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Trend of annual temperature and frequency of extreme events in the MATOPIBA region of Brazil

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Abstract During the 1980s, a new agricultural frontier arouse in Brazil, which occupied part of the states of Maranhão, Tocantins, Piauí, and Bahia. Currently, this new frontier is known as the MATOPIBA region. The region went through intense transformations in its social and environmental characteristics, with the emergence of extensive areas of intensive agriculture and large herds. The purpose of this research was to study the climatic variabilities of temperature in the MATOPIBA region through extreme climate indexes of ClimAp tool. Data from 11 weather stations were analyzed for yearly air temperature (maximum and minimum) in the period of 1970 to 2012. To verify the trend in the series, we used methods of linear regression analysis and Kendall-tau test. The annual analysis of maximum and minimum temperatures and of the temperature extremes indexes showed a strong positive trend in practically every series (with p value less than 0.05). These results indicated that the region went through to a significant heating process in the last 3 decades. The indices of extreme also showed a significant positive trend in most of the analyzed stations, indicating a higher frequency of warm days during the year.

1 Introduction

During the mid-1980s, a new agricultural frontier arouse in Brazil, which occupied part of the states of Maranhão, Tocantins, Piauí, and Bahia. Currently, this new frontier is known as the MATOPIBA region, an acronym formed by the junction of the abbreviations of the four states. According to the Köppen's climate classification, the region has a tropical climate with dry winter, average annual temperature above 25 °C, and annual rainfall between 1000 and 1900 mm (Alvares et al. 2013).

Bounded on the west by the Legal Amazon and on the east by the northeastern semi-arid, the region has undergone intense transformations in its social and environmental characteristics.

Extensive areas of intensive agriculture (mechanized) and large herds emerged, thus creating a very different scenario from the native vegetation and small-scale family farming, predominant until the end of the 1980s in the MATOPIBA (Santos 2007). The Projections of Agribusiness developed by the Ministry of Agriculture, Livestock and Supply of Brazil indicates that the MATOPIBA region might reach a grain production of 16.7 million tons in 2020/2021, and a planted area of 7.5 million ha, but it might reach 10.0 million ha in its superior limit (MAPA 2011).

Another important factor of change in the environmental scenario of the region was the urban growth driven by the considerable growth in population, especially in the last 2 decades, which generated substantial changes in the occupation and land use. The city of Barreiras, for example, which is located in the west of the state of Bahia, presented an increase in population of approximately 680% from 1970 to 2013 (Pina and Mondardo 2013; IBGE 2013). The change of land

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use emerges as one of the main signatures of the new Antropocena era (Steffen et al. 2007). Across the planet, the change in land use is occurring in many different ways and to different degrees due to direct and indirect human activities. In the tropics, deforestation is widespread, as the land is being cleared for agriculture (DeFries et al. 2002). Baldocchi and Ma (2013) investigated the effect of land use on differences in air temperature analyzing energy flux measurements in two contrasting landscapes, an oak bush and an annual pasture, both growing under similar weather conditions. The potential average daily temperature of the air above the Oak Savannah aerodynamically rougher and optically darker was 0.5 °C warmer than above the annual pasture aerodynamically smooth and optically brighter. In general, these biophysical variables provided mechanistic information to diagnose and predict how changes in air temperature will follow the changes in the use or management of land. The study concludes that the change in land use is cause significant impact on the local climate of a region. Pires (2015) studied about how climate change and additional deforestation can affect the productivity of major commodities and pastures in Brazil until 2050. The simulations showed that, as well as in the case of soybeans, pasture productivity is predicted to decrease in central-northern Brazilian regions and slightly increase in southern regions. Spera et al. (2016) used remote sensing techniques to map land-use change across the Cerrado from 2003 to 2013. During this period, cropland agriculture more than doubled in area, with 74% of new croplands sourced from previously intact Cerrado vegetation. They find that these changes have decreased the amount of water recycled to the atmosphere via evapotranspiration each year.

In this context, the detailed study of meteorological data presents itself as an important indicator in the investigation of possible changes and climatic trends, especially of air temperature, demonstrating the degree of temporal consonance of these variables with the environmental changes on the surface. Therefore, the objective was to analyze and identify the changes in the climate of the region through the maximum and minimum temperature data.

As with virtually all contemporary research activities, arouse the need to use computational means for the analysis of meteorological data. Thus, in this research, we opted for the use of a new tool that could meet the objectives and methodology of this study: ClimAp—application for analysis of climatic series, version 2.1 (Salvador 2014). The first version of this application was developed as part of a research project at the postgraduate course in meteorology of the Federal University of Campina Grande (UFCG, acronym in Portuguese for *Universidade Federal de Campina Grande*), in the state of Paraíba, in partnership with the National Institute of Meteorology (INMET, acronym in Portuguese for *Instituto Nacional de Meteorologia*).

2 Area of study, data, and methodology

2.1 Area of study

The MATOPIBA region (Fig. 1) is located in an area between the Amazonian region and the northeastern semi-arid, comprising the south part of Maranhão, the central-eastern part of Tocantins, the southern part of Piauí, and the western part of Bahia (CONAB 2013; Mingoti et al. 2014; Miranda et al. 2014).

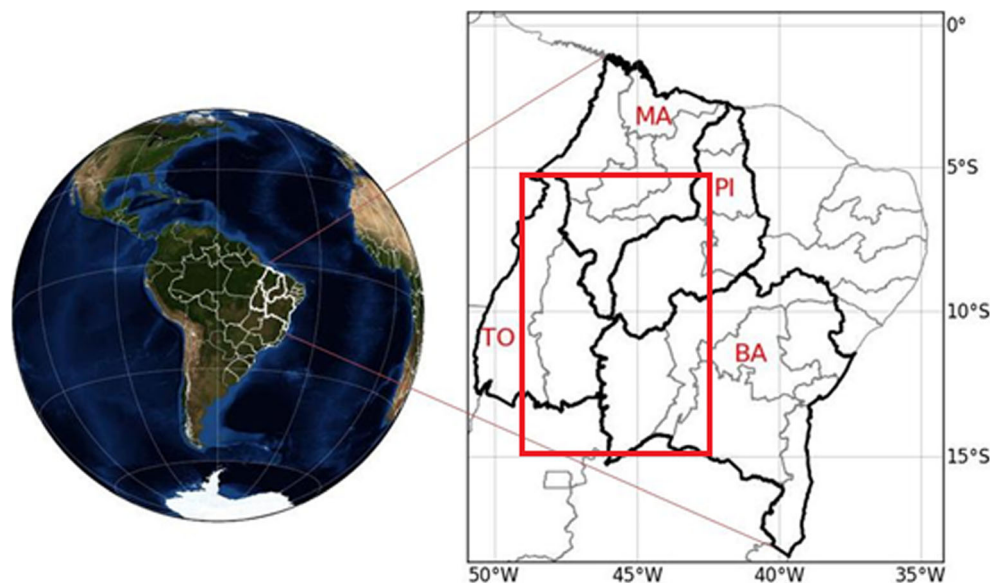**Fig. 1** Location of the MATOPIBA region
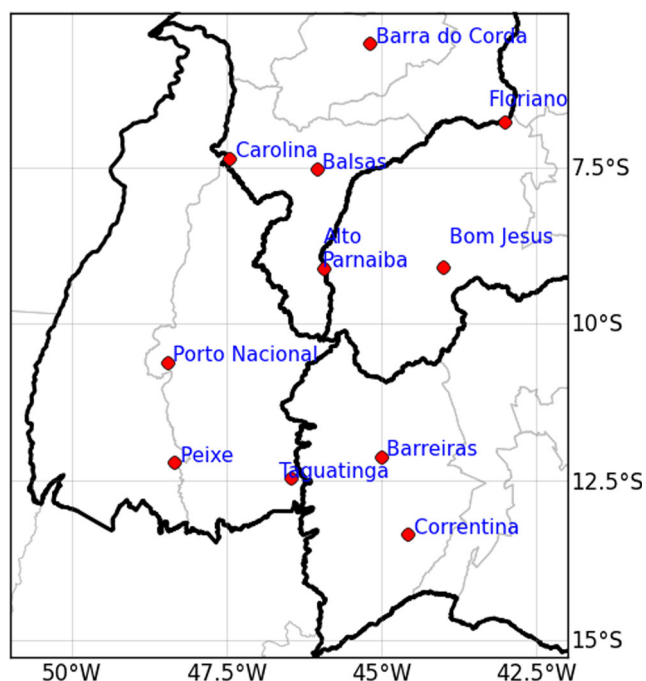
Table 1 Location of the weather stations

Locations	Coordinates		
	Lat.	Lon.	Alt (m)
Alto Parnaíba–MA	09° 06′ S	45° 56′ W	285.05
Balsas–MA	07° 32′ S	46° 02′ W	259.38
Carolina–MA	07° 20′ S	47° 28′ W	192.83
Barra do Corda–MA	5° 30′ S	45° 13′ W	153.00
Porto Nacional–TO	10° 43′ S	48° 25′ W	239.20
Peixe–TO	12° 00′ S	48° 22′ W	242.49
Taguatinga–TO	12° 24′ S	46° 25′ W	603.59
Floriano–PI	06° 46′ S	43° 01′ W	123.27
Bom Jesus–PI	09° 06′ S	44° 07′ W	331.74
Barreiras–BA	12° 09′ S	45° 00′ W	439.29
Correntina–BA	13° 20′ S	44° 37′ W	549.47

2.2 Data

In this study, we used series of observed daily data of air temperature (maximum and minimum) from 11 conventional weather stations of INMET relating to the period of 1970–2012. Table 1 shows the location of the weather stations, and Fig. 2 presents a map with the spatial distribution of the stations.

2.3 Methodology

From daily data of maximum and minimum temperatures, we derived series of annual maximum temperature and annual

Fig. 2 Map of the location of the weather stations

minimum temperature. It was also analyzed the annual frequency of extreme temperature events to detect possible trends in temperature in the region during the period from 1970 to 2012. The tool used for data analysis and calculation of the indexes was the ClimAp 2.1—application for analysis of climatic series (Salvador 2014). The choice of ClimAp was due to the quality of its graphics output and easy to use. Ten indexes were used in this study:

i.   Tmax: Annual mean maximum temperature (°C)
ii. Tmin: Annual mean minimum temperature (°C)
iii. Tmax95p: Number of days with maximum temperature ≥ 95th percentile (occurrences/year)
iv. Tmin95p: Number of days with minimum temperature ≥ 95th percentile (occurrences/year)
v.   Tmax5p: Number of days with maximum temperature ≤ 5th percentile (occurrences/year)
vi. Tmin5p: Number of days with minimum temperature ≤ 5th percentile (occurrences/year)
vii. Tmaxx: Highest maximum temperature in each year (°C)
viii. Tmaxi: Lowest maximum temperature in each year (°C)
ix. Tminx: Highest minimum temperature in each year (°C)
x.   Tmini: Lowest minimum temperature in each year (°C)

These indexes were statistically analyzed using linear regression methods (LR) and Kendall-tau test to identify trends in their historical series.

The LR (Stanton 2001; Rencher and Christensen 2012) considers that the relation of the response to the variables is a linear function of some parameters. This is a mathematical process by which are derived the parameters α and β of a function $f(X)$. These parameters determine the characteristics of the function that relates a variable Y with another X, which is represented by a line called "line of regression." This line

Table 2 Annual averages of maximum and minimum temperatures

Locations	Annual averages (°C)	
	Max	Min
Alto Parnaíba–MA	32.88	20.35
Balsas–MA	32.40	21.58
Carolina–MA	32.55	21.97
Barra do Corda–MA	32.39	21.30
Porto Nacional–TO	33.39	21.62
Peixe–TO	32.97	20.87
Taguatinga–TO	31.62	20.54
Floriano–PI	33.69	22.72
Bom Jesus–PI	33.46	20.30
Barreiras–BA	32.29	18.73
Correntina–BA	31.13	17.95

Table 3 Results of linear regression and of Kendall-tau test for maximum temperature (Tmax)

Location	LR		Kendall		Trend
	r	p value	tau	p value	(+S, −S, +NS, −NS, NT)[a]
Alto Parnaíba–MA	0.75	0.0000	0.59	0.0001	+S
Balsas–MA	0.76	0.0000	0.57	0.0001	+S
Carolina–MA	0.85	0.0000	0.65	0.0000	+S
Barra do Corda–MA	0.76	0.0000	0.59	0.0001	+S
Porto Nacional–TO	0.77	0.0000	0.59	0.0001	+S
Peixe–TO	0.75	0.0000	0.53	0.0001	+S
Taguatinga–TO	0.76	0.0000	0.53	0.0001	+S
Floriano–PI	0.74	0.0000	0.58	0.0001	+S
Bom Jesus–PI	0.64	0.0000	0.49	0.0001	+S
Barreiras–BA	0.61	0.0001	0.44	0.0002	+S
Correntina–BA	0.71	0.0000	0.56	0.0001	+S

[a] +S significant positive trend, −S significant negative trend, +NS no significant positive trend, −NS no significant negative trend, and NT no trend

explains, generally and theoretically, the relation between these two variables, X and Y. The equation can be defined as follows:

$$Y = \alpha + \beta X, \tag{1}$$

where:

Y represents the explained variable (dependent) or value you want to estimate

α is a constant that represents the interception of the line with the vertical axis

β is a constant that represents the inclination or angular coefficient of the line

X is the explanatory variable (independent) and represents the explicative factor in the equation.

Student's t test was used to obtain the statistical significances of the correlation coefficients. It was used in the statistical significance level of 95% ($p < 0.05$). Thus, it was obtained the critical correlation coefficient (r_c), which is a value for which the hypothesis is accepted or not accepted. Statistics.

The Kendall-tau correlation coefficient is a measure of association for ordinal variables (Kendall 1948; Abdi 2007). An advantage of τ over the LR is the fact that it is not influenced by variance or by *outliers*, since it is a bimodal coefficient (Eq. 2). The coefficient is defined as:
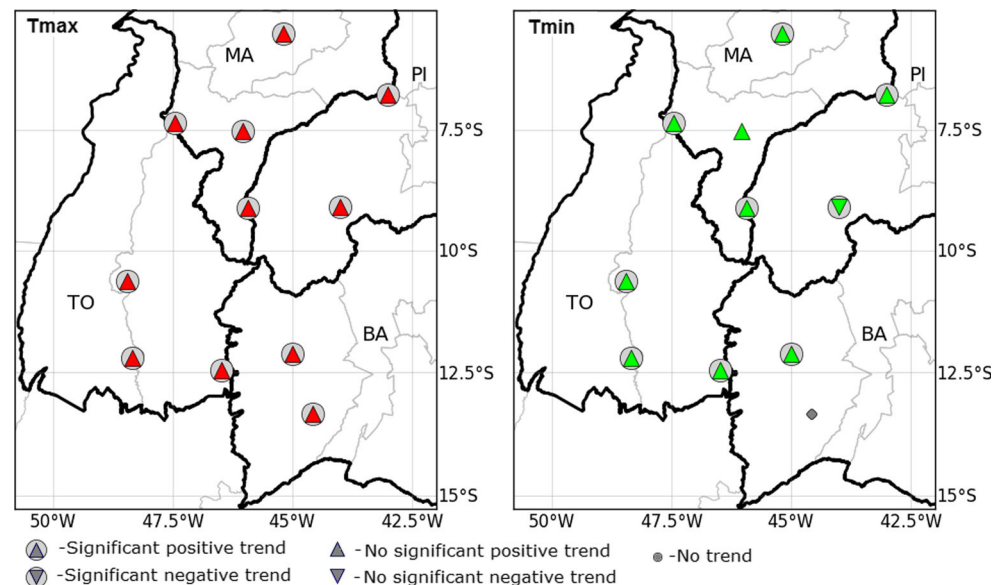

Fig. 3 Trend of the indexes Tmax and Tmin

Table 4 Analysis of linear regression and of Kendall-tau test for minimum temperature (Tmin)

Location	LR		Kendall		Trend
	r	p value	tau	p value	$(+S, -S, +NS, -NS, NT)^a$
Alto Parnaíba–MA	0.63	0.0001	0.45	0.0002	+S
Balsas–MA	0.25	0.0981	0.17	0.1091	+NS
Carolina–MA	0.82	0.0000	0.63	0.0000	+S
Barra do Corda–MA	0.63	0.0001	0.36	0.0010	+S
Porto Nacional–TO	0.85	0.0000	0.70	0.0000	+S
Peixe–TO	0.63	0.0001	0.46	0.0001	+S
Taguatinga–TO	0.77	0.0000	0.62	0.0000	+S
Floriano–PI	0.58	0.0001	0.44	0.0002	+S
Bom Jesus–PI	−0.41	0.0065	−0.28	0.0094	−S
Barreiras–BA	0.66	0.0000	0.48	0.0001	+S
Correntina–BA	0.09	0.5690	0.02	0.8260	NT

[a] +S significant positive trend, −S significant negative trend, +NS no significant positive trend, −NS no significant negative trend, and NT no trend

$$\tau = \frac{n_c - n_d}{\frac{1}{2}n(n-1)}, \qquad (2)$$

where n_c is the number of concordant pairs, and n_d is the number of discordant pairs of the data set. Alternatively, τ is the probability that two points drawn from the joint distribution are concordant, in other words:

$$\tau = prob\left[\left(x-x'\right)\left(y-y'\right) > 0\right] \qquad (3)$$

Its values range from −1 to 1, with 1 indicating the maximum direct concordance, −1 the maximum inverse concordance, and 0 indicating the lack of concordance.

The null hypothesis H_0 means that there is not a trend in the series, while the alternative hypothesis, H_1, indicates the opposite. In this study, the null hypothesis (H_0) is not rejected

when the statistical significance test (p value) indicates a value higher than the maximum significance level (α) of 5%, in other words, p value ≤ 0.05 in at least one of the tests.

3 Analysis and results

3.1 Annual temperature

Table 2 shows that annual mean temperatures are typical of tropical regions with maximum values exceeding 30 °C. The averages were calculated using the period of 1970–2012.

All series of maximum temperature presented the same pattern of positive trend, with significant trend for the significance level of 95%, both in the LR analysis as in the Kendall-tau test (Table 3). The maps in Fig. 3 show the homogeneous spatial aspect of trends in the period. The fact that there is a

Fig. 4 Annual maximum and minimum temperatures of *Bom Jesus/PI* with line of linear regression
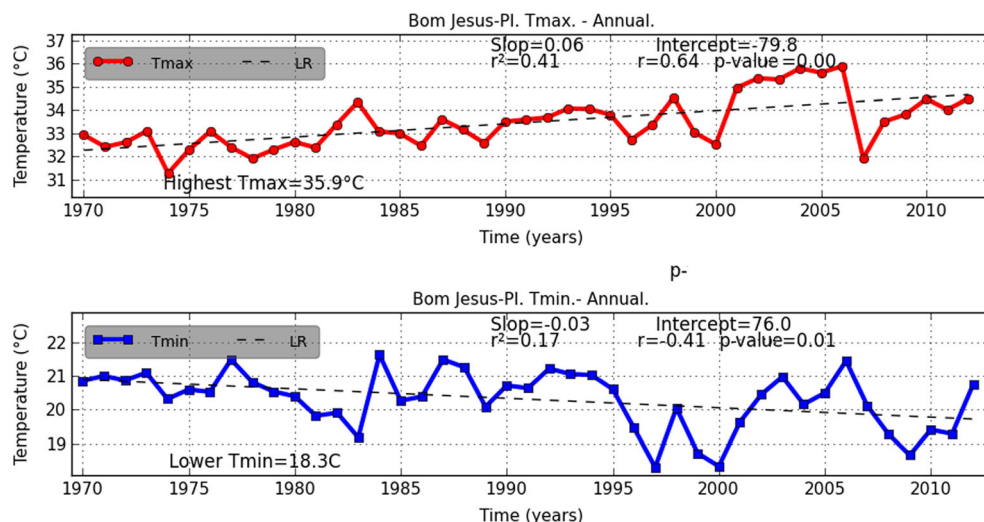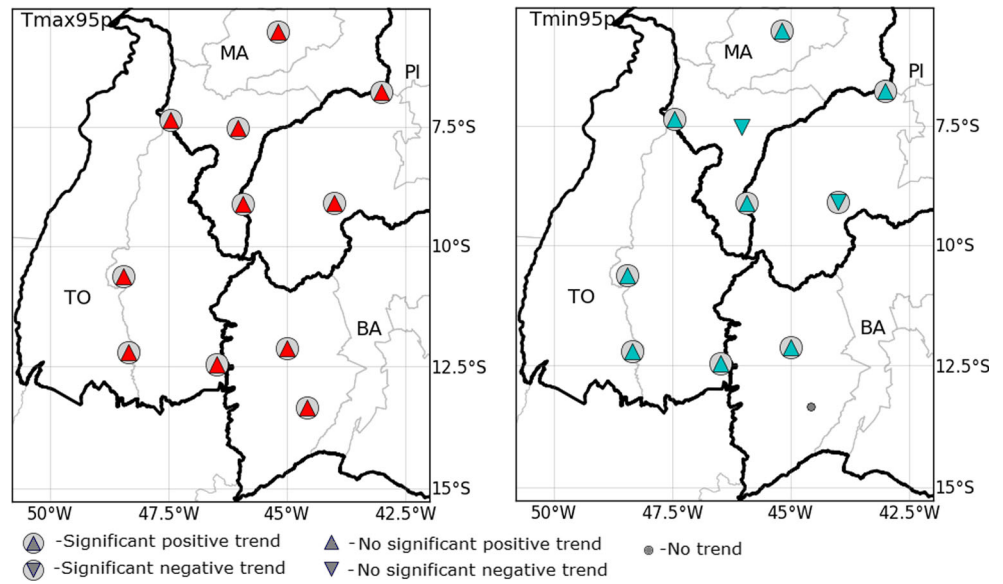
Fig. 5 Trend of the indexes
Tmax95p and Tmin95p

pattern of positive trend of maximum temperature demonstrates that there has been, in the region, a warming period during the course of the last decades, with gradually warmer years, illustrating that this is not a punctual phenomenon, but a regional behavior.

In every statistical significance test, the *p* value was inferior to the significance level of 0.05 (reliability level of 95%), both in the LR analysis as in the Kendall-tau correlation. Table 3 shows that all Pearson correlations (*r*) found for LR above 0.6 were high for an $r_c = 0.29$ in series of 43 years. The Kendall-tau test also presented significant correlations above 0.43 with *p* value much lower than the limit of 0.05.

Most series of minimum annual temperature also presented a strong positive trend behavior (Table 4). However, the locality of *Bom Jesus/PI* presented a negative trend with statistical significance in both tests. In the series of the locality of *Balsas/MA*, no trend of statistical significance was detected for the analyzed period (Fig. 3). In the series of the locality of *Correntina/BA*, no trend was detected for the analyzed period.

Fig. 6 Tmax95p and Tmin95p of
Alto Parnaiba/MA with line of
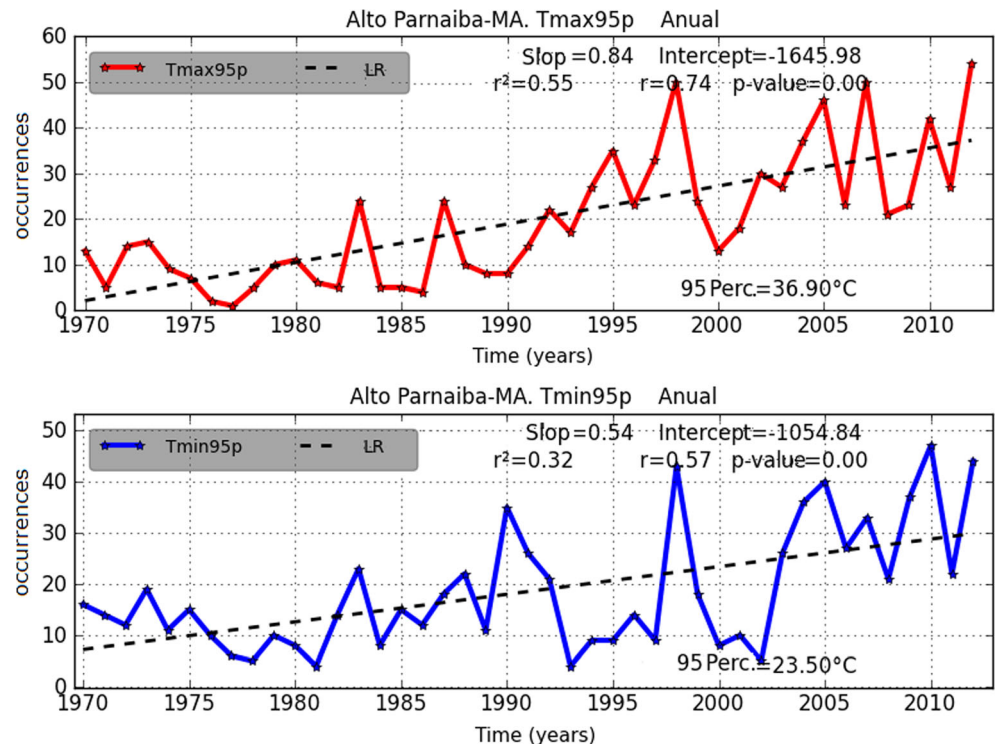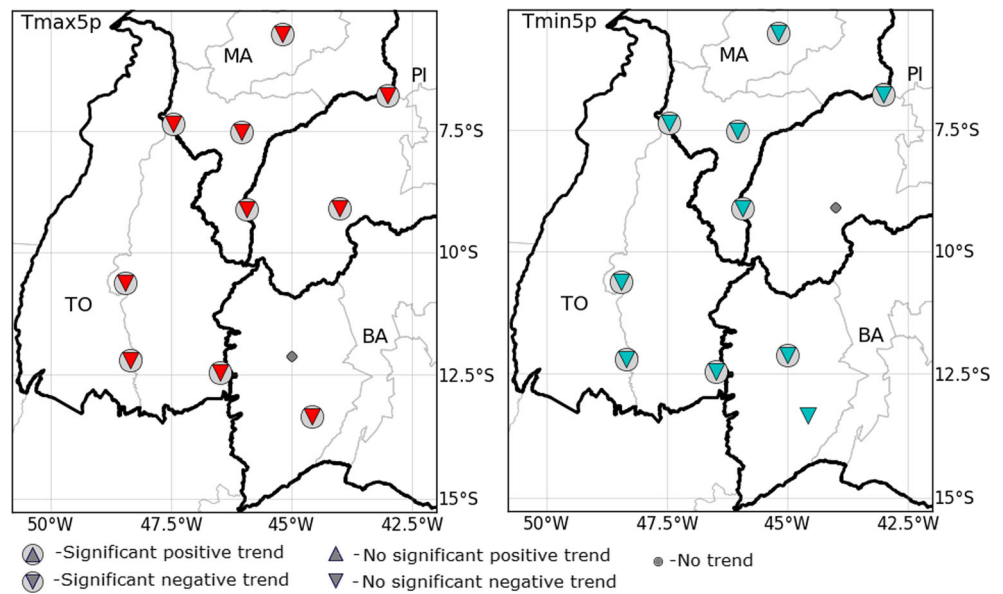linear regression

Fig. 7 Trend of the indexes Tmax5p and Tmin5p

This particularity in *Bom Jesus/PI*, with positive trends in maximum temperature and negative in minimum temperature (Fig. 4), possibly occurred due to anthropic activities of deforestation and urbanization, with its own characteristics and different from the other MATOPIBA locations, producing an effect similar to desertification. In other words, it was possibly produced a decrease of the humidity column of the atmosphere above the area without the vegetation. Therefore, at night, there is a greater loss of the terrestrial radiation, leading the area to a cooling. During the day, there is an excessive heating of the area, since there is a decrease of the energy used for evaporation, and the extra energy warms the surface and the atmosphere, increasing the temperature.

3.2 Indexes of extremes

The Tmax95p and Tmin95p indexes that represent, respectively, the number of occurrences per year with maximum and minimum temperature equal or above the 95 percentile indicate that the frequency of very warm days has increased significantly. In both indexes predominated the series with statistically significant positive trends, with the exception of three series of Tmin95p: *Balsas/MA* and *Bom Jesus/PI*, with negative trend without statistical significance, and *Correntina/BA*, without trend (Fig. 5).

The Tmax95p and Tmin95p indexes, in the series with significant trend, had their angular coefficients indicating a rate of elevation of these extremes between 0.5 and 1.5

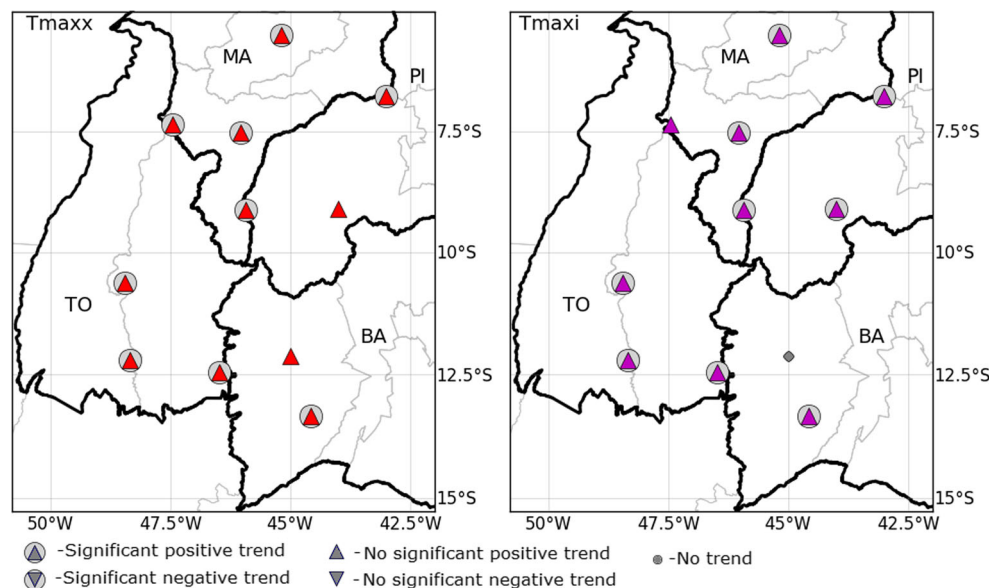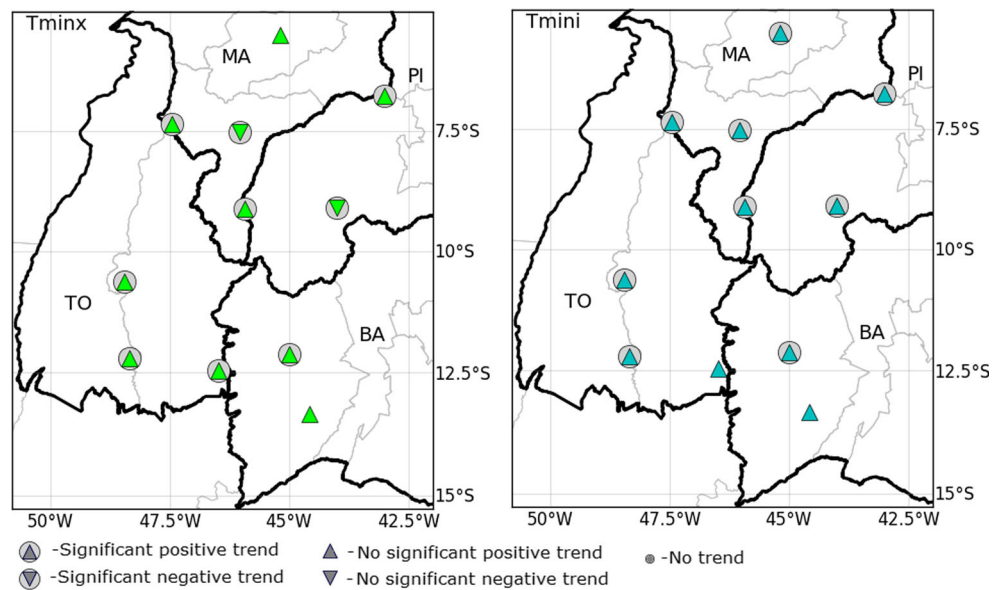**Fig. 8** Trend of the indexes Tmaxx and Tmaxi

Fig. 9 Trend of the indexes Tminx and Tmini

occurrences/year. Figure 6 shows the example of the *Alto Parnaíba/MA* series, in which a strong trend to increase can be observed, with 0.84 occurrences/year for Tmax95p (95th percentile = 36.9 °C) and 0.54 occurrences/year for Tmin95p (95th percentile = 23.5 °C).

The indexes of occurrences of maximum and minimum temperatures equal or below the 5% percentile indicated a decrease in the number of occurrences per year in almost all of the analyzed series. Only Tmax5p in *Barreiras/BA* and Tmin5p in *Bom Jesus/PI* did not present trend (Fig. 7).

The Tmax5p and Tmin5p indexes in the series with statistically significant negative trend had their angular coefficients indicating a reduction rate between −0.25 and −0.9 occurrences/year. Just as, for example, in *Porto Nacional/TO*, with decrease of −0.35 occurrences/year for Tmax5p, with 5th percentile = 28.3 °C, and −0.84 occurrences/year for Tmin5p, with 5th percentile = 17.5 °C. These results indicate that, with each passing year, the occurrence of days and nights with mild temperatures has been increasingly rare.

The Tmaxx and Tmaxi indexes (highest and lowest maximum temperature in each year) had positive trend in almost every series (Fig. 8), except for the Tmaxi series in *Barreiras/BA*, which presented no trend. The Tminx and Tmini indexes in *Balsas/MA* and *Bom Jesus/PI* also presented positive trend in almost all localities (Fig. 9), except for the Tminx index, which presented a statistically significant negative trend.

In general, when checking the record series of maximum and minimum temperatures and the frequency of very warm days (95th percentile), the results demonstrate that there has been a process of increase of these extremes of air temperature. On the other hand, the frequency of cooler days (5th percentile) per year has presented negative rates, indicating that the region has been more susceptible to the occurrence

of days and nights with more elevated temperatures in the last decades.

4 Conclusions

Most indexes of air temperature presented strong trend for increase. This heating may be associated to large-scale factors, such as global warming, and local factors, such as anthropic actions. Researchers as, for instance, Santos (2011), for the state of Utah in the USA; Caesar et al. (2011) for the Indo-Pacific area; and Silva et al. (2012) for the state of Bahia, found similar results. However, these researchers observed a greater homogeneity of increase in minimum temperature while, in the present study, it was for maximum temperature.

Likewise, the extreme temperature climate indexes also presented a rise in the frequency of warm days per year. This warming of the air is coherent with the effects of anthropogenic action over the local environment (Steffen et al. 2007; Spera et al. 2016).

The results demonstrate that the environmental change process, driven by the socioeconomic growth in the MATOPIBA region, strongly affected the climatic characteristics around the weather stations, which registered a gradual increase in annual temperature and in the frequency of very warm days in the region.

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