CHAPTER 7: THE ENSO MODULATION OF THE CLIMATE OF MEXICO.

7.1. INTRODUCTION.

Previous chapters have shown that different climatic regimes exist in Mexico, and that clear changes are occurring in the most important meteorological variables. Several large-scale atmospheric controls modulate the climate of the country; among these teleconnections, the El Niño-Southern Oscillation exerts an important influence over the fluctuations of precipitation and temperature throughout the country (Magaña and Gay, 2001). Identification of the spatial and temporal patterns of these climatic fluctuations over Mexico is the aim of the chapter seven.

It is very well known that the climate of Mexico is highly seasonal (see section 2.3). In order to find linear correlations between rainfall and temperature with El Niño – Southern Oscillation (ENSO) Kendall's tau-b statistic (see section 3.3.5) will be applied. Annual, wet (May-Oct) and dry (Nov-Apr) season standardised versions of the extreme weather and ENSO indices are used. As the length of the time-series of Niño 3.4 and MEI starts in 1950 instead of 1931 for precipitation and 1941 for temperature, we have to deal with the fact that we cannot use the full capacity of these meteorological variables (see section 3.2.3). Based on the results of the regionalisation using Principal Component Analysis (see chapter 4), only regional precipitation averages are available and not regional temperature time-series.

Climatic responses to large-scale atmospheric controls are frequently delayed in time. For this reason, cross correlation is applied to find the optimal time-shifts that maximise the correlations between the meteorological variables and the ENSO indices; but also to check the spatial consistency when compared with the results of the direct linear correlations. For this purpose, monthly time-series of regional rainfall averages and extreme weather (precipitation and temperature) indices are (lag) correlated with the ENSO indices.

Linear and lag correlations are calculated in this chapter between the meteorological variables and the different ENSO indices. Section 7.2 describes the relationships between the SOI index and the meteorological variables. Linear correlations involving regional precipitation averages and the extreme weather indices are described in section 7.2.1, while the relationships of the same variables and SOI using lag correlation are explored in section 7.2.2. Analyses using the Niño 3.4 standardised index follow the same pattern: linear correlations with regional precipitation averages are assessed first and with extreme weather indices in section 7.3.1. Section 7.3.2 evaluates the lag correlations of El Niño 3.4 later with the same variables. Finally, sections 7.4.1 and 7.4.2 explore the linear and lag correlations respectively of MEI with regional precipitation averages and extreme weather indices.

The analysis of similarities and differences among the different results are evaluated in the concluding section 7.5. Spatial and temporal climatic patterns among the results from relationships with the ENSO indices are also analysed in this section.

7.2. THE SOI (SOUTHERN OSCILLATION INDEX) INFLUENCE.

The first analysis to be performed in this chapter is the linear correlation between standardised regional averages and SOI indices using Kendall tau-b (see section 3.3.5). The main purpose of the next sections is to correlate (linearly) the regional time series constructed using the results obtained with PCA and three different ENSO indices. The regional time series are classified into three different seasons: Annual, Wet (May-Oct) and Dry (Nov-Apr) seasons. For the rest of the chapter, the three ENSO indices considered in the correlations are: the Southern Oscillation Index (SOI), El Niño 3.4 index and the Multivariate El Niño Index (MEI).

Every time series are in their standardised versions in order to *explicitly avoid* (as much as possible) external influences in the analysis, like altitude (see section 4.2.1). The regional series of precipitation extend from 1931 to 2001 (sections 3.2.1 and 3.2.2), i.e., they use 71 years of instrumental data. Meanwhile, the three ENSO indices have different periods of record: SOI starts on 1866 and finishes in 2004, the Niño 3.4 index and MEI periods are shorter and extend from 1950 to 2004 (see section 3.2.3). Therefore, for this study, they differ in their starting year but coincide, in 2001 as the final year of instrumental temperature and precipitation data. The main objective when using three different standardised indices of ENSO is to test the consistency of the results (linear or lag correlations) with the regional precipitation series.

Basically, there is a correspondence (synchronised in time) between the time series of ENSO indices and regional precipitation when the (linear) correlations analysis are applied, except for the cases in which dry (the November and December months of the year before are computed) are correlated to wet seasons. For instance, wet season standardised versions of regional precipitation averages and SOI indices of 1932 can be correlated, but when we correlate the wet season regional precipitation averages with the

Dry Season SOI of 1932, we use the November and December 1931 indices of SOI also to calculate the November to April index of SOI. In these cases a lag response (frequently seen) is expected in the results, between large-scale atmospheric controls and the meteorological variables. A more precise example of this kind of lagged response will be presented in section 7.2.2 using monthly data.

7.2.1. LINEAR CORRELATION.

Regional Precipitation Averages.

The first analysis to be applied is a linear correlation (Kendall tau-b) between regional precipitation and the different seasonal versions of the standardised SOI index. As described in section 7.2., the SOI is the only index with the possibility of correlating with the regional precipitation series using the full potential of the dataset (1931 to 2001). Firstly, we will start with a description of the regions with the most significant (statistically speaking) results (Fig. 7.1), and at the same time extract the most important climatic patterns associated to these correlations. We have classified the results from positive/negative correlations and separated their levels of statistical significance at either the 5 or 1% level. The seasonal influence will be briefly mentioned here, as later on in this section a more specific analysis is made when the results are contrasted with the extreme weather indices.

One of the regions with the most consistent climatic patterns (being partly modulated) by the El Niño phenomenon is the northern area of the Baja Californian Peninsula (Magaña et al., 2003). In this region, regardless of season, all the statistically significant correlations are negative (for negative anomalies of SOI the regional precipitation is positive, i.e., above normal precipitation during El Niño years). Most of the correlations are statistically significant at the 1% level. This climatic pattern is consistent across all the seasonal (annual, wet and dry) time series for regional precipitation averages. Negative correlations are also observed within the North American Monsoon – also called the Mexican Monsoon – Region (NAMR). All these correlations are better than the 1% level of statistically significance, and the seasonality shows that they are mainly present during the dry season (Nov-Apr). It is worth pointing out that in the

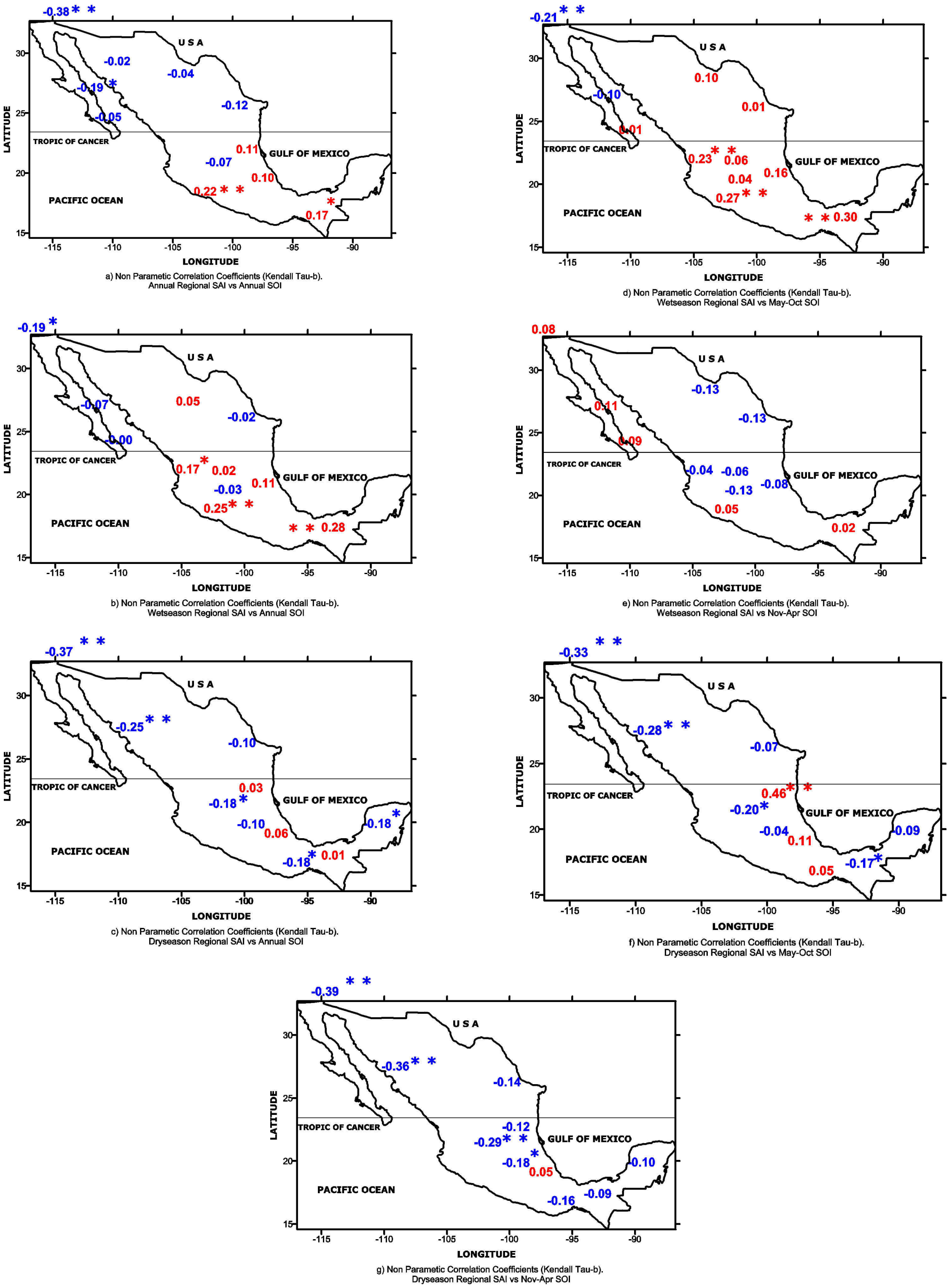


Fig. 7.1. Linear correlations (Kendall tau-b) between the standardised versions of the precipitation regional averages and the Southern Oscillation Index (SOI). Red numbers represent positive and blue numbers negative correlations. * means statistical significant at 5% level and ** at 1% level.

north-western part of Mexico; winter precipitation has a large influence (in percentage terms) on the annual rainfall totals (see section 4.1.2.2).

Some of the correlations between the regional precipitation and the annual SOI are better than the 1% level of statistical significance: positive correlations are observed during the rainfall wet season in the southern Pacific, particularly the south-eastern rainforest and the Michoacán state regions (negative annual SOI or El Niño-like conditions are associated to less than normal precipitation). The same climatic pattern of positive correlations (also statistically significant at the 1% level) is replicated during the May-Oct (wet) season for the south-eastern rainforest region [Fig. 7.1 b) and d)].

A consistent climatic pattern is observed across all the regions having the greatest correlations and statistically significant results: there is a clear latitudinal transition from north to south across Mexico (Cavazos and Hastenrath, 1990). It is interesting to note that this climatic pattern of the most statistically significant correlations is slightly concentrated geographically along the Pacific coast of Mexico. The North Pacific regions within the northern Baja California peninsula and the NAMR respond during the dry season with above normal precipitation during El Niño-like conditions, and dry regimes are seen for the same regions during La Niña [Figs. 7.1 c) and f)]. Meanwhile, the regions along the southern Pacific coast are associated with positive correlations, i.e., deficit rainfall (referred to their long-term means) during the El Niño phase.

Among all the statistically significant results, the greatest correlation (+0.46, better than the 1% of statistical significance) is seen in the La Huasteca (see Table 4.1) region [Fig. 7.1 f)]. This is the only significant result for this region, and is observed when the rainfall dry season is correlated to the wet season of SOI. Therefore, dry conditions are to be expected under El Niño-like conditions for La Huasteca region. Negative correlations (precipitation above normal, during El Niño) at better than the 1% of statistical significance are observed within the north-western part of Mexico, especially for the rainfall dry season combinations [Fig. 7.1 c), f) and g)]. It is well documented (Mosiño and García, 1974) that boreal winter precipitation (closely in correspondence to what is called the dry season of precipitation for the rest of the country) is very important in terms of the annual totals. This climatic pattern can be clearly noted in both the Mexican Monsoon and the northern Baja Californian regions during the November to April (dry season) period.

The Trans Mexican Volcanic Belt (TMVB or Neovolcanic axis) region is also affected during the dry rainfall season. Most of the stations, in this region, are located at high altitudes. Therefore, as mentioned in section 2.2, the precipitation within this region is strongly influenced – among other geographical factors - by polar fronts (Jauregui, 1997) during the Northern Hemisphere winter. Negative correlations (precipitation below normal) are observed, in this region of high altitude stations, relating the dry rainfall season to both the annual and wet seasons of SOI. All these results are statistically significant at the 5% level.

Earlier in this section, when analysing the stations with the most significant correlations, it was mentioned that, for the annual totals and wet season for precipitation (see Fig. 7.1), a latitudinal response of the climate of Mexico can be observed during El Niño conditions: wetter patterns for the northern part of the country and drier conditions in the south, and that they are mainly geographically concentrated along the Pacific coast (Englehart and Douglas, 2001). The clearest latitudinal climatic transition is found when the Annual SAI (precipitation regional averages) is correlated to the Annual SOI [figure 7.1 a)]. Quite similar, but less clear is the climatic picture when we observe the relationships between wet (May-Oct) SAI (Standardised Anomaly Index) and the annual SOI [figure 7.1 b)].

A similar analysis to the latitudinal climatic features can be applied searching for coastal or continental climatic patterns related to the most (statistically) significant results. Seasonality also plays an important role in the relationships, with annual and wet seasons for the SOI having the clearest results. The greatest correlations are strongly linked to the annual SOI [Figs. 7.1 a), b) and c)]. Utilising either the annual or wet (season) versions of the SAI, the results exhibit a clear coastal pattern, especially along the Pacific coast, probably with SST as a modulator (Giannini et al., 2001). These are the same combinations that have the best results for the latitudinal climatic transition. However, the largest correlations are found for the annual compared to the wet season SOI. Two regions appear consistently with statistically significant correlations: the Northern part of the Baja Californian peninsula and the south-eastern regions. No continental/coastal climatic pattern is found when using the dry season (Nov-Apr) SOI for correlations [Fig. 7.1 e) and g)].

Of all the seven possible combinations (see fig 7.1), it is the annual SOI [Figs. 7.1 a), b) and c)] that best modulates the rainfall in Mexico, i.e., showing the largest and statistically significant correlations. It can be easily observed in the maps that relate the annual SOI with both the annual and wet season (May-Oct) SAI; a latitudinal climatic transition is clearly seen, especially when the annual SOI is correlated to annual SAI, with greater correlations than when combining with wet season (May-Oct) SAI. The responses of the dry season (Nov-Apr) SAI (regional precipitation) to the annual SOI show a nationally widespread pattern of negative correlations (wetter conditions during El Niño-like years). The Yucatan Peninsula region (RD7 in Table 4.3) is the most interesting result here, although it does not have the largest correlation. It seems that the highly variable amount of rainfall during the hurricane season has an important influence for the rest of the other seasons of SOI (see also section 4.1.2). Wet (May-Oct) and dry (Nov-Apr) seasons SAI have two very different responses to the wet season (May-Oct) SOI. An almost nationally widespread pattern of positive correlations (drier conditions during El Niño phase) can be observed for the wet season (May-Oct) SOI, except for some regions along the Gulf of Mexico, especially for the La Huasteca region (RA7 in Table 4.1), that has the largest correlation (with annual SOI) of all the seasonal combinations. Lastly, when the impact of the dry season (Nov-Apr) SOI is considered, an almost national coverage of negative correlations (wetter conditions during El Niño) can be perceived, the strongest relationships are present within the north-western part of the country especially the North American Monsoon and the North Baja California regions.

Meanwhile, no clear climatic pattern is observed when the dry season (Nov-Apr) SAI and wet season (May-Oct) SOI are correlated [Fig. 7.1 f)].

Extreme Weather Indices.

Precipitation.

For this research, besides the regional precipitation averages, we have correlated the Southern Oscillation Index with the extreme weather indices. Precipitation and extreme temperature indices were extracted using the R software (see chapters 5 and 6). To calculate the extreme indices, daily data of temperature and rainfall extending from 1941 to 2001 have been used (chapter 5), while for the regional average analysis, monthly data (1931-2001) was used (chapter 6). In addition, we are changing the analysis from regional (PCA regions averages, see section 3.3.3) to local (sites) time series; therefore, the results of this analysis can be contrasted with those of the regional series. Both data sets are correlated with three different seasonal (annual, wet –May-Oct- and dry –Nov-Apr-) SOI indices in their standardised versions.

The first analysis performed in this section is to correlate linearly the standardised annual SOI and the extreme precipitation indices (refer to section 3.3.4 for extreme weather indices definitions). As mentioned in the former section, the SOI index allows the use of the full length of the extremes time-series. It is important to note here the practical impossibility, for most of the indices, of dealing (as monthly indices are not available in the results, but only the extreme annual rainfall indices) with seasonal versions of the indices of extremes.

The set of precipitation extreme indices when correlated with the annual SOI show clear results and climatic patterns for two of the indices: Consecutive Dry Days (CDD) and the annual maximum 1-day precipitation (RX1day). These indices are presenting two different aspects of the rainfall extremes evaluation with drier conditions for the former and wetter conditions for the latter. The CDD index map [Fig. 7.2 a)] depicts a clear national pattern of positive correlations, mainly concentrated in the northern part of the country, where four out of the five most statistically significant correlations are found.

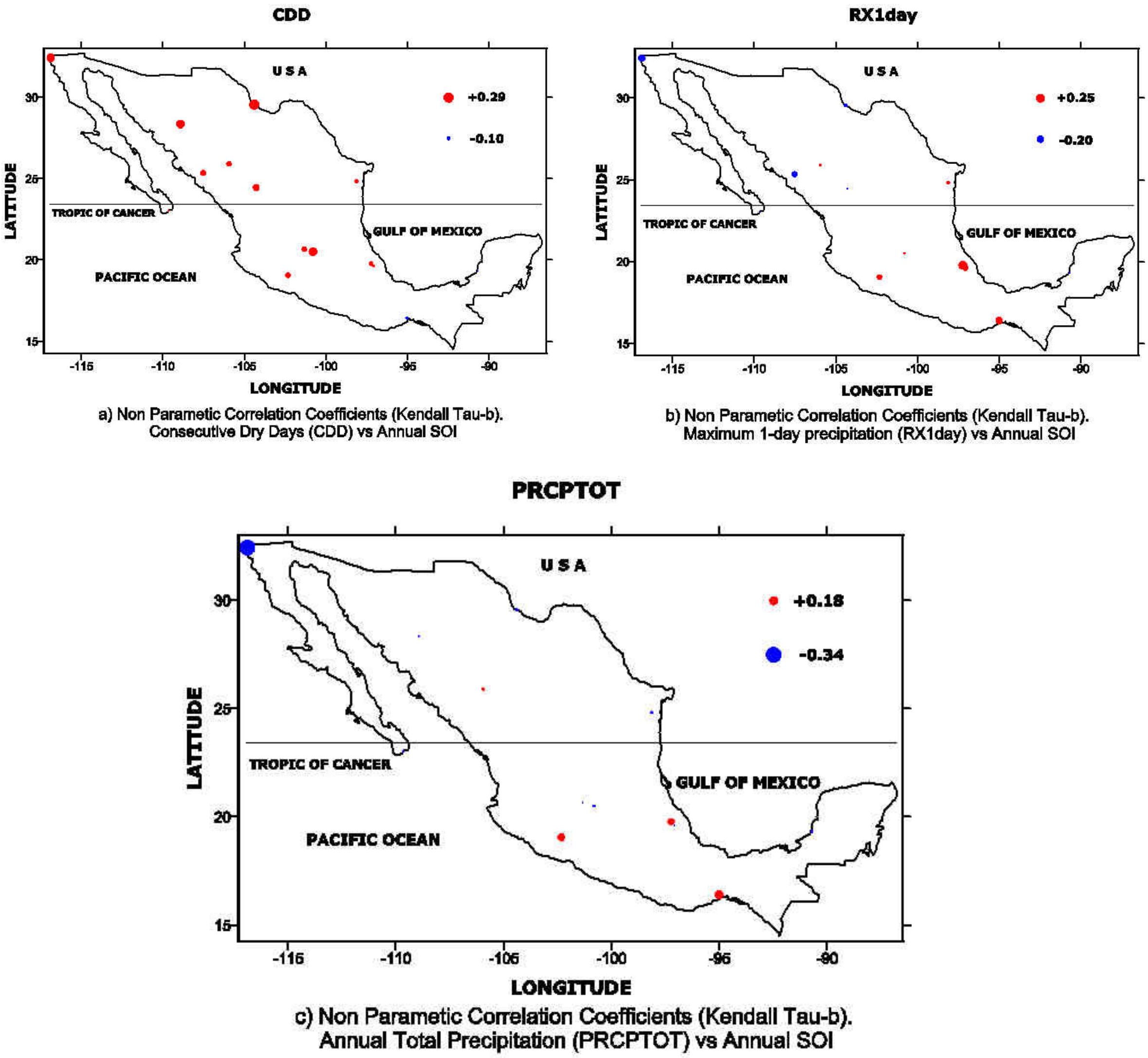


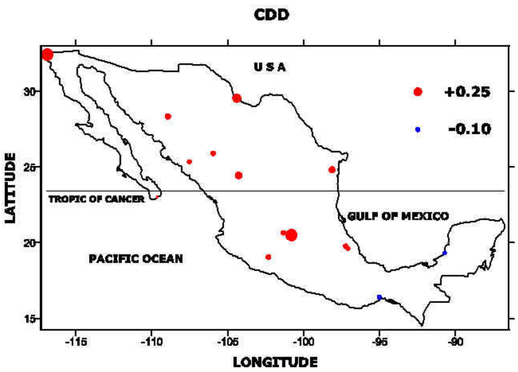
Fig. 7.2. Linear correlations (Kendall tau-b) between the Extreme Precipitation Indices and the Annual Southern Oscillation Index (SOI). Circles in red are representing a positive and in blue negative correlations.

Then, during El Niño (Niña) atmospheric conditions below (above) normal precipitation is experienced especially in the northern (southern) Mexico. In the meantime, RX1day [Fig. 7.2 b)] is linked to a latitudinal climatic transition: positive correlations south the Tropic of Cancer (considering this as a geographic limit) and negative in the northern part of the country. But, there is also a longitudinal transition: southern (positive) correlations are related to the Atlantic Ocean (Gulf of Mexico), while the negative (northern) correlations are linked to the Pacific Ocean: three out of the four statistically significant correlations are located at the stations along the Pacific Ocean.

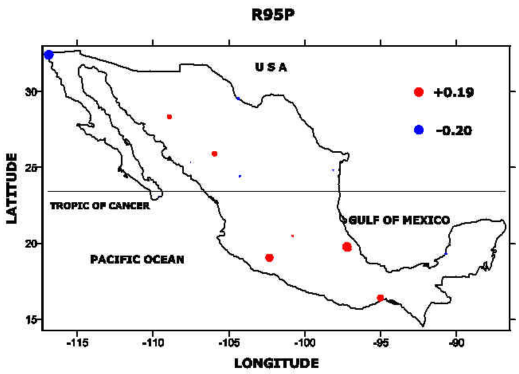
There are two stations having the most statistically significant results, for CDD and RX1day: Presa Rodríguez, BC, in the Baja Californian peninsula; and Atzalán, Ver. in the Gulf of Mexico (station numbers 2 and 34 in Table 5.1). Negative correlations are prevalent in the extreme indices of the Presa Rodríguez station, i.e., during El Niño-like conditions above normal precipitation is observed here; geographically speaking, this station is located in the most north-western part of the country, north of the *Tropic of Cancer*. Below normal precipitation is observed in Atzalán, Ver.; which is located south of the Tropic of Cancer. Positive correlations (+0.25) for RX1day mean that during El Niño phase, drier conditions are dominant at this location. The largest correlation (-0.34) of all the extreme indices (when correlated with the standardised annual SOI) is found for the total annual precipitation (PRCPTOT) [Fig. 7.2 c)] at La Presa Rodríguez station. The negative correlation indicates that above normal precipitation is linked to El Niño-like conditions (negative SOI).

Similar to the correlations for precipitation extreme indices with the annual SOI, the standardised version of the wet season (May-Oct) SOI was used to calculate linear correlations. As mentioned in section 2.2.1 the wet season accounts for at least 70% of the total annual precipitation across much of the country. Therefore, it is expected that some similarities arise between the correlations utilising annual SOI and wet season SOI.

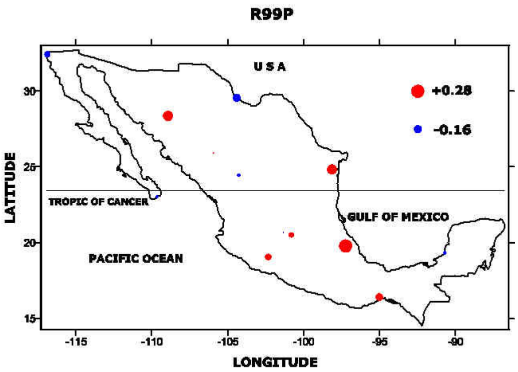
We can start reviewing the maps of extreme indices (Fig. 7.3) with the best correlations, as already done using the annual SOI. The precipitation extreme indices that show the clearest climatic patterns are: CDD, R95P, R99P, RX1day and PRCPTOT (for their definitions refer to section 3.3.4). With the exception of CDD [Fig. 7.3 a)], the rest of the rainfall indices are linked to wetter conditions. In fact, three out of five of these indices are related to a heavy rainfall threshold (R95P, R99P and RX1day), and as their units are millimetres, they can be directly compared with precipitation totals or the normal amount.



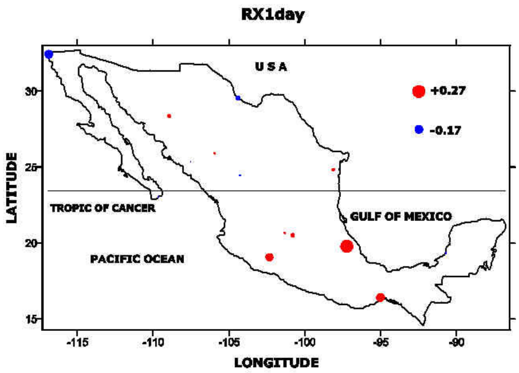
a) Non Parametic Correlation Coefficients (Kendall Tau-b).
Consecutive Dry Days (CDD) vs Wet SOI



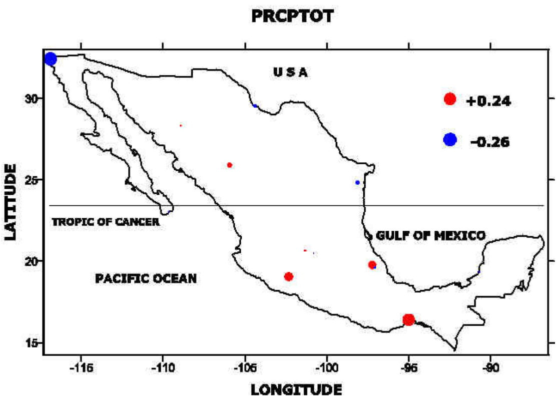
b) Non Parametic Correlation Coefficients (Kendall Tau-b).
Very Wet Precipitation (R95P) vs Wet SOI



c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Extremely Wet Day Precipitation (R99P) vs Wet SOI



d) Non Parametic Correlation Coefficients (Kendall Tau-b).
Max 1-day precipitation (RX1day) vs Wet SOI



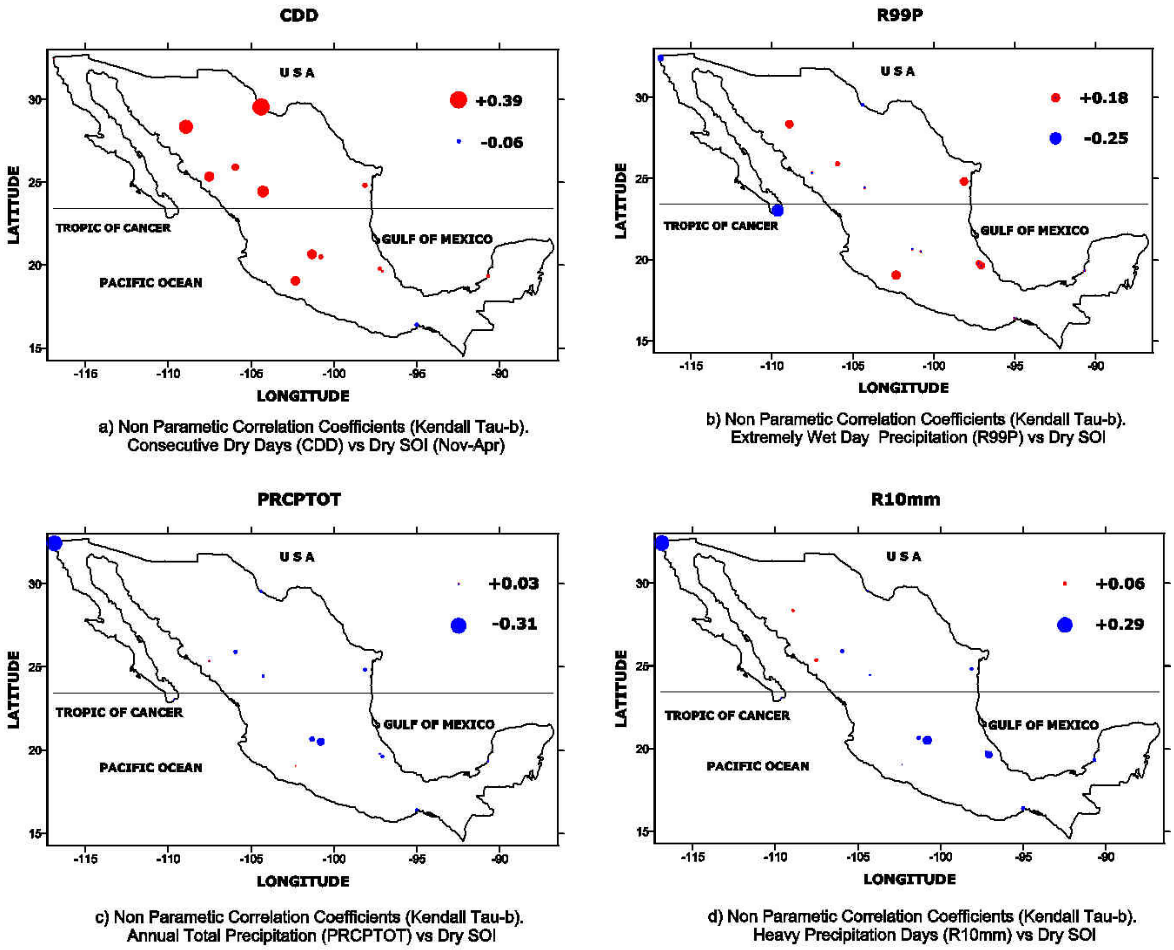
e) Non Parametic Correlation Coefficients (Kendall Tau-b).
Annual Total Precipitation (PRCPTOT) vs Wet SOI

Fig. 7.3. Linear correlations (Kendall tau-b) between the Extreme Precipitation Indices and the May-Oct (wet season) Southern Oscillation Index (SOI). Circles in red are representing a positive and in blue negative correlations.

Among the results with the clearest patterns, the only index that directly measures drier conditions is CDD. Positive correlations are widespread nationally for this index. According to these linear relationships between the wet season SOI and CDD [Fig. 7.3 a)], wetter conditions are mainly observed during El Niño-like conditions. Nevertheless, amongst all the stations only two have statistically significant results: Celaya in Central Mexico, and Presa Rodríguez in the most north-western part of the country (station numbers 16 and 2 in Table 5.1) . More days exceeding the 95th percentile (R95P) are seen in a nearly nationally widespread pattern of positive correlations [Fig. 7.3 b)]. This means that during El Niño conditions fewer rainy days surpass the 95th percentile. For the R95P index, Atzalán and Presa Rodríguez (station numbers 34 and 2 in Table 5.1) are the only stations with statistically significant results: positive for Atzalán and negative correlation for Presa Rodríguez. Although, no clear climatic pattern is observed for the index that measures days exceeding the 99th percentile [(R99P, Fig. 7.3 c)], it can be mentioned that the most important results are located along both coasts. It is worth noting that two out of the three stations with statistically significant correlations, are found along the Gulf of Mexico. There is no latitudinal climatic transition in these correlations, but two of these stations with statistically significant results are located north of the tropic of Cancer: Yecora within the Mexican or North American Monsoon Region –NAMR- (RA11 in Table 4.1) and San Fernando in the North-eastern part of the country (station numbers 32 and 33 in Table 5.1). Meanwhile, Atzalán (located in the Los Tuxtlas region; station number 34 in Table 5.1) is the only station with a correlation better than the 1% statistical significant level. Similar correlation patterns to those of R95P are found for the RX1day index [Fig. 7.3 d)]. Positive correlations are dominant across the country, however only Atzalán station, which is located on the Gulf of Mexico, has a positive correlation that is better than the 1% level of statistical significance. Finally, the PRCPTOT [Fig. 7.3 e)] index shows a climatic pattern similar to that of R95P with almost a national pattern of positive correlations, except the Presa Rodríguez station in the most north-western part of Mexico (station number 2 in Table 5.1) with a negative correlation, and statistically significant at the 1% level. The other largest correlation is located at Juchitán (station number 27 in Table 5.1) within the Southern Pacific coastal region.

The regional climatic features of the ENSO modulation during the May to October period were explored earlier in section 7.2.1. Now, we will evaluate local responses of the extreme climate indices to the wet season SOI, and some interesting climatic features arise. The stations that appear more frequently with statistically significant results are: Presa Rodríguez (north-western Mexico; station number 2 in Table 5.1), Atzalán (Central Gulf of México; station number 34 in Table 5.1) and Juchitán (Southern Pacific coastal region; station number 27 in Table 5.1). The Presa Rodríguez station has statistically significant results for the SDII, CDD, CWD, R20mm and PRCPTOT. A closer study of those correlations shows that, in general, during El Niño conditions, above normal precipitation is prevalent at this location. The station at Atzalán, Ver. shows statistically significant positive correlations in the rainfall extreme indices SDII, R95P, R99P and RX1day. Interpreting the relationships of these indices with the wet season SOI it can be concluded that, during prevalent El Niño conditions, mainly below normal precipitation is observed at Atzalán station. Juchitán in Oaxaca State shows significant correlations for the R20mm, RX5day and PRCPTOT indices. At this station, all the correlations relate to drier conditions during El Niño phase (Cavazos and Hastenrath, 1990). Probably, more stations with statistically significant results are required to strongly support this conclusion, but it can be said that above normal precipitation is observed north of the Tropic of Cancer and drier conditions south of this defined geographic limit during with El Niño-like years.

The last analyses of linear correlation (Kendall tau-b) are now to be applied between the dry season SOI (November to April) and the rainfall extreme indices. As mentioned in section 4.1, for most of Mexico, the dry season does not account for much of the precipitation totals, except in the north-western part of the country (winter precipitation prevails in this latter region, Magaña et al., 2003). For this reason, it is expected that the dry season SOI climatic patterns differ in some sense from those of the other seasons [annual and wet (May-Oct) season].



a) Non Parametic Correlation Coefficients (Kendall Tau-b). Consecutive Dry Days (CDD) vs Dry SOI (Nov-Apr)

b) Non Parametic Correlation Coefficients (Kendall Tau-b). Extremely Wet Day Precipitation (R99P) vs Dry SOI

c) Non Parametic Correlation Coefficients (Kendall Tau-b). Annual Total Precipitation (PRCPTOT) vs Dry SOI

d) Non Parametic Correlation Coefficients (Kendall Tau-b). Heavy Precipitation Days (R10mm) vs Dry SOI

Fig. 7.4. Linear correlations (Kendall tau-b) between the Extreme Precipitation Indices and the Nov-Apr (dry season) Southern Oscillation Index (SOI). Circles in red are representing a positive and in blue negative correlations.

Among the correlations between the extreme rainfall indices and the dry season SOI, the most (statistically) significant results are seen for the CDD, PRCPTOT and R99P indices. The CDD [Fig. 7.4 a)] shows that the most statistically significant results are located along the Pacific Ocean coast especially within the North American Monsoon (or Mexican Monsoon) Region (NAMR; RA11 in Table 4.1). This is an area in which winter precipitation has an important role in the annual rainfall totals, as mentioned in section 2.2.1. Strong EL Niño (La Niña) conditions reinforces the oceanic and atmospheric conditions that lead to wetter (drier) patterns along the Pacific Ocean coast in Mexico. The scale of the results is larger than regional: a nationally widespread pattern of positive correlations with the dry season is observed. This means that, during El Niño, wetter conditions or fewer Consecutive Dry Days are prevalent nationally. Above normal precipitation is also observed for the PRCPTOT index [Fig. 7.4 c)] during El Niño conditions. A national pattern of negative correlations for PRCPTOT show wetter conditions during the negative phase of SOI. However, only two of these stations have statistically significant correlations: Celaya in Central Mexico, and Presa Rodríguez in Tijuana (station numbers 16 and 2 in Table 5.1), whose correlation is better than the 1% level of statistical significance. The next two indices with the clearest results are related to a set limit, one expressed in mm and the other in percentage terms. Nevertheless, these indices show two very different responses for dry season SOI: negative for R10mm and positive correlations for R99P. Negative correlations are dominant across the country for the R10mm index [Fig. 7.4 d)] for Mexico this means more rainy days exceeding the 10mm threshold. Among all these results only three of them are statistically significant, but only La Presa Rodríguez (station number 2 in Table 5.1) has a correlation better than 1% statistical significance. In the meantime, a continental pattern of positive correlations is seen for R99P [Fig. 7.4 b)], although none of these results are statistically significant, while a completely different pattern of negative correlations are seen across the Baja Californian peninsula, where the station at San José del Cabo has the largest correlation that is statistically significant at the 1% level.

Amongst all the results using the dry season SOI, Ojinaga and Yecora within NAMR (RA11 in Table 4.1) have the largest correlations throughout all the rainfall extreme indices. Both stations have the best correlations for the CDD index, and better than the 1% statistical significance level. These results strongly support what has been already established in section 4.2.1 about the importance of the winter precipitation in the Mexican Monsoon region (Ropelewski et al., 2004). Therefore, at regional and local levels, the CDD correlations are climatically coherent. It can be said that, across México, less Consecutive Dry Days (and possibly precipitation above normal) can be expected during El Niño conditions.

Temperature.

Another aspect of extreme weather likely related to SOI is the daily temperature. At two different levels, the correlations from this study can be compared with the former results: at the local level with the correlations from the extreme rainfall indices, and at the regional scale with the results from the regional precipitation averages. The temperature extreme indices will be correlated, consecutively with annual, wet (May-Oct) and dry (Nov-Apr) season standardised versions of the SOI; just as undertaken for regional precipitation averages and rainfall extremes indices in the previous section.

Annual SOI.

Maps of temperature extreme indices correlated with the annual SOI that have the clearest results include: TR20, TN10p, TN90p, TX90p, DTR and TXx (for definitions refer to section 3.3.4). For an easy interpretation, these indices will be analysed in groups according to the units by which they are measured (days, %, and °C). The results for the TR20 index [Fig. 7.5 a)] show a nearly national climatic pattern of negative correlations. Despite this, statistically significant results are geographically concentrated along the Pacific Coast, north of the Tropic of Cancer, within the NAMR and the Baja California peninsula. These correlations are pointing to a slight increase in warmer (tropical) nights during El Niño conditions. The next three indices evaluated are associated with percentile thresholds: TN10p, TN90p and TX90p, and they are expressed as a percentage of days per year. The first two indices are related to night and the last to day temperatures. An almost national climatic pattern of positive correlations is observed for the TN10p index [Fig. 7.5 b)]. Climatically, this means that the percentage of days the temperature is below the 10th percentile is reduced, i.e., during the negative phase of the Southern Oscillation (El Niño) a warming on minimum temperatures is experienced. Statistically significant results are concentrated along the Pacific Coast, especially in the Baja California peninsula. Correlations better than the 1% level of statistical significance are found north of the Tropic of Cancer. A widespread warming signal is also seen across

Mexico during El Niño-like years for TN90p [Fig. 7.5 c)]. There is a slight concentration of statistically significant (negative) correlations in the southern part of the country. The largest correlations are found at Atzalán (-0.25) and Matías Romero (-0.23) stations, the former located along the Gulf of Mexico coast, and the latter on the southern Pacific coast. Significant results are also found in central Mexico and the Baja California Peninsula. The TX90p index [Fig. 7.5 d)] shows a similar climatic pattern to that of TN90p. Negative correlations are present almost nationally. Just as with TN90p [Fig. 7.5 c)], all the largest correlations are significant at the 5% level of statistical significance, except Atzalán (station number 34 in Table 6.1) that is significant at the 1% level. According to these results, cooler temperatures are dominant during El Niño conditions for TX90p. The DTR index [Fig. 7.5 e)] is also showing an almost national pattern of positive correlations, except for one of the southernmost stations (Santo Domingo Tehuantepec) on the South Pacific coast with a statistically significant result. Therefore, during El Niño conditions DTR decreases. According to the results, this decrease of the DTR index is likely caused by a net increase in minimum temperatures. Finally, for the TXx (Hottest Day) index , a clear pattern of negative correlations is seen along the Mexican Pacific coast, but it is only the station at Matías Romero in Oaxaca (station number 28 in Table 6.1) that has a correlation (-0.31) better than the 1% level of statistical significance. Meanwhile, positive correlations are observed in continental central and northern Mexico, but only the correlation at San Fernando (station number 33 in Table 6.1) is statistically significant. The results for the TXx lead to warmer maximum temperatures during El Niño phases.

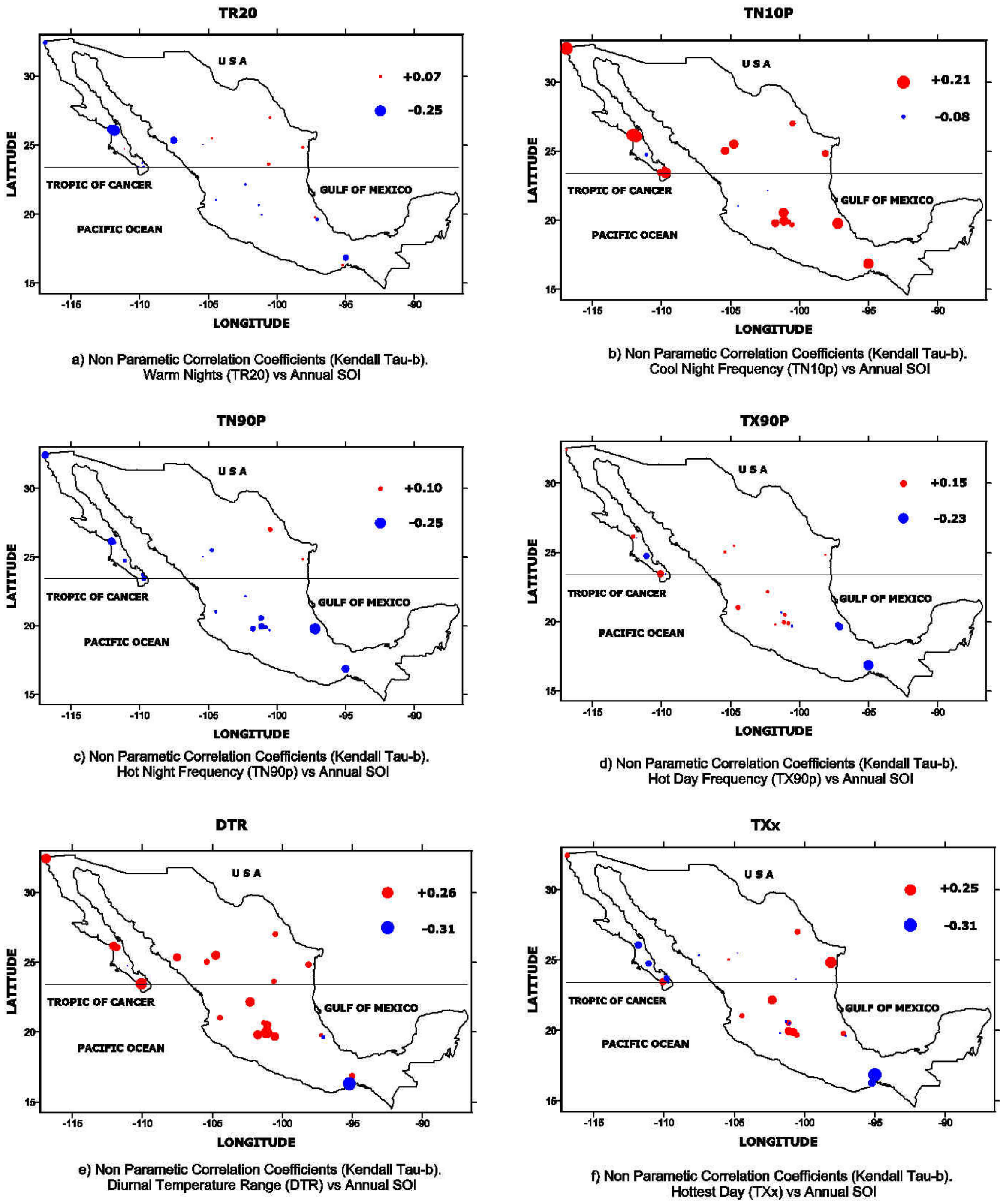


Fig. 7.5. Linear correlations (Kendall tau-b) between the Extreme Temperature Indices and the Annual Southern Oscillation Index (Annual SOI). Circles in red are representing a positive and in blue negative correlations.

Observing the stations with the largest (linear) correlations among the temperature extreme indices, we found that Matías Romero (station number 28 in Table 6.1) is the station that has the most statistically significant results (TX10p, TX90p and WSDI). According to its correlations, during the El Niño phase, warmer conditions are found at this site in the southern Pacific coastal region. In order to compare with a station north of the Tropic of Cancer that also has the largest number of statistically significant results, we have selected San Fernando (station number 33 in Table 6.1), in the north-western part of the country, near the Gulf of Mexico. This location has statistically significant results for SU25 and WSDI. The indices correlations for San Fernando show cooling conditions during El Niño phase. In general, an evident pattern of warmer temperatures during El Niño conditions (utilising the standardised annual SOI index) is seen among the different extreme temperature indices. This is especially true for the minimum temperatures that show consistently increased values in their associated indices during El Niño.

Wet Season SOI.

In order to directly compare with their counterparts from the regional rainfall series and precipitation extreme indices, wet season SOI is used in this section for correlation with the temperature extreme indices. Linear correlations are applied between the wet season (May-Oct) SOI and the temperature extreme indices. The indices with the clearest results and their corresponding maps are going to be analysed dividing them into three different groups according to their measurement units. The first indices to be analysed are FD0 and SU25 (days). TN10p and TN90p are the indices with a percentage limit to be interpreted after. Finally, measured in degrees Celsius (TNn and TXx) are the last indices to be considered.

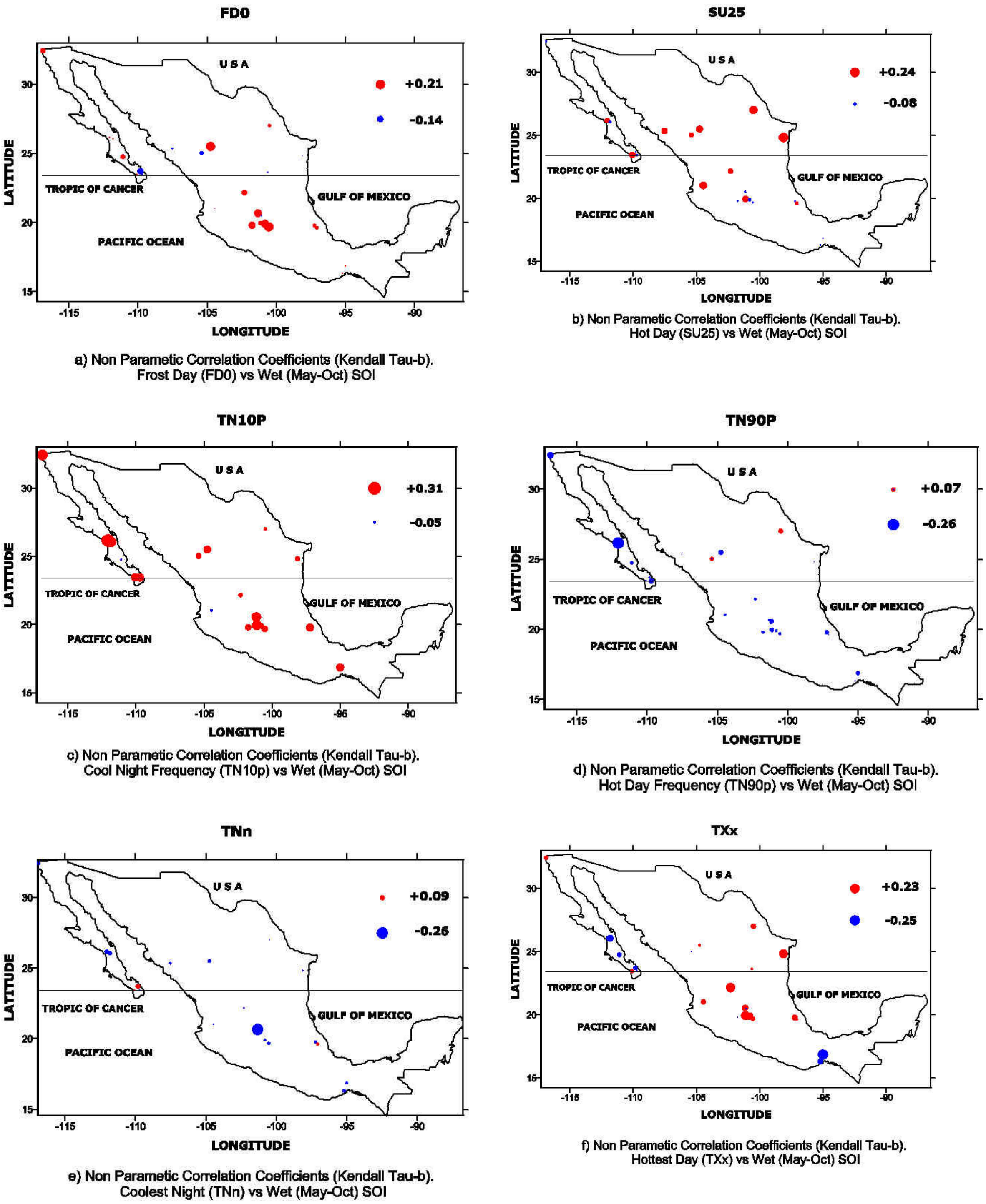


Fig. 7.6. Linear correlations (Kendall tau-b) between the Extreme Temperature Indices and the wet season Southern Oscillation Index (wet season SOI). Circles in red are representing a positive and in blue negative correlations.

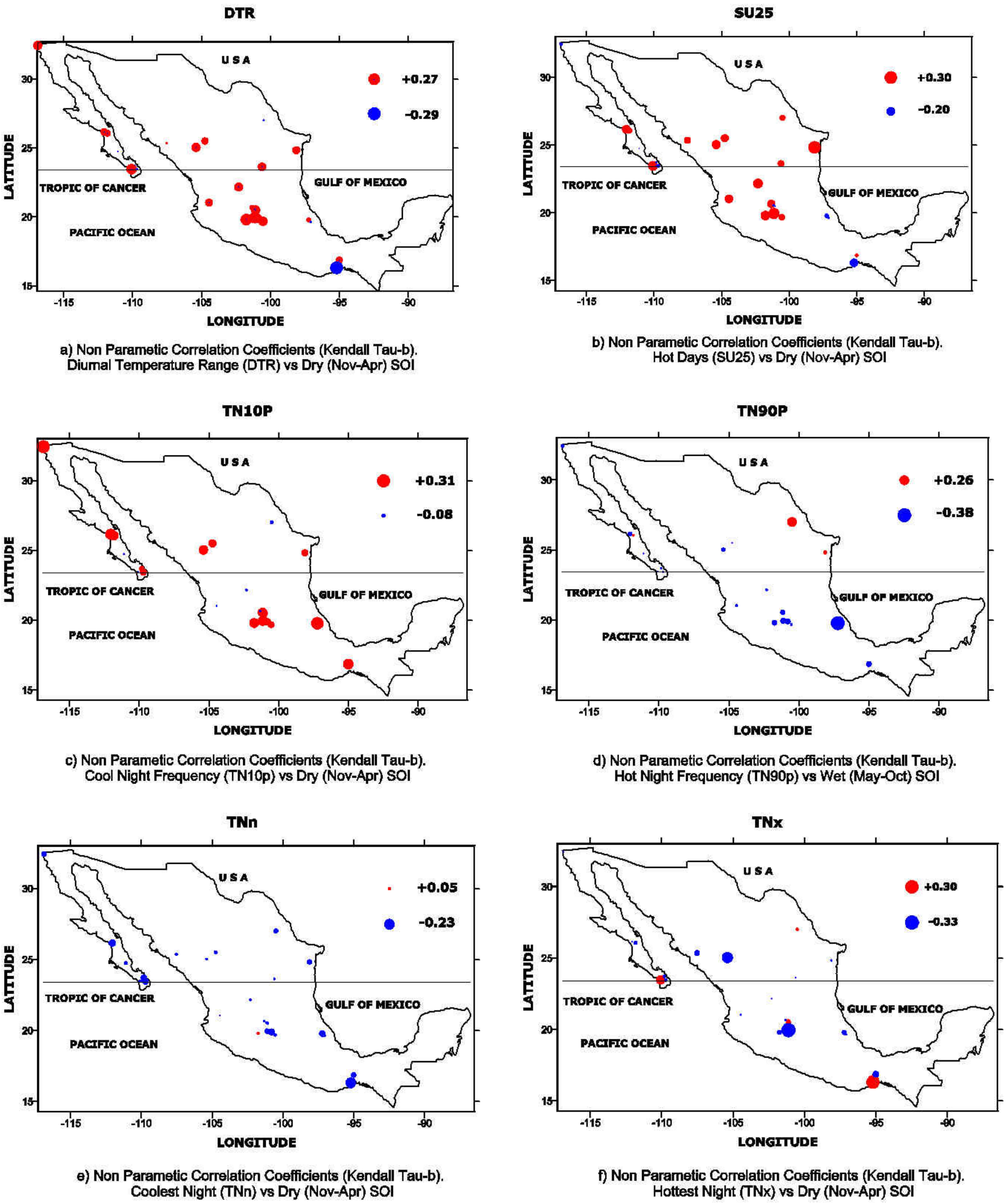
The first extreme index to be analysed with May-Oct (wet season) SOI is FD0 (Frost Days, TN< 0°C). A national climatic pattern of positive correlations could easily be observed in [Fig. 7.6 a)]. Only two stations at high altitude (Ciudad Hidalgo and El Palmito; station numbers 23 and 14 in Table 6.1) have statistically significant results: they are located in the Meseta Central (Central Mexican Highlands). Their positive correlations are better than the 5% level of statistical significance. The largest correlations are also geographically concentrated in the western half of the country. A slightly similar pattern is observed for the SU25 (summer days above 25 °C) index. Positive correlations are geographically widespread especially from Central to Northern Mexico [Fig. 7.6 b)]. San Fernando (station number 33 in Table 6.1) in the north-eastern part of Mexico has the largest positive correlation (+0.24), which is statistically significant at the 5% level. The correlations imply a net decrease in both indices (FD0 and SU25) during El Niño conditions. The extreme indices that exceed a set limit (TN10p and TN90p) show a clear pattern towards warmer temperatures during El Niño conditions, especially within the Baja California Peninsula. A national pattern of positive correlations could be clearly observed in the TN10p map [Fig. 7.6 c)]. The largest correlations are found at La Purisima and La Presa Rodriguez (station numbers 5 and 2 in Table 6.1), statistically significant at the 1 and 5% levels respectively. A national climatic pattern of mostly negative correlations is seen in the TN90p index [Fig. 7.6 d)]. The same stations as in TN10p have the largest correlations for TN90p, however, this time their correlations are better than the 1% level of statistical significance. The last group of indices (TNn and TXx) have °C as their measurement units. A clear national pattern of negative correlations is observed for the TNn index. Nevertheless only Irapuato (-0.26) in Central Mexico (station number 17 in Table 6.1) has a statistical significant (better than the 1% level) result. In general, absolute minimum temperatures (TNn) increase during El Niño conditions. The Hottest day (TXx) index shows a rough coastal/continental climatic pattern. Negative correlations are observed along the Pacific Coast, while positive correlations are seen over the interior, with the exception of the San Fernando (station number 33 in Table 6.1) in the north-western part of the country. All these correlations are statistically significant at the 5% level; and geographically concentrated in the central/northern part of the country. For the TXx index, warmer (colder) temperatures are observed during El Niño (La Niña) conditions.

La Purísima (station number 5 in Table 6.1) is the station that has most indices (CSDI, TN10p, TN90p and TR20) with statistically significant results. All these extreme temperature indices are pointing towards warmer conditions. The index with the greatest positive correlation is CSDI (0.36), and the largest negative correlation is observed in the TN90p index (-0.26); both correlations are statistically significant at the 1% level.

Dry Season SOI.

The final stage in analysing the relationships between the extreme temperature indices and the Southern Oscillation Index is to correlate the dry season version (November to April period) of the standardised SOI and the temperature extreme indices. The maps with the clearest climatic patterns are going to be described, and compared with the previous results (the linear correlations using the standardised annual and wet season). The extreme indices were grouped according to their measurement units are: days (DTR and SU25), percentage (TN10p and TN90p) and °C (TNn and TNx). Considering the local scale, the stations with most statistically significant correlations (indices) are analysed. Finally the greatest correlations among all the indices are contrasted in order to find consistency among the resulting climatic patterns.

Temperature extreme indices that measure the number of days a temperature exceeds a set limit are considered first. Positive correlations are observed over most of the Mexican territory for the DTR index [Fig. 7.7 a)]. Statistically significant results are basically concentrated in Central and Southern Mexico, only Santa Gertrudis station, within the Baja California Peninsula (station number 8 in Table 6.1) is located slightly north of the Tropic of Cancer; and the only negative correlation is found at Santo Domingo Tehuantepec in the southern Pacific (station number 29 in table 6.1). In general, during El Niño conditions decreasing DTRs are seen across Mexico. Meanwhile, positive



a) Non Parametic Correlation Coefficients (Kendall Tau-b). Diurnal Temperature Range (DTR) vs Dry (Nov-Apr) SOI

b) Non Parametic Correlation Coefficients (Kendall Tau-b). Hot Days (SU25) vs Dry (Nov-Apr) SOI

c) Non Parametic Correlation Coefficients (Kendall Tau-b). Cool Night Frequency (TN10p) vs Dry (Nov-Apr) SOI

d) Non Parametic Correlation Coefficients (Kendall Tau-b). Hot Night Frequency (TN90p) vs Wet (May-Oct) SOI

e) Non Parametic Correlation Coefficients (Kendall Tau-b). Coolest Night (TNn) vs Dry (Nov-Apr) SOI

f) Non Parametic Correlation Coefficients (Kendall Tau-b). Hottest Night (TNx) vs Dry (Nov-Apr) SOI

Fig. 7.7. Linear correlations (Kendall tau-b) between the Extreme Temperature Indices and the Dry Season Southern Oscillation Index (dry season SOI). Circles in red are representing a positive and in blue negative correlations.

correlations are almost nationally widespread for the SU25 index [Fig. 7.7 b)]. However, the largest correlations are concentrated in Central and Northern Mexico, precisely the area strongly affected by polar fronts during the boreal winter (see section 2.2.2). San Fernando and Cuitzeo del Porvenir are the only two stations with significant correlations (station numbers 33 and 21 in Table 6.1), these results are statistically significant at better than the 1 and 5% levels respectively. According to these results, colder temperatures are generally observed for the SU25 index during El Niño.

The TN10p and TN90p indices show warmer temperatures during El Niño conditions. A national climatic pattern of positive and negative correlations is observed for TN10p and TN90p respectively. Nevertheless there are subtle differences between these indices. The TN10p map [Fig. 7.7 c)] shows that statistically significant positive correlations are geographically concentrated along both the Atlantic and Pacific coasts. For this index, the stations with the largest correlations (statistically significant at the 1% level) are: La Presa Rodriguez in the northern Baja California Peninsula (station number 2 in Table 6.1) and Atzalán in the Central Gulf of Mexico (station number 34 in Table 6.1). Meanwhile, negative correlations are the most significant results for the TN90p index [Fig. 7.7 d)]. The largest correlation (-0.38) is seen once more at Atzalán. Geographically speaking, the greatest correlations are mainly located within the southern part of Mexico; only La Purísima station in the peninsula of Baja California (station number 5 in table 6.1) is slightly north of the Tropic of Cancer. The only positive correlation (+0.27) among the results for TN90p is found at the Lampazos station in the north-western part of Mexico (station number 26 in Table 6.1) that breaks the simplicity of this climatic pattern.

Finally, let us evaluate two night-time temperature indices that are measured in °C units. An almost national pattern of negative correlations is observed for TNn, and TNx. Statistically significant results are concentrated along the Pacific Coast for the TNn index [Fig. 7.7 e)]. Although national, the climatic pattern for TNx [Fig. 7.7 f)]; the most significant results for this index are found at the Santiago Papasquiaro and Cuitzeo del Porvenir (station numbers 15 and 21 in table 6.1), both are located above 1500 m.a.s.l., and have negative correlations better than the 1% level of statistical significance. Both extreme indices basically respond with warmer temperatures to atmospheric El Niño conditions.

An almost national climatic pattern (with a component along the Pacific Ocean) of warmer temperatures is seen across Mexico during El Niño-like years. This is especially evident in the case of minimum temperatures that lead to decreasing DTRs across most of the country.

7.2.2. LAG CORRELATION (SOI).

Precipitation Regional Averages.

Local climate responses to ENSO are sometimes difficult to prove, because most of the time these climatic variations take a variable period of time to be evident. For this reason, lag-cross correlation was selected as an alternative to find connections between the climate of Mexico and ENSO. The aim of this technique is to find the lag that maximises the correlation between the variables. Therefore, our objective here is to determine how long it takes, for a certain location, to fully respond to ENSO. This response can be expressed as a small or large fluctuation from the normal climatic conditions.

The lag-cross correlation (using the public software SPSS for Windows, Release 11.0.1, that applies the Pearson correlation coefficient) is used in this section to establish the relationships between the monthly time-series of the standardised Southern Oscillation Index (SOI) and the regional precipitation averages. Theoretically, positive or negative lags are possible in the process of finding the optimal correlations, but spatial consistency is also expected when contrasting the different responses of the regional precipitation to the ENSO influence.

REGION	CENTRAL LOCATION		SOI			NIÑO 3.4			MEI		
	LONGITUDE	LATITUDE	CORR +	CORR -	LAG	CORR +	CORR -	LAG	CORR +	CORR -	LAG
R1	-101.19	20.77	1.00E-99	-0.114	0	0.12	1.00E-99	-3	0.106	1.00E-99	-3
R2	-97.14	19.62	0.086	1.00E-99	1	1.00E-99	-0.092	1	1.00E-99	-0.068	0
R3	-99.85	25.28	0.138	1.00E-99	20	0.13	1.00E-99	-2	0.145	1.00E-99	-3
R4	-104.35	27.39	1E-99	-0.145	-1	0.212	1.00E-99	-2	0.218	1.00E-99	-3
R5	-110.25	23.77	1E-99	-0.097	1	0.12	1.00E-99	-4	0.14	1.00E-99	1
R6	-114.73	32.55	1E-99	-0.12	7	0.191	1.00E-99	2	0.204	1.00E-99	3
R7	-98.78	22.72	1E-99	-0.145	2	0.185	1.00E-99	3	0.208	1.00E-99	1
R8	-111.76	26.23	0.115	1.00E-99	1	1.00E-99	-0.126	1	1.00E-99	-0.134	-1
R9	-92.77	17.38	1E-99	-0.074	-11	0.077	1.00E-99	-3	0.081	1.00E-99	-3
R10	-102.93	18.48	0.066	1.00E-99	20	0.075	1.00E-99	-14	0.057	1.00E-99	4
R11	-109.65	28.42	1E-99	-0.128	0	0.105	1.00E-99	0	0.135	1.00E-99	0

Table 7.1. Lag cross-correlations between the standardised versions of Regional Precipitation Averages and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads. Regions displayed here are defined in Table 4.1.

In order to evaluate the level of coherence, the lag cross-correlation is applied in this section between standardised SOI and Regional Precipitation Averages. The greatest negative correlations are observed in Regions four, seven, and eleven (RA4, RA7 and RA11 respectively, regions defined in Table 4.1). Correlations and time shifts are similar in magnitude between them -0.15(-1), -0.15(+2), and -0.13(0). The largest positive correlation is found in RA3 (+0.14), but the timing (+20 months) is quite different when compared with the other correlations of the same sign. The clearest geographical teleconnection of ENSO is located in the north-western part of Mexico: the Northern Baja California Peninsula and the Mexican Monsoon regions share similar correlations and timing responses to ENSO modulation. Three of the regions with the largest correlations are located north of the Tropic of Cancer, although their meteorological responses are quite different: wetter conditions are found in the north-western region of Mexico, while the northeast experiences drier conditions. In general it can be said that during El Niño, wetter conditions prevail for northern Mexico, and close to the peak of El Niño-like conditions. This is consistent with the results of the correlation analysis using Kendall tau-b.

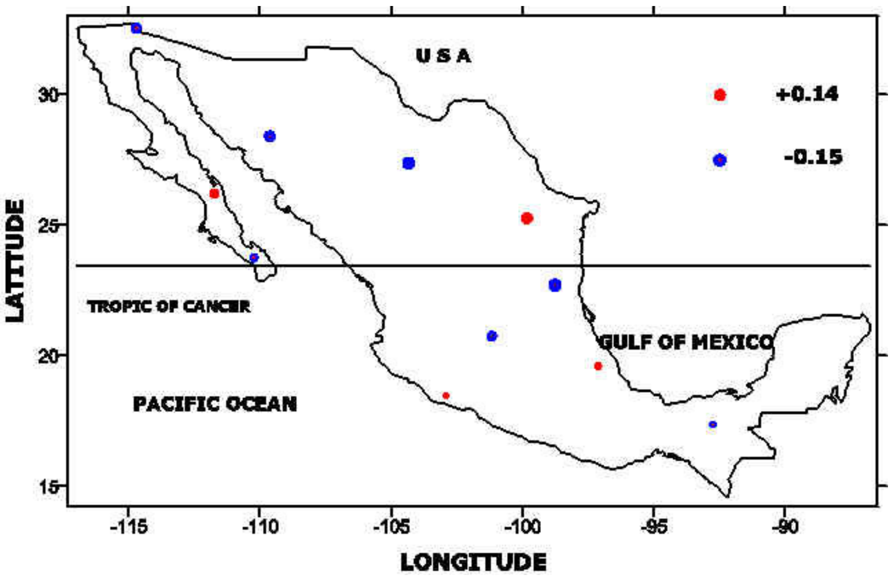


Fig. 7.8. Lag cross-correlations between the standardised versions of Regional Precipitation Averages and the Southern Oscillation Index (SOI). Red circles represent positive and blue circles negative correlations.

Extreme Weather Indices.

Extreme Rainfall Indices

The maximum 1-day precipitation (RX1day) shows a roughly differential climatic pattern of peninsular and continental variations (Table 7.2 and Fig. 7.9). For instance, in the north-western part of Mexico, the northern Baja Californian peninsula (Presa Rodríguez, station number 2 in Table 5.1) has a different response (negative correlation) and timing when compared to stations within the Mexican monsoon region. Yecora in the State of Sonora (station number 32 in Table 5.1) is at the core of this North American Monsoon (or Mexican Monsoon) region, with an altitude reaching 1500 m.a.s.l. Yecora is responding with a net decrease in precipitation amounts (+0.13) during La Niña conditions. Meanwhile, the Presa Rodríguez station is showing negative correlations (-0.11); it is the clearest climatic pattern with wetter conditions during El Niño-like years. The impact in the south-eastern area within the Yucatán Peninsula is nearly negligible.

The north-western part of Mexico shows (with exception of the station at Yecora) a coherent climatic pattern of wetter conditions during El Niño phase (Dettinger et al., 2001), and the (lag) time of response is around the peak of this phenomenon (see Fig. 7.9).

	STATION	LONGITUDE	LATITUDE	SOI		NIÑO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	CELAYA	-100.82	20.53	-0.091	11	0.081	7	0.057	4
2	IRAPUATO	-101.35	20.68	-0.063	-12	0.052	-17	0.040	-21
3	ATZALAN	-97.25	19.80	0.084	1	-0.156	1	-0.097	1
4	LAS VIGAS	-97.10	19.65	-0.060	11	-0.091	-5	-0.089	-3
5	SAN FERNANDO	-98.15	24.85	-0.060	7	0.061	6	-0.051	20
6	GUANACEVI	-105.97	25.93	-0.090	0	0.094	-3	0.101	-3
7	SAN JOSE DEL CABO	-109.67	23.05	-0.071	13	0.096	7	0.094	6
8	PRESA RODRIGUEZ	-116.90	32.45	-0.114	0	0.172	2	0.174	0
9	BADIRAGUATO	-107.55	25.37	-0.092	-1	0.085	4	0.093	1
10	CHAMPOTON	-90.72	19.35	-0.099	-21	0.067	6	0.097	-22
11	JUCHITAN	-95.03	16.43	-0.084	17	0.130	18	0.132	16
12	APATZINGAN	-102.35	19.08	0.058	-12	-0.054	-11	-0.033	3
13	FCO. I MADERO	-104.30	24.47	-0.068	-3	0.097	5	-0.056	-14
14	OJINAGA	-104.42	29.57	-0.087	-2	0.074	-4	0.060	-4
15	YECORA	-108.95	28.37	0.129	19	-0.129	15	-0.145	14

Table 7.2. Lag cross-correlations between the RX1day (Max 1-day Precipitation) Index and the different standardised versions of the ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

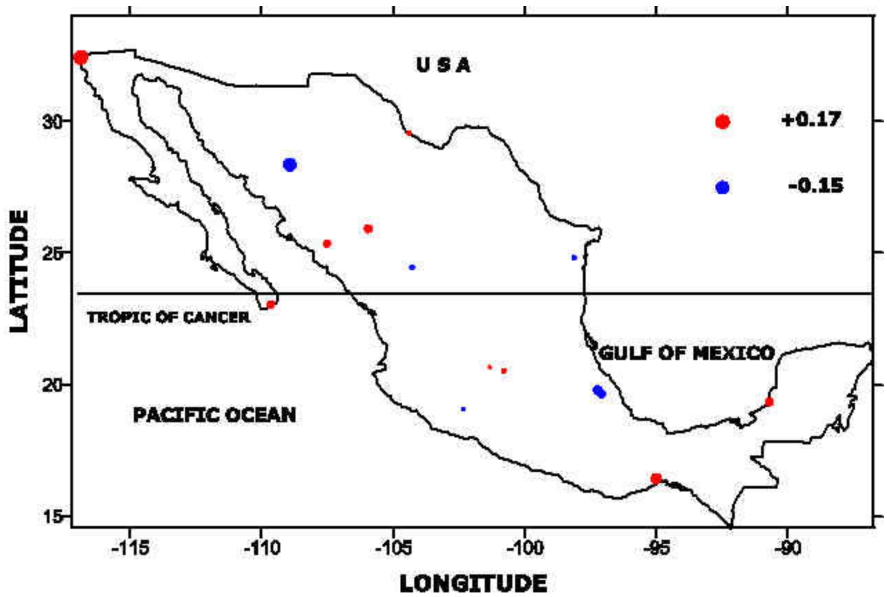


Fig. 7.9. Lag cross-correlations between the RX1day (Max 1-day Precipitation) Index and the standardised version of the Southern Oscillation Index (SOI). Red circles represent positive and blue circles negative correlations.

A climatic feature has been repeating consistently throughout the extreme indices: wetter conditions during El Niño phase, for the Presa Rodríguez station (-0.14 correlation, 0 months lag) in North Baja California Peninsula (station number 2 in Table 5.1). This climatic feature is also true for the RX5day index (Table 7.3 and Fig. 7.10). At the core of the Mexican Monsoon (or North American Monsoon) Region, the climatic response to ENSO takes time to be fully developed. The high-altitude Yecora station in Sonora (station number 32 in Table 5.1), this location experiences drier conditions (+0.22 correlation) during the negative phase of SOI (El Niño). Precipitation below normal is also observed at the South Pacific coast (Juchitán) in Oaxaca (station number 27 in Table 5.1) during El Niño-like conditions near the peak of this phenomenon. A Pacific Ocean component is involved in the ENSO modulation for the 5-day maximum precipitation, although the timing response is similar for the stations at Presa Rodríguez and the Juchitán in Oaxaca, the climatic responses are quite different. Correlations between SOI and RX5day are consistent with the climatic picture already observed for RX1day and the same ENSO index.

	STATION	LONGITUDE	LATITUDE	SOI		NINO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	CELAYA	-100.82	20.53	-0.092	11	0.098	7	0.077	7
2	IRAPUATO	-101.35	20.68	-0.059	11	0.051	7	-0.055	-7
3	ATZALAN	-97.25	19.80	0.069	4	-0.144	1	-0.108	2
4	LAS VIGAS	-97.10	19.65	0.073	-5	-0.098	1	-0.095	3
5	SAN FERNANDO	-98.15	24.85	0.055	21	0.042	7	0.060	-10
6	GUANACEVI	-105.97	25.93	-0.079	0	0.084	-3	0.093	2
7	SAN JOSE DEL CABO	-109.67	23.05	-0.067	22	0.088	6	0.083	6
8	PRESA RODRIGUEZ	-116.90	32.45	-0.138	0	0.166	2	0.163	0
9	BADIRAGUATO	-107.55	25.37	-0.092	-1	0.085	4	0.093	1
10	CHAMPOTON	-90.72	19.35	-0.102	-21	0.072	-20	0.104	-22
11	JUCHITAN	-95.03	16.43	0.103	0	0.125	18	0.130	16
12	APATZINGAN	-102.35	19.08	0.049	-4	-0.054	24	-0.029	-14
13	FCO. I MADERO	-104.30	24.47	-0.045	-3	0.098	6	0.063	7
14	OJINAGA	-104.42	29.57	-0.063	-9	0.060	17	0.040	-23
15	YECORA	-108.95	28.37	0.129	19	-0.129	15	-0.145	15

Table 7.3. Lag cross-correlations between the RX5day (Max 5-day Precipitation) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

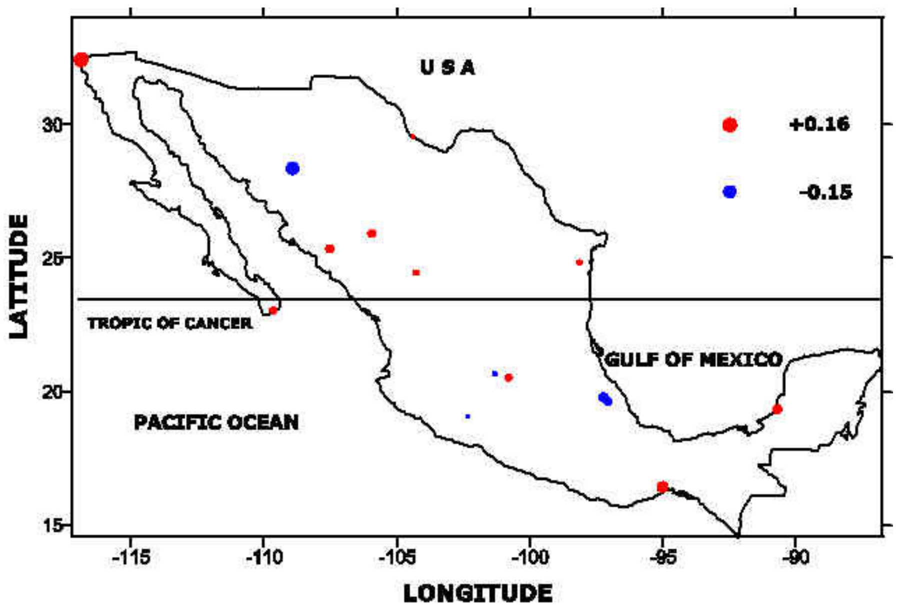


Fig. 7.10. Lag cross-correlations between the RX5day (Max 5-day Precipitation) Index and the standardised version of the Southern Oscillation Index (SOI). Red circles represent positive and blue circles negative correlations.

Extreme Temperature Indices.

DTR

No clear lag pattern is seen correlating DTR and the SOI indices (table 7.4 and fig. 7.11). Highest correlations are slightly concentrated over the southern part of Mexico near the Pacific Ocean. Neither positive nor negative correlations show a clear climatic pattern. There is no clear pattern for the time-lags of response of the different stations to the ENSO phenomenon.

	STATION	LONGITUDE	LATITUDE	SOI		NINO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	PABELLON DE ARTEAGA	-102.33	22.18	0.087	5	-0.072	-7	-0.099	-10
2	PRESA RODRIGUEZ	-116.9	32.45	0.150	4	-0.138	2	0.074	-11
3	COMONDú	-111.85	26.08	0.081	7	-0.103	7	-0.102	3
4	EL PASO DE IRITU	-111.12	24.77	-0.169	-12	0.112	-8	0.167	21
5	LA PURíSIMA	-112.08	26.18	0.129	6	-0.156	-24	-0.237	-23
6	SAN BARTOLO	-109.85	23.73	0.109	-20	0.082	16	-0.148	-22
7	SANTA GERTRUDIS	-110.1	23.48	0.181	-4	-0.137	19	-0.219	-2
8	SANTIAGO	-109.73	23.47	0.084	5	0.081	13	0.095	10
9	EL PALMITO	-104.78	25.52	-0.080	-24	-0.053	-3	0.083	-24
10	SANTIAGO PAPASQUIARO	-105.42	25.05	-0.127	24	0.181	24	0.132	24
11	IRAPUATO	-101.35	20.68	-0.084	20	-0.045	6	0.102	18
12	PERICOS	-101.1	20.52	0.068	-20	-0.059	17	-0.077	-10
13	SALAMANCA	-101.18	20.57	-0.071	9	-0.077	-7	-0.082	-10
14	CUITZEO DEL PORVENIR	-101.15	19.97	0.154	16	-0.157	-7	-0.235	-9
15	HUINGO	-100.83	19.92	-0.061	11	-0.066	-7	0.078	10
16	CIUDAD HIDALGO	-100.57	19.7			0.108	23	0.097	21
17	ZACAPU	-101.78	19.82	0.116	-19	-0.095	-19	-0.130	-22
18	AHUACATLAN	-104.48	21.05	-0.069	21	0.078	-21	0.075	-21
19	LAMPAZOS	-100.52	27.03	0.134	-3	-0.138	-3	-0.175	-3
20	MATIAS ROMERO	-95.03	16.88	0.150	-24	-0.147	-24	-0.338	-24
21	SANTO DOMINGO TEHUANTEPEC	-95.23	16.33	-0.191	-2	0.148	1	0.265	-5
22	MATEHUALA	-100.63	23.65	0.094	7	-0.105	7	-0.116	6
23	BADIRAGUATO	-107.55	25.37	0.104	3	-0.102	-1	-0.166	1
24	SAN FERNANDO	-98.15	24.85	0.061	7	0.043	13	-0.065	24
25	ATZALAN	-97.25	19.8	-0.129	20	0.109	18	0.117	18
26	LAS VIGAS	-97.1	19.65	-0.187	20	0.109	18	0.247	19

Table 7.4. Lag cross-correlations between the DTR (Daily Temperature Range) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

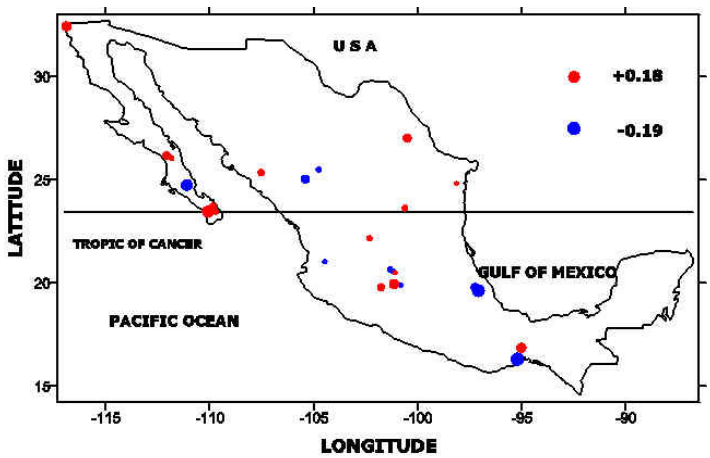


Fig. 7.11 Lag cross-correlations between the DTR (Daily Temperature Range) and the Southern Oscillation Index (SOI). Red circles express positive correlations, and blue circles show negative correlations.

TN10P

Prevailing positive correlations are observed for the TN10P index, although their corresponding lags are not quite homogeneous (Table 7.5). In addition, positive correlations are greater in magnitude than negative correlations. These positive relationships are geographically concentrated in the Baja California Peninsula, but they are also present in the Gulf of Mexico and Michoacán State (Fig. 7.12). The two largest correlations are in the central part of the Baja California Peninsula: La Purísima (station number 5 in Table 6.1) with a correlation of +0.21 and a lag of +2, then Comondú with a lag of -2 and a positive correlation of +0.16. Both are just examples of the dominant tendency towards warmer temperatures during an El Niño phase.

	STATION	LONGITUDE	LATITUDE	SOI		NIÑO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	PABELLON DE ARTEAGA	-102.33	22.18	0.082	22	0.099	0	-0.101	-16
2	PRESA RODRIGUEZ	-116.9	32.45	0.203	-2	-0.182	4	-0.260	3
3	COMONDú	-111.85	26.08	0.164	-2	-0.156	0	-0.174	0
4	EL PASO DE IRITU	-111.12	24.77	-0.135	-7	0.140	-9	0.147	-9
5	LA PURíSIMA	-112.08	26.18	0.210	2	-0.212	2	-0.264	2
6	SAN BARTOLO	-109.85	23.73	-0.058	-11	0.083	-16	-0.131	9
7	SANTA GERTRUDIS	-110.1	23.48	0.096	-24	-0.078	21	0.067	10
8	SANTIAGO	-109.73	23.47	0.135	0	-0.134	6	-0.114	-3
9	EL PALMITO	-104.78	25.52	0.091	13	-0.104	11	-0.137	10
10	SANTIAGO PAPASQUIARO	-105.42	25.05	0.088	3	0.139	-10	-0.126	11
11	IRAPUATO	-101.35	20.68	-0.125	1	0.122	-1	0.168	-2
12	PERICOS	-101.1	20.52	0.121	11	-0.077	14	-0.182	12
13	SALAMANCA	-101.18	20.57	0.087	-15	-0.094	-16		
14	CUITZEO DEL PORVENIR	-101.15	19.97	0.169	19	-0.174	16	-0.230	15
15	HUINGO	-100.83	19.92	-0.120	1	0.094	0	0.150	0
16	CIUDAD HIDALGO	-100.57	19.7	0.110	5	0.130	20	0.124	22
17	ZACAPU	-101.78	19.82	0.094	-23	-0.152	-10	0.145	23
18	AHUACATLAN	-104.48	21.05	-0.136	1	0.104	2	0.181	1
19	LAMPAZOS	-100.52	27.03	0.087	0	-0.083	-1	-0.128	2
20	MATIAS ROMERO	-95.03	16.88	0.125	2	-0.097	-16	-0.200	-16
21	SAN FERNANDO	-98.15	24.85	-0.113	19	0.085	20	0.125	3
22	ATZALAN	-97.25	19.8	0.184	6	-0.145	7	-0.203	7
23	LAS VIGAS	-97.1	19.65	-0.123	20	-0.097	6	0.120	24

Table 7.5. Lag cross-correlations between the TN10P (Cool Night Frequency) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

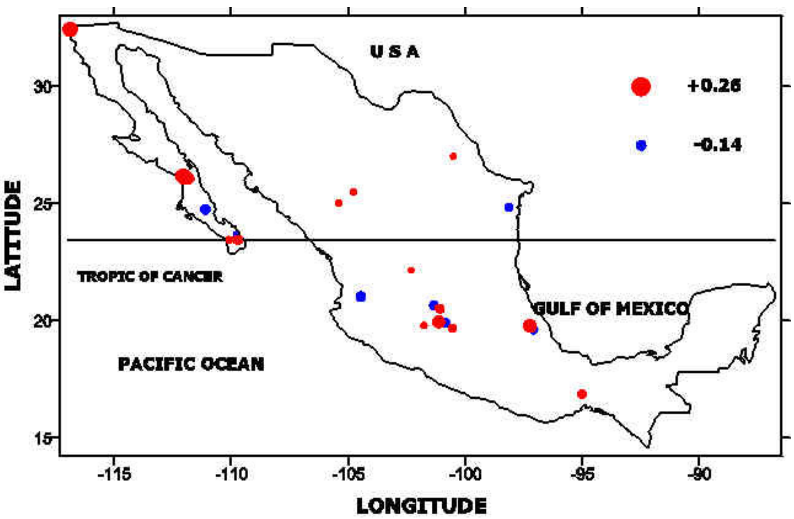


Fig. 7.12. Lag cross-correlations between the TN10P (Cool Night Frequency) and the Southern Oscillation Index (SOI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

TN90P

There is no clear geographical pattern when we correlate the SOI and the TN90P index (Table 7.6 and Fig. 7.13). Nevertheless, an interesting feature has arisen here: both correlations (positive and negative) and the lags are descending from south to north in a geographic way following the same pattern of descending correlations (Table 7.6). Negative correlations are greater at a number of stations, and more consistent in their results. These relationships show a preference for the central and northern stations, and a northwards descending pattern in the magnitude of correlations and lags. The continental stations have a dominant characteristic being mostly at high altitude. In climatic terms, the dominant negative correlations observed in Fig 7.13 lead to colder night-temperatures under El Niño conditions. Results of applying lag correlations to TN90P are in accordance with those of linear correlations (Figs. 7.5, 7.6 and 7.7) when the negative correlations are considered, these are leading to more frequent warmer (colder) night-temperatures close to the strongest El Niño (La Niña) conditions, while the positive correlations show an average lag of about 20 months behind the frequency reach its peak, suggesting odd results of the statistical method in trying to match the largest correlations.

	STATION	LONGITUDE	LATITUDE	SOI		NIÑO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	PABELLON DE ARTEAGA	-102.33	22.18	0.086	-24	-0.061	5	0.104	-6
2	PRESA RODRIGUEZ	-116.9	32.45	-0.152	5	0.181	0	0.241	1
3	COMONDú	-111.85	26.08	-0.097	-5	0.088	-2	0.071	10
4	EL PASO DE IRITU	-111.12	24.77	0.110	-18	0.117	3	-0.081	-15
5	LA PURíSIMA	-112.08	26.18	0.124	-15	0.168	-24	0.154	-24
6	SAN BARTOLO	-109.85	23.73	-0.123	-19	0.096	-20	0.151	-24
7	SANTA GERTRUDIS	-110.1	23.48	0.079	-20	-0.056	-16	-0.079	-19
8	SANTIAGO	-109.73	23.47	0.105	-16	-0.117	22	0.088	2
9	EL PALMITO	-104.78	25.52	0.092	-18	0.089	11	-0.100	-20
10	SANTIAGO PAPASQUIARO	-105.42	25.05	0.115	-15	0.079	24	-0.120	-16
11	IRAPUATO	-101.35	20.68	0.214	-18	-0.195	-20	-0.306	-20
12	PERICOS	-101.1	20.52	-0.097	5	0.103	5	0.151	4
13	SALAMANCA	-101.18	20.57	0.144	-18	0.164	5	0.131	5
14	CUITZEO DEL PORVENIR	-101.15	19.97	-0.161	7	0.140	14	0.214	5
15	HUINGO	-100.83	19.92	-0.171	7	0.252	6	0.221	5
16	CIUDAD HIDALGO	-100.57	19.7	0.109	20	-0.172	22	-0.189	22
17	ZACAPU	-101.78	19.82			0.106	-23	0.168	4
18	AHUACATLAN	-104.48	21.05	-0.133	6	0.210	5	0.171	5
19	LAMPAZOS	-100.52	27.03	0.110	-2	-0.138	0	-0.124	-2
20	MATIAS ROMERO	-95.03	16.88	-0.117	5	0.098	-14	0.185	-13
21	SAN FERNANDO	-98.15	24.85	-0.083	13	-0.069	0	0.111	12
22	ATZALAN	-97.25	19.8	-0.208	8	0.162	6	0.213	7
23	LAS VIGAS	-97.1	19.65	0.149	-19	-0.155	-20	-0.237	-21

Table 7.6. Lag cross-correlations between the TN90P (Hot Night Frequency) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

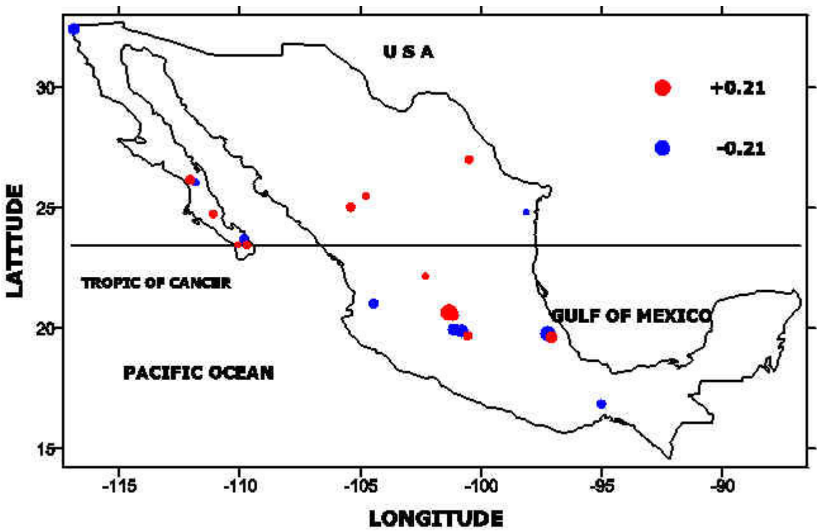


Fig. 7.13 Lag cross-correlations between the TN90P (Hot Night Frequency) and the Southern Oscillation Index (SOI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

TNn

Warmer absolute minimum temperatures are observed in southern Mexico under El Niño conditions. Negative correlations are found when we (lag) correlate the TNn index (coolest night) and the SOI (Table 7.7). Largest correlations are found mostly south of the Tropic of Cancer. Although the greatest negative correlation is observed at Matías Romero station (station number 28 in Table 6.1) in the Southern Pacific coast, three of the four largest correlations are located in Michoacán State, and all of them are above the 1000 m.a.s.l. limit, so clearly altitude is exerting its influence in these results (Fig. 7.14). Nevertheless, it also important to point out that the time shifts are not homogeneous among these stations. It can be said that during El Niño phase the TNn index show a pattern towards warmer conditions for the southern part of Mexico.

	STATION	LONGITUDE	LATITUDE	SOI		NINO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	PABELLON DE ARTEAGA	-102.33	22.18	-0.052	-8	-0.053	-1	-0.026	-3
2	PRESA RODRIGUEZ	-116.9	32.45	0.080	-17	-0.048	-24	-0.087	18
3	COMONDú	-111.85	26.08	-0.058	2	0.053	5	0.082	1
4	EL PASO DE IRITU	-111.12	24.77	0.078	-13	-0.068	-13	-0.071	-14
5	LA PURíSIMA	-112.08	26.18	0.061	-16	0.074	5	0.074	-23
6	SAN BARTOLO	-109.85	23.73	0.058	20	-0.063	20	0.077	-24
7	SANTA GERTRUDIS	-110.1	23.48	-0.058	-23	0.066	19	0.079	-24
8	SANTIAGO	-109.73	23.47	0.057	-15	0.052	6	0.056	2
9	EL PALMITO	-104.78	25.52	-0.044	17	0.057	17	0.054	13
10	SANTIAGO PAPASQUIARO	-105.42	25.05	-0.070	16	0.067	16	0.075	13
11	IRAPUATO	-101.35	20.68	0.080	-17	-0.048	-24	-0.087	18
12	PERICOS	-101.1	20.52			0.046	17	0.074	-9
13	SALAMANCA	-101.18	20.57	-0.050	-9	0.037	-19	0.055	-10
14	CUITZEO DEL PORVENIR	-101.15	19.97	-0.137	16	0.128	16	0.161	14
15	HUINGO	-100.83	19.92	-0.058	5	0.048	6	-0.044	-4
16	CIUDAD HIDALGO	-100.57	19.7	-0.098	5	0.077	6	0.071	10
17	ZACAPU	-101.78	19.82	-0.121	-8	0.150	-10	0.130	-10
18	AHUACATLAN	-104.48	21.05	0.063	21	-0.059	-21	-0.073	-20
19	LAMPAZOS	-100.52	27.03	0.063	21	-0.043	23	-0.042	17
20	MATIAS ROMERO	-95.03	16.88	-0.174	-19	0.158	-16	0.262	-19
21	SANTO DOMINGO TEHUANTEPEC	-95.23	16.33	-0.060	3	0.104	-4	0.074	-3
22	MATEHUALA	-100.63	23.65	-0.057	24	0.061	-9	0.075	23
23	BADIRAGUATO	-107.55	25.37	-0.067	3	0.041	-15	0.089	-11
24	SAN FERNANDO	-98.15	24.85	-0.042	4	-0.044	23	-0.042	18
25	ATZALAN	-97.25	19.8	-0.083	5	0.066	8	0.095	-1
26	LAS VIGAS	-97.1	19.65	0.084	19	0.077	-9	-0.097	16

Table 7.7. Lag cross-correlations between the TNn (Coolest night) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

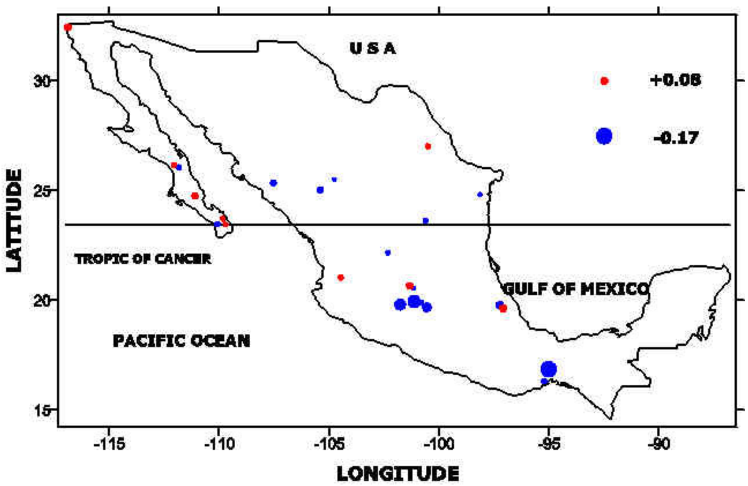


Fig. 7.14. Lag cross-correlations between the TNn (Coolest night) and the Southern Oscillation Index (SOI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

TNx

Regarding the sign of the results, most of the stations with the largest correlations are located south of the Tropic of Cancer. A clear pattern of positive correlations can be easily observed nationwide, but the largest ones are clearly concentrated south of the Tropic of Cancer (Fig. 7.15). Only El Paso de Iritu station (+0.10 correlation and a lag of -15 months) slightly north of this geographic limit is the exception. Time shifts are quite similar for both the positive and negative correlations (see Table 7.8). Negative correlations are showing mainly also negative lags, meanwhile the positive correlations are showing a preference towards positive time shifts. Although positive correlations are geographically prevalent, negative correlations are larger in magnitude. In general, the maximum night temperatures increase during El Niño conditions.

	STATION	LONGITUDE	LATITUDE	SOI		NIÑO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	PABELLON DE ARTEAGA	-102.33	22.18	0.078	-14	-0.082	-13	-0.042	-17
2	PRESA RODRIGUEZ	-116.9	32.45	-0.081	-5	0.086	-5	0.082	3
3	COMONDú	-111.85	26.08	-0.094	18	0.071	20	0.080	12
4	EL PASO DE IRITU	-111.12	24.77	0.102	-15	-0.068	-11	-0.081	-15
5	LA PURíSIMA	-112.08	26.18	-0.101	5	0.092	3	0.136	2
6	SAN BARTOLO	-109.85	23.73	-0.052	-23	-0.060	18	0.061	2
7	SANTA GERTRUDIS	-110.1	23.48	0.057	-14	0.040	-3	-0.058	-17
8	SANTIAGO	-109.73	23.47	0.054	-15	0.065	-6	0.063	-10
9	EL PALMITO	-104.78	25.52	0.052	-17	-0.045	-1	-0.049	-16
10	SANTIAGO PAPASQUIARO	-105.42	25.05	0.074	-15	-0.104	-13	-0.089	-16
11	IRAPUATO	-101.35	20.68	0.102	-16	-0.050	22	-0.131	-17
12	PERICOS	-101.1	20.52	-0.072	2			0.080	1
13	SALAMANCA	-101.18	20.57	0.063	-16	0.074	3	0.068	2
14	CUITZEO DEL PORVENIR	-101.15	19.97	-0.128	3	0.101	4	0.165	2
15	HUINGO	-100.83	19.92	0.111	-15	0.124	5		
16	CIUDAD HIDALGO	-100.57	19.7	0.103	21	-0.108	22	-0.012	19
17	ZACAPU	-101.78	19.82	-0.090	6	0.132	5	0.120	2
18	AHUACATLAN	-104.48	21.05	0.106	21	-0.095	-13	-0.126	19
19	LAMPAZOS	-100.52	27.03	0.080	-2	-0.066	-1	-0.042	-3
20	MATIAS ROMERO	-95.03	16.88	-0.161	3	0.123	-20	0.270	-20
21	SANTO DOMINGO TEHUANTEPEC	-95.23	16.33	0.137	-14	-0.103	24	-0.181	16
22	MATEHUALA	-100.63	23.65	0.097	-16	0.077	7	0.064	7
23	BADIRAGUATO	-107.55	25.37	-0.087	3	0.061	-3	0.093	1
24	SAN FERNANDO	-98.15	24.85	0.098	-2	-0.072	-1	-0.073	-4
25	ATZALAN	-97.25	19.8	-0.130	5	0.103	7	0.146	10
26	LAS VIGAS	-97.1	19.65	0.117	-21	-0.109	-6	-0.188	-7

Table 7.8. Lag cross-correlations between the TNx (Hottest night) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

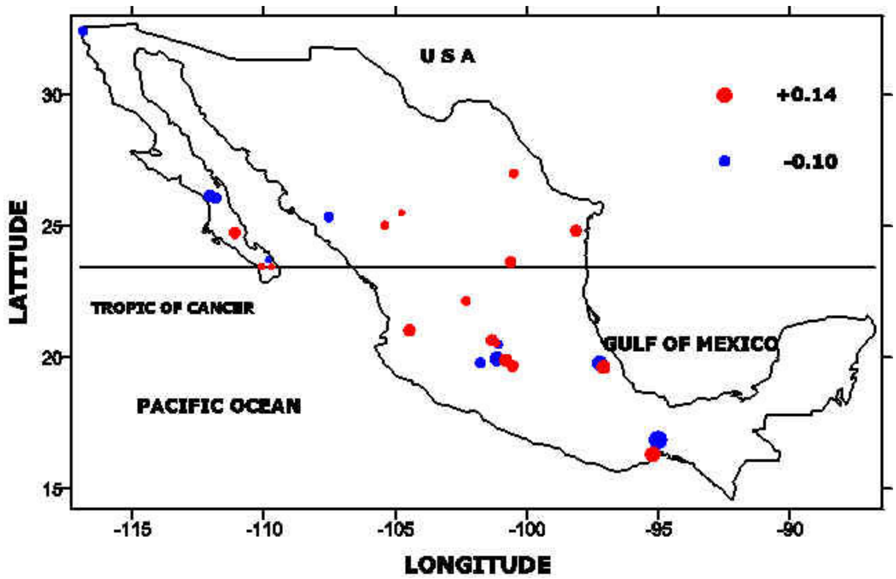


Fig. 7.15. Lag cross-correlations between the TNx (Hottest night) and the Southern Oscillation Index (SOI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

TX10P

Colder day temperatures are observed for the TX10P index during El Niño conditions. Negative correlations are widespread in the country, although they are geographically concentrated in the central-western part (Fig. 7.16). These negative relationships dominate both in magnitude and number compared to the positive correlations. For both positive and negative correlations lags are quite similar (Table 7.9). The greatest correlation is found at Cuitzeo del Porvenir in Michoacán state (station number 21 in Table 6.1) with a negative correlation of -0.19 and a time shift of -2 months. According to the geographical distribution it seems that the Pacific Ocean is partly modulating the frequency of hot days in the western part of Mexico.

	STATION	LONGITUDE	LATITUDE	SOI		NIÑO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	PABELLON DE ARTEAGA	-102.33	22.18	-0.161	-1	0.127	-1	0.181	-11
2	PRESA RODRIGUEZ	-116.9	32.45	0.143	14	-0.167	15	-0.220	12
3	COMONDú	-111.85	26.08	-0.171	-6	-0.125	0	-0.142	-2
4	EL PASO DE IRITU	-111.12	24.77	0.151	-12	-0.093	10	-0.155	10
5	LA PURíSIMA	-112.08	26.18	-0.107	-22	0.169	-16	0.226	-22
6	SAN BARTOLO	-109.85	23.73	-0.065	-16	-0.107	8	0.100	-17
7	SANTA GERTRUDIS	-110.1	23.48	-0.184	1	0.140	7	0.207	-3
8	SANTIAGO	-109.73	23.47	0.101	-5	-0.142	9	-0.144	9
9	EL PALMITO	-104.78	25.52	0.109	9	0.150	-2	0.129	-3
10	SANTIAGO PAPASQUIARO	-105.42	25.05	-0.124	23	0.082	0	0.093	0
11	IRAPUATO	-101.35	20.68	-0.113	-2	0.077	-1	0.115	-21
12	PERICOS	-101.1	20.52	-0.083	0	0.077	-1	-0.067	13
13	SALAMANCA	-101.18	20.57	-0.078	0	0.091	13	0.109	-22
14	CUITZEO DEL PORVENIR	-101.15	19.97	-0.192	-2	0.258	-2	0.263	-3
15	HUINGO	-100.83	19.92	0.092	10	-0.091	13	-0.152	12
16	CIUDAD HIDALGO	-100.57	19.7	-0.161	-2	0.189	-1	0.172	-1
17	ZACAPU	-101.78	19.82	-0.129	-20	-0.115	-8	0.168	24
18	AHUACATLAN	-104.48	21.05	-0.172	1	0.195	-1	0.228	0
19	LAMPAZOS	-100.52	27.03	-0.070	-2	-0.079	-23	0.074	-11
20	MATIAS ROMERO	-95.03	16.88	0.084	-9	0.113	-5	-0.107	-10
21	SAN FERNANDO	-98.15	24.85	-0.105	-2	0.091	0	0.093	2
22	ATZALAN	-97.25	19.8	0.081	9	-0.085	-9	-0.071	24
23	LAS VIGAS	-97.1	19.65	0.157	-4	-0.129	-11	-0.208	-17

Table 7.9. Lag cross-correlations between the TX10P (Cool day frequency) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

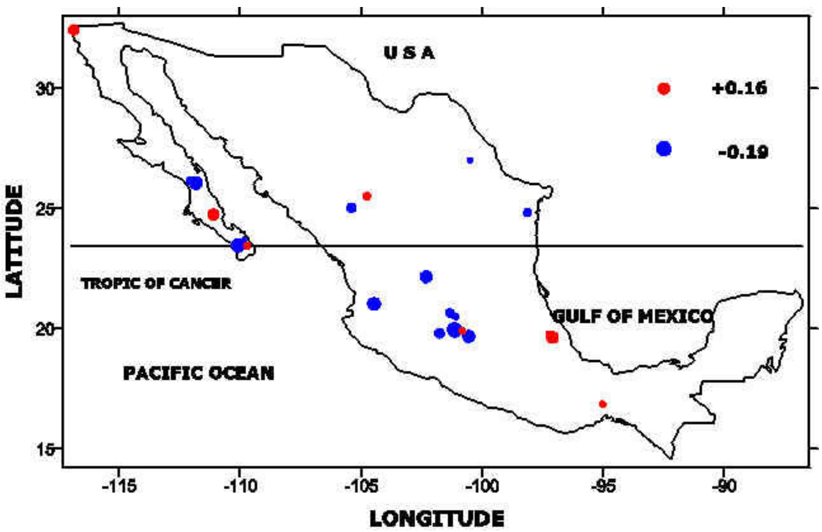


Fig. 7.16. Lag cross-correlations between the TX10P (Cool day frequency) and the Southern Oscillation Index (SOI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

TX90P

For the lag correlation between the TX90P and the SOI indices, positive correlations are prevalent from Central to Northern Mexico, especially over the western side of the country (Fig. 7.17). Time shifts for the negative correlations are quite similar, and except for the Presa Rodriguez (station number 2 in table 6.1) they are concentrated in the range between -3 to +5 months, but that is not the case for the positive ones that show a great variation between -14 to +16 months of lag making it difficult to find the optimal relationship (Table 7.10). Positive correlations mean that during El Niño phase the percentage of hot days exceeding the upper 90 percentile increases, i.e., warmer day temperatures. It can also be said, like in the case of the TX10P, that the Pacific Ocean exerts a partial influence over the Hot Day frequency.

	STATION	LONGITUDE	LATITUDE	SOI		NIÑO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	PABELLON DE ARTEAGA	-102.33	22.18	0.110	1	-0.136	-15	-0.173	-15
2	PRESA RODRIGUEZ	-116.9	32.45	-0.126	22	0.066	-6	0.107	-24
3	COMONDú	-111.85	26.08	-0.126	-5	-0.077	7	0.106	-7
4	EL PASO DE IRITU	-111.12	24.77	-0.089	21	-0.076	-21	0.121	12
5	LA PURíSIMA	-112.08	26.18	0.113	-4	0.092	11	-0.087	-13
6	SAN BARTOLO	-109.85	23.73	0.103	-11	-0.139	-13	-0.125	-14
7	SANTA GERTRUDIS	-110.1	23.48	0.127	-3	-0.089	1	-0.156	-5
8	SANTIAGO	-109.73	23.47	-0.074	18	0.156	13	0.150	10
9	EL PALMITO	-104.78	25.52	-0.143	-5	0.119	-5	0.142	-7
10	SANTIAGO PAPASQUIARO	-105.42	25.05	0.147	-24	-0.105	-11	-0.159	-21
11	IRAPUATO	-101.35	20.68	0.130	-19	-0.153	-16	-0.195	-18
12	PERICOS	-101.1	20.52	-0.102	3	-0.131	15	0.170	2
13	SALAMANCA	-101.18	20.57	-0.093	4	0.156	3	0.168	2
14	CUITZEO DEL PORVENIR	-101.15	19.97	0.101	-22	-0.120	-22	-0.119	-22
15	HUINGO	-100.83	19.92	0.135	-12	0.203	3	0.212	2
16	CIUDAD HIDALGO	-100.57	19.7	0.081	-22	0.138	24	0.152	24
17	ZACAPU	-101.78	19.82	0.205	14	-0.196	15	-0.239	16
18	AHUACATLAN	-104.48	21.05	0.075	0	-0.115	18	-0.118	17
19	LAMPAZOS	-100.52	27.03	0.167	-3	-0.203	-1	-0.258	-2
20	MATIAS ROMERO	-95.03	16.88	-0.191	3	0.140	4	0.230	1
21	SAN FERNANDO	-98.15	24.85	0.094	-1	0.081	13	-0.071	-21
22	ATZALAN	-97.25	19.8	0.194	16	0.167	17	0.247	0
23	LAS VIGAS	-97.1	19.65	-0.170	3	0.164	6	0.233	6

Table 7.10. Lag cross-correlations between the TX90P (Hot day frequency) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

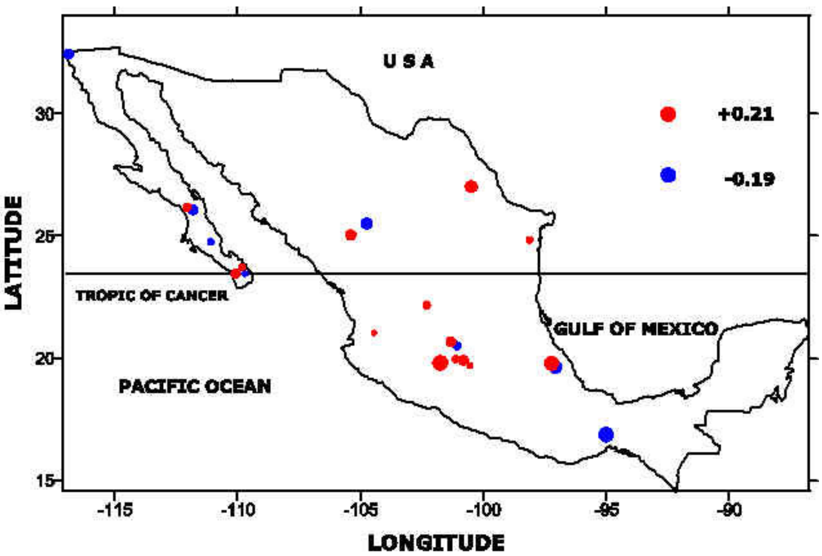


Fig. 7.17. Lag cross-correlations between the TX90P (Hot day frequency) and the Southern Oscillation Index (SOI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

TXn

Two different climatic patterns are found for the TXn index. Positive correlations prevail in Central and Northern Mexico, while in the Southern part of the country negative correlations show a few significant results (Table 7.11). This climatic transition from negative in the south to positive correlations in the central and northern part of the country is nearly evident, but not a clear geographical pattern. Although the clusters of positive correlations are clearer for northern Mexico, negative correlations are greater in magnitude (Fig. 7.18). Time shifts are dissimilar for both positive and negative correlations. According to these results, coolest days increase in temperature during El Niño conditions in the western part of Mexico for the central and northern part of the country.

	STATION	LONGITUDE	LATITUDE	SOI		NIÑO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	PABELLON DE ARTEAGA	-102.33	22.18	0.132	-2	-0.113	-1	-0.133	-3
2	PRESA RODRIGUEZ	-116.9	32.45	-0.064	18	0.069	16	0.066	12
3	COMONDú	-111.85	26.08	0.141	1	-0.126	-2	-0.136	0
4	EL PASO DE IRITU	-111.12	24.77	-0.069	-8	-0.062	-24	0.082	12
5	LA PURíSIMA	-112.08	26.18	0.074	-15	-0.057	-13	-0.082	-17
6	SAN BARTOLO	-109.85	23.73	0.048	20	0.065	9	-0.078	19
7	SANTA GERTRUDIS	-110.1	23.48	0.120	1	-0.102	0	-0.159	-5
8	SANTIAGO	-109.73	23.47	0.062	2	0.085	13	0.080	12
9	EL PALMITO	-104.78	25.52	-0.086	18	0.101	17	0.087	16
10	SANTIAGO PAPASQUIARO	-105.42	25.05	0.112	-2	-0.105	-24	-0.103	-22
11	IRAPUATO	-101.35	20.68	0.107	-1	-0.107	-1	-0.101	-3
12	PERICOS	-101.1	20.52	0.073	-2	-0.099	-2	0.059	14
13	SALAMANCA	-101.18	20.57	-0.108	13	0.092	13	-0.083	-21
14	CUITZEO DEL PORVENIR	-101.15	19.97	0.110	-2	-0.122	-2	-0.097	-5
15	HUINGO	-100.83	19.92	-0.107	13	0.106	13	0.126	13
16	CIUDAD HIDALGO	-100.57	19.7	0.080	-2	-0.093	-1	-0.071	4
17	ZACAPU	-101.78	19.82	0.113	-19	0.086	-10	-0.100	-24
18	AHUACATLAN	-104.48	21.05	0.096	-2	-0.129	0	-0.133	2
19	LAMPAZOS	-100.52	27.03	0.059	-2	-0.053	23	-0.053	17
20	MATIAS ROMERO	-95.03	16.88	-0.142	2	0.127	-8	0.117	-10
21	SANTO DOMINGO TEHUANTEPEC	-95.23	16.33	-0.194	-7	0.217	-4	0.283	-5
22	MATEHUALA	-100.63	23.65	-0.059	18	-0.069	-15	-0.055	5
23	BADIRAGUATO	-107.55	25.37	-0.086	12	0.121	13	-0.135	-3
24	SAN FERNANDO	-98.15	24.85	0.058	-3	-0.056	-13	-0.047	-6
25	ATZALAN	-97.25	19.8	-0.034	-9	-0.056	12	-0.063	4
26	LAS VIGAS	-97.1	19.65	-0.152	-10	0.156	-6	0.207	-13

Table 7.11. Lag cross-correlations between the TXn (Coolest day) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

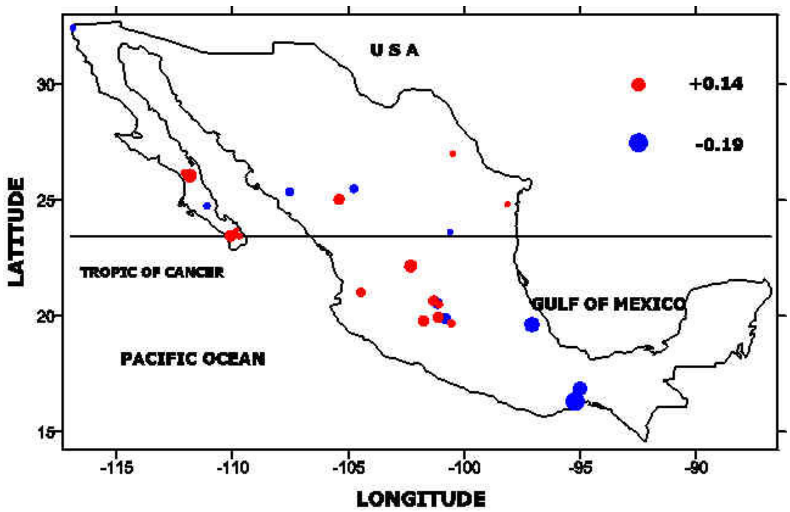


Fig. 7.18. Lag cross-correlations between the TXn (Coolest day) and the Southern Oscillation Index (SOI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

TXx

A rough latitudinal climatic transition is observed for the (lag) correlation of the Hottest day (TXx) and the SOI index. Positive correlations dominate in the central and northern part of Mexico, and negative correlations prevail over southern Mexico (Fig. 7.19). Among the largest correlations negative relationships are greater in magnitude than the positive ones (Table 7.12). This climatic feature is especially observed in the Santo Domingo Tehuantepec station in Oaxaca with a negative correlation of -0.21 and a lag of -5; while among the positive, the greatest correlation is observed in the Santa Gertrudis in the southern tip of the Baja Californian peninsula (station number 8 in Table 6.1), with a correlation of +0.14 and a lag of -2. Nevertheless, no matter the sign of the correlations, lags do not show a clear pattern. For central and northern Mexico colder temperatures are found for the TXx during El Niño conditions.

	STATION	LONGITUDE	LATITUDE	SOI		NINO 3.4		MEI	
				CORR	LAG	CORR	LAG	CORR	LAG
1	PABELLON DE ARTEAGA	-102.33	22.18	0.093	-2	-0.101	-15	-0.099	-18
2	PRESA RODRIGUEZ	-116.9	32.45	0.096	0	0.089	-18	0.091	-21
3	COMONDú	-111.85	26.08	-0.088	-7	0.850	-6	0.093	12
4	EL PASO DE IRITU	-111.12	24.77			0.052	-6	0.096	12
5	LA PURíSIMA	-112.08	26.18	0.062	-16	0.069	9	-0.114	-17
6	SAN BARTOLO	-109.85	23.73	0.063	-20	0.065	9	-0.096	-17
7	SANTA GERTRUDIS	-110.1	23.48	0.137	-2	-0.125	24	-0.184	6
8	SANTIAGO	-109.73	23.47	-0.049	13	0.065	15	0.075	12
9	EL PALMITO	-104.78	25.52	0.059	-15	-0.046	-15	0.047	11
10	SANTIAGO PAPASQUIARO	-105.42	25.05	0.119	-16	-0.109	-13	-0.137	-16
11	IRAPUATO	-101.35	20.68	0.089	-17			-0.135	-19
12	PERICOS	-101.1	20.52	-0.056	3	-0.065	21	0.078	1
13	SALAMANCA	-101.18	20.57	-0.094	2	0.097	3	0.088	2
14	CUITZEO DEL PORVENIR	-101.15	19.97	-0.048	12	-0.099	-3	-0.069	-5
15	HUINGO	-100.83	19.92	0.079	-11	-0.090	-13	0.080	10
16	CIUDAD HIDALGO	-100.57	19.7	-0.092	15	-0.090	-1	0.092	23
17	ZACAPU	-101.78	19.82	0.136	17	-0.121	19	-0.159	16
18	AHUACATLAN	-104.48	21.05	0.075	-1	-0.103	-2	-0.095	-3
19	LAMPAZOS	-100.52	27.03	0.100	-2	-0.079	-1	-0.088	-6
20	MATIAS ROMERO	-95.03	16.88	-0.123	-9	0.121	5	0.182	0
21	SANTO DOMINGO TEHUANTEPEC	-95.23	16.33	-0.212	-5	0.234	-3	0.304	-4
22	MATEHUALA	-100.63	23.65	-0.057	21	0.076	15	0.054	22
23	BADIRAGUATO	-107.55	25.37	-0.072	11	0.098	12	-0.111	3
24	SAN FERNANDO	-98.15	24.85	0.145	1	0.127	23	0.085	24
25	ATZALAN	-97.25	19.8	-0.120	14	0.117	17	0.176	5
26	LAS VIGAS	-97.1	19.65	-0.163	2	0.139	3	0.194	6

Table 7.12. Lag cross-correlations between the TXx (Hottest day) and the different ENSO indices: the Southern Oscillation Index (SOI), El Niño 3.4 index, and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Lags (leads) are expressed in months and related to the maximum correlation found after trying several lags and leads.

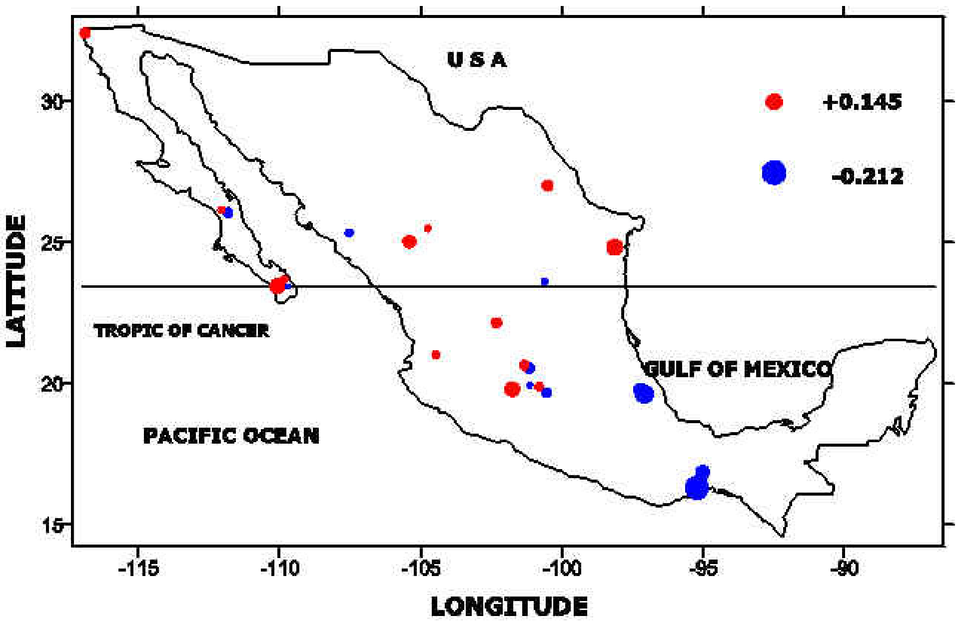


Fig. 7.19. Lag cross-correlations between the TXx (Hottest day) and the Southern Oscillation Index (SOI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

There are two clear climatic patterns when we correlate extreme temperature indices and the SOI. Minimum (night) temperatures increase during El Niño conditions, and maximum (day) temperatures are cooler during the same phase. Changes in minimum temperatures related indices have a geographical preference towards southern Mexico and high altitude stations, while maximum temperature results are spatially concentrated in the western half of the country.

Summary of the results (SOI).

Regardless of the geographical scale (regional precipitation averages or local sites), a latitudinal transition (using the Tropic of Cancer as a geographic limit) is observed in the response (using the Kendall tau-b linear correlation method) of rainfall to the annual and wet season (May-Oct) versions of the Southern Oscillation Index (SOI). During El Niño years wetter conditions are prevalent in northern Mexico and drier conditions in the south of the country. Meanwhile, homogeneous national conditions are dominant when the rainfall (regional averages and extreme indices) are linearly correlated with the dry season (Nov-Apr) SOI. The largest impacts (correlations) are observed in the north-western part of the country (the North American Monsoon or Mexican Monsoon Region –RA11 in Table 4.1- and north part of the peninsula of Baja California). Nevertheless, because of the limited number of stations in the case of daily rainfall data (extreme indices), a careful interpretation must be applied to the results of the analysis of linear correlations between extreme rainfall indices and SOI. In the case of the analysis of linear correlation between the extreme temperature indices and SOI, a clear national pattern of increasing minimum temperatures is observed regardless of whether the annual, wet season (May-Oct) or dry season (Nov-Apr) is used. As when we considered rainfall, the conclusions of this analysis can be affected by the limited number of stations with daily temperature data.

The analysis of lag correlation between the Southern Oscillation Index (SOI) and the rainfall and temperature data are consistent with the results of the linear correlation using Kendall tau-b. Lag-cross correlations of SOI with the precipitation regional averages show a latitudinal climatic transition in the results (considering the Tropic of Cancer as a geographic limit). The most affected region by the ENSO phenomenon is the north-western part of Mexico: the North American Monsoon (or Mexican Monsoon) Region (NAMR, RA11 in Table 4.1) and the northern part of the peninsula of Baja California. Wetter conditions are prevalent in northern Mexico during El Niño years (negative SOI), and the largest correlations are mostly observed near of the peak of the ENSO conditions. At local (sites) scale the correlation of the rainfall extreme indices with SOI show that the most important results occur in the north-western part of the country, near the peak of the El Niño (La Niña) conditions. Regardless the geographical scale, according to the results, the Pacific Ocean appears as an important modulator of the precipitation. Moreover, the analysis of lag correlation between the extreme temperature indices and SOI show a national pattern of increasing minimum temperatures near the strongest conditions of the ENSO phenomenon.

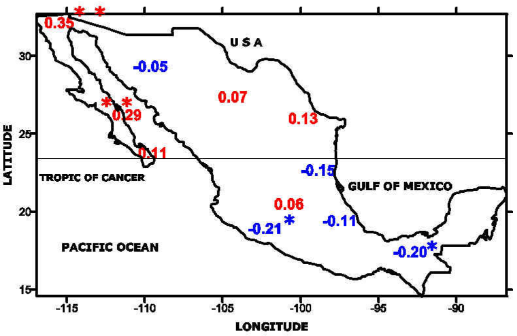
7.3. (EL) NIÑO 3.4 (INDEX) INFLUENCE.

7.3.1. LINEAR CORRELATION.

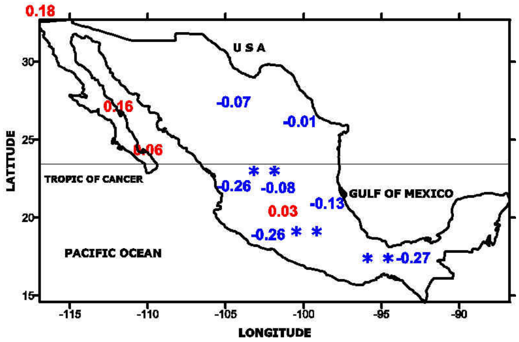
Regional Precipitation Averages.

The first analysis in this section aims to correlate linearly (using Kendall-tau b) the Niño 3.4 index with regional precipitation averages. Seasonal (annual, wet and dry seasons) versions of both time-series are used in order to test the possibility of having a local response of the rainfall to the large-scale phenomenon. The length of the Niño 3.4 index is shorter (1950-2001) than the time-series of the regional precipitation (1931-2001), reducing the potentiality of generating a more complete picture of variability as with the case of the Southern Oscillation Index (SOI). Nevertheless, in order to avoid external influences like altitude, standardised versions of these time series will be used for the analysis.

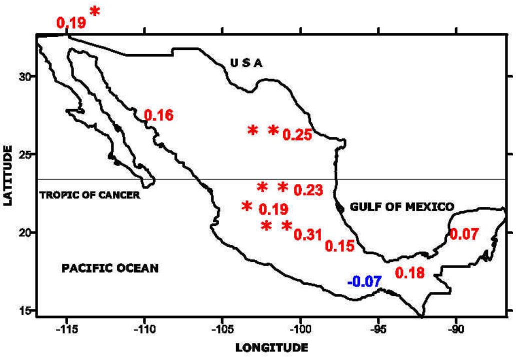
With the exception of those correlations close to zero, a clear latitudinal climatic pattern can be appreciated when correlating the annual version of the regional precipitation averages and the annual Niño 3.4 [Fig. 7.20 a)]. Negative correlations are found south of the selected geographic limit (Tropic of Cancer), and all these results are statistically significant at the 5% level. Positive correlations are observed north of this divide; and they are statistically significant at the 1% level. Therefore, drier conditions are dominant during El-Niño like years in the southern part of Mexico, and annual precipitation totals above normal are found in the northern part of the country, geographically concentrated within the Baja California peninsula.



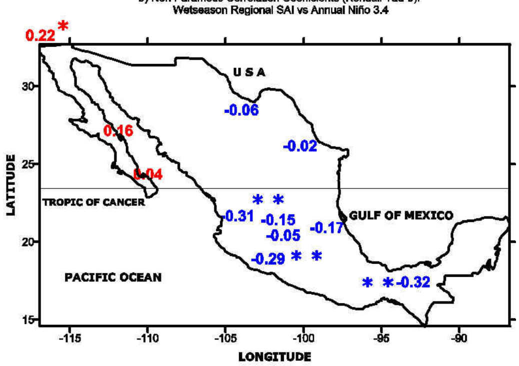
a) Non Parametic Correlation Coefficients (Kendall Tau-b). Annual Regional SAI vs Annual Niño 3.4



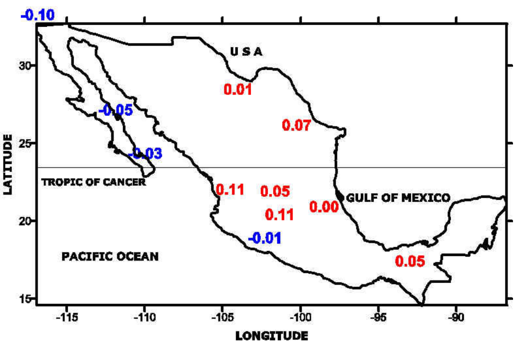
b) Non Parametic Correlation Coefficients (Kendall Tau-b). Wetseason Regional SAI vs Annual Niño 3.4



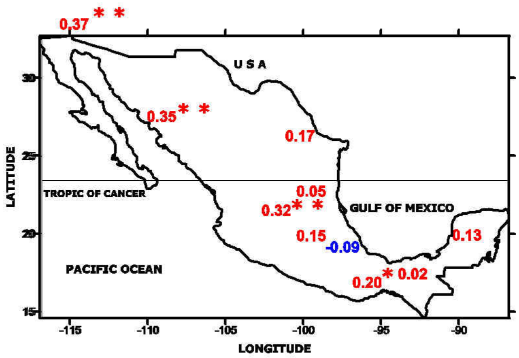
c) Non Parametic Correlation Coefficients (Kendall Tau-b). Dryseason Regional SAI vs Annual Niño 3.4



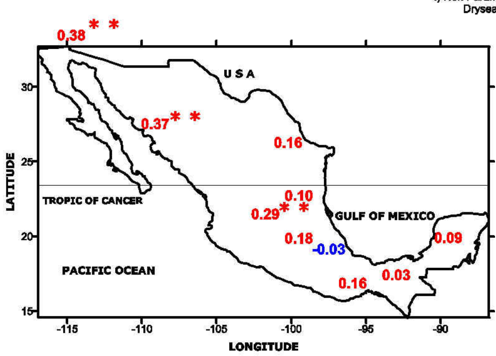
d) Non Parametic Correlation Coefficients (Kendall Tau-b). Wetseason Regional SAI vs May-Oct Niño 3.4



e) Non Parametic Correlation Coefficients (Kendall Tau-b). Wetseason Regional SAI vs Nov-Apr Niño 3.4.



f) Non Parametic Correlation Coefficients (Kendall Tau-b). Dryseason Regional SAI vs May-Oct Niño 3.4.



g) Non Parametic Correlation Coefficients (Kendall Tau-b). Dryseason Regional SAI vs Nov-Apr Niño 3.4.

Fig. 7.20. Linear correlations (Kendall tau-b) between the standardised versions of the regional precipitation averages and the Niño 3.4 index. Red numbers represent positive and blue numbers negative correlations. * means statistical significant at 5% level and ** at 1% level.

With the exception of the neovolcanic belt region (refer to section 4.2.2) that breaks the climatic picture [Fig. 7.20 b)], a combined pattern of continental/peninsula and latitudinal transitions can be observed for the wet season rainfall averages. In the first case, negative correlations are found over the Mexican mainland; all the statistically significant correlations are concentrated south of the Tropic of Cancer. Positive correlations are located within the Baja California peninsula, but no significant results are observed here. Disregarding the close to zero correlations a latitudinal climatic transition is found when correlating wet season regional precipitation (Standardised Anomaly Index, SAI) and annual Niño 3.4 [Fig. 7.20 b)]. Drier conditions dominate south of the Tropic of Cancer for El Niño-like years.

An almost national widespread pattern of positive correlation is found when correlating dry season SAI of rainfall and the annual version of Niño 3.4. Statistically significant results are concentrated from central to northern Mexico [Fig. 7.20 c)]. It is interesting to observe that, the north-eastern part of the country is clearly responding during the winter to the annual Niño 3.4 modulation that was not seen for the annual and wet seasons. Perhaps the fact that polar fronts could extend as far as southern Mexico is affecting the rainfall amount during this season (Giddings et al., 2005). Nevertheless, the largest correlation is found in the Neovolcanic Axis region, an area of high altitude sites that is certainly influencing the results. A clear climatic pattern of wetter conditions during the El Niño phase is observed almost nationally.

A continental factor is evident when we correlate wet season (May-Oct) regional SAIs and the wet season version of Niño 3.4 indices. A homogeneous picture of negative correlations is found across mainland Mexico [Fig. 7.20 d)], while positive correlations are prevalent within the Baja California peninsula. A pattern of southwards increasing negative correlations is found for the continental part of the country. Meanwhile, the positive correlations increase northwards, reaching the highest correlation in the northern part of the Baja California Peninsula. Nevertheless, the largest correlations are negative and located south of the Tropic of Cancer; therefore, drier conditions are dominant during (wet season) El Niño years for the southern part of Mexico.

The main characteristic when correlating the wet season (May-Oct) version of the regional precipitation averages and the dry season (Nov-Apr) Niño 3.4 is that no statistically significant results are found [(Fig. 7.20 e)]. It can be said, however, that drier conditions are observed in mainland Mexico, while above normal precipitation totals are found within the Baja California peninsula during El Niño-like years.

A national climatic pattern is clear when correlating the dry season (Nov-Apr) version of the regional precipitation series and the wet season (May-Oct) Niño 3.4 index [Fig. 7.20 f)]. Disregarding the negative correlation (nearly zero correlation is observed in this region) in the Los Tuxtlas region, positive correlations are prevalent across most of Mexico. So, wetter conditions are observed during El Niño-like years, for this combination. The largest correlations among all the results are found in the north-western part of Mexico, the area where winter precipitation has a strong influence on the annual totals (Mosiño and García, 1974). However, the Mexican central highlands, a region with stations of high altitude is the only region showing a statistically significant result at the 1% level like in the northern counterparts. Only the Oaxaca region on the South Pacific coast has another significant correlation south of the Tropic of Cancer. It seems that there is a wet season (May-Oct) Pacific Ocean modulation of the winter precipitation during El Niño conditions.

Positive correlations are observed in most of the country, when correlating the dry season (Nov-Apr) SAI (Standardised anomaly indices) of regional precipitation and the dry season version of El Niño 3.4 index [Fig. 7.20 g)]. As in the other combinations the highest correlations are consistently observed in the north-western part of the country: the North American Monsoon (Mexican Monsoon) and the northern Baja California peninsula regions. Although not statistical significant the Yucatan Peninsula region appears with a clear correlation, in the hurricane-free (Nov-Apr or dry) season, pointing to the importance of the disruption of the normal climatic patterns that have for some of the times extraordinary precipitation totals associated with tropical cyclones (Englehart and Douglas, 2002). Another important climatic feature is that most of the stations with significant correlations are linked with the Pacific Coast. Wetter conditions are to be expected for the regional precipitation averages during El Niño phase for the dry season (Nov-Apr). The most evident characteristic of the application of linear correlation (Kendall's tau-b) between the standardised versions of the regional precipitation averages and El Niño 3.4 index is the strong influence of seasonality in the results. The most statistically significant correlations are observed during the annual and the wet (May-Oct) precipitation seasons: drier conditions are observed during the El Niño phase for the southern (considering the Tropic of Cancer as a geographic limit) part of Mexico, when correlating with the annual and wet season (May-Oct) Niño 3.4 indices. This latitudinal climatic transition is also accompanied with a continental/peninsula pattern; defining continental as the mainland (the non-coastal territory), and the peninsula of Baja California. Wetter conditions for the north (peninsula) and the clear climatic picture of drier conditions for the southern part (continental) of Mexico are observed. Regional rainfall averages for the dry season (Nov-Apr) show precipitation above normal across almost the entire country.

Changing the spatial scale to regional levels, we can clearly see some consistency across the results. Among the positive correlations (wetter conditions), two regions appear frequently: North Baja California (near the Mexico-USA border), and the Mexican Monsoon Region (or North American Monsoon, RA11 in table 4.1); both in the north-western part of Mexico, areas strongly influenced by a winter pattern of precipitation and the Pacific Ocean. Meanwhile, the South-eastern rainforest, the Southern Pacific and the Nayarit Coast regions show the highest consistency among the negative correlations, leading to precipitation below normal during the El Niño phase.

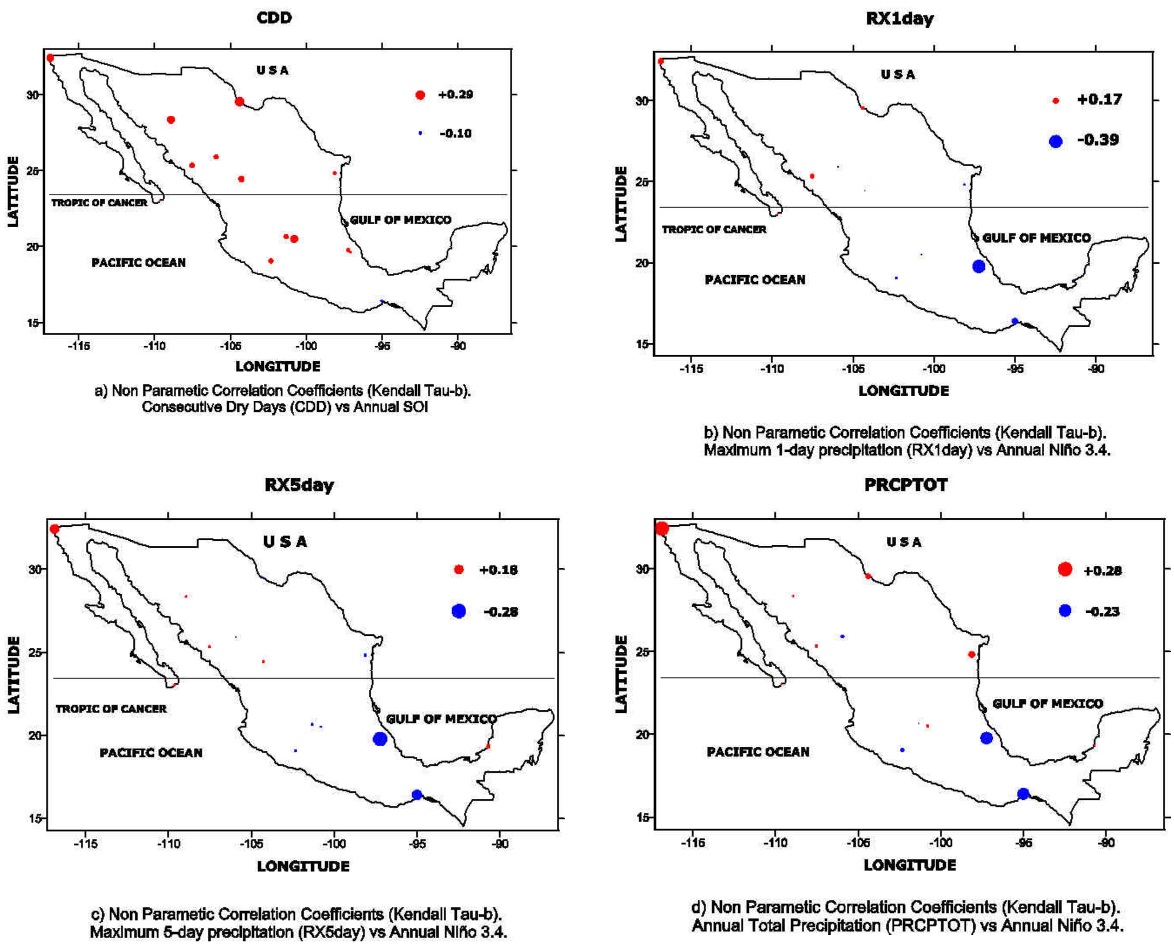
Extreme Weather Indices.

Precipitation.

Extracted from daily data of rainfall and temperature, weather extreme indices are correlated with the Niño 3.4 index. The length of the extreme indices is defined from 1941 to 2001, but 1951 is the starting year of the Niño 3.4 index. Therefore, it was not possible to use the full potential of the meteorological data. The maps with the clearest results – largest correlation values with statistically significant results – are selected to extract the most important climatic patterns of the extreme weather indices modulated by ENSO (through El Niño 3.4.). Seasonal analyses are proposed to evaluate the subtle differences on the climate of Mexico. Annual, wet season (May-Oct) and dry season (Nov-Apr) are used in both the extreme weather (precipitation and temperature) and the Niño 3.4 indices. The analysis is expected to test the latitudinal climatic transition of the Mexican climate allowing a comparison against the results of the correlations of the extreme indices and SOI.

Linear correlation (using Kendall's tau-b) between precipitation extremes and the annual Niño 3.4 indices is the first combination to be addressed in this section. With the exception of the RX5day, all other indices (CDD, RX1day and PRCPTOT) were also analysed using SOI (see section 7.2.1). The Consecutive Dry Days (CDD) index [Fig. 7.21 a)] shows negative correlations at three stations from central to northern Mexico, two of them can be considered to be within the area of influence of the Mexican Monsoon system: Yecora (-0.23, linear correlation) and Ojinaga (-0.30), while Celaya (-0.29) is located in central Mexico [station numbers 32, 11 and 16 in Table 5.1 and Fig. 3.6 a)]. In geographical terms, the most significant results (Celaya and Ojinaga; statistically significant at the 1% level) are in a central line from a longitudinal perspective. Only southern stations with statistically significant results are found for RX1day [Fig. 7.21 b)]. Negative correlations are prevalent south of the Tropic of Cancer, pointing to drier conditions at these sites during El Niño conditions. Two of these stations: Atzalán (-0.39) and Las Vigas (-0.21) are within the Los Tuxtlas region [stations number 34, and 35 in Table 5.1 and Fig. 3.6 a)]. Juchitán, near the South Pacific coast [station number 27 in Table 5.1 and Fig. 3.6 a)] has a correlation of -0.26 and a statistical significance better than the 1% level. Similar results are observed for the RX5day index [Fig. 7.21 c)]: negative correlations are dominant south of the geographical limit defined by the Tropic of Cancer. The maximum 5-day precipitation shows statistically significant results at Atzalán (-0.28) and Juchitán (-0.25) stations, heading to drier conditions during El Niño. These stations are also present with the largest correlations and statistical significance for the RX1day index. Finally, the annual total precipitation (PRCPTOT) [Fig. 7.21 d)] shows some similarity to the results of the already analysed indices (CDD, RX1day and RX5day). The most significant correlations show a latitudinal climatic pattern. In the northern part of Mexico, the Presa Rodríguez [station number 2 in Table 5.1 and Fig. 3.6 a)] show a positive correlation (+0.28) that is statistically significant at the 1% level, that leads to precipitation above the normal for this location. Meanwhile, south of the Tropic of Cancer, Atzalán (-0.23) and Juchitán (-0.23) stations show statistically significant (better than the 5% level) negative correlations. Therefore, drier conditions are dominant for these sites in the southern part of the country.

A clear latitudinal transition is observed for the extreme precipitation indices when correlated with the Niño 3.4 index. Northern stations show a pattern towards above normal precipitation; especially a decreasing trend in the Consecutive Dry Days (CDD) index. However, the most consistent climatic picture is among the indices that measure changes in wet days (RX1day, RX5day and PRCPTOT). During El Niño, drier conditions are prevalent for the stations south of the Tropic of Cancer. This statement is particularly true for the Atzalán and Juchitán [station numbers 34 and 27 in Table 5.1 and Fig. 3.6 a)], near the narrower land mass of the Tehuantepec isthmus in southern Mexico.



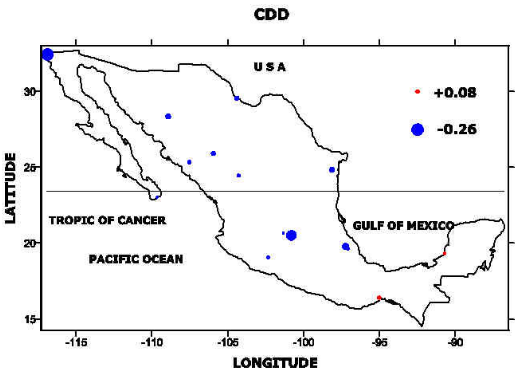
a) Non Parametic Correlation Coefficients (Kendall Tau-b). Consecutive Dry Days (CDD) vs Annual SOI

b) Non Parametic Correlation Coefficients (Kendall Tau-b). Maximum 1-day precipitation (RX1day) vs Annual Niño 3.4.

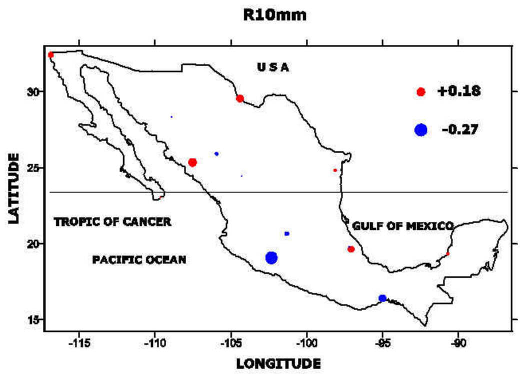
c) Non Parametic Correlation Coefficients (Kendall Tau-b). Maximum 5-day precipitation (RX5day) vs Annual Niño 3.4.

d) Non Parametic Correlation Coefficients (Kendall Tau-b). Annual Total Precipitation (PRCPTOT) vs Annual Niño 3.4.

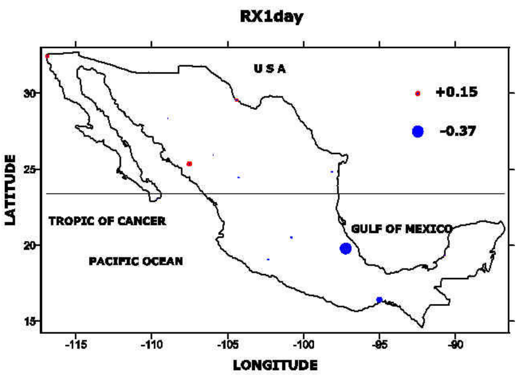
Fig. 7.21. Linear correlations (Kendall tau-b) between the Extreme Precipitation Indices and the Annual Niño 3.4 Index. Circles in red are representing a positive and in blue negative correlations.



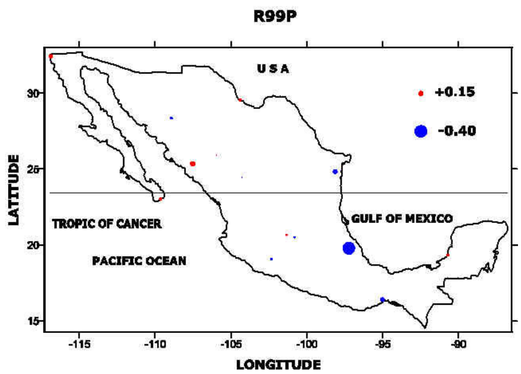
a) Non Parametic Correlation Coefficients (Kendall Tau-b).
Consecutive Dry Days (CDD) vs (May-Oct) Niño 3.4.



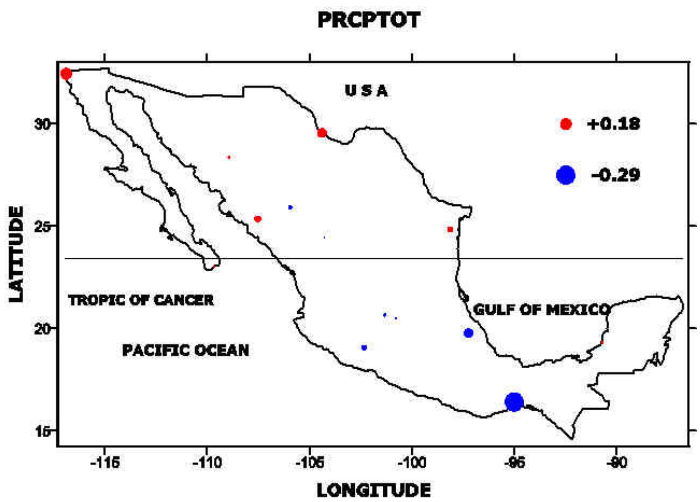
b) Non Parametic Correlation Coefficients (Kendall Tau-b).
Heavy Precipitation Days (R10mm) vs (May-Oct) Niño 3.4.



c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Maximum 1-day precipitation (RX1day) vs (May-Oct) Niño 3.4.



d) Non Parametic Correlation Coefficients (Kendall Tau-b).
Extremely wet day precipitation (R99P) vs (May-Oct) Niño 3.4.



e) Non Parametic Correlation Coefficients (Kendall Tau-b).
Annual Total Precipitation (PRCPTOT) vs (May-Oct) Niño 3.4.

Fig. 7.22. Linear correlations (Kendall tau-b) between the Extreme Precipitation Indices and the Wet Season (May-Oct) Niño 3.4 Index. Circles in red are representing a positive and in blue negative correlations.

Wet Season

The relationships between the extreme precipitation indices and May-Oct (wet season) Niño 3.4 index are the next assessment in this section. May to October is the period (wet season) when most of the annual total precipitation occurs (see section 2.2 in chapter 2). Therefore, it is expected that the results will be close to those of the annual Niño 3.4 index. The precipitation extreme indices to be analysed with Niño 3.4 are: CDD, R10mm, RX1day, R99P and PRCPTOT, because they have the clearest and most important results amongst the potential rainfall indices evaluated. When compared with those evaluated using the annual El Niño 3.4, R10mm and R99P indices have been included this time.

The first precipitation extreme index to be analysed is the Consecutive Dry Days (CDD). An almost national pattern of negative correlations (less consecutive dry days during El Niño years, i.e., wetter conditions) is observed for CDD [Fig. 7.22 a)] when correlated with the May-Oct Niño 3.4 index. Although not statistically significant there is a clear concentration of the largest correlations in the western part of Mexico, especially within the Mexican Monsoon Region. The highest result is observed at Presa Rodriguez station in North-western Mexico [station number 2 in Table 5.1 and Fig. 3.6 a)], right on the border Mexico-USA border, its correlation (-0.26) is better than the 1% of statistical significance. In central Mexico, Celaya and Atzalán [station numbers 16 and 34 in table 5. 1 and fig. 3.6 a)] have correlations (-0.25 and -0.21 respectively) statistically significant at the 5% level; it is also important to mention that both stations are located above the 1500 m.a.s.l. The heavy precipitation days index (R10mm) shows a prevalence of negative correlations across the country [Fig. 7.22 b)], but the climatic pattern is not as clear as for CDD. The largest relationships are found for Apatzingán and Juchitán [station numbers 20 and 27 in Table 5. 1 and Fig. 3.6 a)] with correlations of -0.27 and -0.22 respectively; both above the 5% of statistical significance. Geographically speaking, it can be said that there is a strong Southern Pacific connection with the results, pointing to a clear ENSO modulation of this extreme index. Evaluated in the same measuring units (as mm) R10mm, the RX1day index or max 1-day precipitation show a clear southern climatic pattern [Fig. 7.22 c)]. The most significant correlations are located at Atzalán (-

0.37), Juchitán (-0.26), and Las Vigas (-0.22) [station numbers 34, 27, and 35 in Table 5.1 and Fig. 3.6 a)]. They are located near the Tehuantepec isthmus, the narrower continental land mass of Mexico. The correlations at two of these stations (Atzalán and Juchitán) are better than the 1% level of statistical significance. No significant results are found in the northern part of Mexico. Most significant correlations for the R99P index [Fig. 7.22 d)] are observed along the eastern part of Mexico, near the Gulf of Mexico coast. The largest results are observed at Atzalán, Las Vigas and San Fernando [station numbers 34, 35 and 33 in Table 5.1 and Fig. 3.6 a)]. The last two have statistically significant correlations (-0.23 correlation in both cases) better than the 5% level. However, the largest correlation (-0.40) is found within the Los Tuxtlas region at Atzalán, and the relationship is significant at the 1% of significant level. It is possible (as these three stations with statistically significant results are along the coast of the Gulf of Mexico) that the hurricane season could be affecting the results of this index. Finally, annual total precipitation only shows significant results south of the Tropic of Cancer, close to the results already observed for the RX1day index. The stations with the largest correlations are geographically located near the Tehuantepec Isthmus. Highest correlations are found at Juchitán (-0.29) and Atzalán (-0.21) better than the 1 and 5% of statistical significance respectively [station numbers 27 and 34 in Table 5.1 and Fig. 3.6 a)]. PRCPTOT results [Fig. 7.22 e)] lead to a climatic pattern of precipitation below normal in the southern part of Mexico, while no clear pattern evident over the northern part of the country.

The results when precipitation extreme indices and the (May-Oct) Niño 3.4 index are correlated show that the most significant changes occur south of the Tropic of Cancer. Negative correlations prevail in most of the extreme indices analysed pointing to drier conditions during El Niño, especially for the southern part of the country. Only the Presa Rodriguez and San Fernando stations, both located in northern Mexico [station numbers 2 and 33 in Table 5.1 and Fig. 3.6 a)] break with this climatic picture. Two interesting features also appear when analysing these combinations: most of the significant results are geographically concentrated in southern Mexico near the Tehuantepec Isthmus and although explicitly avoided (using the standardised version of the Niño 3.4), it seems that high altitudes play an important role in the climatic responses of the extreme rainfall indices to ENSO.

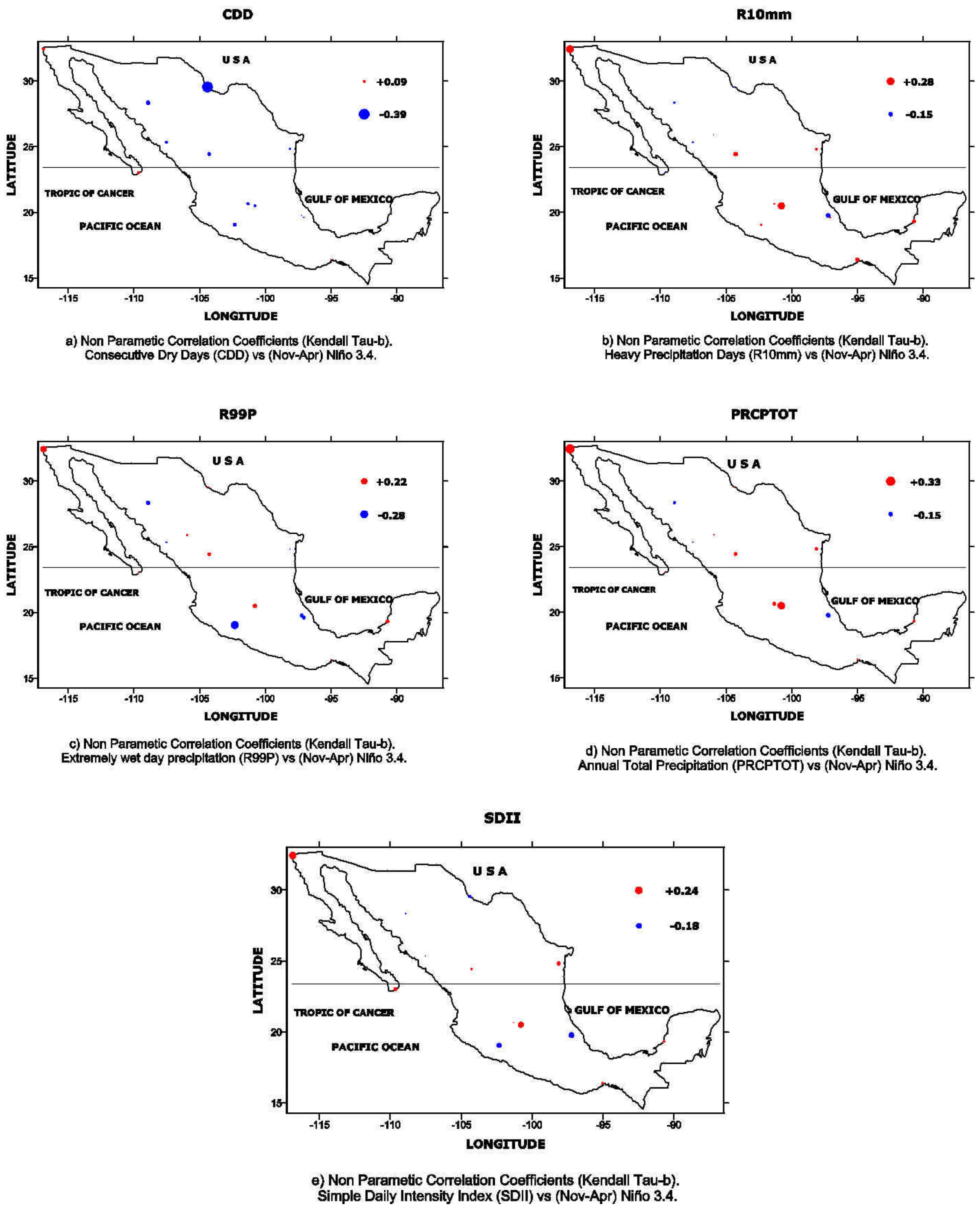


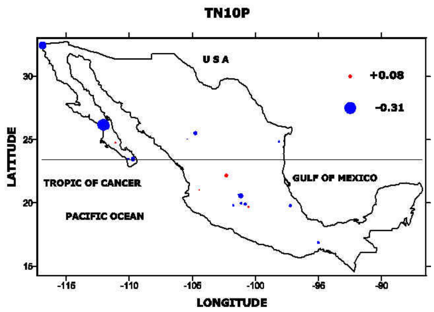
Fig. 7.23. Linear correlations (Kendall tau-b) between the Extreme Precipitation Indices and the Dry Season (Nov-Apr) Niño 3.4 Index. Circles in red are representing a positive and in blue negative correlations.

Dry Season

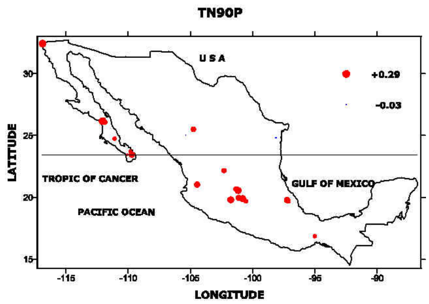
The last analysis among the extreme precipitation indices is to correlate them with the dry season (Nov-Apr) Niño 3.4 index (Fig. 7.23). The November to April period is the dry season for much of Mexico, except some northern areas of the country, where winter precipitation makes a large contribution to the annual total rainfall (see section 2.3). This climatic pattern contrasts markedly with much of the rest of the country. The extreme indices to be analysed are: CDD, R10mm, R99P, PRCPTOT and SDII. When compared with the annual and wet seasons RX1day and RX5day do not have significant results, and SDII is evaluated here, but was not assessed in the previous analyses.

For the November to April season, the Consecutive Dry Days (CDD) is the first index to be evaluated. Then, most significant results are found in northern Mexico [Fig. 7.23 a)], especially within the influence of the Mexican Monsoon Region (section 2.2.2). Almost a national picture of negative correlations (fewer consecutive dry days, i.e., wetter conditions) is observed for CDD. Ojinaga (-0.39) and Yecora (-0.24) [station numbers 11 and 32 in Table 5.1 and Fig. 3.6 a)] have the largest correlations among all the stations, and both are statistically significant at the 1% level. Mostly positive correlations are evident in central and northern Mexico for the Heavy Precipitation Days (R10mm), and they are slightly concentrated in the western half of the country [Fig. 7.23 b)]. The Presa Rodriguez in the most north-western part of the country [station number 2 in Table 5.1 and Fig. 3.6 a)], near the border with the USA shows the largest correlation (-0.28), and the result is statistically significant at the 1% level. A latitudinal transition can be seen in the results of the extremely wet day precipitation (R99P) index [Fig. 7.23 c)]. South of the Tropic of Cancer, Juchitán [station numbers 27 in Table 5.1 and Fig. 3.6 a)] has the largest negative correlation (-0.28); in northern Mexico the highest (positive) correlation (+0.22) is observed at the Presa Rodríguez station. Both results are statistically significant at better than the 5% level. Despite this climatic transition, no clear climatic pattern can be found in the R99P index. Wetter conditions are dominant in central and northern Mexico according to the annual precipitation totals (PRCPTOT) results [Fig. 7.23 d)]. No clear climatic pattern can be extracted from the results, but it can be mentioned that the largest correlation values are observed in the central and northern part of the country, coinciding with the importance of winter precipitation in annual totals. The highest positive correlation (+0.33) is found at the Presa Rodríguez station, at better than 1% of statistical significance. Lastly, only one significant correlation is seen when we evaluate the Simple Daily Intensity Index (SDII). Although not clear, positive correlations can be observed in Central and Northern Mexico; wetter conditions are dominant during the El Niño phase [Fig. 7.23 e)]. A clear example of this picture, is the Presa Rodriguez station that has the only significant correlation (+0.24) among the results, in the north of the Baja California peninsula, the correlation is statistically significant at the 5% level.

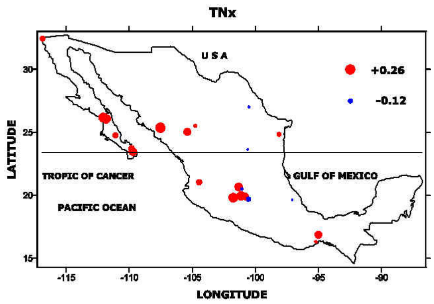
In general, above normal precipitation can be observed during the (Nov-Apr) Niño 3.4 index, when it is correlated with the extreme rainfall indices. Geographically speaking, this climatic pattern is concentrated in central and northern Mexico. The Presa Rodriguez [station numbers 2 in Table 5.1 and Fig. 3.6 a)] has consistently shown this pattern of wetter conditions during the "dry" season of El Niño. Meanwhile, only one statistically significant correlation has been observed (across all the indices) for the southern part of Mexico. Therefore, it can be concluded than the dry season (Nov-Apr) Niño 3.4 is modulating the precipitation extreme indices mostly in the northern part of Mexico.



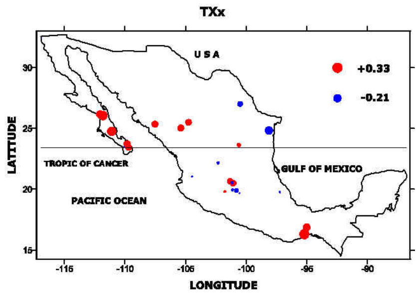
a) Non Parametic Correlation Coefficients (Kendall Tau-b).
Cool Night Frequency (TN10p) vs Annual Niño 3.4



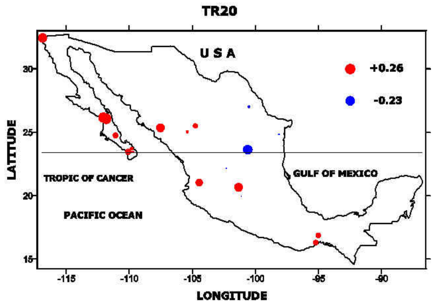
b) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hot Night Frequency (TN90p) vs Annual Niño 3.4



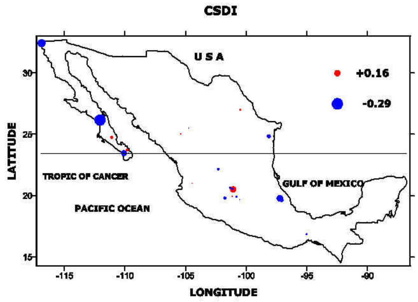
c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hottest Night (TNx) vs Annual Niño 3.4



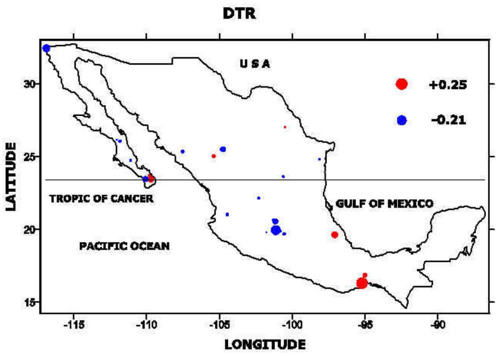
d) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hottest Day (TXx) vs Annual Niño 3.4



e) Non Parametic Correlation Coefficients (Kendall Tau-b).
Warm Nights (TR20) vs Annual Niño 3.4



f) Non Parametic Correlation Coefficients (Kendall Tau-b).
Cold Spell Days Index (CSDI) vs Annual Niño 3.4



g) Non Parametic Correlation Coefficients (Kendall Tau-b).
Daily Temperature Range (DTR) vs Annual Niño 3.4

Fig. 7.24. Linear correlations (Kendall tau-b) between the Extreme Temperature Indices and the Annual Niño 3.4 Index (Annual Niño 3.4). Circles in red are representing a positive and in blue negative correlations.

Temperature.

The other aspect of weather extremes to be correlated with the Niño 3.4 index is temperature. The different seasonal versions (annual, May-Oct and Nov-Apr) of Niño 3.4 will in this section be correlated with the extreme temperature indices. The length of the time series is the same as for precipitation (1941-2001). A latitudinal climatic transition is also expected in this analysis; we consider the Tropic of Cancer as a geographical limit to define different regime patterns.

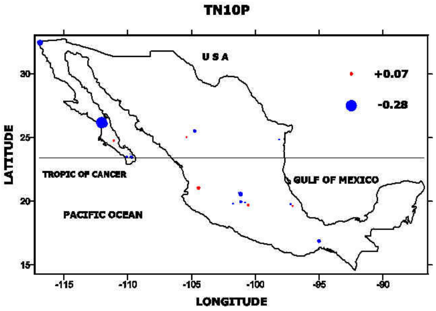
The extreme temperature indices considered, because of their clear results, when correlated with the annual Niño 3.4 index are: TN10P, TN90P, TNx, TXx, TR20, CSDI and DTR. These parameters have been divided, in such a way that minimum and maximum temperatures are evaluated first, and then the DTR that summarise the differences between maximum and minimum temperatures. The Cool Night Frequency (TN10P) shows [Fig. 7.24 a)] mostly a pattern of negative correlations (fewer cool nights, i.e., warmer temperatures). All significant results are located north of the Tropic of Cancer, particularly within the Baja California peninsula. Highest correlations are observed at La Purísima (-0.31) and the Presa Rodríguez (-0.27) [station numbers 5 and 2 in Table 6.1 and Fig. 3.6 b)], both correlations are better than the 1% level of statistical significance. A clear national climatic picture of positive correlations is observed for the Hot Night Frequency (TN90P) index. The most significant results are geographically concentrated in central and northern Mexico [Fig. 7.24 b)]. La Purísima and the Presa Rodríguez stations have the largest correlations both with values of +0.29, and they are statistically significant at the 1% level. The rest of the significant correlations located in Central Mexico are high altitude stations [Salamanca, Zacapu and Huingo; stations number 19, 24 and 22 in Table 6.1 and Fig. 3.6 b)] that exceed 1500 m.a.s.l. Warmer conditions are then expected for the TN90P index during an El Niño phase. A similar pattern as for the TN90P can be seen for the Hottest Night (TNx) index [Fig. 7.24 c)]. Positive correlations are almost nationally widespread. The largest correlations are slightly biased to the western half of the country near or along the Pacific coast. Warmer temperatures are then expected at night during El Niño phases. Warmer conditions are also dominant during the day time temperatures according to the TXx correlations [Fig. 7.24 d)]. Indeed, positive correlations can be observed over much of the country. Because of the geographical location of many of the significant correlations, it seems that the Pacific Ocean has a strong influence on this index. The correlations at Santo Domingo Tehuantepec and El Paso de Iritu [stations 29 and 4 in Table 6.1 and Fig. 3.6 b)] are all at better than the 1% level of statistical significance. Warm or tropical nights index (TR20) also shows a prevalence towards positive correlations [Fig. 7.24 e)]. The most significant results are concentrated in the peninsula of Baja California and north of the Tropic of Cancer. In accordance with these correlations, more nights above the 20°C threshold are expected during El Niño. Less clear is the climatic profile for the Cold Spell Days Index (CSDI). Negative correlations are observed in the Baja California peninsula and the Los Tuxtlas region [Fig. 7.24 f)]. Fewer spells of 6 consecutive days when TN<10^{th} percentile of 1961-1990 are expected for the Purísima, Comondú and Atzalán [station numbers 5, 3 and 34 in Table 6.1 and Fig. 3.6 b)]. Finally, lower values of the Daily Temperature Range (DTR) are observed during El Niño in Central and Northern Mexico, while they increase in the southern half of the country [Fig. 7.24 g)]. Therefore, we can speak of a latitudinal transition in the response of the DTRs for this index.

A clear increase in these extreme indices associated with minimum temperatures is observed when correlated with the annual version of the Niño 3.4 index. Warming conditions are found in central and northern Mexico, which is especially clear for the stations north of the Tropic of Cancer in the Baja California Peninsula (La Purísima, Presa Rodríguez and Comondú). Although increasing, maximum temperatures do not have a clear pattern like the changes in minimum temperatures.

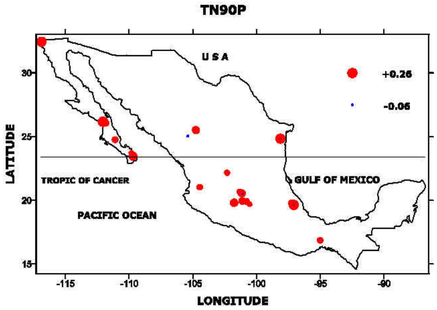
Wet Season

In this section we correlate extreme temperature indices and the May to October version of the Niño 3.4 index. Due to their significant results the indices to be analysed in this section are: TN10P, TN90P, TNx, TXx, TR20, CSDI and DTR. They have been classified in such a manner that the indices related to minimum and maximum temperatures are analysed first, finishing with DTR that combines the maximum and minimum temperatures in an index.

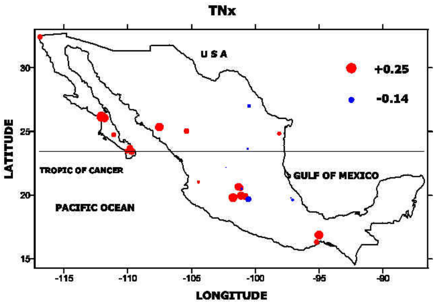
The first index associated with minimum temperatures evaluated is the Cool Night Frequency (TN10P) [Fig. 7.25 a)]. Mostly negative correlations are seen across the country; the most significant results are observed north the Tropic of Cancer in the peninsula of Baja California. La Purísima, Comondú, and the Presa Rodríguez [station numbers 5, 3, and 2 in Table 6.1 and Fig. 3.6 b)] are the stations with the largest correlations, but only at La Purísima are the results better than the 1% level of statistical significance. According to these results, the frequency of cool nights decreases during the May-Oct (wet season) El Niño phase. An almost nationally widespread pattern of positive correlations is found for the Hot Night Frequency (TN90P) [Fig. 7.25 b)]. Therefore, warmer nights can be expected during the rainfall wet season (May-Oct) under El Niño conditions for TN90P. The highest correlations for this index are seen at La Presa Rodríguez and La Purísima [station numbers 2 and 5 in Table 6.1 and Fig. 3.6 b)], both statistically significant at the 5% level. The Pacific Ocean seems to be a strong influence in the modulation of the extremes associated with minimum temperatures. This is especially true when we evaluate the Hottest Night Index (TNx) [Fig. 7.25 c)]. The largest (positive) correlations are geographically concentrated in the western half of Mexico, but only the result at La Purísima (+0.25) is statistically significant at the 5% level. Nevertheless, warmer nights could expect to be dominant in the western part of Mexico during the May to October period of El Niño phase. A latitudinal climatic transition can also be observed in the results of the Hottest Day Index (TXx) [Fig. 7.25 d)]. Positive correlations are prevalent in the western part of Mexico, especially near the Pacific coast and the Baja California peninsula. In fact, the most significant results are found here, north of the Tropic of Cancer at Comondú and El Paso de Iritu [station numbers 3 and 4 in Table 6.1 and Fig. 3.6 b)], being both below the 1% level of statistical significance. Warmer day time conditions along the Pacific Coast and cooler temperatures in the northeast part of Mexico are to be observed during May-Oct (wet season) El Niño. Mixed climatic patterns are found for the Tropical Nights (TR20) [Fig. 7.25 e)]. Nevertheless, the largest (positive) correlations are seen in the Mexican Monsoon Region and the Baja Californian peninsula in the northwest part of Mexico. More nights above the 20°C limit are expected for these regions during May-Oct (wet season) El Niño. Negative correlations are evident within the Baja Californian peninsula for the Cold Spell Days Index (CSDI) [Fig. 7.25 f)], i.e., fewer spells are present when a fully developed El Niño is occurring during the May to October period (wet season). Only one statistically significant (at the 5% level) result is found for the Daily Temperature Range (DTR) index. Positive correlations are slightly stronger south of the Tropic of Cancer. But, no clear climatic pattern is observed for DTR [Fig. 7.25 g)].



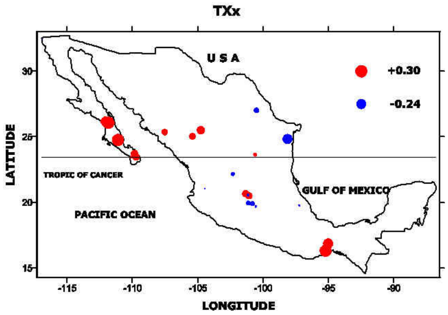
a) Non Parametic Correlation Coefficients (Kendall Tau-b).
Cool Night Frequency (TN10p) vs (May-Oct) Niño 3.4



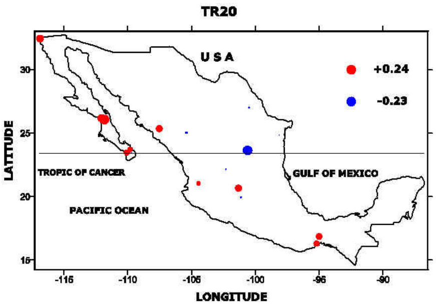
b) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hot Night Frequency (TN90p) vs (May-Oct) Niño 3.4



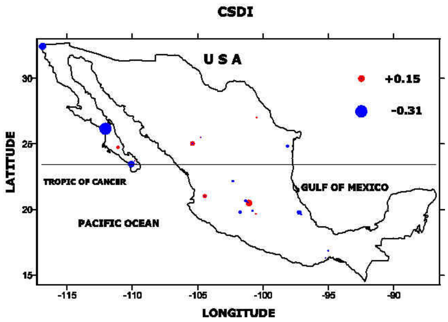
c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hottest Night (TNx) vs (May-Oct) Niño 3.4



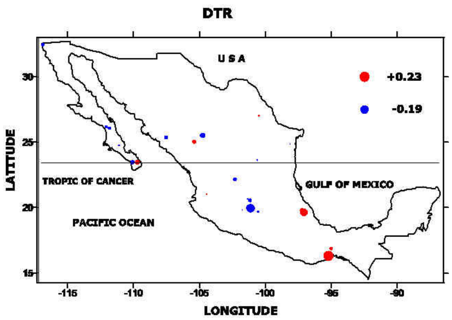
d) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hottest Day (TXx) vs (May-Oct) Niño 3.4



e) Non Parametic Correlation Coefficients (Kendall Tau-b).
Warm Nights (TR20) vs (May-Oct) Niño 3.4



f) Non Parametic Correlation Coefficients (Kendall Tau-b).
Cold Spell Days Index (CSDI) vs (May-Oct) Niño 3.4



g) Non Parametic Correlation Coefficients (Kendall Tau-b).
Daily Temperature Range (DTR) vs (May-Oct) Niño 3.4

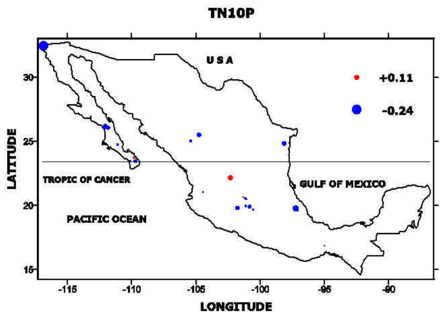
Fig. 7.25. Linear correlations (Kendall tau-b) between the Extreme Temperature Indices and the Wet Season (May-Oct) El Niño 3.4 Index (Wet Niño 3.4). Circles in red are representing a positive and in blue negative correlations.

The temperature extreme indices show an almost general pattern of warmer conditions when (they are) correlated with the May to October (wet season) standardised version of Niño 3.4. Geographically speaking these warming conditions prevail over the Baja California peninsula, but also along the Pacific coast within the Mexican monsoon region (RA11 in table 4.1).

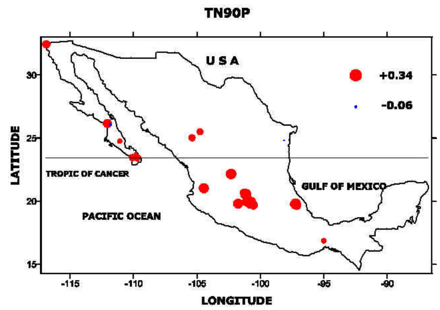
Dry Season

The application of the linear correlation between the temperature extreme indices and the November to April version of Niño 3.4 is the last analysis to be performed. The indices to be analysed in this section are: TN10P, TN90P, TNn, TNx, TX10P, TR20, and CSDI. These indices have been divided aiming to analyse in the first place minimum temperatures but finishing this time with a measure of cold spell days (CSDI).

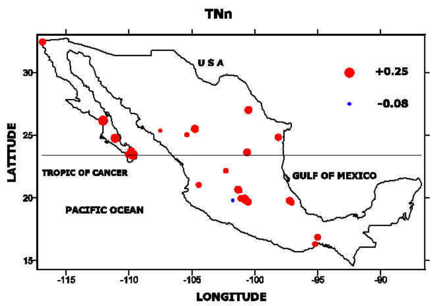
Although not clear, a national pattern of negative correlations is dominant for the TN10P index [Fig. 7.26 a)]. The only statistically significant correlation (-0.24) is observed at La Presa Rodríguez [station number 2 in Table 6.1 and Fig. 3.6 b)] in the north of Baja California. In general, it can be said that warmer temperatures prevail during Nov-Apr (dry season) El Niño. A national climatic picture of positive correlations is found for the TN90P index [Fig. 7.26 b)]. Most significant results are concentrated in Central Mexico, and south of the Tropic of Cancer. An interesting feature is seen for this index, all the stations are above 1500 m.a.s.l. It can be concluded that the frequency of nights exceeding the 90th percentile increases during El Niño (Nov-Apr). Positive correlations are also nationally widespread for the Coolest Night Index (TNn) [Fig. 7.26 c)], but, the largest correlations with statistically significant results are located within the peninsula of Baja California, north the Tropic of Cancer. Warmer conditions for the TNn index are nationally observed during (Nov-Apr) El Niño. Almost the same national pattern of positive correlations is repeated for the TNx index [Fig. 7.26 d)]. The highest correlations are geographically located in Central and Northern Mexico (within the area of influence of the Mexican Monsoon). Except for Badiraguato in the north-western part of the country [station number 31 in Table 6.1 and Fig. 3.6 b)], all these stations exceed 1500 m.a.s.l. Warmer nights are then expected during El Niño. The most significant results north of the Tropic of Cancer are also observed for the TX10P [Fig. 7.26 e)]. There is a clear continental/peninsula climatic pattern for this index: most continental land shares positive correlations, while within the peninsula of Baja California negative correlations are dominant. The greatest correlation (better than the 1% level of statistical significance) is found at Santiago (-0.31) [station numbers 9 in Table 6.1 and Fig. 3.6 b)]. The fact that this large correlation is occurring during the Nov-Apr period points to a clear example of the role that winter precipitation plays in the area, especially during El Niño years. According to these results, warmer temperatures are to be expected in the Baja California peninsula during the November to April period of El Niño phase. Mexico is nearly dominated by positive correlations when the TR20 [Fig. 7.26 f)] and the (Nov-Apr) Niño 3.4 indices are correlated. The largest correlations are geographically biased to the western half of the country; all these results are statistically significant at the 5% level. An increasing number of warmer nights (TN>20°C) are observed during (Nov-Apr) El Niño conditions. A mixed pattern of positive and negative correlation is found for the Cold Days Spell Index [Fig. 7.26 g)]. Although most significant results [Comondú and Las Vigas; station numbers 3 and 35 in Table 6.1 and Fig. 3.6 b)] are negative correlations statistically significant at the 5% level, the climatic picture is not geographically clear for this index. Nevertheless, fewer spells of cold days (warmer temperatures) can be expected during the Nov-Apr period of El Niño.



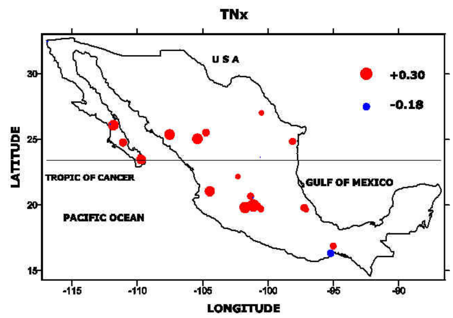
a) Non Parametic Correlation Coefficients (Kendall Tau-b).
Cool Night Frequency (TN10p) vs (Nov-Apr) Niño 3.4



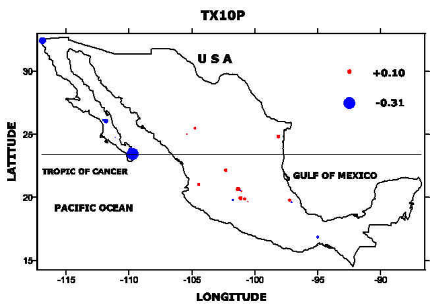
b) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hot Night Frequency (TN90p) vs (Nov-Apr) Niño 3.4



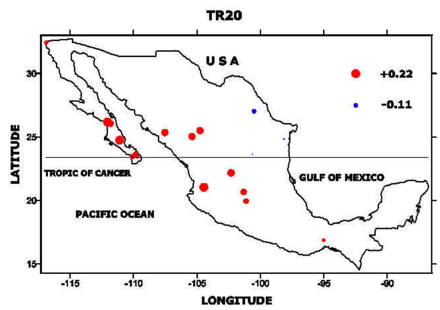
c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Coolest Night (TNn) vs (Nov-Apr) Niño 3.4



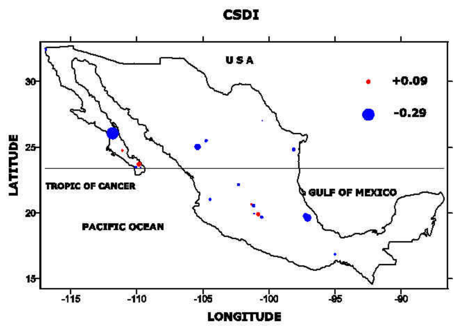
d) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hottest Night (TNx) vs (Nov-Apr) Niño 3.4



e) Non Parametic Correlation Coefficients (Kendall Tau-b).
Cool Day Frequency (TX10p) vs (Nov-Apr) Niño 3.4



f) Non Parametic Correlation Coefficients (Kendall Tau-b).
Warm Nights (TR20) vs (Nov-Apr) Niño 3.4



g) Non Parametic Correlation Coefficients (Kendall Tau-b).
Cold Spell Days Index (CSDI) vs (Nov-Apr) Niño 3.4

Fig. 7.26. Linear correlations (Kendall tau-b) between the Extreme Temperature Indices and the Dry Season (Nov-Apr) El Niño 3.4 Index (Dry Niño 3.4). Circles in red are representing a positive and in blue negative correlations.

Warmer temperatures during the November to April (the rainfall dry season) period during El Niño events are to be expected across most of Mexico. This is especially true for minimum temperatures indices (TN10P, TNn, TNx and TN90P); results lead to a persistence of warmer conditions during El Niño phase for central and northern Mexico. The same geographical pattern could be said to apply to the maximum temperatures, but it is less clear. Clearer results prevail in the Baja Californian peninsula. However, no clear geographical climatic picture is observed for the CSDI Index; but certainly above normal temperatures are to be expected. Therefore, a nationally widespread pattern of warmer temperatures is very likely to be found during the November to April "season" of El Niño.

7.3.2. LAG CORRELATION.

Regional Precipitation Averages

Positive correlations are a dominant characteristic of the largest correlation values between Regional Precipitation Averages and the Niño 3.4 index (see Table 7.1). Similar time shifts (-2, +2, and +3 months) are observed for regions RA4 (Central Mexican Highlands), RA6 (North Baja California) and RA7 (La Huasteca Region) (see Table 4.1 for the regional definitions and their climatic characteristics). Correlations increase when moving from west to east and south to north (See Fig. 7.27). In this sense, the largest response of the regional precipitation averages to Niño 3.4 is located in the north-western part of Mexico (RA4 and RA6) just as it was observed when they were correlated with SOI, with a delayed time-shift. La Huasteca region (RA7) has a quite similar climatic response in its correlations and lags. In fact, according to these results, it can be said that wetter conditions are found during El Niño phase for northern Mexico near to El Niño peak conditions.

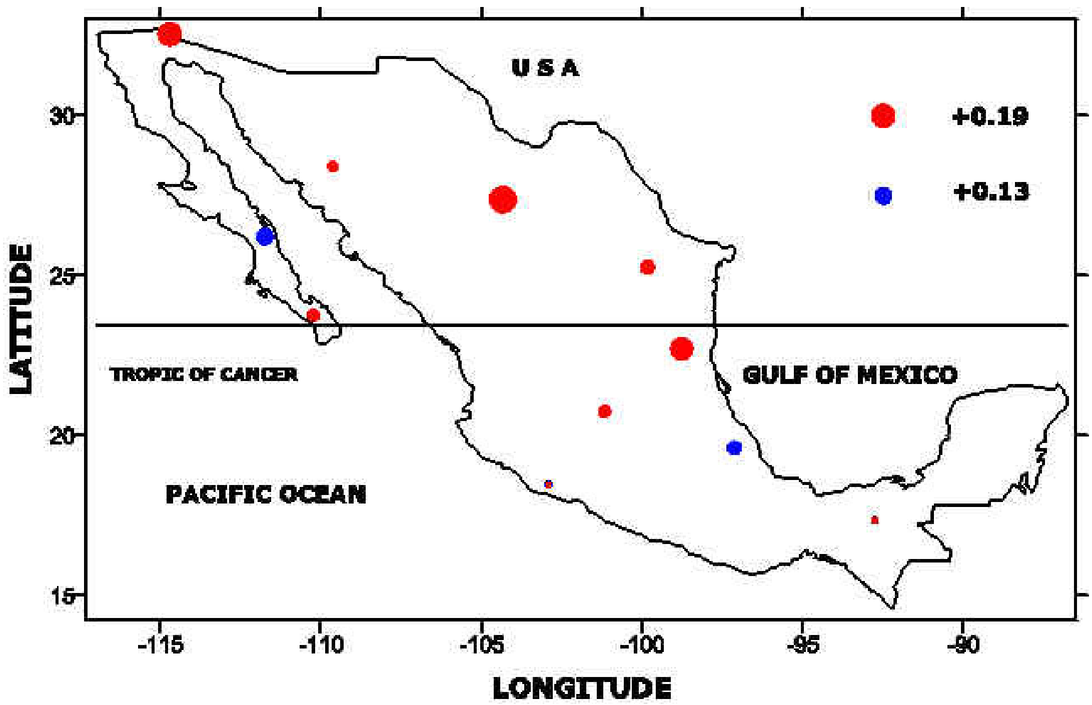


Fig. 7.27. Lag cross-correlations between the standardised versions of Precipitation Regional Averages and the El Niño 3.4 index. Red circles represent positive and blue circles negative correlations.

Extreme Weather Indices.

Extreme Rainfall Indices

Because of their clear statistically significant results, only two rainfall extreme indices will be analysed. Both extreme indices are related to maximum precipitation: the maximum 1-day precipitation (RX1day) and the maximum 5-day precipitation (RX5day).

The strongest response of the maximum 1-day precipitation (RX1day) to El Niño (expressed by the Niño 3.4 index) is observed within the most north-western part of Mexico, at La Presa Rodríguez in the northern Baja Californian Peninsula [station number 2 in Table 5.1 and Fig. 3.6 a)], with a positive correlation of +0.17 and a lag of 2 months (Fig. 7.28). A similar timing of the response occurs for Atzalán near the coast of the Gulf of Mexico [station number 34 in Table 5.1 and Fig. 3.6 a)], its correlation is of negative sign (-0.16) meaning dry conditions during El Niño phase.

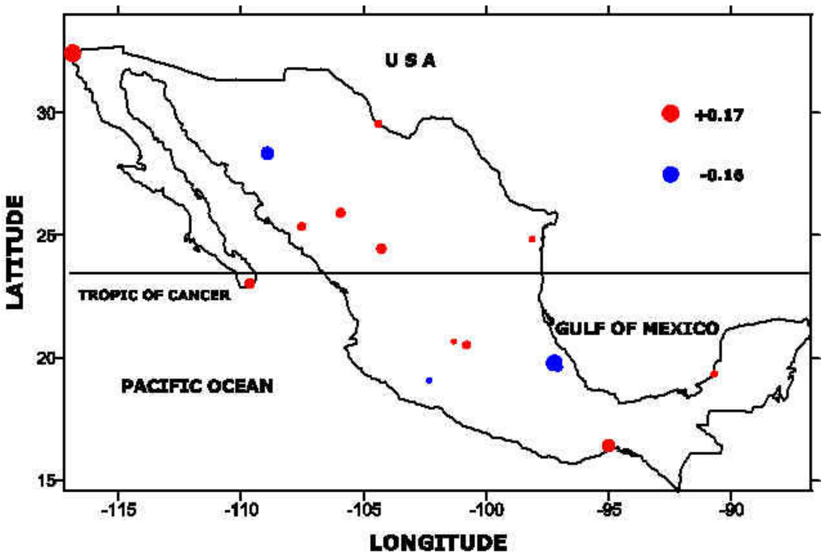


Fig. 7.28. Lag cross-correlations between the RX1day (Max 1-day Precipitation) Index and the standardised version of the El Niño 3.4 Index. Red circles represent positive and blue circles negative correlations.

Less clear are the results in the south Pacific station region for the Juchitán in the state of Oaxaca state [station number 27 in Table 5.1 and Fig. 3.6 a)] that responds with a net increase of the amount of rainfall for 1-day maximum but the correlation is small (+0.13) and with a long delay (+18 months). Similar timing characteristics but a net decrease (-0.13) in the 1-day maximum precipitation is observed at Yecora within the Mexican Monsoon region [station number 32 in Table 5.1 and Fig. 3.6 a)]. The climatic pattern found for RX1day is: wetter conditions are dominant during El Niño for the RX1day index.

The climatic response of the maximum 5-day precipitation to Niño 3.4 index is basically replicating the pattern already seen for the maximum 1-day rainfall (Fig. 7.29). The strongest response is observed at Presa Rodríguez [station number 2 in Table 5.1 and Fig. 3.6 a)], in which RX5-day is positively correlated (+0.17) to the Niño 3.4 index, meaning that the amount of maximum 5 day precipitation increases during El Niño-like years.

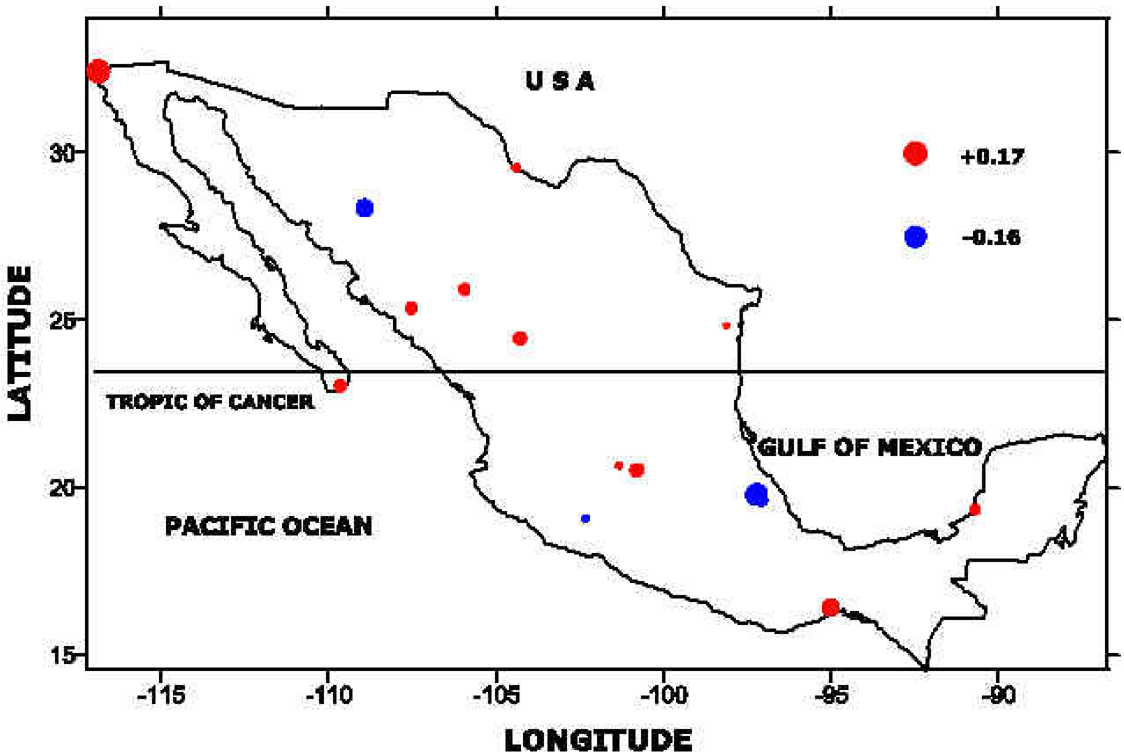


Fig. 7.29. Lag cross-correlations between the RX5day (Max 5-day Precipitation) Index and the standardised version of the El Niño 3.4 Index. Red circles represent positive and blue circles negative correlations.

Drier conditions are observed within the North American Monsoon Region (also called Mexican Monsoon Region; RA11 in table 4.1) with a negative correlation (-0.13) for Yecora [station number 32 in table 5.1 and fig. 3.6 a)], the timing being quite different for both stations (see table 7.2). Nevertheless, stations with positive correlations (wetter conditions) in north-western Mexico share a similar timing (close to the peak) of response to El Niño conditions.

Wetter conditions dominate most of the country when rainfall extreme indices are evaluated (using lag correlations) under El Niño conditions. The most significant results are concentrated along the Pacific Ocean coast, especially in the north-western part of the country, and these climatic responses are observed near to the peak of the El Niño phenomenon.

Extreme Temperature Indices

Patterns of delayed (or simultaneous) climatic responses of temperatures to El Niño (using the Niño 3.4 index) are going to be explored in this section. The extreme indices to be considered are: TN10p, TN90p, TNn, TNx, TX10p, TX90p, TXn, TXx, and DTR. Minimum-related extremes correlations are evaluated first, then maximum-related indices, and finally DTR to assess if the most significant changes are occurring for minimum or maximum extremes.

No clear climatic picture is observed for the TN10P index. A mixed combination of positive and negative correlations (warmer conditions during El Niño years) is observed across the country, particularly in Central Mexico (Fig. 7.30).

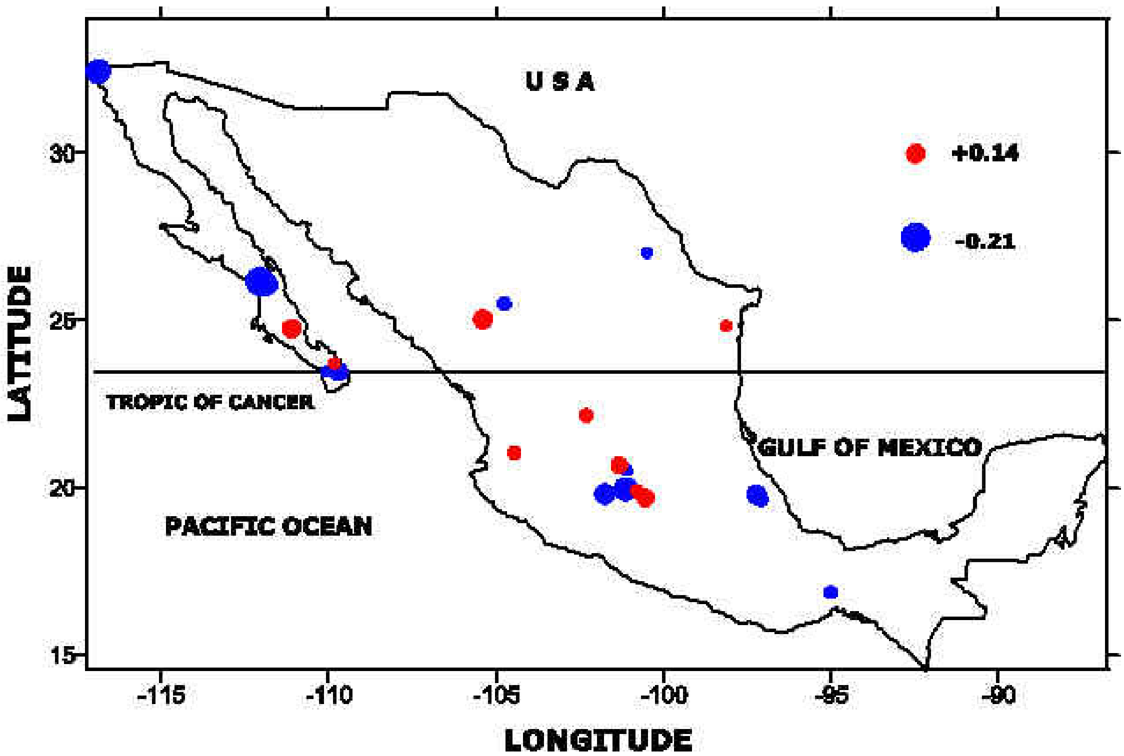


Fig. 7.30 Lag cross-correlations between the TN10P (Cool Night Frequency) and El Niño 3.4 Index. The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

Nevertheless, among these contrasting patterns for TN10P, two regions show clusters of negative correlations: Los Tuxtlas and Oaxaca (near the influence of the Tehuantepec isthmus, where a narrow land area is the bridge between the Atlantic and Pacific oceans) and within the northern part of the Baja Californian peninsula (see Table 7.5). It is precisely, within the Baja Californian peninsula that the time-shifts are similar, the rest of the correlations do not show consistency among their lags.

Positive correlations prevail in Mexico for the TN90P index (Fig. 7.31), especially in the western half of the country. A positive timing of response is also associated to these correlations (Table 7.6). Longer (negative) time-shifts are linked to negative correlations. A clear modulation of El Niño, leading to warmer temperatures is observed in the western half of Mexico (especially along the Pacific coast and the Baja Californian peninsula). The timing pattern seems to incorporate an early response in the south and then moving to the north finishing in the peninsula of Baja California near the border with the USA.

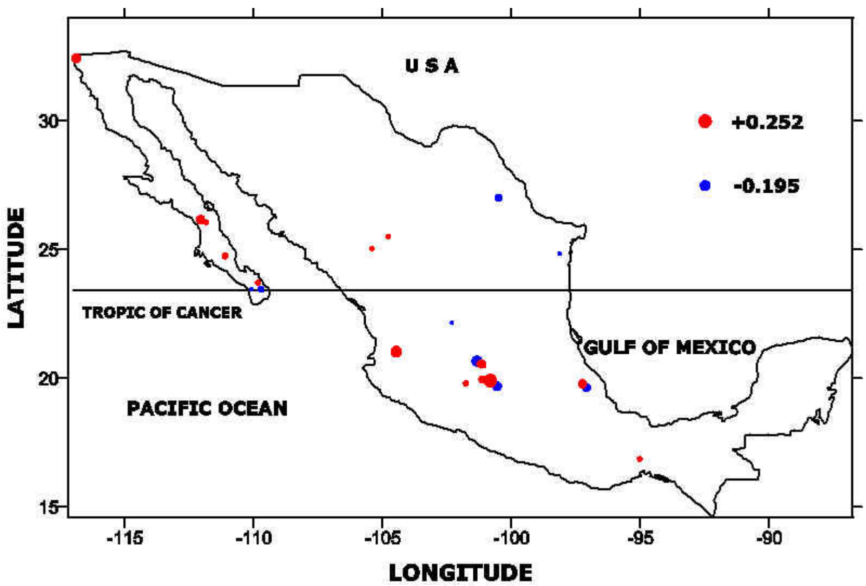


Fig. 7.31 Lag cross-correlations between the TN90P (Hot Night Frequency) and El Niño 3.4 Index. The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

The largest positive correlation values are observed south of the Tropic of Cancer for the Coolest Night Index (TNn). These results are also geographically concentrated in the western half of the country (Fig. 7.32). Meanwhile all negative correlations are close to zero (Table 7.7). Climatically the lags associated with the largest positive correlations are located in the Zacapu and Santo Domingo Tehuantepec in southern Mexico [station numbers 24 and 29 in Table 6.1and Fig. 3.6 b)]; their negative time-shifts are -10 and -16 months respectively. Warmer (colder) conditions dominate the coolest night-temperatures during El Niño (La Niña) phase.

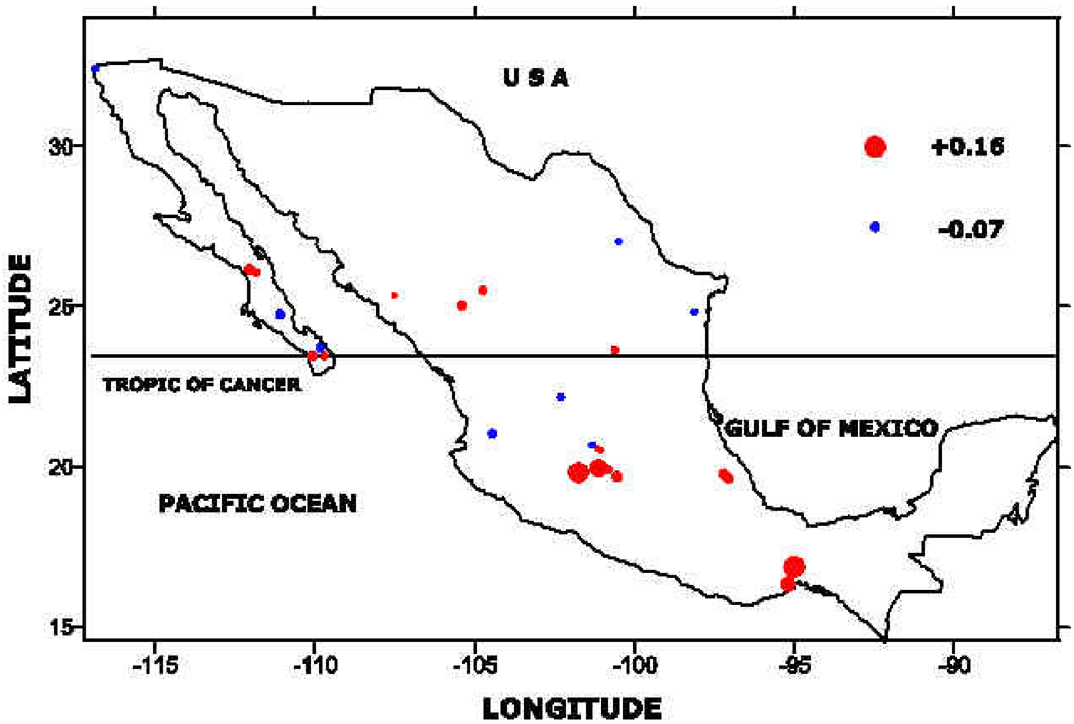


Fig. 7.32 Lag cross-correlations between the TNn (Coolest night) and El Niño 3.4 Index. The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

Warmer temperatures prevail for the Hottest Night Index (TNx) during El Niño conditions (Fig. 7.33). Time lags show that the largest positive correlations imply climatic responses close to the peaks of El Niño phase. Most significant results are found in the southern part of Mexico in Michoacán state [Zacapú, Huingo, and Ciudad Hidalgo; station numbers 24, 22 and 23 in Table 6.1and Fig. 3.6 b)], but it is really with Las Vigas station in Los Tuxtlas region [station number 35 in Table 6.1 and Fig. 3.6 b)] that these stations share similarity, showing variations between -6 and +5 months in the time-shifts (Table 7.8). So, we can speak of dominant warmer night temperatures south of the Tropic of Cancer near to the peak of El Niño-like conditions.

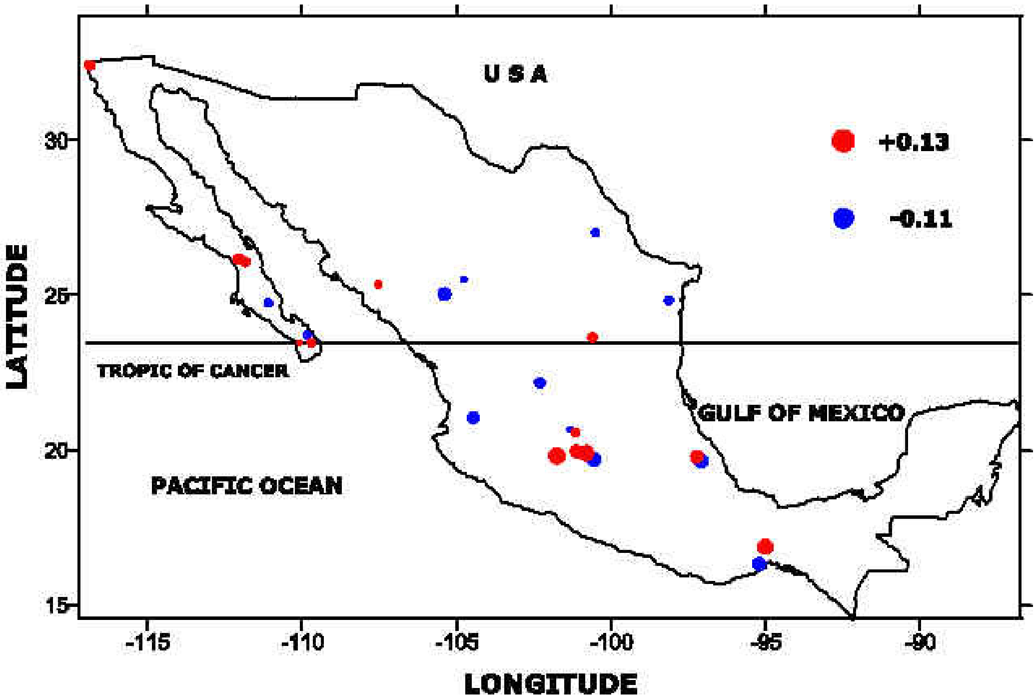


Fig. 7.33 Lag cross-correlations between the TNx (Hottest night) and El Niño 3.4 Index. The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

Close to the strongest El Niño conditions are the correspondent climatic responses of the Cool Night Frequency Index (TX10P). The largest positive correlation values are observed in the western half of Mexico near the Pacific coast (Fig. 7.34). Here, the station time-lag responses are, on average, one month behind the peak of El Niño-like phase (Table 7.9). Less clear are the negative correlations, especially the variability of the time-lags that fluctuate between -11 and +15 months when looking for the best correlation. Geographically speaking these negative correlations are located in the Baja California peninsula, although Las Vigas, near the Gulf of Mexico [station number 35 in Table 6.1 and Fig. 3.6 b)], shows a significant decrease in the TX10P index. But, the clearest climatic picture when applying the lag correlation technique between TX10P and the Niño 3.4 indices shows decreasing frequencies of night temperatures below the 10th percentile, i.e., warmer conditions during El Niño, with variable times of response, especially in the western half of Mexico.

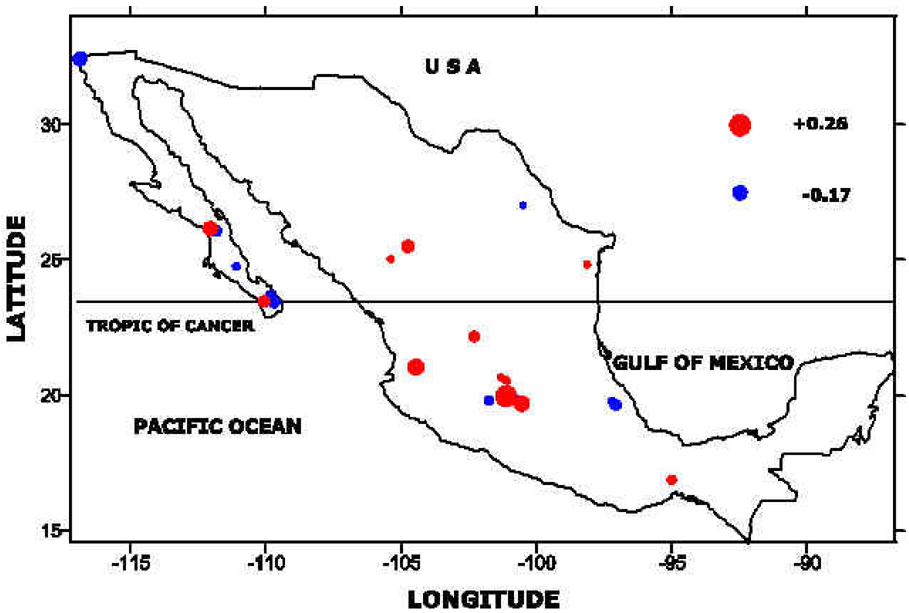


Fig. 7.34 Lag cross-correlations between the TX10P (Cool Day Frequency) and El Niño 3.4. The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

Although a clear climatic pattern is observed for the Hot Day Frequency Index (TX90P); positive correlations are dominant in the southern part of Mexico, especially within the Los Tuxtlas region (Fig. 7.35). Similar also are the timings of response of these southern stations, having the greatest impact on day temperatures near to the peak of El Niño phase (Table 7.10). Warmer day temperatures are observed within the southern part of the country close to the peak of El Niño conditions.

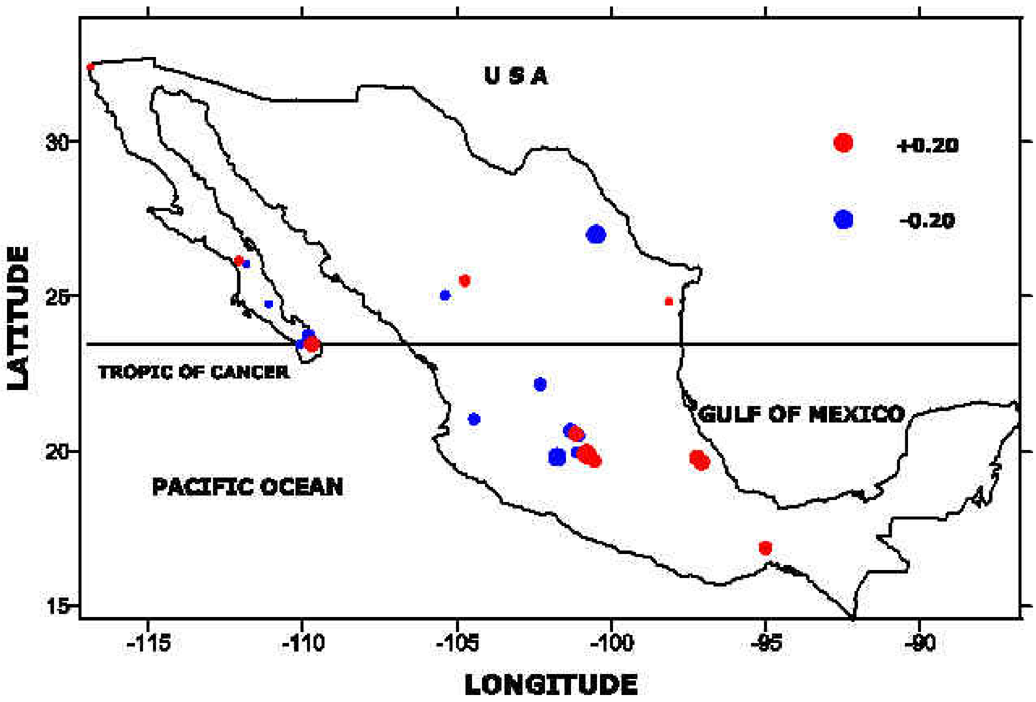


Fig. 7.35 Lag cross-correlations between the TX90P (Hot Day Frequency) and El Niño 3.4 Index. The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

Mixed climatic patterns are found for the TXn index, with no clear spatial distribution of negative correlations (Fig. 7.36). Time-shifts to find the best correlation with El Niño 3.4 index are also quite dissimilar (Table 7.11). Negative correlations are mostly geographically located in the western half of Mexico. However, clearer results are found in the southern part of the country. Consistency (spatially) is observed for positive correlations and time-lags (-6 months average) which are close to the strongest conditions of the El Niño phenomenon. Therefore, according to these results, warmer day temperatures are expected during El Niño phase, close to its peak.

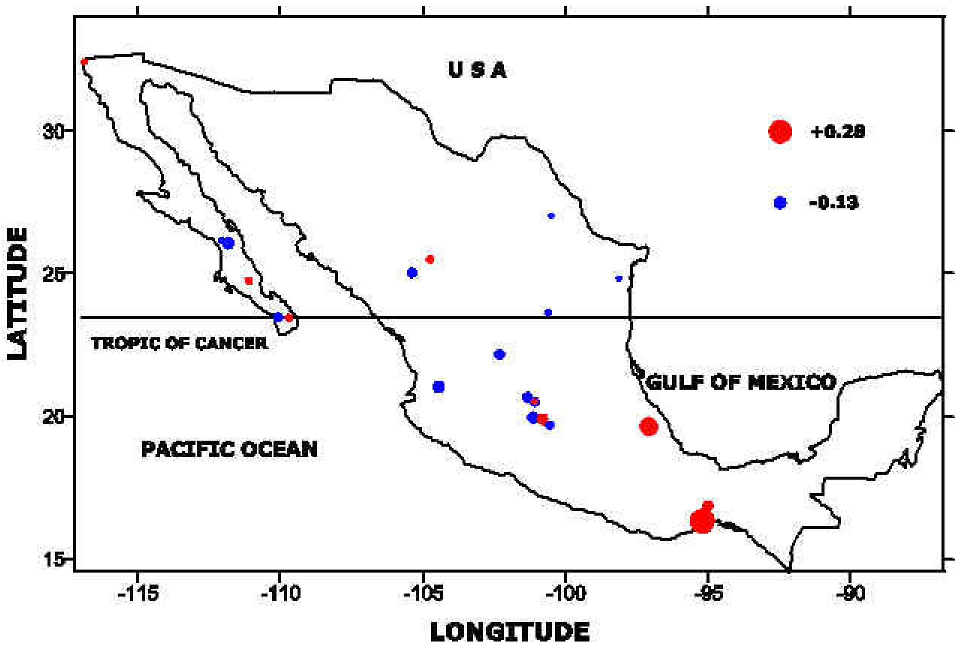


Fig. 7.36 Lag cross-correlations between the TXn (Coolest Day) and El Niño 3.4 Index. The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

A longitudinal climatic transition in continental Mexico could be observed for the Hottest day Index (TXx). Roughly, positive correlations are dominant in the eastern part of Mexico, while negative correlations are prevalent in the western part of the country (Fig. 7.37). Positive correlations are located along the Atlantic Coast, except the most southern station in Oaxaca that, in fact, it has the greatest correlation (+0.23) among all the results. Time lags for these positive correlations are very similar, climatically responding with warmer temperatures close to the peak of El Niño (Table 7.12). Negative correlations are geographically biased to the western half of the country, but time-shifts of climatic impact to El Niño are quite different. North of the Tropic of Cancer in the Baja California peninsula positive correlations prevail. Nevertheless, these correlations in the peninsula are not large enough to be considered significant in terms of correlations and time response consistency. Warmer conditions are found for TXx in the eastern half of Mexico close to the strongest conditions of El Niño.

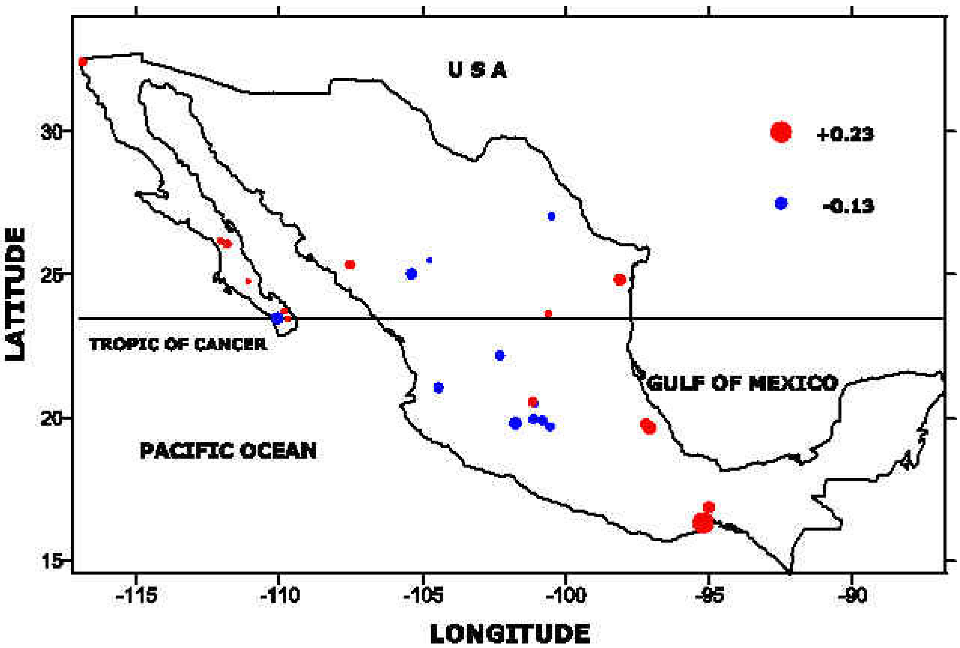


Fig. 7.37 Lag cross-correlations between the TXx (Hottest Day) and El Niño 3.4 Index. The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

Largest (negative) correlations for the DTR index are geographically concentrated in central and northern Mexico (Fig. 7.38 and Table 7.4). As evident in the already analysed extreme indices, changes in minimum temperatures are clearer than in the maximum-related indices, and certainly more strongly are reflected in the decreasing DTRs.

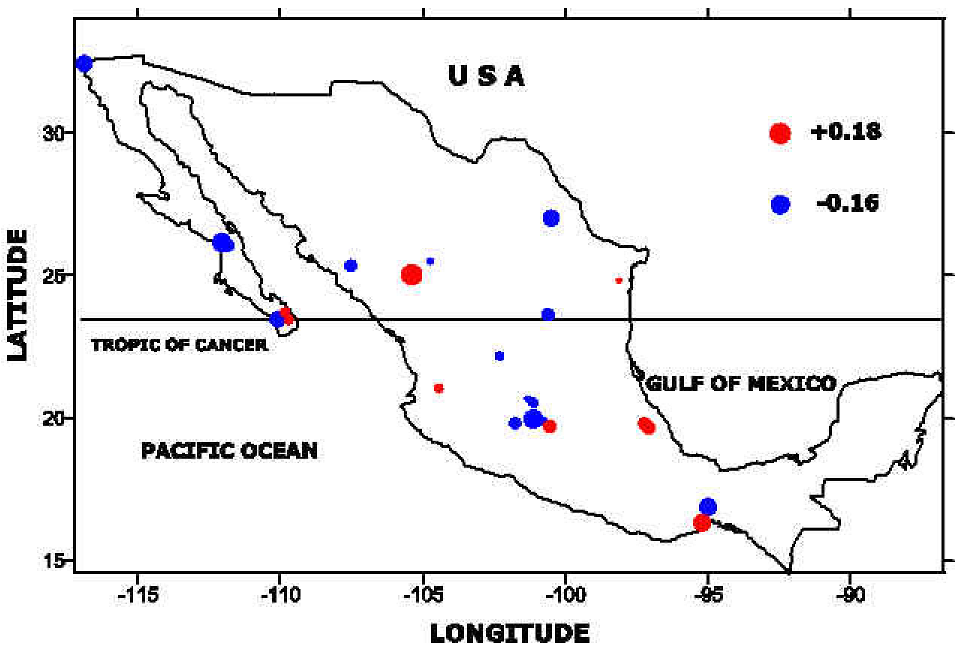


Fig. 7.38 Lag cross-correlations between the DTR (Daily Temperature Range) and El Niño 3.4 Index. The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

A clear climatic pattern towards warmer temperatures is clear when we correlate extreme temperature indices and Niño 3.4. However, we have to point out that maximum temperature related indices have a geographic preference for changes in the southern part of the country. Meanwhile, minimum temperature indices are basically varying north of the Tropic of Cancer.

Summary of the section (El Niño 3.4 Index).

The results of the (correlations) analysis of influence of the El Niño 3.4 index on temperature and precipitation show strong consistency with those of SOI (section 7.2). This coherence can be fully observed in the latitudinal transition and the seasonal factor of the climatic patterns. No matter the variable analysed (precipitation or temperature) or the scale used (regional or local), the timing response of the best results is close to the peak of El Niño conditions.

A latitudinal climatic transition is observed when the annual and wet season (May to October) Standardised Anomaly Indices (SAI) of precipitation are used. Wetter conditions in northern Mexico (especially the north-western part of the country) and drier conditions in the South prevail during El Niño years. In addition, this climatic transition shows a preference of the largest correlations for the sites along the Pacific coast. An almost national pattern of above (below) normal precipitation during El Niño (La Niña) years is seen for the dry season (November to April) of the rainfall SAIs. These climatic patterns are also replicated for the precipitation extreme indices, but the importance of the dry season rainfall on the north-western part of Mexico is clearer.

Contrasting climatic conditions are also observed for the temperature extreme indices. During El Niño years, changes in maximum temperatures prevail in southern Mexico, while in the North of the country the most important variations are seen in minimum temperatures. Nevertheless, these climatic patterns are mostly concentrated along the Pacific Ocean coast in Mexico. The most important results also show a timing response close to the strongest ENSO conditions.

7.4. THE MEI (MULTIVARIATE ENSO INDEX) INFLUENCE.

7.4.1. LINEAR CORRELATION.

Precipitation Regional Averages.

The last El Niño index to be linearly correlated (using Kendall's tau-b) to the regional precipitation averages is the Multivariate ENSO Index (MEI). As in the previous sections the time-series are divided into annual, wet (May-Oct) and dry (Nov-Apr) seasons for both the regional averages and the MEI indices. The final aim is to find either spatial or temporal climatic patterns of the impacts of El Niño in the regional rainfall averages.

Taking the Tropic of Cancer as a geographical limit, a clear latitudinal transition could be observed when correlating the annual versions of SAI and MEI. Positive correlations are found in northern Mexico, while negative correlations prevail in the southern part of the country [Fig. 7.39 a)]. The highest correlation values are concentrated within the Baja California Peninsula. This climatic pattern has been consistent across the other combinations of regional averages and ENSO indices: the greatest correlations are positive, and can be seen in the northern part of the peninsula. These results are mostly better than the 1% level of statistical significance. Negative correlations are located along the southern Pacific coast. These correlations are statistically significant at the 5% level. Nevertheless, there is an evident geographic pattern (along the Pacific Ocean) of the annual total rainfall in a clear transitional climatic pattern; during El Niño years the annual regional precipitation totals are above their normal for the northern part of the country, especially in the peninsula of Baja California; while drier conditions are observed for the southern Pacific coast.

Closely replicating the former results the correlation between the wet season (May-Oct) SAI and the annual MEI shows a differential climatic pattern: negative correlations south of the Tropic of Cancer and positive north of this geographical limit [Fig. 7.39 b)]. Wetter conditions are experienced during El Niño years for the northern half of Mexico and below normal precipitation is dominant during the same phase of ENSO for the southern part of the country. It is clear that all the stations with statistically significant correlations (these results are better than the 1% level of statistical significance) are concentrated along the Pacific Ocean coast suggesting a strong modulation of the summer regional precipitation by ENSO. The only region that breaks this clear climatic pattern is the Neovolcanic Belt region, but its correlation is close to zero.

Positive correlations prevail all over the country when correlating dry season (Nov-Apr) SAI and Annual MEI [Fig. 7.39 c)]; this is one of the clearest climatic patterns across all the combinations of the rainfall extreme indices and MEI. Statistically significant correlations are concentrated from central to northern Mexico. Let us recall that, during winter polar fronts heavily influence the temperature and rainfall of the northern part of Mexico (section 2.3). This can be easily seen as the highest correlations are found in the northern Baja California peninsula and the high altitude Neovolcanic Belt region. Above normal precipitation above their normal is observed during the boreal winter in northern Mexico during El Niño years.

Drier conditions are observed in the southern part of Mexico, and wetter climatic regimes for the Baja California peninsula during El Niño phase. Positive correlations are dominant when we correlate the wet season (May-Oct) SAI and wet season MEI north of the Tropic of Cancer [Fig. 7.39 d)], especially in the Baja Californian peninsula where the greatest correlation (better than the 1% level of statistical significance) is found within the northern part of the peninsula. Meanwhile, negative correlations prevail along the southern coast of the Pacific Ocean. Two areas break this precipitation pattern, the Neovolcanic Belt and the central northern part of Mexico, although, both regions show near zero correlations, so they can easily be disregarded as affecting the whole climatic picture described above.

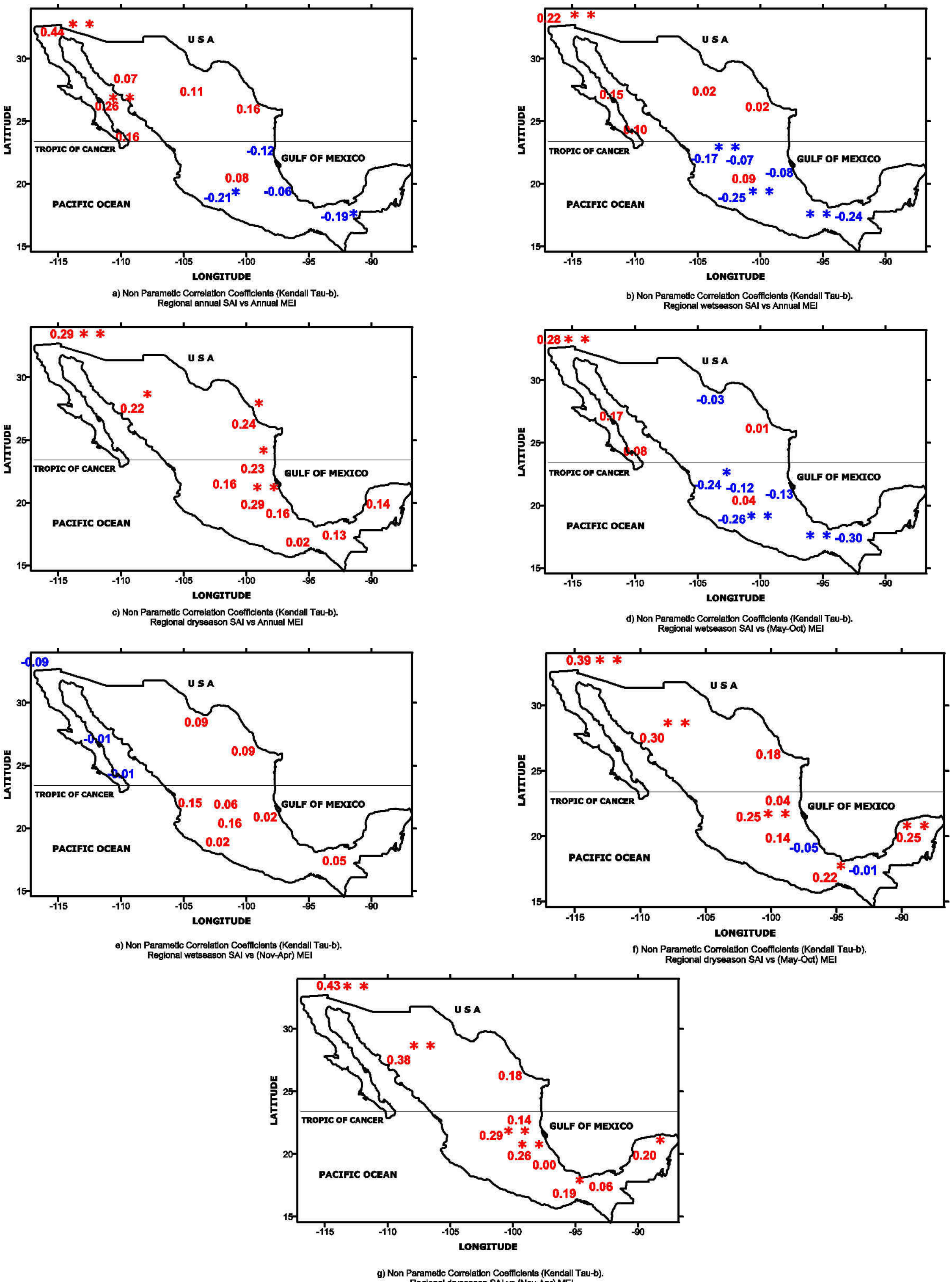


Fig. 7.39. Linear correlations (Kendall tau-b) between the standardised versions of the regional precipitation averages and the Multivariate El Niño Index (MEI). Red numbers represent positive and blue numbers negative correlations. * means statistical significant at 5% level and ** at 1% level.

Although there is a clear differentiation between continental and coastal climatic patterns, no statistically significant correlations are observed when correlating wet season (May-Oct) SAI and dry season (Nov-Apr) MEI. Wetter conditions (positive correlations) are found in mainland Mexico, while below normal precipitation (negative correlations) is evident within the Baja Californian peninsula, during El Niño phase [Fig. 7.39 e)].

The climatic pattern of almost nationally widespread positive correlations when correlating dry season (Nov-Apr) SAI and wet season (May-Oct) MEI [Fig. 7.39 f)] is quite similar to the former relating dry season (Nov-Apr) SAI and annual MEI [Fig. 7.39 c)]. Nevertheless, there are a couple of regions that break this climatic picture: Los Tuxtlas and the southeast rainforest regions. The largest correlations are found in the north-western part of the country, a very well known region affected by winter rainfall patterns. It is also the first time that we have found a statistically significant result for the Yucatán peninsula. Precipitation above normal is dominant across most of Mexico for the dry rainfall season when El Niño phase is present during the wet season (May-Oct).

A clear national pattern of positive correlations is found when dry season (Nov-Apr) SAI and dry season (Nov-Apr) MEI are correlated [Fig. 7.39 g)]. In fact, the greatest correlation (+0.43) is found at the northern Baja Californian peninsula and close to this result is the correlation for the Mexican Monsoon Region (+0.38), both correlations are statistically significant at the 1% level. A strong phase of El Niño phenomenon must reinforce the atmospheric conditions that make the winter precipitation an important part of the annual precipitation totals (see section 2.2.1). It is during this season that we see the regional precipitation fully responding to the dry season (Nov-Apr) ENSO modulation across the Yucatan peninsula. It is possible that the nearly chaotic hurricane-associated rainfall can strongly affect the precipitation patterns during the other seasons (annual and wet seasons), implying that this region is unlikely to be climatically coherent with its neighbouring regions. The Neovolcanic Belt and the Mexican central Highlands regions are clearly modulated by ENSO during the dry season (Nov-Apr). High altitude stations and polar fronts during winter, can possibly explained the significant correlations in these areas (Metcalfe et al., 2000).

Two different geographical patterns are observed when the temperature extreme and MEI indices are correlated. A latitudinal climatic transition is observed for the annual and wet season (May-Oct) SAIs (Standardised Anomaly Indices). Wetter conditions are found for the northern part of Mexico, with below normal precipitation evident for the southern part of the country. A nationally widespread pattern of wetter conditions dominates the Dry Season (Nov-Apr) SAIs combinations. Both geographical climatic pictures are observed regardless of the season of the MEIs.

Extreme Weather Indices.

Precipitation.

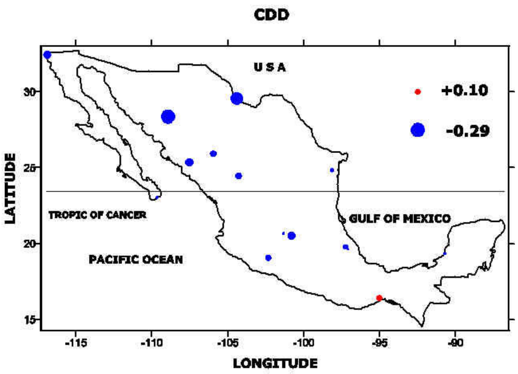
In this section extreme precipitation indices will be correlated (linearly) with the seasonal versions (annual, May-Oct and Nov-Apr) of MEI. The indices with the greatest number of statistically significant results will be analysed. A comparison among the maximum and minimum temperatures related indices is then made, and finally among all the responses of the indices to the seasonal MEIs.

When the significance of the correlations with the annual MEI is considered, the extreme precipitation indices to be analysed are: CDD, CWD, R99P, RX1day, and PRCPTOT (see definitions in section 3.3.3). These give the clearest results when we correlate extreme precipitation indices and the annual MEI.

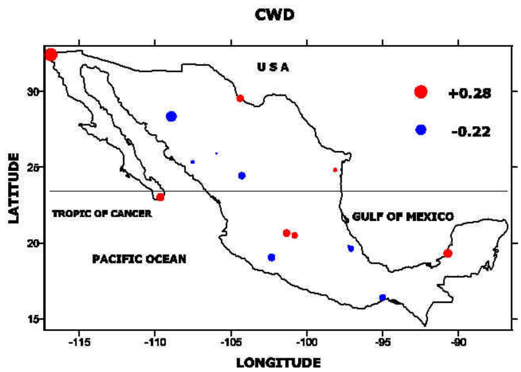
The climatic pattern for the CDD index [Fig. 7.40 a)] shows the most statistically significant results, geographically concentrated in central and northern Mexico, especially within the region of influence of the North American Monsoon (NAM, see table 4.1) or Mexican Monsoon. The prevalent negative correlations lead to wetter conditions during El Niño phase, mostly north of the Tropic of Cancer. A mixed climatic picture is observed for the CWD index [Fig. 7.40 b)]. A decrease in the number of

Consecutive Wet Days is found along the North Pacific Coast within the NAMR. Meanwhile, the largest positive correlation (statistically significant at the 1% level) is observed at the Presa Rodríguez station (Tijuana) that means wetter conditions under El Niño-like years. A longitudinal climatic pattern is seen for the R99P index [Fig. 7.40 c)]. Negative correlations are dominant along the Atlantic coast, while positive correlations are observed at the northern Pacific coast at Tijuana. Therefore, more days exceeding the 99^{th} percentile are observed in the north of the Baja California peninsula, and drier conditions for those stations along the Gulf of Mexico. Just like in the results of R99P, a coastal pattern can be observed for the RX1day index [Fig. 7.40 d)]. Although only three statistically significant results are found, a latitudinal climatic transition can be observed for RX1day. The 1-day maximum precipitation (in mm) decrease in Los Tuxtlas Region, and increase for Presa Rodríguez station in Tijuana. Correlations which are statistically significant at the 1% level show a strong response to El Niño. No clear climatic pattern is observed for the PRCPTOT index [Fig. 7.40 e)]. The only statistically significant correlation (at the 1% level) is found at the Presa Rodríguez station, i.e., annual total rainfall increases at Tijuana during El Niño-like years.

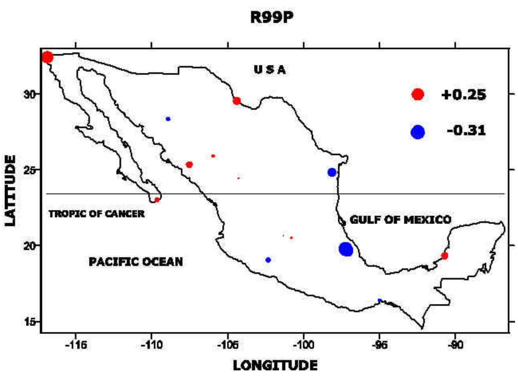
Consistently wetter conditions are observed for the northern part of the Baja California peninsula. Drier conditions are more variable (geographically speaking), ranging from the North American Monsoon to the Los Tuxtlas region. But, roughly we can conclude that when we correlate extreme rainfall indices with the annual version of MEI, wetter conditions are dominant north of the Tropic of Cancer and drier conditions prevail in southern Mexico. There is also a longitudinal transition: southern (positive) correlations are related to the Atlantic Ocean (Gulf of Mexico), while the negative (northern) correlations are linked to the Pacific Ocean: three out of the four statistically significant correlations are located at stations along the Pacific Ocean.



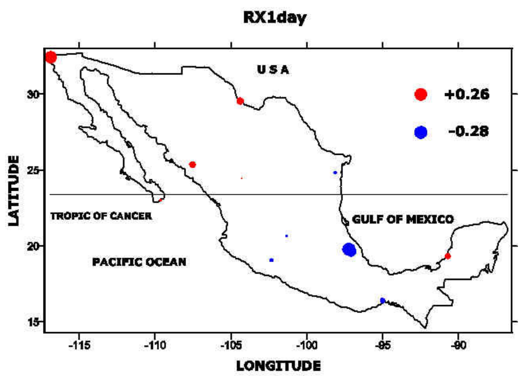
a) Non Parametic Correlation Coefficients (Kendall Tau-b).
Consecutive Dry Days (CDD) vs Annual MEI



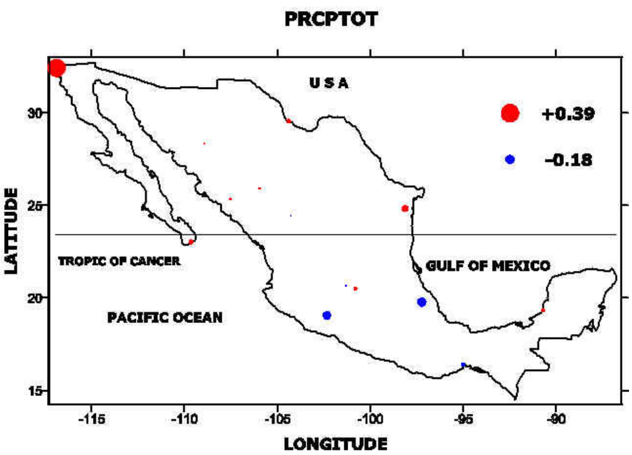
b) Non Parametic Correlation Coefficients (Kendall Tau-b).
Consecutive Wet Days (CWD) vs Annual MEI



c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Extremely wet day precipitation (R99P) vs Annual MEI



d) Non Parametic Correlation Coefficients (Kendall Tau-b).
Annual maximum 1-day precipitation (RX1day) vs Annual MEI

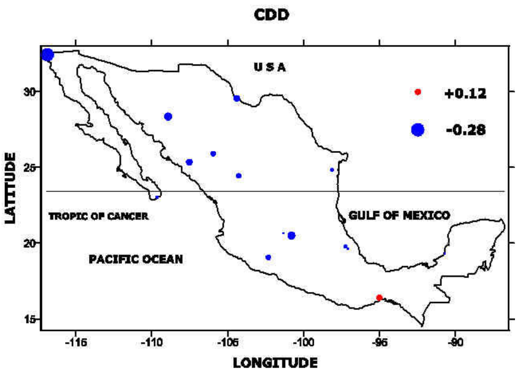


e) Non Parametic Correlation Coefficients (Kendall Tau-b).
Annual Total Precipitation (PRCPTOT) vs Annual MEI

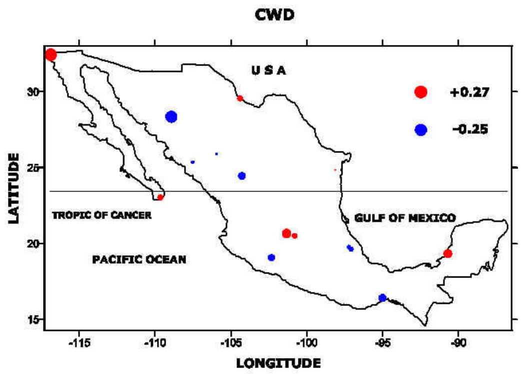
Fig. 7.40. Linear correlations (Kendall tau-b) between the Extreme Precipitation Indices and the Annual Multivariate ENSO Index (MEI). Circles in red are representing a positive and in blue negative correlations.

The application of linear correlations (Kendall's tau-b) between precipitation extreme indices and the May-Oct (wet season) version of MEI is analysed here. Because of their clear results, the indices to be considered are: CDD, CWD, R99P, RX1day and PRCPTOT. These are precisely the same indices analysed with the annual MEI, so a direct comparison is possible with those results.

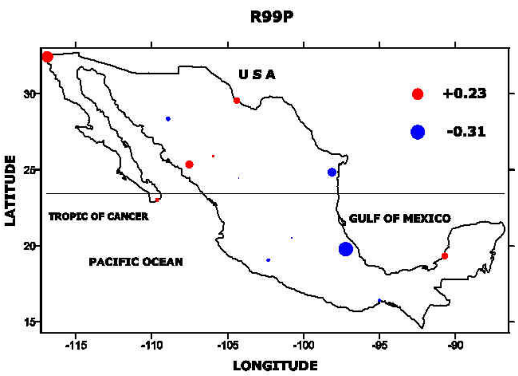
The extreme indices involving consecutive conditions of dryness (CDD) or wetness (CWD) are analysed first. A national climatic pattern of negative correlations can be seen for CDD [Fig. 7.41 a)], but statistically significant results are concentrated from central to northern Mexico within the western half of the country. Therefore, wetter conditions are dominant for these stations during El Niño phase. A mixed picture of positive and negative correlations is observed across the country for the Consecutive Wet Days (CWD) index [Fig. 7.41 b)]. For those stations with statistically significant results, drier conditions (fewer consecutive wet days) are observed in mainland Mexico, while more Consecutive Wet Days are seen during El Niño-like conditions for Presa Rodríguez in Tijuana. A longitudinal climatic response is observed for the R99P index [Fig. 7.41 c)]. More days of extreme rainfall exceeding the 90^{th} percentile are observed at Presa Rodríguez, and the opposite (less days surpassing that limit) are seen along the Gulf of Mexico coast during El Niño conditions. With the exception of San Fernando in the north-eastern part of Mexico, similar geographic patterns to that of the R99P are found for the RX1day index [Fig. 7.41 d)]. During El Niño phase, the max 1-day precipitation increases at the Presa Rodríguez station in the northern part of the Baja California peninsula, while this index decreases in the Los Tuxtlas region, where the correlation is statistically significant at the 1% level. The annual total precipitation (PRCPTOT) index does not show a clear spatial distribution across Mexico [Fig. 7.41 e)]. The only statistically significant correlation is observed at the Presa Rodríguez station in Tijuana. Wetter conditions are then dominant for this part of northern Baja California during El Niño-like conditions. The only station that shows statistically significant results (wetter conditions) for PRCPTOT is Presa Rodríguez in the northern part of the Baja California



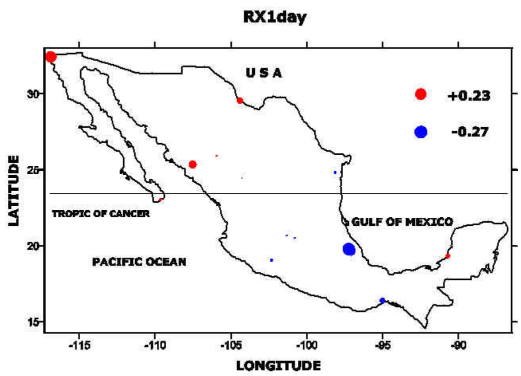
a) Non Parametic Correlation Coefficients (Kendall Tau-b).
Consecutive Dry Days (CDD) vs May-Oct MEI



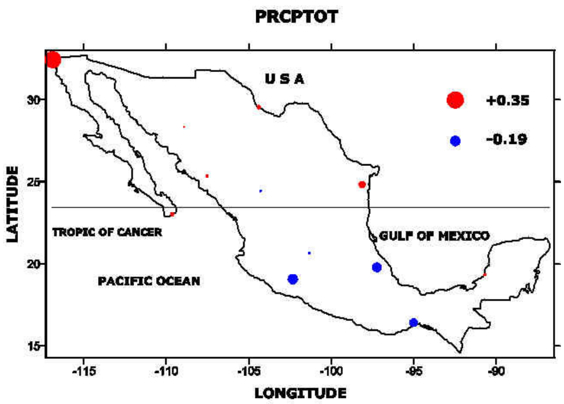
b) Non Parametic Correlation Coefficients (Kendall Tau-b).
Consecutive Wet Days (CWD) vs May-Oct MEI



c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Extremely wet day precipitation (R99P) vs May-Oct MEI



d) Non Parametic Correlation Coefficients (Kendall Tau-b).
Annual maximum 1-day precipitation (RX1day) vs May-Oct MEI



e) Non Parametic Correlation Coefficients (Kendall Tau-b).
Annual Total Precipitation (PRCPTOT) vs May-Oct MEI

Fig. 7.41. Linear correlations (Kendall tau-b) between the Extreme Precipitation Indices and the wet season (May-Oct) Multivariate ENSO Index (MEI). Circles in red are representing a positive and in blue negative correlations.

peninsula, supporting the conclusions so far observed across this chapter that, this region is strongly affected by El Niño-like conditions.

Wetter conditions are mainly observed in the northern part of the Baja Californian peninsula, and below normal precipitation is found in mainland (the continent) Mexico. It is important to point out here that these results are consistent with the former correlations using annual MEI.

The final analysis for extreme rainfall indices is to correlate linearly these parameters with the Nov-Apr version of the Multivariate Index (MEI). As mentioned in section 3.2.1, November to April is the dry period for most of the country, so we expect different spatial patterns to those resulting from annual and wet season. Having the most significant results, the extreme indices to be analysed in this section are CDD, CWD, RX1day and PRCPTOT.

The spatial distribution of the negative correlations for the CDD index shows predominance in the western half of central and northern (continental) Mexico [Fig. 7.42 a)]. Fewer consecutive dry days are expected during El Niño conditions for these stations; especially those within the influence of the North American Monsoon System. Less clear is the climatic pattern for the Consecutive Wet Days (CWD) [Fig. 7.42 b)]. Although most of the correlations are positive across the country, the only statistically significant result is found at the southern tip of the Baja Californian peninsula, where more consecutive wet days are to be expected during El Niño-like years. One statistically significant correlation is observed for the RX1day index [Fig. 7.42 c)], but this time it is located in the northern part of the Baja California peninsula. The annual maximum 1-day precipitation increases under El Niño conditions. The annual total precipitation (PRCPTOT) tends to be above normal during El Niño for the central and northern regions of Mexico [Fig. 7.42 d)]. The largest correlations are positive and are observed at Celaya (central) and Tijuana (northern) stations, both results are statistically significant at the 1% level.

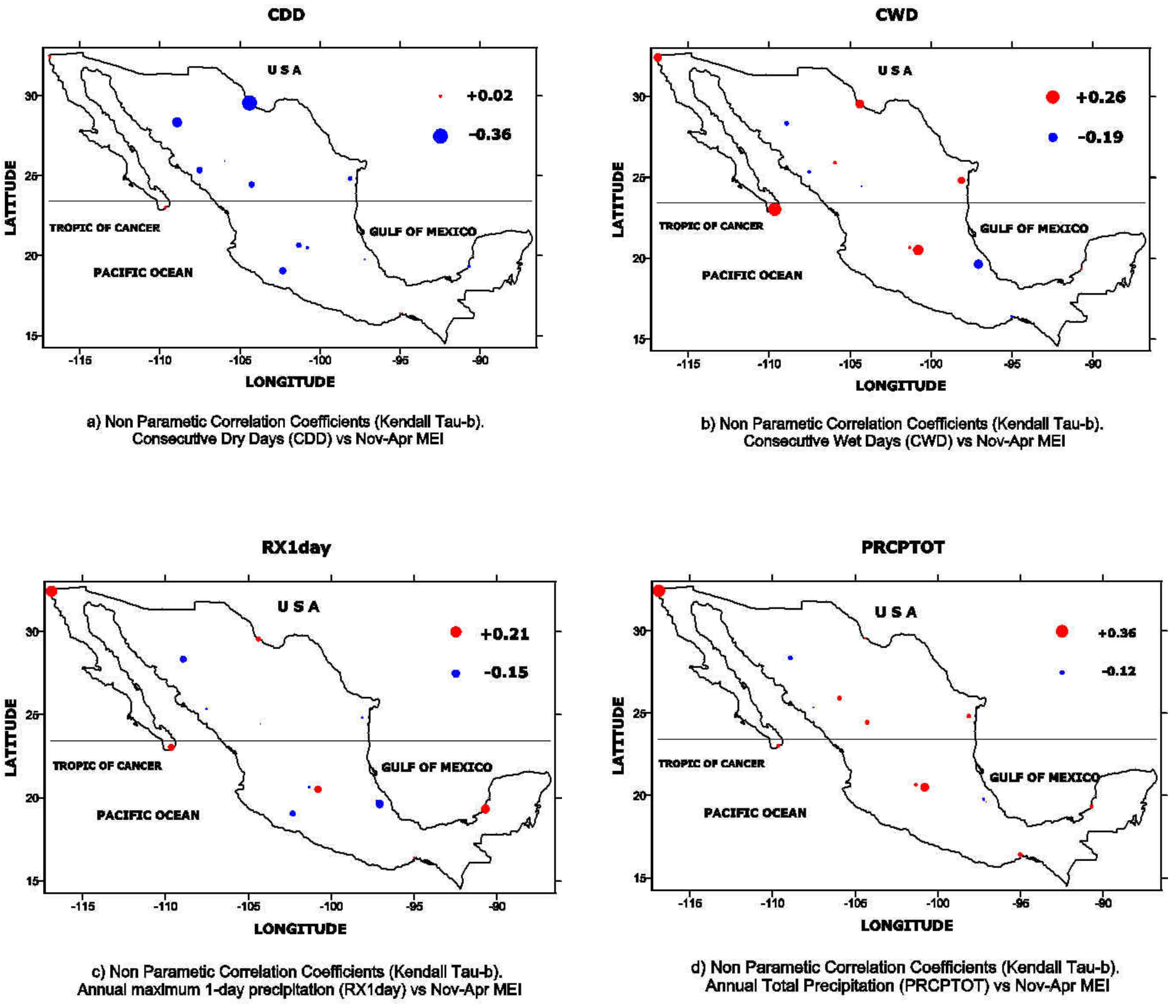


Fig. 7.42. Linear correlations (Kendall tau-b) between the Extreme Precipitation Indices and the dry season (Nov-Apr) Multivariate ENSO Index (MEI). Circles in red are representing a positive and in blue negative correlations.

Extreme precipitation above the normal is expected especially in central and northern Mexico under El-Niño like conditions. This climatic picture is consistently observed across all the rainfall extreme indices when they are correlated with the annual version of MEI. These results support the very well known winter rainfall patterns that are a substantial fraction of the annual total precipitation in those regions of the country.

Temperature.

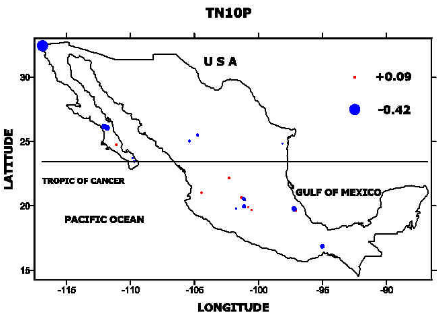
The last analysis of linear correlation of this chapter combines temperature extreme indices and the seasonal versions (annual, wet and dry) of MEI. As mentioned for the SOI and Niño 3.4 indices, the results from this section can be compared at different temporal and spatial scales with the regional precipitation averages and extreme rainfall indices. The (linear) correlation between the temperature extreme indices and the annual Multivariate Index is the first part of this section. Because of their clearest results the indices to be analysed are TN10P, TN90P, TNn, TNx, TR20, TX10P, TXx and DTR.

A national climatic pattern of negative correlations can be seen for the TN10P index [Fig. 7.43 a)]. Fewer days are occurring in which TN<10th percentile. The largest negative correlations –statistically significant at the 1% level- are geographically concentrated within the Baja California peninsula. Warmer conditions are then expected in Central and the northern Baja California during El Niño phase. A similar spatial distribution (when compared with TN10P) is observed for the TN90P index, but this time the climatic pattern is for positive correlations [Fig. 7.43 b)]. In the central region and north of the Tropic of Cancer in the Baja California peninsula more days when the night temperature exceeds the 90th percent are expected during El Niño conditions. Warmer temperatures are also likely to occur during El Niño for the TNn index [Fig. 7.43 c)]. Although this pattern is geographically widespread across the country, most significant results are concentrated in the western half of the country. With the exception of the variable correlations in central Mexico, most of the country show positive correlations for the TNx index, especially in the western part of the country [Fig. 7.43 d)]. Warmer night temperatures are expected during El Niño phase for most of Mexico. Night temperatures also increase during El Niño similar to the results for the TR20 index [Fig. 7.43 e)]. Most significant results are seen in the north-western part of the country. A rough pattern of positive correlations in the main part of continental Mexico and negative correlations along the Baja California peninsula is observed for the TX10P index [Fig. 7.43 f)]. Most significant results are found in the peninsula of Baja California, where fewer days below the 10th percentile limit are dominant during El Niño conditions. Warmer day temperatures prevail over most of Mexico during the El Niño phase. Positive correlations are found for the TXx index across the country, but most significant results are located along the Pacific Ocean coast [Fig. 7.43 g)]. One interesting negative correlation in the north-eastern part of Mexico breaks this pattern. In San Fernando colder day temperatures are prevalent during El Niño-like years. A latitudinal transition is observed for the most significant results of the DTR index [Fig. 7.43 h)]. Negative correlations are seen in the central and the southern tip of the Baja California peninsula, while only one positive correlation –statistically significant at the 5% level- is observed in the southern pacific coast in Oaxaca. In general, decreasing DTRs are evident across Mexico during El Niño-like conditions.

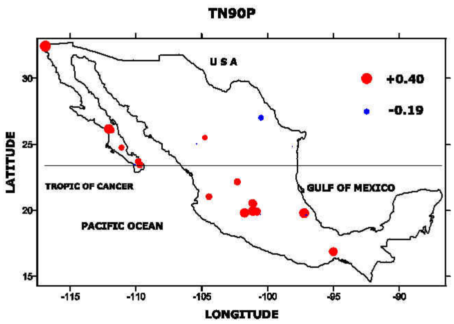
Linear relationships between the temperature extreme indices and the annual MEI show a national pattern of increasing minimum temperatures during El Niño-like conditions. This is especially clear north of the Tropic of Cancer. Warming conditions (for the stations close to the northern Pacific Ocean) during El Niño are also expected for the indices related to maximum temperatures. According to the results, a decrease in Daily Temperature Range index show that the greater changes are occurring in minimum temperatures.

Linear correlations of the extreme indices with the May to October (Wet Season) version of MEI will be assessed in this section. The indices with the best results (the largest numbers of significant correlations) are: TN10P, TN90P, TNn, TNx, TR20, TX10P, TX90P, TXx and DTR.

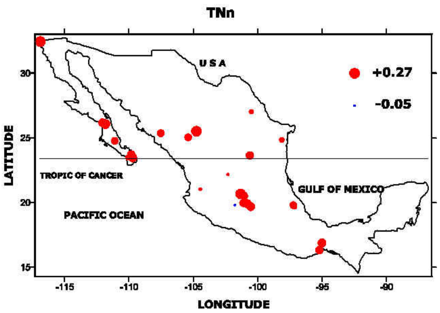
Extreme indices related to minimum temperatures (TN10P, TN90P, TNn and TNx) are the first to be analysed. Negative correlations prevail in most of the country during El Niño conditions for the TN10P index [Fig. 7.44 a)]. The clearest geographical pattern of statistically significant results is found in the Baja California peninsula, north of the Tropic of Cancer. Significant correlations are also observed in central and southern Mexico. Therefore, it can be said that the number of days when TN<10th percentile decreases during El Niño phase, leading to warmer temperatures. Positive correlations are dominant across Mexico for the TN90P index [Fig. 7.44 b)]. The spatial distribution of the most significant results is very similar to that for the TN10P index. Warmer conditions are dominant during El Niño phase across Mexico, especially within the Baja California peninsula. Positive correlations are also dominating Mexico for the TNn index [Fig. 7.44 c)]. Nevertheless, the most significant correlations are mostly found in the western part of the country from central to northern Mexico. The largest correlations are observed at Presa Rodríguez and El Palmito in the north-western part of the country, a region where winter rainfall is very important to the annual total precipitation. Warmer night temperatures are expected throughout Mexico during El Niño conditions, especially in the western half of the country. Positive correlations are also nationally widespread for the TNx index, except for Ciudad Hidalgo and Atzalán stations in central Mexico [Fig. 7.44 d)]. For the TR20 index [Fig. 7.44 e)], night temperatures increase during El Niño conditions across the country for most of Mexico, with a slight geographical preference to the western half of the country. A mixed climatic pattern is observed, although the largest (statistically significant) correlations are positive. Geographically these positive relationships are biased to the western half of the country along the Pacific Ocean coast, suggesting an important influence of the El Niño years. Warmer tropical nights (TR20) are observed during El Niño years in most of Mexico especially within the north-western part of the country, in the area of influence of the North American Monsoon System (NAMS) or Mexican Monsoon Region (RA11 in Table 4.1). Only a few statistically significant correlations are found within the mixed climatic pattern of the TX10P index [Fig. 7.44 f)]. The largest negative correlations are geographically concentrated in the Baja California peninsula, and north of the Tropic of Cancer. Warmer day temperatures are likely to be seen under El Niño conditions in the northern part of the



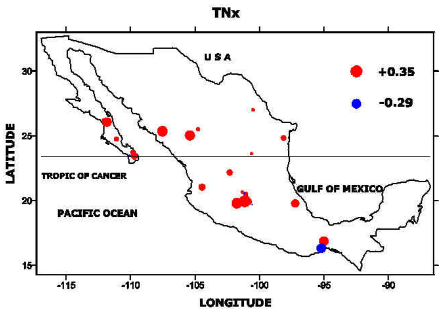
a) Non Parametic Correlation Coefficients (Kendall Tau-b).
Cool Night Frequency (TN10p) vs Annual MEI



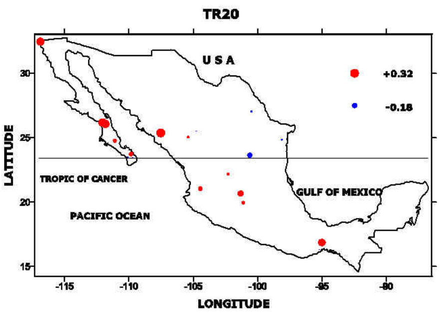
b) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hot Night Frequency (TN90p) vs Annual MEI



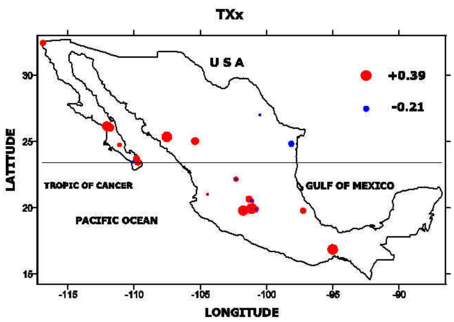
c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Coolest Night (TNn) vs Annual MEI



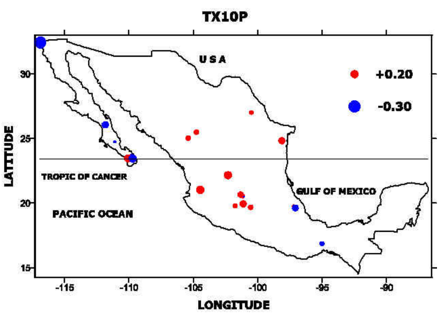
c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hottest Night (TNx) vs Nov-Apr MEI



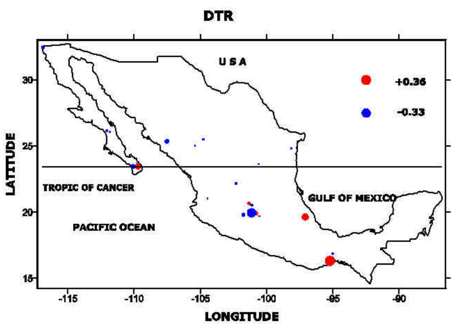
e) Non Parametic Correlation Coefficients (Kendall Tau-b).
Warm Nights (TR20) vs Annual MEI



g) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hottest Day (TXx) vs Annual MEI

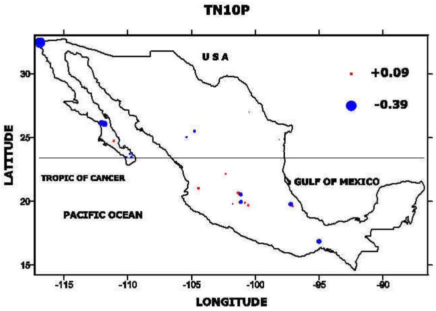


f) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hot Day Frequency (TX10p) vs Annual MEI

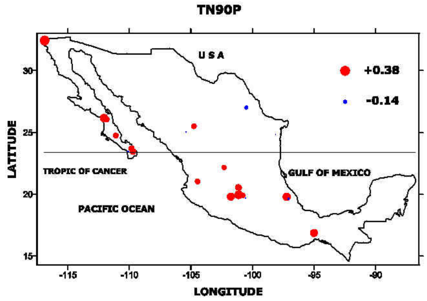


h) Non Parametic Correlation Coefficients (Kendall Tau-b).
Diurnal Temperature Range (DTR) vs Annual MEI

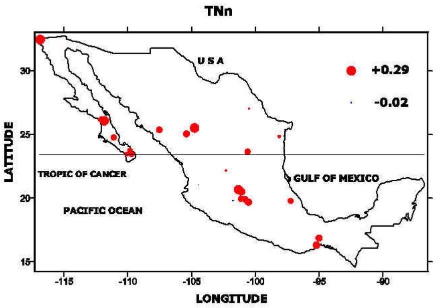
Fig. 7.43. Linear correlations (Kendall tau-b) between the Extreme Temperature Indices and the Annual Multivariate ENSO Index (Annual MEI). Circles in red are representing a positive and in blue negative correlations.



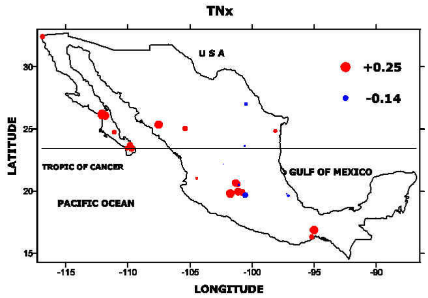
a) Non Parametic Correlation Coefficients (Kendall Tau-b).
Cool Night Frequency (TN10p) vs May-Oct MEI



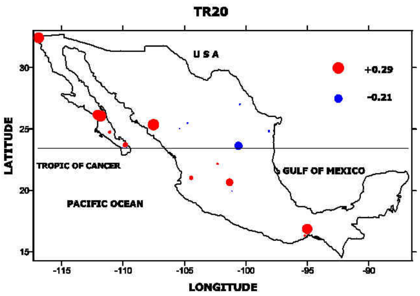
b) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hot Night Frequency (TN90p) vs May-Oct MEI



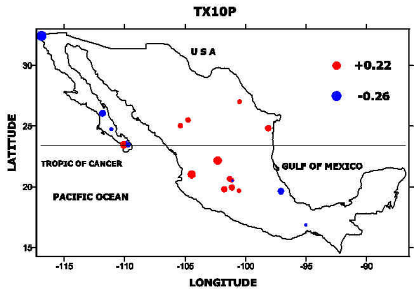
c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Coolest Night (TNn) vs May-Oct MEI



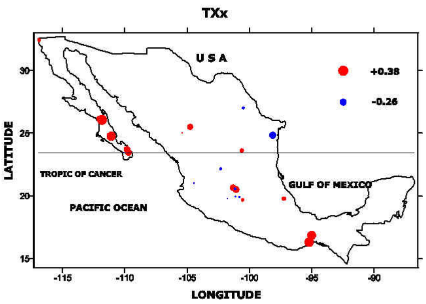
c) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hottest Night (TNx) vs (May-Oct) Niño 3.4



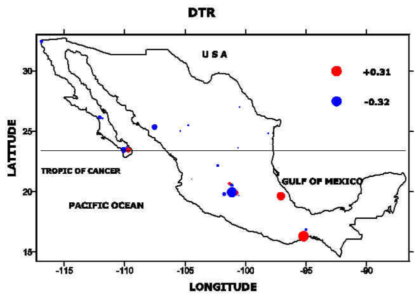
e) Non Parametic Correlation Coefficients (Kendall Tau-b).
Warm Nights (TR20) vs May-Oct MEI



f) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hot Day Frequency (TX10p) vs May-Oct MEI



g) Non Parametic Correlation Coefficients (Kendall Tau-b).
Hottest Day (TXx) vs May-Oct MEI



h) Non Parametic Correlation Coefficients (Kendall Tau-b).
Diurnal Temperature Range (DTR) vs May-Oct MEI

Fig. 7.44. Linear correlations (Kendall tau-b) between the Extreme Temperature Indices and the wet season (May-Oct) Multivariate ENSO Index (Annual MEI). Circles in red are representing a positive and in blue negative correlations.

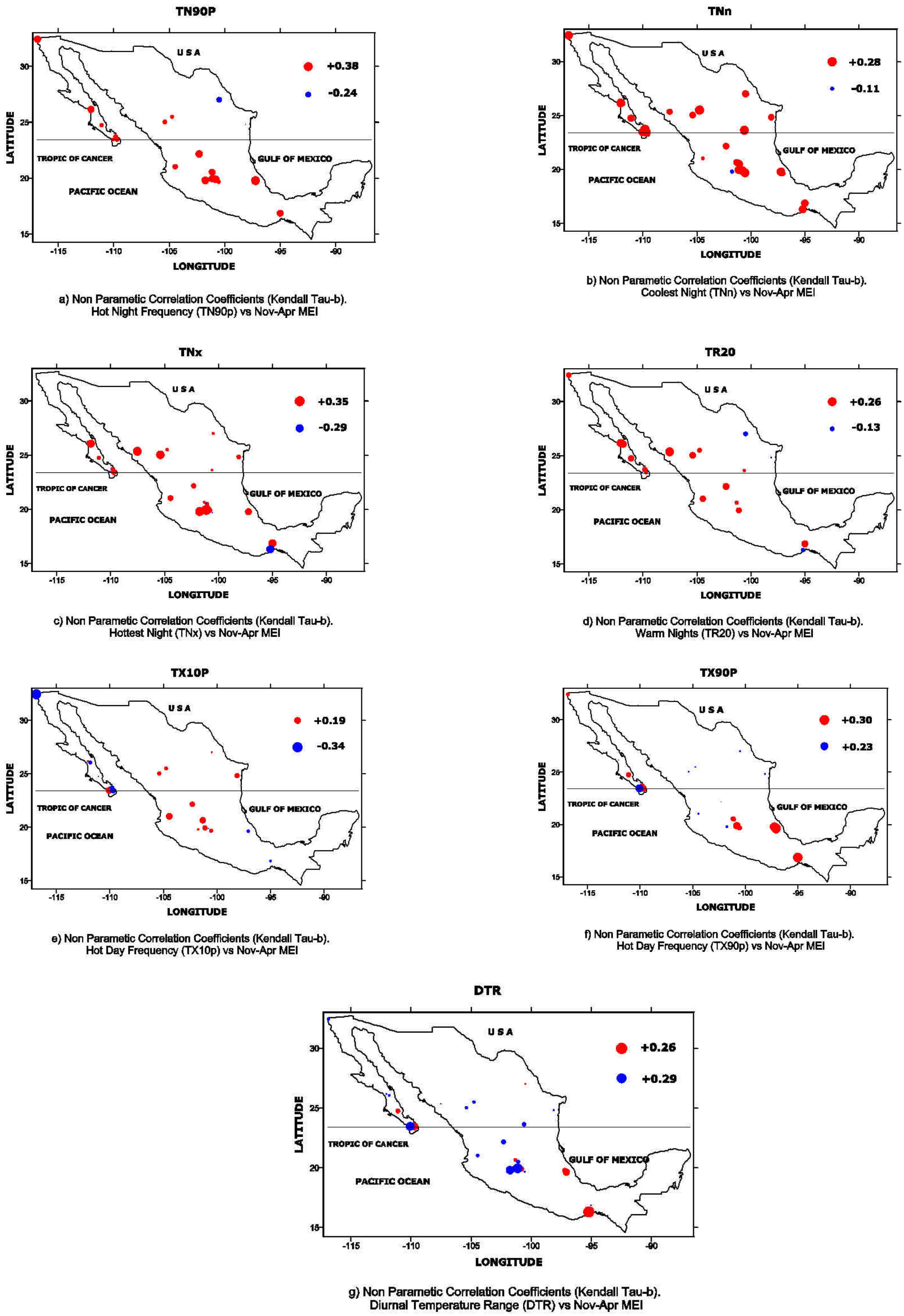
Baja California peninsula and Los Tuxtlas regions. Positive correlations are almost nationally prevalent across Mexico for the TXx index [Fig. 7.44 g)]. Warmer (day) temperatures are observed almost nationally, especially along the Pacific coast. The most significant exception to this pattern is observed at the San Fernando station in north-eastern Mexico. Finally, (statistically significant) negative correlations are found in central and northern Mexico, and positive correlations in the southern part of the country for the DTR index, especially near the Tehuantepec isthmus [Fig. 7.44 h)].

In accordance with the former results when the extreme indices and the wet season (May-Oct) MEI are linearly correlated, increasing temperatures are observed across Mexico. The most significant changes are mainly found in the minimum temperatures, therefore, directly affecting the Daily Temperature Range values. Geographically, climatic responses of maximum and minimum temperatures are concentrated in the northern part of the country.

The last set of indices to be analysed are those resulting from the correlation of the temperature extremes and the dry season (Nov-Apr) MEI. For their clarity in the results the group of extreme temperature indices to be evaluated are TN90P, TNn, TNx, TR20, TX10P, TX90P and DTR. Minimum temperature indices are assessed first, and then maximum temperature parameters finishing with the DTR index.

The Hot Night Frequency (TN90P) index is evaluated first. An almost national pattern of positive correlations can be observed in [Fig. 7.45 a)]. Statistically significant results are geographically concentrated in Central Mexico for TNn. This is particularly true for the largest correlations that are located within the area of the so called Neovolcanic axis, all these stations (Atzalán, Zacapú and Huingo, see table 3.2) are above the 1500 m.a.s.l [Fig. 7.45 b)]. Indeed, an almost national pattern of positive correlations can be easily seen. Nevertheless, the most significant results are geographically concentrated in Central and Northern Mexico. The largest correlation values (mainly positive) are spatially concentrated in continental Mexico, and especially biased to the western half of the country, for the TNx index [Fig. 7.45 c)]. During the peak of El Niño conditions there is a net increase in the night maximum temperatures, in northern Mexico. Positive correlations dominate central and northern Mexico when the TR20 index is evaluated [Fig. 7.45 d)]. There is a clear tendency for these statistically significant results to be located in the western half of the country. Warmer tropical nights (TN>20C) are observed during El Niño conditions for northern Mexico. A continental/peninsular climatic pattern is observed for the TX10P index: positive correlations are found in continental Mexico, while within the Baja California peninsula negative correlations are dominant, and these are the only statistically significant results [Fig. 7.45 e)]. Therefore, warmer day temperatures are observed in the Baja California peninsula during El Niño phase. A different kind of transition is observed for the TX90P index [Fig. 7.45 f)]. The statistically significant results are divided in a latitudinal way: positive correlations are geographically concentrated south the Tropic of Cancer, and negative correlations are located north of this limit within the Baja California peninsula. More days when the minimum temperature exceeds the 90^{th} percentile are observed in the southern part of the country during El Niño conditions, while fewer days below this percentile are found under the same climatic conditions. Negative correlations are prevailing across Mexico for the DTR index. Nevertheless, only a few of the results are statistically significant. Those are mostly concentrated in Central Mexico and on the southern tip of the Baja Californian peninsula. The only significant positive correlation is observed at Santo Domingo Tehuantepec on the southern coast of the Pacific Ocean. The DTR climatic pattern is reflecting that most significant changes are occurring in minimum temperatures, especially from central to northern Mexico [Fig. 7.45 g)].

Linear correlations between the temperature extreme indices and the Nov-Apr (dry season) MEI show an almost national climatic pattern of increase in temperatures for El Niño years. However, the most significant results are observed in minimum temperatures indices like TN90P, TNn, TNx, and TR20. Geographically these important changes in night temperatures are mostly concentrated north of the Tropic of Cancer. A net decrease in the DTR index from central to northern Mexico is a direct consequence of these warmer minimum temperatures.



a) Non Parametic Correlation Coefficients (Kendall Tau-b). Hot Night Frequency (TN90p) vs Nov-Apr MEI

b) Non Parametic Correlation Coefficients (Kendall Tau-b). Coolest Night (TNn) vs Nov-Apr MEI

c) Non Parametic Correlation Coefficients (Kendall Tau-b). Hottest Night (TNx) vs Nov-Apr MEI

d) Non Parametic Correlation Coefficients (Kendall Tau-b). Warm Nights (TR20) vs Nov-Apr MEI

e) Non Parametic Correlation Coefficients (Kendall Tau-b). Hot Day Frequency (TX10p) vs Nov-Apr MEI

f) Non Parametic Correlation Coefficients (Kendall Tau-b). Hot Day Frequency (TX90p) vs Nov-Apr MEI

g) Non Parametic Correlation Coefficients (Kendall Tau-b). Diurnal Temperature Range (DTR) vs Nov-Apr MEI

Fig. 7.45. Linear correlations (Kendall tau-b) between the Extreme Temperature Indices and the dry season (Nov-Apr) Multivariate ENSO Index (Annual MEI). Circles in red are representing a positive and in blue negative correlations.

7.4.2. LAG CORRELATION.

Precipitation Regional Averages (MEI).

Consistency is seen among the resultant climatic patterns when the three different ENSO indices (including MEI) and the Regional Precipitation Averages are correlated. Positive correlations are observed in the following regions (definitions and climatic characteristics in Table 4.1): RA4, RA7, RA6 and RA3 (Fig. 7.46). Three of them are geographically located north of the Tropic of Cancer; only La Huasteca at the fringes of this limit does not strictly comply with this condition. Timings are similar and close to the strongest El Niño conditions. According to these results with MEI (and the other ENSO indices used in this chapter) it is evident that during El Niño (close to the peak of its phase) wetter conditions are prevalent in the northern part of Mexico, particularly when we consider the Tropic of Cancer as a geographical limit.

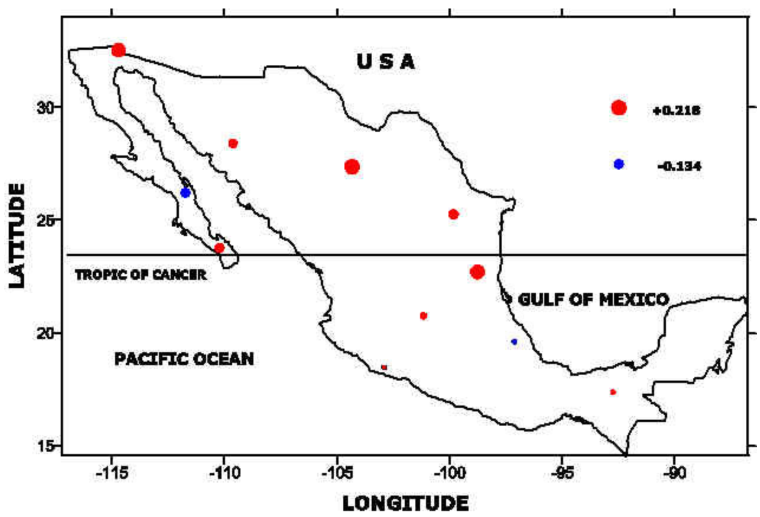


Fig. 7.46. Lag cross-correlations between the standardised versions of Precipitation Regional Averages and the Multivariate El Niño Index (MEI). Red circles represent positive and blue circles negative correlations.

Extreme Weather Indices.

Extreme Precipitation Indices

Consistency is the main characteristic of the extreme rainfall indices when they are correlated with the different El Niño indices, and MEI is not an exception. For the RX1day index (Fig. 7.47), the largest positive correlation (+0.174) is found at La Presa Rodríguez (northern part of the Baja California Peninsula), meaning wetter conditions right at the peak of El Niño phase. A positive correlation (+0.101) is also seen in the Guanaceví station within the Desertic north of Mexico, and a similar time-shift (-3). Therefore, a (small) net increase is seen in the amount of maximum 1-day precipitation associated to El Niño-like years. A delayed (+14 months lag) ENSO-impact is observed at the core of the Mexican Monsoon region. Maximum 1-day rainfall amounts at the Yecora station show a small net decrease (-0.145 correlation) during El Niño conditions, contrasting with its neighbouring stations.

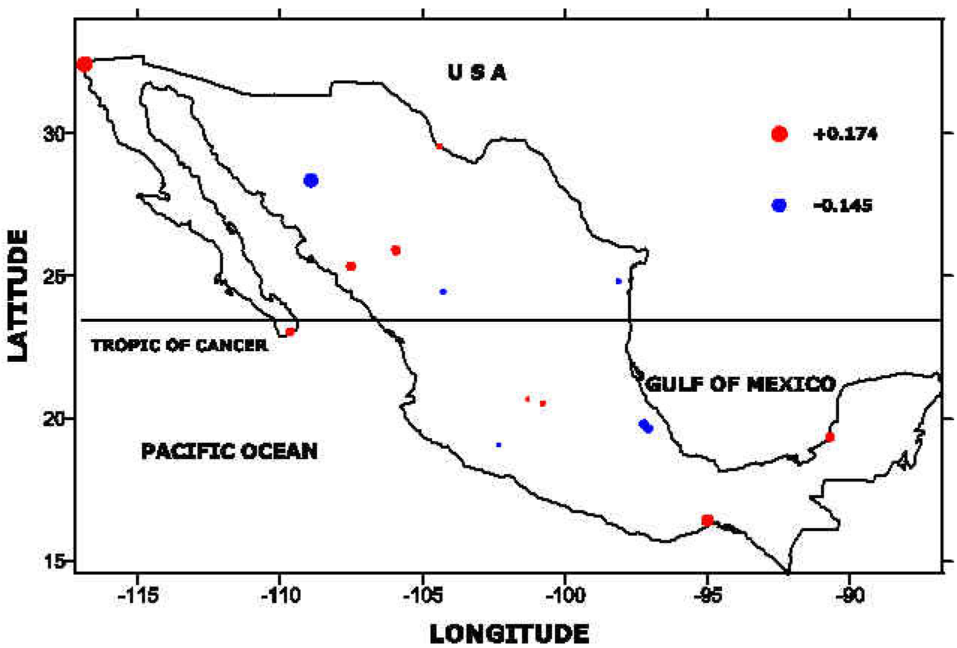


Fig.7.47. Lag cross-correlations between the Maximum 1-day precipitation (RX1day) Index and the Multivariate El Niño Index (MEI). Red circles represent positive and blue circles negative correlations.

Wetter conditions for the Northern part of the Baja Californian Peninsula are the constant feature among the different ENSO indices for the rainfall extreme indices. This climatic feature is also observed when the RX5day is lag-correlated with MEI (Fig. 7.48), although with different responses and timings as the largest correlations are in the north-western part of Mexico, at La Presa Rodriguez within the Baja California peninsula (correlation +0.163 and lag = 0) and within the Mexican Monsoon Region for the Yecora station in Sonora (correlation -0.145, lag=+14). Although with different time-shifts, it is evident that the Pacific Ocean exerts a greater influence (Mechoso et al., 2004) than the Atlantic one, especially at those stations along the northern Pacific coast. Finally, RX5day results are close to those correlations already observed applying the MEI to the RX1day index.

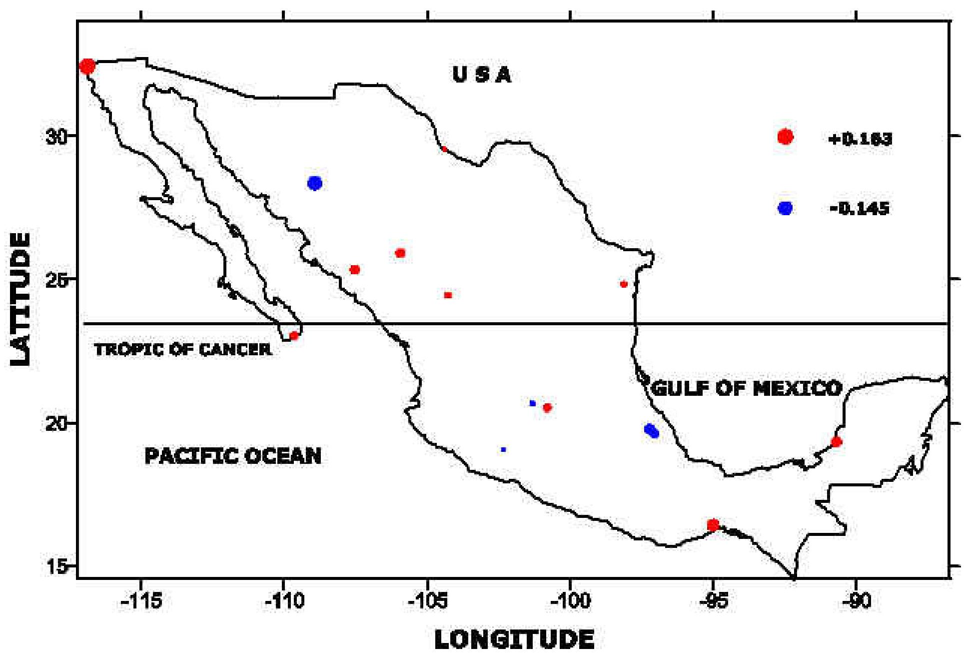


Fig. 7.48. Lag cross-correlations between the Maximum 5-day precipitation (RX5day) Index and the Multivariate El Niño Index (MEI). Red circles represent positive and blue circles negative correlations.

Prevalent wetter conditions are observed in north-western Mexico and the Baja Californian peninsula. These climatic responses are seen close to the peak of El Niño phase for the rainfall extreme indices.

Extreme Temperature Indices

The resulting (lag) correlations between DTR and MEI show a variable response across Mexico (Fig. 7.49). No spatial homogeneity is found among the positive or negative correlations. In fact, the greatest correlations (Santo Domingo Tehuantepec and Matías Romero) are both located within the Tehuantepec Isthmus region (Southern Pacific coast), but their time-shifts (see table 7.4) are quite different (-5 and -24 months respectively). Despite, its variable time lag responses, the most significant below normal precipitation (greatest negative correlations) seems to have a geographic component along the Pacific Ocean coast.

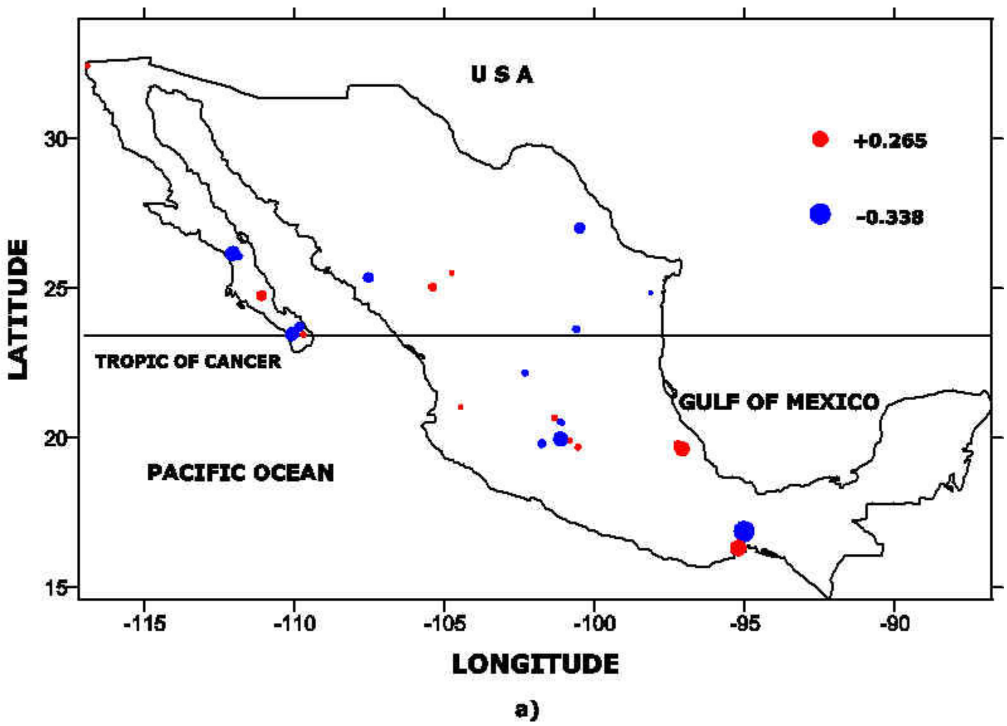


Fig. 7.49 Lag cross-correlations between the DTR (Daily Temperature Range) and the Multivariate El Niño Index (MEI). Red circles express positive correlations, and blue circles show negative correlations.

A mixed spatial distribution of positive and negative correlations is seen across Mexico for the TN10P index (Fig. 7.50). In central Mexico high altitude stations seem to be linked to these positive correlations, only the station at Ahuacatlán (900 m) is below the level of 1500 m.a.s.l. Negative correlations are widespread nationally but with no real clear climatic pattern. Optimal time-shift responses to the modulation of El Niño are similar among the positive correlations, as they are close to the peak of this phenomenon. Therefore, with the exception of a set of high-altitude stations in Central Mexico, a pattern of warmer conditions is observed across Mexico.

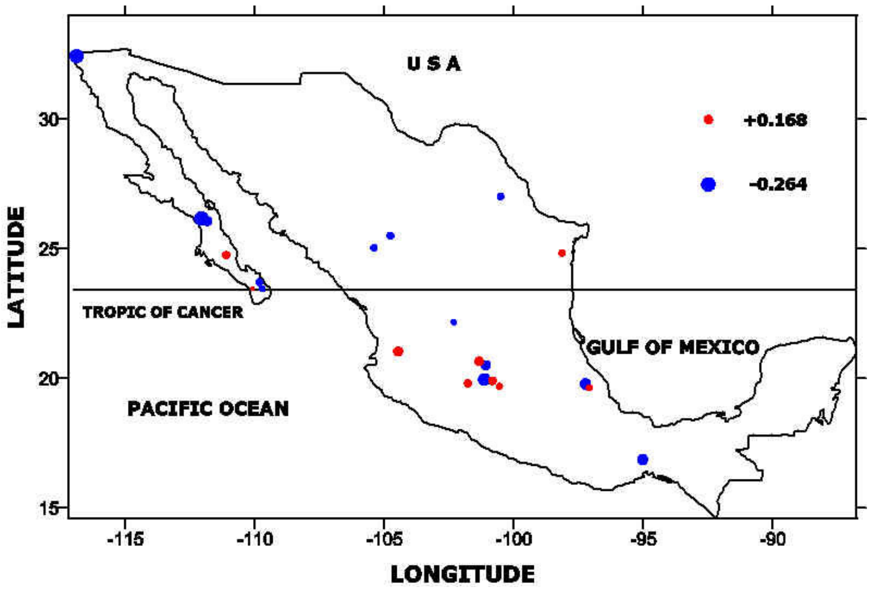


Fig. 7.50. Lag cross-correlations between the TN10P (Cool Night Frequency) and the Multivariate El Niño Index (MEI). Red circles express positive correlations, and blue circles show negative correlations.

A combination of positive and negative correlations -similar to the pattern observed for TN10P- without a clear climatic picture is seen when we evaluate the TN90P Index (Fig. 7.51). In the main continental Mexico, central and southern regions in Mexico are dominated by positive correlations with similar relationships also seen in the peninsula of Baja California. Time lags for the best climatic responses are associated with these correlations close to the peak of El Niño (see table 7.6). In general, more frequent cool nights exceeding the 90th percentile (warmer conditions) are observed close to the strongest El Niño conditions.

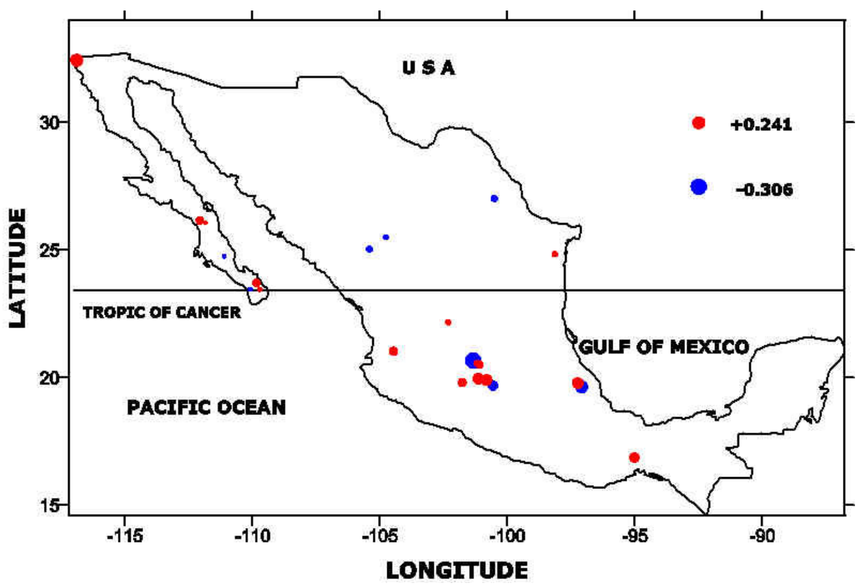


Fig. 7.51. Lag cross-correlations between the TN90P (Hot Night Frequency) and the Multivariate El Niño Index (MEI). Red circles express positive correlations, and blue circles show negative correlations.

Mostly positive correlations are seen across Mexico for the Coolest Night (TNn) Index. Lower negative correlations are spatially dispersed from Central to Northern Mexico (Fig. 7.52). Nevertheless when we compare the different time-shifts of response to the MEI index, for the positive correlations we find variable time responses (ranging from -19 to +10 months of lag to get the best climatic correlation) and more homogeneous time-shifts for the negative correlations (+16 to +18 months of lag). Although with different time-lags of climatic responses, warmer night temperatures are dominant across Mexico during El Niño phase.

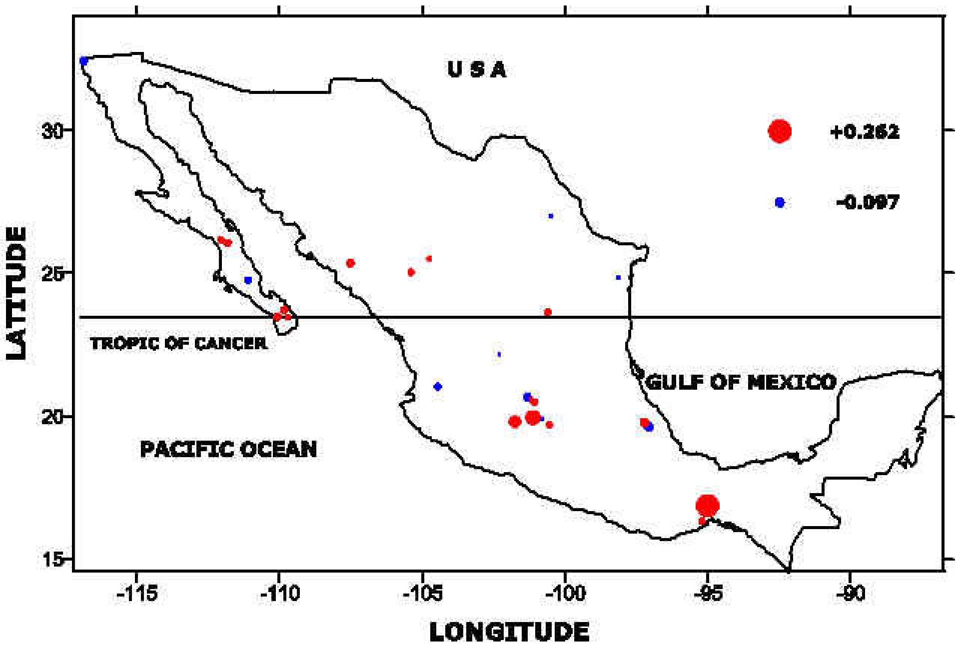


Fig. 7.52. Lag cross-correlations between the TNn Index (Coolest Night) and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

A mixed combination of positive and negative correlations is found for the TNx Index. Positive correlations prevail mostly in the Baja California peninsula, while negative correlations are spatially distributed across continental Mexico (Fig. 7.53). The time response of this index to El Niño modulation is very variable lags found for the negative correlations (-17 to +16 months), while more consistency is observed for the positive correlations (between +2 to +4 months of lag). Warmer conditions (at night time) dominate in Central and South Mexico near to the peak (average of 2 months response) of El Niño phase.

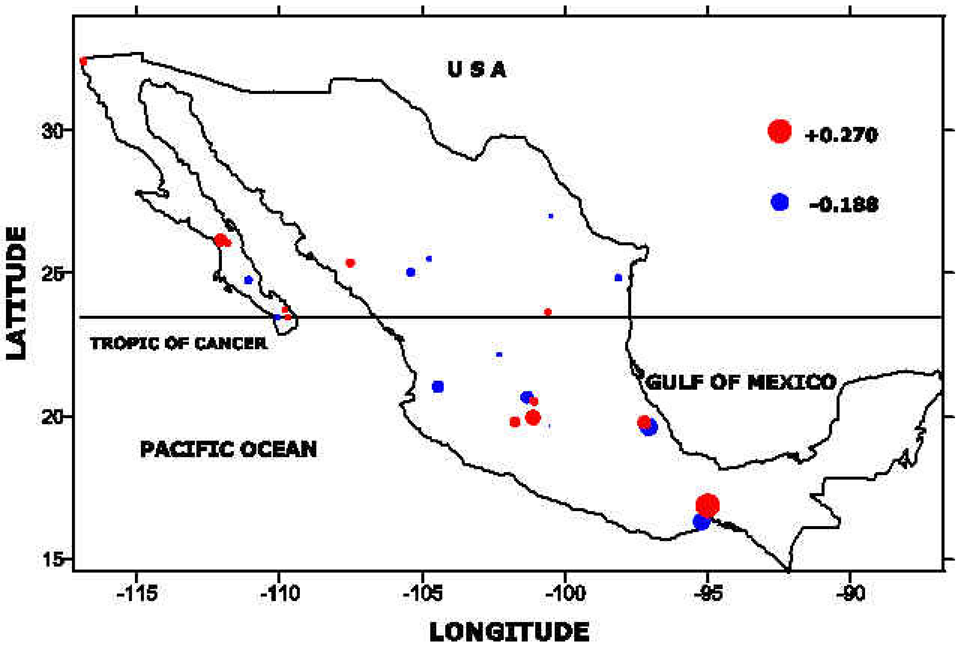


Fig. 7.53. Lag cross-correlations between the TNx Index (Hottest Night) and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

Positive correlations prevail in central and northern Mexico, with variable time-lags (ranging from -22 to 0 months) among the largest positive correlations for the TX10P (see Fig. 7.54 and Table 7.9) index. Negative correlations are found in central and southern Mexico and the northern part of the Baja Californian peninsula, with also a great variability in the lag of response to ENSO modulation. Positive correlations are slightly greater than negative and also in spatial extent. In accordance with these results an increasing frequency of cool days in central and northern Mexico with variable time lags are to be expected during El Niño conditions.

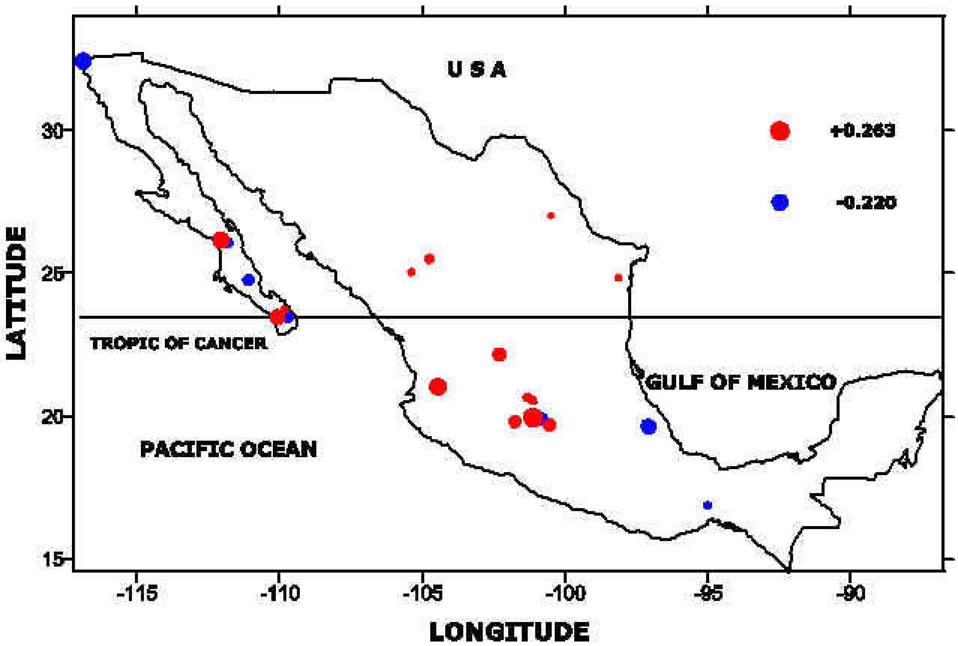


Fig. 7.54. Lag cross-correlations between the TX10P Index (Cool Day Frequency) and the Multivariate El Niño Index (MEI). The linear correlation is calculated using the Pearson function. Red circles express positive correlations, and blue circles show negative correlations.

A latitudinal transition in mainland Mexico is observed for TX90P. Positive correlations prevail in central and southern Mexico, while the negative correlations are dominant from Central to northern Mexico, especially in the western half of the country (Fig. 7.55). This climatic picture is not as clear within the Baja California peninsula, where mixed correlations can be observed. Similar time lags are seen for the positive correlations, that show that the strongest climatic response evident near (+3 months lag of average) the peak of El Niño. According to these results, hot nights are more frequent close to the strongest El Niño conditions in central and southern Mexico. Meanwhile, fewer hot nights are expected for northern Mexico, with variable timings of response.

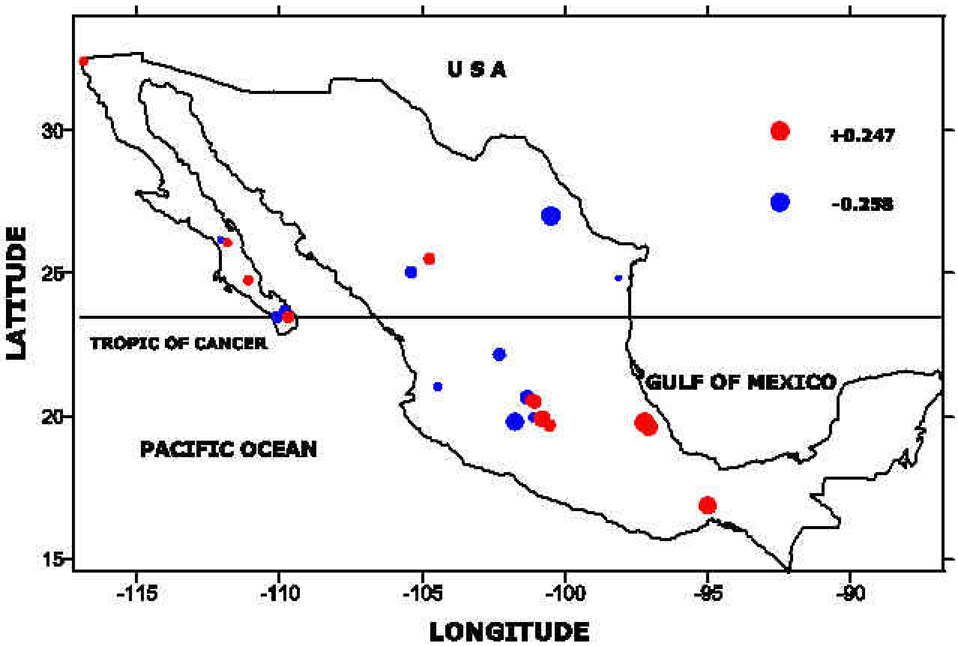


Fig. 7.55. Lag cross-correlations between the TX90P Index (Hot Day Frequency) and the Multivariate El Niño Index (MEI). Red circles express positive correlations, and blue circles show negative correlations.

A longitudinal climatic transition is observed in the results for the Coolest Day Index (TXn). Negative correlations predominate in the western part of Mexico, and the largest positive correlations prevail in southern Mexico near to the Tehuantepec Isthmus (Fig. 7.56). Time-lags are associated with negative correlations range from -5 to 0 months for the greatest correlations. Colder days are likely to be found from Central to Southern Mexico in the western half of the country close to the peak of El Niño-like conditions.

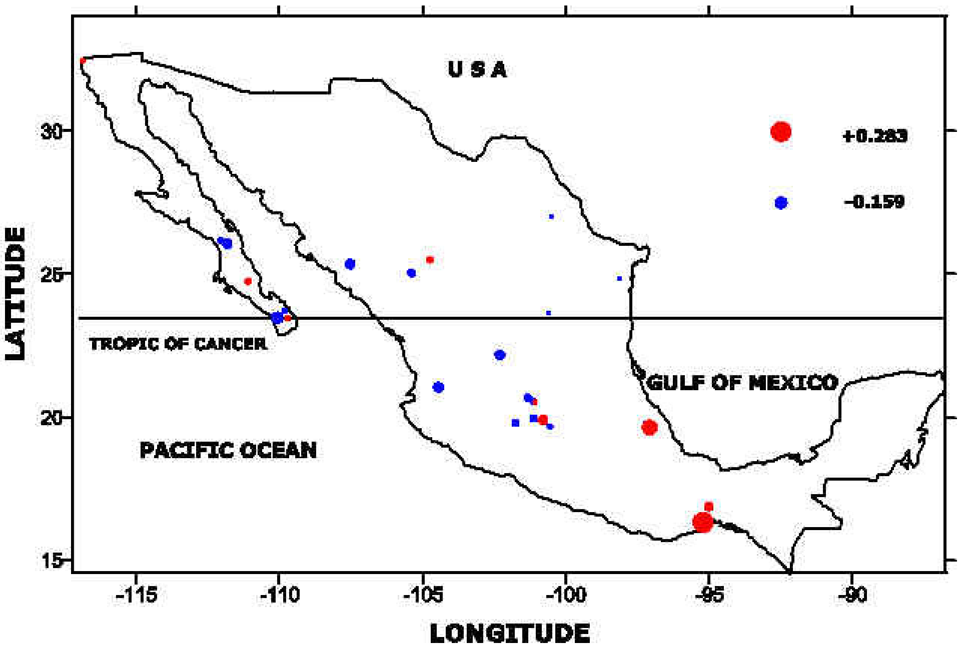


Fig. 7.56. Lag cross-correlations between the TXn Index (Coolest Day) and the Multivariate El Niño Index (MEI). Red circles express positive correlations, and blue circles show negative correlations.

A clearer meridional pattern is found for the TXx when compared with the climatic picture observed for TNx (Fig. 7.57). Positive correlations are observed along the Atlantic coast from the northeast until we reach the Tehuantepec Isthmus in southern Mexico. In contrast, negative correlations dominate the western half of Mexico, except the most north-western station in Tijuana (La Presa Rodríguez). The greatest correlation (+0.304) is found within the South Pacific coast at Santo Domingo Tehuantepec station, having a time-lag of -4 months to fully respond to the El Niño modulation. According to these results, during El Niño conditions warmer day temperatures are observed along the Gulf of Mexico close to the peak of the phenomenon, while colder temperatures are likely to be observed in the western part of the country, with variable time responses.

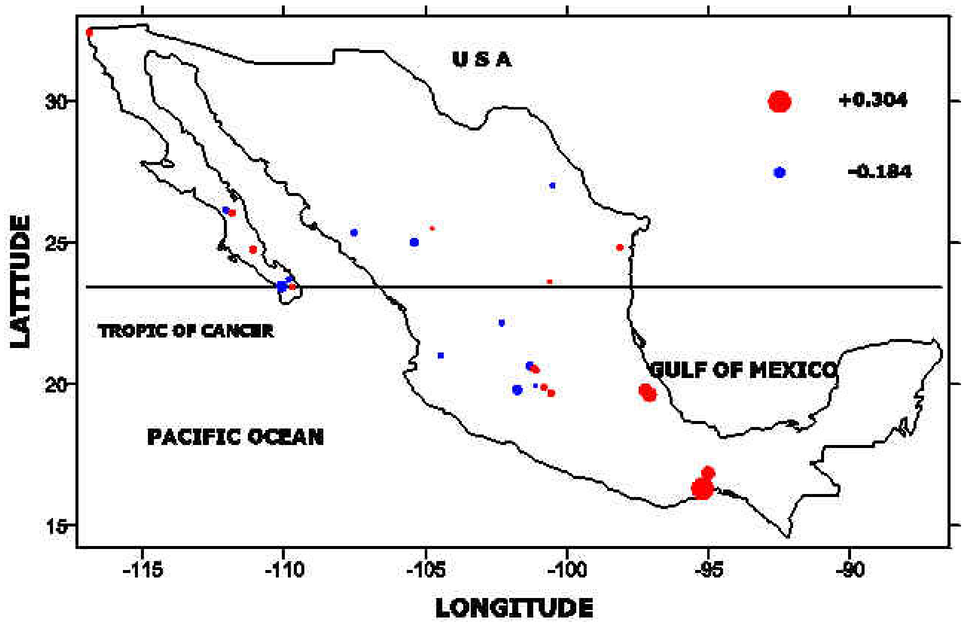


Fig. 7.57. Lag cross-correlations between the TXx Index (Hottest Day) and the Multivariate El Niño Index (MEI). Red circles express positive correlations, and blue circles show negative correlations.

Summary of the section (MEI).

Kendall tau-b (linear) and lag correlations of the precipitation and temperature time-series with the Multivariate El Niño Index (MEI) have shown consistency with the analyses of SOI and Niño 3.4 indices (see sections 7.2 and 7.3).

A clear seasonality factor is observed in the geographical patterns of precipitation that is (partially) modulated by the MEI. When the annual and wet season (May-Oct) of (Regional) Standardised Anomaly Indices (SAI) are considered, a clear latitudinal transition is seen: wetter (drier) conditions are observed North (South) of the Tropic of Cancer during El Niño (La Niña) years. Meanwhile, above (below) normal precipitations are seen nationally for the dry season (Nov-Apr) SAIs under El Niño (La Niña) years. These climatic patterns (latitudinal transition or national wet or dry conditions) are replicated for the local scale (sites) when the extreme precipitation indices are analysed. Nevertheless, the largest correlations are geographically concentrated along the western coast, suggesting an important role of the Pacific Ocean, and particularly the sea surface temperatures (SSTs) in the rainfall totals and extremes. The clearest results are seen in North-western Mexico, especially the Northern part of the peninsula of Baja California. The timing of the largest responses for precipitation are close (a few months lag) to the strongest El Niño conditions.

When correlated with MEI, extreme temperature indices have less clear results. Linear correlations (Kendall tau-b) show a national pattern of increasing minimum temperatures, especially north of the Tropic of Cancer, and the maximum temperature changes are mainly concentrated along the Pacific Ocean coast. Another aspect of the analysis of the ENSO modulation (utilising MEI) is to apply lag correlations on extreme temperature indices. Variable time lags are found with the different extreme indices but the largest correlations are observed close to the peak of El Niño (La Niña) conditions. In geographic terms, there are no clear climatic patterns for either maximum or minimum temperatures, when the lag correlation method is applied. Due to this lack of consistency in the maximum and minimum temperature indices, no spatial homogeneity is observed for the Daily Temperature Range (DTR).

7.5. CONCLUSIONS TO THE CHAPTER.

This chapter has dealt with the final major analysis of this thesis. The aim has been to determine the characteristics of the large-scale atmospheric control (El Niño-Southern Oscillation phenomenon) of the main meteorological variables (precipitation and temperature) across Mexico. ENSO is the main modulator of the precipitation across the country (Magaña et al., 2003), and also has a great influence in the hurricane activity (Reyes and Troncoso, 1999). Using instrumental data at different temporal and spatial scales, linear (Kendall's tau-b) and lag correlations have been applied to explore the modulation of ENSO on recent climatic changes in Mexico.

Linear correlations of the seasonal SAIs (Standardised Anomaly Index) and the ENSO indices (SOI, Niño 3.4 and MEI) show consistency across the results. A clear latitudinal transition can be observed when the annual and wet season SAIs and annual and (May-Oct) ENSO indices are correlated. Wetter conditions are found north of the Tropic of Cancer, while below normal precipitation is evident in southern regions. More extended geographically are the results when the dry season (Nov-Apr) SAIs and dry season ENSO indices are combined: an almost national climatic pattern of wetter conditions prevails this time. Regardless of these seasonal variations, the regions with the most consistent results (largest correlations) are mainly found in the north-western area: the North American Monsoon (or Mexican Monsoon) region and Northern Baja California peninsula. It is important to point out that these regions are strongly affected by winter rainfall patterns contrasting with the climatic patterns of rest of the country.

Rainfall extreme indices results replicate the seasonal effect that has been already described in the case of regional precipitation. A latitudinal transition is directly responding to sesonal ENSO modulations. When we combine the annual and wet season (May-Oct) versions of the SAIs and ENSO indices, the correlations show that wetter conditions prevail north of the Tropic of Cancer, and drier conditions dominate the southern part of Mexico. This latitudinal transition of wetter in northern and drier conditions in southern Mexico is also seen for the correlations between dry (Nov-Apr) SAIs and ENSO indices. Nevertheless, the most significant results are found in the northern part of the country, this can be fully appreciated in the climatic response at Presa Rodriguez (north-western) to the ENSO modulation.

At regional and local scales, when lag correlations are applied, precipitation is consistently responding close to the peak of El Niño-like conditions with amounts above their normals mainly in the north-western part of Mexico, especially the Mexican Monsoon and the northern Baja California peninsula. This climatic picture is also coincident with the results obtained applying linear correlation using Kendall tau-b.

Due to the difficulty of developing regional temperature averages (see sections 4.3), temperature is only evaluated at the local scale. Nevertheless, linear and lag correlations were also applied to the extreme temperature indices.

When linear correlations have been applied, the greatest changes in extreme temperatures with ENSO phases are found in the indices related to minimum temperatures. Geographically, warmer temperatures are observed across all the country, but the most significant results are found in the northern part of Mexico. Although no clear pattern could be found when lag correlations were applied between extreme temperature and ENSO indices, it can be concluded that warmer temperatures are observed south of the Tropic of Cancer, close to the peak of El Niño conditions. This climatic picture is especially true for the indices related to minimum temperatures.

The core processes of the El Niño Southern Oscillation (ENSO) phenomenon occur in a latitudinal band along the equatorial Pacific Ocean. As Mexico lies in the (northern) climatic transition between tropical and extratropical conditions, we needed a technique to explore the time-dependence between the Mexican temperature and precipitation and ENSO; for this purpose the lag-cross correlation method was applied to those meteorological parameters. The largest impacts on local and regional scales are mostly observed close to the peak of El Niño (La Niña) conditions. But, as we have seen in this chapter, the ENSO modulation is also associated to seasonal and geographical characteristics. For example, two regions are largely influenced by El Niño: the Mexican Monsoon region (see Table 4.1) during the wet season (May-Oct) and the North Baja Californian peninsula during the dry season (Nov-Apr). The possibility of (approximately) knowing the time of the greatest response of the precipitation to ENSO could have practical applications in agriculture; for instance, directly in the tomato crops in the Mexican Monsoon region and indirectly in the wine production in the northern region of the peninsula of Baja California.

The climatic responses at regional and local levels of rainfall and temperatures to ENSO are clear. A latitudinal climatic transition (if we define the Tropical of Cancer as a geographical limit) in precipitation can be appreciated with the wet season (May-Oct) and annual versions of the ENSO indices. Wetter conditions are found in northern Mexico; while drier conditions prevail in the southern part of the country. Under extra-tropical conditions, an almost national pattern of wetter conditions are seen when the dry season (Nov-Apr) ENSO conditions are dominant. Nevertheless, the time of response of the precipitation is directly linked to the spatial scale, regional time-series are strongly affected close to the peak of El Niño conditions, and precipitation extremes are more variable in their timing with ENSO modulation. Temperature extremes do not reflect a clear climatic picture. Although significant changes can observed in the extreme indices related to minimum temperatures, the geographical distribution is less clear as is their response timing. Fluctuations toward warming can be appreciated across all Mexico, the largest correlations are found in the northern part of the country especially the Baja California peninsula, but the impacts are first observed in southern Mexico close to the peak of El Niño conditions. Precipitation seems more climatically stable in its response to ENSO than temperature, especially regional rainfall averages.