STUDY OVER EL NIÑO AND LA NIÑA INFLUENCE ON MEAN TEMPERATURE TRENDS AND PRECIPITATION IN BRAZILIAN REGIONS

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Abstract
The objective of this work is to describe and analyze historical series of climatic parameters of mean air temperature and rainfall, in June and December, in cities in Brazil. The data related to the daily historical series were obtained from 243 meteorological stations of the National Institute of Meteorology (INMET) and analyzes were performed by applying statistical tests for detecting possible trends in the referred time series. It was observed that the non-parametric tests of Mann-Kendall and Pettitt are the most suitable for the analysis of climatic variables, allowing to detect when a significant trend in a certain region of the country occurs. The correlation of these climatic magnitudes with the occurrence dates of the El Niño and La Niña phenomena allowed us to observe a strong association of the average temperature increase in years of strong El Niño events, especially in the month of December.

Keywords: Statistical tests. Climate change. Brazilian regions. Environmental impact.

ESTUDO DA INFLUÊNCIA DO EL NIÑO E LA NIÑA NAS TENDÊNCIAS DE TEMPERATURA MÉDIA E PRECIPITAÇÃO NAS REGIÕES BRASILEIRAS

Resumo
O objetivo deste trabalho é descrever e analisar séries históricas de parâmetros climáticos de temperatura média do ar e precipitação, nos meses de junho e dezembro, em cidades do Brasil. Os dados referentes às séries históricas diárias foram obtidos de 243 estações meteorológicas do Instituto Nacional de Meteorologia (INMET) e as análises foram realizadas por meio da aplicação de testes estatísticos para detecção de possíveis tendências nas referidas séries temporais. Observou-se que os testes não paramétricos de Mann-Kendall e Pettitt são os mais indicados para a análise de variáveis climáticas, permitindo detectar quando ocorre uma tendência significativa em determinada região do país. A correlação dessas magnitudes climáticas com as datas de ocorrência dos fenômenos El Niño e La Niña permitiu observar uma forte associação do aumento da temperatura média em anos de fortes eventos de El Niño, principalmente no mês de dezembro.

Palavras-chave: Testes estatísticos. Mudanças Climáticas. Regiões brasileiras. Impacto ambiental.

ESTUDIO DE LA INFLUENCIA DE EL NIÑO Y LA NIÑA EN LAS TENDENCIAS DE LA TEMPERATURA PROMEDIO Y LA PRECIPITACIÓN EN LAS REGIONES BRASILEÑAS

Resumen
El objetivo de este trabajo es describir y analizar series históricas de parámetros climáticos de temperatura media del aire y precipitación, en los meses de junio y diciembre, en ciudades de Brasil. Los datos referentes a la serie histórica diaria se obtuvieron de 243 estaciones meteorológicas del Instituto Nacional de Meteorología (INMET) y los análisis se realizaron mediante la aplicación de pruebas estadísticas para detectar posibles tendencias en la referida serie temporal. Se observó que las pruebas no paramétricas de Mann-Kendall y Pettitt son las más adecuadas para el análisis de variables climáticas, permitiendo detectar cuando se presenta una tendencia significativa en determinada región del país. La correlación de estas magnitudes climáticas con las fechas de ocurrencia de los fenómenos

de El Niño y La Niña permitió observar una fuerte asociación del incremento de la temperatura media en años de eventos fuertes de El Niño, principalmente en el mes de diciembre.

Palabras-clave: Pruebas estadísticas. Cambio climático. Regiones brasileñas. Impacto medioambiental.

INTRODUCTION

The average increase in atmospheric air temperature on the planet is evident, according to the fifth report of the International Panel on Climate Change (IPCC), eleven of the last twelve years of recorded data are among the hottest of the period from 1850 to 2006. It was observed a linear increase of approximately 0.13°C per decade in the last 50 years (1957 to 2006), approximately twice as high as observed in the period between 1850 and 1956 (IPCC, 2014).

Changes in air temperature impact the planet, with consequences related to advances in forest deforestation, melting of polar ice caps, extreme drought events and increases in rainfall rates in some regions, in addition to the possible rise in sea level, among others factors (MARENGO; VALVERDE, 2007). According to IPCC-AR5, climate change poses risks to food production with major impacts on global rural areas due to water availability, food security, infrastructure and changes in food and non-food crop production (IPCC, 2014).

Local urban effects that arise due to urbanization, such as heat islands, interfere with the detection of trends in air temperature rise in meteorological records and historical series analyzes. Therefore, global scale phenomena and the urbanization of the region in which the meteorological station is located may be related to the climatic trends observed in the historical series analyzed (BLAIN et al., 2009).

The El Niño-Southern Oscillation (ENSO) is an oceanic event associated with a fluctuation of a global-scale tropical and subtropical pattern, with preferred time scales of two to about seven years (IPCC, 2014).

According to the National Oceanic and Atmospheric Administration (NOAA), El Niño is an oceanic-atmospheric climate phenomenon characterized by periodic warming of the surface waters of the Central and Eastern Pacific Ocean. El Niño represents the hot episode of the ENSO, and the La Niña phenomenon is related to the period of cooling of the Sea Surface Temperature (SST) in the central Pacific (NOAA, 2017).

El Niño/La Niña affects, with greater intensity, some political regions of Brazil, as is the case of the North, Northeast and South regions of the country. Droughts, floods and heat waves are consequences that can occurin the country if El Niño phenomenon becomes more frequent and intense (MARENGO, 2006).

The southern region of Brazil has a strong association between precipitation anomalies and El Niño and La Niña events (GRIMM et al., 1998). According to Berlato et al. (2005), in Rio Grande do Sul state, the ENSO phenomenon directly influences crop productivity. Since El Niño episodes cause precipitation above the climatological average and the La Niña events cause periods of drought in the region.

This work aims to contribute to climate studies in political regions of Brazil. Analyzes of trends in time series of mean air temperature and rainfall at maximum of winter and summer, June and December, respectively, were performed. The locations and dates of the significant trends were identified through statistical tests applied to meteorological station data, making it possible to understand the climatic variabilities in the Brazilian regions and the correlation with the occurrence dates of the El Niño and La Niña phenomena.

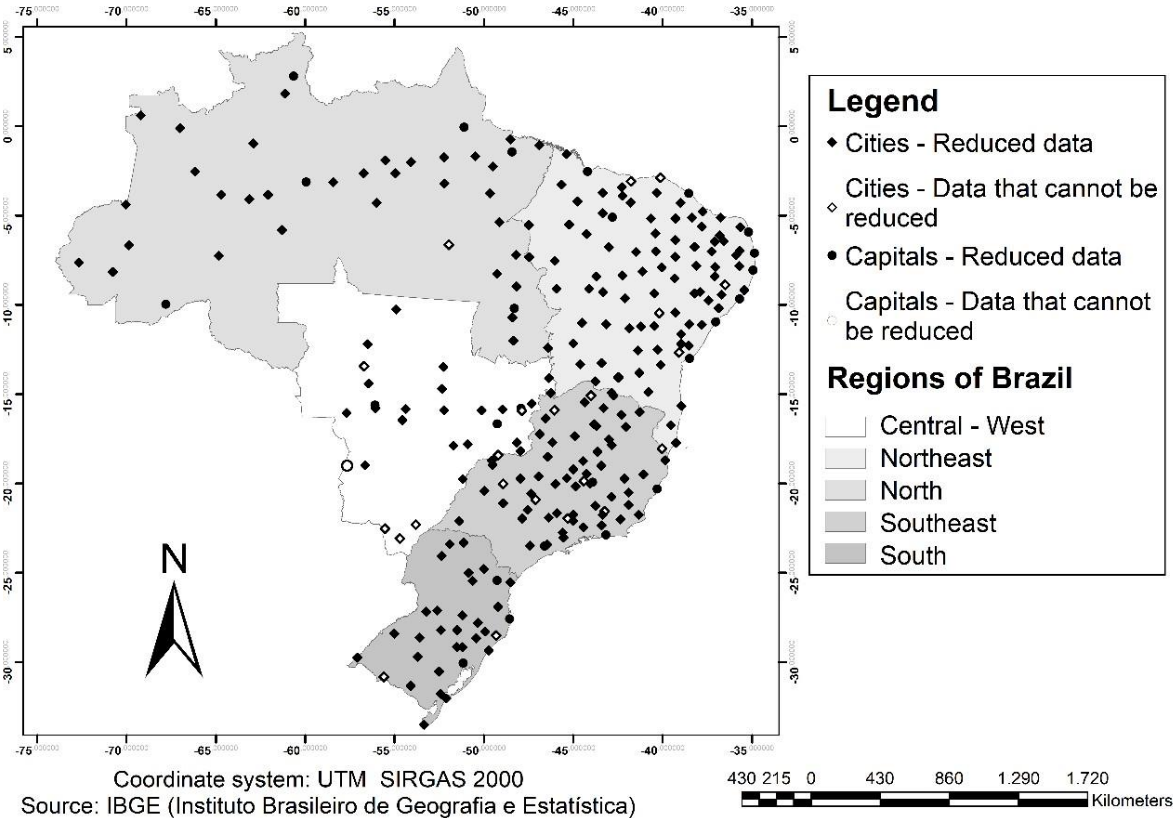
MATERIAL AND METHODS

With an area of approximately 8,515,767,049 km^2, being located between longitudes -75° and -35°, and latitudes 5° and -30°, Brazil is a country that currently has a total of 5570 cities, in addition to the Federal District. These cities are spread throughout the five major political regions: South, Southeast, Central-West, North and Northeast (IBGE, 2017).

Daily data of total rainfall and average monthly air temperature of 243 locations were used, 25 of them being state capitals (Figure 1), distributed through the five major Brazilian Regions. Data were obtained through the Meteorological Database for Teaching and Research (BDMEP) of the National Institute of Meteorology (INMET), considering the period from 1961 to 2015 (INMET, 2018).

According to INMET, the BDMEP is an information database that assists, in addition to teaching and research activities, other applications in meteorology, hydrology, water resources, public health and the environment. The data are housed digitally and cover historical series, which relates to daily measurements, in accordance with the international technical standards of the World Meteorological Organization (WMO).

Figure 1: Representative map of Brazil with the location of each INMET metereological station. The stations in black are those selected for the present study of climatic trends of the historical series



Source: Elaborated by the authors.

Currently the BDMEP has 266 conventional meteorological stations, with daily data available since January 1st, 1961. The map represented by Figure 1 shows the spatial distribution of the 266 INMET conventional weather stations being worked on in this project. As it is possible to verify, in some regions of Brazil there are no meteorological stations installed until the present moment, as it happens with the capitals Campo Grande (MS) and Porto Velho (RO), in the southern part of Pará and Amazonas states, besides some regions in the north of Mato Grosso. Thus, the survey performed corresponds to 90.67% of the INMET measuring stations.

The mean temperature was calculated as the daily arithmetic mean between the minimum and maximum temperatures, variables provided by INMET. Thus, trends were analyzed in the time series of monthly average of the average temperature and the monthly total of precipitation, for the months of June and December.

After the data collection and organization, statistical treatment was done on it using different computer programs developed in the Microsoft Excel application. These programs, especially created to identify and map the evolution of climatic parameters of interest, also allow the generation of graphs and verify the occurrence of an eventual trend (PENEREIRO; FERREIRA, 2012).

The Mann-Kendall sequential test was presented and discussed by Sneyers (1990). According to Goossens and Berger (1986), it is the most appropriate method to analyze climatic variables, allowing to approximately detect and locate the starting point of a given trend. It is considered that, in the hypothesis of series stability, the succession of values occurs independently, and the probability distribution must always remain the same (simple random series).

Moraes et al. (1995) also describe this method considering a series of $\boldsymbol{Y_i}$, of $\boldsymbol{N}$terms, $\boldsymbol{1 \leq i \leq N}$to be analyzed. The test consists of the sum of the number $\boldsymbol{t_n} = \sum_{i=1}^{N} \boldsymbol{m_i}$ of terms $\boldsymbol{m_i}$ in the series, relative to the value $\boldsymbol{Y_i}$ whose previous terms ($j < i$) are less than the same ($Y_j < Y_i$). For series with large number of terms (N), under the null hypothesis ($\boldsymbol{H_0}$) of absence of trend $\boldsymbol{t_n}$, will present a normal distribution with mean $\boldsymbol{E(t_n)} = \frac{\boldsymbol{N \cdot (N-1)}}{\boldsymbol{4}}$ and variance $\boldsymbol{var(t_n)} = \frac{\boldsymbol{N \cdot (N-1) \cdot (2 \cdot N+5)}}{\boldsymbol{72}}$, respectively.

Testing the statistical significance of $\boldsymbol{t_n}$ for the null hypothesis, using a bilateral test, it can be rejected for large values of the statistic $\boldsymbol{U(t_n)}$ through Equation 1.

$$\boldsymbol{U(t_n)} = \frac{\boldsymbol{(t_n - E(t_n))}}{\sqrt{\boldsymbol{var(t_n)}}} \qquad (1)$$

The probability value $\boldsymbol{\alpha_1}$ is calculated by means of a reduced normal table, such that: $\boldsymbol{\alpha_1 = prob(|U| > |U(t_n)|)}$. Being $\boldsymbol{\alpha_0}$ the level of significance of the test (usually $\boldsymbol{\alpha_0 = 0.05}$), the null hypothesis is accepted if $\boldsymbol{\alpha_1 > \alpha_0}$. If the null hypothesis is rejected, it will imply the existence of a significant trend, and the statistical signal $\boldsymbol{U(t_n)}$ indicates whether the trend is increasing ($\boldsymbol{U(t_n) > 0}$) or decreasing ($\boldsymbol{U(t_n) < 0}$).

The starting point of a change in the series can be determined by applying the same principle to the inverse series. In this case, in its sequential version, the equation $\boldsymbol{U(t_n)}$ is calculated in the direct sense of the series, starting from the value $\boldsymbol{i = 1}$ up to $\boldsymbol{i = N}$, generating the statistic $\boldsymbol{-1.96 < U(t_n) < 1.96}$ ($\boldsymbol{1,96}$ corresponds to $\boldsymbol{\alpha_0 = 0.05}$), and, in the inverse sense of the series, starting from the value $\boldsymbol{i = N}$ up to $\boldsymbol{i = 1}$, generating the statistic $\boldsymbol{U^*(t_n)}$. The intersection of the two curves $\boldsymbol{U(t_n)}$ and $\boldsymbol{U^*(t_n)}$ is where the approximate point of trend change is located, if that point occurs within the confidence interval $\boldsymbol{-1.96 < U(t_n) < 1.96}$.

The Pettitt test (PETTITT, 1979) is also a non-parametric test using a version of the Mann-Whitney test (FREUND, 2006), where two samples $\boldsymbol{Y_1, Y_2 \ldots, Y_t}$ and $\boldsymbol{Y_{t+1}, Y_{t+2}, \ldots, Y_T}$ are checked whether they come from identical populations.

The statistic $\boldsymbol{U_{t,T}}$ counts the number of times a member of the first sample is larger than a member of the second sample, which can be written according to Equation 2.

$$\boldsymbol{U_{t,T} = U_{t-1,T} + \sum_{j=1}^{T} sgn\left(Y_i - Y_j\right)}; \text{ for } \boldsymbol{t = 2, \ldots, T} \tag{2}$$

where: $\boldsymbol{sgn(x) = 1}$ for $\boldsymbol{x > 0}$; $\boldsymbol{sgn(x) = 0}$ for $\boldsymbol{x = 0}$ and $\boldsymbol{sgn(x) = -1}$ for $\boldsymbol{x < 0}$.

From this, the statistic $\boldsymbol{U_{t,T}}$ is then calculated for values of $\boldsymbol{1 \leq t \leq T}$, and the statistic $\boldsymbol{K(t)}$ of the test is the maximum absolute value of $\boldsymbol{U_{t,T}}$. The statistic $\boldsymbol{K(t)}$ finds the point where there was a sudden change in the mean of a time series and its significance can be evaluated through the equation: $\boldsymbol{p \cong 2 \cdot e^{\left(\frac{-6 \cdot (K(t))^2}{(T^3 + T^2)}\right)}}$. The abrupt change point is the one where the value of $\boldsymbol{t}$ occurs for the maximum of $\boldsymbol{K(t)}$. Through the inversion of the previous equation it is possible to infer the critical values of $\boldsymbol{K(t)}$ by means of Equation 3.

$$\boldsymbol{K_{crit.} = \pm\sqrt{\frac{-\ln\left(p/2\right) \cdot (T^3 + T^2)}{6}}} \tag{3}$$

The level of significance of the change for both tests is estimated for the levels of 5% to 10% corresponding to the values of ± 1.96 and ± 1.65, respectively.

RESULTS AND DISCUSSIONS

Considering the possibility of jointly analyzing the results obtained by applying the non-parametric tests in the climatic time series of the treated locations, it was chosen to present tables with the trends recorded for summer (December) and winter (June) maximums in each Brazilian political region.

Tables 1 and 2 present, for December and June, the results of the statistical tests applied on the parameters of monthly total rainfall and average monthly temperature, considering the cities of the Brazilian regions present in the survey. The symbolism (+) was used to represent the trends of increase, (-) for trends of decrease and (?) For the locations that did not present significant trends.

There were a significant number of locations that did not present trends, which was higher than the number of cities in which there were positive or negative trends. This behavior was verified for both variables addressed.

Table 1: Locations classified in relation to the climatic tendency identified by the non-parametric statistical tests applied for precipitation

Regions of Brazil	**December**			**June**		
	(–)	**(+)**	**(?)**	(–)	(+)	(?)
Central-West	1	0	22	0	2	21
Northeast	3	0	87	5	5	80
North	1	1	38	0	2	38
Southeast	1	1	58	0	2	58
South	2	0	28	1	2	27
Total	8	2	233	6	13	224

Source: Elaborated by the authors.

In the case of precipitation (Table 1), in December, the decreasing trends were higher than those of increase with eight and two cities, respectively. The highest amount of rainfall occurred in June, in thirteen cities scattered across the country with positive trends and only 6 locations with negative trends.

With regard to the Great Regions of Brazil, the Northeast showed more negative trends for the precipitation parameter in December and June. It was also the region that indicated more trends of rainfall in June, with five classified locations.

Table 2: Locations classified in relation to the climatic tendency identified by non-parametric statistical tests applied to mean temperature

Regions of Brazil	**December**			**June**		
	(–)	**(+)**	**(?)**	(–)	(+)	(?)
Central-West	0	13	10	0	8	15
Northeast	4	16	70	4	23	64
North	0	27	13	0	20	20
Southeast	1	22	36	1	21	38
South	1	7	22	1	4	26
Total	6	85	151	6	76	163

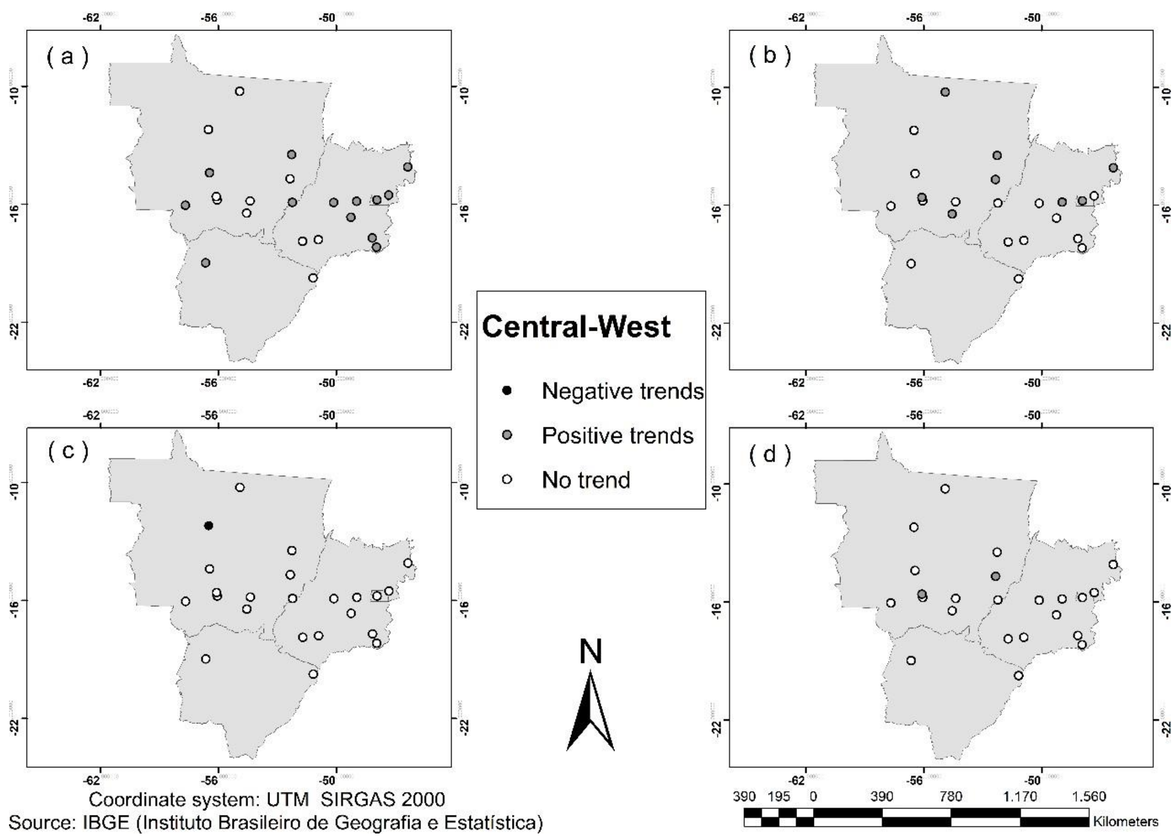
Source: Elaborated by the authors.

The mean temperature variable (Table 2) showed more positive than negative trends in both months. The North region had a greater number of positive trends in the month of December, with 27 cities. However, at the peak of winter, it was the Northeast region that had a greater number of locations with increase and decrease of temperature.

In order to visually represent the results obtained, in relation to Brazil as a whole and its main regions, maps were made for the months of June and December. They symbolize the verified trends, in addition to the localities that did not show significant trends.

In relation to the Central-West region (Figure 2), it can be seen that most cities exhibit positive trends for the two climatic variables, without considering the absence of trends.

Figure 2: Representative map of the Central-West region with the trends distribution for: a) average temperature in December, b) average temperature in June, c) precipitation in December and d) precipitation in June

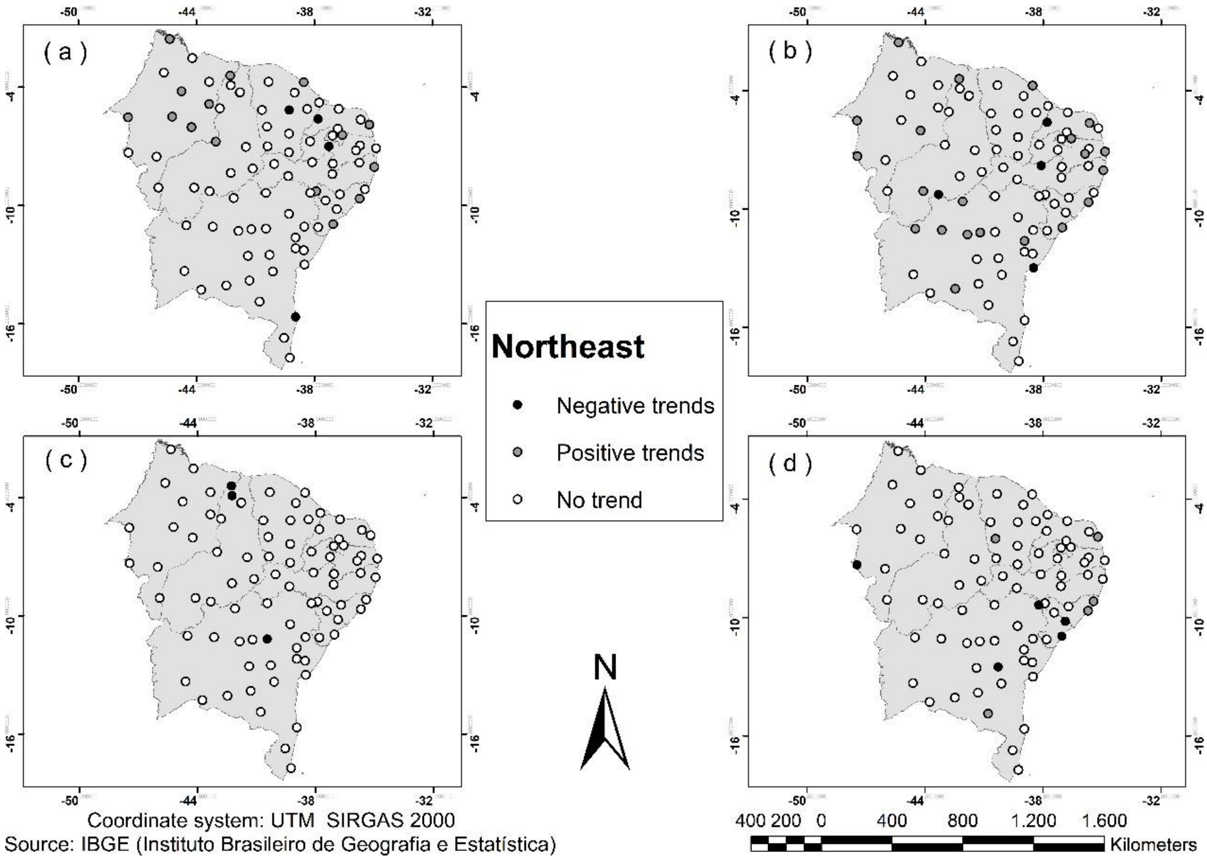


Source: Elaborated by the authors.

For the average temperature variable, the states of the Central-West presented only increasing trends in summer and winter maxima. For precipitation, most of the localities presented no tendency. However, in relation to the month of December there is a negative trend in the state of Mato Grosso. In the month of June, only upward trends were detected for temperature and precipitation parameters.

Figure 3 shows the increase and decrease trends analyzed for the Northeast, highlighting the negative trends of mean temperature and precipitation in the region. In addition to significant trends in the North part of Northeast, which is most affected in the El Niño years with periods of drought.

Figure 3: Representative map of the Northeast region with the distribution of trends for: a) average temperature in December, b) average temperature in June, c) precipitation in December and d) precipitation in June



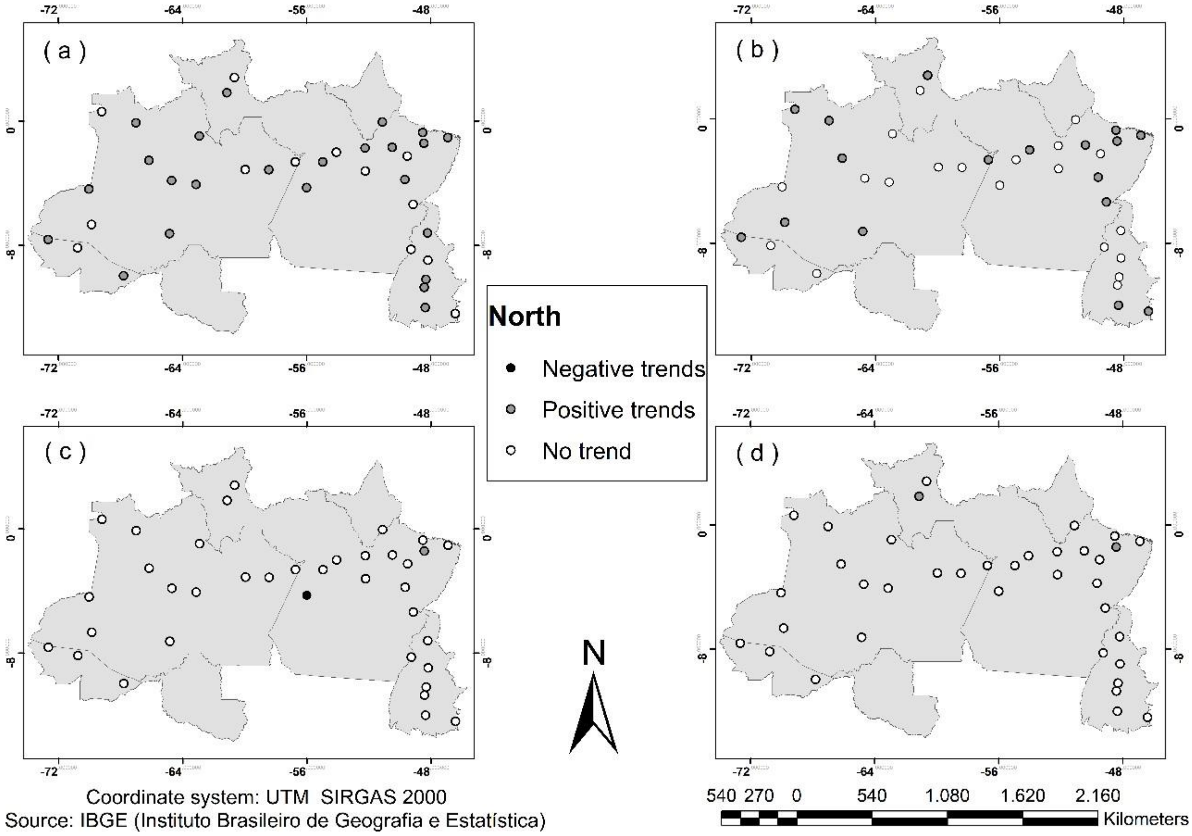
Source: Elaborated by the authors.

When analyzing the Northeast region spatially, there is an increase in mean temperature for several locations in the state of Maranhão and the coast for the month of December. But for the month of June, trends of increase are also concentrated in the state of Bahia and negative tendencies are more scattered throughout the region.

In relation to the precipitation parameter, it is observed many locations without significant trends. At the peak of the summer, there were no positive trends, only negative ones. But in June, the number of cities with increased and decreased rainfall is the same, with ten locations showing significant trends.

The northern region, represented by Figure 4, recorded temperature increase in several locations and few significant trends for the precipitation variable.

Figure 4: Representative map of the North region with the distribution of trends for: a) average temperature in December, b) average temperature in June, c) precipitation in December and d) precipitation in June

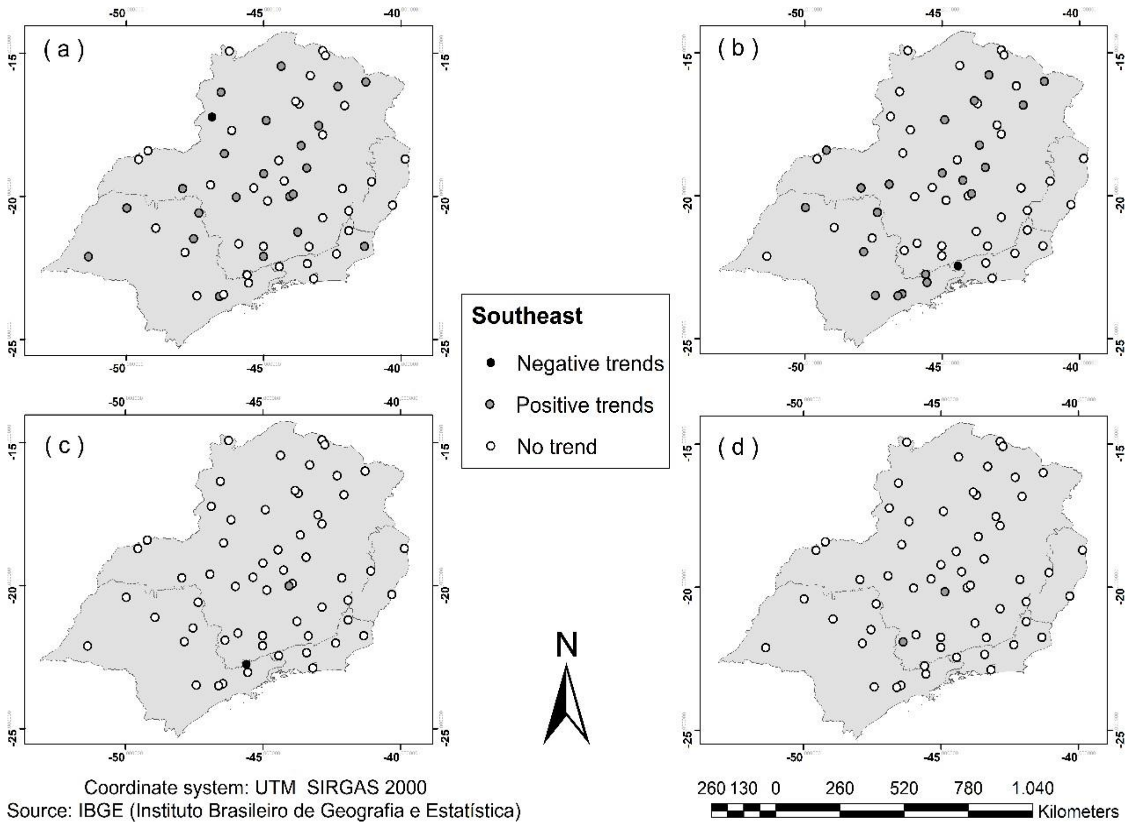


Source: Elaborated by the authors.

In the months of December and June, the locations of the region registered only positive trends for the parameter average temperature, with most of them in the states of Amazonas and Pará. Related to precipitation in the north of the country, increasing trends are located in the north of the region and a negative trend has been recorded in the state of Pará.

In relation to the Southeast region (Figure 5), it can be observed that most of the locations, which show significant trends, show an average temperature rise in December and June.

Figure 5: Representative map of the Southeast region with the distribution of trends for: a) average temperature in December, b) average temperature in June, c) precipitation in December and d) precipitation in June



Source: Elaborated by the authors.

In Minas Gerais, in December, 16 of the cities surveyed in the study presented tendencies for temperature increase and 23 cities in the state showed no significant trends.

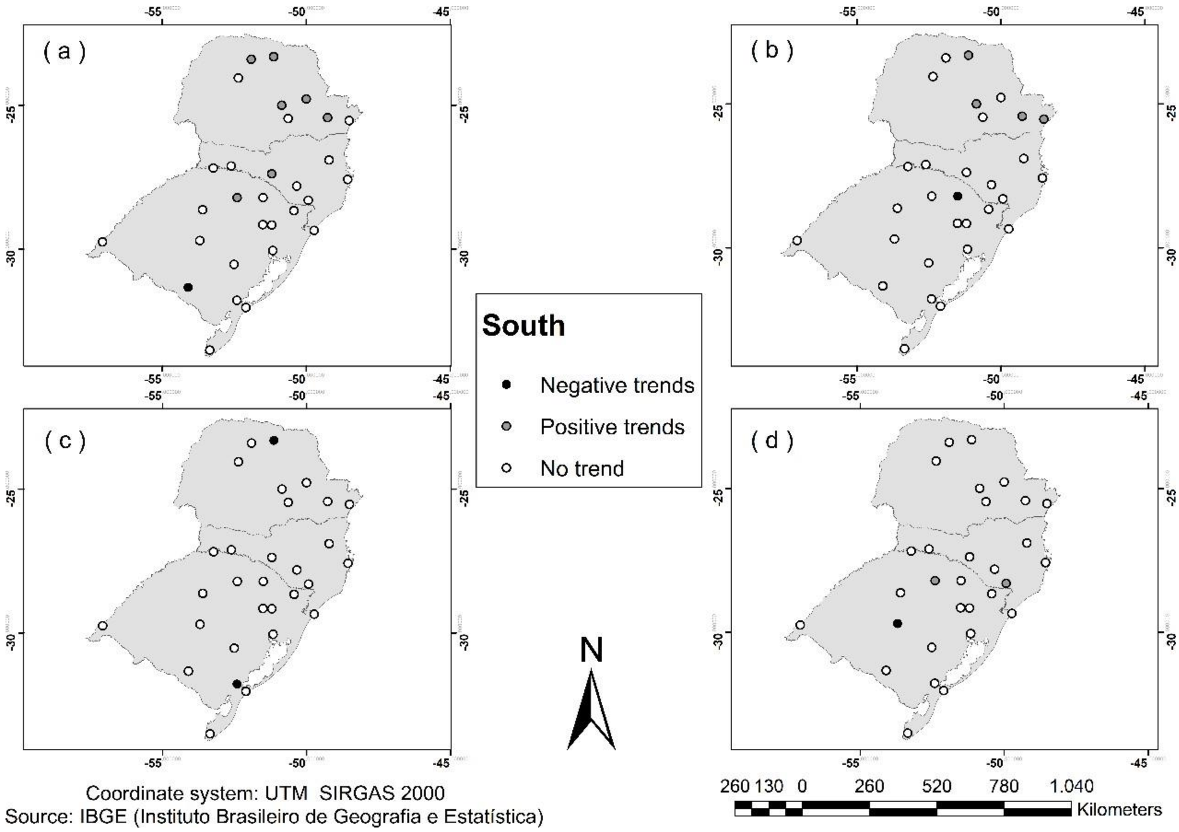
In the maps referring to the precipitation, it was detected an increase and decrease of rains. However, the absence of trends for this climatic variable is numerous.

Figure 6 shows the trends analyzed for the South region. The trends of average temperature increase in the region in December and in the state of Paraná in the month of June stand out.

In December, two locations were identified with decreasing rainfall and, in June, two locations with increased rainfall and only one city in Rio Grande do Sul State registered a negative trend.

The reduction of the data collected and the analysis of the dates of significant trends, besides the spatial distribution verified through the maps are important in the correlation of the evolution occurred regionally and, if possible, to the global changes. Many studies on El Niño and La Niña emphasize the influence of these phenomena on the climate of the Brazilian regions. According to Marengo (2006), its impacts are most strongly observed in the South, Northeast and North regions of the country.

Figure 6: Representative map of the South region with the distribution of trends for: a) average temperature in December, b) average temperature in June, c) precipitation in December and d) precipitation in June



Source: Elaborated by the authors.

The impacts of the phenomenon vary by region. In the North, there were droughts, which affected the Amazon, associated with El Niño. The Northeast region may present droughts during the El Niño years. And in the South of Brazil droughts occur during La Niña and abundant rains during the El Niño (MARENGO, 2006).

The El Niño Southern Oscillation can be studied in biennia, since the episode begins in the middle of the year before the peak of the phenomenon, which occurs in the summer (December, January and February), and dissipates a few months after it reaches its maximum intensity.

The years of ENSO were selected according to the study period and used for the correlation with the results of the trends observed in each Brazilian region. According to the National Oceanic and Atmospheric Administration (NOAA), El Niño episodes occurred in the following years: 1966, 1973, 1978, 1980, 1983, 1987, 1988, 1992, 1995, 1998, 2003, 2007 and 2010. The episodes of La Niña were detected in the years 1962, 1971, 1974, 1976, 1989, 1999, 2000, 2008, 2011 and 2012 (NOAA, 2017).

In the Northeast region, the average temperature variable pointed to increasing trends for several locations, highlighting the years of 1989, 1990, 1999 and 2000 at the peak of the summer. For the month of June, the years of 2008 and 2009 stand out. Negative trends for this variable were verified only in the decade of 2000, but in a few cities.

The influence of El Niño is stronger in the north part of the Northeast causing droughts of various intensities. Negative trends for precipitation in December 2002, 2005 and 2010 were observed in the states of Piauí and in the northern region of Bahia. As for June, in 1995 and 2002, there was a decrease in rainfall for locations in the state of Bahia, Sergipe and Maranhão.

The increase in rainfall was detected only in June, with emphasis on the years 1999 and 2000, which were La Niña occurence years. According to Marengo and Oliveira (1998), abundant rainfall is possible over the semi-arid region of the Northeast if the atmospheric and oceanic conditions on the Atlantic Ocean are favorable and occur simultaneously with the La Niña phenomenon.

The Northern region exhibited a high number of trends of average temperature increase in both December and June. At the peak of summer, most of these wererecorded in the decade of 1990 between 1990 and 1997. At the peak of winter, positive trends occurred mainly in the years 1982, 1986, 1991, 1994 and between 2001 and 2008, which coincide with periods of weak to moderate El Niño.

The other region that is strongly impacted by these climatic phenomena is the South region. Highlighted are the locations of the state of Paraná, such as Curitiba, Londrina and Ivaí, which registered positive trends of average temperature in December 1984, 1987 and 1998 and in the month of June in 1999, 1991 and 1999, respectively.

At first, it can not be said that the trends analyzed in the Central-West and Southeast regions of the country correlate with El Niño/La Niña. However, many trends, mainly of average temperature increase, were verified in years of occurrence of the phenomena.

In the Central-West, when considering the average temperature, the year 1997 is evidenced by the number of positive trends in winter, the years of 1988 and 2009 also stood out in June. As for December, in the decade of 1990 between 1992 and 1995, it recorded the highest number of positive trends for temperature in the region.

Many positive trends for the medium temperature climate variable were analyzed in the Southeast region, with a significant number of trends recorded in the 1980s and 1990s. Positive trends in December 1983, 1986, 1992 and 1993 are relevant for this study, since these are periods of El Niño occurrence. In June, most of the locations presented increasing trends in the years 1998 and 1999.

In the Central-West region, no location registered trends of average temperature decrease and in the Southeast there were few places. It is known that La Niña can cause slightly below average temperatures during winter in the region (MARENGO; OLIVEIRA, 1998).

The increasing urbanization of urban centers, combined with the degradation of natural resources and the increasing deforestation of forest remnants, contribute to the change in global climate. Concern about climate change has been growing over the last few years, however, doubt and disregard still prevail in the mentality of managers and civil society.

Global warming and the changing atmospheric and oceanic dynamics of the planet are associated with several consequences, promoting the reduction of food security, due to the approximation of an unsustainable scenario that is aggravated by the decrease of water availability, exponential increase of deforestation and changes in the food production itself, in relation to the inadequate management of the soil.

Studies that contribute to reduce uncertainty regarding global climate change are essential for understanding how anthropic activities and the resulting worsening climate phenomena have a strong impact on the planet.

CONCLUSION

With the analysis of the trends verified in each political region of the country, it became possible to correlate with the dates of occurrence of the El Niño and La Niña phenomena. It is worth noting that it is not possible to state that these events are the main causes of the observed trends for the average monthly temperature and total rainfall. The anthropogenic changes, geographic characteristics and biodiversity of each region are also factors that affect the Brazilian climate.

The increase in mean air temperature was significant in all regions of Brazil, especially in the month of December, during years that stood out for presenting strong events of El Niño phenomenon, such as the 1982-1983 biennium, in 1987 and 1992. According to NOAA, the most intense El Niño event, registered so far, since 1895 was detected during the biennium of 1997-1998, being able to cause high temperatures in the country and verified in this study, mainly in the North and Central-West regions.

The present study allows a greater understanding about the influence of global phenomena in the regions of Brazil, with the application of statistical tests on historical series of meteorological variables. In addition to contributing to the search for solutions to reduce the real consequences of climate change and to the awareness about the preservation of natural resources and environmental quality, always aiming at a sustainable development of societies.

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