Study on changing trends in climatic extremes in the Brazilian territory

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Abstract. *It is noticeable that the climate trends are changing over time. The effects of this phenomenon are felt and commented on by the entire population, mainly when there is an increase in climatic extremes, for example, in the maximum or minimum temperature of a given year. Thus, this work presents a study on trends in extreme climate indices in 11 different regions of Brazil. These indicators measure, for example, the percentage of hot days and hot nights, the maximum, minimum and average temperatures, in addition to the total annual precipitation and consecutive very wet / rainy days. Data from each Brazilian climatic regions, from 1961 to 2019, were used. Statistical tests were used to indicate not only the existence of trends (increasing or decreasing), but also the confidence interval of these trends, as well as the value of the increase. The results indicate a trend of significant increases in the percentage of hot days and hot nights, increase in maximum, minimum and average temperatures in the different regions studied. Some seasons of the year showed changes in precipitation events, increasing the concentration of rain in short periods, besides an increase in the number of consecutive days without precipitation.*

Keywords: Climate change, climatic extremes, trend analysis, timeseries.

1. Introduction

One of the themes that occupies the scientific and academic circles in recent years is the study of climate change in the world. As the climate continues to change, the risks associated with climate extremes take on an ever greater importance. By definition, climate extremes are rare events, but are becoming more likely as changes continue to affect the global climate [Easterling et al. 2016]. Some of the strongest signs of climate change related to extremes on record are reductions in the number of cold days and nights and increases in the number of warm days and nights, as well as an increase in the number of heavy precipitation events. The climatological study of the past is extremely important, allowing us to understand the present, in addition to contributing to better research on the behavior of the climate in the future.

Knowledge of the distribution and volume of precipitation throughout the year is a determining factor for an efficient management of domestic and industrial water supply, in addition to the generation of electricity in countries that depend directly on hydroelectric power. Likewise, the extremes and average values of temperature directly influence the quality of life of the population and also the economic activities, such as agricultural planning. While certain activities are better developed in regions with lower temperatures, others need higher temperatures.

The analysis of climate observations recorded at regular periods over time becomes essential when the objective is to predict or identify cycles and trends. In fact, the time series may contain information about past observations that allow researchers to forecast future behaviour. The objective of analyzing a time series is to identify non-random patterns in the variables of interest. These analyses, when applied to climate series, can help identify relevant trends, especially in indicators of extreme climatics, such as the number of days with maximum or minimum temperatures, consecutive number of dry days, or rainfall concentration in shorter periods.

There are different methodologies and techniques used to identify trends in climate, mainly related to precipitation and temperature. There are different statistical methods in the literature that can be used to identify positive or negative trends in time series. In the context of climate series, the Mann-Kendall tests [Mann 1945, Kendall 1975] and Sen's slope [Sen 1968] are frequently used.

To create a set of indices that can be used to allow comparisons between regions and identify possible climate change, the World Meteorological Organization (WMO) created a working group called Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI), which defines 27 climate indicators as considered central, based on daily measurements, 16 referring to temperature and 11 referring to precipitation. Since the extremes used as indicators of climate change have a much broader context than traditional indicators, this indicator model was chosen because of its wide use in extreme weather studies that identified past, current and future climate trends, as noted by [Nóbrega et al. 2015] and [Natividade et al. 2017].

This work presents a methodology for verifying the existence of significant trends in climate extremes, mainly focusing on extreme trends related to temperatures and rainfall. Objectively, indicators that measure the number of hottest and coldest days of the year, maximum and minimum temperature of the year were used, in addition to the average temperature. In the context of rainfall, the indicators measure the number of consecutive days with and without rain, maximum daily volume of rainfall and annual amount of precipitation. The occurrence of significant changes in these indicators has a considerable impact on the population's life. The increase in the number of days of drought, for example, has important consequences for water consumption, in addition to impacting the generation of electricity by hydroelectric plants. The increase in the maximum annual temperatures or in the number of hot days in a year influences energy consumption habits and generates relevant impacts on agriculture.

In this paper, we calculate and analyze these indicators for 11 Brazilian cities, each with a different climate configuration, to identify whether trends are changing throughout the Brazilian territory. Results are analyzed using confidence intervals compatible with other works in the literature.

The remainder of this text is organized as follows. Section 2 presents a literature review. Section 3 describes data acquisition and preprocessing analysis. Section 4 describes trend analysis methods. Section 5 presents the experiments and the results obtained. Section 6 presents our conclusions.

2. Related Works

The literature includes various approaches for climate change detection, applied to specific regions. This article aims to gather the best practices from previous work that involve time series analyses, and applies such techniques to identify change trends in extreme indices, for a variety of regions in Brazil.

Statistical analysis of time series data is used by many works. A study seeking correlations with the dynamics of use and evolution of occupation in the upper Uberaba/MG basin in the last three decades [Santos and Nishiyama 2016] identifies significant trends of decreasing annual rainfall totals, as well the rainfall in the dry period, using different statistical tests. Changes in the hydrological and climatic behavior in the Parnaíba river basin, in Northeastern Brazil, are also identified by [Penereiro and Orlando 2013]. Considering the complexity of linking changes to the natural and anthropogenic effects of climate, the analysis presents alerts to the care that should be taken when observing the possible causes of changes in time series. On the other hand, the experiments confirm the existence of trends of change in the maximum, minimum and average temperature series, in addition to the annual precipitation.

Using data from the city of Viçosa (MG), [Avila-Diaz et al. 2020] present a review of trend analysis methods in extreme climate indices. From the study, the authors demonstrate the existence of increasing trends at a significance level of 5% in the extremes of annual temperature, as well as an increase in the frequency of torrential rains during the summer and a reduction during the winter. Along the same lines, [Alencar et al. 2014] perform an analysis in the database of different climate indicators in the city of Catalão/GO, using non-parametric tests such as Mann-Kendall and Sen's Slope. The methods identify an evolution of the maximum and minimum temperature, with statistically significant trends of increase for both extreme temperature indices, and also a decrease of relative humidity, in addition to significant increases observed in the reference evapotranspiration for different months along the year and for the annual series.

Next section presents the methodology used in this work for data acquisition and analysis, expanding on the works mentioned, and covering data from several climatic regions throughout Brazil, so that comparative analyses can be conducted.

3. Data acquisition and analysis

The National Institute of Meteorology (INMET) has more than 400 meteorological stations, conventional and automatic, spread throughout the Brazilian territory. In this study, were used daily data from 11 different meteorological stations as shown in Figure 1 with their geographic locations. These cities were chosen because they represent different climatic regions of the Brazilian territory, most were chosen cities with a more extensive database and with the smallest possible amount of missing data.

City/State	Climate region
(1) Araxá/MG	Semi-wet mild mesothermic
(2) Barbalha/CE	Semi-arid hot 6-8 dry months
(3) Belém/PA	Hot wet
(4) Belo Horizonte/MG	Sub-hot semi-moist with 4 to 5 dry months
(5) Cabrobó/PE	Semi-arid hot 9-11 dry months
(6) Caparaó/MG	Mild mesothermic wet
(7) Cuiabá/MT	Hot semi-moist
(8) Curitiba/PR	Mild mesothermic superwet
(9) Manaus/AM	Hot superwet
(10) São Simão/SP	Sub-hot wet
(11) São Paulo/SP	Sub-hot superwet

Figure 1. Stations used and location

The eleven climatic regions chosen for this study can be identified in (Figure 2).

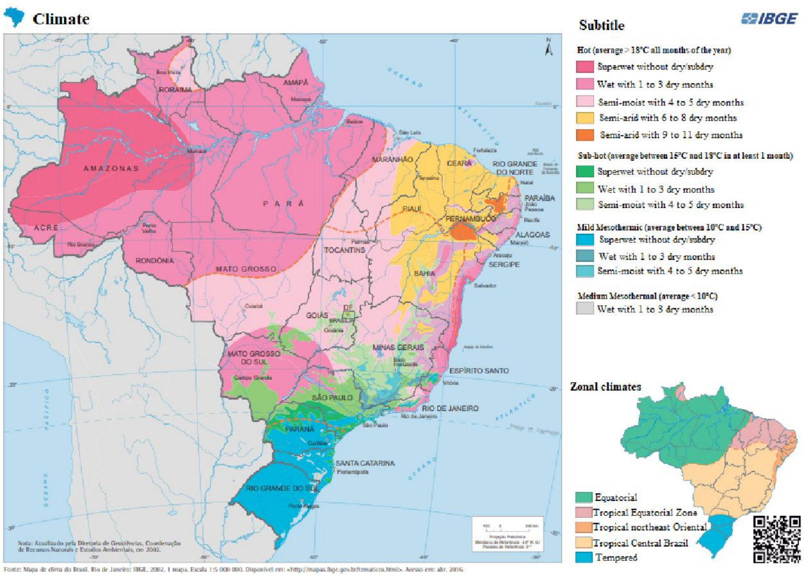

Figure 2. Brazil weather chart. Adapted from [IBGE 2002]

To perform the calculation of indicators of climatic extremes, the study uses parameters from the Meteorological Database of INMET (BDMEP)[1]. The parameters are date, daily minimum temperature, daily maximum temperature and total daily precipitation.

[1]https://bdmep.inmet.gov.br/

Table 1 contains the definition of the extreme temperature indicators used in this work.

TXx	Hottest day	Highest daily maximum temperature value	°C
TX10P	Cold days	Percentage of days with minimum daily temperature <10th percentile of the period	% of days
TX90P	Hot days	Percentage of days with maximum daily temperature >90th percentile of the period	% of days
TNn	Coldest night	Lowest daily minimum temperature value	°C
TN10P	Cold nights	Percentage of days with minimum daily temperature <10th percentile of the period	% of days
TN90P	Hot nights	Percentage of days with minimum daily temperature >90th percentile of the period	% of days

Table 1. Extreme temperature indicators recommended by ETCCDMI

Table 2 contains the definition of extreme rainfall indicators used in this work. Both set of extreme indices were obtained from ETCCDMI site[2].

PRCPTOT	Total precipitation per period	Total annual precipitation on wet days with daily precipitation rate >1mm	mm
R95P	Very rainy days	Total annual precipitation when the daily precipitation rate >95th percentile of precipitation for the selected period	mm
RX1DAY	Maximum precipitation in 1 day	Highest volume of rain recorded in 1 day	mm
RX5DAY	Maximum precipitation in 5 days	Highest volume of rain recorded in 5 consecutive days	mm
CDD	Consecutive dry days	Maximum number of consecutive dry days with daily precipitation rate >1mm	days
CWD	Consecutive wet days	Maximum number of consecutive wet days with daily precipitation rate <1mm	days

Table 2. Extreme rainfall indicators recommended by ETCCDMI

In addition to the aforementioned indices, the mean annual temperature (Tmean) was calculated for all cities.

The time series of daily data obtained from BDMEP were transformed into subseries for each respective index of interest, for example, for TXx (Table 1), a new time series was generated containing the maximum temperature recorded for each year in the main time series. In a similar way, done for RX5day (Table 2), a new series is generated containing the largest amount of precipitation recorded in 5 days of each year of the main time series. All indices were calculated using the computational package RClimdex [Zhang and Yang 2004].

4. Methods of trend analysis

The main objective of trend analysis is to identify the existence of significant trends of increasing or decreasing in a data series. Tests for detecting these trends can be classified as parametric and non-parametric methods. The parametric tests require the data to be independent and normally distributed, while non-parametric tests only require the data to be independent [Mirabbasi et al. 2020]. For this study, the non-parametric Mann-Kendall and Sen's Slope tests were used.

[2]http://etccdi.pacificclimate.org/list_27_indices.shtml

4.1. Mann-Kendall Test

The Mann-Kendall test [Mann 1945, Kendall 1975] is a robust, sequential, non-parametric method used to determine whether a given data series has a statistically significant tendency to change its pattern of data behavior over time. As it is a non-parametric method, it does not require normal data distribution [Yue et al. 2002]. Another advantage of this method is that it is little influenced by abrupt changes or non-homogeneous series [Zhang et al. 2009, Neeti and Eastman 2011].

The method is based on the rejection or not of the null hypothesis (H_0), that there is no trend in the data series, adopting a significance level (α). The level of significance can be interpreted as the probability of making the error of rejecting H_0 when it is true. The statistical variable S, for a series of n data from the Mann-Kendall test, is calculated from the sum of the signs (sgn) of the difference between pairs of all values in the series (x_i) in relation to their future values (x_j), expressed in Equations 1 and 2.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{1}$$

$$sgn(x_j - x_i) = \begin{cases} +1 & \text{if} \quad x_j > x_i \\ 0 & \text{if} \quad x_j = x_i \\ -1 & \text{if} \quad x_j < x_i \end{cases} \tag{2}$$

When $n = 10$, the variable S can be compared with a normal distribution, in which its variance, $Var(S)$, can be obtained from Eq. 3, in which t_i represents the number of repetitions of an extension i. For example, a historical series with three values equal to each other would have 1 repetition of extension equal to 3, or $t_i = 1$ and $i = 3$.

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(i)(i-1)(2i+5)}{18} \tag{3}$$

The index Z_{MK}, generated by Mann-Kendall test, follows the normal distribution, in which its mean is equal to zero. Positive values indicate an increasing trend and negative ones, a decreasing trend. According to the sign of S, the index Z_{MK} of the normal distribution is calculated from Eq. 4:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{for} \quad S > 0, \\ 0 & \text{for} \quad S = 0, \\ \frac{S+1}{\sqrt{Var(S)}} & \text{for} \quad S < 0. \end{cases} \tag{4}$$

As it is a two-tailed test, the absolute value of Z_{MK} to reject the H_0 must be greater than $Z_{\alpha/2}$. For example, for $\alpha = 0.05$, $Z_{0.05/2} = Z_{0.025} = 1.96$, with the value obtained from the table of standard normal distribution. Therefore, the series will be considered to have a significant trend at the 0.05 level if $|Z_{MK}| > 1.96$, 0.10 level if $|Z_{MK}| > 1.65$ and 0.15 level if $|Z_{MK}| > 1.44$.

In this article, the Mann-Kendall test was used to identify trends of increasing or decreasing values in extreme weather indices. It was also applied to the Tmean indicator to verify the existence of a trend of change in the average annual temperature.

4.2. Sen's slope estimator

Despite the efficiency of the Mann-Kendall test, it does not provide the magnitude of the trends detected and can be complemented by the slope estimator proposed by [Sen 1968]. This method is insensitive to outliers and missing data, being more rigorous than linear regression curvature, providing a more realistic measure of trends in time series. As described by [Portela et al. 2011], it is necessary first to estimate the Q statistic, given by:

$$Q_{ij} = \frac{X_j - X_i}{j - i} \quad \text{for} \quad i < j \tag{5}$$

where X_i and X_j represent the values of the variable under study in the years i and j. Positive or negative value for Q indicates increasing or decreasing trend, respectively. If there are n values in the analyzed series, then the number of estimated pairs of Q is given by $N = n(n-1)/2$. Sen's slope estimator is the median of the N values of Q_{ij}.

Using the BDMEP dataset, the extreme indices described in Table 1 and Table 2 were calculated at an annual interval for each of the cities selected to represent the different climate regions defined by IBGE. With the database complete and aiming at detecting significant trends with the proper quantification, the non-parametric Mann Kendall test, complemented by the Sen's slope estimator that identifies the amplitude of the trends, was applied to the time series of the 13 chosen indices.

5. Results And Discussion

The results obtained through the Mann-Kendall Test and Sen's slope estimator, for the trends of the temperature indicators and their respective amplitudes, are shown in Table 3 and can be replicated from the instructions provided in our repository **https://gitlab.com/filipesantos.lf/study-on-changing-trends.git**. Performing an analysis of the results, considering a margin between 0.15 and 0.05 of significance for the results obtained, all cities analyzed show significant trends of increasing in average (Tmean), maximum (TXx) and minimum (TNn) temperature. All cities, without exception, show positive trends for Tmean, which represent an increase in the average annual temperature recorded, reaching up to 0.39ºC/decade.

At a confidence level of 0.05, 8 out of 11 cities show an upward trend for the TXx as observed in Table 3. The 3 remaining participants, all from subclimates with wet characteristics, show trends at the level of 0.10, very close to 0.05. We identify increases of up to 0.54ºC/decade in the maximum temperature for the city of Araxá.

Almost all cities show significant trends at the 0.05 level of increase for TNn, which represents the minimum temperature, reaching maxima of up to 1.15°C/decade for the city of Manaus. The city of São Simão is the only one in which the tendency is identified at a 0.15 level of significance.

Both indices, TX90P and TN90P, mostly show positive trends. These trends represent the increase in the percentage of hot days and hot nights per decade by up to 5% and 4.87% for TX90P and TN90P respectively.

	Araxá	Belém	Belo Horizonte	Cabrobó	Caparaó	Cuiabá	Curitiba	Manaus	São Simão	São Paulo	Barbalha
TXx Z_{MK}	**3.00***	1.90**	**4.46***	**2.53***	1.82**	**4.19***	**3.00***	**4.08***	1.91**	**4.22***	**5.15***
TXx ^{c}	0.54	0.17	0.44	0.34	0.40	0.34	0.27	0.16	0.28	0.40	0.43
TX10P Z_{MK}	**-3.73***	**-3.37***	-1.88**	**-2.66***	-1.13	**-3.84***	**-3.78***	**-6.88***	**-2.27***	**-5.60***	**-4.78***
TX10P ^{d}	-1.65	-1.92	-0.46	-3.00	-0.65	-0.87	-0.89	-0.97	-0.83	-1.51	-3.01
TX90P Z_{MK}	**4.92***	**4.67***	**3.37***	**3.29***	**2.04***	**3.80***	**3.20***	**5.14***	**4.08***	**5.28***	**5.53***
TX90P ^{d}	4.18	3.15	1.33	5.09	1.60	2.31	1.41	1.82	2.33	2.45	4.44
TNn Z_{MK}	**2.43***	**4.28***	**4.05***	**2.49***	**3.17***	**2.58***	**2.76***	**4.31***	1.52***	**4.17***	**3.30***
TNn ^{c}	0.82	0.31	0.48	0.43	0.75	0.50	0.47	1.15	0.38	0.70	0.42
TN10P Z_{MK}	**-5.64***	**-5.68***	**-5.71***	**-3.29***	**-3.93***	**-3.47***	**-5.84***	**-2.81***	**-3.92***	**-5.68***	-1.86**
TN10P ^{d}	-2.17	-2.32	-2.55	-4.73	-3.38	-1.30	-2.05	-0.68	-1.44	-2.29	-1.73
TN90P Z_{MK}	**4.10***	**6.12***	**6.51***	**3.38***	**2.98***	**4.29***	**5.71***	**4.72***	**3.54***	**6.90***	0.59
TN90P ^{d}	2.96	3.44	3.73	4.87	3.77	2.22	2.57	1.27	1.82	2.59	0.22
Tmean Z_{MK}	**6.62***	**7.31***	**6.17***	**5.24***	**2.80***	**5.09***	**6.15***	**5.62***	**3.72***	**6.94***	**5.19***
Tmean ^{c}	0.39	0.27	0.28	0.28	0.22	0.21	0.33	0.25	0.20	0.37	0.36

| * results with 0.05 significance level | ** results with 0.10 significance level | *** results with 0.15 significance level
| ^{d} represents the unit (%days/decade) | ^{c} represents the unit (ºC/decade)

Table 3. Results for tests applied to annual temperature indicators. The lines below of the "Z_{MK}" lines represent the amplitude of the trends.

Similarly, we have negative trends for TX10P and TN10P, which represents the decrease in the percentage of cold days and cold nights per decade, with an estimate of up to -3.00% and -4.73% for TX10P and TN10P respectively.

The results for the TXx and TX90p indices agree with the results obtained by [Silva et al. 2019], which record increasing trends for these indices in the Northeast and in the Brazilian Amazon regions between 1980 and 2013. Moreover, the significant trends of increase in hot days and hot nights (TX90p and TN90p) and a reduction in cold days and cold nights (TX10p and TN10p) in the state of Minas Gerais are in agreement with [Natividade et al. 2017].

Table 4 presents the trends and their respective amplitudes for the rainfall indicators. In the analysis of rainfall, unlike the results obtained for temperature indicators, we have identified few trends.

	Araxá	Belém	Belo Horizonte	Cabrobó	Caparaó	Cuiabá	Curitiba	Manaus	São Simão	São Paulo	Barbalha
CDD Z_{MK}	1.16	0.83	1.45***	-1.10	1.00	-0.98	-0.55	-0.79	-0.24	0.46	**2.69***
CDD ^{dd}	2.50	0.00	2.20	-3.33	1.96	-2.22	-0.30	-0.18	-0.38	0.25	8.86
CWD Z_{MK}	-1.20	0.62	-1.81**	-0.63	-0.11	-0.64	-1.17	-0.94	-1.02	1.02	**-2.04***
CWD ^{dd}	-0.68	0.29	-0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.63
RX1DAY Z_{MK}	0.87	1.13	-0.10	-1.23	1.75**	0.06	**2.48***	**3.03***	1.82**	**3.30***	0.01
RX1DAY ^{mm}	2.82	2.56	-0.21	-3.97	3.73	0.13	3.50	3.00	2.48	4.58	0.05
RX5DAY Z_{MK}	0.03	**2.93***	1.17	-0.36	1.69**	1.91**	0.70	**3.33***	-1.22	1.36	-0.43
RX5DAY ^{mm}	0.47	10.97	5.70	-2.42	10.78	6.00	2.00	4.03	-4.18	4.19	-2.00
R95P Z_{MK}	0.22	**4.48***	-0.30	**-2.12***	1.37	**2.03**	1.88**	**2.49***	0.00	**2.84***	1.02
R95P ^{mm}	7.24	98.27	-5.00	-32.85	21.67	27.77	21.85	19.80	-1.03	33.53	26.25
PRCPTOT Z_{MK}	-0.82	**5.43***	0.55	**-2.89***	-0.02	**3.83***	1.79**	**2.39***	-0.44	**3.10***	-0.45
PRCPTOT ^{mm}	-51.42	204.84	16.76	-88.02	-2.72	80.50	39.59	35.44	-12.62	64.70	-22.40

| * results with 0.05 significance level | ** results with 0.10 significance level | *** results with 0.15 significance level
| ^{d} represents the unit (%days/decade) | ^{c} represents the unit (ºC/decade)

Table 4. Results for tests applied to annual rainfall indicators. The lines below of the "Z_{MK}" lines represent the amplitude of the trends.

Of greater importance, there is an increase in very rainy days (R95P) and in total annual precipitation (PRCPTOT) for the Hot climate and its subclimates, except for the semi-arid hot from 6 to 8 dry months region, in addition to the city of São Paulo/SP, which represents the Sub-hot superwet, with peaks of up to 98.27 mm and 204.84 mm of rain per decade for rainy days and total annual precipitation in the city of Belém/PA as show in Table 4.

The RX5DAY index shows a positive trend for the cities of Belém/PA and Manaus/AM, with an estimated increase of 10.97 mm/decade and 4.03 mm/decade, respectively, for the maximum volume of rain recorded in 5 consecutive days.

At the RX1DAY, we have a positive trend for Curitiba/PR, Manaus/AM and São Paulo/SP at 3.50 mm/decade, 3.00 mm/decade and 4.58 mm/decade, respectively. The results observed for the city of Manaus from 1960 to 2019 are consistent with those obtained by [Santos et al. 2012] that record increasing trends for the period 1971 to 2007 of the total annual precipitation volume (PRCPTOT), of maximum precipitation accumulated over five consecutive days (Rx5day) and wet/rainy days (R95p) indicating that Manaus could suffer from increased extreme rainfall.

The city of Barbalha is the only one to present consistent results on CDD and CWD, with an increase of 8.86 days/decade and a decrease of 0.63 days/decade respectively. The increase in consecutive dry days and the decrease in wet days may represent a possible bad distribution of rain for the region.

The city of Belo Horizonte shows a trend towards the decrease of consecutive days of rain (CWD) and increase of consecutive dry days (CDD) at significance levels of 0.15 and 0.10, respectively, which would raise the question of whether the bad distribution of rainfall observed in the city is a trend for the coming years. It should be noted that with fewer consecutive rainy days, more consecutive dry days and maintenance of the common rainfall volume, the volume tends to be higher for a smaller number of days. In fact, in January 2020 the 123-year-old city has recorded an all-time high precipitation for a single month: 935.2mm (the annual average is 1,602.6mm).

In order to compare the popular perception and the results obtained by the trend tests, graphs in the format of "warming stripes"[3] were generated for the average temperatures of all cities analyzed during the studied period.

Figure 3 shows warming stripes for cities with hot climates that present an average temperature above 18°C every month of the year. We observe that the average temperature has been increasing in recent decades, reaching annual values of up to 29°C.

Figure 4 shows the average temperature of the sub-hot region, which, according to IBGE, presents an average temperature between 15ºC and 18ºC in at least 1 month. It can be seen that the cities of Belo Horizonte and São Paulo, capitals of their respective states and large urban centers, present fluctuations in temperature increases above 21ºC from the 1980s onwards.

Figure 5 shows average temperature graphs of the mild mesothermal region which, according to the IBGE, presents an average temperature between 10°C and 15°C, where we observe similar results to the other aforementioned regions with temperature increases greater than 17°C in the last decades.

6. Conclusions

This study analyzed the progression of maximum, minimum and average temperatures along the respective data intervals for 11 Brazilian cities, ranging between 1961 and 2019, identifying increases in the extremes and in the annual average temperature. It becomes clear from the results that the annual average, maximum and minimum temperature, as

[3]https://showyourstripes.info/

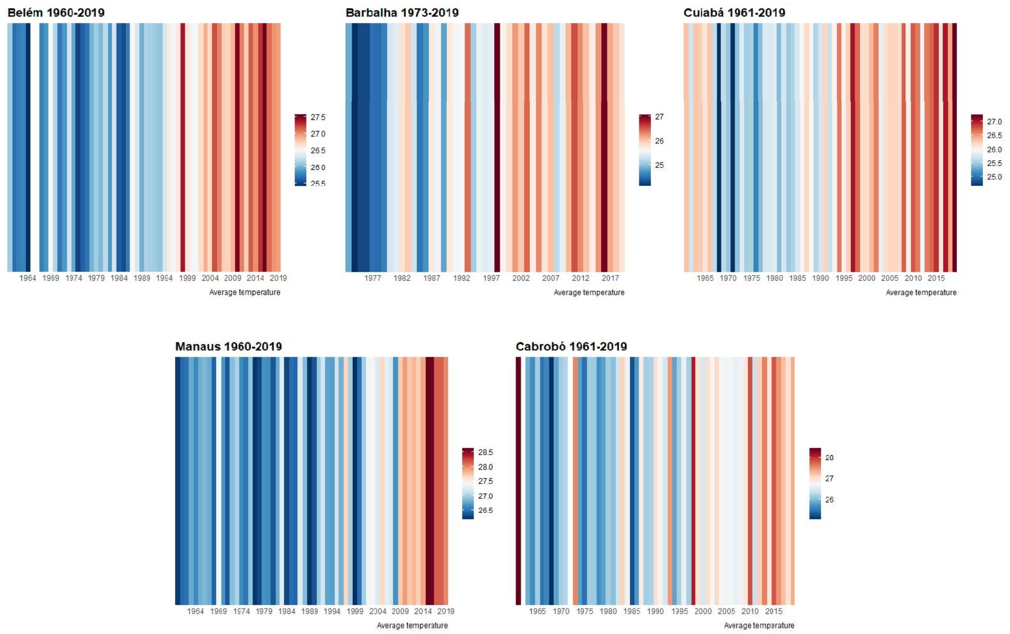

Figure 3. Warming stripes hot region

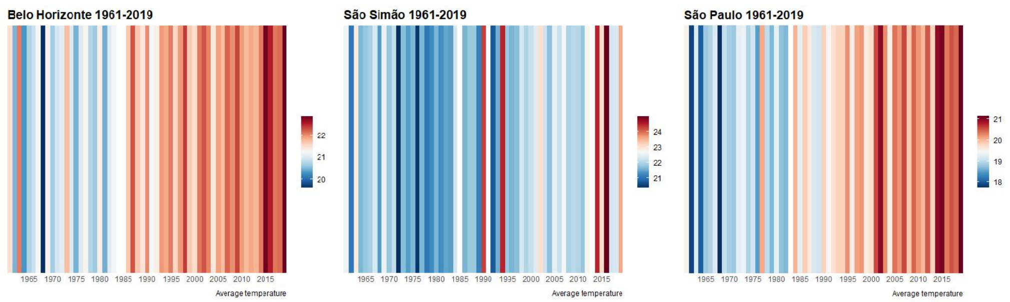

Figure 4. Warming stripes sub-hot region

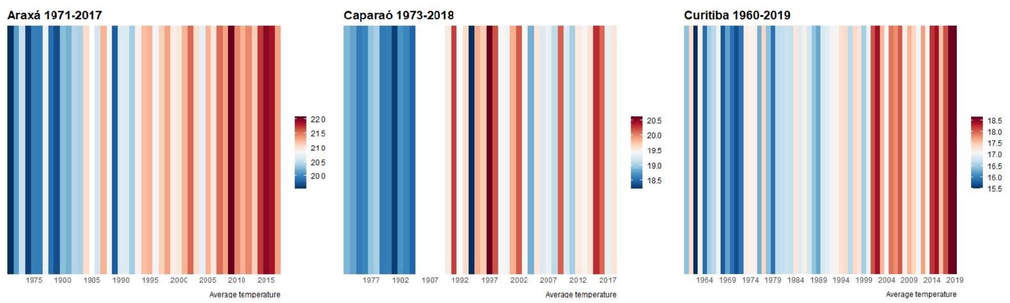

Figure 5. Warming stripes mild mesothermal region

well as hot days and nights, have been increasing over the years and the trend is for them to continue to increase. The database and, consequently, the indices were more consistent for the most populated cities; this was displayed more transparently by the "warming stripes".

As expected, analyzing rainfall indicators is harder than analyzing temperatures. However, interesting results were obtained for the hot region, indicating an increase in annual rainfall and an increase in rainy days for the region, as well as for the city of São Paulo.

The importance of the results obtained goes beyond becoming aware of social impacts in terms, e.g., of the population experiencing warmer days or more intense rainfall throughout the year. In fact it is very likely that the local economy of the different regions analyzed, for example, the agricultural activity, will be affected by the new climate pattern which the results display.

In order to obtain deeper and longer-range analyzes for the climate indicators that better describe their behaviors, the existence of databases that go beyond the period analyzed in this study (1961 to 2019) would be necessary. However, the lack of equally extensive databases and the existence of many data gaps affect the choice of cities for analysis and becomes an impediment in the comparison of more comprehensive long-term analyses for some regions.

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