CHAPTER 6: TEMPERATURE EXTREME INDICES.

6.1. INTRODUCTION.

2005 was the equal warmest (with 1998) global average surface temperature (http://www.nasa.gov/vision/earth/environment/2005_warmest.html). It is important to realise, however, that these extreme conditions in 2005 took place without concomitant El Niño conditions, as was the case in 1998. Temperatures have risen by 0.7°C during the 20th century (IPCC, 2007) that has also been the warmest for the Northern Hemisphere during the last millennium (Osborn and Briffa, 2006). At the continental scale, Europe experienced unusual warmth during the 2003 heatwave; and it was probably the warmest summer since at least 1500 (Luterbacher et al., 2004). Furthermore, this "surprising" climatic pattern closely agrees with some of the scenarios of future climate (2080s) rather than the 1961-1990 normals; and at the local level, averaged June-July-August (JJA) Tmax at Basel, Switzerland exceeded the 29° C threshold for the first time in its long-term instrumental records (Beniston, 2004). At a larger scale, a global study of weather extremes (Alexander et al., 2006) shows a marked upward tendency in daily temperature extremes, particularly towards less cold rather than warmer conditions across the world.

Partly caused by the warm atmospheric conditions of 1998, one of the warmest years on record (a year also associated with the 1997-1998 ENSO phenomenon, one of the strongest ENSOs ever recorded, Magaña, 1999), large areas of North America were under drought conditions during the period between 1998 and 2002 including the Canadian Prairie Provinces, the United States (especially the western states and the Great Plains regions) and northern and western Mexico (Cook et al., 2004). In fact the intensity of the drought ranged from severe to extreme conditions in nearly 30% of the conterminous USA at the beginning of June 2002 (Lawrimore et al., 2002). Due to the intense drought of 1998 (On May 9, 1998, Mexico City recorded 33.9° C, the warmest day on instrumental records, http://www.dbc.uci.edu/~sustain/ENSO.html) the Mexican government needed to intervene financially in order to mitigate the impacts in twelve northern states of the country (Magaña, 1999). Because of these extreme dry conditions the water supply for agricultural purposes was so scarce along the USA-Mexican border (Cason and Brooks, La Jornada 6/6/2002) that, in Mexico, the federal government and most of the northern Mexican states needed to negotiate in order to comply with the 1944 treaty with the USA that deals with Transboundary water management (Venegas, La Jornada 6/6/02).

The evidence is then accumulating: across different scales of time and space scales, the global climatic conditions are likely moving towards warming. With warming of average temperatures we should expect increases in both the intensity and the frequency of weather extremes (Beniston and Stephenson, 2004). Despite, these diverse efforts to assess weather extremes there is still a necessity for the improvement of daily data archives to undertake these studies especially, in developing countries (New et al., 2006). This chapter aims to deal with the evaluation of extremes events in daily temperatures in Mexico, in order to help to fill a research gap for the region in climatic studies.

Changes in temperature extremes at local scales are analysed using daily temperature records. Here, we discuss the results of calculating non-parametric linear correlations in extreme temperature indices (defined in section 3.3.4) with time from 26 sites with the longest and more complete (data from 1941 to 2001) daily temperature series (Table 6.1; see also table 3.2 and fig. 3.6). All the stations are tabulated (in Table 6.1), whether their positive or negative correlation was statistically significant at the 5 or 1% level and those locations with the greatest number of cases (extreme indices, for their definitions see table 3.1 in chapter 3) evaluated. The purpose is to identify whether the correlations are spatially coherent across the country. Is the pattern of correlations random or is there a spatial structure?

In order to overcome the restriction of working at a local scale, the second analysis of the chapter was undertaken with the extreme temperature indices independently. The parameters were analysed separately in three different groups. The first group deals with the temperature intensity in °C, with the two remaining groups working with records exceeding set limits: the first kind of limit relates to absolute temperature thresholds in °C, and the second with a percentile (variable from season to season and between stations) limit. The main purpose of these tests was to check spatial consistency in the patterns: local versus larger scales.

With the similar objective of contrasting geographical (latitudinal, longitudinal or elevational) transitions, the next analysis deals with the extreme temperature indices and not solely the individual stations. The statistically significant correlations of the indices with time were counted using two different approaches to evaluation: considering statistical significance levels (positive/negative at the 5 or 1% level) and identifying warmer/colder conditions according to the extreme temperature indices. For both assessments the Tropic of Cancer was established as a geographic limit to separate the southern and northern part of Mexico.

The last analysis of the chapter calculates linear trends using the least-squares approach of the R software explained in section 3.3.4. A pair of stations north and south of the Tropic of Cancer having the largest number of statistically significant results were selected in order to calculate and geographically compare the linear trends among the chosen time-series.

6.2. DISCUSSION.

In order to evaluate which stations with daily data from 1941 to 2001 are experiencing the most drastic changes in the daily temperature records, we have tabulated the stations with extreme temperature indices (defined in table 3.1 of section 3.3.4) that are exceeding the statistical significant levels at the 5 and 1% (Table 6.1). We have decided –as a preliminary stage to further analyses, to consider only those stations that had at least 7 indices with statistically significant results. Two stations have 11 statistically significant results, two more have 8 and a further three have 7. These parameters have been separated into positive or negative correlations (of the temperature extreme indices with time) in order to facilitate the identification of patterns leading locally towards warming or cooling conditions.

El Paso de Iritu, Baja California (station number 4 in Table 6.1), in the northern part of Mexico, according to the climatic division defined by the Tropic of Cancer; and Ahuacatlán, Nayarit (station number 25 in Table 6.1); south of the Tropic of Cancer are the stations that have more statistically significant results than the rest, both of them independently counting 11 extreme weather indices. The Baja Californian station (El Paso de Iritu) shows that indices related to minimum temperature (TN90p, TN10p, TNn, TNx, TXn, TX10p, CSDI) are the most important in terms of changing climatic patterns. Clearly, at this station, we can observe positive correlations (warming trends) for the night time temperatures (TN90p, TN10p, TNn and TNx). As for the southern station (Ahuacatlán) eight out of the eleven indices (SU25, TN90p, TNn, TNx, TR20, TX90p, TXx and WSDI) with statistically significance at 1% level emphasise negative correlations (cooling trends). Contrasting the results of Ahuacatlán with those of el Paso de Iritu, it can be stated that the extreme climate indices of maximum temperatures are tending towards cooler temperatures. A warming/cooling latitudinal transition can be observed between these two stations with the most statistically significant indices.

Number*	STATION	STATE	Pos. Corr. Statist. Signif. at 5%	Pos. Corr. Statist. Signif. at 1%	Neg. Corr. Statist. Signif. at 5%	Neg. Corr. Statist. Signif. at 1%
1	PABELLON DE ARTEAGA	AGS			SU25, TXx, WSDI	TX90p
2	PRESA RODRIGUEZ	BC	TXx	SU25, TX90p		TX10p
3	COMONDú	BCS	DTR, SU25	TNn, TXn		TNx, TX10p
4	EL PASO DE IRITU (11)	BCS	TN90p, Tx90p, TXn, TXx	CSDI, DTR, TN10p		TNn, TNx, TR20, TX10p
5	LA PURíSIMA	BCS				
6	SAN BARTOLO	BCS		TNn		TN10p
8	SANTA GERTRUDIS (8)	BCS		TNn	SU25, TXx	TN90p, TNx, TR20, TX90p, WSDI
9	SANTIAGO (7)	BCS	TXn	DTR, TX90p, TXx	FD0	TN90p, TX10p
14	EL PALMITO	DUR	TXn	TNn, TX90p	TNx	FD0, TN10p
15	SANTIAGO PAPASQUIARO	DUR		TNn, TXn	TN10p	FD0
17	IRAPUATO	GTO		CSDI, TX10p		SU25, TN90p, TXn
18	PERICOS	GTO		TNn, TNx	DTR	FD0, TN10p, TX10p
19	SALAMANCA (8)	GTO	TNn	TX10p	SU25, TN10p	DTR, TX90p, TXx, WSDI
21	CUITZEO DEL PORVENIR	MICH	TXx	TNn	CSDI, DTR	FD0, TN10p
22	HUINGO	MICH	CSDI		DTR	TN90p
23	CIUDAD HIDALGO	MICH				TN90p, TNx
24	ZACAPU (7)	MICH	CSDI, TX10p		TXx	DTR, SU25, TX90p, WSDI
25	AHUACATLAN (11)	NAY	CSDI	TX10p	TN10p	SU25, TN90p, TNn, TnX, TR20, TX90p, TXx, WSDI
26	LAMPAZOS	NL			TNx, TXx	
28	MATIAS ROMERO (7)	OAX	TX90p	TNx, TR20, TXx, WSDI	TN10p	DTR
29	SANTO DOMINGO TEHUANTEPEC	OAX		TXn, TXx	TR20	TNx
30	MATEHUALA	SLP		TXx		
31	BADIRAGUATO	SIN	TR20			
33	SAN FERNANDO	TAM			WSDI	
34	ATZALAN	VER	TNn, WSDI	TX90p, TXx		Tn10p
35	LAS VIGAS	VER		TXn	CSDI, SU25, WSDI	TN90p, TX10p

Table 6.1. List of temperature stations (with data from 1941 to 2001) show correlations (Kendall's tau) between the temperature extreme indices with time, that are statistically significant at 5 and 1% level. The stations with the most statistically significant correlations are marked with (11), (8), and (7) depending on the number. * Stations numbers are in correspondence with Table 3.2 and Fig. 3.6.

	STATION	STATE	Non Significant Correlations
1	PABELLON DE ARTEAGA	AGS	FD0, ID, TR20, GSL, CSDI, TNx, TXn, TNn, DTR, TN10p, TX10p, TN90p
2	PRESA RODRIGUEZ	BCN	FD0, ID, TR20, GSL, WSDI, CSDI, TNx, TXn, TNn, DTR, TN10p, TN90p
3	COMONDú	BCS	FD0, ID, TR20, GSL, WSDI, CSDI, TXx, TN10p, TN90p, TX90p
4	EL PASO DE IRITU	BCS	FD, SU25, ID, GSL, WSDI
5	LA PURíSIMA	BCS	FD0, SU25, ID, TR20, GSL, WSDI, CSDI, TXx, TNx, TXn, TNn, DTR, TN10p, TX10p, TN90p, TX90p
6	SAN BARTOLO	BCS	FD0, SU25, ID, TR20, GSL, WSDI, CSDI, TXx, TNx, TXn, DTR, TX10p, TN90p, TX90p
7	SANTA GERTRUDIS	BCS	FD0, ID, GSL, CSDI, TXn, DTR, TN10p, TX10p
8	SANTIAGO	BCS	SU25, ID, TR20, GSL, WSDI, CSDI, TXx, TNx, TNn, TN10p
9	EL PALMITO	DUR	SU25, ID, TR20, GSL, WSDI, CSDI, TXx, DTR, TX10p, TN90p
10	SANTIAGO PAPASQUIARO	DUR	SU25, ID, TR20, GSL, WSDI, CSDI, TXx, TNx, DTR, TX10p, TN90p, TX90p
11	IRAPUATO	GTO	FD0, ID, TR20, GSL, WSDI, TXx, TNx, TNn, DTR, TN10p, TX90p
12	PERICOS	GTO	SU25, ID, TR20, GSL, WSDI, CSDI, TXx, TXn, TN90p, TX90p
13	SALAMANCA	GTO	FD0, ID, TR20, GSL, CSDI, TNx, TXn, TN90p
14	CUITZEO DEL PORVENIR	MICH	SU25, ID, TR20, GSL, WSDI, TNx, TXn, TX10p, TN90p, TX90p
15	HUINGO	MICH	FD0, SU25, ID, TR20, GSL, WSDI, TXx, TNx, TXn, TNn, TN10p, TX10p, TX90p
16	CIUDAD HIDALGO	MICH	FD0, SU25, ID, TR20, GSL, WSDI, CSDI, TXx, TXn, TNn, DTR, TN10p, TX10p, TX90p
17	ZACAPU	MICH	FD0, ID, TR20, GSL, TNx, TXn, TNn, TN10p, TN90p
18	AHUACATLAN	NAY	FD0, ID, GSL, TXn, DTR
19	LAMPAZOS	NL	FD0, SU25, ID, TR20, GSL, WSDI, CSDI, TXn, TNn, DTR, TN10p, TX10p, TN90p, TX90p
20	MATIAS ROMERO	OAX	FD0, SU25, ID, GSL, CSDI, TXn, TNn, TX10p, TN90p
21	SANTO DOMINGO TEHUANTEPEC	OAX	FD0, SU25, ID, GSL, WSDI, CSDI, TNn, DTR, TN10p, TX10p, TN90p, TX90p
22	MATEHUALA	SLP	FD0, SU25, ID, TR20, GSL, WSDI, CSDI, TNx, TXn, TNn, DTR, TN10p, TX10p, TN90p, TX90p
23	BADIRAGUATO	SIN	FD0, SU25, ID, GSL, WSDI, CSDI, TXx, TNx, TXn, TNn, DTR, TN10p, TX10p, TN90p, TX90p
24	SAN FERNANDO	TAM	FD0, SU25, ID, TR20, GSL, CSDI, TXx, TNx, TXn, TNn, DTR, TN10p, TX10p, TN90p, TX90p
25	ATZALAN	VER	FD0, SU25, ID, TR20, GSL, CSDI, TNx, TXn, DTR, TN10p, TX10p, TN90p
26	LAS VIGAS	VER	FD0, ID, TR20, GSL, TXx, TNx, TNn, DTR, TN10p, TX90p

Table 6.2. List of temperature stations (with data from 1941 to 2001) show correlations (Kendall's tau) between the precipitation extreme indices with time, that are not statistically significant. * Stations numbers are in correspondence with Table 3.2 and Fig. 3.6.

Two stations independently account for 8 statistically significant indices. Santa Gertrudis –in the southern part of the Baja Californian peninsula- is located just north of the Tropic of Cancer (station number 8 in Table 6.1). Four out of eight correlations of the temperature extreme indices that are statistically significant at the 1% level lead to a clear cooling trend at this location. This is especially true for night-time temperature indices (TNn, TN90p, TNx and TR20) at Santa Gertrudis. Salamanca in the State of Guanajuato (station number 19 in Table 6.1) is the southern station for the analysis. Just as in the former case, four extreme indices show correlations leading to cooler conditions; the results are statistically significant at the 1% level, and basically related to changes in day-time temperatures (TX10p, TX90p, TXx, and WSDI). Prevailing cooling trends affect Santa Gertudris and Salamanca stations, one in the northern part and the other in central Mexico.

Finally, when those stations with 7 statistically significant indices are considered, three different locations are evaluated: Santiago, Zacapu, and Matías Romero (stations number 9, 24 and 28 in Table 6.1, respectively). Santiago is at the southern tip of the Baja Californian Peninsula, located just north of the Tropic of Cancer. Although correlations of the indices for Santiago are mixed between positive and negative ones, clear variations towards warming conditions can be observed, as the more statistically significant changes are principally occurring for the day-time temperatures (TX90p, TXx and TX10p). The first of the two southern stations to be analysed is Zacapu in Michoacán State. Four out of the seven indices with statistically significant results are for the most significant, 1% level (DTR, SU25, TX90p and WSDI). The changes taking place at the Zacapu occur in the day-time temperature indices, leading to clear cooling conditions. Matías Romero (in the State of Oaxaca) is the only station, located well south of the Tropic of Cancer near the Pacific Ocean, with statistically significant correlations. These changes are concentrated (four out of seven) all at the positive 1% level (TNx, TR20, TXx and WSDI), and are also slightly biased towards variations in night-time temperatures. Overall, at Matías Romero a clear trend towards warmer conditions can be observed.

6.2.1. EXTREME TEMPERATURE INDICES.

In this section, we can simplify the description of the results. The extreme temperature indices (defined in section 3.3.4) can be classified into three groups: one group measures the temperature change (°C) (TNn, TNx, TXn, TXx, and DTR) the second calculates the frequency (number of cases or days) the index is exceeding a defined threshold (WSDI, SU25, TR20, CSDI, and FD0), and the last group also defines the percentage of time an index is exceeding a percentile limit (TN10p, TN90p, TX10p and TX90p). It is expected that this separation of magnitude, frequency, and percentage can lead us to a better understanding of the specific details of the extreme temperatures in Mexico.

The first group to be considered in the evaluation of temperature extremes deals with the changes in the absolute values (°C) of temperature. The warmest day [TXx, fig. 6.1 a)] is the first index to be assessed. Positive correlations (warmer conditions) are located along both Atlantic and Pacific Coasts, but those statistically significant at the 1% level are concentrated within the southern part of the country. In contrast, negative correlations (cooler conditions) are, basically concentrated in Central Mexico.

Another (day-time) temperature to be evaluated is the TXn index or coolest day [fig. 6.1 c)]. An almost national pattern of positive correlations (between the temperature extreme indices with time) can be observed for this index; this is especially true if we consider that most of the sites have statistically significant results. Geographically these positive trends are located along both Mexican coasts. Of all the indices that are statistically significant, only Irapuato (station number 17 in Table 6.1) is experiencing a negative correlation and this site is located in Central Mexico (Mexican Highlands). Another interesting characteristic to point out about this index is that most of the statistically significant results are concentrated in the northern part of the country.

Night-time temperature variations are described by two indices: Coolest night [TNn; fig. 6.1 d)] and Hottest night [TNx; fig. 6.1 b)]. TNn shows predominantly positive correlations at the 1% statistically significant level, especially along the Pacific Coast. This coastal pattern is not present along the Atlantic coast except for Las Vigas station in Veracruz State (station number 35 in Table 6.1). In the evaluation of this index we have only found two decreasing (both statistically significant at 1% level) correlations (with time): Ahuacatlán in Nayarit state (station number 25 in Table 6.1), and El Paso de Iritu in southern Baja California (station number 4 in Table 6.1). The Hottest night [TNx; fig. 6.1 b)] shows mostly negative correlations among the sites that have statistically significant results. Among those with clear negative patterns (statistically significant at 1% level), they are geographically concentrated along the North Pacific Coast at the tip of the peninsula of Baja California, except for Ahuacatlán, Nayarit and Ciudad Hidalgo in Michoacán state (stations number 25 and 23 in Table 6.1, respectively). Ciudad Hidalgo makes a contrasting negative/positive transition with the station Pericos in Guanajuato State (station number 18 in Table 6.1), the same contrasting pattern is found in Oaxaca state of the South Pacific Coast (station number 28 and 29 in Table 6.1, respectively). Considering only statistically significant results, we can roughly observe a negative (cooling/north) and positive (warming/south) climatic transition.

Finally, the DTR (Daily Range Temperature) index [fig. 6.1 e)] shows a marked tendency towards increasing values across Mexico. Among all the results, the few negative correlations (the difference between maximum and minimum temperatures is decreasing) with time are located in the southern part of the country. Again, contrasting (negative/positive) correlations are observed in the Guanajuato/Michoacán states region and the coast of Oaxaca state in the South Pacific Area. Also there are slightly more indices with significant results in the southern part compared to the north part of Mexico for the DTR index.

Warmer conditions are mainly observed along the Pacific coast of Mexico, when the temperature extreme indices measuring changes in °C are evaluated.

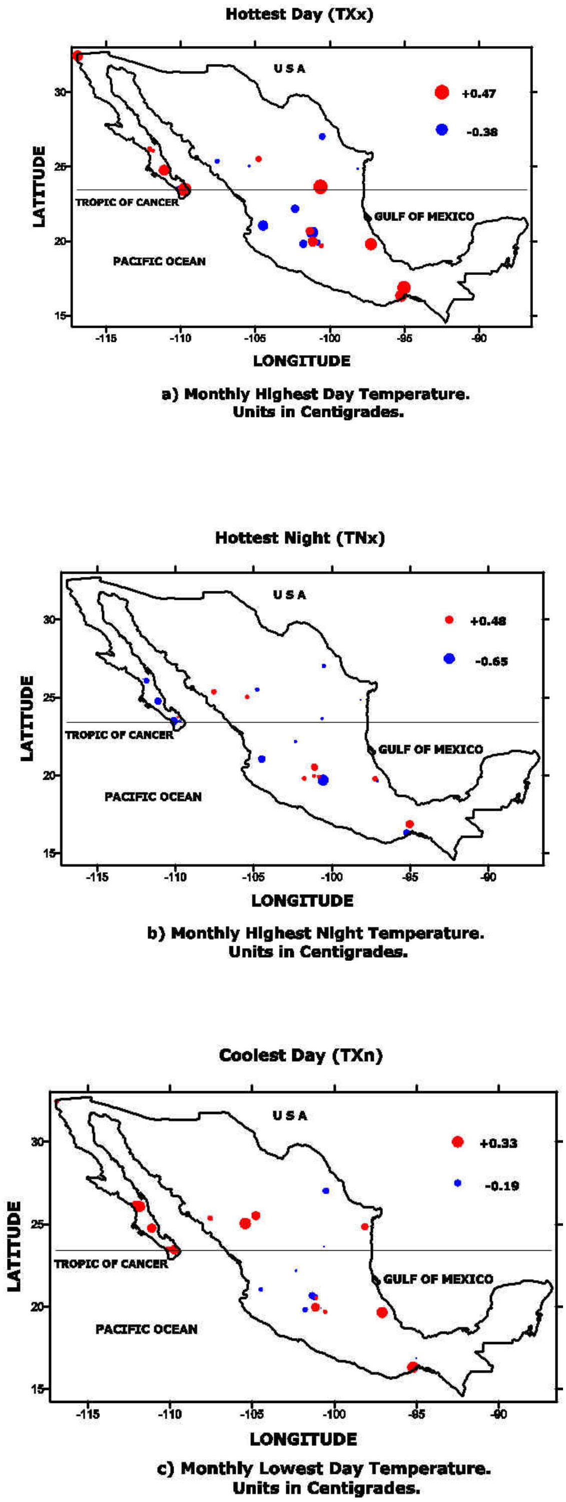


Fig. 6.1. Extreme temperature indices maps, intensity in °C. A Kendall's tau-b (linear) correlation analysis has been applied between the temperature extreme indices and time. Circles in red are representing a positive and in blue a negative correlation.

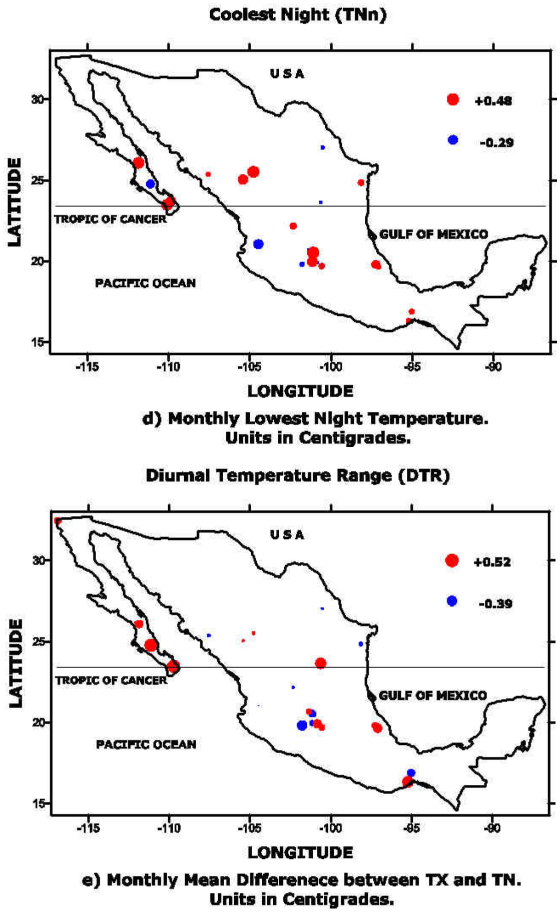


Fig. 6.1. Extreme temperature indices maps, intensity in °C. A Kendall's tau-b (linear) correlation analysis has been applied between the temperature extreme indices and time. Circles in red are representing a positive and in blue a negative correlation.

The second group of indices (fig. 6.2) to be assessed are those that count the frequency of exceeding a set limit; the first index to be considered is FD0 (Frost Days) [fig. 6.2 a)]; this index counts the number of times the daily minimum temperature is below the 0° C threshold. Negative correlations (with time) are observed at the southern tip of the Baja Californian peninsula with a statistical significance of 5% that points to warmer conditions in the region. Similar results are found in northern and central Mexico:

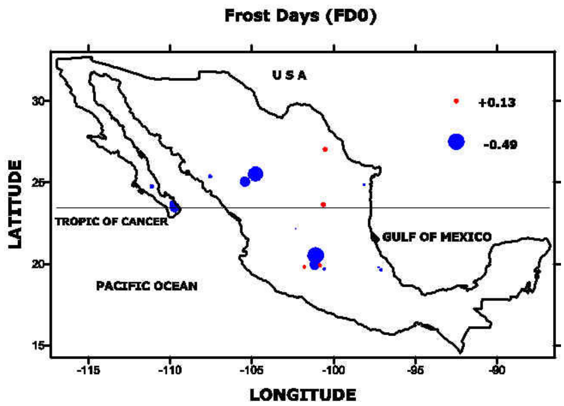
Durango, in the north; Guanajuato and Michoacán in the south. All the results in this part of continental Mexico are statistically significant at the 1% level. Probably the most interesting feature is that in Central Mexico, both stations (Pericos, Guanajuato; and Cuitzeo, Michoacan; stations number 18 and 21 in Table 6.1) are varying in correspondence, opposite to what has already been observed (contrasting patterns) in the earlier analysed indices in this chapter. From central to northern Mexico (including the Peninsula of Baja California) statistically significant counts (warming trends) are observed for the FD0 index.

Another index that measures the changes in the number of warm day-time temperatures is the SU25 (Hot Days) index [fig. 6.2 b)], in this case the upper limit to be exceeded is 25° C. Positive secular correlations with statistical significance below the 1% level are found in the Baja Californian peninsula. There is also a corridor of positive correlations in the eastern part of Mexico. A contrasting pattern of negative correlations with statistically significant results (at the 1% level) can be observed across central Mexico, and especially on the Mexican Plateau. Two regions show contrasting positive/negative patterns on this index: the southern tip of Baja Californian Peninsula and the Tuxtlas region near the Gulf of Mexico. A clear tendency of positive correlations (warmer conditions) with statistically significant results is evident in the north of Mexico.

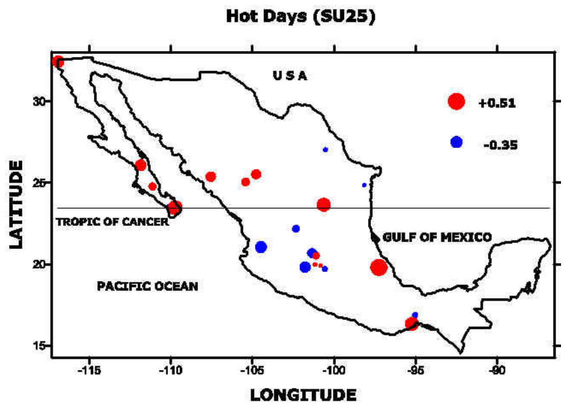
Night-time temperatures are also evaluated in this group; one of the indices that deals with this kind of variations is the Warm Nights (TR20) index [fig. 6.2 c)]. It defines the annual count of daily minimum temperatures that are above the 20° C threshold. The southern tip of the peninsula of Baja California according to the results is experiencing negative correlations with statistical significance below the 1% level. In contrast, just across the Gulf of California in the North American Monsoon Region (NAMR), also called Mexican Monsoon Region (see section 4.2.1), we can observe positive correlations at the 1% statistical significance level. One of the stations with the most consistent results is Ahuacatlán in Nayarit (station number 25 in Table 6.1); this location is again showing a decreasing correlation (with time) of the night temperatures, and is statistically significant at the 1% level. However, the stations within the South Pacific region in the state of Oaxaca show contrasting negative/positive patterns. Overall, there is not a clear geographical pattern for this temperature extreme index.

Warm Spell Duration (WSDI) Index [fig. 6.2 d)] is an index that annually counts the number of cases when for at least 6 consecutive days the day temperature (TX) exceeded the 90th percentile of 1961-1990. There are more statistically significant results at the 1% level in central Mexico, and they share negative correlations (with time) in general. Only one positive correlation with statistical significance at 1% is located in the southern part of the country (Matías Romero, Oaxaca; station number 28 in Table 6.1). Contrasting results (positive/negative correlations) are observed within the Tuxtlas region in the state of Veracruz. Significant results with negative correlations at the 1% level are mainly concentrated in western Mexico. Negative correlations are observed in the west, central and northern Mexico.

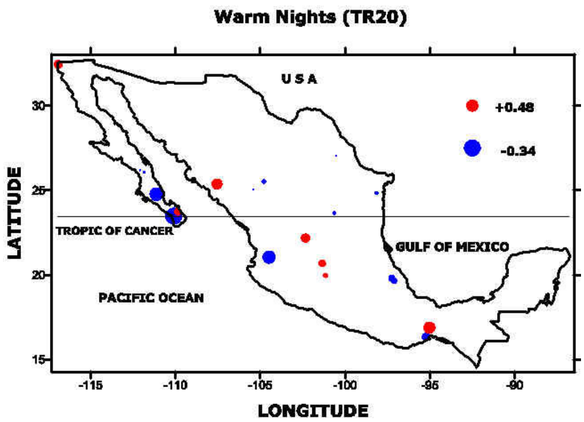
Lastly in this group, the Cold Spell Duration (CSDI) Index [fig. 6.2 e)] counts annually the number of at least 6 consecutive days when the night temperatures (TN) are below the 10th percentile of 1961-1990. Just north of the tropic of cancer within the peninsula of Baja California a positive correlation with statistical significance at the 1% level can be observed at El Paso de Iritu station (station number 4 in Table 6.1), leading to a cooling trend at this location. Ahuacatlán (station number 25 in Table 6.1), once more, like in the indices already assessed in this section shows a positive correlation statistically significant at the 5% level, leading towards colder conditions. Contrasting patterns of negative/positive correlations are evident across central Mexico within the Michoacán/Guanajuato states region. Warming conditions are observed at Las Vigas station (station number 35 in Table 6.1) near the Gulf of Mexico, this negative correlation with time is statistically significant at the 5% level. A clear pattern towards colder conditions for northern Mexico can be observed; less evident is the climatic divide from colder (north) to warmer (south) conditions for the entire country.



a) Annual count when TN (daily minimum) < 0 C.
Units in Days.

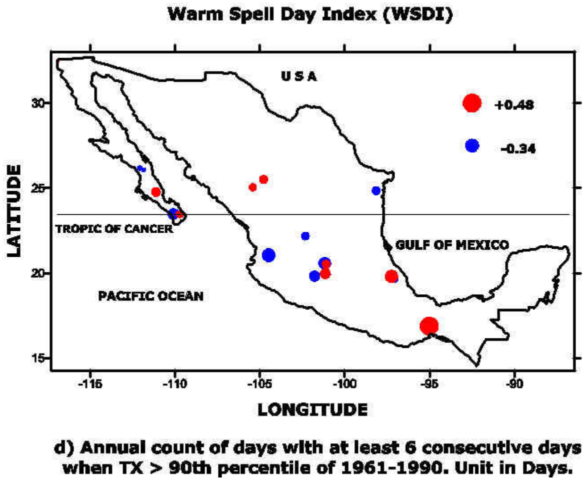


b) Annual count when TX (daily maximum) > 25 C.
Units in Days.



c) Annual count when TN (daily minimum) > 20 C.
Units in Days.

Fig. 6.2. Extreme temperature indices maps, frequency measured in days. A Kendall's tau-b (linear) correlation analysis has been applied between the temperature extreme indices and time. Circles in red are representing a positive and in blue a negative correlation.



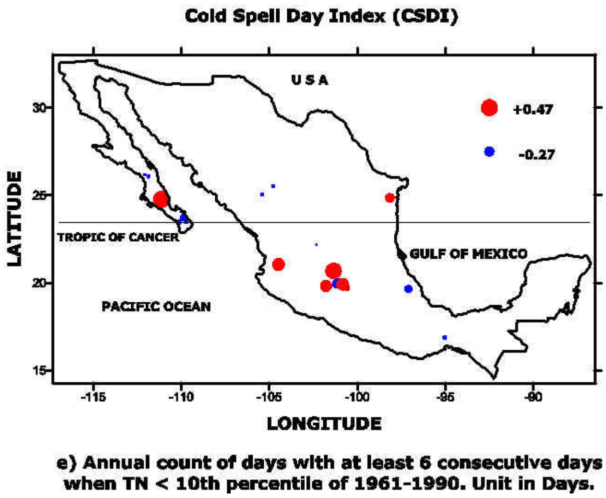


Fig. 6.2. Extreme temperature indices maps, frequency measured in days. A Kendall's tau-b (linear) correlation analysis has been applied between the temperature extreme indices and time. Circles in red are representing a positive and in blue a negative correlation.

Except for a national pattern of warmer conditions for the Hot days index (SU25), no other clear geographic characteristic is seen among the group of indices that exceed a limit in ° C.

The last group of indices deals with the percentage of time a record exceeds a percentile limit. The cool night frequency (TN10p) is the first index [fig. 6.3 a)] to be evaluated. Contrasting correlations of TN10P with time are observed at the southern tip of the Baja Californian peninsula; both results (positive and negative correlations) are statistically significant at the 1% level. In Durango state (northern part of Mexico) negative correlations are found, the stations in this area (varying coherently) show a clear warming climate pattern. A positive correlation which is statistically significant at the 5% level is observed near the Central Pacific Coast at Ahuacatlán, Nayarit (station number 25 in Table 6.1); the records suggest a slight change to cooler conditions. For the Guanajuato/Michoacán states within the Mexican Highlands region, the results show contrasting temperature patterns, most of them are significant at the 1% level. However, near the Gulf of Mexico, clear negative correlations are found for Las Vigas station (station number 35 in Table 6.1), with statistical significance at the 1% level, leading locally to warmer conditions. Slightly warmer conditions can be observed at the South Pacific coast; the station at Matías Romero in the state of Oaxaca (station number 28 in Table 6.1) has experienced a negative correlation with a significance of 5% level. There is no clear climatic pattern for the TN10p index across the country, although warming conditions are dominant in the southern part of Mexico.

Another parameter to be analysed in this group is the Cool Day frequency index or TX10p [fig. 6.3 b)]. A widespread pattern of negative correlations (of TX10P with time) is affecting the peninsula of Baja California; furthermore all these results are statistically significant at the 1% level pointing to widely warmer conditions. A clear trend to colder conditions is present at Ahuacatlán station in Nayarit state (station number 25 in Table 6.1), as a positive correlation with a statistical significance below the 1% level is locally observed here. A positive trend is also found within the Guanajuato/Michoacán region, as here correlations are statistically significant at both the 5 and 1% level are present.

Therefore, we can conclude colder conditions have been experienced in the area. Warmer conditions at Las Vigas station (station number 35 in Table 6.1) within the Tuxtlas region are indicated by negative correlations with a statistical significance below the 1% observed in TX10p [fig. 6.3 b)] with time. No clear climatic picture is found in the evaluation of the cool day frequency index (TX10p). Nevertheless, roughly contrasting continental/coastal patterns are present. Negative correlations and, in consequence, warmer conditions are observed along both the Atlantic and Pacific coasts. Colder conditions (as a result of positive correlations) are prevailing within the continental and highland parts of Mexico.

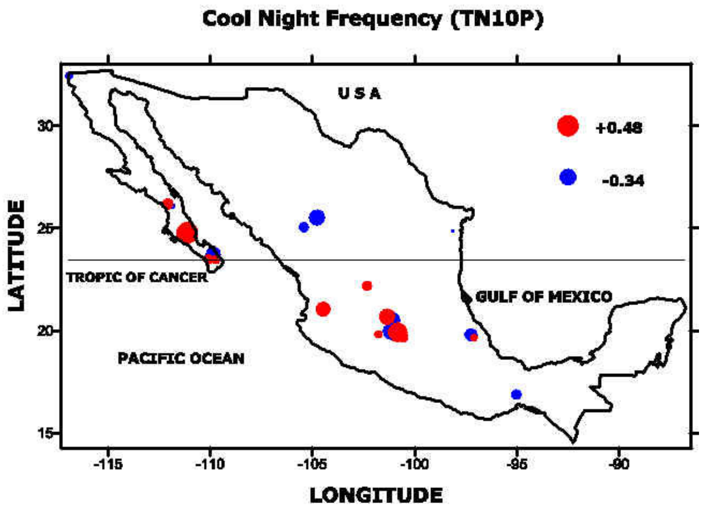
A trend towards warmer conditions can be assessed by two different parameters: Hot Night frequency (TN90p) and the Hot Day frequency (TX90p) indices. TN90p [fig. 6.3 c)] shows negative secular correlations with statistical significance below the 1% level at the southern tip of the peninsula of Baja California. However, contrasting correlations are found within the Guanajuato/Michoacán states, both are statistically significant at the 1% level. In Ahuacatlán, Nayarit (station number 25 in Table 6.1); a clear decreasing correlation is observed heading towards locally cooler conditions; this result is statistically significant at the 1% level. In Los Tuxtlas region in Veracruz, regional contrasting patterns can be observed, although only at Las Vigas (station number 35 in Table 6.1) is the decreasing trend statistically significant at the 1% level, meaning clear cooling conditions here. Finally, statistically significant at the 5% level, positive correlations are found for Matías Romero, Oaxaca (station number 28 in Table 6.1); slightly warming patterns are prevailing in this part of the southern Pacific. Overall, the TN90p index shows no clear coherent climatic patterns in Mexico. Mostly contrasting correlations are found across the country.

The Hot Day frequency (TX90p) is the last index [fig. 6.3 d)] of this group to be considered. Prevailing climatic patterns in the Baja Californian peninsula show positive correlations (statistically significant at both the 5 and 1% level) with time from the southern tip northwards to the Mexico-USA border at the Presa Rodríguez –Tijuana-

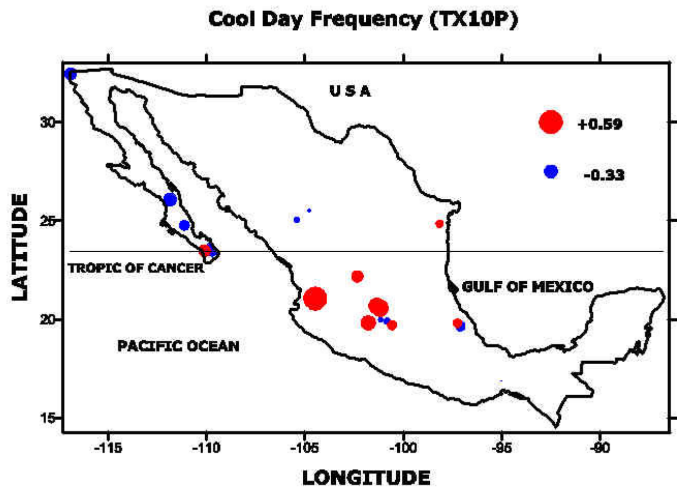
(station number 2 in Table 6.1), pointing towards warmer conditions in this north-western region. In north continental Mexico at El Palmito station (station number 14 in Table 6.1), a positive correlation with statistical significance of 1% level means warmer conditions locally. Central Mexico shares a regional pattern to colder conditions; indeed a widespread area shows negative correlations with statistical significance below the 1% level. Finally, positive correlations (warmer conditions) are observed at Las Vigas (station number 35 in Table 6.1) in the Gulf of Mexico and Matías Romero (station number 28 in Table 6.1) in the Southern Pacific region. But only at Las Vigas does the correlation reach the 1% level of statistical significance. Although a climatic divide can be seen in the results, showing patterns to warmer conditions in the north to colder conditions in Central Mexico, the positive correlations in Las Vigas and Matías Romero in southern Mexico leave the TX90P with no simple climatic pattern. No clear geographic pattern is seen in the group of indices that exceed a percentile limit.

The mean annual range of temperature shows a visible latitudinal transition (see fig. 6.4), just as it is observed in the case of precipitation (fig. 2.1). In the case of the range of temperature more contrasting conditions (between the maximum and minimum temperatures) are observed in northern Mexico, and the differences become smaller as we move towards the far south of the country (Mosiño and García, 1974).

In order to evaluate the changes of the temperature extremes (from a geographical perspective) it was decided to count the number of cases in which the variation of the indices at both the 5 and the 1% of statistical significance (see table 6.2). As considered in the case of rainfall extremes (see section 5.2) we are testing a latitudinal transition in the results. For the purposes of this analysis, the Tropic of Cancer is defined as an artificial geographical divide. For this assessment to be independent it was decided to work with the extreme indices directly instead of the stations. Counting these indices in such a manner can give us an additional insight into how the extreme parameters are (or not) concentrated geographically. Therefore, using the Tropic of Cancer as a limit we are going to be able to appreciate the changes of the temperature extreme indices, and

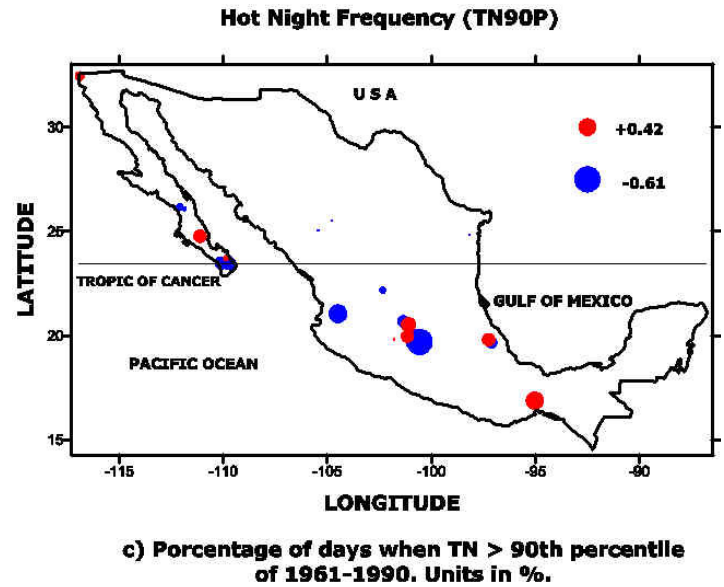


a) Porcentage of days when TN < 10th percentile of 1961-1990. Units in %.



b) Porcentage of days when TX < 10th percentile of 1961-1990. Units in %.

Fig. 6.3. Extreme temperature indices maps, frequency measured in days. A Kendall's tau-b (linear) correlation analysis has been applied between the temperature extreme indices and time. Circles in red represent a positive and in blue a negative correlation.



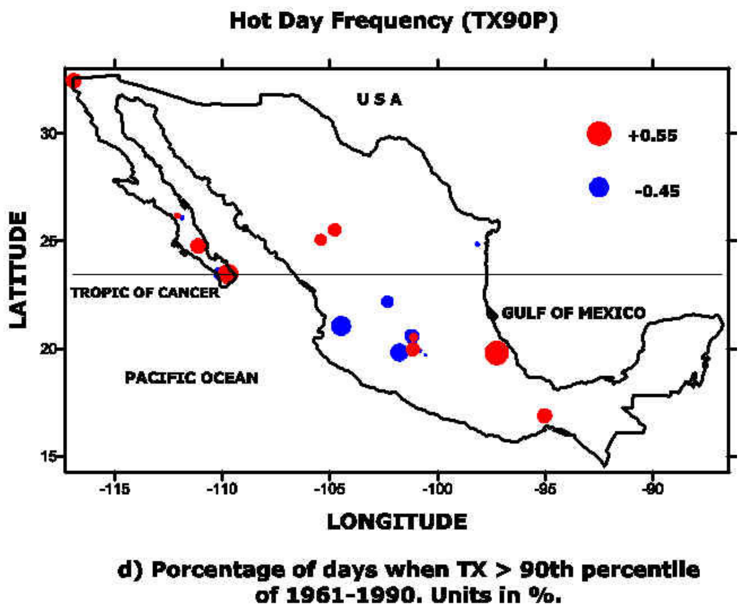


Fig. 6.3. Extreme temperature indices maps, frequency measured in days. A Kendall's tau-b (linear) correlation analysis has been applied between the temperature extreme indices and time. Circles in red represent a positive and in blue a negative correlation.

determine if there are subtle differences between the variations in the north or south of the county or the indices are fluctuating accordingly.

In order to compare different (possibly contrasting) climatic patterns, a counting of extreme indices (regardless of where they are, except north or south) with statistically significant secular correlations was made. Defining the number of cases, using indices instead of stations, can give us the possibility of observing dynamically the variations of the extreme temperatures. For this purpose, we classify these variations into two different modes: one deals with the levels of statistical significance (Table 6.2.) and the other with trends to warmer or cooler conditions (Table 6.3.), both with the already defined North/South transition. That is, for example, the counting of the indices with negative correlations below the 5% level of statistical significance in the northern part of the country accounts for eight cases (Table 6.2); it could be that one station accounts for more than one statistically significant temperature extreme index.

	North	**South**	**Total**
Pos. Corr. (5%)	10	9	19
Pos. Corr. (1%)	16	17	33
Neg. Corr. (5%)	8	16	24
Neg. Corr. (1%)	18	33	51
Total	52	75	127

Table 6.3. Geographical patterns of positive/negative correlations (temperature extreme indices with time using Kendall's tau) with statistical significant levels at 5 and 1%. The number of cases is classified defining the Tropic of Cancer as the limit to separate the northern/southern regions.

We are going to assess important variations in indices below statistically significant levels. A separation was then made into positive and negative correlations with statistical significant levels at 5 and 1% levels. Regardless of the statistical levels, the number of negative cases is, in general, greater than the positive ones. This is fully appreciated when we observe that the sum of number of negative correlations is 75 (24+51) is greater than the positive ones that are only 52 (19+33).

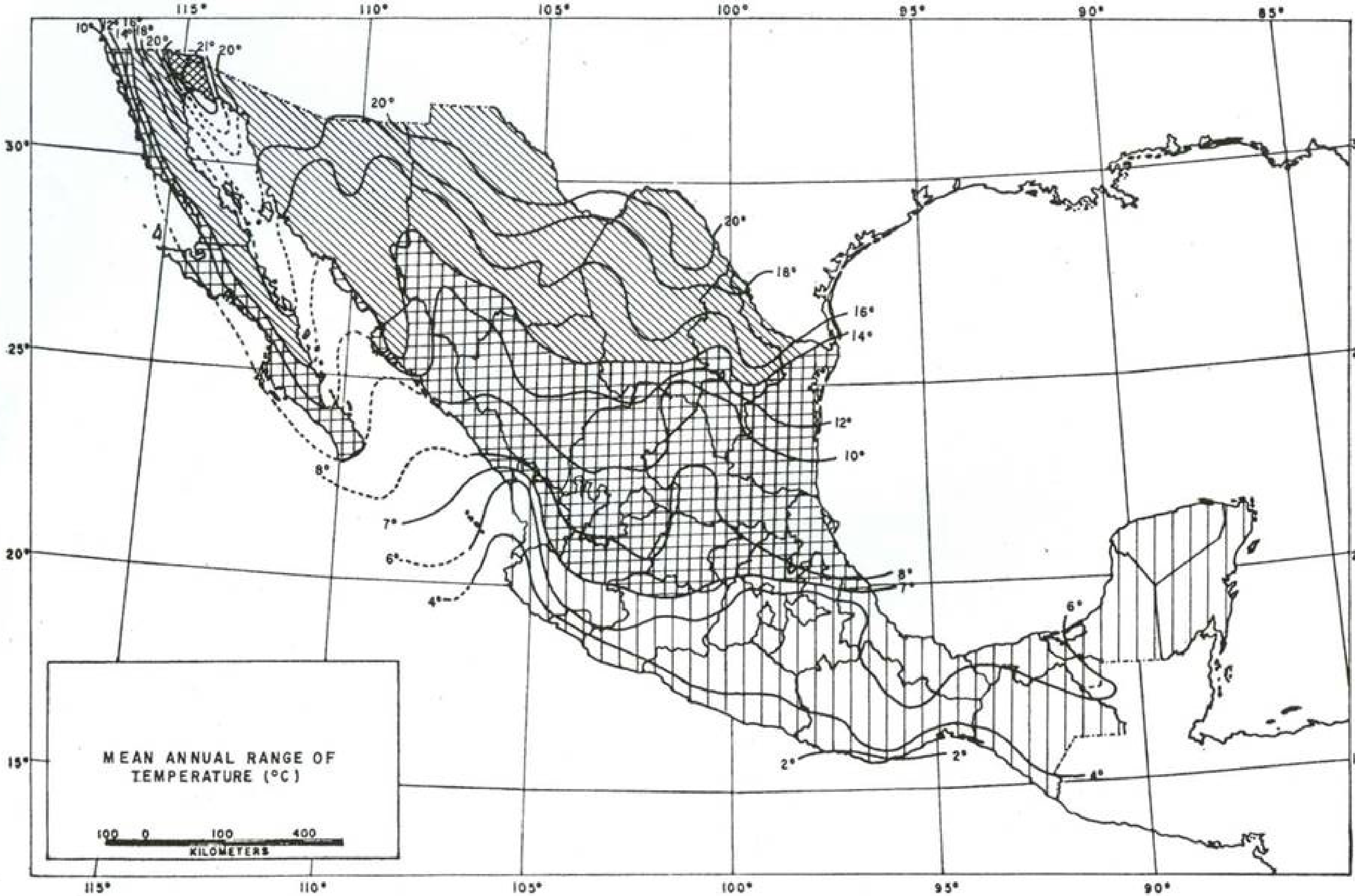


Fig. 6.4. Mean Annual Range of Temperature; according to Mosiño and García (1974).

The second option to test the latitudinal transition in temperature (see Fig. 6.4) is to deal with warm or cold conditions across Mexico, the results are shown in table 6.3. The number of cases heading to cold conditions is greater than for warm conditions, as well as more indices are concentrated in the southern part of the country than in the north. Another interesting feature that can be observed is: with the exception of cold conditions in the south, the number of cases is very similar for the rest of the conditions considered in this table.

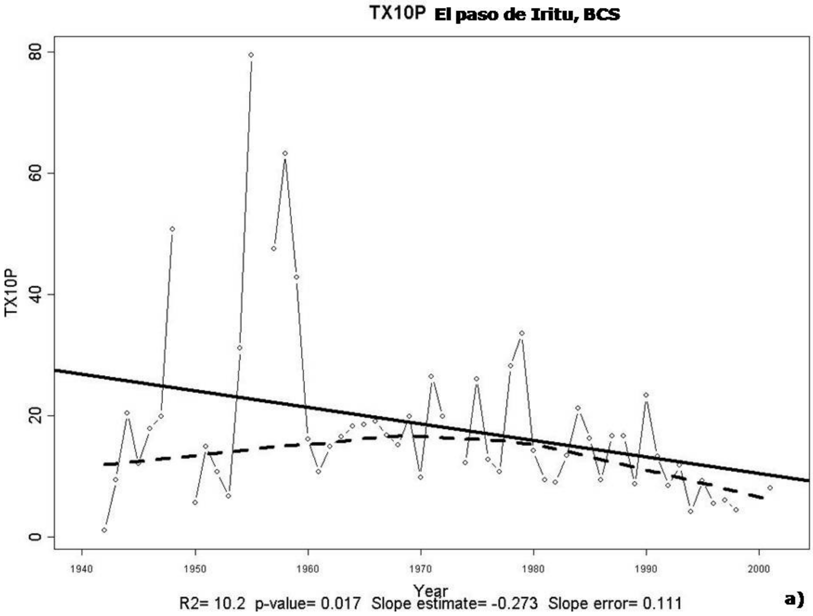
	North	**South**	**Total**
Warm	33	27	60
Cold	27	40	67
Total	60	67	127

Table 6.4. Geographical patterns of positive/negative correlations (temperature extreme indices with time using Kendall's tau) with statistical significant levels at 5 and 1%. The number of cases is classified defining the Tropic of Cancer as the limit to separate the northern/southern regions.

6.2.2. LINEAR TREND ANALYSIS.

Linear trends using least-squares approaches is the last analysis applied in this chapter to two stations in the northern and two stations in the southern part of the country. These sites have the largest number of statistically significant (non-parametric) correlations with time, according with the former calculations of this chapter utilising Kendall tau-b (see section 3.3.5). As mentioned in section 5.2.2 the presence of a positive autocorrelation can influence the estimation of a significant trend. Serial correlations for all the extreme indices are computed SPSS 14.0 prior to the linear trend analysis.

Firstly, linear trends are analysed in the most frequent indices (with statistically significant results) that measure changes in the maximum temperatures, i.e., TX10p (Cool Day Frequency) and TXx (Hottest Day). Linear trends in minimum temperature indices [Cool Night frequency (TN10p), and Coolest Night (TNn)] that have more statistically significant results among the selected stations are assessed next. Lastly in order to observe one index that combines the variations of maximum and minimum temperatures, the trends in the Diurnal Temperature Range (DTR) are evaluated.



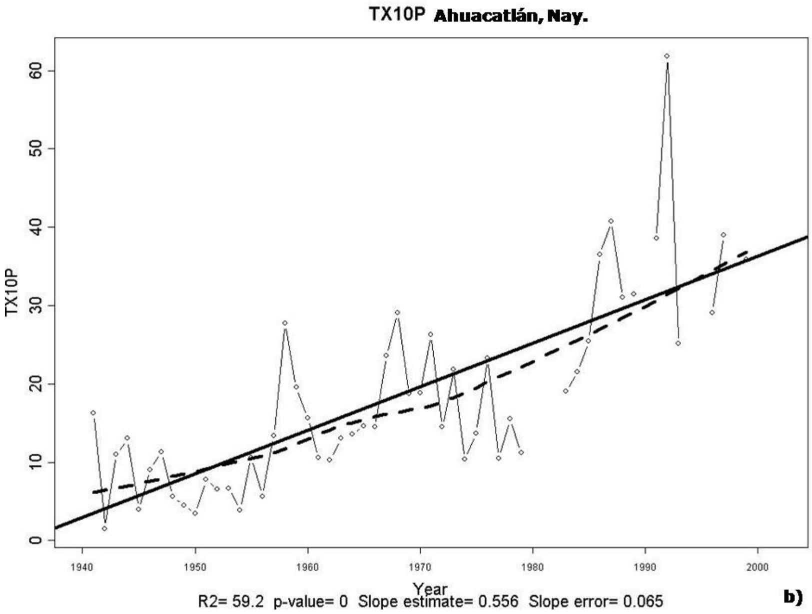
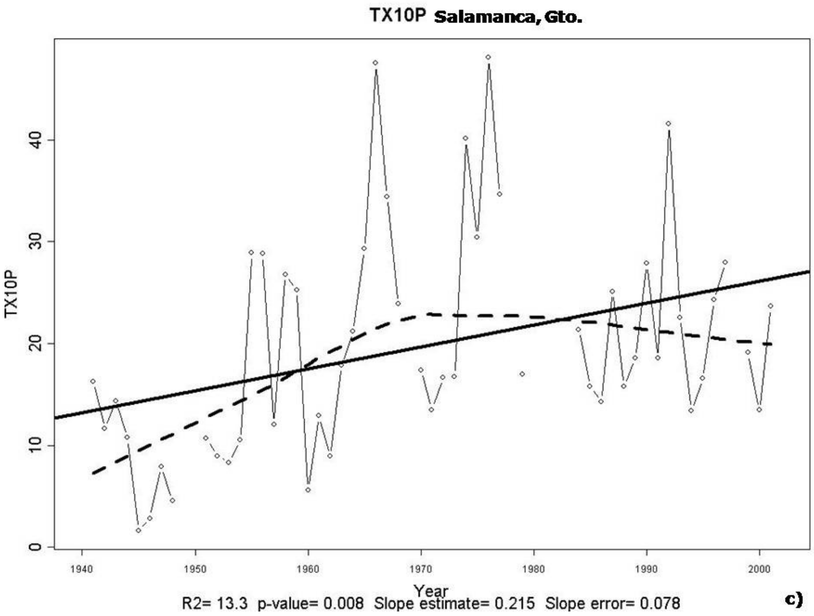


Fig. 6.5. Linear trend analysis applied to the Cool Day frequency (TX10p) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].



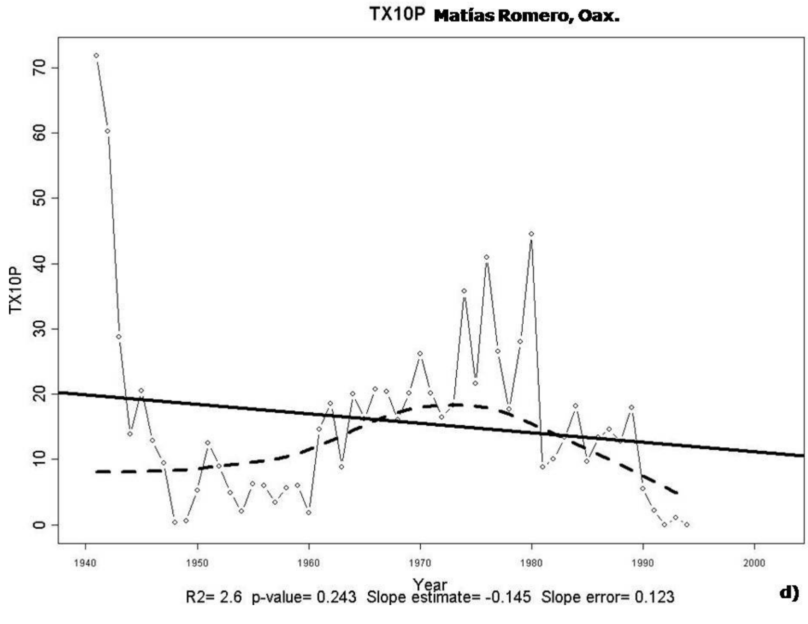
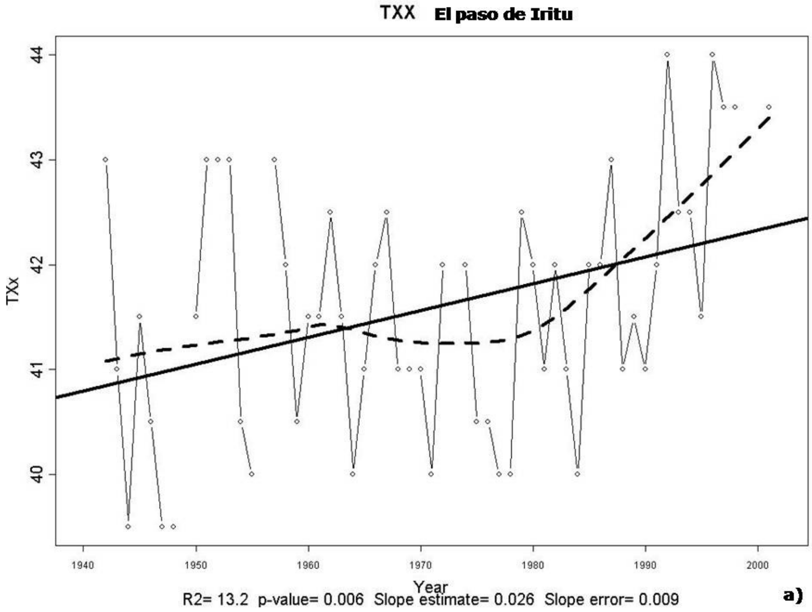


Fig. 6.5. Linear trend analysis applied to the Cool Day frequency (TX10p) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].



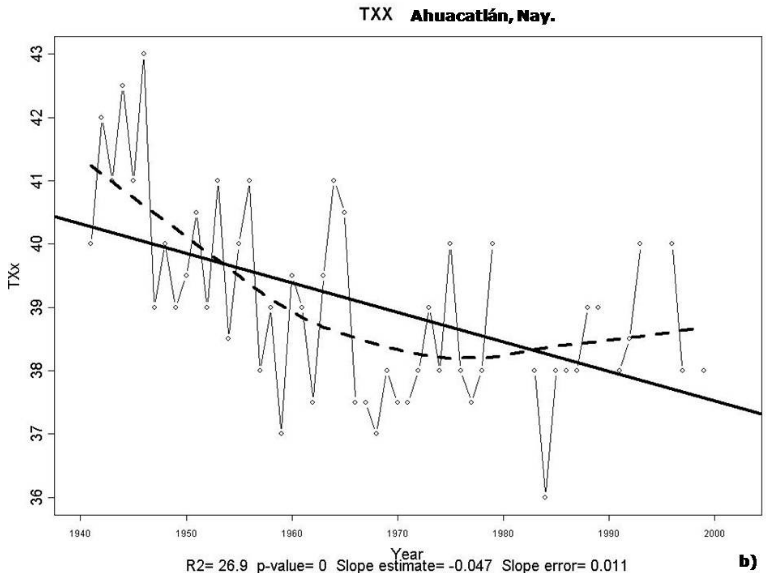
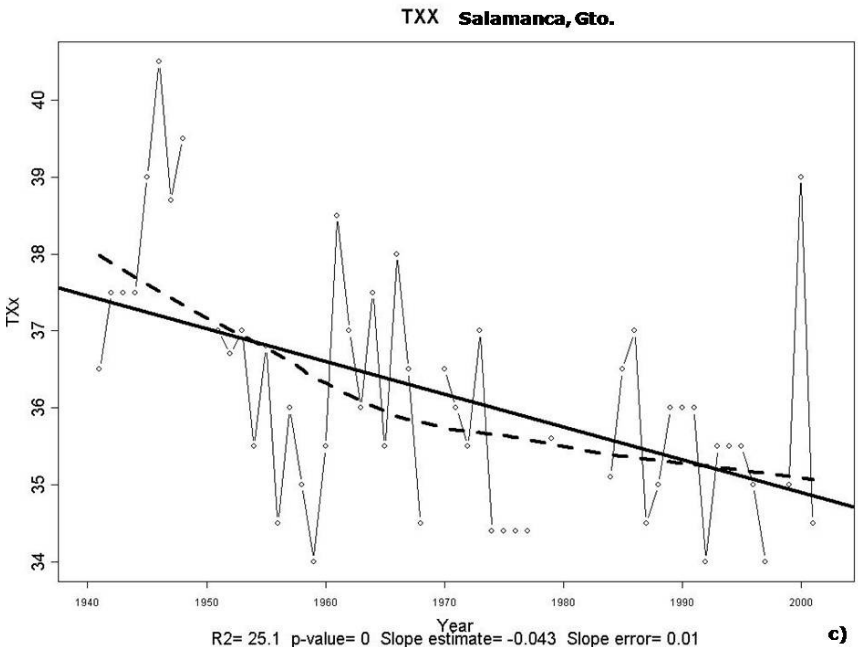


Fig. 6.6. Linear trend analysis applied to the Hottest Day (TXx) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].



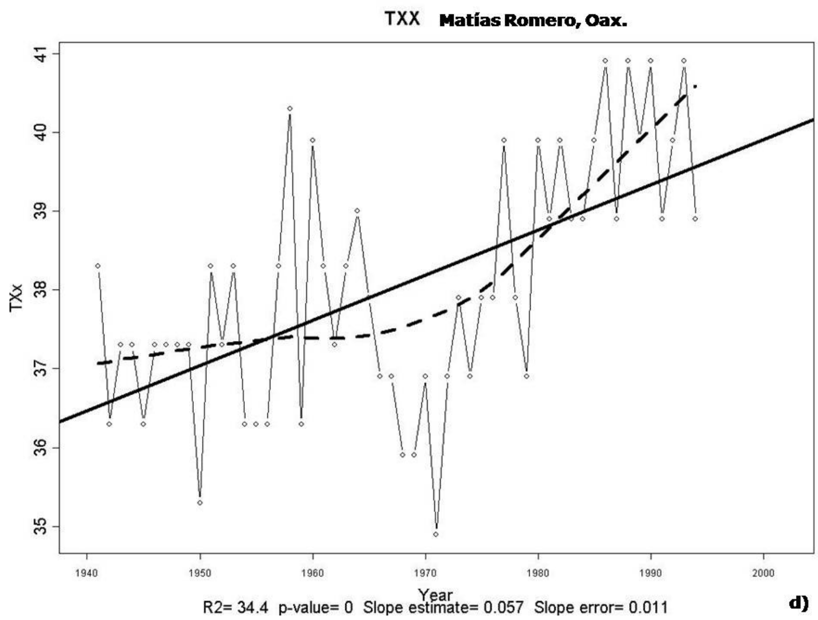
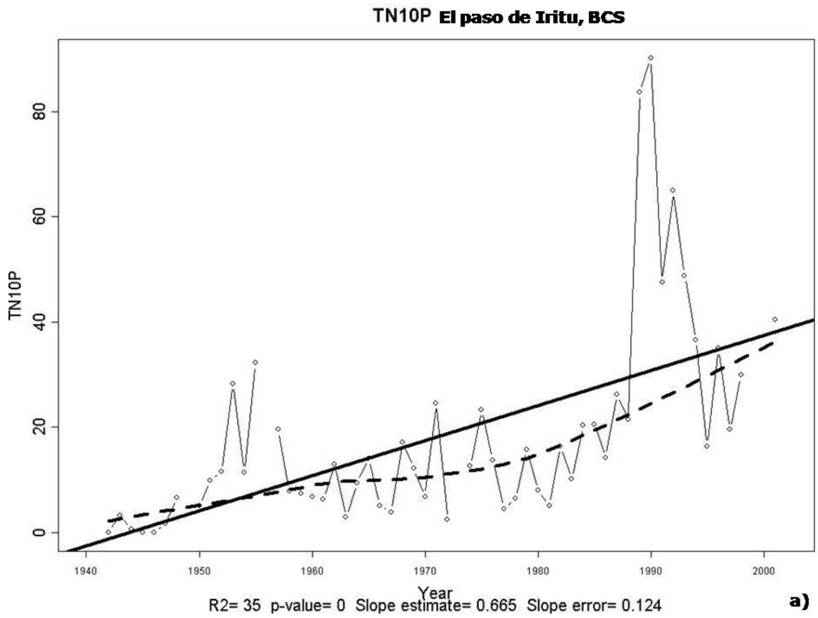


Fig. 6.6. Linear trend analysis applied to the Hottest Day (TXx) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].

Contrasting patterns are observed in the northern part of Mexico for El Paso de Iritu [fig. 6.5 a)] in south Baja california, and Ahuacatlán [fig. 6.5 b)] in the State of Nayarit for the TX10p (Cool day frequency, see table 3.1) index; both stations are located close to the Pacific Ocean. Differences in the sign of the trends can be seen for both stations: the largest slope is positive (+5.6 % / decade) and is present at Ahuacatlán leading to cooling conditions; while El Paso de Iritu station has a negative trend of -2.7 % / decade, that points to warmer conditions at this site.

The largest observed trends for TXx are located south of the Tropic of Cancer. Matías Romero [fig. 6.6 d)] in Oaxaca (south Pacific coast) shows a secular variation of approximately +0.6 °C / decade; while a negative trend of -0.5 °C / decade for the Ahuacatlán and Salamanca stations [figs. 6.6 b) and c)]. Therefore, contrasting trends are observed between central and southern Mexico among the selected stations.

The first index to be assessed among the minimum temperature indices is TN10p (Cool night frequency, see table 3.1). The largest trends of the results are found in the northern part of Mexico, close to the Pacific Ocean. Both positive trends at El Paso de Iritu and Ahuacatlán [figs. 6.7 a) and b)] lead to colder conditions, and are also of similar magnitude: +6.6 % / decade.



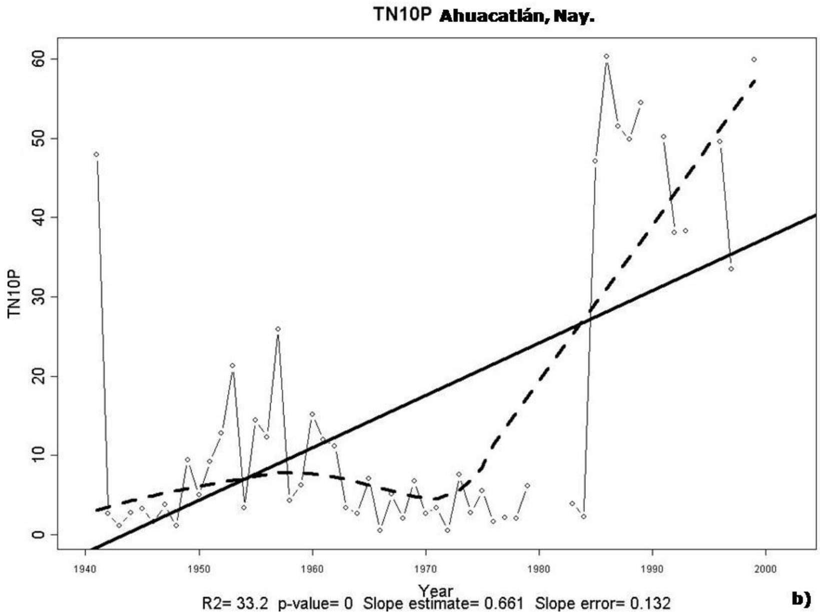
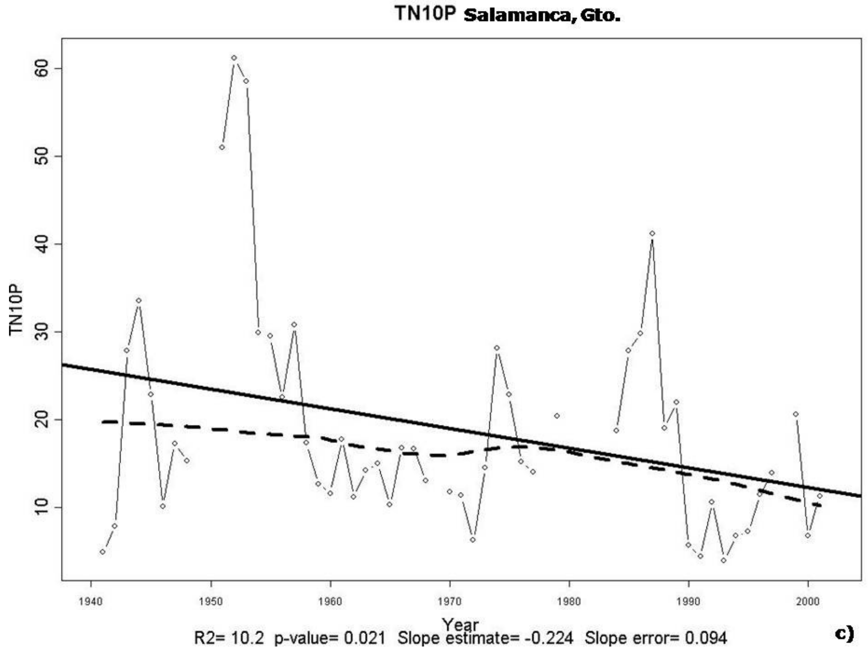


Fig. 6.7. Linear trend analysis applied to the Cool Night frequency (TN10p) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].



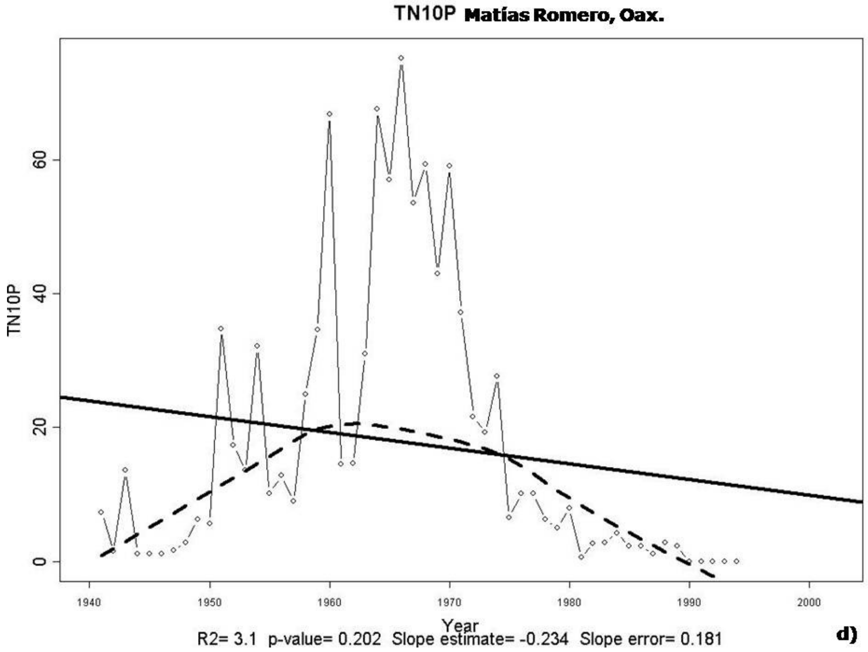
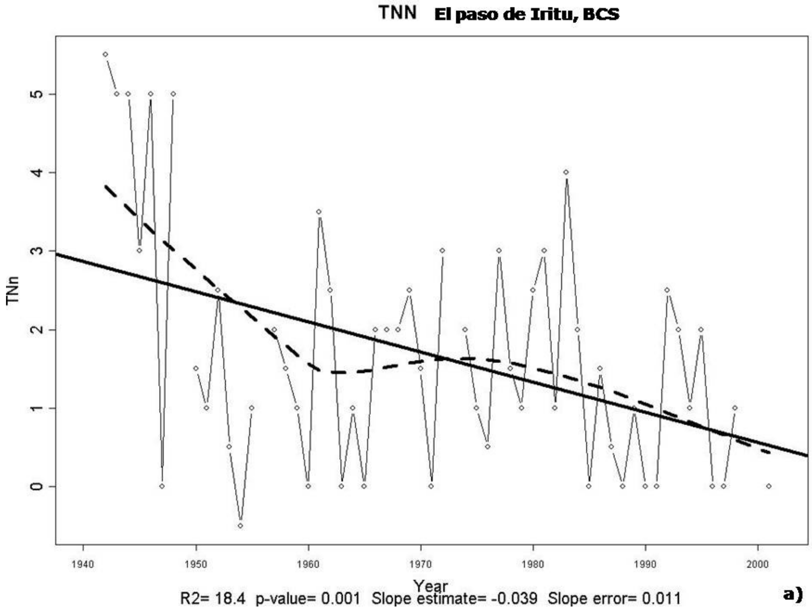


Fig. 6.7. Linear trend analysis applied to the Cool Night frequency (TN10p) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].



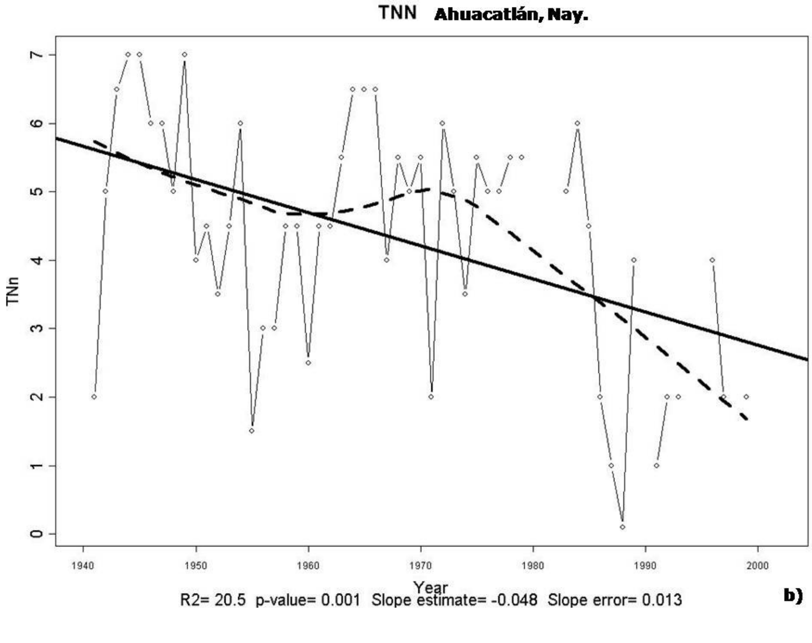
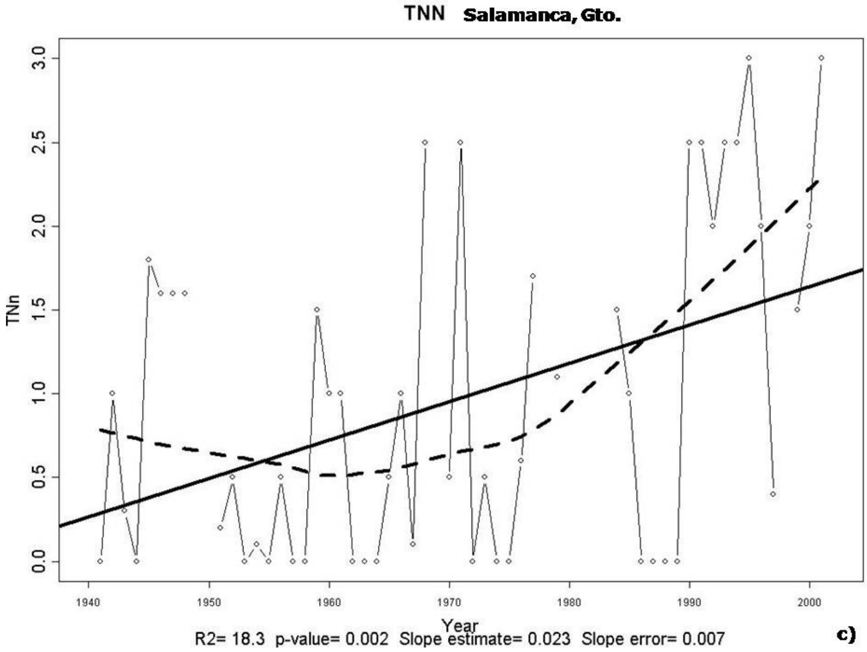


Fig. 6.8. Linear trend analysis applied to the Coolest Night (TNn) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].



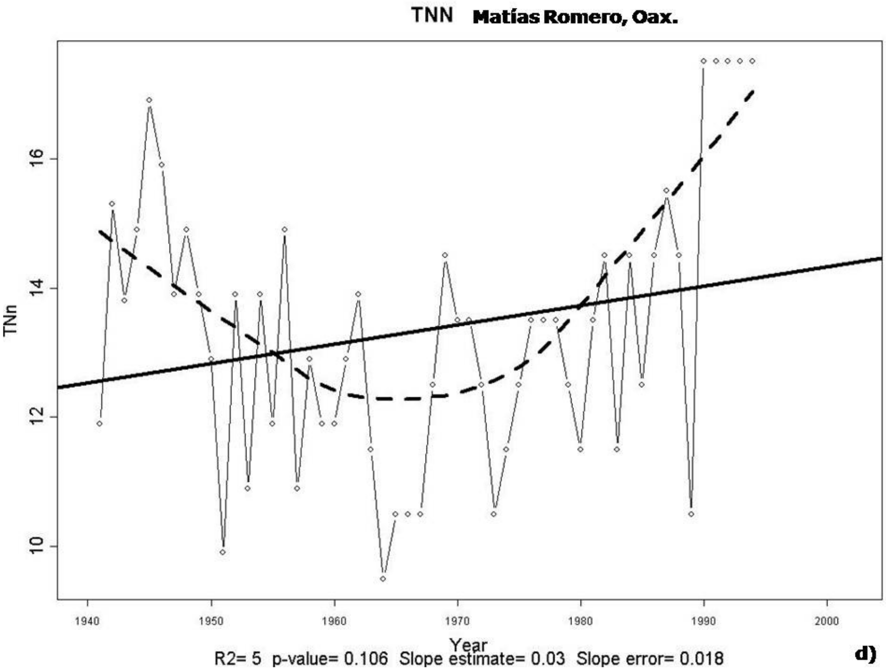
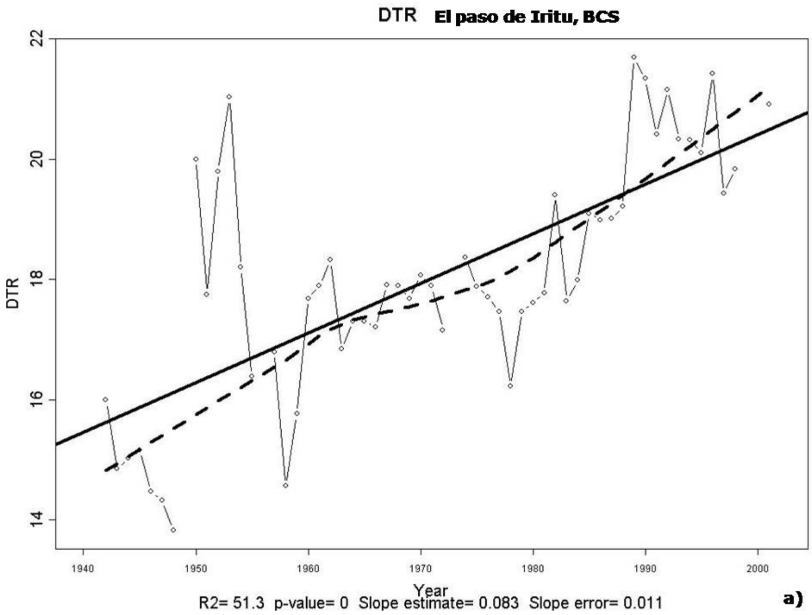


Fig. 6.8. Linear trend analysis applied to the Coolest Night (TNn) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].



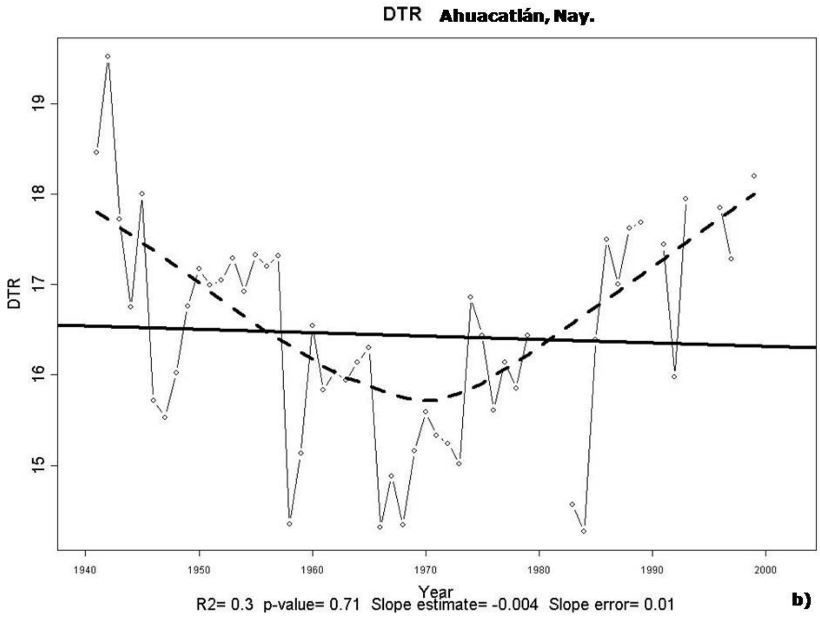
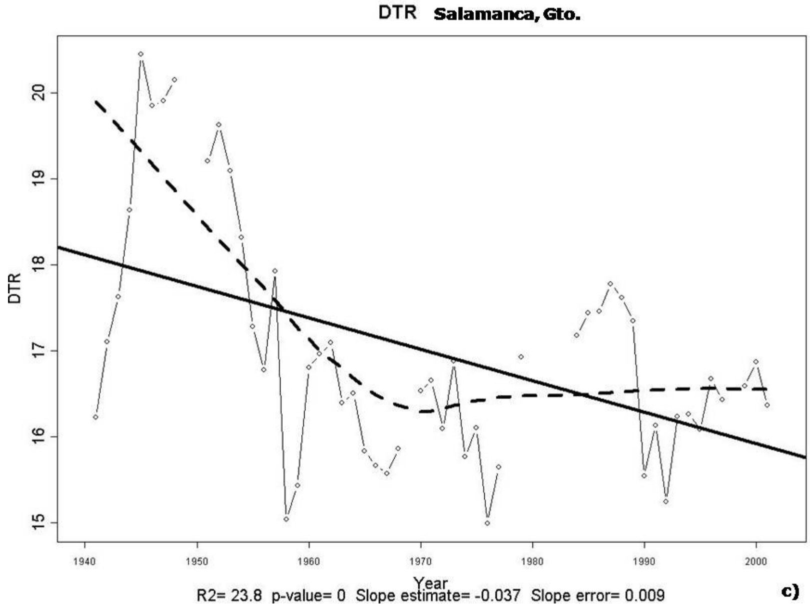
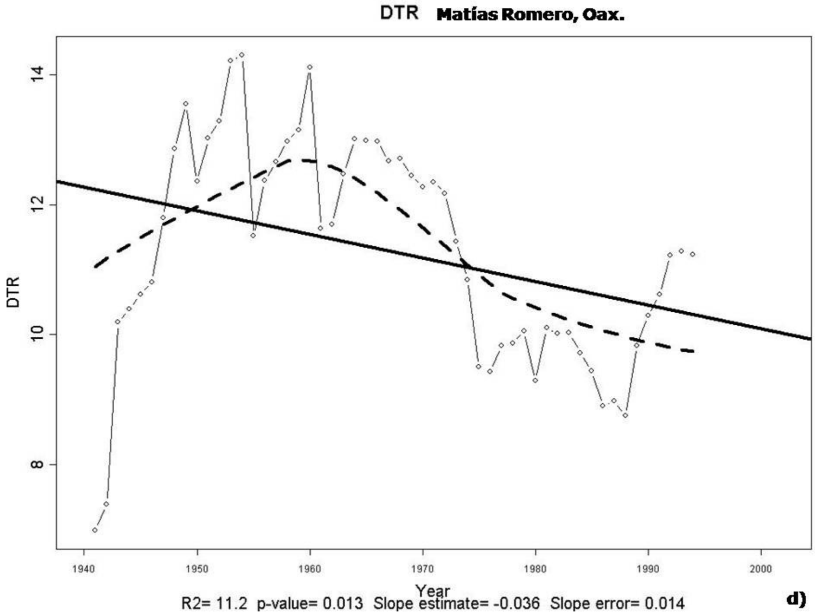


Fig. 6.9. Linear trend analysis applied to the Daily Temperature Range (DTR) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].



c)



d)

Fig. 6.9. Linear trend analysis applied to the Daily Temperature Range (DTR) using the least-square approach of the R software (see section 3.3.4). Two stations in northern Mexico are considered [El Paso de Iritu, a); Ahuacatlán b)] and two in the southern part of the country [Salamanca, c); Matías Romero d)].

When we analyse the Coolest night (TNn), the northern stations: El Paso de Iritu [fig. 6.8 a)] and Ahuacatlán [fig. 6.8 b)] show the largest trends -0.4 and -0.5 °C / decade respectively. Both stations in the northern Pacific coast are heading towards cooler conditions.

Lastly, the Daily Temperature Range (DTR) was selected in order to evaluate the combined effect of changes in maximum and minimum temperatures (see table 3.1). The largest trend is positive and observed at El Paso de Iritu (+0.8 °C / decade) [fig. 6.9 a) and b)]; Salamanca and Matías Romero [figs. 6.9 a) and b)] have similar magnitudes of trends (-0.4 °C / decade). For the chosen stations an incresing trend is observed in the north and a decreasing trend in southern Mexico.

Studying the linear trends, we can appreciate that two stations have the largest trends for four out of the five selected indices. El Paso de Iritu [fig. 6.9 a)] mainly show changes in minimum temperatures, while at Ahuacatlán [fig. 6.9 b)] variations can be equally seen in the maximum and minimum temperatures indices but not in the DTR index. Geographically, one of these stations is located just north (El Paso de Iritu) and the other south of the Tropic of Cancer (Ahuacatlán). Nevertheless, both sites are close to the Pacific Ocean. It seems that the results are independent of the stations latitude coordinates and the Pacific Ocean is the main regulator of the temperature extremes indices assessed; but it is difficult to conclude it with only two stations. If the Pacific Ocean is the key, among the physical causes we can mention are: the Sea Surface Temperatures (SSTs), the Pacific Decadal Oscillation (PDO) and the ENSO phenomenon. The ENSO hypothesis is going to be explored in deep in chapter 7.

6.3. CONCLUSIONS TO THIS CHAPTER.

In order to have a broader picture of climate change it is necessary to not only study the variations in mean temperature but also the fluctuations of variability, which include extremes. It is precisely these kinds of climatic events that have a great impact on public perception (outside the scientific community) about a changing climate (Beniston and Stephenson, 2004). It is widely accepted that the necessity to expand our understanding on weather extremes is important. The lack of studies in developing countries does not always allow the correct prevention (or mitigation) of the impacts of these extraordinary climatic events. This chapter has aimed to contribute to the subject, by covering this research deficiency in Mexico.

At different scales of space and time, and with dissimilar rates, extreme temperatures are changing in Mexico. At local levels, there are two stations that clearly show these significant fluctuating (taking the climatological mean as a reference) climatic patterns. In the southern tip of the Baja Californian Peninsula, El Paso de Iritu station is getting warmer (for instance, TN90p, TX90p, TXn, and TXx; all with positive correlations with time, statistically significant at the 5% level). On the contrary, cooler conditions are being observed at Ahuacatlán station near the central Pacific coast (For instance, SU25, TN90p, TNn, TNx, TR20, TX90p, TXx, and WSDI; all with negative correlations statistically significant at the 1% level). These results are confirmed when an analysis of trends is applied to four stations (El Paso de Iritu, Ahuacatlán, Salamanca and Matías Romero), that have the largest number of temperature extreme indices with statistically significant results. The clearest pattern to cooling conditions (according to the trends of the temperature extreme indices) is observed at the Ahuacatlán station, in the state of Nayarit in central Mexico, near the Pacific coast. Although these are examples at a local scale a climatic divide can be perceived between warming trends in the north to cooling trends in the south of the country.

The extreme temperature indices were separated into three different groups. According to the results, the groups measuring absolute temperature change (°C) and the one that calculates the frequency (number of cases or days) of the index exceeding a predefined threshold can be directly compared. These groups are coincident showing clear increasing trends for minimum temperatures. The differences are: in the group that measures absolute temperature change, there is a climatic divide (considering the Tropic of Cancer as a latitudinal limit) with warming conditions in northern Mexico and cooling in the southern part of the country. When the frequency above a threshold is calculated another group of stations has a national pattern of warming conditions. However, there are more cases of indices with significant results when considering the annual counts above thresholds (SU25, TR20 and FD0) than when the annual count is extended into spells (WSDI and CSDI). The last group that defines the percentage of time an index is exceeding a percentile limit (TN90p and TX90p) does not show clear climatic patterns.

An analysis with two different approaches gave us an additional insight about the fluctuations of the extreme temperatures in Mexico. In order to simplify the explanation of the results, the extreme temperature indices were classified per statistical significance (5% or 1% levels of statistical significance) or trends of warming or cooling conditions.

Significant changes in extreme temperatures are observed across Mexico. Three separate analyses show that climatic variations in extreme temperatures are occurring at different spatial scales. A geographical transition has been found as a roughly latitudinal divide between warming trends in the northern part of the country to cooling conditions in the south. Clearly, greater increasing trend can be observed in minimum rather than in maximum temperatures.