Effects of ENSO off the southwest coast of Mexico, 1996-1999

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RESUMEN

Este artículo presenta los efectos del ENOS 1997-1998 frente a la costa sur-occidental de México. La influencia de ENOS se observó comparando las anomalías de la temperatura superficial del mar (TSM) de un año a otro de 1996 a 1999 dentro de un periodo de 4 años. Las observaciones satelitales muestran un incremento en la temperatura superficial del mar de 3° a 5° C, así como la inhibición de eventos de surgencia frente a Cabo Corrientes.

PALABRAS CLAVE: ENOS, Pacífico mexicano, temperatura superficial del mar.

ABSTRACT

The effects of ENSO 1997-1998 off the southwest coast of Mexico are evaluated, by comparing sea surface temperature (SST) anomalies from satellite observation over a 4-year period, from 1996 to 1999. We find an increment of sea surface temperatures of 3° to 5° C during ENSO, and an inhibition of the upwelling event off Cabo Corrientes.

KEY WORDS: ENSO, Mexican Pacific waters, sea surface temperatures.

INTRODUCTION

El Niño-Southern Oscillation (ENSO) is associated with the weakening of the tropical trade winds, especially the southeastern trades over the eastern side of the South Pacific anticyclonic gyre. Strong winds induce upwelling of cold, rich and highly productive waters along the South American tropical coasts and over the equatorial band of the Eastern Pacific. Weakening of the trade winds reduces upwelling and raises the ocean temperature by approximately 5°C. The southward motion of warm equatorial waters, and high solar radiation at the surface, produce the temperature increase. The resulting lack of nutrients at the base of the food chain initiates a cycle of biological devastation. Simultaneously, a warm countercurrent appears off the South American coasts, which was christened El Niño by Peruvian fishermen, because it appears by the end of December. Finally the warm waters flowing eastward from Indonesia join with the warm waters of the Eastern Pacific, creating a belt of warm water that may cover one third of the distance around the earth.

The ENSO phenomenon is a natural oscillation of the atmosphere-ocean system. It is a coupled interaction between the atmosphere and the upper layers of the tropical Pacific Ocean. El Niño is the ocean component of the interaction (Wells *et al.*, 1999).

In the Eastern Pacific, ENSO induces decay in primary biological productivity from Peru to California (Barber and Chávez, 1983). Some of the changes observed during an ENSO episode include unusually high ocean surface temperatures, coastal currents directed toward the poles, heavy rains, tropical organism invasion, and massive mortality of local marine forms of life. Mexico is located in the Inter Tropical Convergence Zone (ITCZ), which migrates northward during ENSO events, covering practically the entire Tropical Mexican Pacific.

The effects of ENSO tend to weaken markedly in the Gulf of California (GC), which normally presents a large primary productivity. Cortés and Núñez (1992) found that red tide occurrence off the Mazatlán coasts is inhibited during ENSO events. Similarly, sea level shows the presence of positive anomalies of the mean sea level along the Mexican Pacific coasts during such events (Robles and Christensen, 1983).

Studies based on satellite imagery show a high pigment concentration associated with low temperatures at the GC (Álvarez and Lara, 1991), while for warm waters the opposite has been observed. Santamaría del Angel *et al.* (1994) described an interannual variability in the Gulf of California through a time series generated with CZCS imagery. They found that the ENSO phenomenon caused lower pigment concentrations at and near the entrance of the gulf, where vertical mixing is weak. For locations in the central and northern part of the gulf they found either a weak effect of ENSO or no effect at all.

Studies about the effects of ENSO are more scant as one moves south of Mazatlán, along the Mexican Pacific coast. However, a number of papers related to ENSO phenomenon have recently been published, in an effort to understand the effects of this event on the Mexican Pacific region (e.g. Trasviña *et al.*, 1999; Zamudio *et al.*, 2001).

Herein we describe sea surface temperature observations during a 4-year period. In order to accomplish this aim we use the Advanced Very High Resolution Radiometer (AVHRR) database assembled as part of CONACyT project 076-PÑ. This satellite database contains at present over 4000 AVHRR images.

Study area

The area of study is located off the southwest coast of Mexico (Tropical Pacific Ocean), between 16° to 23°N and from 101° to 112°W, which includes the coasts of states of Sinaloa, Nayarit, Jalisco, Colima, Michoacán and part of Guerrero. The main oceanographic characteristics of the zone are described next.

Two main surface currents meet off the Mexican west coast (12°N-32°N): the California Current (CC) and the North Equatorial Counter Current (NECC). The California Current is wide (up to 800 km), deep (about 500 m), slow (typical velocities of 20 cm/s), and shows persistent motion from north to south, parallel to the western coast of Canada and the United States. Off Mexico, the California Current is characterised by cold water of low salinity (34.5 psu), flowing southwards along the west coast of Baja California peninsula.

The Equatorial Current is a system formed by currents and counter-currents, parallel to the terrestrial equator (Charnock, 1996). From these, only the NECC influences the Mexican southwestern coast (Fernández *et al.*, 1993). This current is characterised by temperate waters of intermediate salinity (34.6 - 34.85 psu). It shows up as a surface poleward flow from 5° to 23°N from middle spring to early winter, and plays an important role transporting subtropical subsurface waters to northern latitudes (Badán *et al.*, 1989).

The zone where the NECC and the CC meet is known as the transition zone and its geographical position is variable (Gallegos *et al.*, 1988). It depends on the relative intensity of these currents and on the prevailing surface winds during the previous six or eight months, mainly in the northern region. In wintertime, when the California Current is most intense, the transition zone is located further south, whilst in summertime, when the counter-current is stronger, the transition zone moves northward. This variation occurs yearly and the transition reaches its extreme positions at the end of these seasons.

In summary, the surface circulation in the Mexican Tropical Pacific region is basically dominated by two major currents and by the meridional displacement of the transition between the two. From the oceanographic viewpoint, there is no evidence in this region of any zonal displacement with enough intensity and persistency, allowing it to be considered as surface current. The northern part of our study area, a triangular area comprised by Cabo San Lucas, Mazatlan and Cabo Corrientes, is a highly dynamic zone which in addition to the confluence of the CC and NECC also has that of the Gulf of California, which provides warm and saline (> 34.9 psu) waters, flowing southwards through the gulf (Griffiths, 1968). The region has a complex thermohaline structure of eddies, fronts and intrusions originated by the confluence of these currents (Alvarez and Lara, 1991).

Methodology

In order to assess the effect of ENSO 1997-1998 on the Southern Mexican Pacific, SST anomaly maps, derived from AVHRR images, prior, during, and after the event were compared. The month of November was chosen as representative in this study because it is a transitional month between dry and rainy seasons and effects of ENSO can easily be appreciated. Selected years are: 1996, considered as a normal year; 1997, ENSO year; 1998, onset of La Niña year; and 1999, a normal year.

Satellite observations

Monthly SST composite maps corresponding to November 1996, 1997, 1998 and 1999 were initially produced. These maps were obtained by simply averaging daily SST images acquired around 20 hrs GMT (14 hrs local time). SST maps were generated following McClain's *et al.* (1985) algorithm for NOAA-AVHRR daytime images and processed with TERASCAN system (Seaspace Corporation). Thermal anomaly maps were generated by two methods:

a) Composites were subtracted from a climatological SST mean of 25°C ($I\mu_1$), which was estimated from data gathered over a 60-year period, from 1920 to 1980 (Secretaría de Marina, 1984). This mean value is characterised by the 25°C isotherm located at around 20°N, traditionally used to identify the northern boundary of surface tropical water masses of the Tropical Mexican Pacific (Trasviña *et al.*, 1999).

b) SST maps of non-ENSO years (1996, 1999 and 2000) were averaged to create a "mean" SST image ($I\mu_2$) which was then subtracted from original SST images corresponding to dates under our consideration. The SST map for the year 2000 was included in order to have more elements in the average of non-ENSO years.

To evaluate thermal differences in a more quantitative way, a transept was chosen to extend over most of the area under investigation, from the tip of Baja California, across sites near San Blas, Cabo Corrientes, Manzanillo, and Lázaro Cărdenas. This transept appears, as a reference, in Figures 1, 2, 3, and 4. SST variations along the transept are depicted in Figures 5 and 6. Histograms corresponding to each of the SST maps were also obtained for visualising the trend of anomalies. Histograms represent a frequency density of calculated values (Figures 7 and 8).

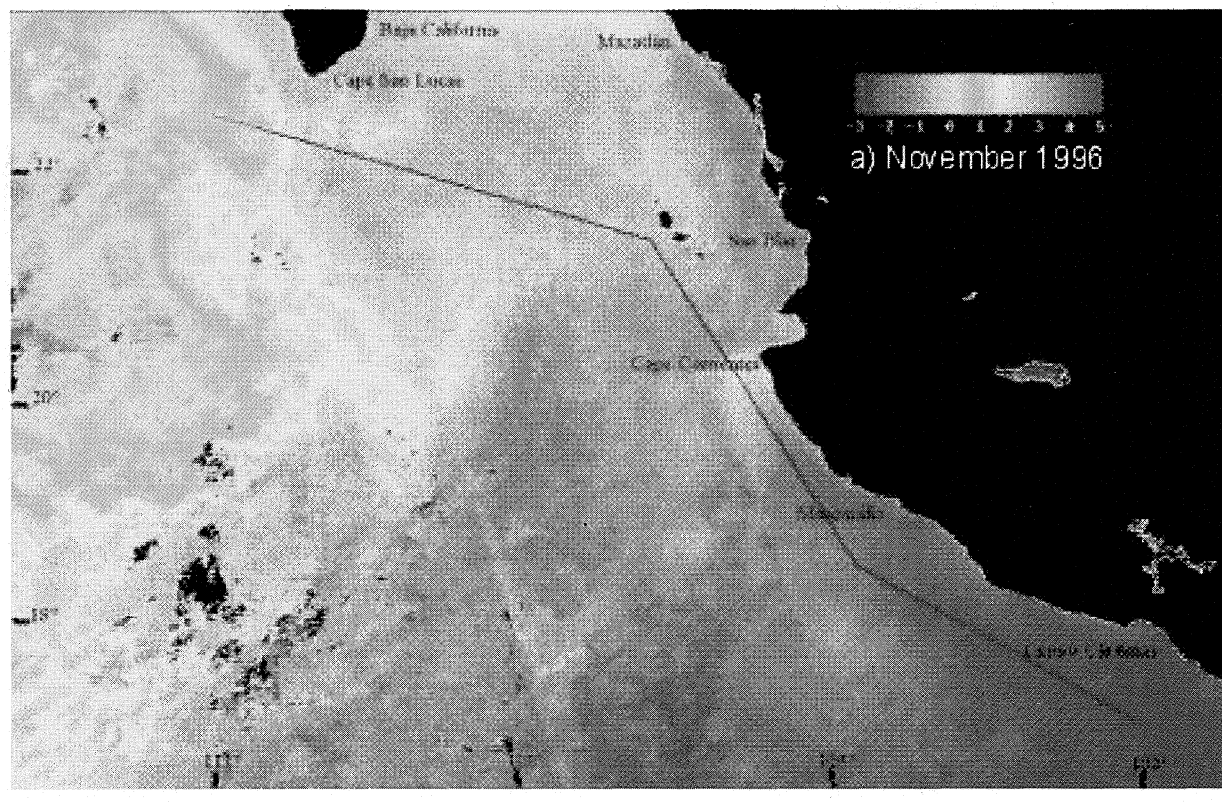

Fig. 1a. SST anomalies map of the Southwest Coast of Mexico for November 1996 and its corresponding transept (blue line). Method 1 ($I\mu_1$).

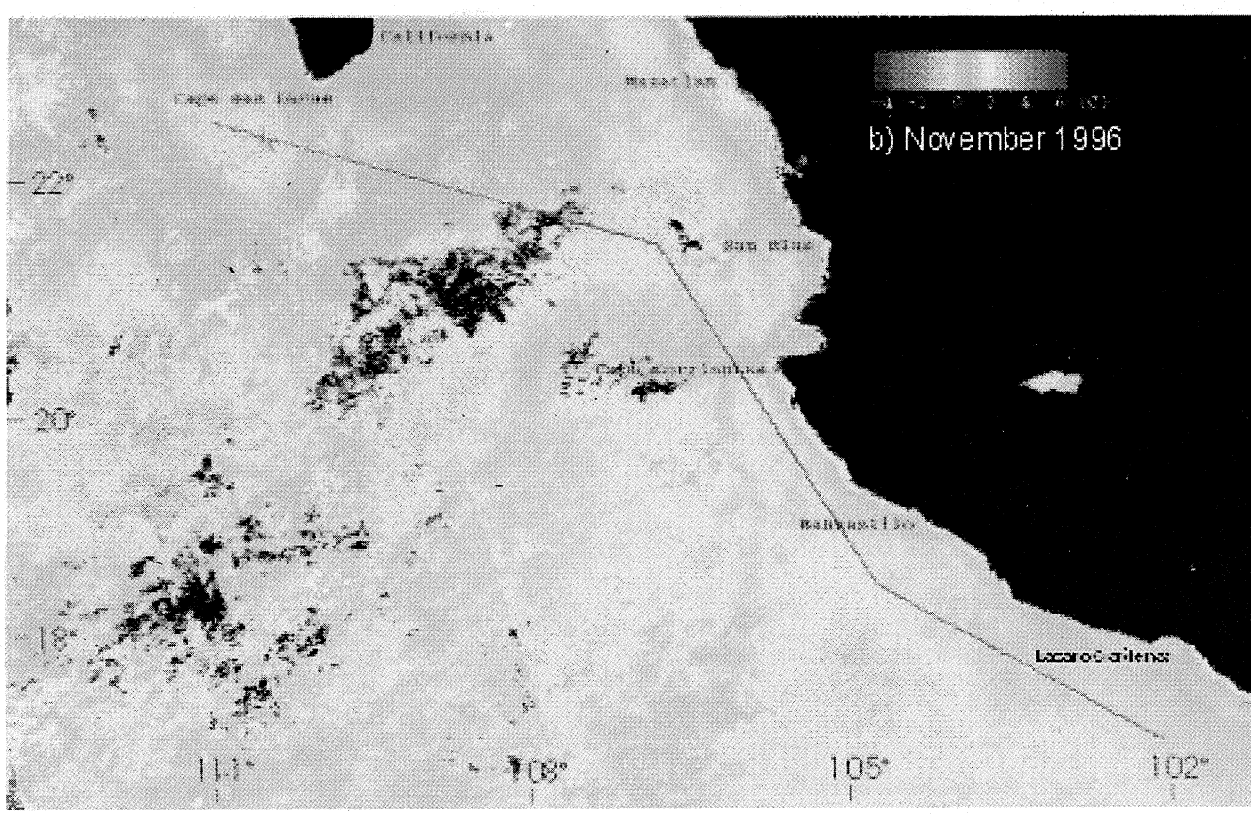

Fig. 1b. SST anomalies map of the Southwest Coast of Mexico for November 1996 and its corresponding transept (blue line). Method 2 ($I\mu_2$).

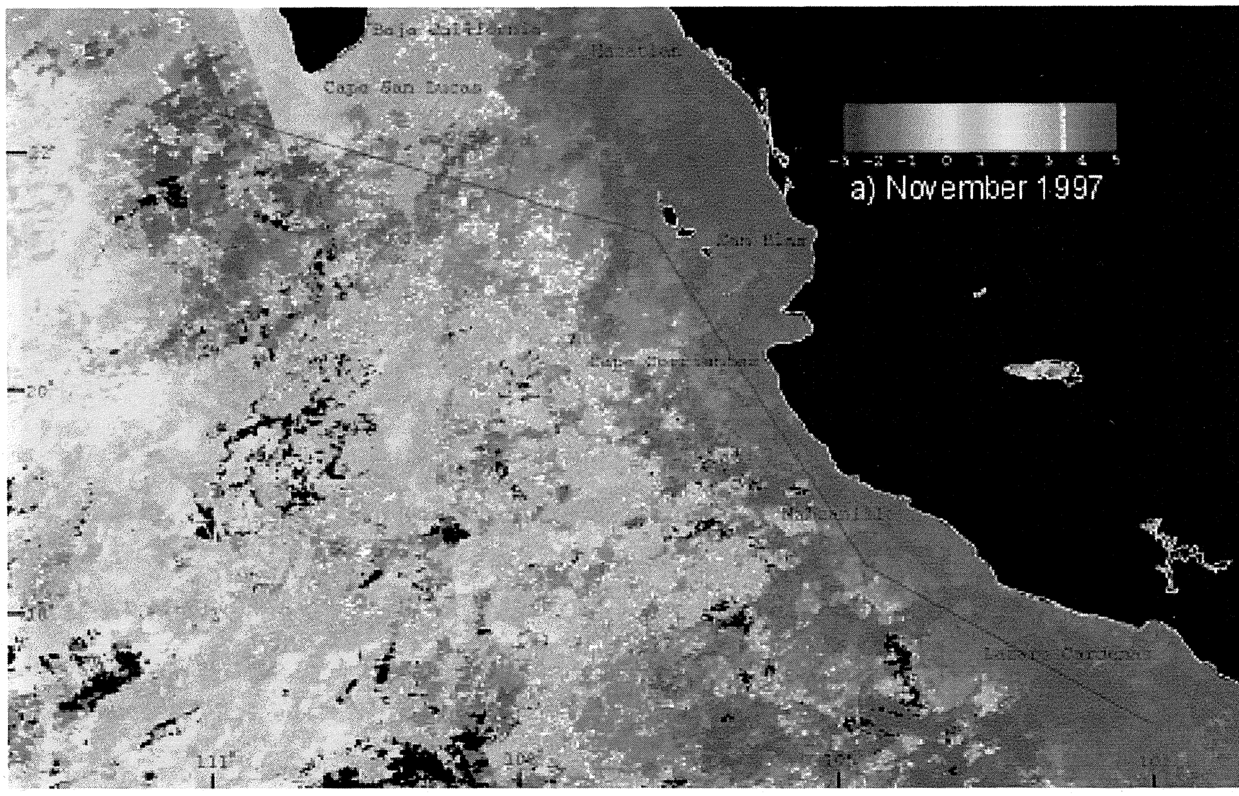

Fig. 2a. SST anomalies map of the Southwest Coast of Mexico for November 1997, and its corresponding transept (blue line). Method 1 ($I\mu_1$).

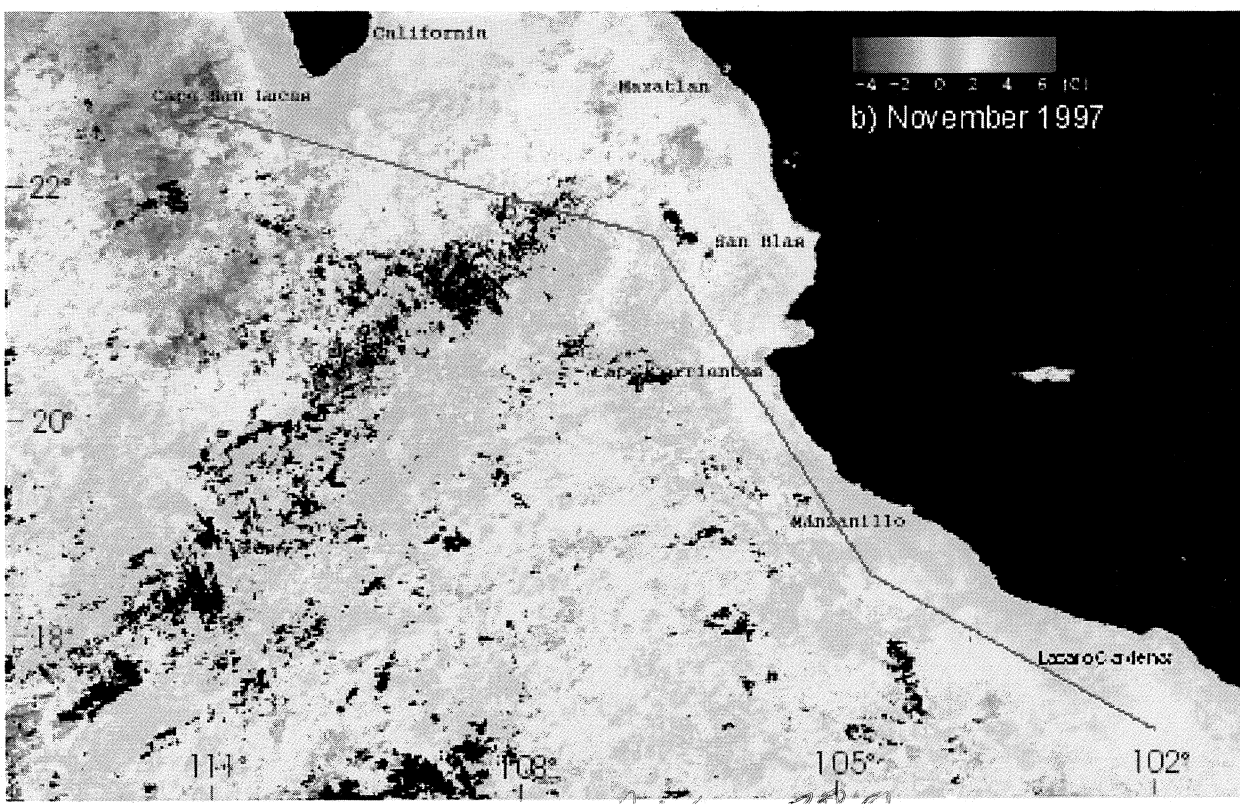

Fig. 2b. SST anomalies map of the Southwest Coast of Mexico for November 1997 and its corresponding transept (blue line). Method 2 ($I\mu_2$).

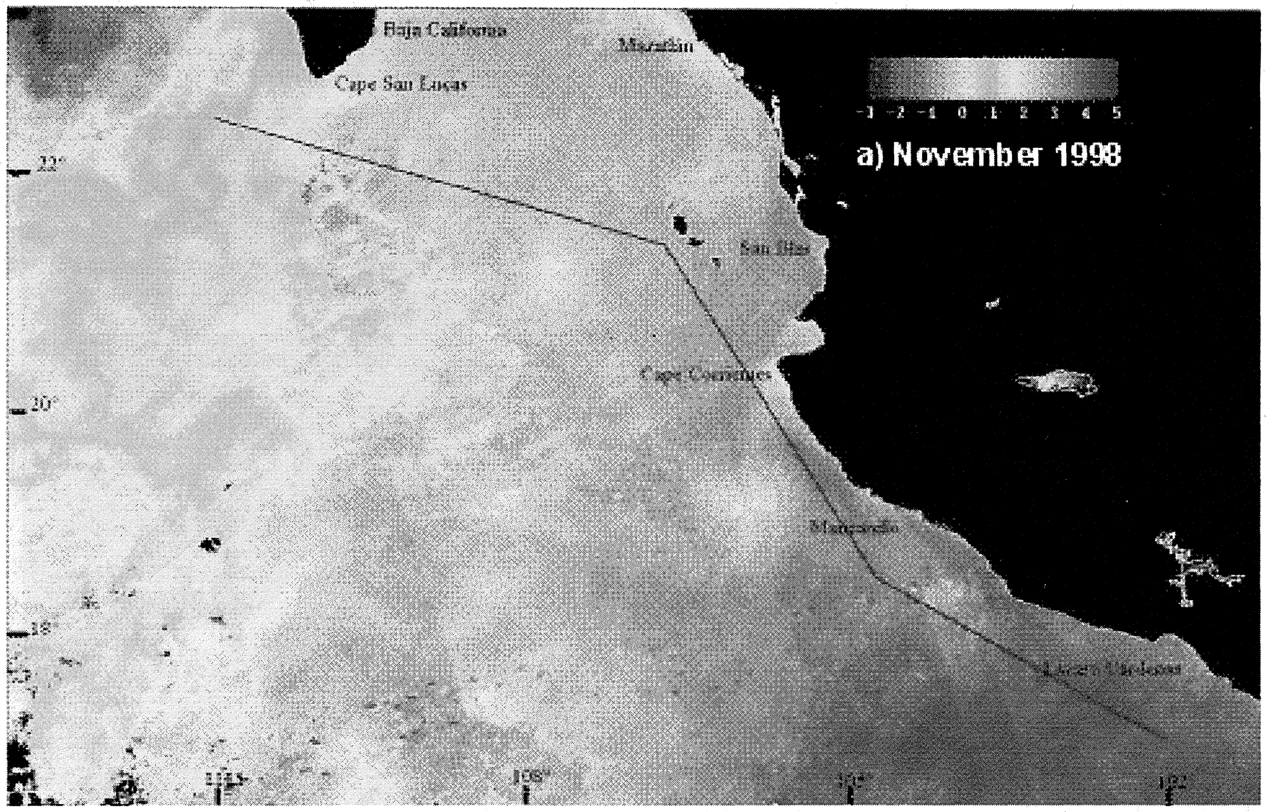

Fig. 3a. SST anomalies map of the Southwest Coast of Mexico for November 1998 and its corresponding transept (blue line). Method 1 ($I\mu_1$).

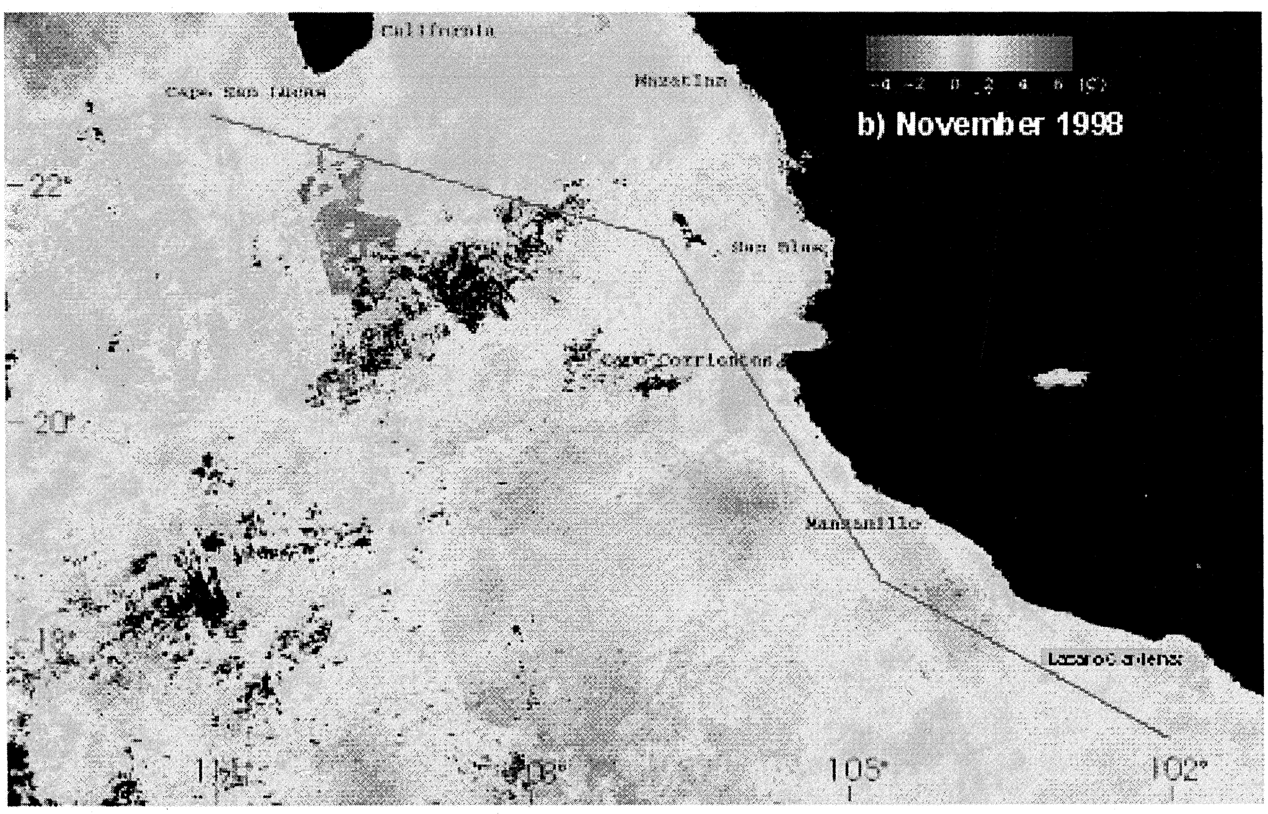

Fig. 3b. SST anomalies map of the Southwest Coast of Mexico for November 1998 and its corresponding transept (blue line). Method 2 ($I\mu_2$).

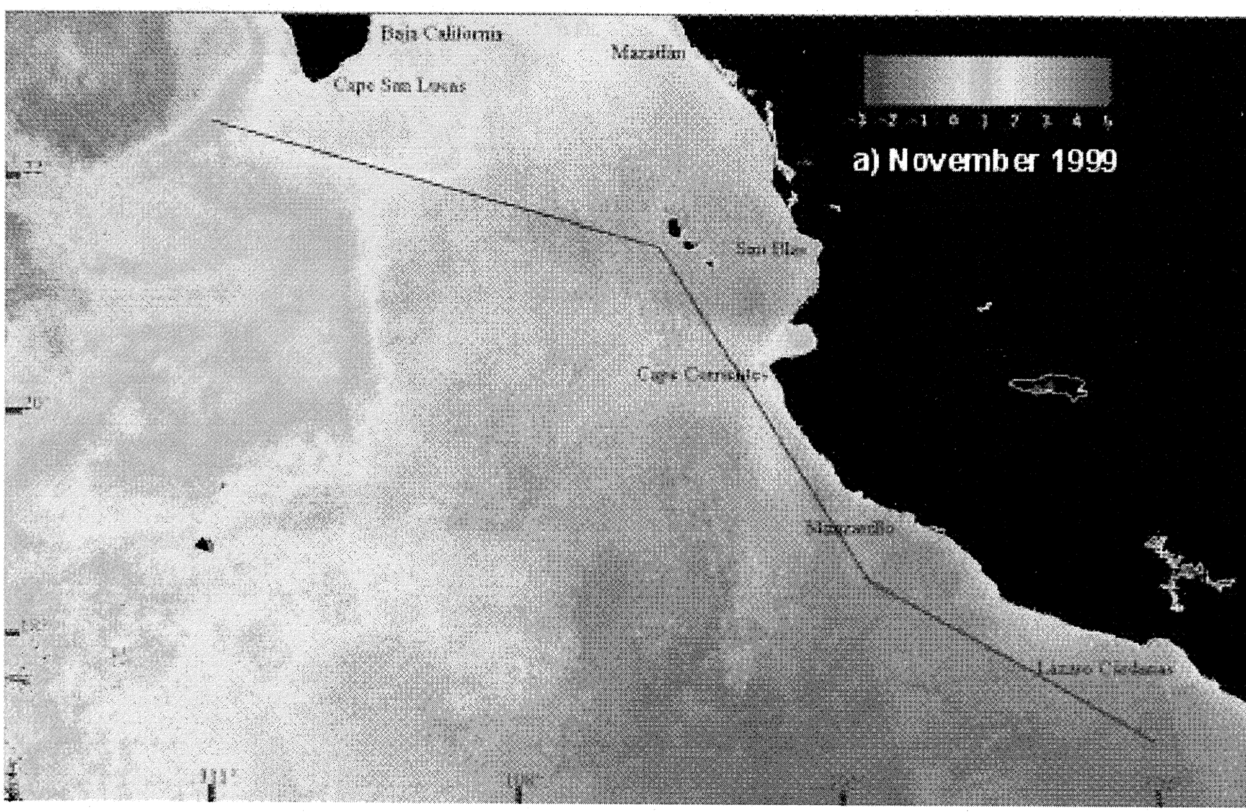

Fig. 4a. SST anomalies map of the Southwest Coast of Mexico for November 1999 and its corresponding transept (blue line). Method 1 ($I\mu_1$).

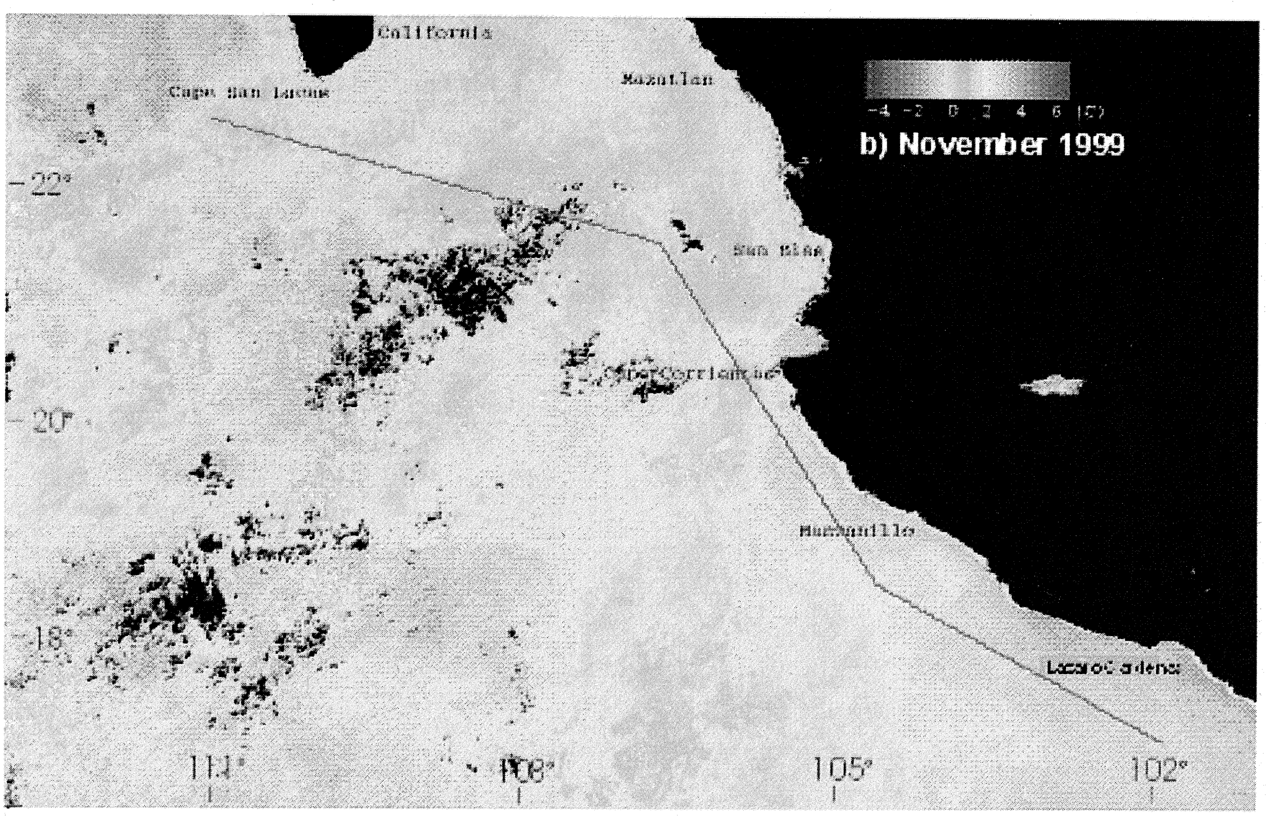

Fig. 4b. SST anomalies map of the Southwest Coast of Mexico for November 1999 and its corresponding transept (blue line). Method 2 ($I\mu_2$).

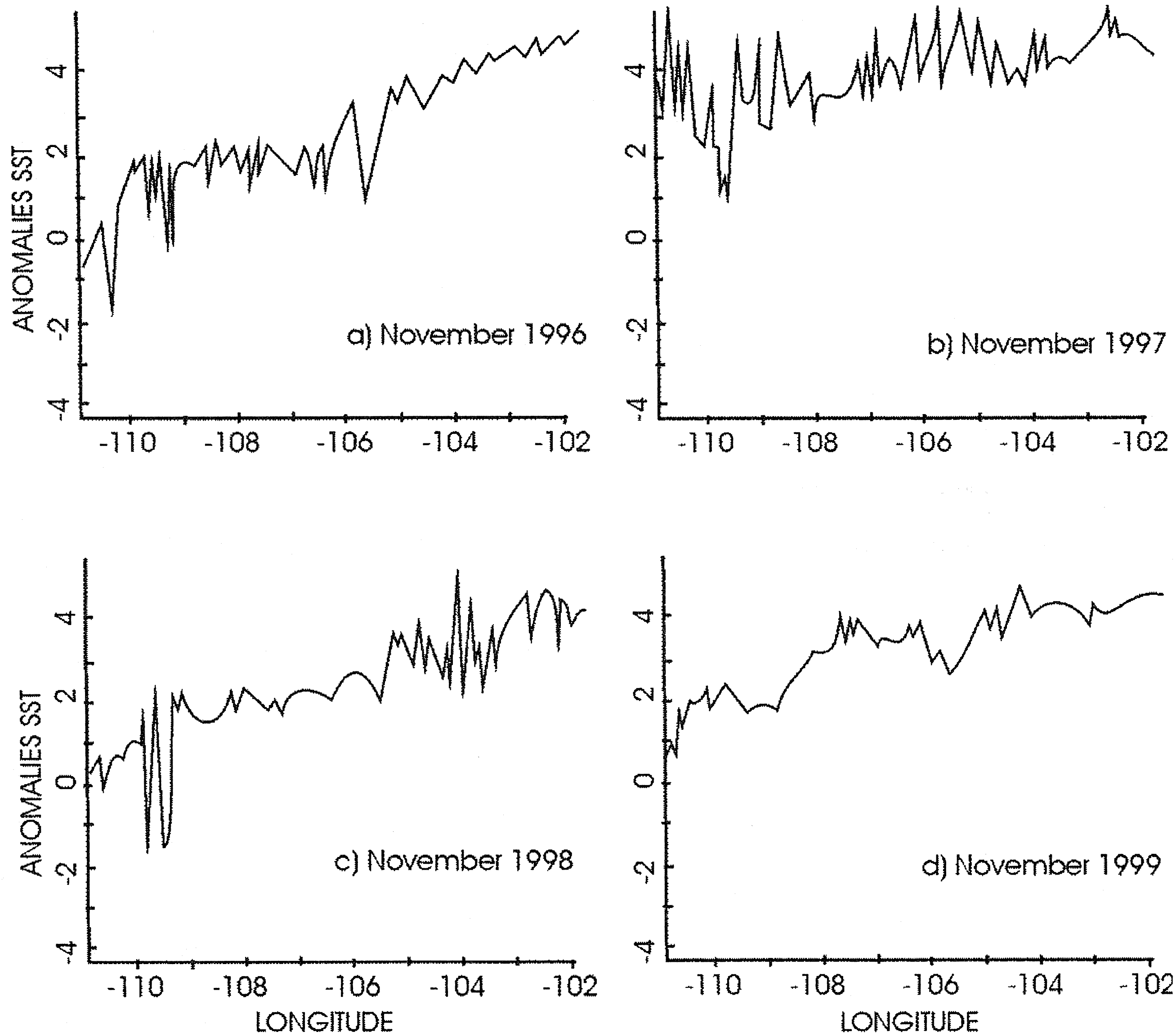

Fig. 5. SST transept profiles corresponding to: a) November 1996; b) November 1997; c) November 1998 and d) November 1999. Method 1 ($I\mu_1$).

Four-year SST comparisons

In this section we present the results observed in SST anomaly maps for each period using the two approaches established in the methodology. The first approach is examined in paragraphs (a), whilst the second one is assessed in sections marked with (b).

I. November 1996

a) Figure 1a shows a composite of SST anomalies for this date estimated by subtracting $I\mu_1$ from the SST values obtained through satellite imagery. Negative anomalies (blue colours) are apparent associated to the California Current on the western side of Baja California peninsula. The Gulf of California Current (GCC), with positive anomalies, is also evident on the eastern part of the peninsula (yellow-orange tones). Higher positive anomalies can be identified as warmer waters coming from the NECC. They are evident off the southwestern Mexican coast (dark orange tones). The contrast of relative colder waters at Cabo Corrientes is noteworthy and also clear in the profile of SST anomalies in the transect corresponding to November 1996 (Figure 5a). The transept profile shows the presence of colder waters located at around 110°W, which correspond to the CC; it also shows a sharp pool of cooler water at about 106°W near Cabo Corrientes area, and finally, it presents higher SST positive anomalies corresponding to NECC, between western latitudes 105° and 102°. The histogram for this composite (Figure 7a) shows the dominance of positive SST anomalies between 2°C and 4°C, with frequencies up to 0.06 relative units. It also shows a smaller contribution of negative or zero SST anomalies, with a maximum of 0.02 units of relative frequency at around 0°C.

b) Figure 1b illustrates the SST anomalies map generated by subtracting $I\mu_2$ from the original SST images. A rather homogeneous distribution of temperatures with slightly higher anomalies at Mazatlán and Cabo Corrientes can be seen. SST anomalies vary from positive values of up to 2°C off southern Cabo San Lucas and Cabo Corrientes (yellow tones). Positive anomalies of about 1°C are observable near Manzanillo and Lázaro Cárdenas (green tones). Negative anomalies are randomly distributed off Mexican coasts. Figure 6a shows the SST profile along the transept. This profile is quite illustrative of the homogeneity observed in the corresponding image; values fluctuate around 0°C, with slightly positive anomalies between western longitudes 110° and 108°. The Cabo Corrientes upwelling area (≈106°W) is seen as an inflection point in the profile separating two different thermal zones. The histogram of the image (see Figure 8a) shows a bi-modal distribution of SST anomalies with a dominance of positive anomalies up to 2°C. The first mode of the distribution is centred at around 0°C with a relative frequency of about 0.12. The second mode is located a little before 1°C with a relative frequency of nearly 0.15.

II. November 1997

a) At this time of the year the ENSO event was almost fully developed. The SST anomaly map for November 1997 is shown in Figure 2a. Warmer conditions than those of the previous year are apparent, with positive

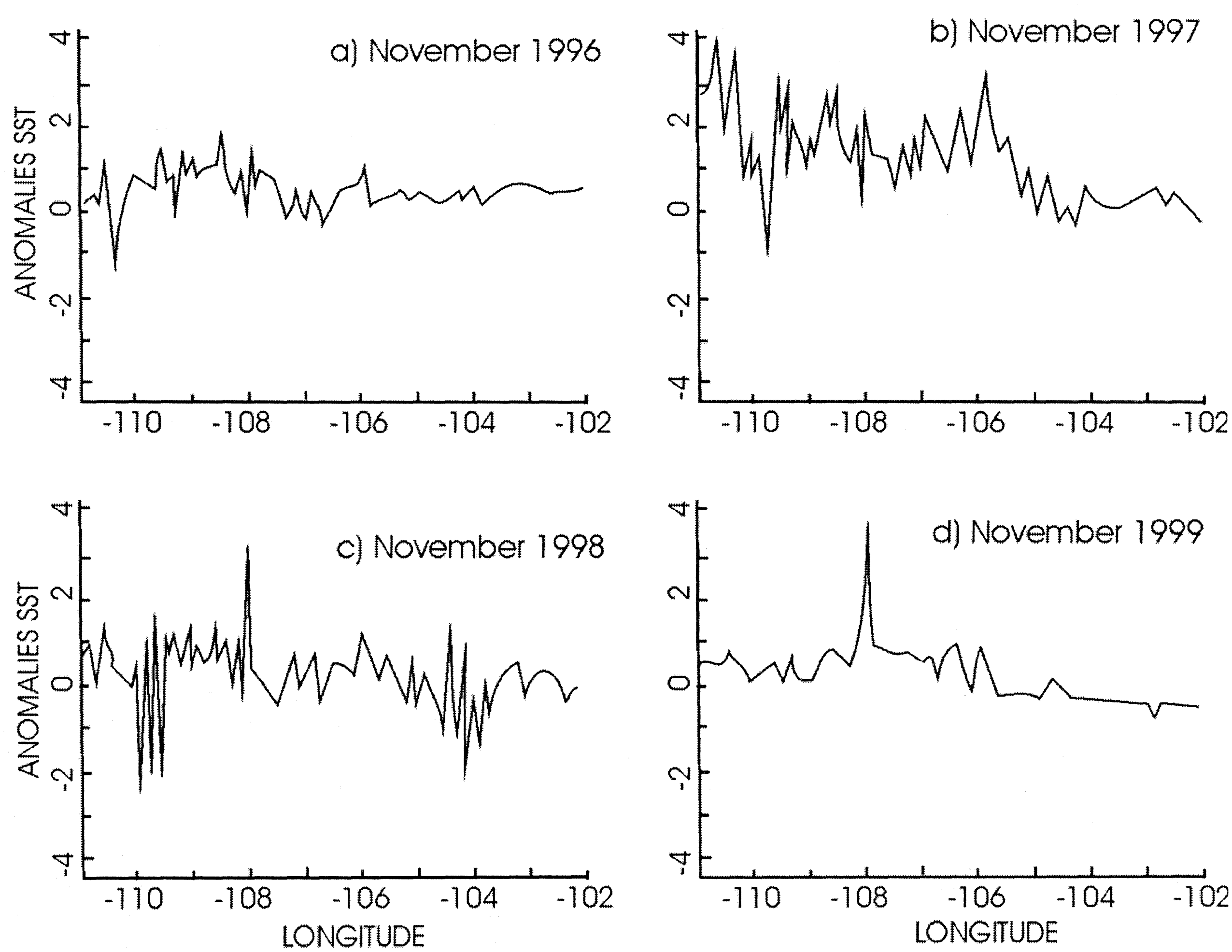

Fig. 6. SST transept profiles corresponding to: a) November 1996; b) November 1997; c) November 1998 and d) November 1999. Method 2 ($I\mu_2$).

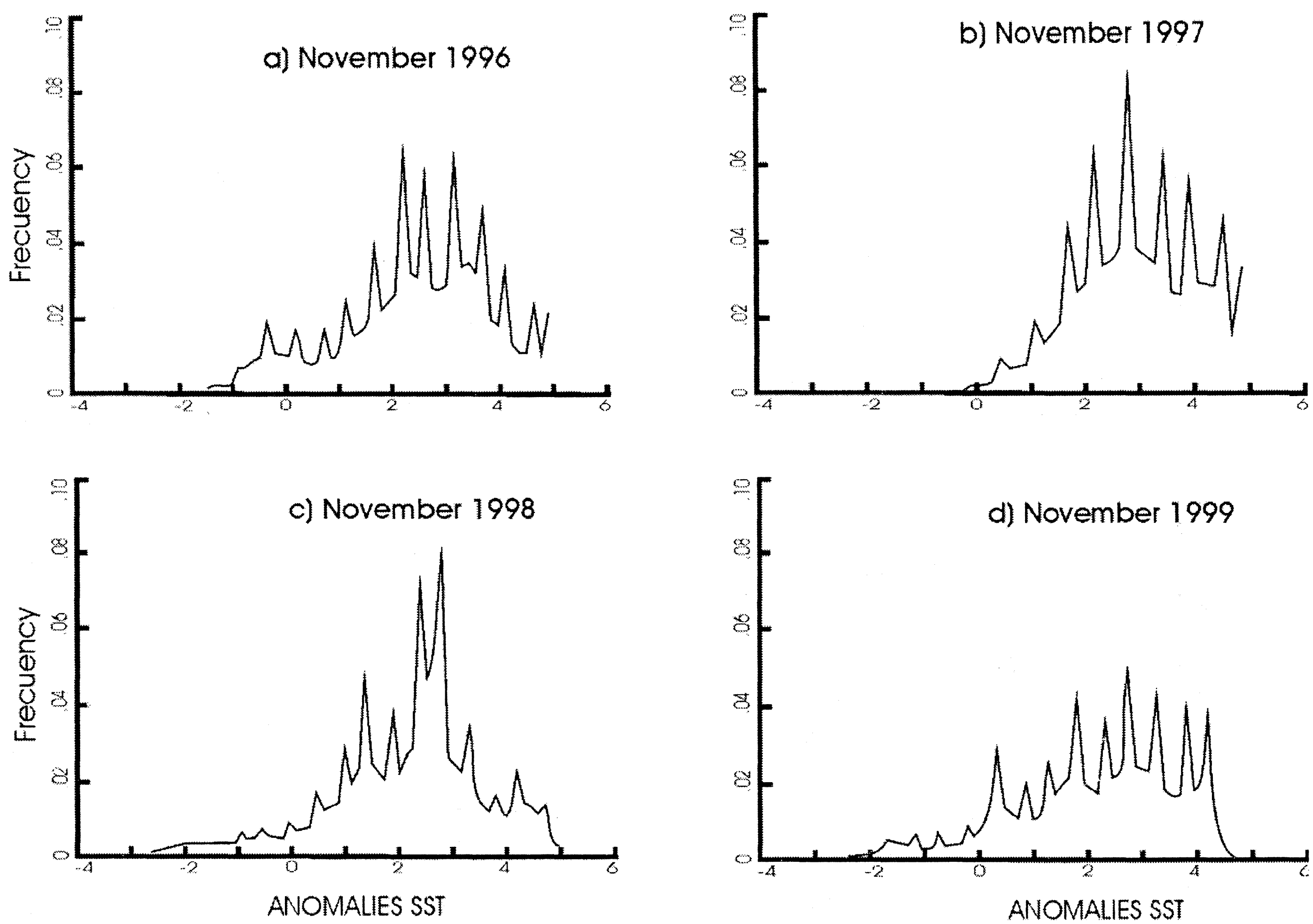

Fig. 7. Histograms of SST anomalies corresponding to: a) November 1996; b) November 1997; c) November 1998 and d) November 1999. Method 1 ($I\mu_1$).

SST anomalies in the entire region and no clear difference between the GCC and NECC. Comparatively, the CC shows a somewhat smaller positive SST anomaly. A nearly constant anomalous trend of about 4°C is evident everywhere (Figure 5b) except for a zone close to Cabo San Lucas (around 109°W), which shows relative colder waters. It must be noted that colder waters are not present at Cabo Corrientes. This fact can be mainly attributed to the ENSO phenomenon.

The dominance of high positive SST anomalies is more evident in the corresponding histogram (see Figure 7b). It shows both the absence of negative SST anomalies and higher frequency, near 0.1, of the positive ones, between 2° and 4°C.

b) By analysing SST anomalies with the second method important changes are observed. Figure 2b shows SST anomalies distributed both in the north and the south. The northern area presents the highest positive SST anomalies up to 6°C off Cabo San Lucas, although the coastal zone shows lower values close to 1°C. Higher SST anomalies with values around 3°C are seen also near Mazatlán, San Blas and Cabo Corrientes areas (yellow-orange tones). The southern region has lower SST anomalies, including negative values. South of the 20°N line, near Cabo Corrientes, lower SST anomalies of about 1°C dominate the region. This is clear off Manzanillo and Lázaro Cárdenas. The corresponding transept profile best illustrates (Figure 6b) the presence of the two zones just described. Higher SST anomalies area is located between 110°W and 106°W, with one local minimum at 110°W (southern Cabo San Lucas) and local maxima off Baja California and near the 106°W (Cabo Corrientes). Farther south SST anomalies are smaller. The histogram of the corresponding image shows a skewed distribution (see Figure 8b), with two larger modes. The first modal peak is located at around 0°C and corresponds to the southern region described above. The second modal peak is centred at around 1°C and stands for the northern region. It is important to observe that the distribution of SST anomalies is wider in this

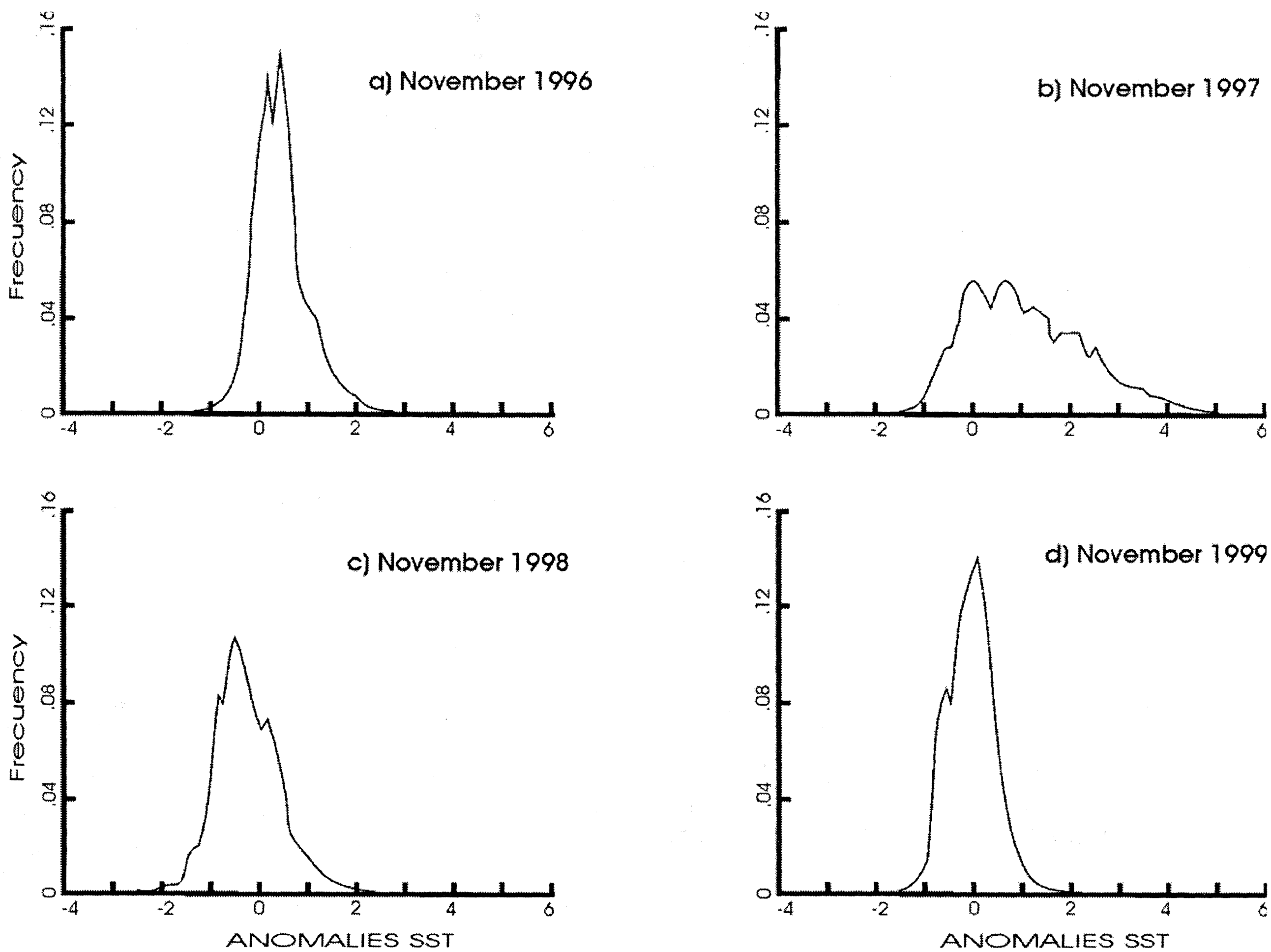

Fig. 8. Histograms of SST anomalies corresponding to: a) November 1996; b) November 1997; c) November 1998 and d) November 1999. Method 2 ($I\mu_2$).

period than in the others and the relative frequency values are lower (≈ 0.04).

III. November 1998

a) This period is characterised by the onset of La Niña. Negative SST anomalies associated to CC (Figure 3a) extends south from Cabo San Lucas and GCC and NECC are also evident in this map. Higher SST anomalies are seen in the southern region of the NECC, whilst slightly lesser temperature differences are manifest in the region of influence of the Gulf of California.

The transept profile for this period (Figure 5c) shows colder waters coming from the CC and their extended influence near Cabo San Lucas area at around 110°W. Again in this profile the Cabo Corrientes upwelling zone (106°W) is apparent as a sharp trough of the anomaly. Higher positive SST anomalies reappear again farther south this region between 105°W and 102°W, caused by warmer waters of the NECC. The histogram of the area shows the presence of negative SST anomalies and a roughly bimodal positive SST anomalies distribution (Figure 7c). One mode is centred at about 1.5°C and the other at 2.7°C. The latter approaches a frequency of 0.08 relative units.

b) Figure 3b shows the SST anomalies map for November 1998 with a predominance of very small anomalies all over the map (green tones), although positive values (green and yellow tones) and negative ones (green and blue) are also present. The northern part of the transept covers regions mainly dominated by null anomalies (from Cabo San Lucas to Cabo Corrientes). The southern part of the transept presents negative SST anomalies off Manzanillo and Lázaro Cárdenas. The transept profile supports this description (Figure 6c). The most remarkable areas are located at 110°W off Cabo San Lucas and the zone located between Manzanillo and Lázaro Cárdenas at 104°W. The histogram of the map shows a gaussian-shaped profile with a mean value centred a little before 0°C (Figure 8c). Values are grouped between –2°C and 2°C, which indicates a nearly homogeneous distribution.

IV. November 1999

a) Negative SST anomalies are observable off the western side of Baja California peninsula (Figure 4a) and, hence, can be associated with the CC. NECC is apparent with higher positive SST anomalies. The area under the influence of the GCC has slightly smaller positive SST anomalies; especially near the region between Cabo San Lucas and San Blas.

The profile of the SST transept shows a number of interesting features (Figure 5d). Between western latitudes 110° and 108°, a mean SST anomaly of 2°C is clear, except for a trough centred at 109°W, south of Cabo San Lucas. There is a clear confluence of the two main currents with a mixture of relatively cold waters coming from the CC and warm waters from the Gulf of California. Beyond 108°W, higher positive anomalies are present as a result of the confluence of GCC and NECC with a mean SST anomaly of about 3°C. The upwelling of Cabo Corrientes causes a sharp depression around 106°W. The presence of the NECC is seen between 105°W and 102°W. The mean SST anomaly in this region is about 3.5°C. The histogram (Figure 7d) shows a larger presence of negative SST anomalies than in the previous cases. Positive SST anomalies show a tendency for an even distribution, although the predominance in the range of 2°C - 4°C is still found. The shape of the histogram and frequency values less than 0.05 units, suggest the idea of an even distribution of the anomalies.

b) Figure 4b illustrates the SST anomalies map for November 1999 created by subtracting $I\mu_2$. As in the previous case, SST anomalies distribution is rather homogenous, mostly dominated by green and blue tones, which stand for 0°C and -1°C anomalies. The transept covers two regions, separated by a SST anomaly gradient. The northern region has an anomaly close to 0°C (from Cabo San Lucas to Cabo Corrientes), whilst the southern region presents negative anomalies, from south Cabo Corrientes to Lázaro Cárdenas. The transept clearly shows the pattern just described (Figure 6d). Here, SST anomalies values fluctuate around 0°C, and there is a slight difference between the northern and southern regions. There is a remarkable peak located at 108°W, which can be attributed to a positive anomaly patch located just before San Blas. The histogram (Figure 8d) expands between –2°C and 2°C with a central peak located around 0°C with a relative frequency over 0.12. These values indicate the nearly homogenous distribution observed through the second method.

CONCLUSIONS

Satellite images can show the effect of ENSO on the SST distribution off southwestern Mexico. Transepts and histograms have proven to be supportive tools for assessing the effects of ENSO in the Mexican Tropical Pacific. A good analysis of SST anomalies from satellite images depends on the mean SST value considered. Here we used two different approaches and found important differences between the two methods.

The first method, considers 25°C as the mean value and has two main advantages: 1) The mean value was taken from SST data gathered over 60 years over the region and hence, can be considered as climatologically stable; 2) This value has been traditionally used as representative of the region at least up to 20°N. The main disadvantage is that it can either under or overestimated SST anomalies in some important regions (e. g. off Cabo San Lucas). With this method, satellite images show an SST increment in the entire region during ENSO year 1997-1998, as compared to previous and subsequent years. The inhibition of Cabo Corrientes' upwelling is a remarkable feature on ENSO year, due either to wind weakening or variations in the transition zone because of temperature increases.

The second method considered an "average" SST map. The main advantage is that it considers global average values, which allows the creation of a synoptic map, which cannot be accomplished for example by using oceanographic cruises. The main disadvantage is that it is necessary to employ a significant number of images in order to have a climatologically representative SST map. This option will be feasible in the long run.

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