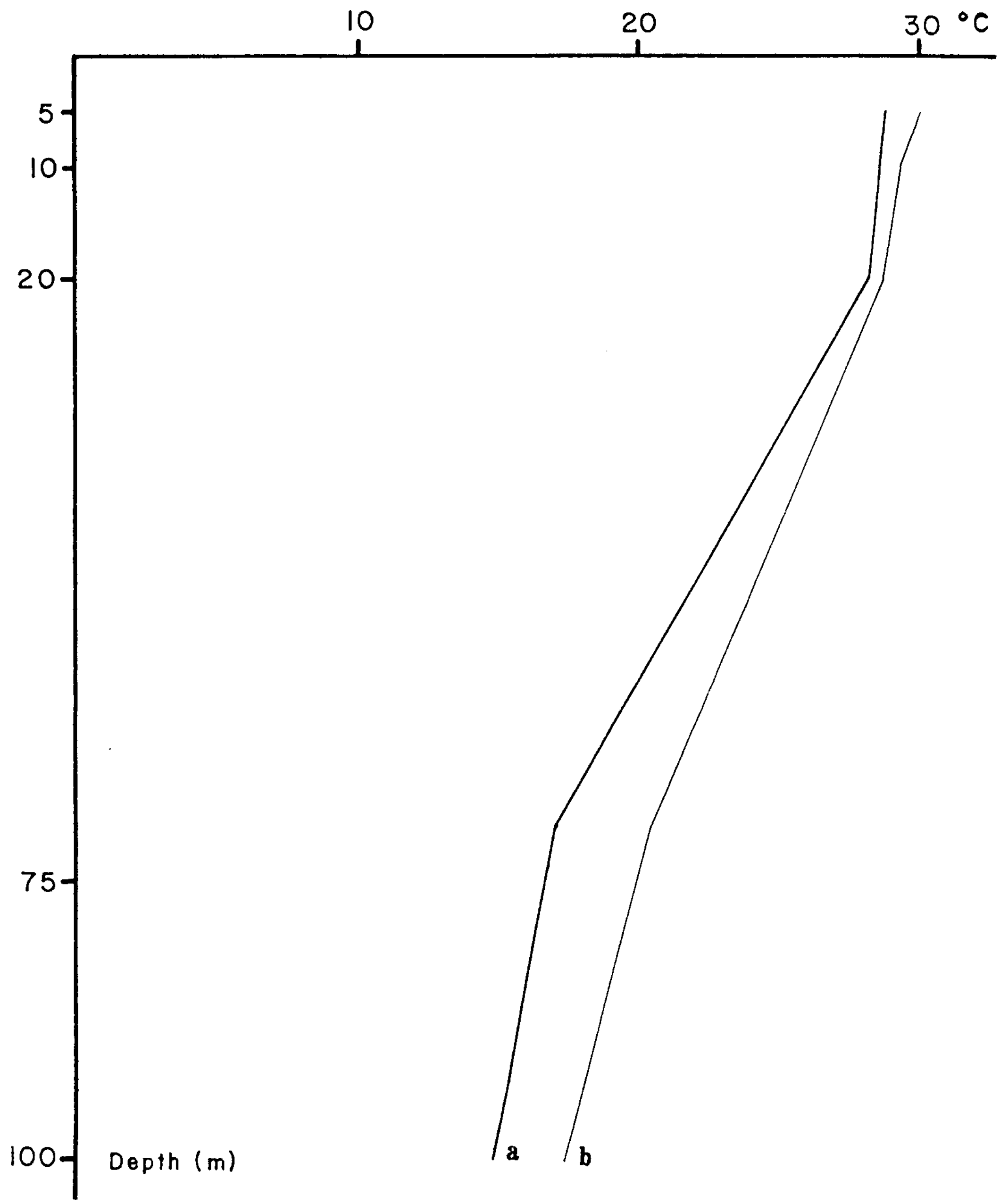

Fig. 3. (a) Average temperature profiles for September 1967 during Eastropac (Love, 2975). (b) Temperature profiles obtained during September 1987.

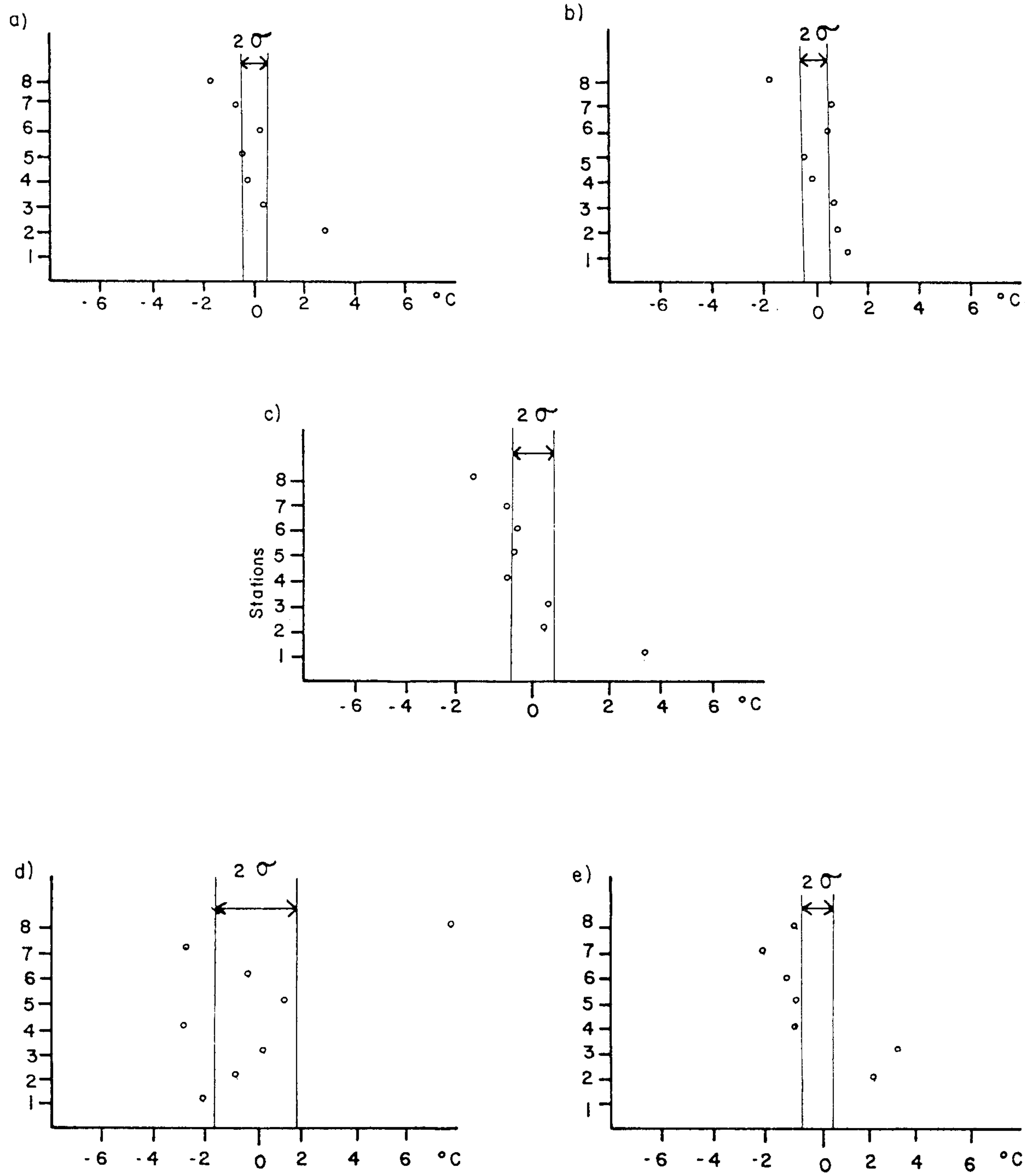

Fig. 4. Temperature anomalies with respect to Eastropac 1967 for depths: a) 5 m, b) 10 m, c) 20 m, d) 75 m, and e) 100 m depth.

Dissolved oxygen

Fig. 5 shows profiles of dissolved oxygen concentration obtained during the eight stations of the transect Manzanillo to Isla Socorro. Surface oxygen values are in the range of 4.0 to 5.0 ml/l. The vertical rate of change is about 0.25 ml/l/m. Fig. 5 shows also the presence of minimum oxygen concentrations near the coast (0.7 ml/l) and about 200 km seaward (0.4 ml/l). The upper limit of the OML is found near the coast (1.07 ml/l) but not very shallow, near to 100 m depth.

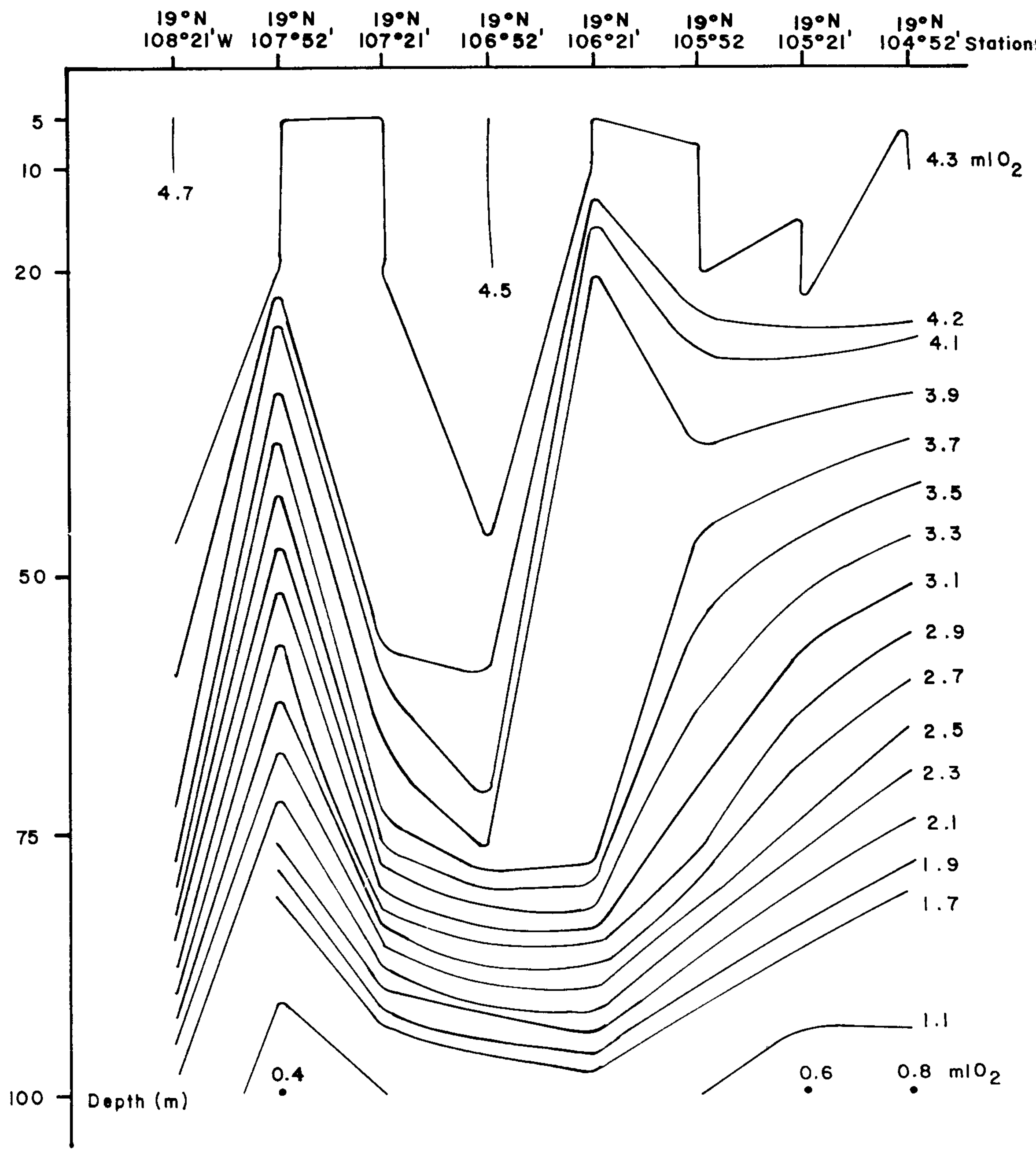

Fig. 5. Oxygen profiles obtained for each station during September 1987.

Salinity

The salinity profiles (Fig. 6) show surface values between 34.8 and 35.0 o/oo i.e., between 0.1 and 0.4 o/oo higher than the surface salinities determined during Eastropac. The largest values (35.1-35.2 o/oo) were found at depths between 75 to 100 m in offshore waters, whereas at the stations taken farther seaward, the profiles have values between 34.8 and 35.0 o/oo homogeneously distributed.

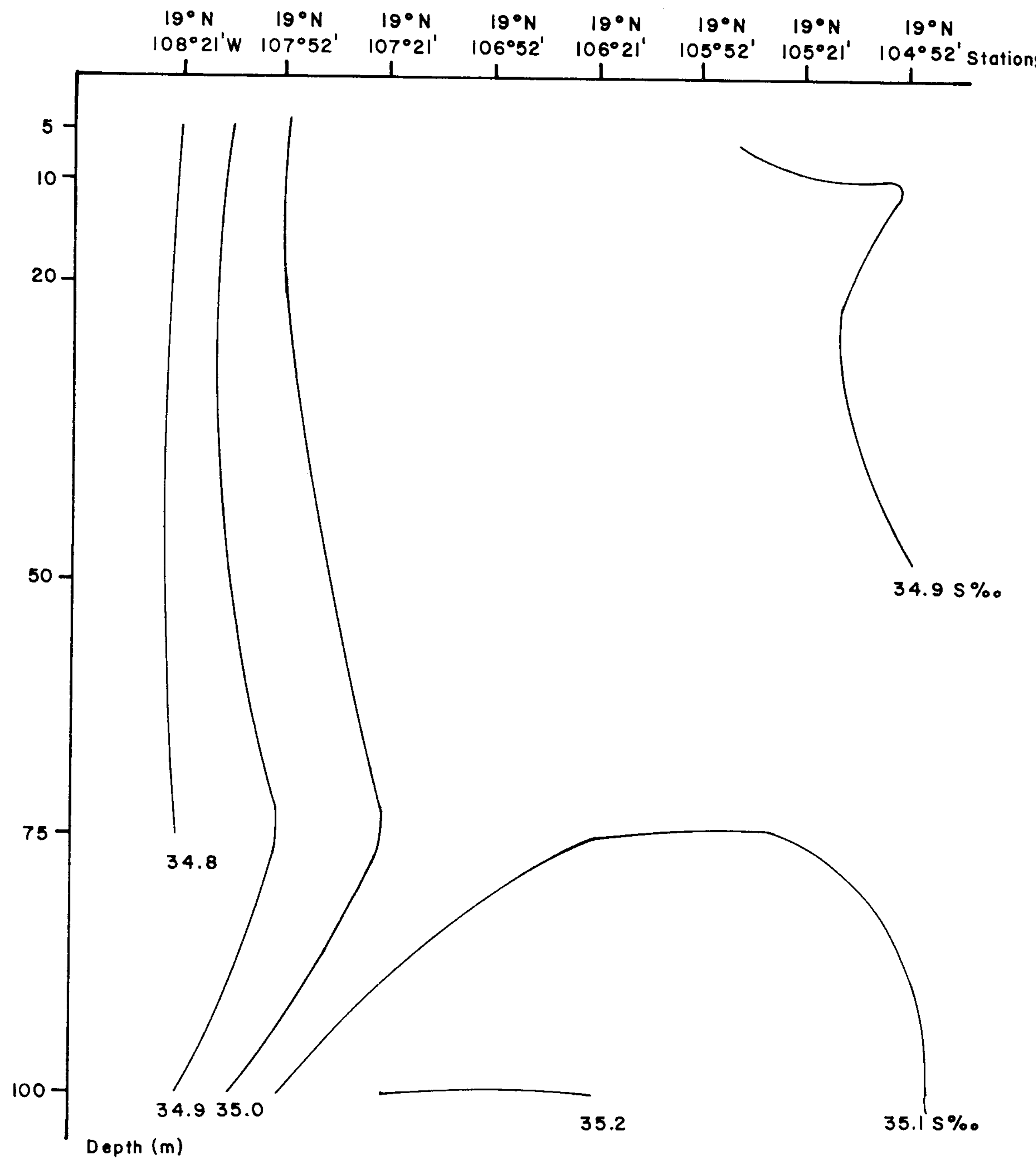

Fig. 6. Salinity profiles obtained for each station during September 1987.

Evolution of the 1986-1987 warm event

Figs. 7 show the monthly sea surface temperature and sea level anomalies expressed in standard deviation units (STDU) from 1985 to 1987 for the hydrographic stations at Ensenada (31.9 N), Acapulco (16.8 N), and Tumaco (1.8 N). Chicama (7.9 S) shows only sea surface temperature anomalies.

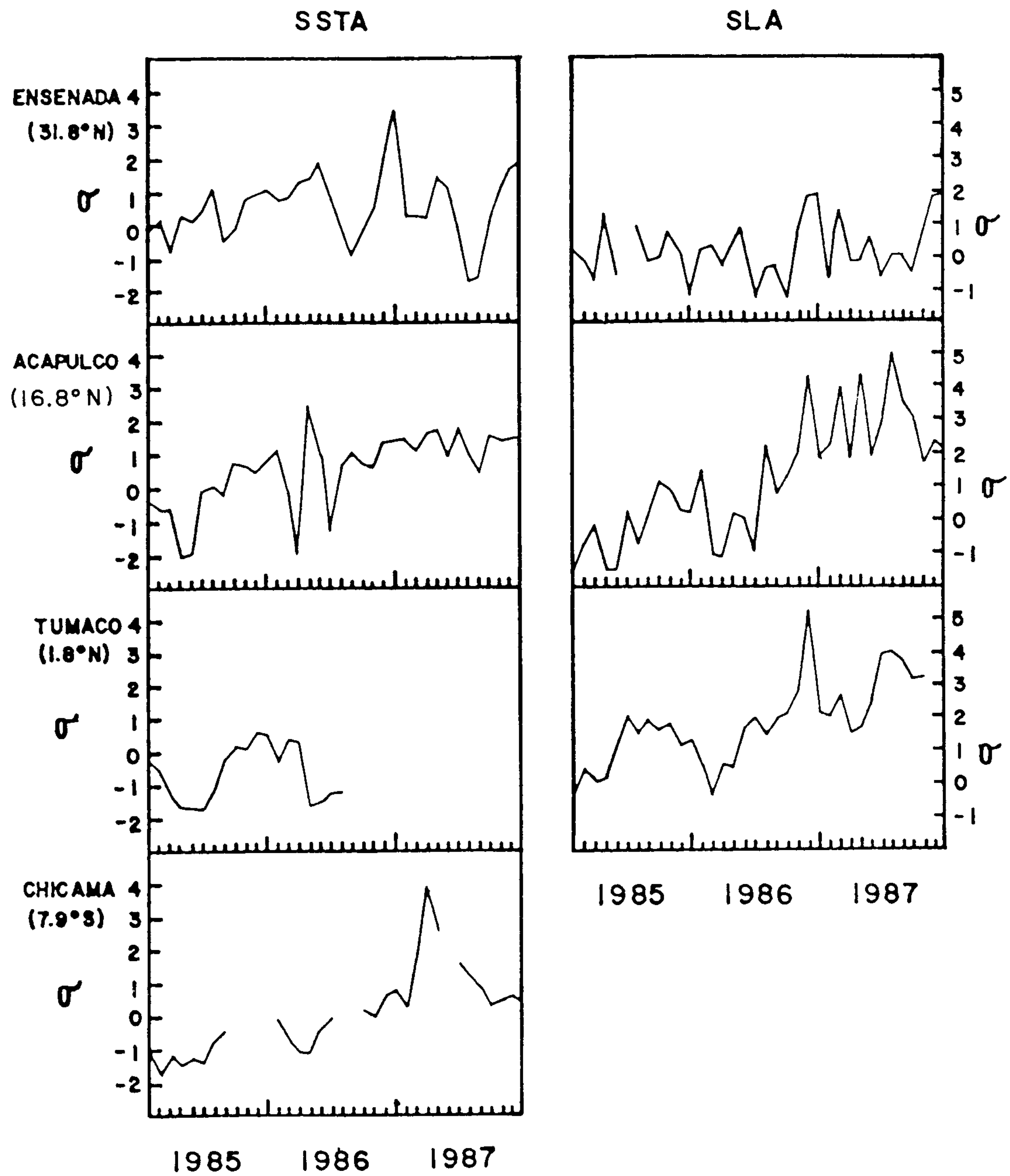

Fig. 7. Evolution of the ENSO 1986-87 along the west coast of the American Continent.

The year 1985, previous to the onset of the warm event shows that while sea level was normal or even below normal along the coast in the latitudinal segment between 32 N and about 2 N, surface temperature remained below normal from January to June-July. It seems that these cooling anomalies were present all over the eastern boundary of the Pacific Ocean since Chicama also exhibited negative SST anomalies from January to August 1985. During the second half of the year sea level and surface temperature show normal values or small positive anomalies.

The year 1986 was quite irregular. Sea surface temperature remained negative in Chicama from January to June. Tumaco showed near normal values of SST and sea level between January and March, but starting in April SST became negative and remained so until July which we have data. Sea level rose in May, reaching 2 STDU in June and stayed so until November, when it reached more than 5 STDU. In Acapulco while January showed positive SSTA and SLA, February and March had negative anomalies for both SST and sea level and during April both SSTA and SLA reached 2.5 STDU remaining with positive small anomalies. In November sea level rose, it reached more than 4 STDU, one month later surface temperature rose to 1.5 STDU. This lag between sea level and surface temperature for Acapulco has been observed previously during other ENSO events (Galindo, 1987). At Ensenada June-August showed negative anomalies for both sea level and sea surface, and the rest of the year showed positive anomalies of SST but near normal values of sea level, however November and December had positive anomalies of both sea surface and sea level. From the above results we can say that the warm event of 1986-87 reached the west coast of Central America and Mexico during October 1986. From the SSTA anomalies at Chicama that we have at our disposal we conclude that the South American coasts were not affected until the beginning of the boreal spring, i.e., during March 1988. Hence the timing of the ENSO 1986-1987 event was out of phase by six months in South America relative to the northern portion of the American Continent. During the year 1987 positive anomalies of sea level and SST were observed the whole year long both at Tumaco and Acapulco. Sea level signals in Tumaco show the double peaked distribution characteristic of classical El Niño events (Rasmusson and Carpenter, 1982) but shifted six months: the first maximum in November instead of April-May and, a second maximun in July-August instead November-December. Acapulco shows a series of peaks during 1987 both for SLA and SSTA. Maxima are also present during November 1986 and August 1987 whereas the minimum minimorum occurs also during March 1987. Figs. 7 show that for the end of 1987 the signals still remained positive mainly at Tumaco and Acapulco.

The results described above are in agreement with the general weakening of the low-level easterlies which began during boreal spring and continued into the fall, together with an increasing of SSTA observed in the central and eastern equatorial Pacific (Kousky, 1988). The most striking aspect of our results is the fact that the signals associated with a canonical El Niño event appeared first along the west coast of the northern portion of the eastern boundary of the Pacific Ocean and not along the South American coast. The spreading of enhanced convection (negative outgoing longwave radiation anomalies) into the central equatorial Pacific observed mainly from September to November and the fact that all the indices used to monitor the Southern Oscillation showed for November that a warm episode was under way (Kousky and Leetmaa, 1988; Kousky, 1988) are consistent with our results.

Discussion

Under normal conditions the main currents that flow in the area of study have been previously described by Wyrtki (1966, 1967). During September the typical circulation pattern in the area is dominated by the North Equatorial Current fed from the south by water masses of the Equatorial Countercurrent through the Costa Rica Dome. The North Equatorial current also receives water supplied from the California Current which leaves the coast of Baja California at about 25 N (Wyrtki, 1965). These waters are of low salinity and low temperature. In the study area insolation is high, therefore heating and evaporation may contribute to producing salinities greater than 34.5 o/oo (Wyrtki, 1967). At this time of the year, average surface temperature is between 28.0 C to 28.5C (Sadler *et al.,* 1987).

The main results obtained in this transect show a warmer SST, about 30 C, and a deepening of the 15 C thermocline compared with Eastropac results obtained during non-El Niño conditions. The OML is also deeper than normal. On the other hand, relatively high salinities were observed near the coast, in particular between 75 to 100 m depth. All the above results suggest advection of subsurface warmer waters flowing northwards, perhaps due to a strengthening of the North Equatorial Countercurrent whose warmer tropical waters may reach the study area either through an enhancement or a northward displacement of the North Equatorial Current. The perturbed thermo-oxy-haline structure thus found is consistent with the positive anomalies of SST and MSL observed along the west coast of Mexico and Central America as it is shown in Figs. 7.

These results indicate besides the sea surface warming, a subsurface warming in onshore waters near the coast, which was probably as a result of advection by poleward transport of tropical water masses.

The delayed onset of the 1986-87 episode shows that the timing of ENSO events occurs also irregularly along the coast of Central America and Mexico where normally is observed a sharp rise of SST and sea level early in March-April (Galindo, 1987). But the most striking fact is that the phase lag is preserved between the appearance of positive anomalies along the west coast of Central America and Mexico with respect to South America, thus the 1982-83 event appeared in Central America as usual in March-April while at Puerto Chicama on the coast of Peru did not begin to rise sharply until September and October 1982 (Rasmusson and Wallace, 1983), i.e., six months later. The actual ENSO event shows also the same lag. Similar timing with respect to the climatological mean annual cycle was also observed in the 1940-41 event (Rasmusson and Wallace, 1983). The understanding of these lags may be seek in the shift of low level winds west of the data line from easterly to westerly, the corresponding east-west seesaw in sea-level pressure and the associated effects on the surface equatorial waters.

Conclusions

1. In September 1987 at 19 N, between 104 W and 108 W, a 480 km transect westwards from the coast of Manzanillo, Mexico (in the northeastern tropical Pacific region) was performed. The results indicate that the thermo-oxy-haline structure of the region was perturbed:

At the surface

Sea surface waters were relatively warm, average temperature in the first 5 m depth was 30 C. That means a positive anomaly of 1.5 C. Salinities increased steadly, with depth at about 150 km from the coast. The maximum values, 35.1 o/oo-35.2 o/oo were observed from 75 m to 100 m depth. Oxigen values were considered normal, between 4 to 5 ml/l.

From 20 m to 100 m depth

At depths below 20 m there was evidence of a subsurface warming. The largest temperature deviations related to Eastropac 1967 were at 75 m depth ($> 2\sigma$). The 15 C thermocline was found depressed at depths down to 100 m. At the same depths, salinity attained its largest values, between 35.1 o/oo to 35.2 o/oo. Near the coast the oxygen minimum concentration was 0.7 ml/l whereas 200 km seaward it was 0.4 ml/l. The Oxygen Minimum Layer (1.07 ml/l) was found near the coast depressed to 100 m depth. These results indicate advection of subsurface warmer waters northwards, perhaps due to the strengthening or northward displacement of the Equatorial Countercurrent.

2. The onset of the warm event 1986-1987 was between October and November 1986 at Tumaco (1.8 N) and Acapulco (16. 8 N). At Ensenada (31.9 N) the largest signals of SST and sea level did not appear until December 1986.

3. In spite that surface warming was observed in the Galapagos Islands in November 1986, the timing of ENSO 1986-1987 along the west coast of South America occurred five months later. The first observed signals of positive SST anomalies at Puerto Chicama were in April 1987.

4. The time evolution of ENSO 1986-1987 shows that the double-peaked distribution of the classical El Niño occurred six months later at Tumaco and less clearly in Acapulco: a first maximun of SST and sea level during November 1986, a minimum in March and a second maximum in July-August 1987.

5. Positive anomalies of SST and sea level remained in December 1987 along the west coast of Central America and Mexico, however there is a decaying trend toward normal

Acknowledgements

The authors wish to express their gratitude to Mr. G. Zenteno who has performed most of the computer calculations. To Mr. H. Cepeda for his assistance in data handling and Mr. Salvador Hernández for his support on board. Last but not least to Mr. J. I. Valencia from HIMAT, Colombia, institution that provided the Tumaco time series of data.

REFERENCES

Arkin Ph. A. and J. E. Janowiak, 1987. The global climate for December 1985-February 1986: Conflicting ENSO signals observed in the equatorial Pacific. *Mon. Wea. Rev..*, **115**, 297-316.

Armada Argentina, 1972. Manual de instrucciones para la obtención de datos oceanográficos H-601, Serv. de Hidrografía Naval. República Argentina.

Barnston, A. G., 1987. The global climate for March-May 1986: Continued uncertainty about the possible onset of an ENSO episode. *Mon. Wea. Rev.*, **115**, 317-335.

Bjerknes, J., 1969. Atmospheric teleconnections from the equatorial Pacific. *Mon. Wea. Rev.*, **97**, 163-172.

Galindo, I., 1987. El Niño/Oscilación Suriana en las costas del Pacífico mexicano. Mem. IIa. Reunión indicativa Act. Regionales Rel. con la Oceanogr., Com. Intersec. Inv. Oceanog. (in press).

Gallegos, G. A., G. de la Lanza, F. Ramos and M. Guzmán, 1984. The 1982-83 warm episode in the offshore waters of Guerrero, Mexico (northeastern tropical Pacific Ocean), *Rev. Geofis.*, **21**, 43-55.

Kousky, V. E., 1988. Evolution of the 1986-87 Pacific warm episode. *WCP Newsletter*, **10**, 10-11, World Climate Programme, WMO.

Kousky, V. E. and A. Leetmaa, 1988. The 1986-87 Pacific warm episode: Evolution of oceanic and atmospheric anomaly fields. Subm. to *J. Dyn. Climate.*

Love, C. M. (Ed.), 1975. Eastropac Atlas. Volume 9, Third survey cruise: September 1967. National Fisheries Service, Circular 330, Washington, D.C.

Philander, S. G. H., 1982. El Niño Southern Oscillation phenomena. *Nature*, **302**, 295-301.

Rasmusson, E. M. and T. H. Carpenter, 1982. Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño *Mon. Wea. Rev.* , **110**, 354-383.

Rasmusson, E. M. and J. M. Wallace, 1983. Meteorological aspects of the El Niño/Southern Oscillation. *Science,* **222**, 1195-1202.

Sadler, J. D., M. A. Lander, A. M. Hori and L. K. Oda, 1987. Tropical marine climatic atlas, volume II. Pacific Ocean, University of Hawaii, UHMET 87-02.

Schickedaz, P. T. and E. G. Bowen, 1977. The computation of climatological power spectra. *J. Appl. Meteorol.*, **16**, 359-367.

Strickland, J. D. H. and T. R. Parsons, 1968. A practical handbook of seawater analysis. Bull 167, Fisheries Res. Board of Canada. Ottawa, 311 pp.

U. S. Climate Analysis Center, 1986a. Climate diagnostics bulletin. July, 1986. National Weather Service, Washington, D.C.

U. S. Climate Analyisis Center, 1986b. Climate diagnostics bulletin. August, 1986. National Weather Service, Washington, D. C.

Wyrtki, K., 1962. The oxygen minima in relation to oceanic circulation. *Deep-Sea Res.*, **9**, 11-23.

Wyrtki, K., 1965. The annual and semiannual variation of sea surface temperature in the North Pacific Ocean. *Limnol. and Oceanog.*, **3**, 307-313

Wyrtki, K., 1965. Surface currents of the eastern tropical Pacific Ocean. *Bull. Inter-American Tuna Comm.*, **IX**, **5**, 271-303.

Wyrtki, K., 1966. Oceanography of the eastern equatorial Pacific Ocean. *Mar. Biol. Ann. Rev.,* **4**, 33-68.

Wyrtki, K., 1967. Circulation and water masses in the eastern equatorial Pacific Ocean. *Int. J. Oceanol. Limnol.,* **1**, 117-147.

Wyrtki, K., 1984. Monthly maps of sea level in the Pacific during the El Niño of 1982 and 1983 in Time Series of Ocean Measuremments, Vol. II, I. O. C. Tech Ser., UNESCO, Paris.

Wyrtki, K. and W. G. Leslie, 1980. The mean annual variation of sea level in the Pacific Ocean. Hawaii Inst. of Geophys., University of Hawaii, 159 pp.