CHAPTER FIVE: EXTREME PRECIPITATION INDICES.

5.1. INTRODUCTION.

On September 14 1988, Hurricane Gilbert hit Cancún on the east coast of the Yucatan Peninsula, and a few days later (on September 17) caused severe damage in Monterrey in north-eastern Mexico. Gilbert is considered the storm of the twentieth century with records for size, straightness of track, lowest atmospheric pressure and total energy (Meyer-Arendt, 1991). At the centre of Gilbert the pressure reached an outstanding low of 888 mb. The beginning of the twentieth-first century has also shown in Mexico one of the most dangerous faces of anthropogenic climate change: weather extremes. In the Atlantic Ocean Basin, 2005 was the most active hurricane season in history (Lawrimore et al., 2005). Several southern Mexican states (Yucatan, Chiapas, Oaxaca, Puebla and Veracruz) were hit by Stan from October 1 to 5 (Hernández-Unzón and Bravo, 2005a), and it was not long (October 22) before Wilma, the strongest hurricane on record, struck the Yucatan Peninsula. This storm set the lowest atmospheric pressure (882 mb) ever recorded, and the highest 24 hrs accumulated precipitation in Mexico (1576 mm at Isla Mujeres), seriously damaging the touristic infrastructure of Cancún (Hernández-Unzón and Bravo, 2005b). These sorts of events illustrate the delicate balance of the climate system between extremes and average weather. Extreme weather events fall within the "probability distribution" fringes of meteorological variables; most of the time revealing an "unexpected" aspect of the known distributional patterns for a location or region.

Seeking simplicity in the description of rainfall extreme indices for 15 stations with daily precipitation (Table 5.1; see also Table 3.2 and Fig. 3.6), we partition the data into two different aspects: one dealing with depth or intensity (amount and rate) and the other with frequency (number of occurrences). We will then examine both sets of indices using linear correlation (with time) involving Kendall’s tau (see section 4.5.1). For some of the most important statistically significant correlations (as Kendall’s tau does not compute the trend magnitude), additionally we plot the least-squares linear trends. Natural mechanisms that partially control their patterns are discussed in relation to all these extreme parameters. The study seeks to find coherent spatial patterns of change among the indices of precipitation extremes, especially when comparing local against regional scales as in the case of the PRCPTOT index (see Table 3.1), or within the resulting regions of the Principal Component Analysis (Section 4.2.1). Therefore, one of the main targets of this chapter (of the indices of rainfall extremes) is the identification of consistencies among several statistically significant correlations, of one single station or a group of stations.

In the second part of the chapter, the hypothesis of a climatic transition between different parts of Mexico is explored further. The Tropic of Cancer has been defined as a geographical threshold for this purpose. Statistically significant correlations of the precipitation extreme indices with time are contrasted either side of this imaginary line for both positive/negative correlations and wet/dry conditions.

5.2. DISCUSSION.

For the purposes of this chapter, the rainfall extreme indices (defined in Table 3.1 of Section 3.3.4) can be classified into two groups: one group measures the precipitation depth (mm) or intensity (mm/day) (PRCPTOT, SDII, R95P, R99P, RX1day and RX5day) and the other calculates the frequency (number of cases) of the index exceeding or not exceeding its defined threshold (CDD, CWD, R10mm, R20mm). It is expected that this separation of magnitude and frequency can give an additional insight into the often subtle differences of the climatic regions across Mexico (Table 5.1).

5.2.1. PRECIPITATION EXTREME INDICES.

As PRCPTOT is probably the most important index reflecting rainfall variations over the entire year, the discussion of extremes will start with the changes of this parameter at local and regional levels. At regional scales (recall the methods to calculate regional series see Section 3.3.3), the most striking characteristic in this index [Fig 5.1. d)] is that significant negative correlations are observed in two different southern regions. The fist is decreasing regional precipitation [Fig 5.1. d)] over the Michoacán coastal

Number*	STATION	STATE	Statist. signif +5%	Statist. signif +1%	Statist. signif -5%	Statist. signif -1%
2	PRESA RODRIGUEZ	BCN	PRCPTOT, R20mm, R95P,SDII			
7	SAN JOSE DEL CABO	BCS	R10mm, R20mm	R25mm		
10	CHAMPOTON	CMP	RX1day,R95P	CWD, PRCPTOT		CDD, SDII
11	OJINAGA	CHIH	CWD			SDII
12	FCO. I. MADERO	DUR				
13	GUANACEVI	DUR	SDII			
16	CELAYA	GTO				
17	IRAPUATO	GTO				
20	APATZINGAN	MICH	R20mm, R25mm, SDII			
27	JUCHITAN	MICH				
31	BADIRAGUATO	SIN				
32	YECORA	SON			R95P	CWD, RX5day
33	SAN FERNANDO	TAM				
34	ATZALAN	VER			CWD	
35	LAS VIGAS	VER	CDD		R99P	R25mm, R95P, RX1day, RX5day

Table 5.1. List of temperature stations (with data from 1941 to 2001) show correlations (Kendall's tau) between the precipitation extreme indices with time, that are statistically significant at the 5 and 1% level. * Stations numbers are in correspondence with Table 3.2 and Fig. 3.6.

Number*	STATION	STATE	Non Significant Correlations
2	PRESA RODRIGUEZ	BCN	R99P, RX1day, RX5day, CDD, CWD, R10mm, R25mm
7	SAN JOSE DEL CABO	BCS	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, CWD, R25mm
10	CHAMPOTON	CMP	R99P, RX5day, R10mm, R20mm, R25mm
11	OJINAGA	CHIH	PRCPTOT, R95P, R99P, RX5day, R10mm, R20mm, R25mm
12	FCO. I. MADERO	DUR	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R20mm, R25mm
13	GUANACEVI	DUR	PRCPTOT, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R20mm, R25mm
16	CELAYA	GTO	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R20mm, R25mm
17	IRAPUATO	GTO	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R20mm, R25mm
20	APATZINGAN	MICH	PRCPTOT, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R25mm
27	JUCHITAN	MICH	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R20mm, R25mm
31	BADIRAGUATO	SIN	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R20mm, R25mm
32	YECORA	SON	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R20mm, R25mm
33	SAN FERNANDO	TAM	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R20mm, R25mm
34	ATZALAN	VER	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, R10mm, R20mm, R25mm
35	LAS VIGAS	VER	PRCPTOT, SDII, R95P, R99P, RX1day, RX5day, CDD, CWD, R10mm, R20mm, R25mm

Table 5.2. List of temperature stations (with data from 1941 to 2001) for which weather extreme indices show correlations (Kendall's tau) between the precipitation extreme indices with time that are no statistically significant. * Stations numbers are in correspondence with Table 3.2 and Fig. 3.6.

area (Region 10 in table 4.1) which is statistically significant at the 1% level. There are two geographical features of this region: the first is that it is located on the Mexican Southern Pacific Coast, so the Pacific Ocean certainly acts as one of the modulators of climatic variations in the area (Mitchell et al., 2002). The second characteristic is that the area is a well known forest zone (Villers-Ruiz and Trejo-Vazquez, 1998). The second is the Southeast rainforest region (Region 9 in table 4.1) which also has a negative correlation and it is statistical significant at the 5% level. This is an area of dense vegetation (García, 1988), within one of the wettest parts of the country. The effects of deforestation are a research topic that could be explored, as both regions are clearly reflecting that the precipitation is decreasing (Masera et al., 1997) that can be caused by the loss of vegetation. But, as will be addressed in Chapter 7, the El Niño Southern Oscillation (ENSO) phenomenon is another atmospheric modulator, complicating the understanding of the causes which control these climatic regions.

At the local level [(Fig 5.1. c)], in opposition to what has been observed with the regional PRCPTOT averages [(Fig 5.1. d)], a positive and significant correlation (with time) is evident for a number of stations. For Champotón, in Campeche State (station number 10 in Table 5.1, see Section 3.3.4.1) the correlation is significant at the 1% level and for Presa Rodríguez in Tijuana at 5% (station number 5 in Table 5.1). It is interesting that both rainfall stations are located at the heads of Peninsulas: Champotón within the Yucatan and Tijuana for the Baja California Peninsula respectively. The rainfall station at Champotón has been added for this analysis of extremes; it was not considered during the Principal Component Analysis (PCA) due to completeness and minimum time-series length conditions not being fulfilled. In Chapter 4, we saw that only during the dry season (November to April) could a climatic-related region be isolated here, as a result of the Principal Components Analysis (PCA). For this coastal area in the Gulf of Mexico Hurricanes during the wet season affect the annual totals (Englehart and Douglas, 2002), often leading to a completely different rainfall pattern when compared with the remaining stations across the country (see section 4.2). For Yecora station (number 32 in Table 5.1) within the North American Monsoon Region (NAMR) or Mexican Monsoon Region (see

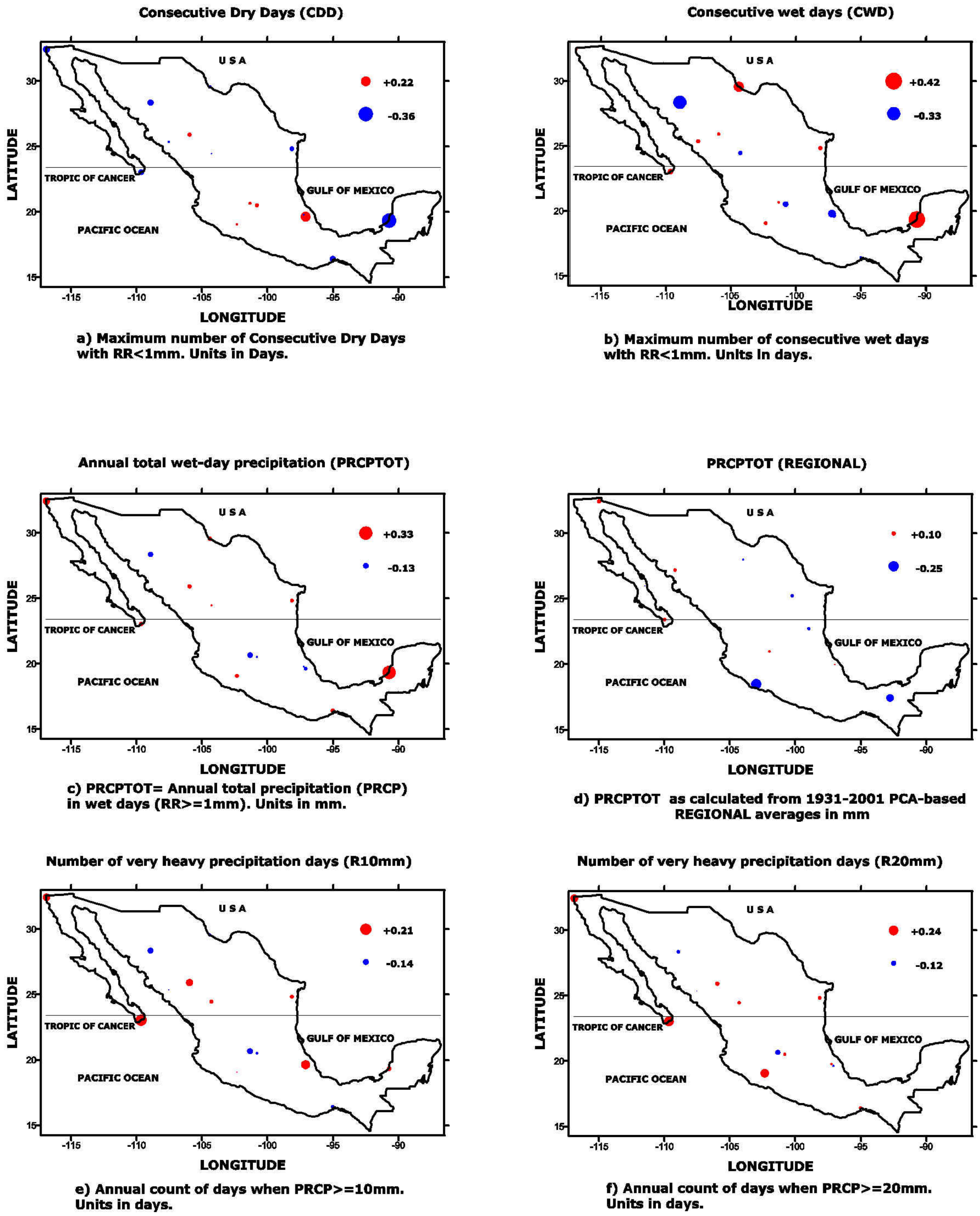
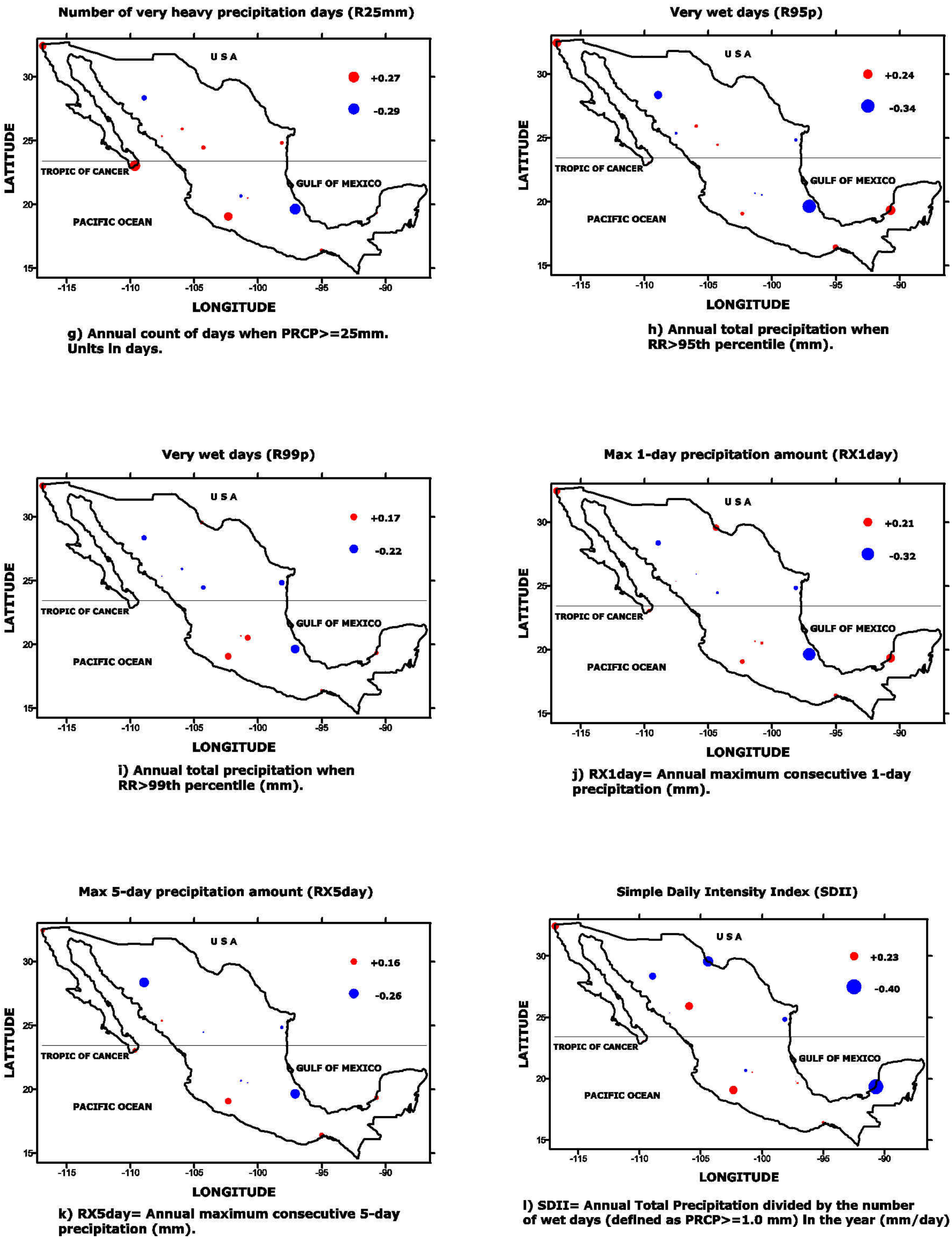


Fig. 5.1. Extreme precipitation indices maps. A Kendall's tau-b (linear) correlation analysis has been applied between the precipitation extreme indices and time. Circles red represent a positive and in blue negative correlations.



g) Annual count of days when PRCP>=25mm. Units in days.

h) Annual total precipitation when RR>95th percentile (mm).

i) Annual total precipitation when RR>99th percentile (mm).

j) RX1day= Annual maximum consecutive 1-day precipitation (mm).

k) RX5day= Annual maximum consecutive 5-day precipitation (mm).

l) SDII= Annual Total Precipitation divided by the number of wet days (defined as PRCP>=1.0 mm) in the year (mm/day)

Fig. 5.1. Extreme precipitation indices maps. A Kendall's tau-b (linear) correlation analysis has been applied between the precipitation extreme indices and time. Circles red represent a positive and in blue negative correlations.

section 4.2), a positive correlation can be observed as well but this time it is not statistically significant.

One index that takes into account not only the total amount of precipitation throughout the year but also reflects changes in daily rainfall is the Simple Daily Intensity Index (SDII). SDII [(Fig 5.1 l)] combines the total amount of annual precipitation and the number of days when rainfall (greater than 0.1 mm) actually occurs (see Table 3.1 in Section 3.3.4). A roughly longitudinal transition can be observed in the results, with an east-west differentiation relatively clear. Positive correlations along the Pacific Coast are evident, suggesting that the ocean can be partly modulating the spatial pattern of SDII. For all the stations along the western side of the country the statistical significance remains below the 5% level. Contrasting negative correlations are observed along the eastern side, the partial connection with the Gulf of Mexico is weaker when compared with the former results along the Pacific Ocean. One pair of stations, Champotón and Ojinaga (station number 10 and 11 in Table 5.1) is below the 1% statistical level of significance for the SDII index. Champotón lies within an area frequently affected by the passing of hurricanes along the Atlantic coast (Jauregui, 2003).

The R95P and R99P [Fig 5.1. h) and i)] indices are used to measure heavy precipitation that exceeds the 95 and 99 percentile thresholds. Statistically significant negative correlations (with time) are found at Las Vigas (station number 35 in Table 5.1) for both indices: at 1% level of significance for R95P and 5% for R99P. As observed for local PRCPTOT [(Fig 5.1. c)], there is a marked positive correlation for the stations located at the head of the Peninsulas (Champotón and Tijuana, see Table 5.1 and Fig. 3.6) when R95P is considered. It can be stated that positive correlations are observed at the Peninsulas and negative correlations for those stations which are more continental.

Very heavy or intense rainfall is measured using the RX1day and RX5day [(Fig 5.1. j) and k)] indices, respectively. Clear negative correlations are observed for Las Vigas (number 35 in table 3.2), which is part of a large rainforest region. Although both extreme indices for this station are statistically significant, it is the RX1day index that lies below the 1% of significant level. Less drastic is the change for the RX5day, for which we can observe only two correlations below the 5% of level of significance. Nevertheless, both correlations show a consistent pattern when compared with the results of R95p and R99p that leads to clear decreasing precipitation at Las Vigas. Although, the Max 5-day precipitation (RX5day index) map does not show any clear geographical pattern, reduced precipitation is also observed in the North American Monsoon or Mexican Monsoon Region (Region 11 in Table 4.1 of Section 4.2) for the RX5day index, lying below the 5% statistical significant level. The only positive correlation leading to increasing rainfall is found at the Champotón station in the Yucatan peninsula. This is possibly linked to enhanced hurricane activity in the region (Pielke et al., 2005).

Amongst the indices that can measure a change to drier conditions is the Consecutive Dry Days (CDD) Index. On the whole, statistically significant results are geographically concentrated in the southern part of the country [Fig 5.1 a)]. Central and Northern areas do not show clear (statistically significant) patterns of changing rainfall. However, contrasting correlations (between the CDD with time) are observed, in the South: an increasing pattern for Las Vigas (station number 35 in Table 3.2) and a negative correlation for Champotón (station number 10 in table 3.2); they are statistically significant at the 5 and 1% level respectively.

If CDD is a measure of dryness; then the Consecutive Wet Days (CWD) index [(Fig 5.1. b)], on the contrary, reflects time-series variations that can lead to wetter conditions. There is little of a geographical pattern to the map for CWD across Mexico. Nevertheless, there is some consistency for the stations Las Vigas and Champotón (station number 35 and 10 in Table 3.2) in comparison with those of CDD: this time a positive correlation (below the 5% of statistical level of significance) is seen for Las Vigas station and a negative correlation for Champoton (below the 1% statistical level of significance). Thus, these two indices both point to wetter conditions for Champotón, Campeche and drier patterns for Las Vigas. Additionally, for the first time in the discussion of rainfall extreme indices one of the stations within the NAMR (Region 11 in Table 4.1) shows a level of statistical significance below the 1% for CWD. This is evident in the negative correlation for the Yecora Station (see table 3.2 in chapter 3) in Sonora. In contrast, though, none of the surrounding stations in the North Pacific area, including the Baja California Peninsula; show similar results. Finally, the border (Mexico-USA) station at Ojinaga (station number 11 in Table 3.2) shows an increasing trend in CWD significant at the 5% level of significance.

Lastly, the persistence of intense precipitation can be measured by the number of cases of daily rainfall exceeding the 10mm, 20mm and 25mm limits, defined as the R10mm, R20mm and R25mm indices. A longitudinal transition can be observed in the maps [(Fig 5.1. e) f) and g)]: positive correlations (increasing precipitation) for the western part of Mexico and negative correlations (reducing precipitation) of these precipitation extreme indices tith time for the eastern part of the country. More stations with statistical significant results, leading to coherent and more easily interpretable regions are found for the R20mm and R25mm indices. Stations with consistent results across the indices are San José del Cabo and Apatzingán (station numbers 7 and 20 in Table 5.1). Coincidently, both stations are located within the western part of Mexico, probably being partly modulated by the Pacific Ocean (Magaña et al., 1999). The most significant result for San José del Cabo is the increase for the R25mm index, being below the 1% of statistical significance level, in addition R10mm and R20mm are significant at 5% statistical level. Positive correlations are also seen for the Apatzingán, where the number of cases surpassing the 20 and 25mm thresholds (R20mm and R25mm) are significant at the 5% level. Negative correlations (with time) are present for Irapuato (station number 17 in Table 5.1) and Las Vigas (both significant at 1%) for the R10mm and R25mm indices respectively. Finally, positive correlation is found at Tijuana (5% statistical significant) for the R20mm index.

In Mexico, rainfall patterns are generally well defined by taking into account total annual precipitation: wet conditions south of the Tropic of Cancer and dry conditions to the north of this geographic limit (see section 2.1). As in the case of regional PRCPTOT, this characteristic opens the possibility of exploring this climatic transition for weather extreme indices as well.

Is there also a latitudinal transition when we study the rainfall extreme indices? Do they preserve the contrasting picture observed for the total annual precipitation (regional PRCPTOT)? Are these patterns following what has been shown for PCA regions (see section 4.2.1)? Table 5.1 shows the distribution of positive and negative Kendall's tau correlations, when levels are statistically significant at 5 or 1%. The patterns of positive/negative correlations with time show the (defined) climatic transition. This can be clearly perceived with statistically significant positive correlations at 1%, in which the number of cases clearly changes from South to North (3 to 0). Champotón (station number 10 in table 5.1) has two statistically significant indices: CWD and PRCPTOT; and R25mm is the statistically significant index for San José del Cabo (station number 7 in Table 5.1). The same contrasting pattern is true when values with negative correlations statistically significant at the 1% level (9 cases) are greater compared to their counterparts at 5% (2 cases). In general, positive correlations that are statistically significant at 5% are more frequent than those at 1% (14 versus 3). In fact, about one half of the numbers of total cases (29 statistically significant correlations) are concentrated in the positive correlations at 5% (14), and around one third with negative correlations significant at 1% (9). Therefore, together they account for about 75% of the cases in total.

South to North contrasting conditions are also evident when statistically significant levels are studied (Table 5.2). The climatic transition is better observed when positive correlations at 5% (8 to 6) are compared to those at 1% (3 to 0), the difference is more drastic for the latter. The eight statistically significant positive correlations at the 5% level in the South are distributed as follows: San José del Cabo (R10mm, and R20mm), Champotón (R95P, RX1day), Apatzingán (R20mm, R25mm, and SDII) and Las Vigas (CDD). Values are greater in the South for both 5 and 1% significant levels regardless of whether positive/negative correlations (of the precipitation extreme indices with time) are considered.

	North	South	Total
Pos. Corr. (5%)	6	8	14
Pos. Corr. (1%)	0	3	3
Neg. Corr. (5%)	1	2	3
Neg. Corr. (1%)	3	6	9
Total	10	19	29

Table. 5.3. Geographical patterns of positive/negative correlations (rainfall extreme indices with time using Kendall's tau) with statistical significant levels at 5 and 1%. The numbers of cases are classified defining the Tropic of Cancer as the divide to separate the northern/southern regions.

Positive and negative significant correlations of the rainfall extreme indices with time can also give us valuable information about wet and dry conditions. These relations are expressed in Table 5.3. Stations with correlations pointing to more precipitation (wet conditions) account for around two thirds (18) of the cases (29), with the southern part of the country reflecting changes in 19 of the totals. The latitudinal climatic transition is better observed during dry than wet conditions, as the northern half of the country has only 4 cases, while the southern part accounts for 7 statistically significant correlations of the total of 11 significant results, showing a change in the rainfall extreme indices to drier conditions.

At local level, the stations Champotón (RX1day, CWD, PRCPTOT, R95P, CDD and SDII) and Las Vigas (CDD, R99P, R25mm, R95P, RX1day, and RX5day) account for nearly 63% of the cases of statistically significant results (using the extreme indices) in the southern part of the country. Likewise, for the northern part, the stations at Presa Rodríguez in Tijuana (PRCPTOT, R20mm, R95P, SDII) and Yecora (CWD, R95P, RX5day) together have around 64% of the totals of statistical significant results. Therefore, for both the north and south, only two stations have about two thirds of the indices with significant correlations.

	North	**South**	**Total**
Wet	6	12	18
Dry	4	7	11
Total	10	19	29

Table. 5.4. Geographical patterns of positive/negative correlations (rainfall extreme indices with time using Kendall's tau) with statistical significant levels at 5 and 1%. The number of cases are classified defining the Tropic of Cancer as the divide to separate northern/southern results.

5.2.2. LINEAR TREND ANALYSIS.

Until now, for non-parametric correlations applied in this chapter on rainfall extreme indices, statistically significant results and spatial analyses have shown us a geographical (north-south) transition in the results. Giving the impossibility of the Kendall-tau test (see section 3.3.5) to calculate the magnitude of the trends, we are now going to study the trends and plots computed by the R software (section 3.3.4) utilizing least-squares fittings. A positive autocorrelation can affect severely the detection of a significant trend, leaving the calculation unreliable (Zhang et al., 2005). In order to test this possibility, serial correlation magnitudes were computed using SPSS 14.0 before the estimation of significant trends, and none of them show a considerable positive autocorrelation able to influence the results.

There is one characteristic that both halves of Mexico (defining the tropic of Cancer as the geographic divide) share: two stations concentrate about two thirds of the total of the statistically significant correlations (Table 5.1). Champotón and Las Vigas in the southern half and Presa Rodríguez and Yecora in the northern half of the country were chosen to evaluate the trends for several rainfall extreme indices. The most prevalent indices among the stations were selected for this assessment. For instance, R95P has statistically significant results in all the stations evaluated, and two of the most important indices PRCPTOT and SDII (see table 3.1) in three of the four stations considered.

The selected indices also give different insights about the secular changes of precipitation in Mexico, like changes in totals (PRCPTOT) or in percentiles as is the case for the R95P and R20mm indices. In this sense, it is expected that the chosen indices will be sufficient to get information on the rainfall indices variations across Mexico, and also to test the hypothesis of (north-south) climatic transition in the country.

The first rainfall extreme index to be analysed is the annual total precipitation (PRCPTOT see Table 5.1). This is one of the most extensively analysed indices in climatology, in which we can clearly observe the differences in the rainfall amounts across the year among the stations considered. A downward trend is found at Las Vigas (station number 35 in table 5.1) pointing towards drier conditions. The magnitude of the trend calculated by least-squares is about -42.7 mm/decade for a climatological mean of 1152.1 mm per year, with a clear decrease in total rainfall since the 1960s [Fig. 5.2 b)]. Wetter conditions are also observed at Champotón, the other southern station assessed [Fig. 5.2 a)]. In fact its positive trend is larger than the observed trend for Las Vigas (+65.1 mm/decade with an annual mean of 1261.7 mm per year). The slight positive trend in hurricane activity during recent decades is likely to be affecting this increased precipitation (IPCC, 2007; Jauregui, 2003). Contrasting trends are also observed in the northern part of the country. Although having several missing years, Yecora station shows a clear decreasing trend (-71.7 mm/decade, and a long-term mean of 1117.6 mm per year) [Fig. 5.2 c)]. Meanwhile a modest positive slope is found for the Presa Rodríguez station in Tijuana with a changing pattern to wetter conditions, its trend shows an increase of 9.9 mm/decade (the long-term mean of the station is 232.9 mm per year). The recent increase in ENSO activity could be affecting the annual total rainfall of this station [Fig. 5.2 d)]. This aspect will be discussed later in Chapter 7.

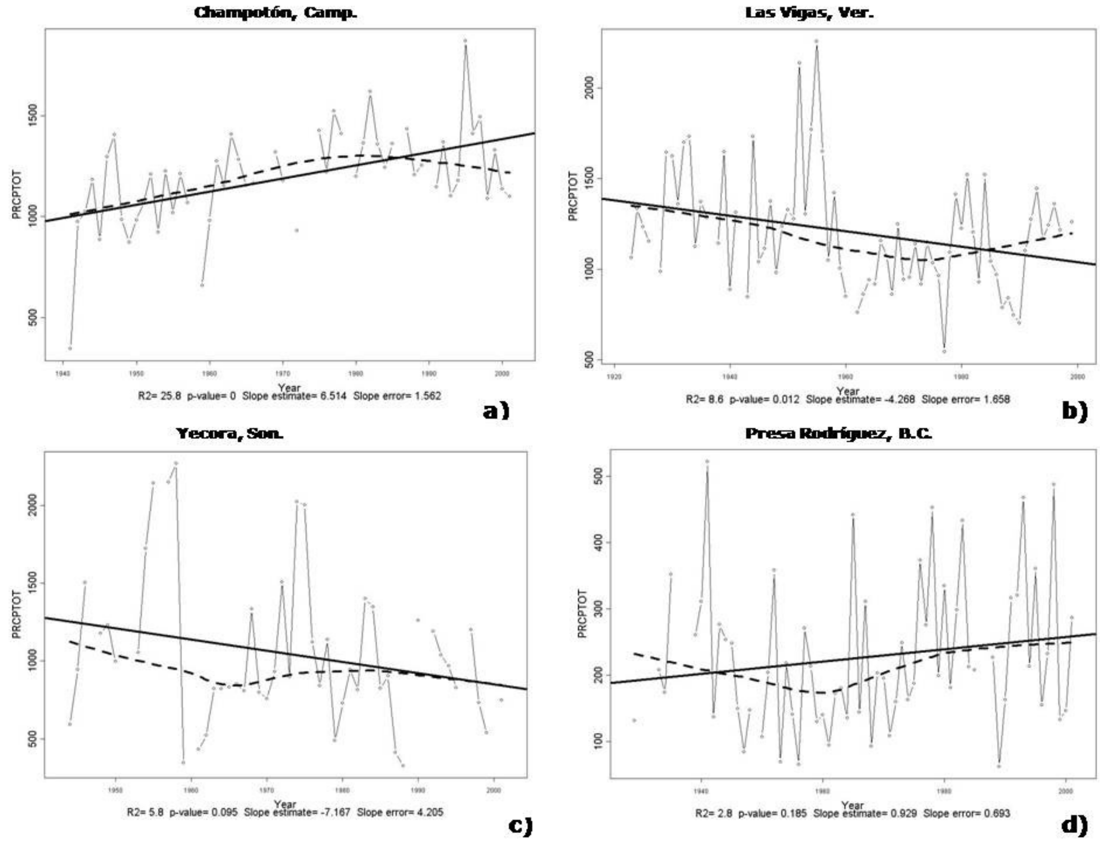


Fig. 5.2. Linear trends calculated using a least-squares fitting on the annual total precipitation (PRCPTOT) of the stations with the largest number of statistically significant results (see Table 5.1).

Contrasting trends are also observed for the R20mm index. As pointed out in Section 3.3.4 (see table 3.1), R20mm counts the number of days per year when daily precipitation exceeds a pre-defined 20 mm threshold. In the northern part of the country, a clear trend of decreasing rainfall is observed at Yecora station (about -1 day/decade) [Fig. 5.3 c)].

Wetter conditions are observed at Tijuana (Presa Rodríguez station), its positive trend (+0.14 days/decade), is, though, almost imperceptible [Fig. 5.3 d)]. The Mexican Monsoon and the ENSO phenomenon are the possible physical mechanisms that partially modulate the R20mm index at Yecora and the Presa Rodríguez stations. Gradual changes in R20mm are also observed in the southern half of the country. A slight positive trend (+0.19 days/decade) is observed at Champotón (station number 10 in Table 5.1), in which sudden jumps occur in a quasi-cyclic mode according to the plot [Fig 5.3 a)], likely being partially modulated regularly by hurricane activity. A modest change towards drier conditions (negative trend of -0.32/decade) is observed at Las Vigas near to the Gulf of Mexico [Fig 5.3 b)]. Therefore, we can say that contrasting conditions are observed in both the northern and the southern part of Mexico. Positive trends are observed in those stations located in the Peninsulas (Presa Rodríguez and Champotón), while negative trends are found in the more continental stations (Yecora and Las Vigas).

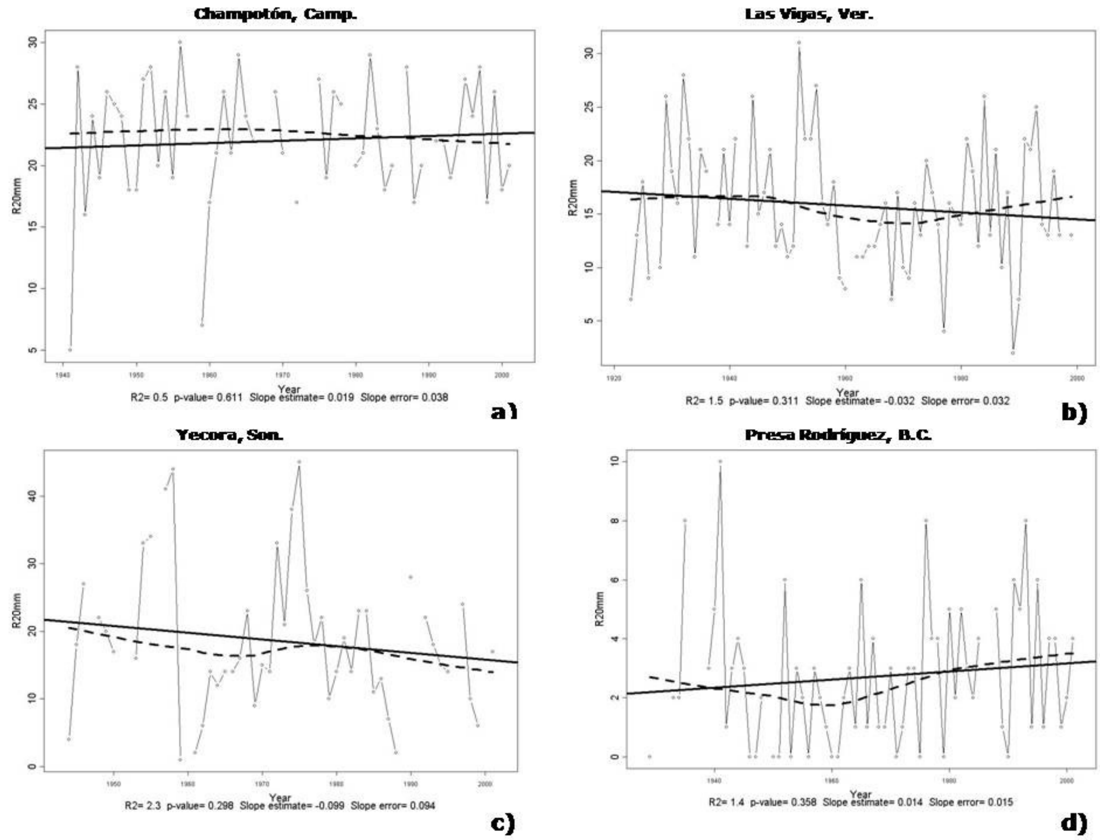


Fig. 5.3. Linear trends calculated using a least-square fitting on the Very Heavy Precipitation Days (R20mm) index of the stations with the largest number of statistically significant results (see Table 5.1).

Contrasting patterns can be appreciated between the stations in both the northern and southern part of Mexico for the R95P index. For instance, in the northern part of Mexico a clear downward trend (-52.7 mm/decade) is observed at Yecora within the Mexican Monsoon (North American Monsoon) Region (see section 4.2.1). A clear decrease in magnitude (amounts) of the peaks is evident for the most recent years. An upward slope is seen for Presa Rodríguez, it has a less pronounced trend than Yecora with a change of about +6.8 mm/decade, and the most important peaks of the indices are found in the 1990s. It is important here to point out that this upward trend in recent peaks is coincident with a period of long "El Niños" during the same decade (Allan and D'Arrigo, 1999). In the South of Mexico, Las Vigas shows an important downward trend (-46.8 mm/decade), leading to drier conditions. As mentioned above for the PRCPTOT index, deforestation (along with El Niño influence discussed in Chapter 7) may be playing an important role in modulating the climate at this location. Meanwhile a recent increasing hurricane activity (Jauregui, 2003) seems to be affecting the R95P index pattern at Champotón (station number 10 in Table 5.1 and Fig. 3.6). A trend of +26.0 mm/decade is found at this station. Overall, for the R95P index, upward trends are found for the stations in the peninsulas (Champotón in the Yucatán peninsula, and Presa Rodríguez in the peninsula of Baja California), and downward trends for the stations within the main continental land (Las Vigas and Yecora).

In the northern part of the country, we can observe consistency with the former indices evaluated when the trends of SDII are considered. An upward trend (+0.2 mm/day/decade) is found at Presa Rodríguez station in Tijuana. A marked increase in the precipitation intensity is especially observed during the last two decades of the records that is apparently in phase with a period of longer El Niños (Allan and D'Arrigo, 1999), and is also linked to an increase in the amount of annual total rainfall [Fig. 5.2 d)] for this station. Slightly larger in magnitude is the negative slope (when compared with Presa Rodríguez station in Tijuana) at Yecora station (-0.7 mm/day/decade). This pattern leading towards drier conditions seems to be directly linked to a decrease in the annual total precipitation [as in Fig. 5.2 d)] rather than the number of wet days [Fig. 5.1 b)]. The southern half of Mexico also shows contrasting patterns between the analysed stations when the SDII is assessed. An almost imperceptible positive trend (+0.16 mm/day/decade) is found at Las Vigas. This is an interesting case, because as we

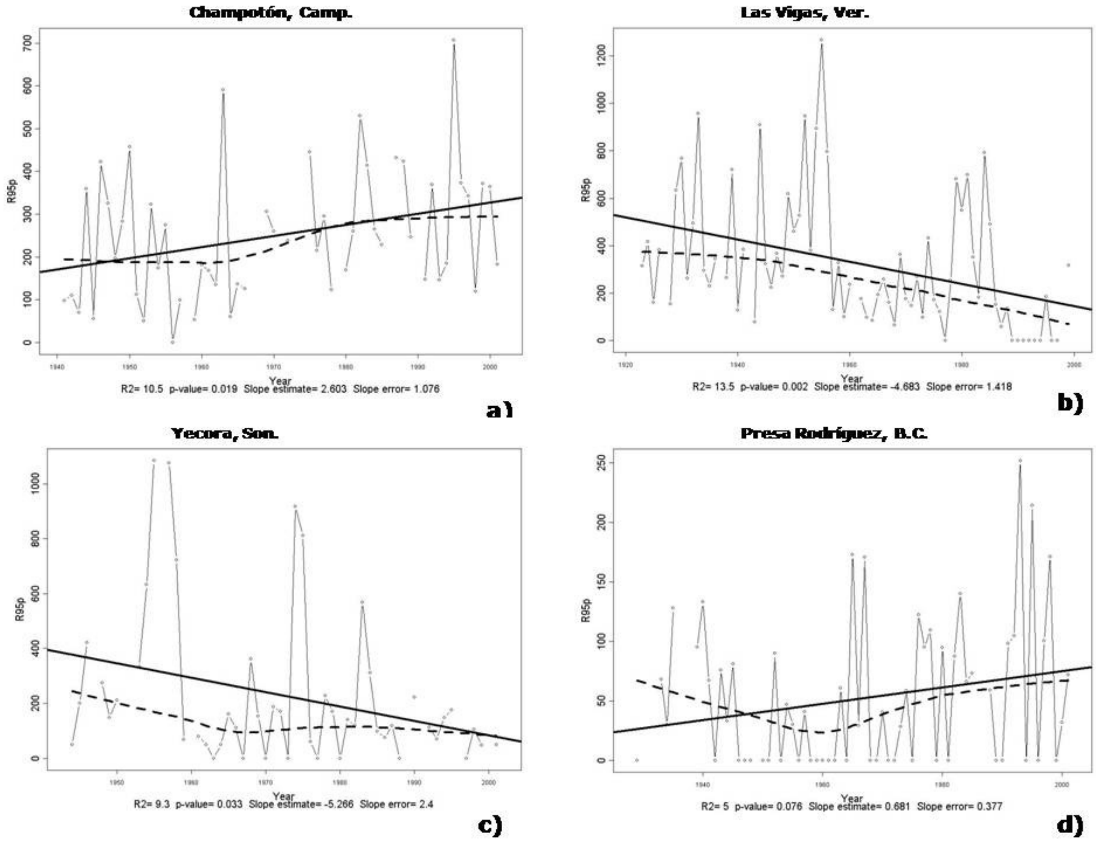


Fig. 5.4. Linear trends calculated using a least-square fitting on the Very Wet Day Precipitation (R95P) index of the stations with the largest number of statistically significant results (see Table 5.1).

have seen the PRCPTOT index [as in Fig. 5.2 b)] pointing towards drier conditions; it seems that the number of wet days has a greater influence on the SDII index [Fig. 5.1 b)]. It is clear that the annual total precipitation is decreasing at a slower rate than the number of days when rains occurs. Finally the clearest trend on SDII is found at Champotón within the Yucatán peninsula. The downward trend (-1.4 mm/day/decade) is directly affected by an increase in the number of wet days [Fig. 5.1 b)] rather than the annual total precipitation (PRCPTOT) that shows a pattern towards wetter conditions. It can be said that this region (Yucatán peninsula) has been recently affected by increasing hurricane activity ([IPCC, 2007](#)), but in also more rainy days have been observed during the year, leading to a decrease in the daily intensity index (SDII) at Champotón.

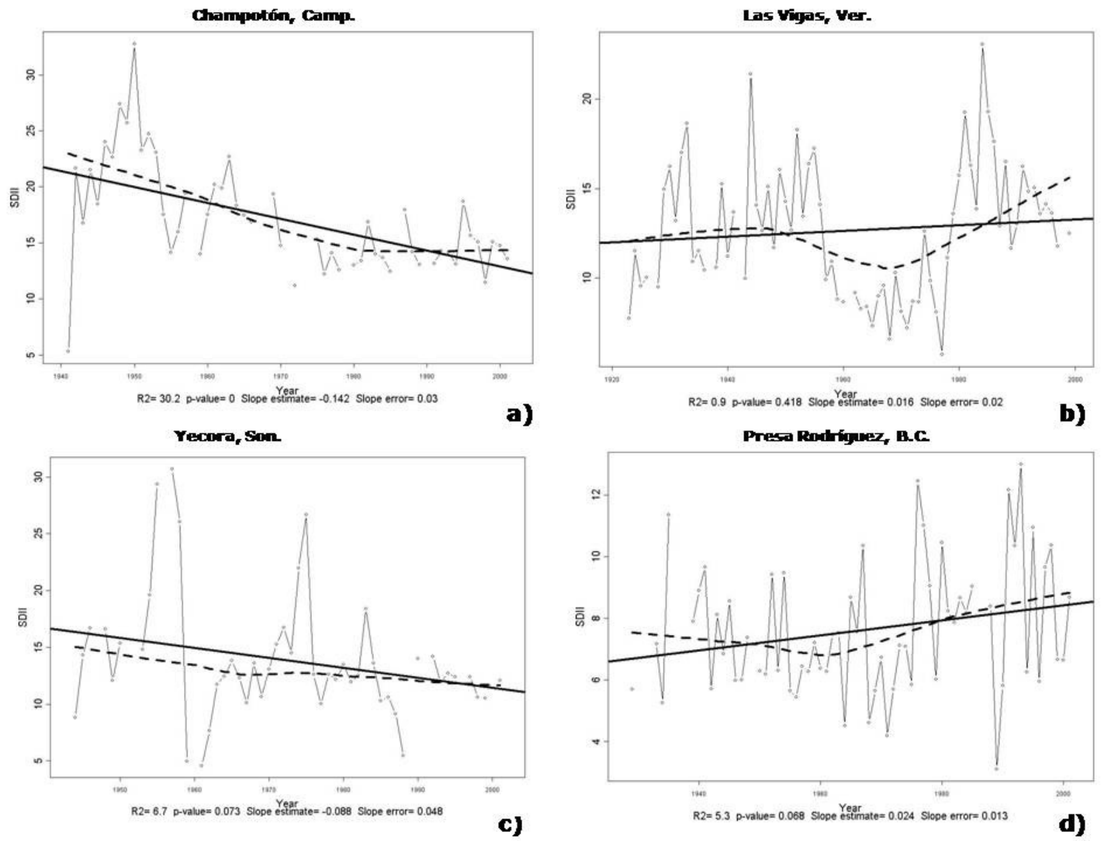


Fig. 5.5. Linear trends calculated using a least-square fitting on the Severity Daily Intensity Index (SDII) index of the stations with the largest number of statistically significant results (see Table 5.1).

Although subtle differences appear when the daily intensity index (SDII) is evaluated, the analysis of trends, for the stations having more statistically significant correlations, has shown consistency across the results. The pattern is clear: increasing trends in the peninsulas and negative trends in the mainland stations. Presa Rodríguez in the peninsula of Baja California, and Champotón in Yucatán are evident examples of how even modest changes in large-atmospheric controls can affect local climates. Within a semi-arid region in Tijuana, the precipitation at the Presa Rodríguez station is strongly affected even with changes in normal atmospheric conditions, like those occurring during El Niño years in this part of the country (Dettinger et al., 2001, Trenberth and Caron, 2000). A different large-atmospheric control is observed at Champotón station within the Yucatán peninsula. Hurricane associated rainfalls can completely disrupt the local climate in comparison with neighbouring locations. This separation from normality is fully appreciated in the PCA of rainfall (section 4.2.1) when a pattern can only be extracted in the dry season (Nov-Apr), evidently linked to the hurricane-free period in the North Atlantic Ocean basin. Less evident are the physical causes that invoke changes in the precipitation extremes in the stations located in main continental Mexico. Nevertheless, Yecora has consistently shown the largest trends of the four studied stations; but we have to say that Yecora also has the greatest percent of missing data, especially for recent years, and this might be affecting the results. Being at the core of the Mexican Monsoon Region (Region 11 in Table 4.1) and with an altitude of 1500 m.a.s.l., Yecora is directly impacted by the secular changes of the summer rainfall patterns (Cavazos et al., 2002). It is important to point out here the contrasting trends (for the different rainfall extreme indices studied) observed between Yecora in Sonora state and Presa Rodríguez in the northern part of the Baja Californian peninsula; the sea of Cortez can be counted as a possible cause for these different climatic patterns (Stensrud et al., 1997). Finally, as Las Vigas station is located within a region of dense vegetation; deforestation is likely to be the main physical force modulating the trends that lead to drier conditions (Villers-Ruíz and Trejo-Vázquez, 1998). However, as is going to be explored in Chapter 7, the El Niño phenomenon cannot be discarded as another atmospheric control partially modulating its rainfall extremes.

5.3. CONCLUSIONS TO THE CHAPTER.

The occurrence of climate extremes is very rare in terms of their frequency, but large when referred to intensity. Therefore, the study of these sorts of events is of great importance because of the impacts they can have on our socio-economic activities. The knowledge of the patterns and changes over time contribute to understand their nature and causes and indirectly to mitigate their damages.

Total Annual Precipitation (PRCPTOT) shows contrasting conditions for local or regional patterns. Regional precipitation reflects a southern decreased precipitation especially for forested regions possibly suggesting a link to deforestation. However, locally increasing precipitation is observed for those stations located at the head of the Baja California and Yucatan Peninsulas.

In different ways both oceans modulate weather extremes in Mexico. If we only consider statistical significant results, increased precipitation patterns are found in the stations near the Pacific Coast; contrasting with a downward trend observed for those along the Gulf of Mexico. The indices considered to identify this geographic transition are expressed as frequency (number of cases) instead of magnitude and rate.

There is another interesting geographic pattern observed in the (linear) correlations of precipitation extreme indices with time across Mexico. Increasing rainfall trends are found for those stations located at the head of the Peninsulas; in contrast to rainfall stations with a continentality factor that show a reduced precipitation. The partial modulation of the climate by the ocean is suggested here as well.

The analysis performed in this chapter is leading towards some interesting results. When considering statistical significant levels, around 60% of the total accounts for the results significant at 5%, and consequently the remaining near 40% are related to a statistical significance at 1%. Disregarding the sign of the correlations and the statistical significance, the number of cases in the south is greater than in the north of the country.

This latitudinal climatic transition is also repeated when wet weather is contrasted to dry conditions. Once more, the southern part of the country consistently outnumbers the number of cases of significant correlations, than in the north.

Four stations involve about two thirds of the total number of statistically significant results: Presa Rodríguez and Yecora (stations number 2 and 32 in Table 5.1) in the northern part of Mexico; in the south Champotón and Las Vigas (stations number 10 and 35 in Table 5.1). When an analysis of trends is performed for these stations, the results show consistency with the other analyses applied in this chapter: stations in the peninsulas exhibit trends towards wetter conditions, while stations within the continent are pointing towards drier patterns. Those stations at the head of the peninsulas (Champotón and Presa Rodríguez) are directly affected by sudden changes in large-atmospheric controls like Hurricanes or ENSO. Although modulated by more gradual variability (mostly deforestation and the Mexican Monsoon) clear changes on rainfall extremes are found for Las Vigas and Yecora station. There is one clear geographical feature after the analysis of trends: either continental or peninsular, all the stations evaluated are close to the Mexican coasts. Therefore, both the Atlantic and Pacific Oceans play a key role partially controlling the evolution of the rainfall extremes across Mexico.