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ANALYSIS OF TEMPERATURE EXTREMES IN THE SOUTH OF BRAZIL

Análise de extremos de temperatura no Sul do Brasil

Analisis de temperaturas extremas en el Sur de Brasil

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Abstract: This research analyzes trends in climatic temperature extremes in southern Brazil (SB), based on eight indices, four absolute and four percentiles for maximum and minimum temperatures (TX and TN), calculated from observed data series of high spatial resolution (0.25°x0.25°) for the period of 1980-2016. The Mann-Kendall test (MK) was used to analyse the significance of trends, in °C/decade. The results showed an increase in the intensity and frequency of extremes in the SB, with overall negative trends being verified for the absolute extremes of TN and positive trends for the absolute extremes of TX, rendering safe to infer that a dilation of the daily temperature range took place in the period. The northern and southern border regions of the SB showed negative trends for the percentages of cold days and nights, whereas the central region of the SB exhibited positive trends for those variables and negative trends for the percentages of warm days and nights, with the opposite being observed for the peripheral region. However, the performed characterization of the behaviour of the aforementioned extreme indices should serve as a warning for agriculture management, as this is one of the most important economic activities in the SB. Special attention must be given to the winter crops, considering the increase/decrease in the number of chill hours.

Keywords: CLIMDEX. Trends. Regional and sub-regional analysis.

Resumo: Esta pesquisa analisa tendências de extremos climáticos de temperatura na região sul do Brasil (SB), baseada em oito índices, quatro absolutos (maiores e menores temperaturas máximas (TX) e mínimas (TN) anuais) e quatro em percentis (porcentagem de dias com TX e TN inferiores ao percentil 10, e de dias com Tmax e Tmin superiores ao percentil 90), calculados a partir de séries de dados observados em alta resolução espacial de 0.25°x0.25°, no período 1980-2016. O teste de Mann-Kendall (MK) foi usado para analisar a significância das tendências, em °C/década. Resultados mostraram aumento da intensidade e frequência de extremos no SB, com tendências negativas generalizadas dos extremos absolutos de TN, e positivas dos extremos absolutos de TX, podendo-se inferir desse resultado uma dilatação da amplitude térmica diária no período. Os extremos norte e sul do SB mostram tendência negativa no número de dias e noites frias, ao passo que a área central do SB mostra tendências positivas no número de dias e noites frias, e negativas no percentual de dias e noites quentes, com a exceção ocorrendo na periferia da região SB. No entanto, os resultados apresentados devem servir de alerta para o gerenciamento de uma das mais importantes atividades econômicas do SB, a agricultura, com especial atenção para culturas de inverno em relação ao aumento/diminuição do número de horas de frio.

Palavras-chave: CLIMDEX. Tendências. Análise regional e sub-regional.

Resumen: Esta investigación analiza las tendencias climáticas extremas en la región sur de Brasil (SB), con base en ocho índices, cuatro absolutos y cuatro en percentiles para TX y TN, calculados a partir de series de datos observadas con alta resolución espacial de 0.25°x0.25°, en el período 1980-2013. Se utilizó la prueba de Mann-Kendall (MK) para analizar la significancia de las tendencias, en °C/década. Los resultados mostraron un aumento en la intensidad y frecuencia de los extremos en el SB, con tendencias negativas generalizadas de los extremos absolutos de TN, y tendencias positivas de los extremos absolutos de TX, pudiendo inferirse una dilatación de la amplitud térmica diaria en el período. Los extremos al norte y sur del SB muestran una tendencia negativa en el número de días y noches fríos, mientras que el área central del SB muestra tendencias positivas en el número de días y noches frías y tendencias negativas en el porcentaje de días y noches cálidas, con la excepción que ocurre en la periferia de la región SB. Sin embargo, los resultados presentados deben servir de advertencia para el manejo de una de las actividades económicas más importantes del SB, la agricultura, con especial atención a los cultivos de invierno en relación al aumento/disminución del número de horas frías.

Palabras clave: CLIMDEX. Tendencias. Análisis regional y subregional.

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1. INTRODUCTION

Recent climate variability has drawn a huge interest from the scientific community so as to investigate the environmental and political aspects arising from scenarios of possible increase in global temperature. According to the Intergovernmental Panel on Climate Change, in its fifth assessment report (IPCC-AR5, 2014), the global temperature could rise at different levels, depending on the kind of climate scenario (Representative Concentration Pathway – RCP) that will prevail until the end of the 21st century. The RCP2.6 scenario presuppose a warming of 0.30°C to 1.70°C, which may be as high as 1.10°C to 2.60°C according to RCP4.5, or ranging from 1.40°C to 3.10° (RCP6.0), and possibly reaching about 2.60°C to 4.80°C if the most dramatic scenario (RCP 8.5) becomes reality. Resulting from those hypothetical elevations, a concurrent rise on the frequency and intensity of extreme weather events is expected (KITOH and ENDO, 2016; MARENGO *et al*., 2016; SCHOOF and ROBESON, 2016; ALEXANDER and ARBLASTER, 2017; MUKHERJEE *et al*., 2018). Therefore, in-depth studies that assess how the influence of possible climate change in those extents impacts the society at local levels are made necessary.

Some of the studies carried out to detect and quantify changes in climate have been concentrating in analysing the mean values trend of variables such as temperature and rainfall (ALEXANDER *et al*., 2006; HEIDINGER *et al*., 2018). Nonetheless, the approach that concerns mean values alone are not always of sufficient efficacy in characterizing changes that are significant enough to negatively impact society. In view of that, an Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDI) have standardized a set of 27 climate indices of extreme temperature and precipitation that works as an analysis tool for climate change in the whole world. Thenceforth, a large amount of researches have been carried out at a global level with the purpose of analysing the change in the pattern of climate extremes by using the ETCCDMI proposed indices (KOSTOPOULOU and JONES, 2005; VINCENT *et al*., 2005; QI and WANG, 2012; GROTJHAN *et al*., 2016; SALVADOR and BRITO, 2018; COSTA *et al*., 2020).

From an economic perspective, the South of Brazil (SB) is one of the most important regions in South America (MARENGO and CAMARGO, 2008). The region is highly dependent on the primary sector and contributes to more of 50% national agricultural production, being naturally exposed, vulnerable, to negative impacts of the occurrence of climate extremes

(REBOITA *et al.*, 2017a; REBOITA *et al.*, 2017b; CARDOSO *et al.*, 2020; GAN *et al.*, 2020; TEIXEIRA and PRIETO, 2020a; TEIXEIRA and PRIETO, 2020b; ARSEGO *et al.*, 2020). Some studies on trend analysis of mean and extreme climate variables have been conducted for part of the SB or for its entirety (VINCENT *et al.*, 2005; MARENGO and CAMARGO, 2008; STRECK *et al.*, 2011; SALVIANO *et al.*, 2016). However, all those works have restricted themselves to a few surface stations, instead of maximizing the amount of available data.

The present study aims to analyse the trend of a sample of extreme climate indices of temperature obtained from ETCCDI for SB by using a set of high spatial resolution grid data that employs the highest possible number of surface stations and robust techniques in order to estimate grid points that lack stations (DA ROCHA JÚNIOR *et al.*, 2019; DA ROCHA JÚNIOR *et al.*, 2020; XAVIER *et al.*, 2016). That way, it is possible to carry out a more detailed assessment of the change in patterns of temperature extremes in the SB for the period of 1980-2016.

2. METHODOLOGY

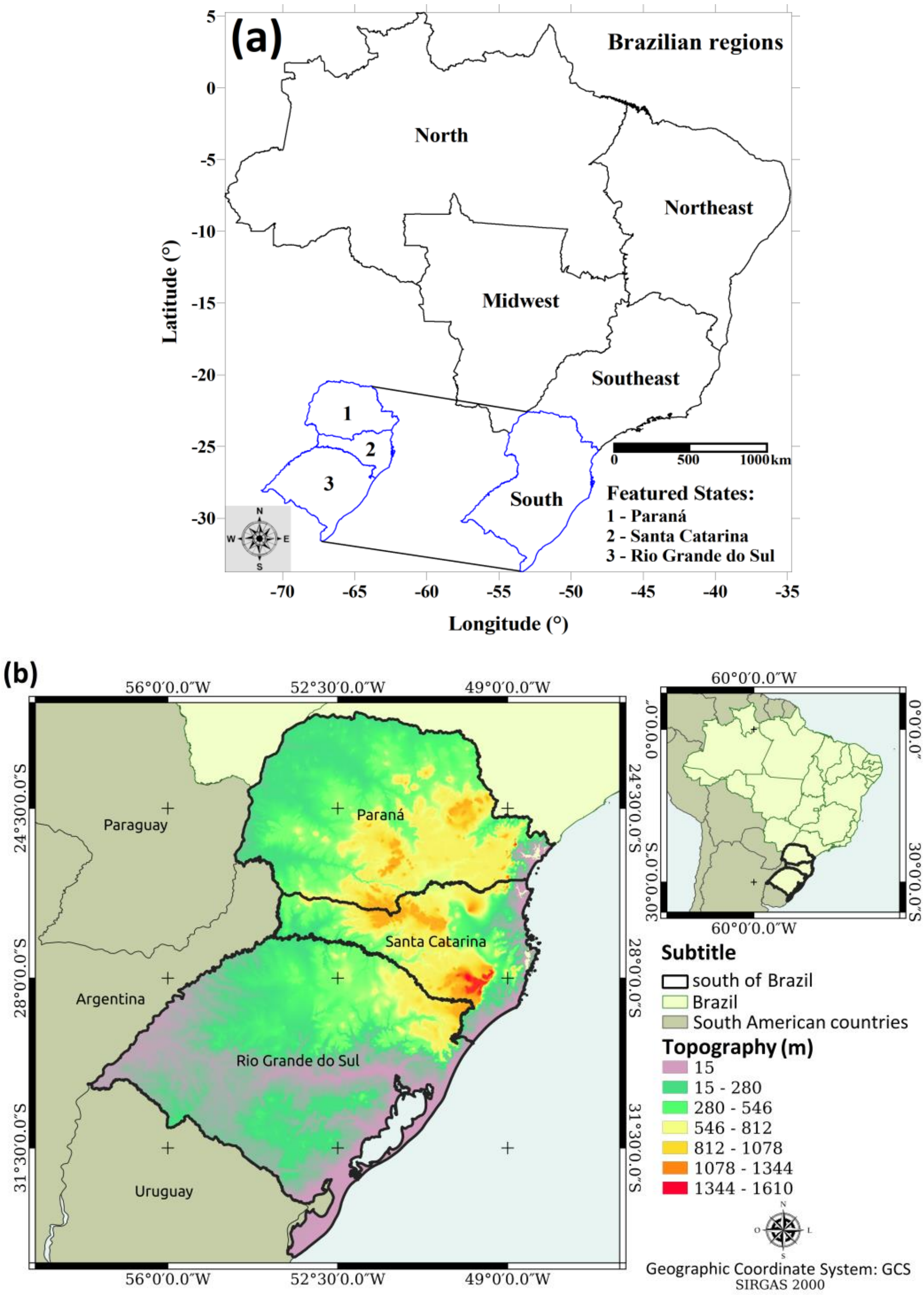
2.1. Study Area and Observed Data

The variables used in this study were Minimum air Temperature (TN) and Maximum air Temperature (TX), obtained from gridded data by Xavier *et al*. (2016) for all the SB. This data source presents a high spatial resolution of 0.25°x0.25°, and several interpolation methods were resorted to. The database builds from the highest number of surface weather stations in Brazil (https://utexas.box.com/Xavier-etal-IJOC-DATA) and comprehends the period of 1980-2016. Originally available in daily resolution, the dataset was later converted to seasonal and annual frequencies. Such data have been widely employed in climate studies on different regions of Brazil (DA SILVA *et al.*, 2019a; PAREDES-TREJO *et al.*, 2019; DA SILVA *et al.*, 2019b; DA ROCHA JÚNIOR *et al.*, 2019; DOS REIS *et al.*, 2020a; DOS REIS *et al.*, 2020b).

According to Xavier *et al*. (2016), the time series of each grid point were constructed based on data from conventional and automatic INMET stations, with two quality indicators for each grid cell: the number of included stations with data, and the geodesic distance of the nearest reporting station with data. A rigorous process of quality control and homogeneity was applied to each time series observed in order to exclude series with many inconsistencies from the analysis. After this step, different interpolation methodologies were tested, such as inverse distance weighting (IDW), angular distance weighting (ADW), and ordinary point kriging (OPK). After the construction of the regular grid with a spatial resolution of 0.25°x0.25° with each method, points related to the observed series are extracted again for comparison with the original data, and in this process, it was found that for TX and TN, the IDW method was the most efficient, with correlation values of 0,91 for both variables.

Comprising three of the country's states with a total area of 576 774,31 km² (Figure 1a), the SB is the smallest among the Brazilian geographic and statistical five major regions, being a little smaller than France, but has the second largest population, with approximately 11.433,957 inhabitants in the state of Paraná, 7.164,788 in Santa Catarina and 11.377,239 in Rio Grande do Sul, according to data collected by The Brazilian Institute of Geography and Statistics (IBGE, acronym in portuguese) for the year of 2018. It is one of the most economically influent regions in the country, with activities in multiple sectors, such as agriculture and livestock, manufacturing, extractivism, and a strong tertiary sector, including tourism. Figure 1b shows the region with emphasis on its topography, where high altitudes can be seen between the mountains of Rio Grande do Sul and Santa Catarina, up to the southeast of Paraná.

Figure 1 – (a) Map of Brazil highlighting the SB perimeter in blue, with its states numbered from north to south and nominally identified: (1) Paraná, (2) Santa Catarina, (3) Rio Grande do Sul, and (b) highlighting the region's topography.



Source: Elaborated by the authors (2021).

2.2. Extreme Indices

The set of indices proposed by ETCCDMI can be grouped in four types: 1) Absolute Indices, 2) Threshold Indices, 3) Duration Indices and 4) Percentile Indices. Eight temperature indices, from the total of 27 ETCCDMI core indices, were analysed. A summary of the eight presently studied ones is presented in Table 1. Those indices have been largely used for analysis of changes in the occurrence of extreme events in regional and global scales (KRUGER *et al.*, 2013; SHEIKH *et al.*, 2015; ABATAN *et al.*, 2016; MCGREE *et al.*, 2019; COSTA *et al.*, 2020).

Table 1- Extreme temperature indices of the absolute type as proposed by ETCCDMI (TXx, TNx, TXn e TNn) and of the percentile type (TN10p, TX10p, TN90P e TX90p).

Symbol	Extended name	Definition	Unit
TXx	Maximum Tmax	Monthly maximum value of daily maximum temperature	°C
TNx	Maximum Tmin	Monthly maximum value of daily minimum temperature	°C
TXn	Minimum Tmax	Monthly minimum value of daily maximum temperature	°C
TNn	Minimum Tmin	Monthly minimum value of daily minimum temperature	°C
TN10p	Cold nights	Percentage of days when TN < 10th percentile	% of days
TX10p	Cold days	Percentage of days when TX < 10th percentile	% of days
TN90p	Warm nights	Percentage of days when TN > 90th percentile	% of days
TX90p	Warm days	Percentage of days when TX > 90th percentile	% of days

Source: Elaborated by the authors (2021).

2.3. Mann-Kendall Test

The MK test (MANN, 1945; KENDALL, 1975) is a nonparametric statistical test widely used in climatology and hydrology for the detection of trends (Z_{MK}) in time series of geosciences variables. It offers the advantages of not requiring any sort of normality adjustments to the data and of having a low sensitivity to abrupt changes in the series. According to the test premises, the null hypothesis (H0) assumes that there is no trend in the data series at a given level of significance, i.e., that the series is independent and randomly ordered. The alternate hypothesis (H1) assumes there is a monotonic trend. Several studies have reported the efficacy of the MK test in identifying trends in climate variables in the past decades, for numerous regions of the world, including, specifically, Brazil (GOOSSENS and BERGER, 1986; YU *et al.*, 2002; BLAIN, 2010; MINUZZI e CARAMORI, 2011; KARMESHU, 2012; PINHEIRO *et al.*, 2013; WU e QIAN, 2017; DA SILVA *et al.*, 2015; LACERDA *et al.*, 2015; DE

OLIVEIRA *et al.*, 2017; DOS REIS *et al.*, 2017; BEZERRA *et al.*, 2018; MUTTI *et al.,* 2019; COSTA *et al.*, 2020).

Given the observations $x_1, x_2, ..., x_n$ in a time series, the MK test for a trend (Z_{MK}) can be applied only if the series is serially independent. Then, it is aimed to test whether the observations in the series are independents from one another and identically distributed or not, i.e., to test for H0 (there is no trend, as the observations are independent and spatially distributed) and H1 (there is a trend, as there is a monotonic trend in the time scale of the observations). Under H0, the S statistic is estimated as in Modarres and Silva (2007):

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

where *xi* is the sequential value of the data; *n* is the size of the time series and *sgn(xi - xj)* = -1 if *(xi - xj)* < 0; *sgn(xi - xj)* = 0 if *(xi - xj)* = 0 or *sgn(xi - xj)* = 1 if *(xi - xj)* > 0. The null hypothesis (H0) is that a data sample $\{X_t: t = 1, 2, ..., n_i\}$ is independently and identically distributed. The Expectation E(S) and the Variance V(S) of the S statistic are given by (2) and (3), respectively:

$$E[S] = 0 \quad (2)$$

$$Var[S] = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)}{18} \quad (3)$$

where n is the number of observations and, in case the series has groups with equal observations, *P* is the number of groups with identical observations and t_p is the number of identical observations in group *P*. A normal distribution of the variable Z is built as shown in (4):

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \quad (4)$$

In a double trend test, the null hypothesis is rejected if $| Z | > Z_{\alpha/2}$, where α is the level of significance. Given the great variability in the data, we consider trends to be statistically significant when the p-value is less than or equal to 10%. A high positive value of the S statistic indicates a strengthening in the trend, whereas a low negative value of

S indicates a weakening in the trend. For more details on the MK test, we recommend reading Wilks (2011).

3. DEVELOPMENT

Figure 2 shows the fields of the presently analysed absolute indices (TNn, TNx, TXn and TXx), which represent the trend in the most extreme values of minimum and maximum temperatures observed in a single day of the year during the studied period. The values correspond to trends in the decadal scale (°C/decade).

Most of the SB present downward trends in the extreme inferior values of TN (Figure 2a), thus indicating an increase in the magnitude of cold extremes. This result is corroborated by the observation of negative trends in TXn (Figure 2c), which may be associated to an increase in diurnal temperature range. The significant trends observed for most of the region in both maps are in the range of -0.5 to -3°C/decade. The most pronounced changes are found in the center-east, in the border between the states of Santa Catarina and Rio Grande do Sul. However, it is also noted a narrow area presenting significant positive trend for TNn in the very east (in the coast) of Santa Catarina (Figure 2a).

Regarding the TNx and TXx indices, upward trends (~1.5°C/decade) are observed for most of the SB, exhibiting a peripheral pattern for TNx (Figure 2b) and reaching up to 90% of the SB territory for TXx (Figure 2d). In the central sector of the SB – more specifically from the southeast of Paraná to the south of Santa Catarina, skipping the east of the latter – significant changes prompting to a decrease in TNx are perceived (Figure 2b). The results point to an increase in the intensity of warm extremes for most of the SB, except for the extreme south of Santa Catarina, which exhibits negative trends for both indices.

Significant trends in the occurrence of cold nights (TN10p – Figure 3a) and cold days (TX10p – Figure 3c) are noted mainly in the extreme north and south of the SB. The northernmost region shows downward trends for both variables (Figures 3a and 3c). Its southernmost counterpart, in its turn, exhibit upward trends for the same variables. Positive trends are also seen in the central portion of the SB – namely in the border between Santa Catarina and Rio Grande do Sul – signalling an increase in the incidence of cold days and nights, whereas negative trends are observed in most of the coast of the SB for TX10p

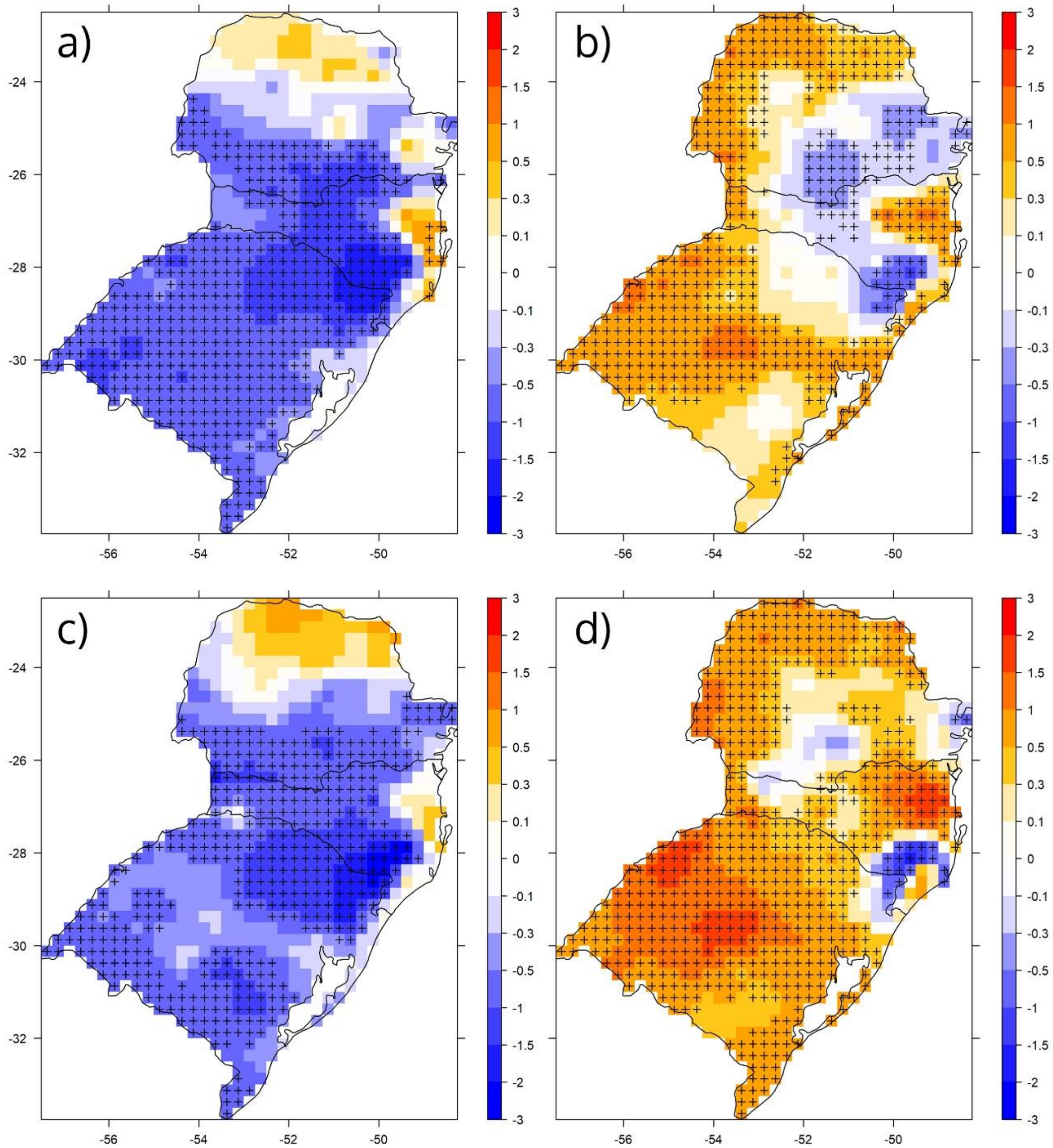
(Figure 3c) and, more prominently, for TN10p (Figure 3a). This last feature seems to be closely related to the topography of this area, where the mountains of Rio Grande do Sul and Santa Catarina are located, with altitudes that exceed 1500m in some points and that maintain high altitudes up to the southeast of Paraná, up to 1000m, as seen in Figure 1b.

As previously noted for TNx and TXx, the upward trends regarding the percentage of warm nights (TN90p) and days (TX90p) also present a peripheral pattern on the SB (Figures 3b and 3d, respectively). Such changes in the rim of the SB vary from +2% to +10% in the number of days per decade. On the other hand, the central part of the SB exhibit downward trends for the same variable, with a variation of -1% to -10% in the number of days per decade, most noticeably for a pocket in the south of Santa Catarina. This is a very relevant result, as it shows a specific dynamic in the trends observed in the elevated areas of the interior of the SB, with a percentage increase in the number of cold nights (TN10p) and warm nights (TN90p), while a decrease in the percentage of cold days (TX10p) and hot days (TX90p). This combination shows that, in fact, there have been more frequent two types of combinations in the mountain areas: less hot days with cooler nights, and less cold days with warmer nights. These combinations favor the increase of daily thermal amplitudes.

Silva et al. (2015) found positive significant trends for almost all the state of Paraná by analysing the TN90p and TX90p indices calculated from surface stations data. Their results are consistent with the ones obtained by the present study and displayed in Figures 2b and 2d. Marengo and Camargo (2008) reported trends of strong increase in TN during the summer for all the SB from 1960 to 2002. The authors also analysed extreme indices and found upward trends for warm days during both the summer and the winter, which is coherent with the result presented in Figure 2d. Similar results are also observed in Vincent *et al*. (2005), who showed negative trends in the extreme values of Tmin analogously to the ones exhibited in Figures 2a and 2c. Streck *et al*. (2011) noticed that trends concerning Tmin and Tmax as well as the diurnal temperature range in the city of Santa Maria (Rio Grande do Sul) respond to the Pacific Decadal Oscillation (PDO). The authors found that, during the cool (warm) phase of the PDO, there is a decrease (increase) in both TX and TN. The analysis period studied by them encompassed parts of both phases of the PDO, a warm phase (1980-1998) and a cool phase (1999-2013).

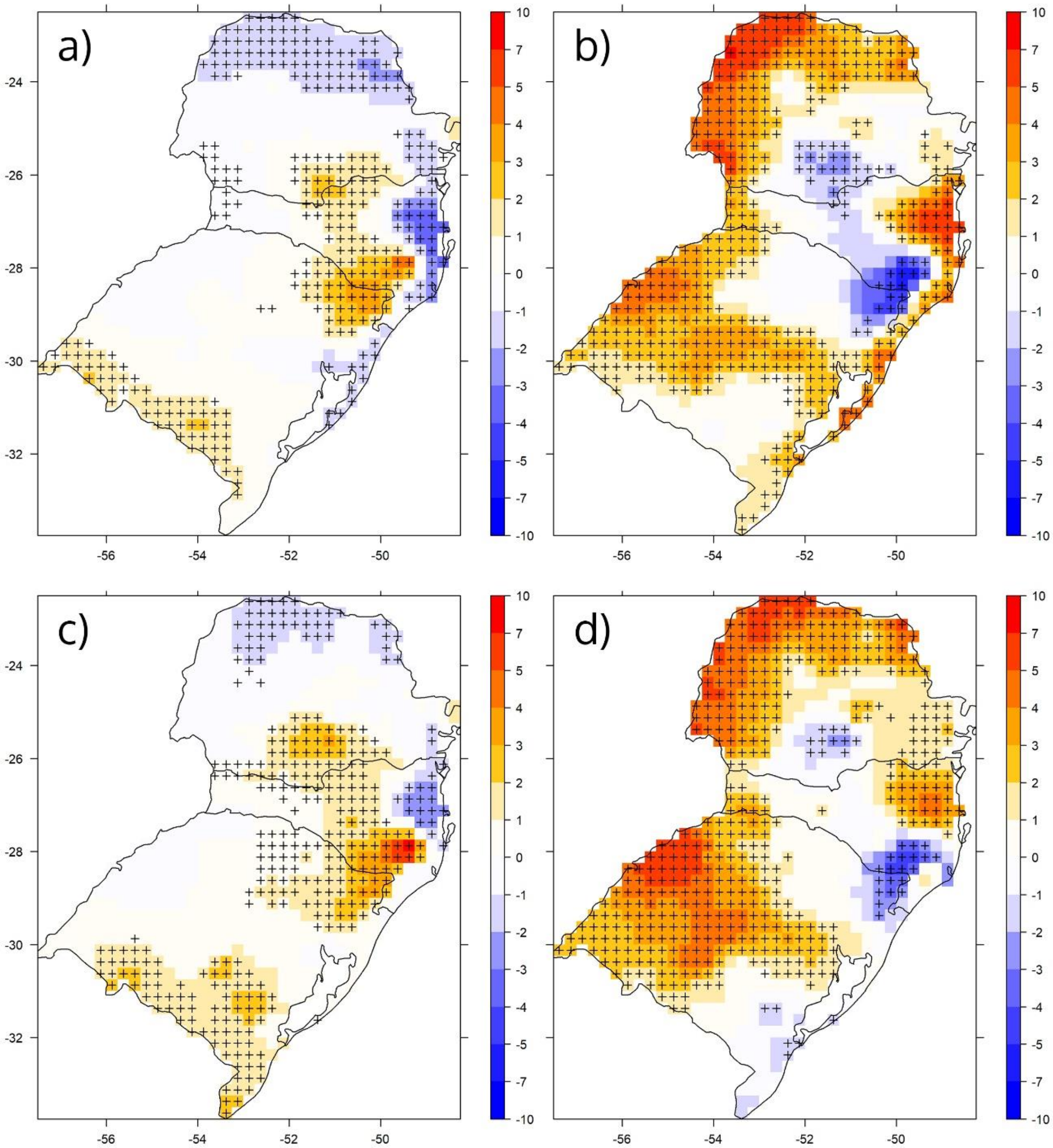
Skansi *et al*. (2013) analysed trends in extreme indices for the whole South American continent, although they were limited to only three weather stations for the SB. Those authors found statistically significant upward trends for the percentile temperature indices of TN90p and TX90p and negative trends for TN10p and TX10p. They also reported, for the region, positive trends of 0.5 to 1.5°C/decade for TNn and TXn relative to the period from 1969 to 2009.

Figure 2 - Values found for the absolute extreme indices a) TNn, b) TNx, c) TXn and d) TXx. Dark crosses on the map indicate statistical significance at 10% level.



Source: Elaborated by the authors (2021).

Figure 3 - Values found for the percentile extreme indices a) TN10p, b) TN90p, c) TX10p and d) TX90p. Dark crosses on the map indicate statistical significance at 10% level.



Source: Elaborated by the authors (2021).

4. CONCLUSIONS

This work analysed trends for the ETCCDMI extreme temperature indices in the South region of Brazil for the period of 1980-2016, by using high resolution grid data obtained from a huge amount of surface weather stations, covering a more than sufficiently long observation period for climate studies.

The results showed a significant increase in both the strength and frequency of temperature extremes in the SB. There is an overall decrease trend for the TNn and TNx indices, while positive trends predominate for TXn and TXx. The sole exception pertains to the central portion of the region, in part of the border shared by Santa Catarina and Rio Grande do Sul, where negative trends were found for TNx, and, in a pocket located in the southeast of Santa Catarina, for TXx as well. The northern and southern edges of the SB exhibited downward (upward) trends for the amount of cold days (nights). The central area of the SB presented positive trends for both cold days and nights. On the other hand, this very region showed negative trends for TN90p and TX90p (warm nights and days), for which nearly all the peripheral area of the SB exhibited upward trends.

It is recommended that a Tipping Point analysis be performed in order to identify whether the trends are continuous or not. If there is continuity, the hypothesis of a long term climate change in the region caused by anthropogenic activity or natural forcings by phenomena of large time scales will be strengthened. If there is discontinuity at around the year of 1999, the hypothesis that the trends were caused by the PDO may prevail.

REFERENCES

ABATAN, A. A. et al. Trends in extreme temperature over Nigeria from percentile-based threshold indices. **International Journal of Climatology**, v. 36, n. 6, p. 2527-2540, 2016.

ALEXANDER, L. V. et al. Global observed changes in daily climate extremes of temperature and precipitation. **Journal of Geophysical Research**, v. 111, D05109, 2006.

ALEXANDER, L. V.; ARBLASTERC, J. M. Historical and projected trends in temperature and precipitation extremes in Australia in observations and CMIP5. **Weather and Climate Extremes**, v. 15, p. 34-56, 2017.

ARSEGO, D. A. et al. Índices Climáticos Associados a Variabilidade Interanual da Produtividade de Arroz no Rio Grande do Sul. **Revista Brasileira de Meteorologia**, v. 35, n. 2, p. 209-218, 2020.

BEZERRA, B. G. et al. Changes of precipitation extremes indices in São Francisco River Basin, Brazil from 1947 to 2012. **Theoretical and Applied Climatology**, v. 135, p. 565-576, 2018.

BLAIN, G. C. Séries anuais de temperatura máxima média do ar no estado de São Paulo: Variações e tendências climáticas. **Revista Brasileira de Meteorologia**, v. 25, n. 1, p. 114-124, 2010.

CARDOSO, C. S.; QUADRO, M. F. L.; BONETTI, C. Persistência e Abrangência dos Eventos Extremos de Precipitação no Sul do Brasil: Variabilidade Espacial e Padrões Atmosféricos. **Revista Brasileira de Meteorologia**, v. 35, n. 2, p. 219-231, 2020.

COSTA, R. L. et al. Analysis of climate extremes indices over northeast Brazil from 1961 to 2014. **Weather and Climate Extremes**, v. 28, p. 100254, 2020.

DA ROCHA JÚNIOR, R. L. et al. Analysis of the Space-Temporal Trends of Wet Conditions in the Different Rainy Seasons of Brazilian Northeast by Quantile Regression and Bootstrap Test. **Geosciences**, v. 9, p. 457, 2019.

DA ROCHA JÚNIOR, R. L. et al. Mudança de Longo Prazo e Regionalização da Evapotranspiração de Referência no Nordeste Brasileiro. **Revista Brasileira de Meteorologia**, v. 35, p. 891-902, 2020.

DA SILVA, R. M. et al. Rainfall and river flow trends using Mann –Kendall and Sen's slope estimator statistical tests in the Cobres River basin. **Natural Hazards**, v. 77, p. 1205-1221, 2015.

DA SILVA, P. E. et al. Análise de Índices de Extremos Climáticos no Nordeste e Amazônia Brasileira para o Período entre 1980 a 2013. **Anuário do Instituto de Geociências**, v. 42, n. 2, p. 137-148, 2019a.

DA SILVA, P. E. et al. Precipitation and air temperature extremes in the Amazon and northeast Brazil. **International Journal of Climatology**, v. 39, n. 2, p. 579-595, 2019b.

DE OLIVEIRA, P. T.; SANTOS E SILVA, C. M.; LIMA, K. C. Climatology and trend analysis of extreme precipitation in subregions of Northeast Brazil. **Theoretical and Applied Climatology**, v. 130, p. 77-90, 2017.

DOS REIS, L. C. et al. Climate Trends in Bom Jesus, soybean production region in Piauí. **Revista Geama**, v. 3, n. 4, p. 196-200, 2017.

DOS REIS, L. C. et al. Caracterização da variabilidade da precipitação no MATOPIBA, região produtora de soja. **Revista Brasileira de Geografia Física**, v. 13, n. 4, p. 1425-1441, 2020a.

DOS REIS, L. C. et al. Analysis of Climate Extreme Indices in the MATOPIBA Region, Brazil. **Pure and Applied Geophysics**, 2020b. https://doi.org/10.1007/s00024-020-02474-4.

GAN, M. A. et al. Ciclones em Superfície nas Latitudes Austrais. Parte III: Energética. **Revista Brasileira de Meteorologia**, v. 35, n. 2, p. 281-300, 2020.

GOOSSENS, C.; BERGER, A. Annual and seasonal climatic variations over the northern hemisphere and Europe during the last century. **Annales Geophysicae**, v. 4 (B-4), p. 385-400, 1986.

GROTJAHN, R. et al. North American extreme temperature events and related large-scale meteorological patterns: a review of statistical methods, dynamics, modeling, and trends. **Climate Dynamics**, v. 46, p. 1151-1184, 2016.

HEIDINGER, H. et al. A new assessment in total and extreme rainfall trends over central and southern Peruvian Andes during 1965–2010. **International Journal of Climatology**, v. 38, n. 51, p. 998-1015, 2018.

KARMESHU. N. **Trend Detectionin Annual Temperature & Precipitation using the Mann Kendall Test - A Case Study to Assess Climate Change on Select States in the Northeastern United States**. Master of Environmental Studies Capstone Projects. University of Pennsylvania. Department of Earth and Environmental Science, 2012.

KENDALL, M. G. **Rank Correlation Methods**. Charles Griffin, London, 1975.

KITOH, A.; ENDO, H. Changes in precipitation extremes projected by a 20-km mesh global atmospheric model. **Weather and Climate Extremes**, v. 11, p. 41-52, 2016.

KOSTOPOULOU, E.; JONES, P. D. Assessment of climate extremes in the Eastern Mediterranean. **Meteorology and Atmospheric Physics**, v. 89, n. 1-4, p. 69-85, 2005.

KRUGER, A. C.; SEKELE, S. S. Trends in extreme temperature indices in South Africa: 1962–2009. **International Journal of Climatology**, v. 33, n. 3, p. 661-676, 2013.

LACERDA, F. F. et al. Long-term temperature and rainfall trends over Northeast Brazil and Cape Verde. **Journal of Earth Science and Climatic Change**, v. 6, n. 8, p. 1-8, 2015.

MANN, H. B. Nonparametric tests against trend. **Econometrica**, v. 13, n. 3, p. 245-259, 1945.

MARENGO, J. A.; CAMARGO, C. C. Surface air temperature trends in Southern Brazil for 1960–2002. **International Journal of Climatology**, v. 28, n. 7, p. 893-904, 2008.

MARENGO, J. A.; TORRES, R. R.; ALVES, L. M. Drought in Northeast Brazil-past, present, and future. **Theoretical and Applied Climatology**, v. 129, p. 1189-1200, 2016.

MCGREE, S. et al. Recent Changes in Mean and Extreme Temperature and Precipitation in the Western Pacific Islands. **Journal of Climate**, v. 32, n. 16, p. 4919-4941, 2019.

MINUZZI, R. B.; CARAMORI, P. H. Variabilidade climática sazonal e anual da chuva e veranicos no Estado do Paraná. **Revista Ceres**, v. 58, n. 5, p. 593-602, 2011.

MODARRES, R.; DA SILVA, V. P. R. Rainfall trends in arid and semiarid regions of Iran. **Journal of Arid Environments**, v. 70, p. 344-355, 2007.

MUKHERJEE, S. et al. Increase in extreme precipitation events under anthropogenic warming in India. **Weather and Climate Extremes**, v. 20, p. 45-53, 2018.

MUTTI, P. R. et al. A detailed framework for the characterization of rainfall climatology in semiarid watersheds. **Theoretical and Applied Climatology**, v. 139, p. 109-125, 2019.

PAREDES-TREJO, F.; BARBOSA, H.; DOS SANTOS, C. A. C. Evaluation of the Performance of SM2RAIN-Derived Rainfall Products over Brazil. **Remote Sensing**, v. 11, p. 1113, 2019.

PINHEIRO, A.; GRACIANO, R. L. G.; SEVERO, D. L. Tendência das séries temporais de precipitação da região Sul do Brasil. **Revista Brasileira de Meteorologia**, v. 28, n. 3, p. 281-290, 2013.

QI, L.; WANG, Y. Changes in the observed trends in extreme temperatures over China around 1990. **Journal of Climate**, v. 25, n. 15, p. 5208-5222, 2012.

REBOITA, M. S. et al. Ciclones em Superfície nas Latitudes Austrais: Parte I - Revisão Bibliográfica. **Revista Brasileira de Meteorologia**, v. 32, n. 2, p. 171-186, 2017a.

REBOITA, M. S. et al. Ciclones em Superfície nas Latitudes Austrais: Parte II Estudo de Casos. **Revista Brasileira de Meteorologia**, v. 32, n. 4, p. 509-542, 2017b.

SALVADOR, M. A.; BRITO, J. I. B. Trend of annual temperature and frequency of extreme events in the MATOPIBA region of Brazil. **Theoretical and Applied Climatology**, v. 133, p. 253-261, 2018.

SALVIANO, M. F.; GROPPO, J. D.; PELLEGRINO, G. Q. Análise de Tendências em Dados de Precipitação e Temperatura no Brasil. **Revista Brasileira de Meteorologia**, v. 31, n. 1, p. 64-73, 2016.

SCHOOF, J. T.; ROBESON, S. M. Projecting changes in regional temperature and precipitation extremes in the United States. **Weather and Climate Extremes**, v. 11, p. 28-40, 2016.

SHEIKH, M. M. et al. Trends in extreme daily rainfall and temperature indices over South Asia. **International Journal of Climatology**, v. 35, p. 1625-1637, 2015.

SILVA, W. L. et al. Tendências observadas em indicadores de extremos climáticos de temperatura e precipitação no estado do Paraná. **Revista Brasileira de Meteorologia**, v. 30, n. 2, p. 181-194, 2015.

SKANSI, M. et al. Warming and wetting signals emerging from analysis of changes in climate extreme indices over South America. **Global and Planetary Change**, v. 100, p. 295-307, 2013.

STRECK, N. A. et al. Variabilidade interdecadal na série secular de temperatura do ar em Santa Maria, RS. **Pesquisa Agropecuária Brasileira**, v. 46, n. 8, p.781-790, 2011.

TEIXEIRA, M. S.; PRIETO, R. B. Eventos Extremos de Chuva no Estado do Rio Grande do Sul, Brasil, entre 2004 e 2013. Parte 1: Definição dos Eventos e Estatísticas. **Revista Brasileira de Meteorologia**, v. 35, n. 1, p. 45-52, 2020a.

TEIXEIRA, M. S.; PRIETO, R. B. Eventos Extremos de Chuva no Estado do Rio Grande do Sul, Brasil, entre 2004 e 2013. Parte 2: Características Sinóticas dos Eventos Persistentes. **Revista Brasileira de Meteorologia**, v. 35, n. 1, p. 53-61, 2020b.

VINCENT, L. A. et al. Observed trends in indices of daily temperature extremes in South America 1960-2000. **Journal of Climate**, v. 18, p. 5011-5023, 2005.

WILKS, D. S. **Statistical Methods in The Atmospheric Sciences**, 3rd ed, Academic Press: Cambridge, MA, USA, 2011.

WU, H.; QIAN, H. Innovative trend analysis of annual and seasonal rainfall and extreme values in Shaanxi, China, since the 1950s. **International Journal of Climatology**, v. 37, p. 2582-2592, 2017.

XAVIER, A. C.; KING, C. W.; SCANLON, B. R. Daily gridded meteorological variables in Brazil (1980-2013). **International Journal of Climatology**, v. 36, p. 2644-2659, 2016.

YU, P. S.; TAO, T. C.; CHOU, C. C. Effects of climate change on evapotranspiration from paddy fields in Southern Taiwan. **Climatic Change**, v. 54, p. 165-179, 2002.