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The influence of the southern oscillation on the winter climate of Nuevo León state, Mexico

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RESUMEN

El propósito de este trabajo es estudiar la influencia de la Oscilación del Sur sobre el clima invernal (noviembre/abril) del Estado de Nuevo León, México. El estudio se fundamenta a través de un análisis de correlación de temperatura media, precipitación, datos de radio-sondeo y un índice de la Oscilación del Sur, definido como bajo cuando la presión a nivel del mar es anormalmente baja/alta en Tahiti/Darwin. Los resultados muestran un aumento significativo de precipitación y una tendencia hacia temperaturas menores en casi todo el estado, especialmente a barlovento de la Sierra Madre Oriental durante el invierno de los eventos de El Niño o fase baja de la Oscilación del Sur. Asimismo, se obtuvieron anomalías negativas de alturas geopotenciales a 850 mb en el Golfo de México durante la misma fase. Estos resultados se asocian con una influencia conjugada de los Nortes sobre la región costera del golfo norte y de los fuertes vientos del oeste que acompañan a la corriente de chorro subtropical durante tales eventos. Los resultados del estudio indican que la Oscilación del Sur tiene un impacto sobre el clima invernal de Nuevo León con influencias modulantes de carácter regional como son los Nortes y la Sierra Madre Oriental.

PALABRAS CLAVE: Oscilación del Sur, clima invernal, Nuevo León, México.

ABSTRACT

The influence of the Southern Oscillation on the winter climate of the State of Nuevo León, Mexico is discussed. The study uses correlation analysis of mean temperature, rainfall, upper-air soundings, and an index of the Southern Oscillation defined as low for anomalously low/high pressure at Tahiti/Darwin. The results show a significant increase of winter rainfall and a tendency to lower temperatures in much of the state, especially to the windward side of the Sierra Madre Oriental during the low Southern Oscillation phase or El Niño events. Negative geopotential height anomalies at 850 mb were also found in the coastal region of the Gulf of Mexico during these events. These results are attributed to a coupled influence of "Norte" invasions in the Gulf coast area, and the enhanced mid-latitude westerlies over Mexico typical of El Niño years. The Southern Oscillation influences the winter climate of Nuevo León, with modulating influences of regional character such as the "Nortes" and the Sierra Madre Oriental.

KEY WORDS: Southern Oscillation, winter climate, Nuevo León, Mexico.

INTRODUCTION

The State of Nuevo León (Figure 1) is exposed to a subtropical regime with influence of tropical storms, summer droughts (Caníiculas), and invasion of continental polar air masses and Nortes which frequently produce light winter rains and sometimes strong frosts.

The Southern Oscillation (SO) is related to circulation changes and regional climate anomalies in diverse parts of the world. This phenomenon has a modulating effect on the rainfall variability (Cavazos and Hastenrath, 1990; Kiladis and Diaz, 1989; Ropelewski and Halpert, 1989, 1986; Rogers, 1988) and the temperature (Kiladis and Diaz, 1989) in Northeastern Mexico, as well as a possible influence on Norte invasions (Cavazos and Hastenrath, 1990). According to Cavazos and Hastenrath (1990) the winter rains are intensified in Tamaulipas and Nuevo León during the low SO phase which is characterized, in Northern Mexico, by a marked influence of the midlatitude westerlies. However, Veracruz and the Isthmus of Tehuantepec, which are exposed to Norte invasions, are characterized by an increased winter rainfall during the high SO phase. This could imply that the frequency of Nortes decreases during the low SO phase, or that the Nortes are deflected before reaching the isthmus.

The present study analyzes the winter climate of the State of Nuevo León in connection with the Southern Oscillation based on stations with more than 20 years of rainfall and temperature data.

DATA

This study is based on long-term surface temperature and rainfall records, upper-air soundings, and an index of the Southern Oscillation. Monthly rainfall totals and monthly mean temperature for all stations in the State of Nuevo León with more than twenty years of data were obtained from the Comisión Nacional del Agua, Monterrey, N.L. (Figure 2). This compilation was used to initiate a bank of meteorological data of the region as well as to obtain a general climatological analysis of the state.

Four upper-air stations located along the coast of the Gulf of Mexico (Figure 1) were used to analyze monthly records of the southwest wind component and geopotential heights at 850 mb level. The data were extracted from US Weather Bureau, ESSA, NOAA (1957-1987).

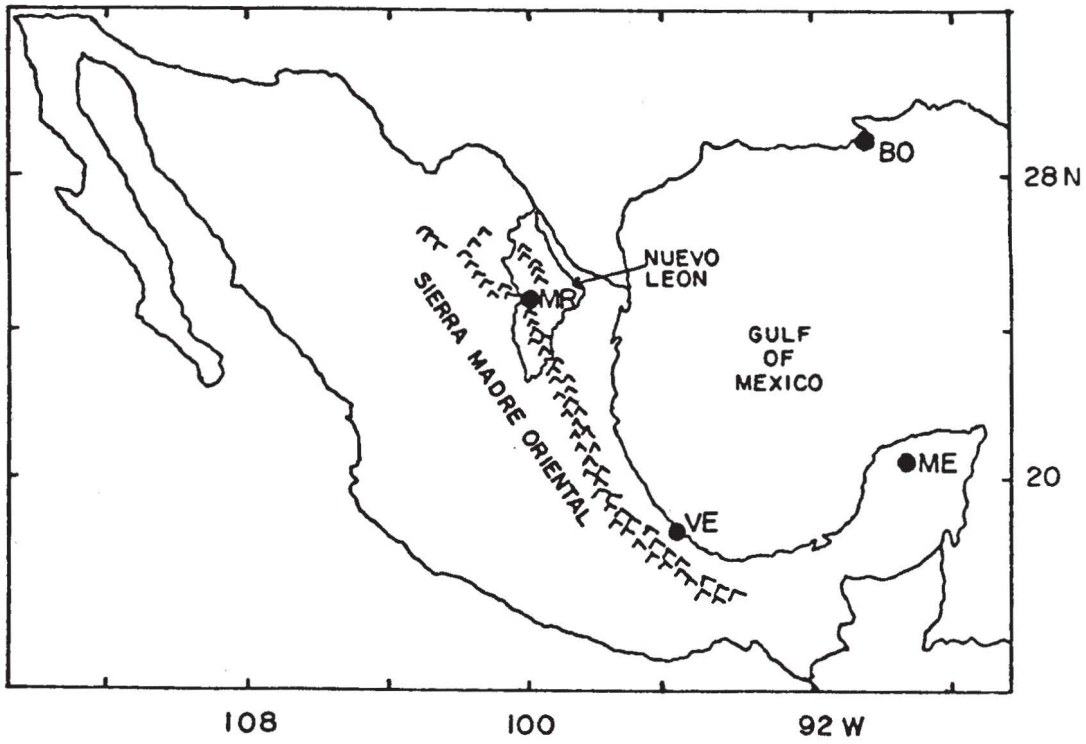

Fig. 1. Map of Mexico showing the State of Nuevo León and the location of four upper-air stations along the Gulf coast area. Boothville: BO, Monterrey: MR, Veracruz: VE, Mérida: ME.

For the Southern Oscillation (SOI), the difference in sea-level pressure at Tahiti minus Darwin was used. A high SO phase is defined by anomalously high/low pressure at Tahiti/Darwin.

WINTER CIRCULATION PATTERNS

Nuevo León state lies in a subtropical zone of intense interaction among maritime tropical (mT), continental tropical (cT), and continental polar (cP) air masses, which conflict to generate the extreme climate of the state. The general circulation over Northeastern Mexico is strongly affected by the North Atlantic high. During the summer semester (May/October) the humid easterly flow leads to the rainy season as illustrated by the annual rainfall patterns at representative stations (Figure 3). Rainfall and frosts during the winter semester (November/April) are produced by midlatitude cyclones incursioning into the subtropical zone. The Sierra Madre Oriental, trending SE to NW (Figure 1), contributes to the rising of air masses on the windward side of the mountains. It represents an orographic shadow for most of the southern part of the state (high plateau).

During northern winter, the upper-tropospheric circulation is dominated by the Subtropical Westerly Jet, with westerlies extending deep into the tropics (Hastenrath, 1988, p.107). Upper-air troughs and ridges cross over Mexico, determining the main weather features (Mosiño and García, 1974). At this time of the year, the trade winds affect only the southernmost portion of the country; rainfall is less in Northeastern Mexico. A subsidence inversion in the Gulf of Mexico produces a stratus deck at intermediate levels (Fitzjarrald, 1986); it is observed in Nuevo León during most of the winter.

The strong winds called "Nortes" in the Gulf of Mexico are usually caused by a combination of winter cyclones reaching far South of their normal track, with intense anticyclones in or near the Rocky Mountains. They are commonly preceded by a slow moving cold front and feature widespread cloudiness, low ceiling visibilities, and steady or gusty rains (Anonymous, 1963). The warm waters of the Gulf of Mexico cause low-level heating and enhance convection. The continental polar air masses pick up moisture from the Gulf of Mexico and produce light drizzle ("chipichipi") over the eastern slopes of the Sierra Madre Oriental (Mosiño and García, 1974). Such are the typical weather conditions in the northern and central parts of the state. When the surface temperature drops to 0°C for several hours or more the frost may damage native vegetation and crops. If the Nortes reach deeply enough they may move across the Sierra Madre and extend over the high plateau, generating low temperatures and/or some frontal rainfall.

Nuevo León has a semidry subtropical climate; in the Center and Southeast of the State a subtropical climate prevails due to the Sierra Madre Oriental. Frosts in this region have an incidence up of up to 20 days per year. In the high plateau, which is drier and features more clear winter

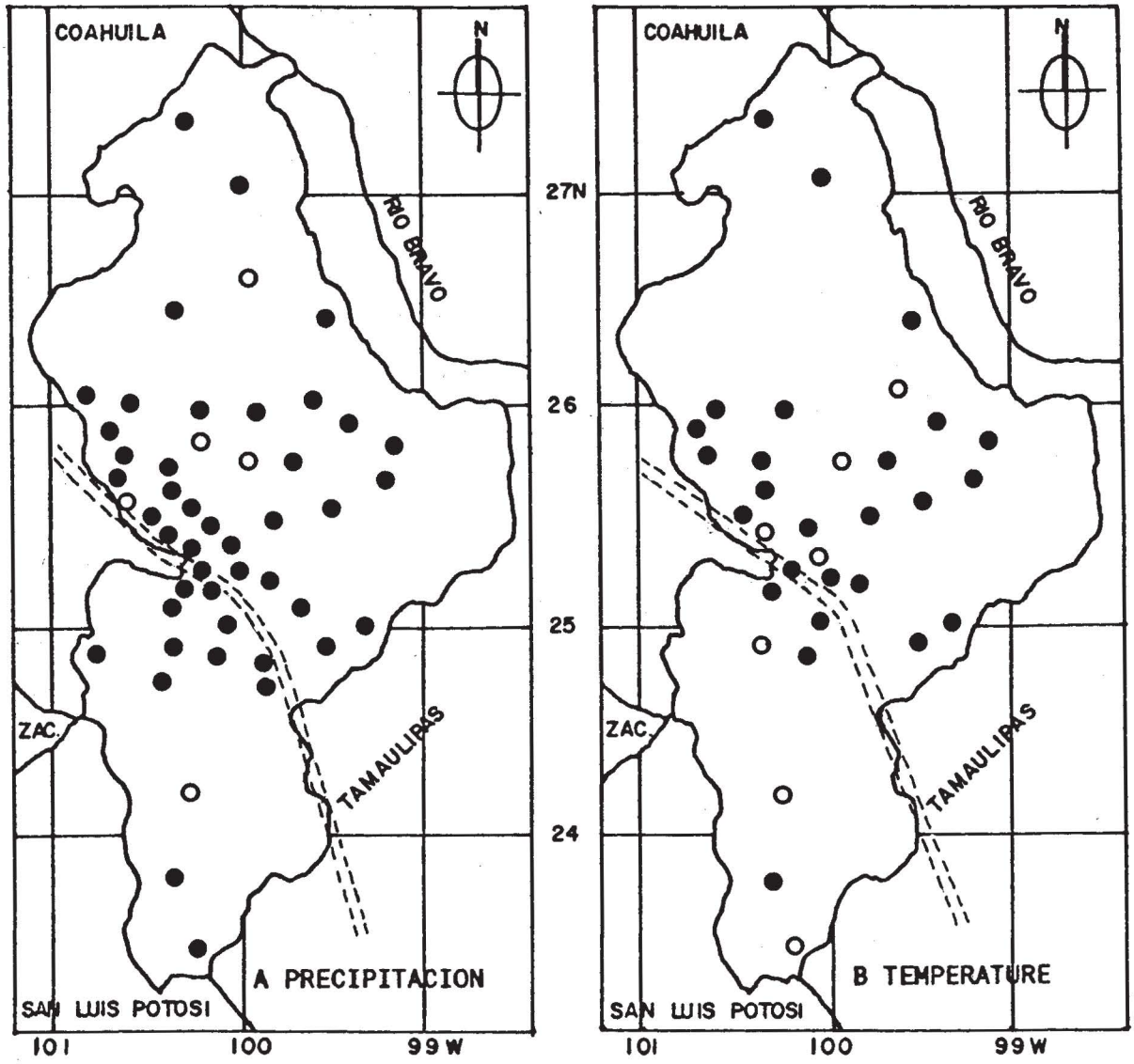

Fig. 2. Meteorological station network in Nuevo León with more than 20 years of (a) Precipitation and (b) Temperature data. Open (solid) circle represents a station with a record of 20-30 years (more than 30 years). Paralled broken lines represent the Sierra Madre Oriental. Period: 1940-88.

days, the frosts occur at a rate of 20 to 60 days per year (S.P.P., 1986, p.17). Frosts in the high plateau are mainly caused by radiation, though advection frosts are also common. Every year there are losses due to frost in the state. During the last 50 years, some uncommonly severe winters have occurred. In 1962, 1983, and 1989 cold cP air masses, sometimes called the "Siberian Express" (1983), caused temperatures to drop down to-11.5° C (1962). Cold air swept into the region for several days and a hard freeze caused severe damage to crops and vegetation. The orange groves in the southeastern part of Nuevo León were specially hit. The "Citrus Region" is the wettest of the state (600-1000 mm annually). It lies next to the Sierra Madre Oriental and is favored by heavy summer rainfalls as well as the winter drizzle produced by the Nortes, as illustrated by the two stations located to the northeast and adjacent to the Sierra (Figure 3; from Cavazos and Molina, 1993). However, even here the rains are very erratic: often the winter drought may extend to the middle of spring and delay the first sowing of the year.

A better knowledge of regional climatic variations would provide a useful management tool for planning strategies of limited natural, agricultural, and economical resources. The Southern Oscillation is not the only possible source of the winter variability in Northeastern Mexico. This study is an attempt to understand one link of the complicated chain of weather phenomena in the region.

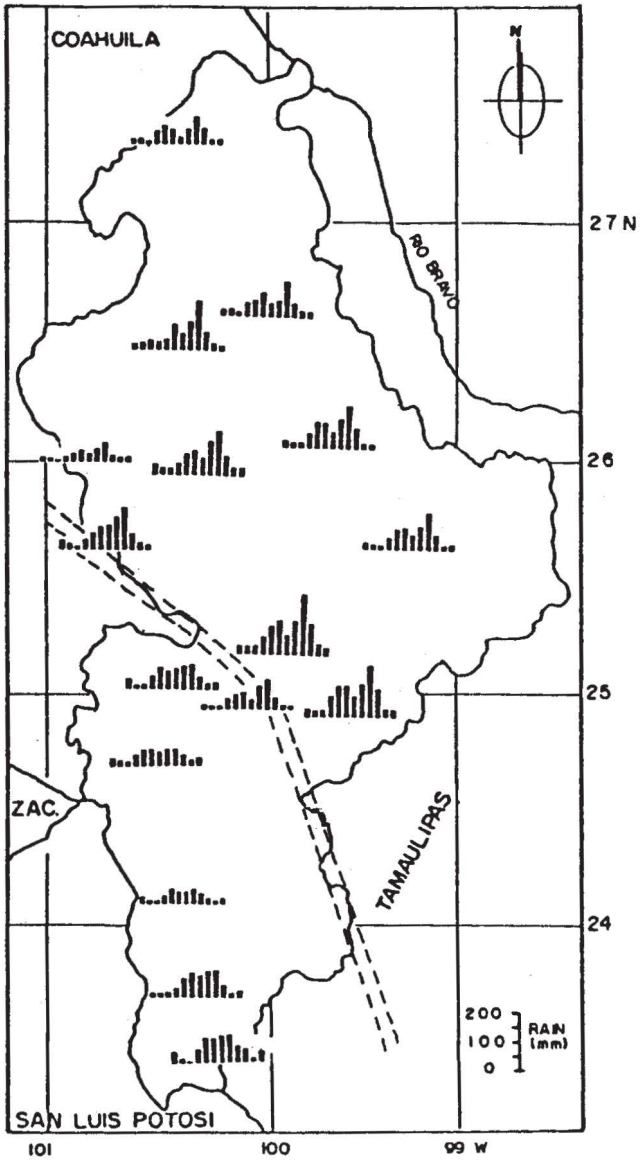

Fig. 3. Annual pattern of rainfall in some stations in Nuevo León. The northern and central parts of the state show two droughts, a short one during summer, called Canícula, and a longer one in winter. In the south of the state, to the lee side of the Sierra Madre Oriental, less rainfall is recorded peaking during summer when enhanced heating is typical over the high plateau. Parallel dashed lines represent the Sierra Madre Oriental.

RESULTS

Rainfall

A winter analysis of rainfall in Nuevo León as related to the Southern Oscillation Index (SOI, Ref. Sec. 3) is shown in Figure 4. All values were negative. Only results significant at 5 or 1 percent level are shown: Namely, November/December (Figure 4a) and January/February (Figure 4b).

The negative rainfall/SOI response suggests increased rainfall in Nuevo León during the winter of the low SOI phase. The significant values in the Center and North of the State (Figure 4) are very interesting, especially to the windward side of the Sierra Madre during January/February, suggesting enhanced rainfall during the low index phase.

Temperature

Winterly correlation patterns between mean temperatures and the Southern Oscillation Index are shown in Figure 5. Positive values indicate low temperatures in the state during most of winter (January/April) of the low SOI phase. The stronger correlations may reveal a marked influence of the Sierra Madre Oriental, in agreement with the rainfall results.

Upper-air

Winter correlations were also calculated between SOI and geopotential heights and the southerly wind component at 850 mb level for the stations shown in Figure 1. For analyses at higher levels see Aceituno (1989) and Douglas and Englehart (1981). Results along the coast of the Gulf of Mexico indicate lower geopotential heights during the low SO phase as illustrated by the positive values in Figure 6, especially at the height of northern winter (Figure 6b). Correlations between SOI and the southerly wind component are weak and do not show any particular pattern (Figure 7). However, during the low SO phase, northerly winds appear to dominate in the northern part of the Gulf coast, while southerly winds may prevail in the Mexican coasts as suggested by the negative values shown in Figure 7.

DISCUSSION

The following interpretation refers to the low SO phase. It is assumed that the opposite would be valid for the high phase of the SO.

According to the preceding results an increase of rainfall and lower temperatures in Nuevo León during winter of the low SO phase is expected. Some regional studies of the effects of the SO show similar results for Northeastern Mexico and the Southeastern United States (Kiladis and Diaz, 1989; Ropelewski and Halpert, 1989, 1986). Cavazos and Hastenrath (1990) obtained analogous results for precipitation in Northern Mexico and found enhanced midtropospheric westerly winds over Central and Northern Mexico during these events.

Aceituno (1989) points out that enhanced southern height gradients over the subtropics during the low SO phase, particularly at 500 mb in the winter of both hemispheres, are associated with an anomalously cold atmospheric column over Mexico and Florida. Douglas and Englehart (1981), Wallace and Gutzler (1981), and Horel and Wallace (1981) have found negative 700 mb height anomalies over the Southeastern United States. Douglas and Englehart (1981) suggest frequent invasions of polar

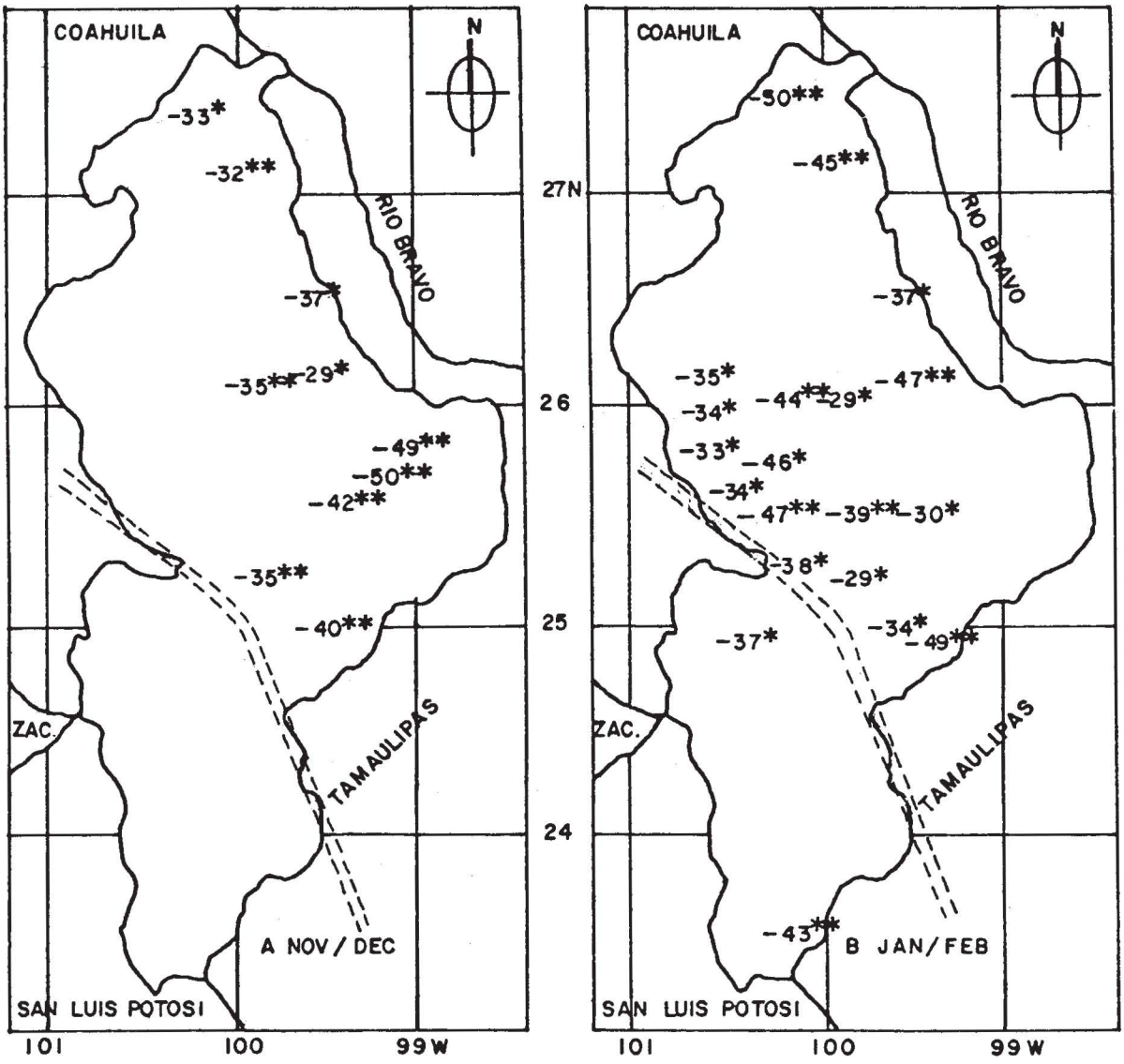

Fig. 4. Correlations (in hundredths) between a Southern Oscillation Index (SOI) and winter rainfall in Nuevo León. (a) November/December, (b) January/February. The March/April pattern was not significant and is omitted. Parallel dashed lines represent the Sierra Madre Oriental. One or two asterisks indicate significance at 5 or 1 percent levels, respectively. Quenouille's (1952, p. 168) method was used to account for the reduction of the effective number of degrees of freedom due to persistence. Only significant values (5 or 1 %) are shown.

fronts into the region and subsequent cyclogenesis in association with low-latitude split flow. Considering the southward displacement and anomalously intensity of the Subtropical Westerly Jet over Northern Mexico, and the invasion of mid-latitude frontal systems during northern winter of the low SOI phase, I believe that the increase of rainfall in Nuevo León may be due to the combined influence of mid-tropospheric westerly winds and Nortes at low levels. On the other hand, as mentioned in Section 4, the scarce winter rains in the region may be favored by Norte invasions. Only when these invasions are very deep, they can cross the sierra and penetrate the high plateau. This may explain the absence of significant values in the south of the state.

The results of Aceituno (1989) and Douglas and Englehart (1981) support our climatic winter analysis of Nuevo León. Moreover, the results at 850 mb level show a tendency to lower geopotential heights during winter of the SO phase. This suggests that a pressure low dominates the Gulf of Mexico especially during January/February (Figure 6.b). Beside enhanced westerly winds this implies lower temperatures, as suggested by the significant values found to the windward side of the Sierra Madre Oriental during most of winter (Figure 5). The tendency to lower temperatures is consistent with the precipitation results: a stratus deck would lower the surface temperatures. Some authors (Kiladis and Diaz, 1989; Yarnal and Diaz, 1986; Wallace and Gutzler, 1981) attribute this kind of cold

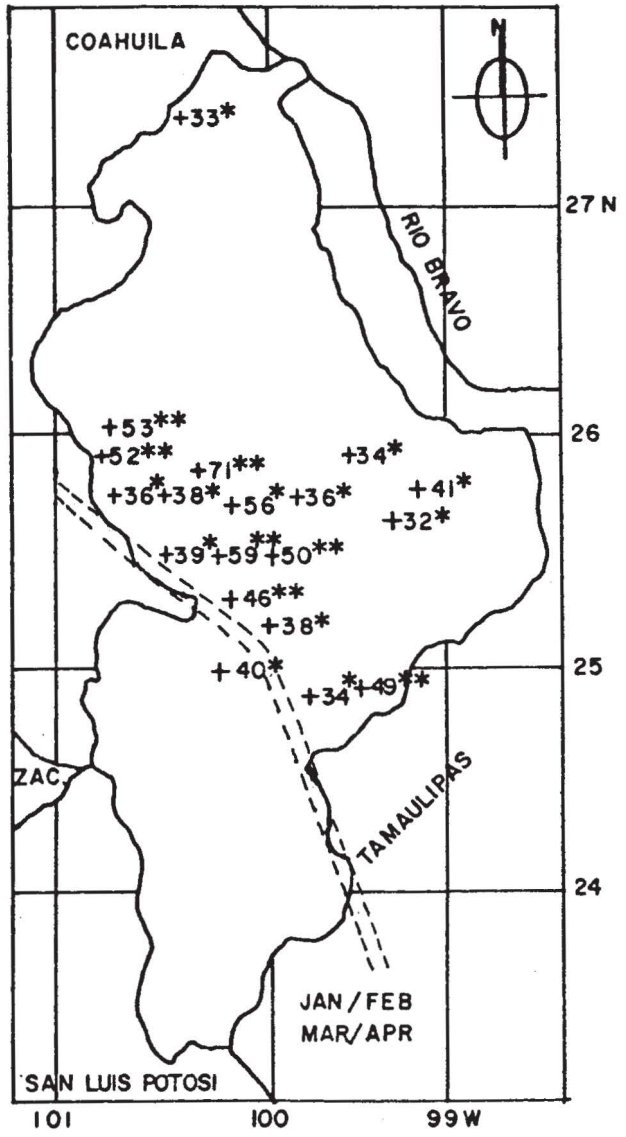

Fig. 5. Correlations (in hundredths) between an SOI and mean temperature in Nuevo León during January/February and March/April. The pattern for November/December was not significant. Symbols as in Fig. 4.

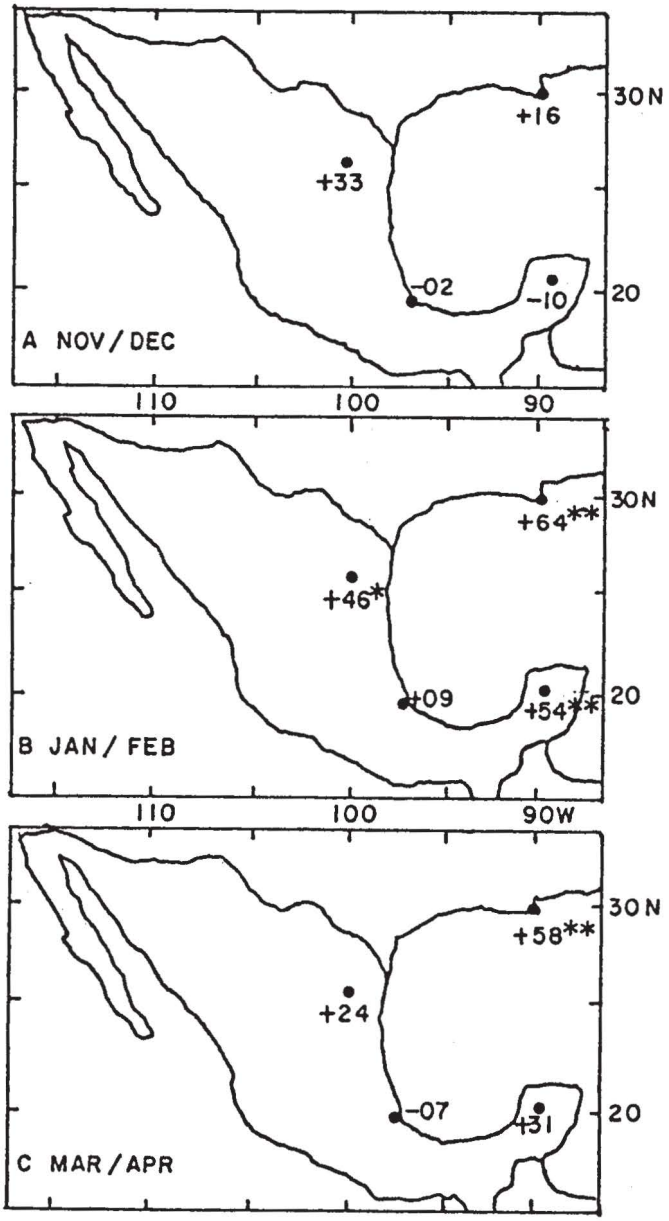

Fig. 6. Correlations (in hundredths) between an SOI and geopotential heights at 850 mb level during (a) November/December, (b) January/February, and (c) March/April. One or two asterisks indicate significance at 5 or 1 percent levels, respectively. Quenouille's (1952, p.168) method was used to account for the reduction of the effective number of degrees of freedom due to persistence.

winter response to the Pacific/North American (PNA) pattern, associated with a strong and southeasterly displaced Aleutian low, an anomalously strong blocking ridge over Western Canada and a deeper than normal upper-level trough located over the Southeastern United States.

As the results for the southerly wind component are not significant (Figure 7), their interpretation is weak. Negative values along the Gulf coast suggest southerly winds at 850 mb level during the low SO phase. For the station at Monterrey, (MO, Figure 1), this supports the hypothesis of enhanced winter rains over the region during the low SO phase: the Nortes generate rainfall over the eastern slopes of the Sierra after picking up moisture from the Gulf of Mexico, even though Nortes ususally move at lower levels.

In conclusion, the Southern Oscillation influences the winter climate of Nuevo León. Two possible modulating influences of regional character, viz. the Nortes and the Sierra Madre Oriental, will be discussed in a future investigation.

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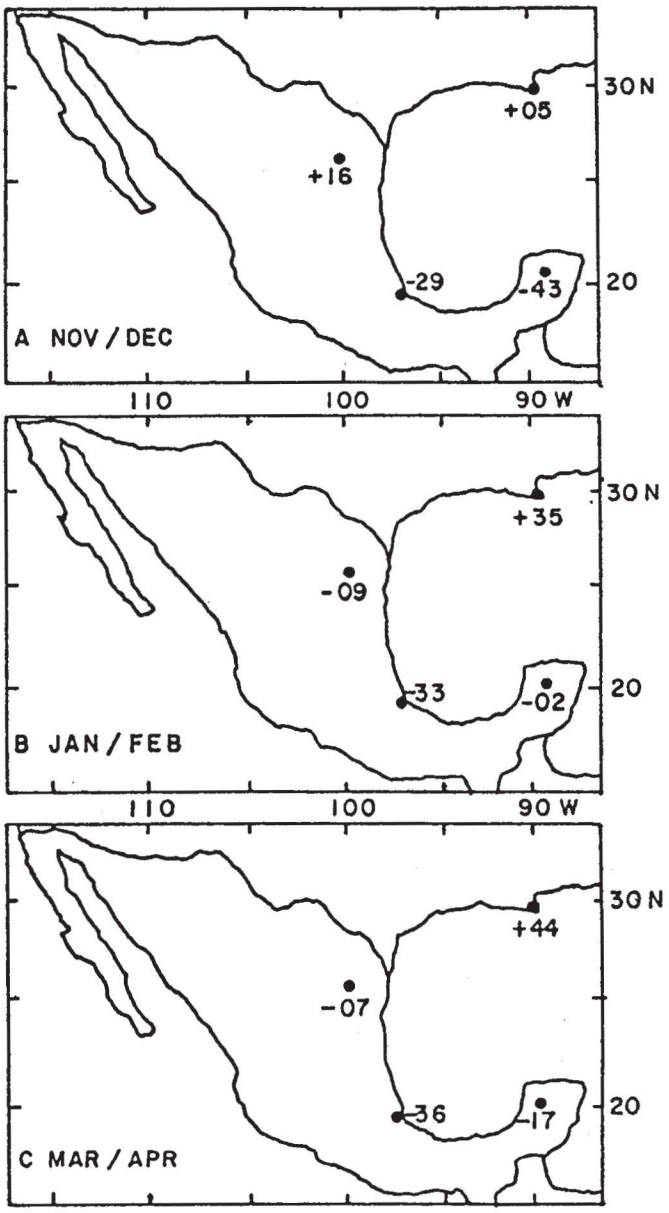

Fig. 7. Correlations (in hundredths) between an SOI and the meridional wind component at 850 mb level during (a) November/December, (b) January/February, and (c) March/April. Symbols as in Fig. 6.

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