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Impact of El Niño on precipitation in Mexico

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RESUMEN

La ocurrencia y características de El Niño/Oscilación del Sur (ENOS) han sido documentadas extensivamente. Es bien sabido que El Niño es capaz de modificar los patrones normales del clima alrededor del mundo. El Niño, y su contraparte La Niña, modifican también los patrones de precipitación en México. En general, durante inviernos El Niño (La Niña), la precipitación aumenta (disminuye) en el noroeste de México, mientras que disminuye (aumenta) en el Istmo de Tehuantepec. El desplazamiento hacia el sur de la corriente de chorro subtropical y el aumento en el número de Nortes sobre la parte sur del Golfo de México constituyen algunos de los mecanismos que modulan la variabilidad del clima invernal. Por otro lado, la señal El Niño en verano en México se refleja como déficit de precipitación. Existen varios mecanismos asociados con El Niño que resultan en anomalías negativas de precipitación sobre la mayor parte de México. Una subsidencia reforzada por causa de un desplazamiento hacia el sur de la Zona Inter Tropical de Convergencia (ZITC), alisios más intensos de lo normal, un menor número de ciclones tropicales en los Mares Intra Americanos y una reducción en la humedad relativa pueden resultar en severas sequías. Estos elementos se combinaron en el verano de 1997 para producir grandes pérdidas socioeconómicas relacionadas con El Niño. Por otra parte, durante años La Niña, las condiciones del clima en México regresan a la normal e incluso pueden resultar en una precipitación por encima de la media. Los actuales esquemas de predicción del clima parecen ser suficientemente buenos para proveer información climática útil para la planeación de ciertas actividades socioeconómicas.

PALABRAS CLAVE: Clima mexicano, El Niño, México, precipitación, Nortes y huracanes.

ABSTRACT

ENSO is capable of affecting normal climatic patterns around the world. El Niño, and its counterpart, La Niña, modify the normal precipitation patterns in Mexico. In general, during El Niño (La Niña) winters, precipitation increases (decreases) over northwestern Mexico, while it decreases (increases) in the region around the Isthmus of Tehuantepec. A southward shift in the position of the subtropical jet stream increases the number of *Northerners* over the southern part of the Gulf of Mexico. A summer El Niño causes a deficit in precipitation. Various mechanisms, associated with El Niño, result in negative precipitation anomalies over most of Mexico. Enhanced subsidence associated with a southward shift of the Inter Tropical Convergence Zone (ITZC), more intense trade winds, a decreased number of tropical cyclones over the Intra Americas Seas (IAS) and reduced relative humidity, may result in severe droughts. These elements produced major socioeconomic loses during the summer of 1997 that could be directly related to El Niño. During La Niña years, climate conditions return to normal or result in enhanced precipitation. Current seasonal prediction schemes appear to be skillful enough to provide useful information in the planning of certain socio-economic activities.

KEY WORDS: Mexican climate, El Niño, Mexico, precipitation, Northerns and hurricanes.

INTRODUCTION

Much of Mexico exhibits a monsoonal climate, with a rainy season during the summer months and a relatively dry season in winter. Fluctuations in precipitation or temperature are associated with cold fronts or *Northerners* during winter (Magaña and Vázquez, 2000), and hurricanes and easterly waves during summer (Amador and Magaña, 2000, Magaña, 1999). The best known planetary scale phenomenon that alters global climate is El Niño/Southern Oscillation (ENSO).

As the number of natural disasters increases, mostly in relation to hydro-meteorological extreme conditions, more people are affected (Figure 1). The need for accurate long range predictions of precipitation or temperature has led to relate El Niño and La Niña phenomena to regional climate. Agriculture, forestry, water management and the health sector demand more detailed climate diagnostics and prognostics of extreme climate conditions. The cost of the 1982-83 El Niño event for Mexico and Central America is estimated at about six hundred million dollars (NOAA, 1994). The El Niño event of 1997-1998 resulted in an even more dramatic economic loss, of the order of two billion dollars for Mexico alone (Delgadillo *et al.*, 1999). The social costs, in terms of loss of life or people who migrate due to anomalous conditions associated with ENSO, represent a major problem for government agencies.

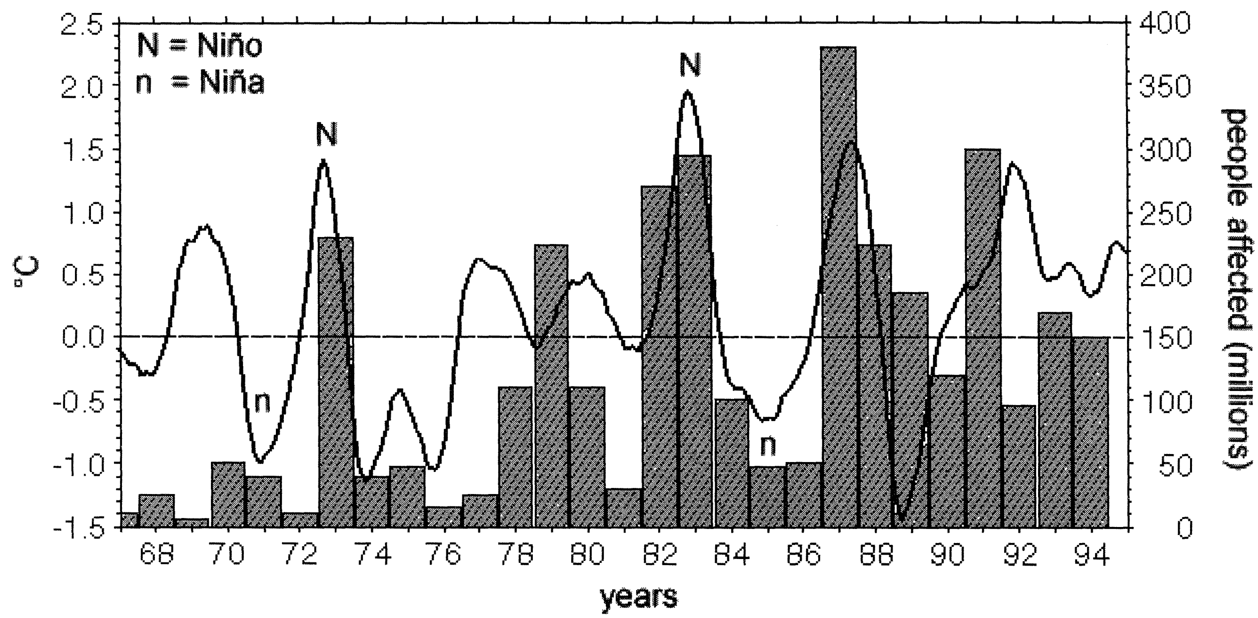

Fig. 1. Number of people affected by natural disasters of all kinds (histogram), and sea surface temperature anomalies in the eastern Pacific (solid line).

Numerous studies on climate variability concentrate on sea surface temperature (SST) anomalies associated with ENSO. These anomalies in SST have proven to be important enough as to reflect global climate variability on an interannual time scale. The existence of relationships between SST in the central-eastern Pacific and precipitation anomalies around the world (e.g., Ropelewsky and Halpert, 1987) has led to constant monitoring and long term forecasts of SSTs in this region (e.g., Anderson *et al.*, 1998). SSTs are nowadays used to predict precipitation anomalies at regional and even local scales.

The enhanced monitoring system for the tropical Pacific, known as the Tropical Ocean Atmosphere (TAO) array, has resulted in substantial progress in our understanding of the ENSO phenomenon. Higher quality monitoring of SSTs and observations of deeper layers of the ocean, allow to skillfully predict El Niño or La Niña conditions several months in advance (e.g., Penland and Matrosova, 1994). Through the analysis of previous ENSO events and their relationships to precipitation, temperature or other observed fields, seasonal prediction schemes have been developed to survey climate variability at various spatial scales (Magaña and Quintanar, 1997). The use of analogues (Barry and Perry, 1973) or multiple regression schemes have become popular tools to generate predictions of precipitation based on the SST forecasts for the Pacific and the Atlantic. Although such simple methods have proven to be useful, a better understanding of the dynamics involved in such relationships is necessary to improve the quality of the forecasts for the planning of socioeconomic activities.

Descriptions of the ENSO phenomenon and its impacts in global climate have been given in a large number of papers (e.g., Díaz and Markgraf, 1994). However, only a few studies have examined the characteristics of the ENSO signal over Mexico during winter and summer (e.g., Cavazos and Hastenrath, 1990; Magaña and Quintanar, 1997). It was not until the intense El Niño event of 1997-98 that the scientific activity related to the impacts of El Niño substantially increased. In most cases, the ultimate goal of these studies has been to better predict seasonal climate anomalies at a regional level.

General Circulation Models (GCMs) are capable to simulate the large scale response of the tropical and extratropical atmosphere to anomalous SSTs over the eastern equatorial Pacific (Mechoso *et al.*, 1987). Such response basically corresponds to quasi-stationary Rossby waves over the extratropics and equatorial Rossby waves over the tropics. But Ting *et al.* (1996) have found that current GCMs do not properly simulate the phase of these quasi stationary waves, because of the inherent internal variability of the midlatitudes, leading to errors in the predicted climate anomalies under El Niño or La Niña conditions. They suggest that the characteristics of the forcing (location and intensity), along with the mean circulation, are crucial to better determine the phase of the ENSO extratropical response.

In recent years, regional climate numerical models begun to be developed to obtain climate anomalies at a mesoscale level (Giorgi, 1990). These models consist of a mesoscale model nested in a GCM. The latter provides the boundary conditions for the mesoscale model to simulate the interaction of the flow with higher spatial resolution boundary conditions (topography and land use). In every case, regional climate simulations require that the large scale atmospheric conditions be properly given in order to generate small-scale climate anomalies.

A prerequisite to improve the quality of seasonal climate predictions, either through the use of statistical or dynamical models, is the understanding of the mechanisms that control climate variability at a regional level. The importance of ENSO as a major modulator of interannual climate variability in Mexico and other parts of the world, requires an analysis of the mechanisms that connect SST anomalies in the eastern Pacific with precipitation or temperature anomalies. Further more, it is necessary to determine the extent to which climate variability may be explained in terms of El Niño or La Niña signals only.

In the present paper, the impacts of the ENSO phenomenon in regional precipitation anomalies over Mexico and Central America are documented. Some dynamical mechanisms involved in the teleconnections between the eastern Pacific and Mexican climate anomalies are examined. Finally, the potential to elaborate seasonal climate predictions based on El Niño signal is discussed, in terms of the needs of information needed in the planning of socioeconomic activities.

2. DATA AND METHODOLOGY

Monthly mean data from the reanalysis of meteorological fields prepared by the National Environmental Prediction Center (NCEP) (Kalnay *et al.* 1996) for the 1958-1999 period have been used for the study of atmospheric circulations over the Mexico, Central America and the Caribbean region. These data include horizontal winds (u,v) and vertical velocity (ω) fields on 2.5×2.5 grids at 12 vertical pressure levels. Monthly sea surface temperature (SST) data for the same periods were obtained from the Reynolds (1998) analysis.

A key element in the present study is the precipitation database. This monthly precipitation gridded data set was constructed using various sources of data, including:

a) Station data for the US, Mexico, Central America and the Caribbean for the 1958-1999 period, taken from the Mexican Weather Service, the Central American Weather Services, and the archives of NCAR.

b) Precipitation estimates from the NCAR/NCEP Reanalysis for oceanic regions.

These data have been analyzed using a Kriging method (Dingman *et al.*, 1988). The interpolation has been performed in a 0.5×0.5 grid. The climatology of precipitation compared well with other precipitation data sets (e.g., Legates and Willmott, 1990), with differences no larger that 10% over some oceanic regions. Since the information for Mexico and Central America was much larger (over 3000 stations for the region) than the ones used in the other analyses, there is confidence that the fine spatial structure of the precipitation patterns is well captured with the present scheme.

For the diagnostic analysis, monthly mean anomalies were constructed by subtracting the mean fields for particular summer or winter ENSO periods, from the corresponding mean climatological field. Throughout the rest of the study, the winter season will be defined as December, January and February, while the summer season will correspond to June, July, August and September.

The analysis consists of creating composite patterns of various fields, for six El Niño winters (1965-66, 1972-73, 1982-83, 1986-87, 1991-92 and 1997-98) and summers (1965, 1972, 1982, 1986, 1991, and 1997), and for six La Niña winters (1964-65, 1970-71, 1973-74, 1975 76, 1988-89, 1998-99), and summers (1964, 1970, 1973, 1975, 1988, 1998), in order to determine composite anomalies during ENSO. It is clear there is inter El Niño or inter La Niña variability. This issue is discussed throughout the text.

3. THE ENSO SIGNAL IN PRECIPITATION

a) Climatology

The climate of the northern hemisphere (NH) tropical Americas is characterized by relatively well defined dry and wet seasons. The former takes place during winter, while the latter occurs in summer (Figure 2). However, in some regions, as the northern part of the Baja California peninsula or Sonora, the rainy season takes place during the winter months. In other regions, precipitation occurs throughout most of the year, as in the Isthmus of Tehuantepec, or the Caribbean coast of Central America.

Winter climate over the entire region is largely associated with the passage of midlatitude frontal systems, often propagating into the Intra Americas Seas (IAS), constituting the so-called Northerns (Trasviña and Barton, 1997). These systems produce drastic changes in surface temperature along the coast of the Gulf of Mexico, and at times, result in precipitation, enhanced by the orographic effect of the Sierra Madre.

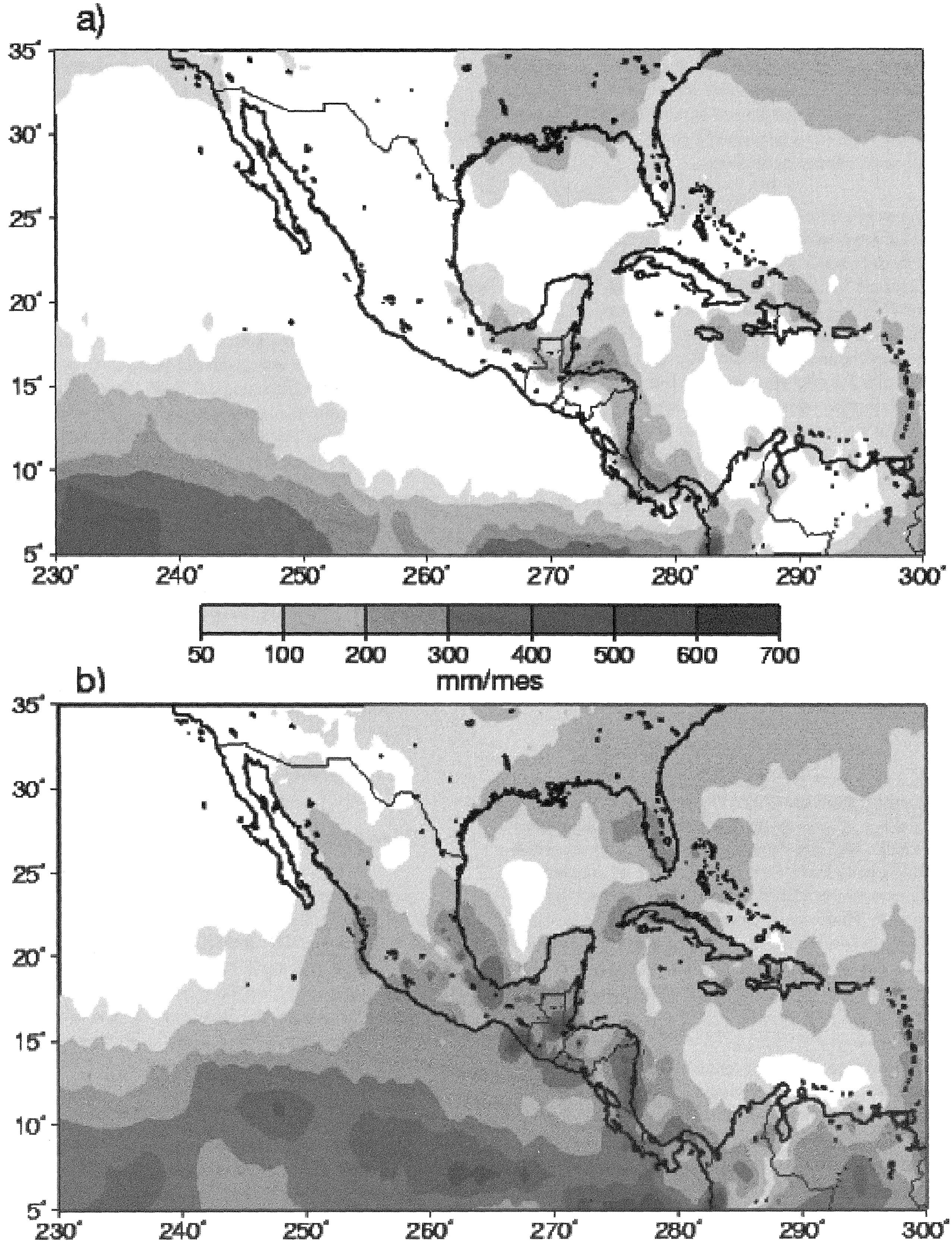

Fig. 2. Seasonal precipitation (mm/month) for a) winter (December, January and February) and b) summer (June, July, August and September).

During summer, tropical convective activity, as in the Inter Tropical Convergence Zone (ITCZ), the Mexican monsoon, easterly waves or tropical cyclones, constitutes the element that results in substantial summer precipitation. When summer climate variability is studied, the presence of two warm pools, one over the northeastern Pacific (off the coast of Mexico) and one over the IAS should be considered. In the former, convective activity is intense, constituting the ITCZ. In the latter, tropical convection is relatively weak due to intense subsidence. The relatively low precipitation over the IAS may be considered abnormal for a warm pool region. The other important element that determines the characteristics of precipitation is the interaction of the topography with the trade winds, which leads to differentiated precipitation patterns in the Caribbean and Pacific coasts of Central America.

One of the peculiarities of the annual cycle of precipitation in this region is the relative minimum in precipitation in the middle of the summer rainy season. The Mid-Summer Drought (MSD) or Canicula, is observed over southern Mexico and Central America (Magaña *et al.*, 1999). It appears to be related to the fluctuations in sea surface temperature (SST) over the northeastern tropical Pacific, which are in turn modulated by the effects of incoming solar radiation, low-level winds and precipitation. During the MSD (July and August), the trade winds intensify, generating intense precipitation along the Caribbean coast of Central America. Actually, the intensification of the trade winds over the Caribbean is related to an enhancement of the low-level jet over the Caribbean. This barotropically unstable low-level jet has been suggested as responsible for the amplification of some circulation anomalies that result in tropical cyclones over the eastern Pacific (Molinari *et al.*, 1997).

b) Winter precipitation anomalies

Changes in winter precipitation over Mexico and Central America are related to fluctuations in frontal and Northern activity. These systems propagate along the jet stream over the Pacific (Figure 3a.). During El Niño years, the anomalous convective heating over the central/eastern Pacific generates a quasi-stationary Rossby wave known as the Pacific North American (PNA) pattern (Horel and Wallace, 1981), with cyclonic circulations off the coast of California and the northern coast of the Gulf of Mexico (Figure 3b). As a result, more frontal systems reaching southern California and the northwestern part of Mexico, produce enhanced precipitation (Figure 4a).

Over central Mexico, the changes in the circulation correspond to enhanced westerlies, i.e., an intense subtropical jet stream through which midlatitude systems may propagate. As a result, midlatitude cyclone activity increases over the IAS, and more Northerns over the Gulf of Mexico and Caribbean Sea pass through (Magaña and Vázquez, 2000). It is interesting that a larger number of Northerns over the Gulf of Mexico results in negative anomalies in precipitation over the Isthmus of Tehuantepec region (Figure 4a). It may be speculated that the more frequent passage of Northerns implies drier conditions over the Isthmus of Tehuantepec and the Caribbean coast of Central America, since the atmosphere does not have enough time to moisten as to produce precipitation when the following system crosses. More midlatitude waves may result in more frequent cold and dry winds that reflect in a negative precipitation anomaly during El Niño winters. Additional options should be explored to explain why El Niño and more Northerns result in less than normal precipitation in the Tehuantepec region.

When the precipitation anomalies during La Niña winters are analyzed (Figure 4b), they appear to be just opposite to those observed during El Niño. However, given the non-linear nature of the climate system, this is not absolutely correct. As a matter of fact, the non-linear character of climate implies for instance, that not all El Niño winter anomalous conditions are equal. There is substantial inter-ENSO variability that reflects as fluctuations in the characteristics (phase and wavelength) of the quasi-stationary Rossby wave over North America (Hoerling and Kumar, 1997) and consequently, in the anomalous precipitation patterns for every El Niño event (Figure 5). There is some uncertainty on whether changes in the phase and amplitude of these quasi-stationary waves correspond to real inter-ENSO variability via teleconnections or internal variability of the mid-latitude circulation. According to Hoerling *et al.* (1997) the signal of anomalous SST during ENSO is small over most of the extratropics and therefore, the potential for modestly useful seasonal predictions based solely on SST information is limited to North America. This result limits the potential to make use of prediction of winter precipitation in northwestern Mexico, which would be highly useful in water administration (Magaña and Conde, 2000). Inter ENSO variability makes some El Niño events to result in negative winter precipitation anomalies, and consequently, in no substantial increases in streamflow (Figure 6) and dam levels (not shown).

The negative anomalies in Central America appear to be mostly related to enhanced subsidence resulting from the anomalously intense convective activity in the equatorial eastern Pacific through a direct circulation of the Walker cell type (Webster 1994).

c) Summer precipitation anomalies

During El Niño summers, negative precipitation anomalies dominate over most of Mexico and the Pacific coast of Central America (Figure 7a). Frequently, these negative

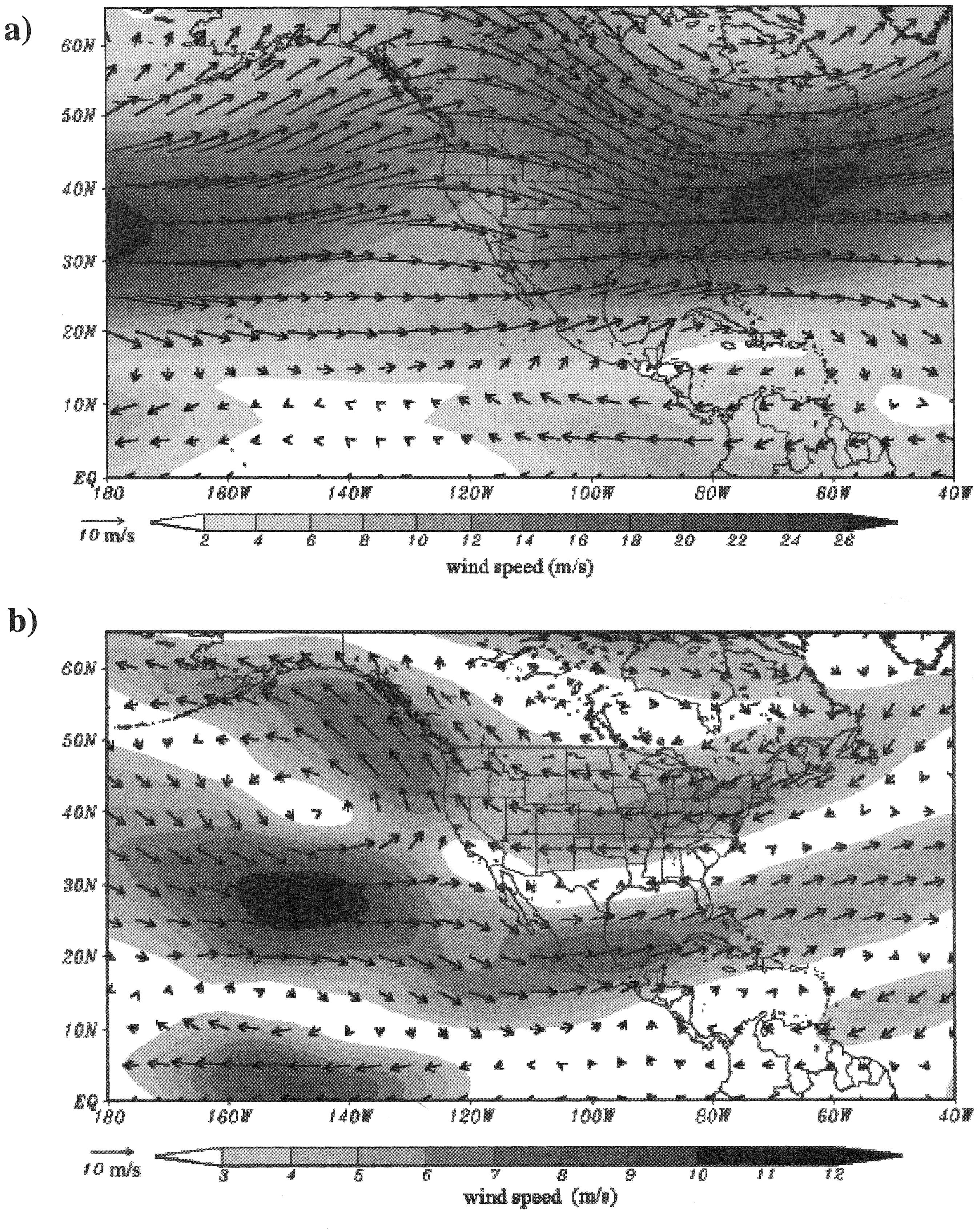

Fig. 3. a) Mean winter atmospheric circulation at 500 mb, and b) composite pattern of atmospheric circulation anomalies at 500 mb during El Niño winters.

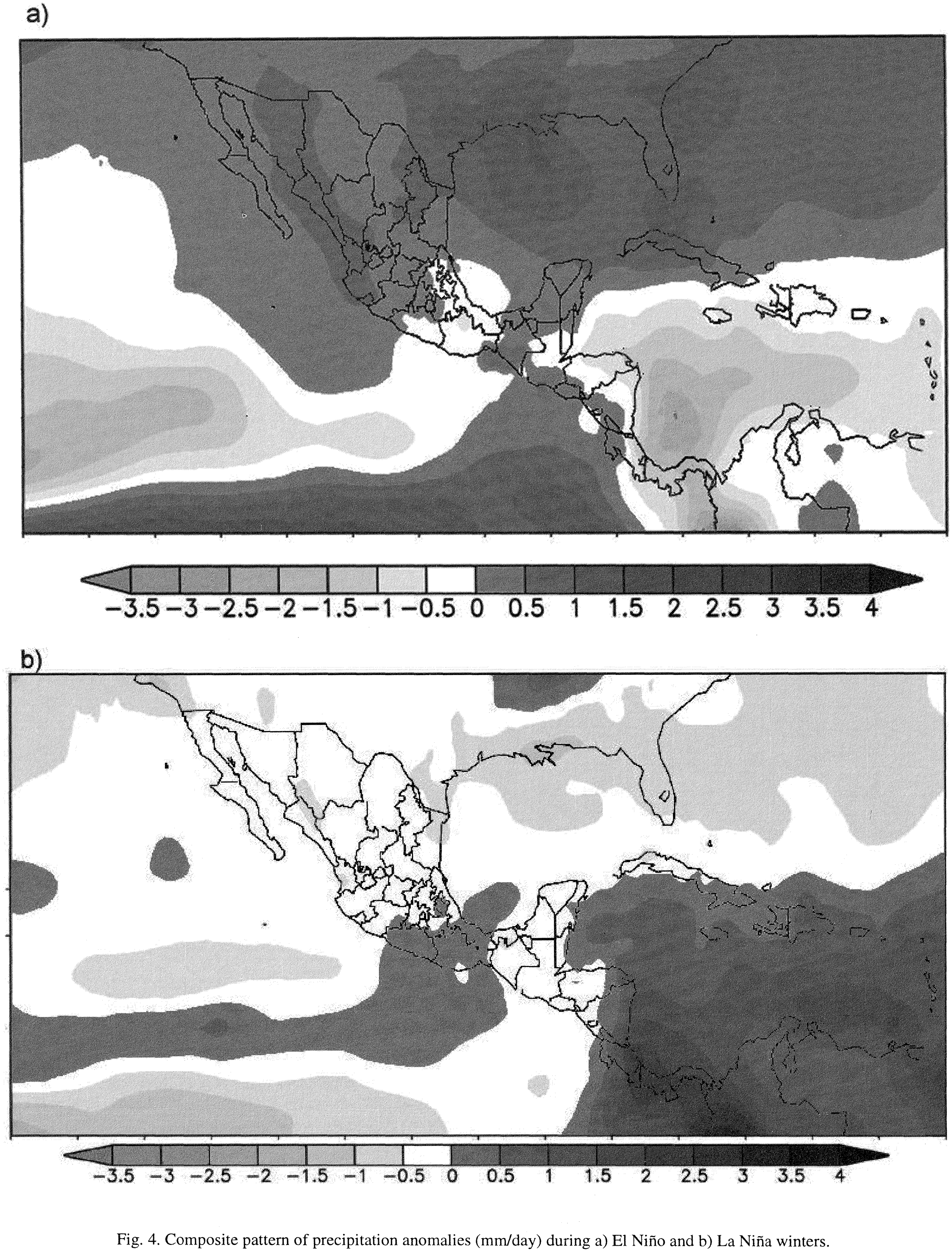

Fig. 4. Composite pattern of precipitation anomalies (mm/day) during a) El Niño and b) La Niña winters.

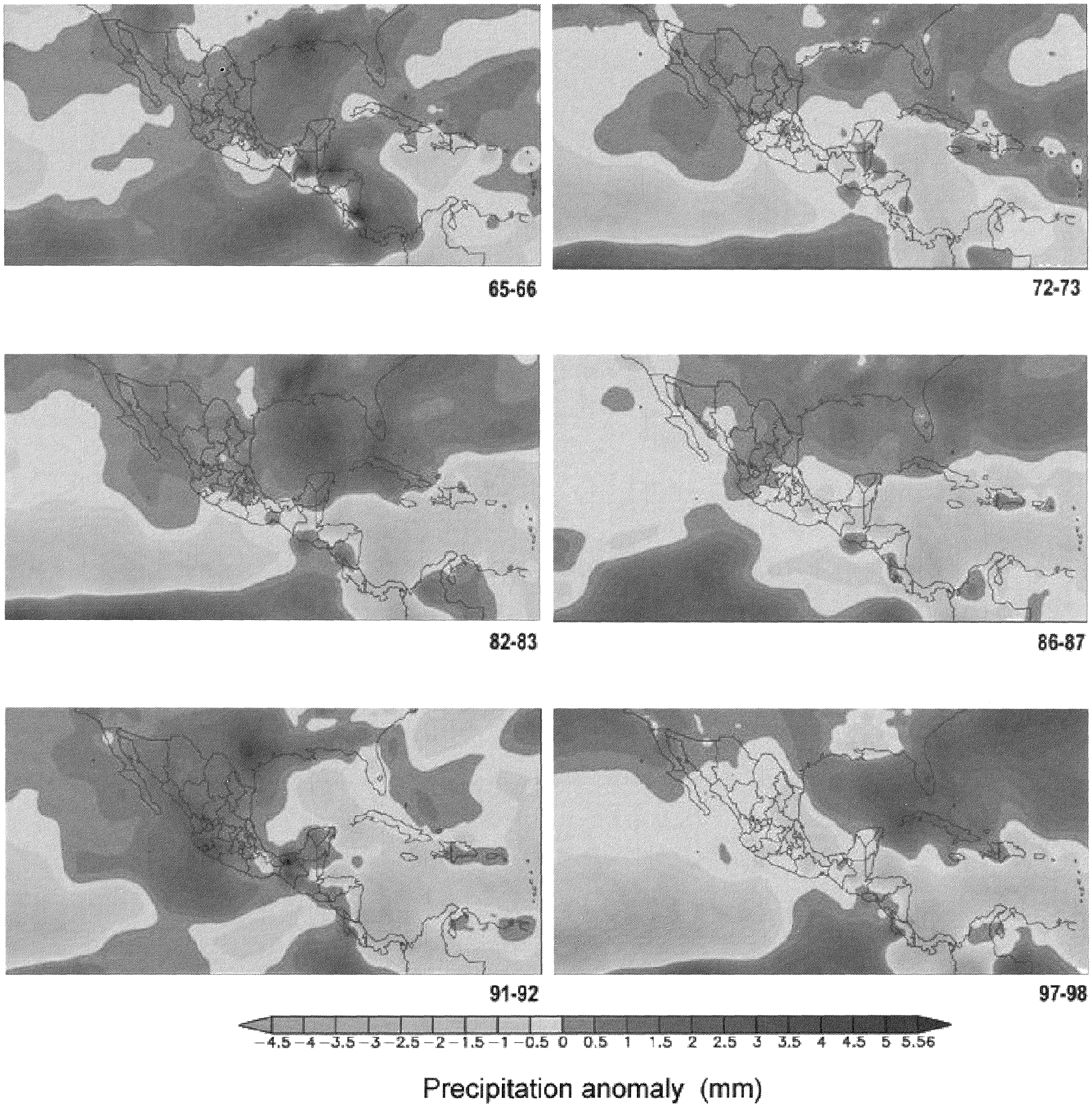

Fig. 5. Precipitation anomalies for various El Niño winters.

anomalies in precipitation constitute a drought. The increased number of El Niño events during the nineties has led to reduced water availability, particularly over northern Mexico, and severe loses in various economic activities. On the other hand, during La Niña events, precipitation is close to normal over most of Mexico and in some cases, it exceeds the climatological mean (Figure 7b). It is interesting to note that the northwestern region, where the Mexican monsoon appears (Douglas *et al.*, 1993), negative precipitation anomalies exist either during El Niño or La Niña summers. Precipitation anomalies over this region do not appear to be related to SST anomalies in the eastern Pacific (Koster *et al.*, 2000). Therefore, more in depth studies are needed to unveil the mechanisms that control the interannual variability of the Mexican monsoon.

In order to determine why negative anomalies in precipitation appear during El Niño summers, it is necessary to

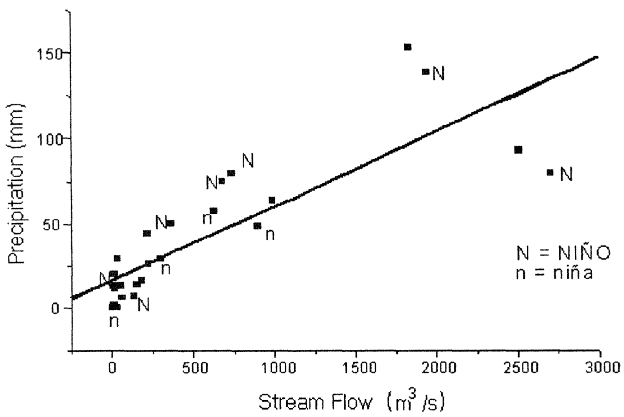

Fig. 6 Dispersion relationship between precipitation (mm) and streamflow (m^3/s) at Huites Hidrological station between Sonora and Sinaloa, for various Decembers. 'N' denotes El Niño events and 'n', La Niña events.

consider the various factors that modulate precipitation. These factors include:

i) The presence of the Inter Tropical Convergence Zone (ITCZ) in the eastern Pacific around 10°N (Figure. 8).

ii) The existence of a low-level jet over the Caribbean Sea, along which easterly waves propagate, and whose interaction with topography over Central America result in intense precipitation along the Caribbean coast of Central America.

iii) Hurricane activity in the IAS and the northeastern Pacific.

iv) Convective activity in the Mexican monsoon region.

The meridional SST gradient over the eastern Pacific, between the cold tongue region and the warm pool off the coast of Mexico, weakens due to the positive SST anomaly associated with El Niño. Therefore, low-level moisture convergence does not occur around 10°N as usual, but tends to remain closer to the equator (Figure 9a), as observed by Magaña and Quintanar (1997). Therefore, during El Niño summers, the ITCZ remains closer to the equatorial eastern Pacific (Walliser and Gautier 1993), and most of Mexico exhibits a relatively dry atmosphere that implies a deficit in precipitation. In addition, intense convection around 5°N produces a intense local Hadley cell with anomalously strong subsidence over northern and central Mexico that inhibits the development of deep convective activity (Figure 9a).

Over the Caribbean Sea, the low-level jet strengthens resulting in increased orographic forcing and precipitation along the Caribbean coast of Central America (Amador and Magaña, 2000). The intense easterly flow appears to result in subsidence along the Pacific coast of Central America and a regional deficit in precipitation.

During La Niña summers, the SST anomalies around the tropical eastern Pacific are almost the opposite to those observed during El Niño events. The meridional gradient in SST in the northeast Pacific increases and anomalously intense moisture convergence occurs around 10°N (Figure 9b). During this period, an intense ITCZ forms around this latitude, closer to the southern coast of Mexico, which allows the occurrence of more frequent southerly moisture surges that produce enhanced precipitation over southern and central Mexico. In contrast to El Niño, during La Niña summers, subsidence over most of Mexico is weak allowing the establishment of deep convective activity over most of the country.

It should be stated that the changes in vertical velocity associated with El Niño and La Niña are always negative around northwestern Mexico, in agreement with the hypothesis that interannual climate variability over this region is not directly related to fluctuations in SST over the eastern Pacific. In fact, the mechanisms that control the interannual variability of the North American monsoon are yet to be explored. The North American Monsoon Experiment (NAME), to be conducted during the second half of this decade, may provide some answers to this problem.

d) El Niño and hurricanes around Mexico

The relationship between hurricane activity and El Niño has been explored by a large number of authors since the eighties (e.g., Gray, 1984). The problem on the relationship of SST anomalies in the tropical eastern Pacific and hurricane activity around the world is subject of active research. It is unclear whether El Niño modulates the number of tropical cyclones over the eastern Pacific (Figure 10a), as it does over the IAS, where less tropical cyclones are observed during El Niño years (Figure 10b).

The lack of statistical relationships between the number of hurricanes in the eastern Pacific and ENSO does not imply that El Niño does not affect the characteristics of the tropical cyclones in this region. It has been documented that the warmer the ocean, the larger the maximum potential intensity of the hurricanes (De Maria and Kaplan, 1994). In other words, warmer SSTs result in increased potential for a hurricane to have more intense winds. Hurricanes do not always reach that maximum potential intensity, since this depends on other dynamical factors.

Among the dynamical mechanisms that have been proposed to explain changes in hurricanes activity in relation to

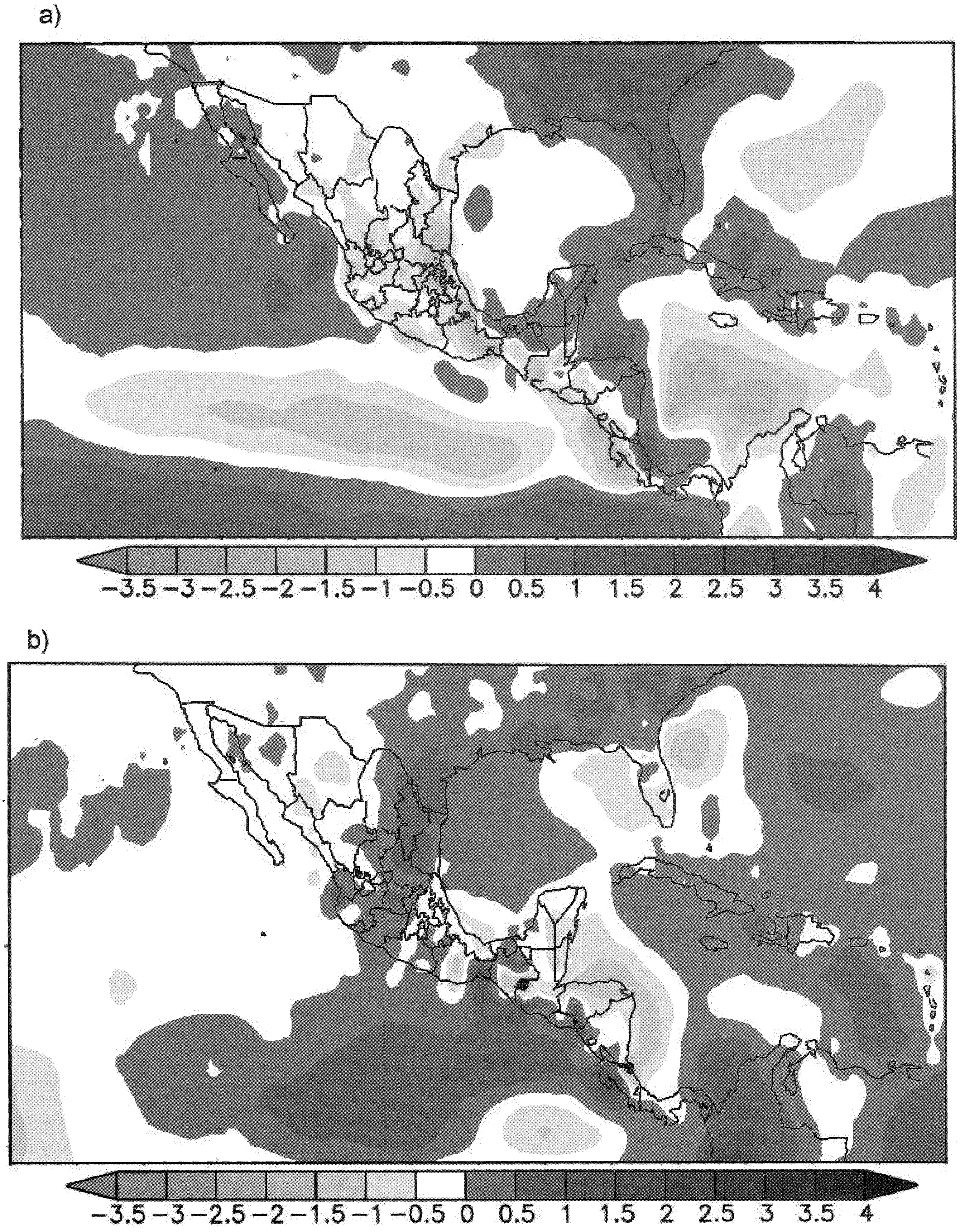

Fig. 7. As in Fig. 4, but for summer.

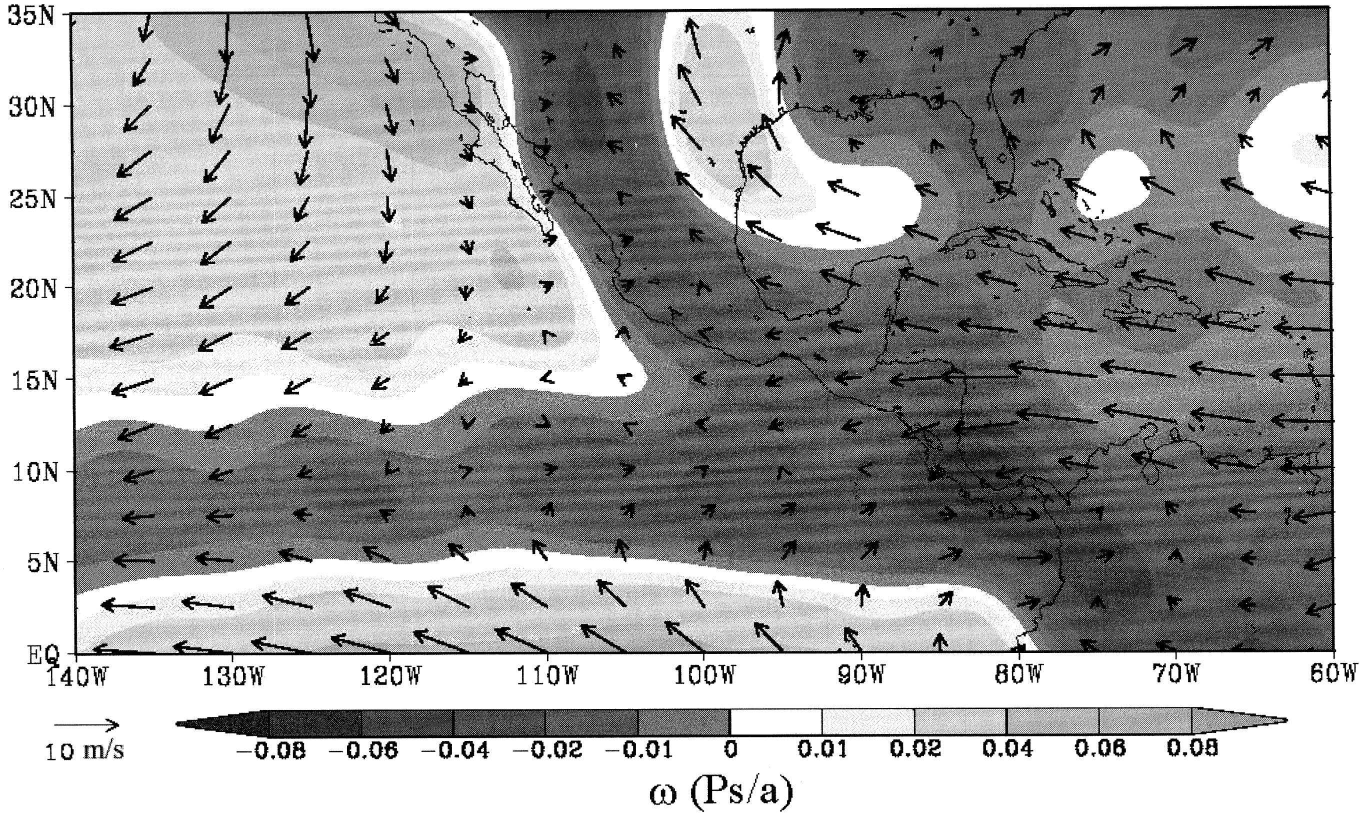

Fig. 8. Mean summer atmospheric circulation at 925 mb and vertical p-velocity ω at 700 mb (Pa/s). Dark (light) shadings correspond to ascending (descending) motions.

El Niño or La Niña, regional SST anomalies, vertical wind shear (difference in zonal wind between 200mb and 850 mb) or humidity in the atmosphere have been considered (precipitable water) (Figure 11). The strengthening in the low-level jet in the Caribbean Sea increases the vertical wind shear and consequently inhibits the formation of tropical cyclones (tropical storms or hurricanes). The intense low-level jet enhances Ekman pumping along the northern South American coast resulting in a negative anomaly in SSTs that may partially contribute to the decrease in the number of tropical cyclones in this region (Amador and Magaña, 2000). The Caribbean region does not show a significant difference in precipitable water between El Niño or La Niña summers.

In the northeast tropical Pacific, the SSTs significantly increase (up to 3°C) during El Niño, the wind shear slightly decreases and no major changes occur in precipitable water. Therefore, the main change in the environment that may affect hurricane activity in the eastern Pacific is related to the SSTs and changes in the maximum potential intensity of tropical cyclones (De Maria and Kaplan 1994). In this context, it may be speculated that the large intensity reached by hurricane Pauline in October 1997 may be associated with the increase in SST along the Mexican Pacific coast due to El Niño. Even more, hurricanes that last longer (more than seven days) are more frequent during El Niño than during non-El Niño years (not shown).

As one of the most important source for precipitation, hurricane variability largely impacts the summer rainfall in Mexico, particularly over the northeastern region (Tamaulipas). It is not clear what percentage of the Mexican precipitation is associated with the passage of hurricanes; but, a single hurricane may lead to a positive seasonal precipitation anomaly at a regional level. In this context, the larger the hurricane activity in the IAS, the better the chances to have a good rainy season, as during La Niña summers.

4. SEASONAL PRECIPITATION PREDICTIONS BASED ON THE ENSO SIGNAL

The relationships between ENSO and precipitation in Mexico may explain up to 40% of the total seasonal variability in rainfall, particularly over southern Mexico (Magaña *et al.*, 1999). For instance, correlation between summer precipitation over the southern part of Oaxaca and ENSO indi-

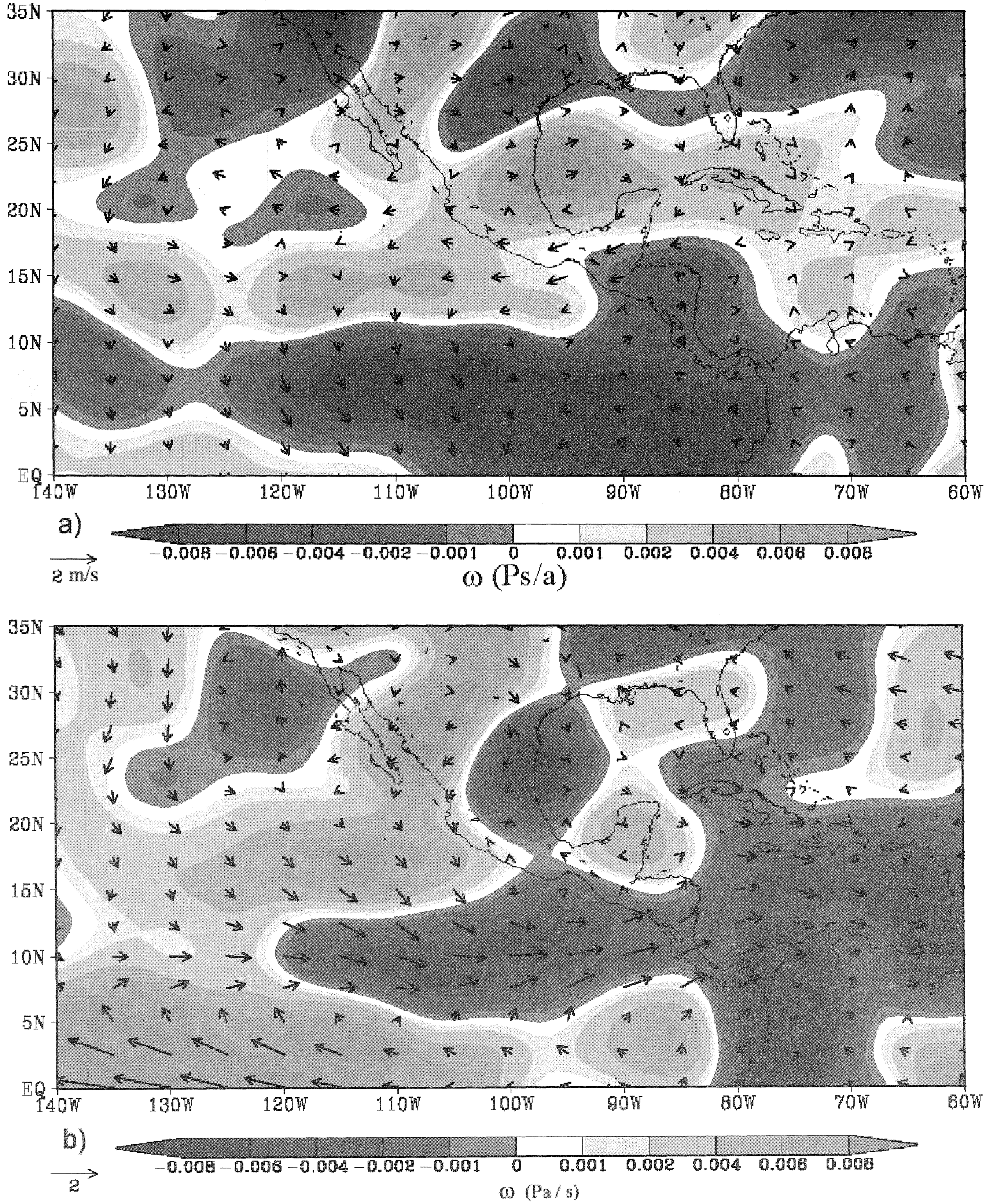

Fig. 9. Composite circulation anomalies (u,v) at 925 mb and vertical p-velocity ω at 700 mb (Pa/s) during a) El Niño and b) La Niña summers.

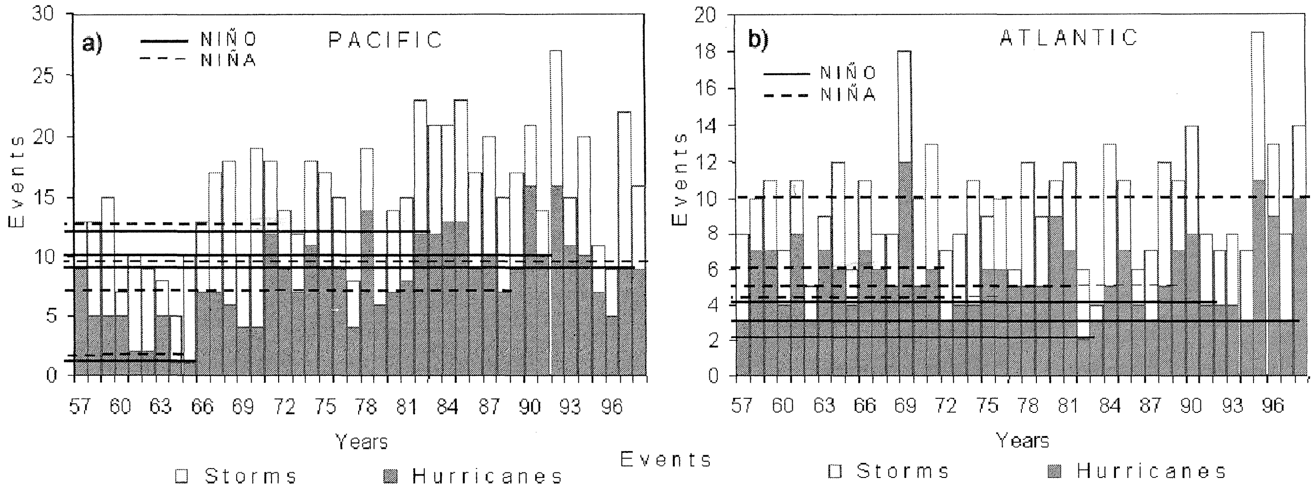

Fig. 10. Number of tropical cyclones, storms (white bars) and hurricanes (dark bars) for the 1957-1998 period a) for the northeastern Pacific and b) for the Caribbean Sea. Solid lines indicate El Niño years. Dashed lines correspond to La Niña years.

ces is above 0.6. The importance of El Niño in recent year has led the meteorological community to elaborate seasonal and even monthly predictions of precipitation anomalies for Mexico based on predicted SSTs. Two basic methods have been followed: analogous and multiple linear regression equations. Until recently, the use of other statistical tools, such as neural networks or even the use of regional climate models (Giorgi, 1990) has not substantially improved the skill of the simpler statistical tools.

Given the availability of SST predictions for the Pacific, the use of analogues to predict rainfall anomalies has been widely used, as in the Mexican Weather Service. However, trends in climate or even interdecadal variability have made this method relatively unreliable, particularly when the El Niño or La Niña signals are weak (Conde *et al.*, 1999). In order to have relatively skillful predictions at a regional level, the ENSO signal needs to be sufficiently strong as to modulate the large-scale precipitation pattern. This was the case of the summer of 1998, when a rapid transition from positive to negative SST anomalies in the eastern Pacific resulted in relatively good monthly precipitation predictions even at a local level (Figure 12). Multiple regression schemes, based on global SST predictions, take into account more predictors than simply El Niño or La Niña signals. This appears to be particularly useful when El Niño forcing does not exist and other factors, such as easterly wave activity, play a more important role in the characteristics of the rainy season.

It appears, nonetheless, that the future of regional climate predictions will rely on the use of improved Regional Climate Models. Preliminary experiments show that a crucial element to obtain reliable predictions at regional spatial scales is the adequate simulation of the boundary conditions by the GCMs (Magaña and Pérez, 1998). For instance, an error of 5° in longitude in the phase of the PNA pattern would result in large errors in the simulated precipitation for winter in northwestern Mexico, given the strong relationship between these factors. Current GCMs do not appear to be capable of reproducing such details of the large-scale circulation, probably because of the internal variability of the midlatitude circulations themselves (Hoerling and Kumar, 1997).

5. SUMMARY AND CONCLUSIONS

During winter, El Niño results in positive precipitation anomalies over northwestern Mexico, and negative precipitation anomalies around the Isthmus of Tehuantepec. The changes in the circulation associated with the PNA pattern force the subtropical jet stream to enhance over south central Mexico. Such change in the large-scale circulation increases Northern activity over the IAS. It is not clear, however why the more frequent passage of Northerns results in negative anomalies in precipitation around southern Mexico and the Caribbean coast of Central America.

Positive precipitation anomalies in northwestern Mexico during winter turn out to be of great importance for the recovery of water levels in dams (Magaña and Conde, 2000). However, the large inter-ENSO variability in the region of Sonora and Chihuahua makes the prediction of winter precipitation anomalies a real challenge. Given the socioeconomic importance of El Niño for the winter climate in the region, more in depth analyses of the mechanisms that control the phase and wavelength of quasi-stationary waves such as the PNA pattern are necessary.

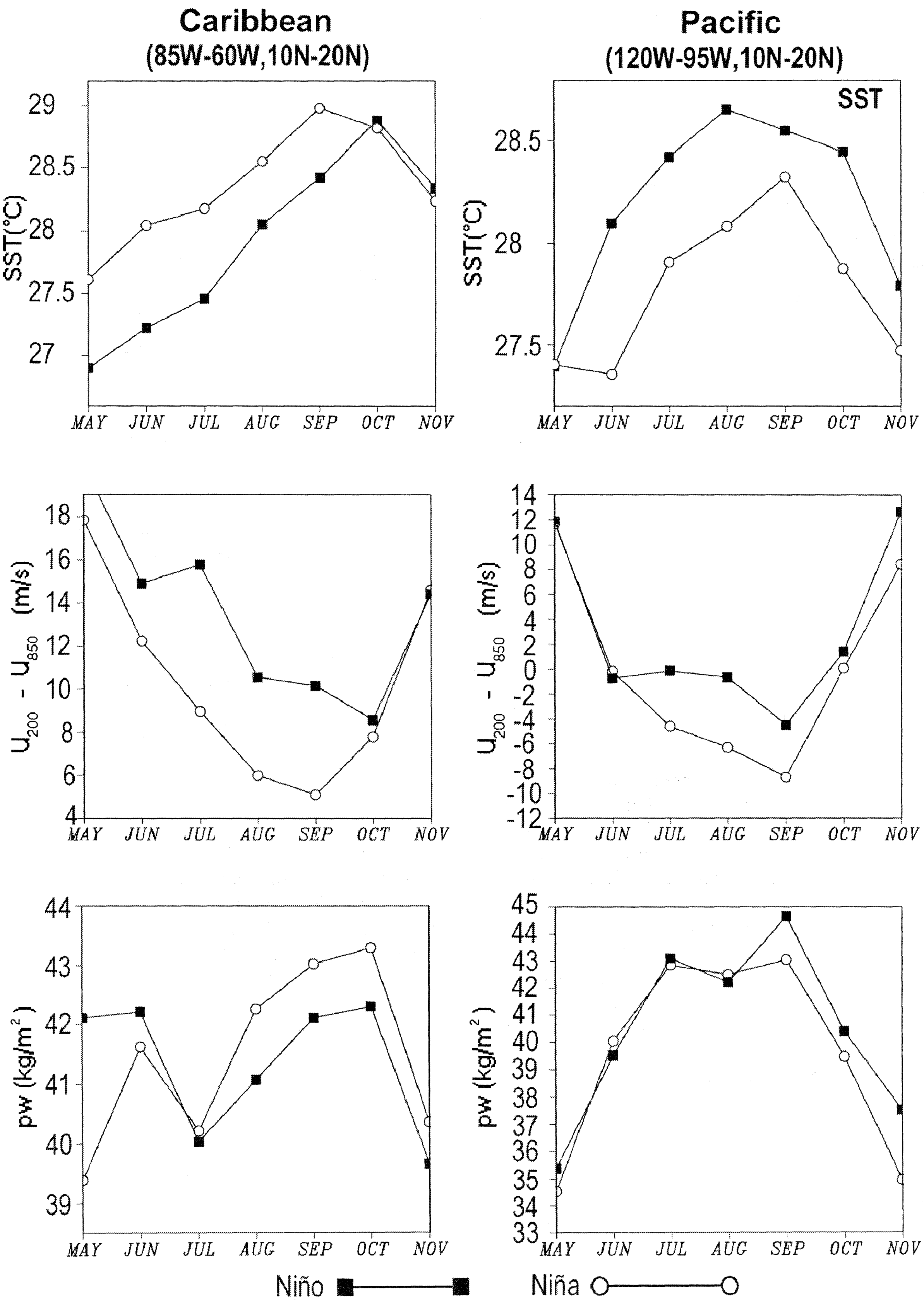

Fig. 11. Area averaged monthly composite values of SST (°C), vertical wind shear (*u* at 200 mb – *u* at 850 mb) (m/s), and precipitable water, for El Niño (solid squares) and La Niña (open circles), a) in the Caribbean Sea , and b) in the northeastern Pacific.

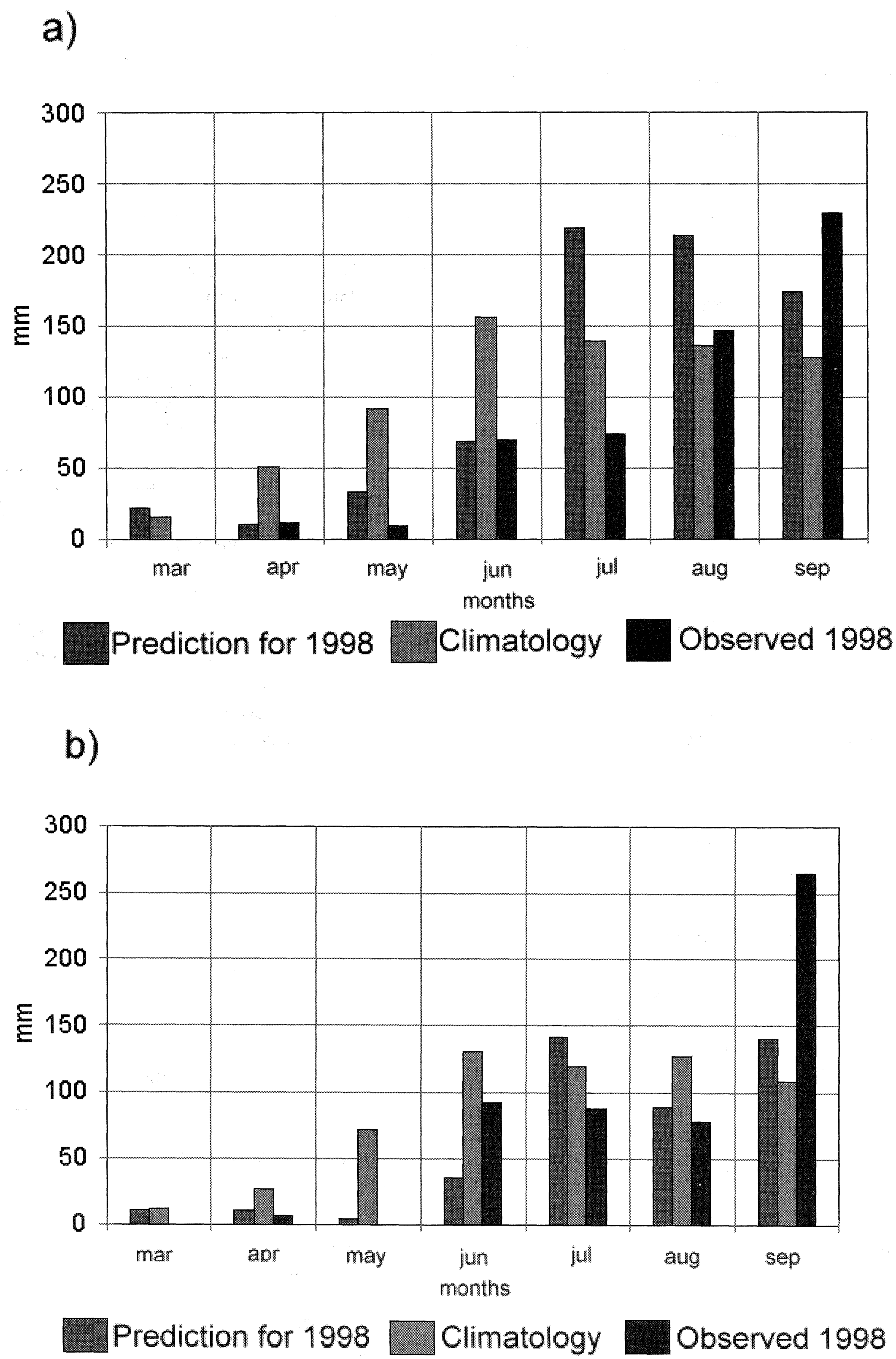

Fig. 12. Monthly precipitation forecasts for a) Apizaco and b) Ixtacuixtla, in the state of Tlaxcala. Dark bars correspond to predicted precipitation (mm), light bars correspond to mean precipitation (mm) and black bars correspond to observed precipitation (mm).

The negative winter precipitation anomaly signal during La Niña appears to be more robust over most of northern Mexico. The anomalous precipitation pattern may even constitute a reliable seasonal prediction during these periods, as during the winter 1999-2000.

El Niño summers usually result in negative precipitation anomalies over most of Mexico and Central America. The elements that force such precipitation deficit include:

i) a southward shift (2° – 3°) in the ITCZ over the eastern Pacific;

ii) enhanced subsidence over northern Mexico; and

iii) a stronger low-level jet over the Caribbean, which in turn results in a more intense wind shear over the IAS and fewer tropical cyclones.

The intense low-level jet intensifies the coastal upwelling over the northern coast of South America leading to negative SST anomalies over the eastern Caribbean. Therefore, the Caribbean low-level jet acts as a link between the eastern Pacific and the IAS.

During La Niña summers, precipitation returns to normal or is even above the climatological mean as a result of:

i) an ITCZ around 10°N,

ii) weaker trade winds over the IAS,

iii) weaker subsidence over northern Mexico, and

iv) a recovery in the number of hurricanes in the Atlantic.

There are some regions though, that appear to be relatively insensitive to the occurrence of La Niña or El Niño. For instance, during summer, northwestern Mexico may exhibit precipitation deficit either during El Niño or La Niña years. The mechanisms that control interannual climate variability over this region are unclear. In fact, this region shows low or null predictability based on SSTs only.

The experience of a severe drought during the intense 1997-1998 El Niño event had a tremendous impact in the socioeconomic activities of Mexico. The estimated costs of the event in the Mexican economy are of the order of 2 billion dollars. Forest fires, losses in agriculture, fisheries, and other disasters have made the Mexican authorities to reflect on the importance of adequate seasonal climate predictions. The recent advances on the prediction of ENSO, and our increased understanding of the mechanisms that control climate variability in Mexico have resulted in skillful seasonal precipitation prediction schemes. Therefore, products of diagnostic and prognostic models are becoming an important tool in the planning of some socioeconomic activities.

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