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Article

Trends in Extreme Climate Indices for Pará State, Brazil

Carlos Antonio Costa dos Santos, Verônica Gabriella de Oliveira

Unidade Acadêmica de Ciências Atmosféricas, Universidade Federal de Campina Grande, Campina Grande, PB, Brazil.

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Abstract

The present study aimed to analyze trends in air temperature and rainfall for 13 locations in the state of Pará using nonparametric tests. Daily data of maximum and minimum air temperatures and precipitation covering the period 1970-2006, collected by the Instituto Nacional de Meteorologia (INMET) have been used. From the results obtained it was observed that the number of warm days and nights per year has increased, thereby providing a significant reduction in the number of cool days and nights in the state. Due to the high space-time variability of precipitation, few localities showed statistically significant trends for indices of extremes dependent on this variable. The days and nights in Belém have been hotter in the last two decades. Therefore, these results are important for future planning of public health and energy for the state of Para, which must adapt to future warming scenarios sectors.
Keywords: RClimdex, Mann-Kendall, climatology.

Tendência de Índices de Extremos Climáticos para o Estado do Pará, Brasil

Resumo

O presente estudo teve como objetivo analisar as tendências da temperatura do ar e precipitação em 13 localidades do estado do Pará, para isso foram utilizados dados diários das temperaturas máxima e mínima do ar e precipitação compreendendo o período de 1970 a 2006, coletados pelo Instituto Nacional de Meteorologia (INMET) e testes estatísticos não paramétricos. Através dos resultados obtidos foram observados que, o número de dias e noites quentes por ano tem aumentado, proporcionando assim uma redução significativa dos dias e noites frias sobre o estado. Devido à alta variabilidade espaço-temporal da precipitação, poucas localidades apresentaram tendências estatisticamente significativas para os índices de extremos dependentes dessa variável. Os dias e as noites na cidade de Belém têm sido mais quentes nas últimas duas décadas. Logo, esses resultados encontrados são importantes para o planejamento futuro dos gestores públicos nos setores de saúde pública e energético para o estado do Pará, os quais deverão se adequar aos cenários futuros de aquecimento.
Palavras-chaves RClimdex, Mann-Kendall, climatologia.

1. Introduction

The society, economy and environment are impacted by the extreme weather or climate events. Thus, an initial step for studies involving the climate change impact is the analysis of extreme indices (Sharma and Babel, 2014). Many studies, such as Aguilar *et al.* (2005), Vincent *et al.* (2005), Alexander *et al.* (2006), Haylock *et al.* (2006), Marengo *et al.* (2009), Marengo *et al.* (2010) have revealed that significant changes in some climate variables have taken place in the South America over the last century. However, it is necessary to have a better understanding about the behavior of some climate variables in local scale.

Aguilar *et al.* (2005) analyzing climate change indices of daily precipitation and temperature, over the 1961-2003 period in Central America and northern South America, observed that these indices reveal a general warming trend in the region. They found that extreme warm maximum and minimum temperatures have increased while extremely cold temperature events have decreased. Additionally, the precipitation indices analyzed indicate no significant increases in the total amount, but rainfall events are intensifying and the contribution of wet and very wet days are enlarging. An examination of the trends over 1960-2000 in the indices of daily temperature extremes in South

Autor de correspondência: Carlos Antonio Costa dos Santos, carlos.santos@ufcg.edu.br, carlostorm@gmail.com.

America has been shown by Vincent *et al.* (2005). Their results indicate no consistent changes in the indices based on daily maximum temperature while significant trends were found in the indices based on daily minimum temperature. Moreover, it was observed significant increasing trends in the percentage of warm nights and decreasing trends in the percentage of cold nights at many stations and, the authors explained that this warming is mostly due to more warm nights and fewer cold nights during the summer and fall.

Marengo *et al.* (2009) used the PRECIS regional climate modeling system to study the distribution of extremes of temperature and precipitation in South America in the recent past (1961-1990) and in a future (2071-2100). It was found that in all the future climate scenarios considered all parts of the region would experience significant and often different changes in rainfall and temperature extremes, as well as, in the future, the occurrence of warm nights will be more frequent in the entire tropical South America while the occurrence of cold night events is likely to decrease. Similarly, significant changes in rainfall extremes and dry spells have been projected, including increasing intensity of extreme precipitation events over western Amazonia which is in agreement with the projected increasing trends in total rainfall in this region.

Moraes *et al.* (2005) evidenced that studies on the climatology of precipitation in the State of Pará (eastern Amazonia) are essential for the planning of agricultural activities. Furthermore, as described above, studies on the climatology of temperature are also important for this region, especially for the State of Pará which has its agriculture stands out for crop production of rice, beans, maize and cassava that are mainly controlled by the amount and distribution of precipitation and temperature. Cox *et al.* (2004) and Li *et al.* (2006) show that some global circulation models suggest that Amazon may be vulnerable to extreme drought in response to movement of dislocations caused by global warming, which can cause loss of tropical forests, with potential acceleration of global warming. It is known that the hydrological cycle of the Amazon region is of great importance (Marengo *et al.*, 2008) because the region plays an important role in the functioning of regional and global climate. Its changes can affect the atmospheric moisture transport from the Amazon region to adjacent regions (Marengo *et al.*, 2008).

The Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI), sponsored by WMO (World Meteorological Organization) Commission for Climatology (CCI) and the Climate Variability and Predictability Project (CLIVAR) has developed a set of indices that represents a common guideline for regional analysis of climate. The indices describe particular characteristics of extremes, including frequency, amplitude and persistence. The core set includes 27 extremes indices for temperature and precipitation (Klein Tank *et al.*, 2009).

This research aims to analyze the temporal trends and spatial distribution of precipitation and temperature extreme climate indices for the State of Pará. The study area in the eastern part of the Amazon is the most vulnerable to changes in climate, and certainly the impact of these changes in hydrology and biodiversity in the region may be larger than those expected in South and Southeast of Brazil. Additionally, there is no study by using this methodology to obtain the spatial-temporal behavior of the extreme climate indices for the study area by using observed daily precipitation and temperature dataset.

2. Material e Methods

2.1. Study area and data

The study area is the State of Pará which is located on the eastern edge of the northern region of Brazil (Fig. 1). Table 1 presents the geographic coordinates of the weather stations used in this study. The Pará State has an area of 1.247.954,666 km^2, representing 14.7% of the entire national territory and according to the 2010 census, its population is approximately 7.581.051 inhabitants (IBGE, 2013). Guyana, Suriname, French Guiana and the state of Amapa are to the north of Para State, Atlantic Ocean to the east, Maranhão to the southeast, Tocantins to the southwest, Roraima to the northwest and the capital of the state being Belem. Amazon river passes through the state of Pará from west to east and discharges into the Atlantic Ocean.

The dataset of daily air temperature and precipitation for the period 1970 to 2006 from 13 weather stations provided by the National Institute of Meteorology (INMET) has been used.

To simplify the terms of the indices of climate extreme events, proposed by Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) of the World Meteorological Organization (WMO) applied to local studies, it was decided to calculate them through RClimdex which is a software developed by Xuebin Zhang and Feng Yang from the Canadian Meteorological Service (Zhang and Yang, 2004). It was used to obtain the climate extreme indices following the method of Zhang *et al.* (2005a,b) and Haylock *et al.* (2006).

The RClimdex provides 27 climate extreme indices (see in Zhang and Yang, 2004), and in this study were selected 11 for temperature and 11 for precipitation analysis (Table 2). The choice of 22 indices was due to the fact adjust to the climatic reality of the study region (high temperatures all year and heavy rainfall), since the RClimdex is designed to be applied worldwide, thus it is necessary to choose the set of indices that best fits to the local conditions of each study. Temperature indices were represented as: SU, TR, TXx, TXn, TNx, TNn, TX10p, TX90p, TN10p, TN90p and DTR. Precipitation indices were represented as: RX1day, RX5day, SDII, R10mm, R20mm, R50mm, CDD, CWD, R95p, R99p and PRCPTOT (Table 2). The annual

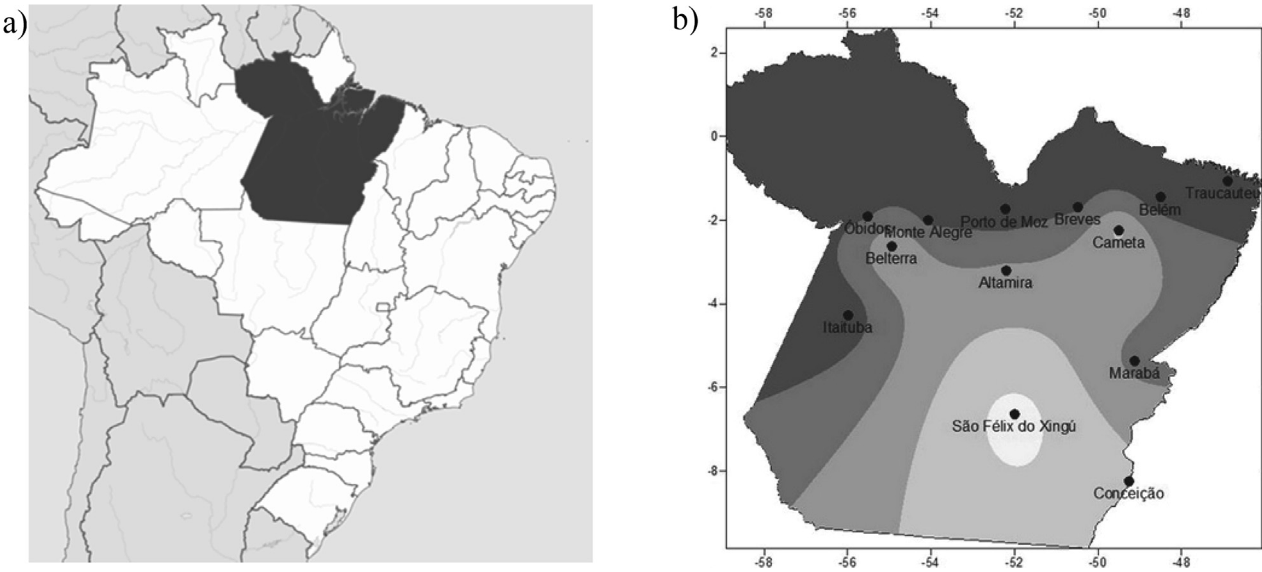

Figura 1 - a) Location of the study area on the map of Brazil and b) spatial distribution of weather stations in the state of Pará.

Tabela 1 - Geographical coordinates of 13 locations in the state of Pará.

Stations	Latitude	Longitude	Altitude(m)
Altamira	-3.20	-52.20	109
Belém	-1.45	-48.50	10
Belterra	-2.63	-54.93	152
Breves	-1.68	-50.48	40
Cameta	-2.24	-49.49	159
Conceição	-8.25	-49.26	165
Itaituba	-4.27	-55.98	15
Marabá	-5.36	-49.11	84
Monte Alegre	-2.00	-54.06	38
Óbidos	-1.91	-55.51	45
Porto de Moz	-1.74	-52.23	15
São Félix do Xingú	-6.64	-51.99	220
Traucauteua	-1.07	-46.90	20

and seasonal trends were obtained by the Least Squares Method.

Signs of trends in climate extreme indices and their statistical significance were analyzed using the nonparametric Mann-Kendall (Mann, 1945; Kendall, 1975), the statistic S of Mann-Kendall test can be calculated according to Eq. (1):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) \quad (1)$$

The signal can be calculated according to the Eqs. (2), (3) and (4):

$$sign(x_j - x_k) = 1 \text{ if } x_j - x_k > 0 \quad (2)$$

$$sign(x_j - x_k) = 0 \text{ if } x_j - x_k = 0 \quad (3)$$

$$sign(x_j - x_k) = -1 \text{ if } x_j - x_k < 0 \quad (4)$$

The statistic S is close to the normal as n increases. The mean and variance are defined in Eqs. (5) and (6).

$$E(S) = 0 \quad (5)$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18} \quad (6)$$

The statistical test $Z(t)$ is used to calculate the trend of a time series and can be obtained according to the Eq. (7).

$$Z(t) = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, \text{ if } S > 0 \\ 0, \text{ if } S > 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, \text{ if } S < 0 \end{cases} \quad (7)$$

The null hypothesis of no trend, H_0 is rejected whenever $Z(t) > Z\alpha/2$ where α is the significance level and $Z\alpha/2$ is the normal variable reduced of the standard normal distribution function, for values ($Z(t) > 0$) increasing trends and for values of ($Z(t) < 0$) decreasing trends (Santos and Portella, 2008). For values of $p \leq 0.05$ statistically significant trend at 5% significance level and $p \leq 0.01$ statistically significant trend at 1% significance level.

3. Results and Discussion

3.1. Temperature indices

From Table 3 it can be seen that the number of warm nights (TR) increased in twelve locations and reduced in only one (São Félix do Xingu). Of the twelve locations that showed increasing trends in the number of warm nights in the year with temperatures above 20 °C, nine have statistical significance at 5% level. The maximum monthly amount of daily maximum temperature (TXx) showed nine locations with increasing trends, but only two are statisti-

Tabela 2 - Definition of climatic extreme indices depending on temperature and precipitation used in this study.

Indices	Name	Definition	Units
SU	Summer Days	Annual count when TX(daily maximum) > 25 °C	Days
ID	Iced Days	Annual count when TX(daily maximum) < 0 °C	Days
TR	Tropical Nights	Annual count when TN(daily minimum) > 20 °C	Days
FD	Frost Days	Annual count when TN(daily minimum) < 0 °C	Days
GSL	Growing Season Length	Annual (1st Jan to 31st Dec) count between first span of at least 6 days with mean temperature > 5 °C and first span after July 1 of 6 days with mean temperature < 5 °C	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temperature	°C
TNx	Max Tmin	Monthly maximum value of daily minimum temperature	°C
TXn	Min Tmax	Monthly minimum value of daily maximum temperature	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temperature	°C
WSDI	Warm Spell Duration Indicator	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days
CSDI	Cold Spell Duration Indicator	Annual count of days with at least 6 consecutive days when TN < 10th percentile	Days
DTR	Diurnal Temperature Range	Monthly mean difference between TX and TN	°C
Rx1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual mean precipitation when PRCP ≥ 1.0 mm	mm
R10mm	Number of heavy precipitation days	Annual count of days when PRCP ≥ 10 mm	Days
R20mm	Number of heavy precipitation days	Annual count of days when PRCP ≥ 20 mm	Days
R50mm	Number of heavy precipitation days	Annual count of days when PRCP ≥ 50 mm	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1 mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1 mm	Days
R95p	Very wet days	Annual total PRCP when RR > 95p	mm
R99p	Extremely wet days	Annual total PRCP when RR > 99p	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR ≥ 1 mm)	mm

Tabela 3 - Trends in climatic extreme indices of temperature for 13 locations in the state of Pará, for the period 1970-2006.

Stations	SU (day)	TR (day)	TXx (°C)	TXn (°C)	TNx (°C)	TNn (°C)	DTR (°C)
Altamira	-0.03	0.20	0.09	0.03	0.06	-0.01	0.05
Belém	0.00	0.69	0.00	0.05	0.02	0.10	-0.02
Belterra	0.16	4.02	0.00	0.06	0.01	0.12	-0.03
Breves	-0.01	4.02	0.01	0.02	0.04	0.13	-0.10
Cametá	-0.01	0.01	0.03	0.04	0.02	0.04	-0.01
Conceição do Araguaia	0.08	5.54	0.05	-0.02	0.06	0.23	-0.08
Itaituba	0.24	1.70	-0.03	0.03	0.01	0.23	-0.04
Marabá	0.07	4.98	0.08	0.02	0.05	0.14	-0.02
Monte Alegre	-0.01	3.41	-0.12	0.01	0.04	0.35	-0.10
Óbidos	-0.10	8.34	-0.20	-0.03	-0.02	0.30	-0.18
Porto de Moz	0.01	2.60	-0.02	0.04	0.04	0.12	-0.06
São Félix do Xingú	0.13	-7.68	0.01	0.06	-0.11	0.12	0.07
Traucauteua	0.28	3.93	0.03	0.04	0.03	0.10	-0.02

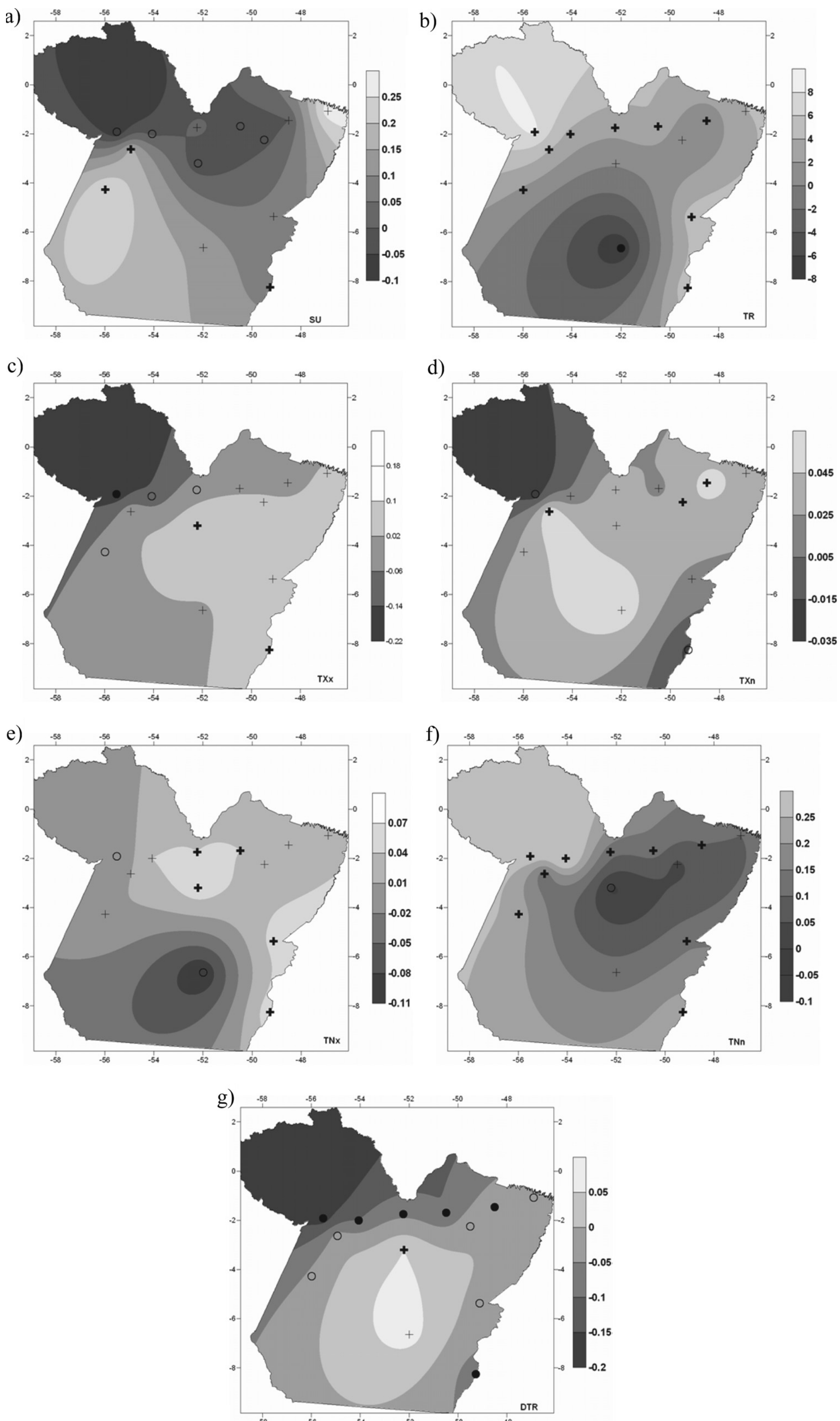

Figura 2 - Spatial variability of trends in extreme climate indices dependent of daily maximum and minimum temperatures for the state of Pará, for the period 1970 to 2006, where: a) SU, b) TR, c) TXx, d) TXn, e) TNx, f) TNn and g) DTR. The symbols correspond to (+) increasing trend not statistically significant, (**+**) increasing trend with statistical significance (O) decreasing trend not statistically significant and (•) decreasing trend with statistical significance, all with the significance at 5% level ($p \leq 0.05$).

cally significant and, four sites were identified with reduction trends, however, only one locality has statistical significance.

Similarly, the minimum monthly amount of daily maximum temperature (TXn) presented eleven locations with increasing trends, with only three statistically significant and two stations with decreasing trends, but without statistical significance. Analyzing the maximum monthly value of daily minimum temperature (TNx) is observed eleven locations showing increasing trends, five with statistical significance. Two locations showed negative trends, but without statistical significance. The index that represents the minimum monthly amount of daily minimum temperature (TNn) showed predominantly increasing trends over the study period. Twelve stations showed positive trends and nine of these were statistically significant. Due to higher magnitudes of the trends occurring in TNn, *i.e.*, the minimum temperature, daily temperature range (DTR) showed trends predominantly negative in eleven locations, six with statistical significance.

From the temperature extremes indices used in this study, there is a trend of increasing temperature for the state of Pará, with more emphasis on the daily minimum temperature that occurs at night, as shown in the indexes TR and TNn the nights in Pará State have become warmer in recent decades. In general for all locations used in the study a significant trend of increasing temperature was observed such changes characteristics in the thermal patterns of the environment studied can be read by the change in the space around the weather stations as a result of the dynamics of urban occupation, or natural environmental conditions due to weather events. However, the environmental heating phenomenon is of concern with regard to the biological processes of plants and animals, and already associated with transmitting vectors of tropical diseases that affect the Northern region of Brazil. Regarding the increase in ambient temperature, it can be inferred that the most pronounced increase in minimum temperatures considerably reduce the daily temperature range (DTR) of the environment, a fact that can also strengthen pathogens and restrict crops that have greater thermal vulnerability.

These results are in agreement with the trends pattern showed in others studies developed by using the same methodology, however for continental or global scale such as Alexander *et al.* (2006) which study the global observed changes in daily climate extremes of temperature and precipitation and Aguilar *et al.* (2005) which analyzed the changes in precipitation and temperature extremes in Central America and northern South America for the period of 1961-2003.

In Figs. 2a to 2g are described spatial distributions of extreme temperature indices for the State of Pará. Figures 2a and 2b show the indices SU and TR, respectively, it is possible to see that the increasing trend of hot days (Fig. 2a) is more present in the southwest region of the State, this can be explained by the continental effect, *i.e.*, it is not the direct effect of continental, but their indirect effects of the vulnerability of these areas produces changes in their ecosystems faster and more intense than coastal areas. Another cause of this increase is the local effects associated with the land use change and cover. Particularly, in the North of Brazil where the climate is humid and hot, this more gradual increase in temperature can cause impacts on water demand in the region due to the increase of evapotranspiration and/or creating heat islands in the municipalities included in the region.

However the greatest indicator of temperature increase in the State of Pará is seen from Fig. 2b, which shows increase of the warm nights with temperatures exceeding 20 °C. The area has a higher increasing trend is in the northwest of the State. According to the IBGE (2014), there is an area of agricultural expansion in this region; the change in the natural landscape can be justification for such increase.

With regard to extreme temperatures for both maximum (Fig. 2c), and minimum values (Fig. 2d) showed no trend, *i.e.*, normal, because the maximum temperature records tend to stay around the average. As can be seen in Fig. 2c and 2d, the larger trend values are observed in the central region of the State and the lowest in the northwest.

Analysis of the extremes of daily minimum monthly temperature, the maximum values (Fig. 2e) show two distinct nuclei one in the central-south with decreasing trend, but without statistical significance and other in the north with increasing trend. From Fig. 2f, which gives the extreme values of minimum temperature increasing trends are seen in almost of the entire state with the exception ofnorth central region where there is a decreasing trend. Increasing minimum temperatures may indicate environmental heating, especially in the night hours as was seen in Fig. 2b.

Finally, analyzing Fig. 2g, which presents the daily temperature range, a significant increase in temperature is seen in the central part of the State of Pará, practically all locations used in this study were found to decrease the temperature range except in Altamira. This factor can be related to the gradual increase in minimum temperature records caused by changes in environmental surface characteristics derived from human activities.

3.2. Precipitation indices

Table 4 shows trends in extreme climate indices of precipitation for 13 locations around the State of Pará, for the period 1970-2006, such indices did not show indications of precipitation changes in the studied locations. It was found that the indices (RX5day, R10mm, R50mm, R95p and PRCPTOT) do not present any statistical significance. However, some locations have positive trend values, such as SDII (0.05 mm/year) and R20mm (0.26 days/year) for Belém and CDD (0.65 days/year) for Belterra.

Regarding the highest daily rainfall in a year the only location that presents statistical significance was Cametá

Tabela 4 - Trends in climatic extreme indices of precipitation for 13 locations in the state of Pará, for the period 1970-2006.

Stations	Rx1day (mm)	Rx5day (mm)	SDII (mm)	R10mm (dias)	R20mm (day)	R50mm (day)	CDD (day)	CWD (day)	R95p (mm)	R99p (mm)	PRCPTOT (mm)
Altamira	0.84	0.41	-0.01	-0.09	-0.15	-0.05	-0.07	-0.07	-2.33	-0.45	-5.44
Belém	0.57	0.47	0.05	0.30	0.26	0.03	0.05	-0.01	4.09	0.66	9.00
Belterra	-0.05	-0.66	0.03	-0.24	-0.07	-0.06	0.65	-0.10	-4.87	-1.27	-8.19
Breves	-0.02	0.82	0.02	0.30	-0.02	0.01	0.09	0.22	1.23	-0.33	4.93
Cametá	-1.72	-1.39	0.01	-0.10	0.06	0.00	-0.06	0.08	-1.53	-2.49	-2.05
C. do Araguaia	0.96	1.47	0.06	-0.20	-0.01	0.05	0.96	-0.03	6.71	4.40	1.98
Itaituba	1.00	1.39	0.03	0.38	0.16	0.05	-0.68	-0.03	5.08	6.77	10.52
Marabá	0.26	-0.64	0.07	-0.29	-0.14	0.21	0.79	0.08	6.53	0.14	-0.05
Monte Alegre	-0.82	0.50	0.03	0.59	0.59	-0.09	-0.89	0.12	-6.74	-8.85	15.24
Óbidos	1.35	1.00	0.02	0.11	0.31	-0.01	0.06	-0.19	2.32	2.89	12.24
Porto de Moz	-1.29	-1.31	-0.08	-0.42	-0.11	-0.06	0.04	0.17	-7.54	-8.55	-11.22
S. F. do Xingú	3.70	3.34	0.05	-0.55	-0.03	0.02	0.69	-0.27	8.34	10.57	0.54
Traucauteua	0.06	-2.13	-0.03	-0.15	-0.12	-0.08	0.34	-0.40	-5.53	-5.56	-7.75

that showed decreasing trend in the order of -1.72 mm/day. Directly related to rainfall patterns in the state of Pará it is possible to associate the decrease in wet consecutive days (CWD) for Óbidos, São Félix do Xingu and Traucauteua which achieved statistical significance, this fact may represent an environmental drying trend, thus decreasing the probability of the occurrence of rainfall. Additionally, the R99p index showed the value of -8.55 mm/day, indicating the reduction of extremely wet days.

Alexander *et al.* (2006) studying global observed changes in daily climate extremes of temperature and precipitation, Aguilar *et al.* (2005) analyzing the changes in precipitation and temperature extremes in Central America and northern South America for the period of 1961-2003 and Haylock *et al.* (2006) observing the trends in total and extreme South American rainfall in 1960-2000 and links with Sea Surface Temperature found results that in some cases are in agreement with those found in this study. The reasons for some differences are in the fact the each study used different dataset, period of data and statistical treatment.

Based on Fig. 3a representing the maximum rate of rainfall in one day (Rx1day) it is possible to see that only in northeastern Pará (Cametá) a negative trend was identified with statistical significance at 5% level. For all other regions of the state both positive and negative trends with no statistical significance were identified. Whereas in Fig. 3b, the maximum precipitation on 5 consecutive days (Rx5day) did not show any statistical significant trend. The analysis of the SDII index (Fig. 3c) showed an increase in the northeastern State and a decrease in the north-central area, both with statistical significance. The number of days with precipitation higher than 10 mm (R10mm) shown in Fig. 3d was not statistically significant.

According to the index R20mm, the number of days with precipitation above 20 mm, it can be observed from Fig. 4a, an increasing trend in the north north-east of the state. The index R50mm, the number of days with precipitation above 50 mm, did not show any trend in all locations studied (Fig. 4b). Analysis of the index CDD, consecutive dry days, from Fig. 4c, it is possible to detect an indication of positive trend in the west-central region of the state.

In the consecutive wet days index (CWD) (Fig. 4d), it is observed that there exists a greater number of locations with negative trends in comparison with other indices studied and are located in the south, northwest and northeast regions of Pará state. In the behavior of very wet days index (R95p) (Fig. 4e) it is noted that there is no statistically significant tendency. Figure 4f illustrates the extremely wet days (R99p), which is part of the six indices that had some statistical trend, it presents a significant decreasing trend at 5% level, located in the northern region of the State, specifically in Porto de Moz. Finally, the analysis of Fig. 4g representing total annual precipitation (PRCPTOT), as well as, RX5day, R10mm, R50mm and R95p indices showed no statistically significant trends.

3.3. Seasonal extreme indices for Belém

The seasonal behavior of 11 indices of climate extremes of temperatures and precipitation for the city of Belém-PA (Table 5), for the period 1970-2006, were analyzed. The value of the minimum daily minimum temperature (TNn) had increased in all seasons of the year during the study period. In Table 5 it is observed that the annual magnitudes of the trends were 0.046 °C, 0.055 °C, 0.056 °C and 0.048 °C for the summer, autumn, winter and spring seasons, respectively. Similar configuration was observed for the seasonal behavior of the maximum value of daily

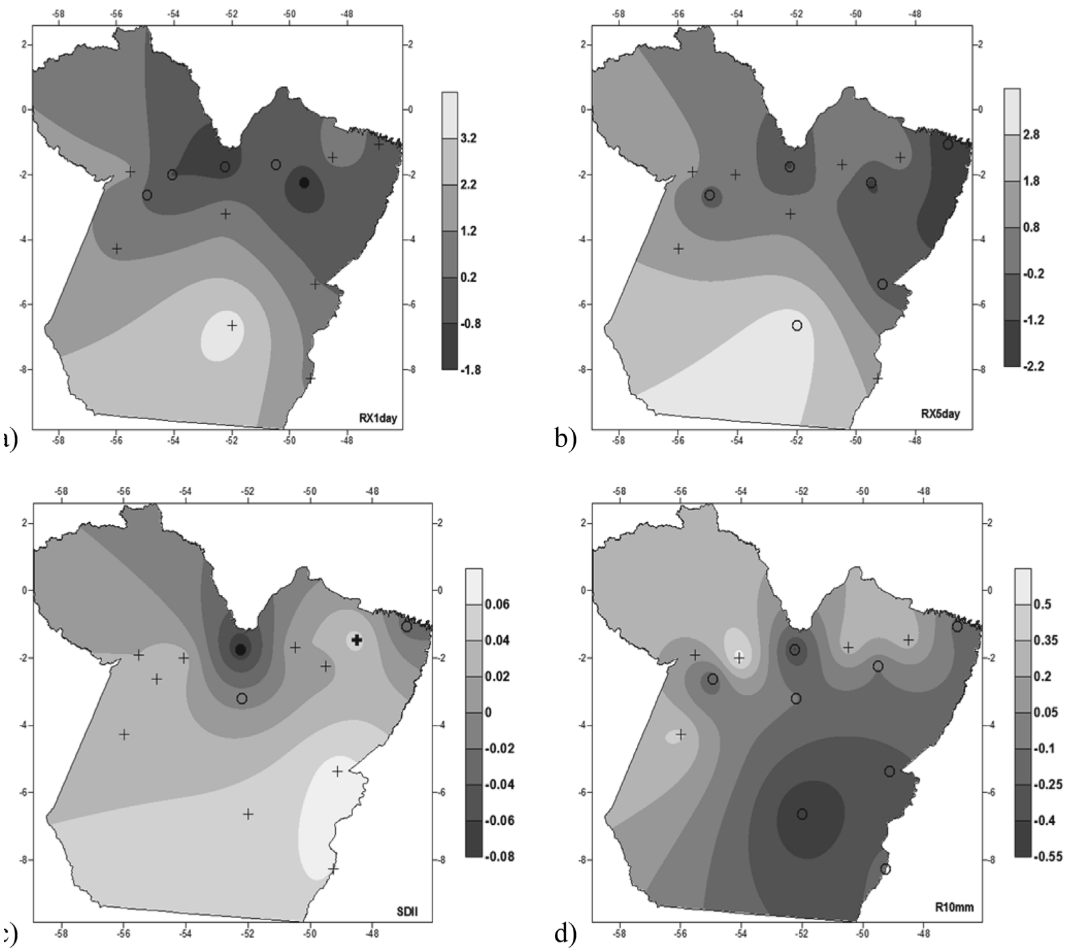

Figura 3 - Spatial variability of trends in extreme climate indices dependent of precipitation for the state of Pará, for the period 1970 to 2006, where: a) RX1day, b) RX5day, c) SDII, d) R10mm. The symbols correspond to (+) increasing trend not statistically significant, (**+**) increasing trend with statistical significance (O) decreasing trend not statistically significant and (•) decreasing trend with statistical significance, all with the significance at 5% level ($p \leq 0.05$).

minimum temperature (TNx) showed no statistically significant trend except for spring. Observing the seasonal variability of the minimum monthly amount of daily maximum temperature (TXn), it is possible to note that in summer and autumn there was no significant trend unlike the winter and spring seasons that showed positive trend. Note that all indices described above show increasing trends in all seasons for the city of Belém, especially the TNn that is statistically significant in all seasons. These results show that the days and nights in Belém tend to be warmer in the coming decades, which will result in an increasing water and energy demand, and may trigger public health problems such as increase in cases of parasites and vectors of disease and heat waves.

Regarding the seasonal behavior of TN10p, TN90p and TX10p indices (Table 5), it is possible to identify predominant increasing trends with statistical significance in all seasons, except TX10p in summer season. The index, TN10p, showed a statistically significant decreasing trend for all stations. In the summer season the reduction was -1.116 days/year, -1.023 days/year in the fall, -1.090 days/year in the winter and -1.085 days/year in the spring. The index for warmer nights (TN90p) showed an increase in all seasons, where the values of trends were 0.649 days/year in the summer, 0.657 days/year in the fall, 0.878 days/year in winter and 0.754 days/year in the spring. Assessing the seasonal behavior of the coldest days (TX10p), it is observed that autumn, winter and spring reduced the number of days with moderate temperatures, obtaining the values -0.317 days/year, -0.369 days/year and -0.351 days/year, respectively. These results corroborate those presented for the TNn, TNx and TXn indices.

Regarding TXx, TX90p, DTR, RX1day and RX5day indices which are showed in Table 5, only the daily temperature range (DTR) has a decreasing trend (-0.026 °C/year) in the winter season, in the other indices and seasons there were no statistically significant trends.

The seasonal values of the trends of daily maximum and minimum temperature (TXx and TNn) showed increasing trends statistically significant at 5% level. Therefore,

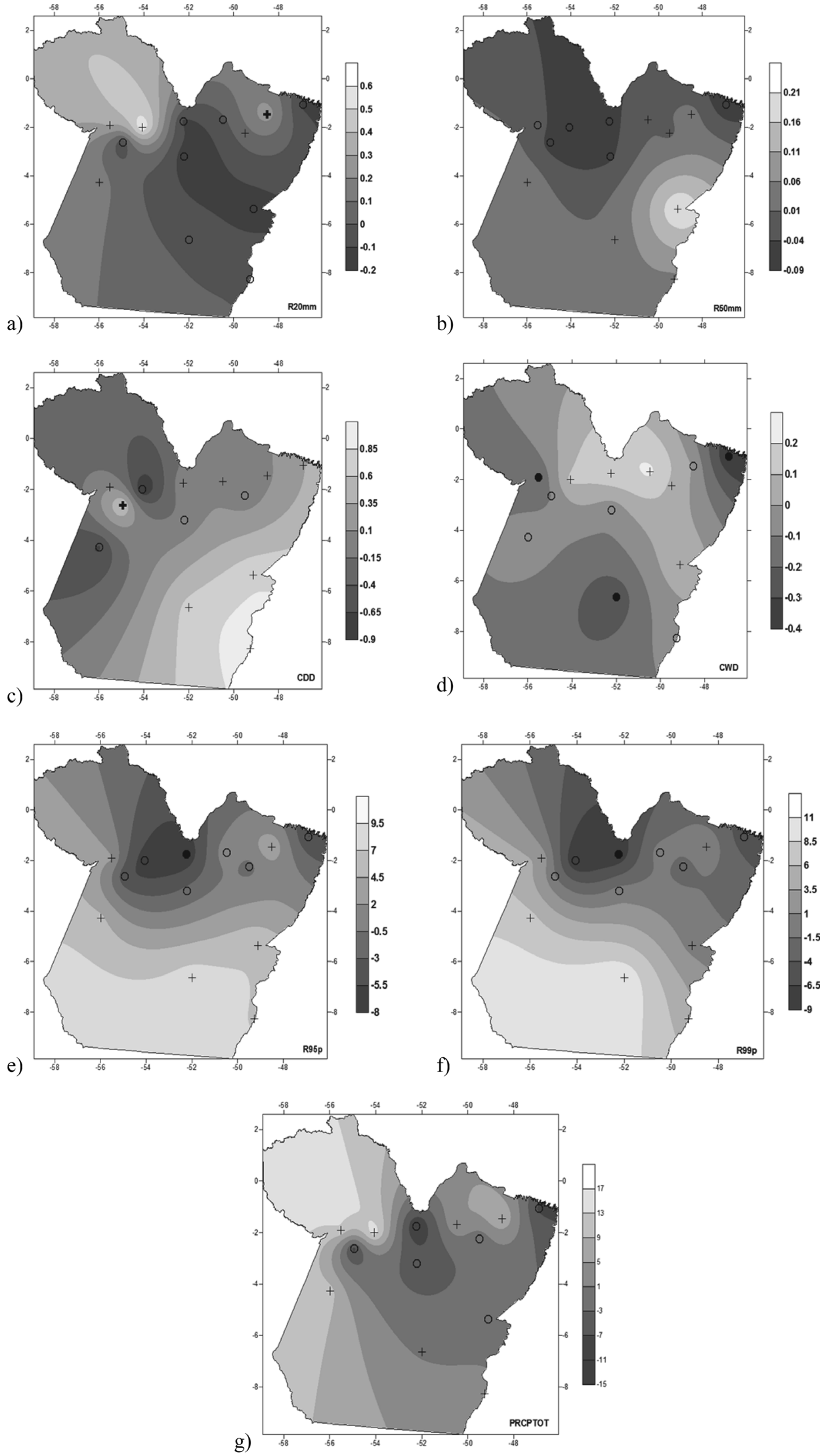

Figura 4 - Spatial variability of trends in extreme climate indices dependent of precipitation for the state of Pará, for the period 1970 to 2006, where: a) R20mm, b) R50mm, c) CDD, d) CWD, e) R95p, f) R99p and g) PRCPTOT. The symbols correspond to (+) increasing trend not statistically significant, (**+**) increasing trend with statistical significance (O) decreasing trend not statistically significant and (•) decreasing trend with statistical significance, all with the significance at 5% level ($p \leq 0.05$).

the maximum temperature is increasing seasonally, as seen in annual average analyzed in Table 5.

As the minimum and maximum temperatures showed increasing trends over the years and minimum temperatures experienced a greater increase, the daily temperature range (DTR) (Fig. 5a) was reduced at the rate of -0.020 °C/year, -0.028 °C/year, -0.026 °C/year and -0.022 °C/year for the summer, fall, winter and spring, respectively.

In the analysis of the seasonal behavior of the coldest nights (TN10p) (Fig. 5b), there is a decrease with high statistical significance during the period of 1970 to 1994, however, from 1994 on-wards no such significant trend was observed. For warmer nights (TN90p) (Fig. 5c), it is observed a reverse behavior of the coldest nights (TN10p), *i.e.*, warmer nights are increasing since 1991. The seasonal

Tabela 5 - Seasonal trends in climatic extremes indices of temperature and precipitation for the city of Belém, for the period 1970-2006.

Indices	Summer	Fall	Winter	Spring
TNn	0.046	0.055	0.056	0.048
TNx	0.039	0.038	0.038	0.034
TXn	0.029	0.026	0.040	0.042
TXx	0.004	0.011	0.014	0.023
TN10p	-1.116	-1.023	-1.090	-1.085
TN90p	0.649	0.657	0.878	0.754
TX10p	-0.159	-0.317	-0.369	-0.351
TX90p	0.396	0.366	0.600	0.788
DTR	-0.020	-0.028	-0.026	-0.022
Rx1day	-0.032	-0.240	0.195	0.120
Rx5day	-0.009	0.289	0.100	0.118

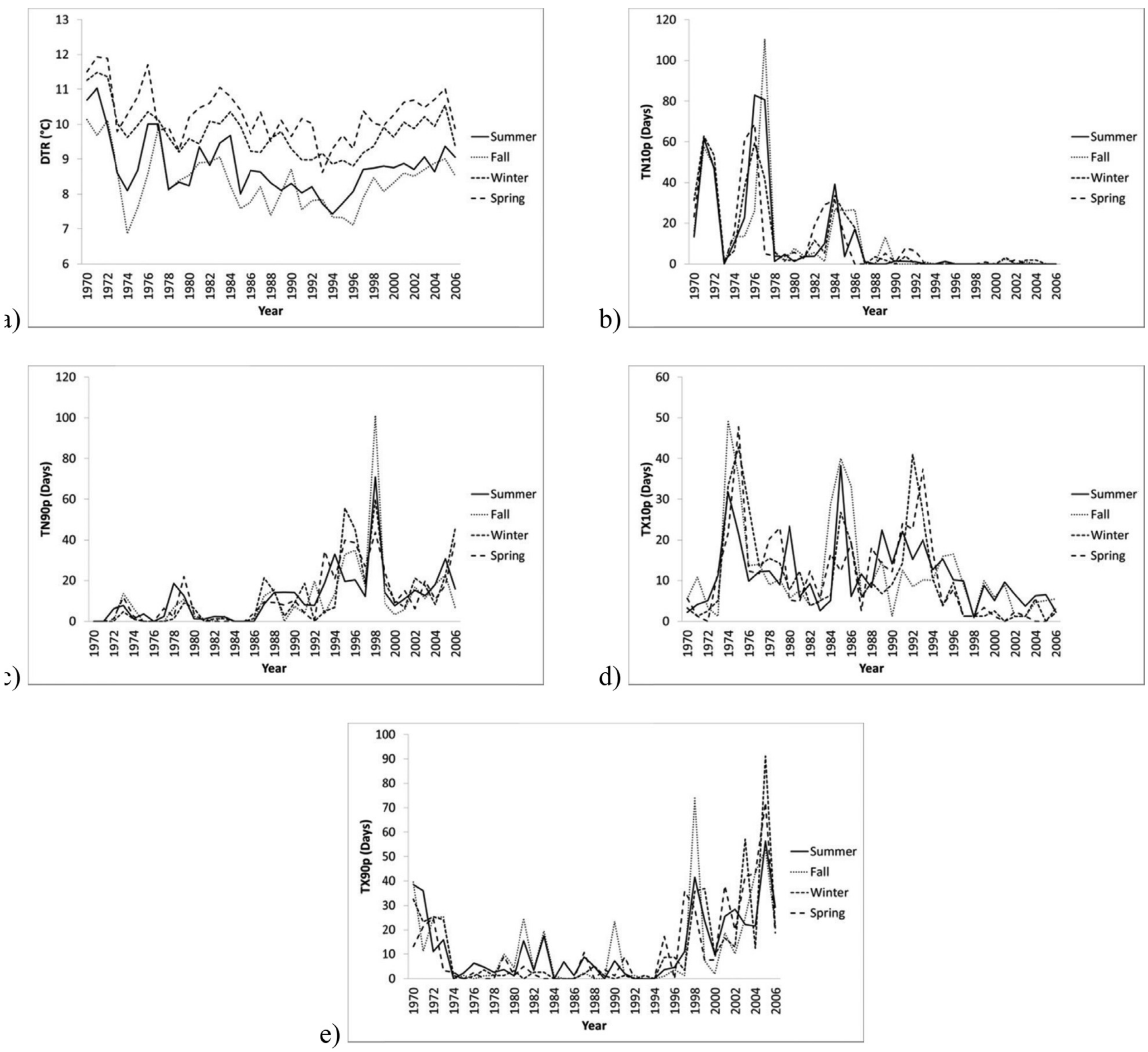

Figura 5 - Seasonal variability of climatic extreme indices statistically significant for the city of Belém-PA, for the period 1970 to 2006, where: a) DTR, b) TX10p, c) TX90p, d) TN10p, e) TN90p.

values of the coldest days (TX10p) (Fig. 5d) show a reduction in the number of days with moderate temperature during the year. Finally evaluating the seasonality of hot days (TX90p) (Fig. 5e), it appears that in all seasons of the year there is an increase in the number of hot days. From Fig. 5, it is possible to identify that from 1990s to the present day there has been an intensification of extreme rates of air temperature over the city of Belém. This information is important for public managers to take initiatives, especially in the public health and energy sectors, making proper planning to scenarios that may arise in the coming decades. It is known that some global circulation models suggest that Amazon may be vulnerable to extreme drought in response to movement of dislocations caused by global warming (Cox *et al.*, 2004 and Li *et al.*, 2006), and with potential acceleration of global warming it is possible to cause loss of tropical forests. Marengo *et al.* (2008) shows that the hydrological cycle of the Amazon region is of great importance because the region plays an important role in the functioning of regional and global climate, and its changes can affect the atmospheric moisture transport from the Amazon region to adjacent regions (Marengo *et al.*, 2008)

4. Conclusions

For the first time, analysis of changes in temperature and precipitation extremes is available for Pará State. The trends of extreme temperature and precipitation indices are good indicators of extreme events. Thus, trend analysis can identify if in a certain region the extreme climate events are increasing or decreasing. According to the results observed for temperature and precipitation for the state of Pará, it can be concluded that:

1) There is a trend of increasing temperature for the state of Pará, with more emphasis on the daily minimum temperature that occurs at night, thus the nights in Pará State have become warmer in recent decades;
2) The spatial distributions of extreme temperature indices for the State of Pará have identified that land use changes and cover, such as areas of agricultural expansion, *i.e.* the change in the natural landscape, can be justification for increase in some temperature indices in the study region;
3) The Pará State is clearly warming over the last decades and extremes of temperature are changing accordingly. Trends for the temperature indices show a large spatial coherence, with a moderate increase in daily maximum temperatures and a large increase in minimum temperatures. This results leads to a decrease of DTR.
4) The spatial coherence of precipitation indices was much lower. Nonsignificant trends of precipitation were found, with very mixed spatial patterns of positive and negative trends when individual stations were studied.
5) The seasonal behavior of the indices of climate extremes of temperatures and precipitation for the city of Belém-PA has shown that all indices presented increasing trends in all seasons, especially the TNn that is statistically significant in all seasons. Thus, the days and nights in Belém tend to be warmer in the coming decades, resulting in an increasing water and energy demand.

The results found in this study are important for understanding the extreme climate indices and future planning in the areas of public health and energy in the state of Para, which should suit to the scenarios of future warming, as well as, these results can contribute for validation of the regional modelling studies.

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