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COMBINED TEMPERATURE-PRECIPITATION MODES AND THEIR RELATIONSHIP WITH LARGE-SCALE CLIMATE INDICES IN PARANÁ, SOUTHERN BRAZIL (1980-2014)

MODOS COMBINADOS DE TEMPERATURA-PRECIPITAÇÃO E SUA RELAÇÃO COM ÍNDICES CLIMÁTICOS DE LARGA ESCALA NO PARANÁ, SUL DO BRASIL (1980-2014)

MODOS COMBINADOS TEMPERATURA-PRECIPITACIÓN Y SU RELACIÓN CON ÍNDICES CLIMÁTICOS A GRAN ESCALA EN PARANÁ, SUR DE BRASIL (1980-2014)

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Abstract: In recent decades, the Northeast of Brazil experienced several episodes of intense drought while other regions were affected by heavy rainfall events that caused severe flooding. The variability of temperature and precipitation in Brazil are associated with large-scale climatic indices, such as the El Niño Southern Oscillation (ENSO), the Multidecadal Atlantic Oscillation (AMO) and the Tropical North Atlantic (TNA). In this study, the 25th and 75th quantiles for temperature and precipitation were used to determine the climatic trends in terms of number of days for the different modes (warm and dry, warm, and humid, cold, and dry or cold and wet). Subsequently, correlation analyses were carried out with nine different climatic indices that influence the regional climate of the state of Paraná in Southern Brazil. Our results highlighted the absence of a dominant mode throughout the

seasons and over the years. We also found spatio-temporal trends in this region. In addition, except for the warm-dry mode where 8 out of 10 stations were correlated with the Niño 1 + 2 index, there were few correlations between the modes and the different climate indices used in this research. Despite the increasing temperature trends, and complex and heterogeneous variations in precipitation regime, our results did not indicate any significant changes in the modes or their relationship with the climate indices.
Keywords: Climate. Temperature. Precipitation. Indices. Brazil.

Resumo: Nas últimas décadas o Nordeste do Brasil passou por vários episódios de secas severas, enquanto outras regiões foram afetadas por intensas chuvas responsáveis por episódios de inundações. A variabilidade da temperatura e da precipitação no Brasil estão associadas a índices climáticos de grande escala, como o El Niño Oscilação Sul (ENSO), a Oscilação Multidecadal do Atlântico (AMO) e o Atlântico Norte Tropical (TNA). Neste estudo foram utilizados os quantis 25 e 75 de temperatura e precipitação para determinar as tendências climáticas em termos de número de dias para os diferentes modos (quente e seco, quente e úmido, frio e seco ou frio e úmido). Posteriormente, foram realizadas análises de correlação com nove diferentes índices climáticos que influenciam o clima regional no Sul do Brasil. Como resultado se destaca a ausência de um modo dominante ao longo das estações no período analisado; bem como de tendências espaço-temporais nesta região. Exceto para o modo quente-seco, no qual 8 de 10 estações foram correlacionadas com o índice Niño 1 + 2, ocorreram poucas correlações entre os modos e os diferentes índices climáticos usados nesta investigação. Apesar das tendências de aumento da temperatura e de variações complexas e heterogêneas no regime de precipitação, os resultados não indicaram mudanças significativas nos modos e nem em sua relação com os índices climáticos.
Palavras-chave: Clima. Temperatura. Precipitação. Índices. Brasil.

Resumen: En las últimas décadas, el noreste de Brasil ha atravesado varios episodios de sequías intensas, mientras que otras regiones se vieron afectadas por fuertes lluvias responsables por graves inundaciones. La variabilidad de temperatura y precipitación en Brasil está asociada con índices climáticos de gran escala, como el Niño Oscilación del Sur (ENSO), la Oscilación Atlántica Multidecadal (AMO) y el Atlántico Norte Tropical (TNA). En este estudio, se utilizaron los cuantiles 25 y 75 de temperatura y precipitación para determinar las tendencias climáticas en términos de número de días para los diferentes modos (cálido y seco, cálido y húmedo, frío y seco o frío y húmedo). Posteriormente, se realizaron análisis de correlación con nueve índices climáticos diferentes que influyen en el clima regional del sur de Brasil. Nuestros resultados destacaron la ausencia de un modo dominante a lo largo de las estaciones y a lo largo de los años. También encontramos tendencias espacio-temporales en esta región. Además, a excepción del modo cálido-seco donde 8 de cada 10 estaciones se correlacionaron con el índice Niño 1 + 2, hubo pocas correlaciones entre los modos y los diferentes índices climáticos utilizados en esta investigación. A pesar de las tendencias crecientes de temperatura y de variaciones complejas y heterogéneas en el régimen de precipitación, nuestros resultados no indicaron cambios significativos en los modos ni en su relación con los índices climáticos.
Palabras-clave: Clima. Temperatura. Precipitación. Índices. Brasil.

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INTRODUCTION

At the global scale, mean annual air temperature has increased by about +0.6°C (Smith; Reynolds 2005) over the 20th century. However, this increase is more pronounced in some regions like Southern Brazil, where the air temperature increased between +0.5 and +0.6°C per decade from 1913 to 2006 (SANSIGOLO; KAYANO, 2010). According to the IPCC (2021; STOCKER, 2014) (IS92), average temperatures in South America follow an increasing trend (about 4°C by 2100), mainly in the Northwest, South and Southeast regions, accompanied by an increase in precipitation of about +10 to +15% during the fall, but a decrease in precipitation of -10 to -15% for the summer season. More specifically for the South and Southeast regions, increases in average precipitation, the intensity and frequency of extreme events since 1960 have been observed, which is a precursor for flooding in urban areas that severely affect crops, ecosystems, people at risk.

The state of Paraná, located in Southern Brazil, was recently affected by hydro-meteorological hazards including the severe floods in 2016, droughts in 2014 (COELHO et al., 2016) and in 2020/2021, along with heat waves (GEIRINHAS et al., 2018). The selection of Paraná for this study is appropriate since it is located in a transitional climate zone characterized by atmospheric instability derived from the complex dynamics between tropical and polar air masses. These air masses allow either a temperate or a tropical climate to prevail, the latter being more present in the north of the state at the borders with the southeastern and central-western regions. For these two regions, the IPCC (2021) projects an increase in the occurrence of dry periods, greater frequency and intensity of extreme precipitation events, and an increase in the number of days with maximum temperatures above 35ºC.

Paraná, like other Brazilian states, has densely populated urban centres, vast areas under cultivation and hydro-electric reservoirs (more than twenty). These factors increase vulnerability to natural hazards. The most destructive natural hazard in the region is caused by extreme weather events that trigger flooding, severe thunderstorms and drought. In the context of global warming, the link between these extreme events and human activities, generated interest in the scientific community, especially in the perspective of adaptation planning and hazard mitigation (HULME, 2014; STOTT et al., 2016; TRENBERTH et al., 2015). Despite the use of various methods to differentiate the respective roles of human and natural factors on climate variability, the results remain inconclusive. Herring et al. (2014) attributes this inconclusiveness to the use of inadequate models and not necessarily the absence of human influence.

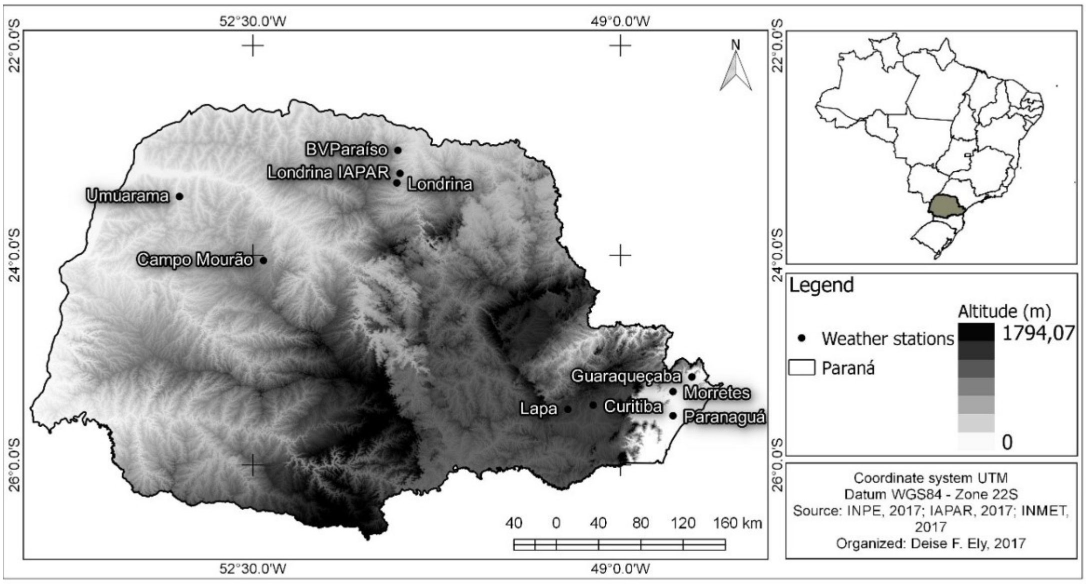
Studies on extreme weather conditions (MARENGO et al., 2009; ALMEIDA et al., 2016; OLIVEIRA et al., 2017; OTTO et al., 2015) have provided a better understanding of climate variability for South America and specifically for Brazil. As stated by Marengo et al. (2009), global models enable greater comprehension of climate change at the global scale but require projection at the regional scale because the adaptation of society, as opposed to mitigation, is strongly linked to local and regional scales. These scales require a more in-depth investigation that make the development of appropriate adaptation strategies possible mainly for impacts on agriculture, water resources management, health among others. In addition, these authors also mentioned that regional projection of climate change is the most important factor to support decision-making systems aimed at reducing population vulnerability.

Climate variables such as temperature and precipitation are frequently studied independently even though they are closely related and tied to atmospheric circulation (DE BARROS SOARES et al., 2017; TRENBERTH et al., 2015). However, the main objective of this study is to assess climate trends by combining precipitation and temperature (modes) from 1981 onwards, and to correlate these modes with 9 atmospheric patterns (Table 4). In this study, we also analyzed the recent climate variability of two regions (north and east) of Paraná, as among the 22 meteorological stations that record daily temperatures and precipitation data in the state, those located in these regions had smaller gaps (less than 20% of missing data) for a longer period. In addition, the proposed methodology will be applied to other stations located in other regions of Paraná. Therefore, the present work will contribute to research on the influence of large-scale climatic oscillations on Southern Brazil, as both the temperature and precipitation variability, and the probability of the occurrence of extreme short-term events are conditioned by large-scale patterns.

STUDY AREA

The state of Paraná is in Southern Brazil (Figure 1) at the confluence of the main atmospheric systems of South America and has more than one rainfall regime. According to the Köppen climate classification, Cfa is the most dominant climatic type in Paraná. This was confirmed in a recent study by Dubreuil et al. (2017) that evaluated the frequency of the occurrence of various types of climates in Brazil for each year between 1964 and 2015. The Cfa climate is subtropical with a mean temperature in the coldest month below 18ºC and average temperature in the hottest month above 22ºC. Other characteristics of Cfa include: hot summers, low frequency of frosts and a tendency for rainfall in the summer, but without a defined dry season.

Figure 1 - Location of the Paraná State (Brazil) and weather stations used in this study.



Source: Elaborated by the authors (2020)

Mendonça (1994) points out that Paraná has an annual rainfall distribution from September to April, with mostly a tropical regime in the north and northwest regions and a subtropical regime in the other areas.

Table 1 presents the historical mean values of climate variables for the period 1971 to 2014 for the stations used in this study. It is important to note that the main objective of this study is to evaluate climate trends, combining precipitation and temperature modes, which were calculated for the 1981 to 2014. The study period ended in 2014 because 18 meteorological stations monitored by the Institute for Rural Development of Paraná - IAPAR/EMATER were closed after 2015. The coldest average temperature (minimum) was recorded at the Lapa station (southeast) while the warmest (maximum temperature) was recorded at Londrina. The Londrina station was also where the lowest average precipitation was recorded (1,109 mm), which is almost half of the average precipitation at the Guaraqueçaba station (2,048 mm). Terassi and Galvani (2017) carried out a regional analysis of rainfall using around fifty precipitation stations, which made it possible to cluster stations together into three major zones: southeast (along the Atlantic coast), southwest (in the Alto Iguaçu watershed) and northeast (in the Ribeira watershed). According to this classification, the Londrina station is in the northeast region, which is the warmest and the driest while the Guaraqueçaba station in the southeast region, is in a wetter zone due to the orographic effect, which favors precipitation on the windward side of Serra do Mar.

Table 1 - Historical average values of climate variables (1971 to 2014) for weather stations analyzed.

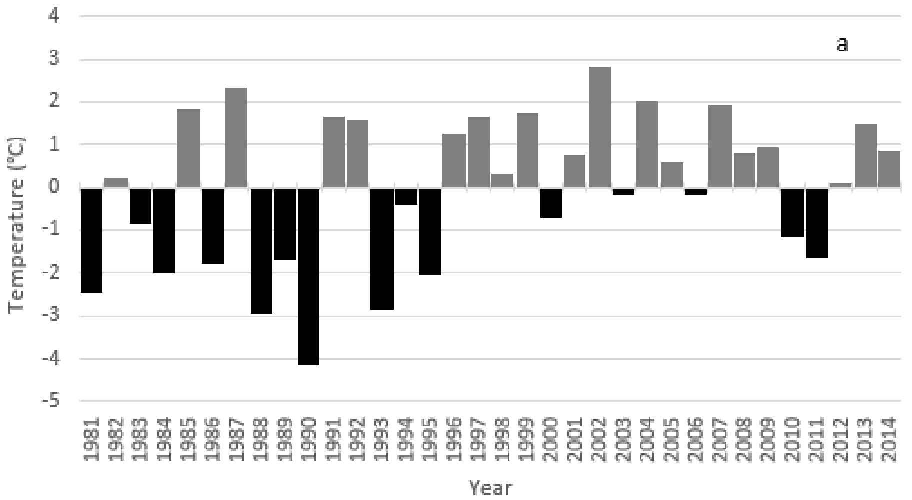
Weather stations	Average maximum temp. (°C)	Average temp. (°C)	Average minimum temp. (°C)	Average prec. (mm)
Bela Vista do Paraíso	27.1	21.3	17.0	1489
Campo Mourão	26.9	20.4	15.1	1628
Curitiba	23.4	17.3	13.2	1435
Guaraqueçaba	26.2	20.8	17.3	2048
Lapa	23.1	17.0	13.1	1646
Londrina	28.0	22.9	16.2	1109
LondrinaIAPAR	27.3	21.0	16.0	1422
Morretes	26.2	20.7	17.3	1981
Paranáguá	26.0	21.4	18.0	1954
Umuarama	27.8	22.1	17.8	1596

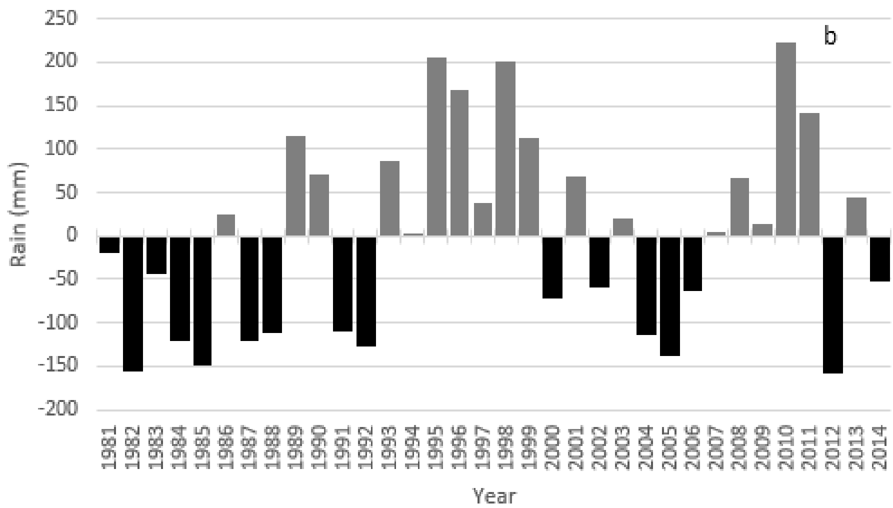
Source: Elaborated by the authors (2020)

The average temperature and precipitation anomalies from 1981 to 2014 are shown in figures 2 a and b respectively. The average elevation of Paraná varies between 300 and 600 m, but the south and eastern regions have altitudes higher than 900 m. In these regions, Cfb is the dominant climate, which is more temperate than Cfa. Average temperature in the coldest month falls below 18°C while mean temperature in the hottest month goes below 22°C with no defined dry season (IAPAR, 2014).

As mentioned earlier, the Paraná territory is in a transition zone and can be characterized by atmospheric instability derived from the complex dynamics between tropical and polar systems that produce different natural hazards caused by weather and climatic events (windstorms, tornadoes, storms, electric discharges, floods, droughts and heat waves). Zavattini and Boin (2013) studied the distribution of climates at the scale of the Paraná River watershed and highlighted the complexity of the transition zone, which is responsible for high instability and heterogeneity of rain distribution. Furthermore, the rainfall patterns were studied in detail by Zandonadi (2009) to better characterize distribution while the extreme events for rain (and temperature as well) were analyzed by Zandonadi et al. (2016).

Figure 2 - (a) Regional temperature (average = 23.7°C) and rainfall (b) (average = 640.0 mm) anomalies.





Source: Elaborated by the authors (2020)

Due to the complexity of atmospheric dynamics that is encountered in Paraná, the possibility of establishing correlations between combined temperature and precipitation variability, and the large-scale patterns can be useful to better understand this kind of relationship in other regions of Brazil and South America.

DATA AND METHODS

Data used and quality control

For this study, daily precipitation and temperature data were utilized between 1981 and 2014. These data were provided by the Meteorological Data Bank for Education and Research (BDMEP - Banco de Dados Meteorológicos para Ensino e Pesquisa, http://www.inmet.gov.br/projetos/rede/pesquisa/) of the Brazilian National Institute of Meteorology (INMET - Instituto Nacional de Meteorologia) and from the Agronomic Institute of Paraná (IAPAR - Instituto Agronômico do Paraná 2014, currently, Instituto de Desenvolvimento Rural do Paraná – IAPAR/EMATER).

In total we analyzed rainfall and temperature data from 10 weather stations (Table 2). For quality control (QC), only stations with missing data under the 20% threshold were selected (AGUILAR et al., 2009; FORTIN; HÉTU, 2014, ACQUAOTTA et al., 2019). For the missing data, two methods were tested to estimate them, first the nearest neighbor approach and the NIPALS (Non-Linear Iterative Partial Least Squares) method (WOLD, 1973); the latter constitutes a principal component analysis (PCA) model that produced better results and was used to estimate the missing values of our datasets.

We also checked for outliers and subsequently tested for data homogeneity (FORTIN et al., 2017, ACQUAOTTA et al., 2019). Table 3 shows the average, minimum and maximum temperature average, minimum and maximum precipitation, along with the standard deviation.

Table 2 - Name, geographical coordinates, and proportion of missing data for weather stations used in this study.

Name station (code)	Lat. S	Long. O	Alt. (m)	Missing data (%)		
				Tmax	Tmin	Prec.
Bela Vista do Paraíso (2251027)	-22.57	-51.12	600	2.9	2.9	2.9
Londrina IAPAR (2351003)	-23.22	-51.10	585	11.6	11.6	11.6
Londrina (83766)	-23.31	-51.10	566	16.3	15.1	14.4
Campo Mourão (83783)	-24.05	-52.36	616	10.2	3.8	3.5
Umuarama (2353008)	-23.44	-53.17	480	3.8	3.8	3.8
Morretes (2548038)	-25.30	-48.49	59	-	-	-
Lapa (2549091)	-25.47	-49.46	910	17.8	17.8	17.8
Curitiba (83842)	-25.43	-49.26	923	5.8	5.8	5.6
Paranáguá (83844)	-25.53	-48.51	4.5	21.4	10.2	9.8
Guaraqueçaba (2548039)	-26.16	-48.51	40	16.3	16.3	16.3

Source: Elaborated by the authors (2020)

Table 3 - Descriptive statistics for the stations used in this study.

	CMO	LDA	UMU	PAR	MOR	LDI	LAP	GUA	CTB	BVP
Mean temp. (°C)	20.4	23.4	22.3	21.5	20.9	21.1	17.0	20.9	17.4	21.5
Mean Std Dev.	3.9	3.7	4.1	3.7	3.7	3.7	3.9	3.8	3.9	3.7
Mean TMin	15.3	16.4	18.0	18.3	17.5	16.1	13.1	17.5	13.4	17.2
Mean TMax	26.9	28.0	27.9	26.0	26.3	27.4	23.2	26.2	23.5	27.2
Mean. prec. (mm)	1687.7	1609.5	1643.2	2258.7	2019.0	1613.0	1564.5	2457.7	1546.2	1521.5
Mean Std Dev.	91.9	98.1	89.5	125.9	106.6	94.4	80.0	134.9	81.6	51.6
Mean PMin	1181.4	1027.5	1251.6	1478.8	1342.6	1153.4	871.7	1615.2	747.1	1072.1
Year	1985	1985	1991	1985	1985	1985	1981	1985	1985	1985
Mean PMax	2526.2	2311.7	2283	3171.9	2646.5	2333.5	2204.9	3279	2068.9	2168.3
Year	1983	2009	1983	1998	2010	2009	1998	2010	1998	2009

CMO : Campo Mourão ; LDA : Londrina ; UMU : Umuarama ; PAR : Paranaguá ; MOR : Morretes ; LDI : Londrina IAPAR ; LAP : Lapa ; GUA : Guaraqueçaba ; CTB : Curitiba ; BVP : Bela Vista do Paraíso.

Source: Elaborated by the authors (2020)

In addition, different climate indicators were used to investigate their relationship with precipitation/temperature modes. The standardized indices used in this study were obtained from the NOAA website (http://www.cpc.ncep.noaa.gov/data). Based on the literature (CAVALCANTI; AMBRIZZI, 2009; GRIMM, 2009; HAYLOCK et al., 2006; LIMBERGER; ELY, 2019), we only considered the most dominant large-scale climate patterns influencing Brazil, and more particularly, the southern states including Paraná (Table 4).

Table 4 - Principal large-scale climate indices used in this study (monthly, seasonal, and annual).

Name	Description	Source
Niño 1+2	Extreme Eastern Tropical Pacific SST (0-10S, 90W-80W)	http://www.nws.noaa.gov/
Niño 3	Eastern Tropical Pacific SST (5N-5S, 150W-90W)	http://www.nws.noaa.gov/
Niño 3.4	East Central Tropical Pacific SST (5N-5S) (170-120W)	http://www.nws.noaa.gov/
ENSO precipitation index (EI, LI and ESPI)	Time series that uses rainfall data in the Tropical Pacific to describe ENSO events.	Curtis and Adler, 2000
TSAI	Tropical Southern Atlantic Index Anomaly of the average of the monthly SST from Eq-20S and 10E-30W.	Enfield et al., 1999.
TNAI	Tropical Northern Atlantic Index Anomaly of the average of the monthly SST from 5.5N to 23.5N and 15W to 57.5W.	Enfield et al., 1999.
PDO	Pacific Decadal Oscillation is the leading PC of monthly SST anomalies in the North Pacific Ocean.	http://research.jisao.washington.edu/pdo/PDO.latest
Tropical Pacific SST EOF	1st EOF of SST 20N-20S, 120E-60W GISST 1948-1949 Reconstructed Reynolds 1950-1981 OI 1982-present	Hoerling et al., 2001.
AMO	Atlantic multidecadal Oscillation	Enfield et al., 2001

Source: Adapted from: http://www.esrl.noaa.gov/psd/data/climateindices/list/.

Quantiles and modes

Percentile is a technique widely used for analyzing extreme events (for example 99th, 95th or 99th) and determining the frequency of different climatic variables. In this research, we used a similar methodology that has been applied in other studies (FORTIN; HÉTU, 2014; BENISTON, 2009; LOPEZ-MORENO et al., 2011). First, this method determines the thresholds (25% and 75% quantiles) for average daily temperature and total precipitation amounts. This approach was chosen since these values make it possible to highlight significant events, and to aid in the recognition of major trends. Therefore, values outside these thresholds were excluded.

The thresholds vary for each station and were used to define different modes, a term commonly used when variables (such as temperature and precipitation) are combined to obtain cold-dry; warm-dry; cold-humid or warm-humid conditions (BENISTON, 2009; LÓPEZ-MORENO et al., 2011; KONG et al., 2020). For temperature, it can be considered as either

Cold (C) when the temperature is below the 25% quantile (T_{25}) or Warm (W), when the temperature is above the 75% quantile (T_{75}). In addition, for precipitation, it can be considered Dry (D) if the precipitation is below the 25% quantile (P_{25}) or Wet (W), if the precipitation amounts are above the 75% quantile (P_{75}). By combining temperatures and precipitation variables, four different modes were obtained: (1) Cold/Dry or CD (T_{25}/P_{25}), (2) Cold/Wet or CW (T_{25}/P_{75}), (3) Warm/Dry or W/D (T_{75}/P_{25}) and, (4) Warm/Wet or WW (T_{75}/P_{75}). These modes represent the climatic conditions at the moderately high ends of the spectrum of the distribution of these variables.

Trend analysis

The nonparametric Mann-Kendall test or MK (MANN, 1945, KENDALL, 1975) was used to analyze the linear trend for the average temperature and total precipitation separately, which were also combined (modes). The Mann-Kendall test is commonly used in hydrological and climatological studies to identify tendencies.

The linear trend for the modes was calculated using the Sen's slope estimator, a nonparametric approach based on the Kendall test (SEN, 1968). Sen's slope estimator does not assume a specific distribution for the data. Furthermore, since autocorrelation in time series can influence the statistical significance of a trend and should be avoided, this was checked to prevent bias in our MK trend analyzes.

RESULTS AND DISCUSSION

Table 5 presents the average number of modes and standard deviation for the stations per decade from 1981 to 2010. From the table, the WW mode seems to be less frequent (average of 5.5 ± 2.1 for all periods) while the WD is the most common mode (average 10.2 ± 4.6 for the overall period) when it is cold. On the other hand, dry conditions (CD, average 7.4 ± 2.9) are less frequent than wet conditions (CW, average 8.9 ± 3.1). The next step included the trend analysis of the time series (precipitation and temperature) that were used to calculate the modes and to determine if there were any statistically significant trends for the different modes presented in Table 5.

Table 5 - The frequency (annual number of days) of the four modes observed over the study period per decade (the values correspond to the average values of the ten weather stations used).

Mean/decade	CD	CW	WD	WW
1981-1990	7.3	9.1	12.3	6.1
1991-2000	7.6	9.6	8.9	4.5
2001-2010*	7.8	9.6	12.6	5.9
Mean	7.4	8.9	10.2	5.5
SD	2.9	3.1	4.6	2.1

*because the datasets end in 2014 the decade 2011-2020 is incomplete and cannot be included in this Table.

Source: Elaborated by the authors (2020)

Climate trends

Very few trends were detected using the MK and Sen's slope tests (Table 6). In fact, only the Lapa station shows a statistically significant positive trend for both temperature and precipitation. In the case of temperature, eight stations showed significant trends, where six were positive and two were negative. For stations located in the northwestern group, two stations indicated negative trends (CMO and LDI) while three other stations (BVP, LDA and UMU) had positive trends. This contradiction makes it difficult to interpret trends at the regional level. The stations of CTB, LAP and PAR, all located in the southeast of the state, also showed positive and significant trends for temperature.

Table 6 - Mann-Kendall test statistic for annual mean total precipitation and annual mean temperature, Kendall's tau, 1980-2014.

Var.	BVP	CMO	CTB	GUA	LAP	LDA	LDI	MOR	PAR	UMU
Prec. MK T	-0.007	-0.009	-0.002	0.007	**0.035**	-0.003	-0.002	0.007	0.009	-0.010
p-value	0.325	0.207	0.784	0.277	**<0.0001**	0.657	0.762	0.319	0.180	0.179
Temp. MK T	**0.015**	**-0.026**	**0.049**	-0.005	**0.017**	**0.056**	**-0.033**	0.009	**0.028**	**0.043**
p-value	**0.022**	**<0.00 01**	**<0.00 01**	0.470	**0.009**	**<0.00 01**	**<0.00 01**	0.162	**<0.00 01**	**<0.00 01**

Trends are assessed to be statistically significant at the significance level of 0.05 if p ≤ 0.05 (bold values).

Source: Elaborated by the authors (2020)

Subsequently, we used the modes (on both seasonal and annual time scale) to explain the climatic variations that took place in our study area (Table 7). Table 7 presents an overview of the number of stations with significant trends (decrease or increase) and nonsignificant changes for each mode based on seasonal and annual periods.

Table 7 - Number of stations with significant negative, positive, or nonsignificant trends for each mode on annual and seasonal basis over the 1980-2014 period (significant at the 5% level).

Period	Modes	Negative	Not significant	Positive
Annual	WW	0	6	4
	WD	0	10	0
	CW	0	10	0
	CD	1	9	0
DJF (summer)	WW	0	8	2
	WD	0	9	1
	CW	0	10	0
	CD	0	10	0
MAM (autumn)	WW	0	8	2
	WD	0	10	0
	CW	0	10	0
	CD	0	10	0
JJA (winter)	WW	0	10	0
	WD	0	10	0
	CW	0	10	0
	CD	0	10	0
SON (spring)	WW	0	0	0
	WD	0	0	0
	CW	0	0	0
	CD	2	8	0

Source: Elaborated by the authors (2020)

Afterwards, we conducted a correlation analysis between the climate indices and the modes. Table 8 summarizes the number of stations that show correlations between modes and climate indices. In general, there is little correlation between the modes and the climate indices. However, for the WD mode based on an annual scale, 8 stations were positively correlated with Niño 1+2. This is consistent with other studies such as Limberger and Ely (2019). Numerous authors (ANDREOLI; KAYANO, 2005; BARROS et al., 2008; GRIMM, 2009; LIMBERGER; ELY, 2019) indicate that periods of drought, which occur when temperatures are high (W) and rainfall is low (D), in southern Brazil, are usually associated with El Nino episodes. Also, there are other climate indices that showed correlation with other modes (depending on the period considered either annual or seasonal) but this represents half (5 out of 10) or less, of the total number of stations used in our study, which makes any further interpretation of our results difficult.

Table 8 - The number of weather stations where modes and climate indices are positively (+) or negatively (-) correlated (statistically significant).

	CD					CW					WD					WW				
	An	Su	A	W	Sp	An	Su	A	W	Sp	An	Su	A	W	Sp	An	Su	A	W	Sp
EI (ENSO)	2+	0	0	0	1+	0	0	0	1+	1+	3+	0	1+	1-	4+	0	0	0	1+	0
LI (ENSO)	1-	0	1+	0	1-	0	0	0	0	2+	0	0	1-	0	3-	0	0	0	1-	0
ESPI (ENSO)	1+	0	0	0	1+	0	0	0	0	2-	1+	0	1+	0	3+	0	0	0	1+	0
AMO	1-	0	1+	1-	0	0	0	1+	0	0	0	0	0	0	0	5+	3+	3+	0	0
PDO	0	0	0	2+	1+	0	1	1+	1+	0	1+	0	1+	0	0	2-	1-	2-	1+	0
TNAI	0	0	0	0	1-	0	1-	0	1+	0	0	0	1+	0	0	2+	1+	1+	0	0
TSAI	1-	0	0	0	0	0	0	0	1-	1-	1-	0	4-	2-	0	3+	2+	1+	0	1-
TP-SST	2+	0	0	1+	0	0	1-	0	1+	1+	4+	0	5+	3+	0	0	0	1-	1+	2+
NINO1+2	2+	0	0	2+	0	1-	0	0	1+	0	8+	0	3+	4+	0	1-	0	0	1+	1+
NINO3	2+	0	0	1+	0	0	0	0	1+	2+	4+	0	5+	3+	0	0	0	1-	1+	2+
NINO4	1+ 1-	0	1-	1-	0	1+	1-	0	0	1+	0	0	1+	0	5-	0	0	1-	0	3+
NINO3.4	1+	0	1-	1+ 1-	0	0	1+ 1-	0	1+	2+	1+	0	5+	3+	0	0	0	1-	1+	2+

An: Annual; Su: Summer; A: Autumn; W: Winter; Sp: Spring.

Source: Elaborated by the authors (2020)

Many studies on climatic extremes have been conducted for various regions in Brazil, but these are mostly based on temperature and/or precipitation (ALMEIDA et al., 2016; OLIVEIRA et al., 2017; OTTO et al., 2015; ELY; DUBREUIL, 2014; MARENGO; CAMARGO, 2008; MENDONÇA, 2006; 2014). However, a few of these studies seek to combine variables and to establish correlations between pluvio-thermal variability and large-scale patterns. In fact, the analysis of rainfall variability in relation to atmospheric patterns is more commonly studied. Marengo et al. (2009) and Grimm (2009) posit that rainfall variability in southern Brazil is associated with ENSO anomalies in the tropical Pacific. More specifically, Sousa

(2006) states that rainfall variability in Paraná is directly linked to El Niño events as significant positive anomalies for rainfall during El Niño events and some negative anomalies during La Niña events were observed. Pinheiro (2016) confirms this observation by identifying a delay of up to six months between the heating of Pacific waters (Niño region 3.4) and eleven months between its cooling and significant positive / negative rainfall events in the Alto Iguaçu watershed located in the southeast of Paraná. Likewise, Liebmann et al. (2004) indicated an intensification of the effects of ENSO in southern Brazil when there is an increase in the SST in the South Atlantic Ocean. Furthermore, at a larger scale, Barros et al. (2008) found that extreme rainfall events are linked to strong ENSO events in the south-east regions of South America in the 20th century, which are also related to the Pacific Decadal Oscillation (PDO). Also, Nascimento Júnior (2013) correlated the spatiotemporal variability of rainfall in Paraná with the PDO and identified significant correlations in autumn and spring based on an annual scale.

To better understand how the large-scale climate indices influence the pluvio-thermal variability in Southern Brazil, Silva (2001) analyzed the seasonal and interannual variability of precipitation with the SST of the Pacific Central-East (PACE) and Atlantic South-West (ATLSW) Oceans. His results demonstrated that a higher percentage of rainy months occurred when positive SSTs are recorded in PACE and ATLSW, but there is no significant correlation when SSTs are negative in both oceans. Cavalcanti and Ambrizzi (2009) point out that in addition to ENSO, the Pacific-South American teleconnection pattern (PSA) influences the convective activity of the South Atlantic convergence zone (SACZ) while the Southern Hemisphere Annular Mode (SAM) influences the displacement of the subtropical and polar jets altering the trajectory of extratropical cyclones. The SACZ is the most important mechanism that brings rainfall during the austral summer. However, in absent or weak SACZ episodes during austral summer, drought normally takes place such as in 1970/1971, 2001 and 2014, (COELHO et al., 2015; OTTO et al., 2015).

The aforementioned studies mainly covered a large extent of South America and even when it is for a more restricted area, it sometimes covers most of Southern Brazil, which is influenced by teleconnections or regional forcing. Considering this, we make two observations: (1) the need to better understand how the climate on a finer (regional) scale is influenced by larger atmospheric patterns and (2) the relevance of testing an approach that combines both precipitation and temperature (modes).

As it relates to the Southeast of Brazil, Otto et al. *(*2015) found no evidence that recent droughts (1953/1954, 1962/1963, 1970/1971, 2001 and 2014/2015) observed events resulted from anthropogenic climate change. The authors however discovered that drought conditions were being driven by changes in water usage and rapid population growth. In addition, Coelho et al. *(*2016) investigated the influence of regional scale processes and teleconnections on the 2014 drought for Southeast Brazil. They found that an increase in SST near the southeast of Brazil had a strong negative influence on precipitation.

In addition, for Rio Claro (São Paulo state), Costa dos Santos et al. (2012) did not find any statistically significant trends for precipitation; however, the temperature increased between 1966 to 2005.

Our results coincide with Costa dos Santos et al. *(*2012). Within this context, a potential increase of air temperature and evaporation could be detrimental for agricultural areas in Paraná, but it could be potentially compensated by a slight increase of precipitation.

Although there is abundant literature on the state of climatic changes in Southern Brazil (MARENGO et al., 2009; SANGIOLO; KAYANO, 2010; ALMEIDA et al., 2016; SOARES et al., 2017; ELY; FORTIN, 2019), some amount of uncertainty exists about these changes for the region. Some authors such as Costa dos Santos et al. (2012); Pedron et al. (2017) found few or no evidence of changes for the total amount of precipitation and/or number of rain days in Southern Brazil even if the number of intense rainy days increased in South America (AGUILAR et al., 2005). However, other authors such as Back (2014); de Barros Soares et al. (2017); Teixeira; Satyamurty (2011), found a statistically significant increase in precipitation for Southern Brazil since the mid-20th century. On the other hand, most authors found significant increase of temperatures (minimum, maximum, average) over the same period (ALMEIDA et al., 2016; DUBREUIL et al., 2017; HAYLOCK et al., 2006; MARENGO; CAMARGO, 2008).

Care should be taken when interpreting the results as modification of the period or the number of stations could give different results. Moreover, as discussed by Stocker (2014) in the 5th IPCC report, availability of climate data covers a relatively short period specifically over the last century, which is relatively limited. Furthermore, the absence of continuous and long-term recordings of past conditions makes it difficult to analyze climatic patterns with a high degree of confidence, which could be important to determine the similarity between the past and current climate. This involves the intensity, frequency, and duration of extreme events such as drought, floods, heat waves, or hurricanes for example (STOCKER, 2014). Even though the method utilized in this study offers various advantages including an integrated approach to analyze the climate variables (combination of temperature and precipitation), there are nevertheless some limitations. For example, the use of average values tends to mask the variability of the extreme values. Furthermore, Zandonadi et al. (2016) observed an increase in the intensity of precipitation without any changes in the total quantities received, which cannot be detected using modes.

CONCLUSIONS

In this study, we assessed climatic trends by combining precipitation and temperature (modes) from 1981 and correlated these modes with 9 atmospheric patterns.

In summary, our study shows:

- the successful use of a combined approach to analyze the quantiles for temperature and precipitation like other studies (FORTIN; HÉTU, 2014; BENISTON, 2009; LOPEZ-MORENO et al., 2011). However, the results in this research did not show any significant trends spatially nor temporally.
- little difference between the four modes over the seasons and years, but these modes seem to have little correlation with the dominant large-scale climate indices which normally influence climatic variability in Southern Brazil.

Several reasons are likely to explain the low spatial and temporal variability of the modes. For example, the geographical position of the study area is in a transition zone where several large and regional climatic factors converge resulting in significant differences between the modes. In addition, other elements need to be considered such as the relatively limited duration of the study period and the number of stations used. Nevertheless, in this study, we used the acceptable threshold for missing data to ensure quality control.

For future research, it would be interesting to extend this approach to other Brazilian states or countries, which would make it possible to assess and highlight the disparities in spatio-temporal variability on larger scales. In addition, the combined use of more restricted quantiles (for example the 10^{th} and 90^{th}) would allow climate variability to be refocused around rare events.

REFERENCES

ACQUAOTTA, F.; FRATIANNI, S.; AGUILAR, E.; FORTIN, G. Influence of instrumentation on long temperature time series. **Climate Change**, v. 156, n. 3, p. 385-404, 2019.

AGUILAR, E.; AZIZ BARRY, A.; BRUNET, M.; EKANG, L.; FERNANDES, A.; MASSOUKINA, ... THAMBA UMBA, O. Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955–2006. **Journal of Geophysical Research**, v. 114, n. D20115, 2009.

AGUILAR, E.; PETERSON, T. C.; OBANDO, P. R.; FRUTOS, R.; RETANA, J. A.; SOLERA, M.;... VALLE, V. E. Changes in precipitation and temperature extremes in Central America and northern South America, 1961–2003. **Journal of Geophysical Research - Atmosphere**, v. 110, n. D23107, 2005.

ALMEIDA, C. T.; OLIVEIRA-JÚNIOR, J. F.; DELGADO, R. C.; CUBO, P.; RAMOS, M. C. Spatiotemporal rainfall and temperature trends throughout the Brazilian Legal Amazon, 1973–2013. . **International Journal of Climatology**, v. 37, n. 4, p. 2013-2026, 2016.

ANDREOLI, R. V.; KAYANO, M. T. ENSO-related rainfall anomalies in South America and associated circulation features during warm and cold Pacific Decadal Oscillation regimes. **International Journal of Climatology**, v. 25, n. 15, p. 2017-2030, 2005.

BACK, A. J. Análise de tendências nos índices de precipitação de Ivaiporã (PR) e Ponta Grossa (PR). In: XLIII Congresso Brasileiro de Engenharia Agrícola, Campo Grande, **Anais [...],** 2014.

BARROS, V. R.; DOYLE, M. E.; CAMILLONI, I. A. Precipitation trends in southeastern South America: relationship with ENSO phases and with low-level circulation. **Theoretical and Applied Climatology**, v. 93, n. 1, p. 19-33, 2008.

BENISTON, M. Trends in joint quantiles of temperature and precipitation in Europe since 1901 and projected for 2100. **Geophysical Research Letters**, v. 36, n. 7, 2009.

CAVALCANTI, I. F. de A.; AMBRIZZI, T. **Teleconexões e suas influências no Brasil**. In: CAVALCANTI, I. F. de A.; FERREIRA, N. J; SILVA, M. G. A. J. da; DIAS, M. A. F. da S. (org.). Tempo e clima no Brasil. Oficina de Textos, São Paulo, p. 317-335, 2009.

COELHO, C. A.; de OLIVEIRA, C. P.; AMBRIZZI, T.; REBOITA, M. S.; CARPENEDO, C. B.; CAMPOS, J. L. P. S. ... Da ROCHA, R. P. **The 2014 southeast Brazil austral summer drought**: regional scale mechanisms and teleconnections. (org.). Tempo e clima no Brasil. Oficina de Textos, São Paulo, p 317-335, 2009.

COSTA dos SANTOS, C.; SATYAMURTY, P.; MACHADO GOMES, O.; GULARTE da SILVA, L. E. M. Variability of extreme climate indices at Rio Claro, São Paulo, Brasil. **Revista Brasileira de Meteorologia**, v. 27, n. 4, p. 395-400, 2012.

CURTIS, S.; ADLER, R. Time series that uses rainfall data in the Tropical Pacific to describe ENSO events. **Journal of Climate**, v. 13, p. 2786–2793, 2000.

BARROS SOARES, D. de; LEE, H.; LOIKITH, P. C.; BARKHORDARIAN, A.; MECHOSO, C. R. Can significant trends be detected in surface air temperature and precipitation over South America in recent decades? **International Journal of Climatology**, v. 37, n.3, p. 1483-1493, 2017.

SANTOS, C. A. C. dos; SATYAMURTY P.; GOMES O. M.; da SILVA L. E. M. G. Variability of extreme climate indices at Rio Claro, São Paulo, Brazil. **Revista Brasileira de Meteorologia**, v. 27, n. 4, p. 395-400, 2012.

DUBREUIL, V.; FANTE, K. P.; PLANCHON, O.; SANT'ANNA NETO, J. L. Les types de climats annuels au Brésil: une application de la classification de Köppen de 1961 à 2015. **EchoGéo**, v. 41, 2017.

ELY, D. F.; FORTIN, G. Trend analysis of extreme thermal indices in south Brazil (1971 to 2014). **Theoretical and Applied Climatology**, v. 139, n. 3, p. 1045-1056, 2020.

ELY, D.; DUBREUIL, V. Évolutions des températures et des précipitations dans le versant sud du bassin de la rivière Paranapanema, Paraná, Brésil. In : Actes du 27e colloque de l'Association Internationale de Climatologie, Dijon, **Anais [...],** 2014.

FORTIN, G.; ACQUAOTTA, F.; FRATIANNI, S. The evolution of temperature extremes in the Gaspé Peninsula, Quebec, Canada (1974–2013). **Theoretical and Applied Climatology**, v. 130, n. 1-2, p.163-172, 2017.

FORTIN, G.; HÉTU, B. Estimating winter trends in climatic variables in the Chic-Chocs Mountains, Canada (1970–2009). **International Journal of Climatology**, v. 34, n.10, p. 3078-3088, 2014.

GRIMM, A. M. **Variabilidade interanual do clima no Brasil**. In: CAVALCANTI, I. F. de A.; FERREIRA, N. J; SILVA, M. G. A. J. da; DIAS, M. A. F. da S. (org.). Tempo e clima no Brasil. Oficina de Textos, São Paulo, p, 353-374. 2009.

GUEIRINHAS, J. L.; TRIGO, R. M.; LIBONATI, R.; COELHO, C. A.; PALMEIRA, A. C. Climatic and synoptic characterization of heat waves in Brazil. **International Journal of Climatology**, v. 38, n.4, p. 1760-1776, 2018.

HAYLOCK, M. R.; PETERSON, T. C.; ALVES, L. M.; AMBRIZZI, T.; ANUNCIAÇÃO, Y. M. T.; BAEZ, J.; CORRADI, V. Trends in total and extreme South American temperature 1960–2000 and links with sea surface temperature. **Journal of Climate**, v. 19, n. 8, p. 1490–1512, 2006.

HERRING, S. C.; HOERLING, M. P.; PETERSON, T. C.; STOTT, P. A. (2014) Explaining Extreme Events of 2013 from a Climate Perspective. **Bulletin American Meteorological Society**, v. 95, n. 9, p. S1–S96, 2014.

HOERLING, M. P.; KUMAR, A.; XU, T. Robustness of the nonlinear climate response to ENSO's extreme phases. **Journal of Climate**, v. 14, n. 6, p. 1277-1293, 2001.

HULME, M. (2014) Attributing weather extremes to 'climate change' A review. **Progress in Physical Geography**, v. 38, n. 4, p. 499–511, 2014.

INSTITUTO AGRONÔMICO DO PARANÁ – IAPAR. **Cartas climáticas do Paraná**. Londrina, 2014. Disponível em:http://www.iapar.br/modules/conteudo/conteudo.php?conteudo=597>. Acesso em: 03 abril. 2014.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE - IPCC. **Climate Change 2021***:* The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press: In Press, Cambridge, 2021.

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

KONG, Q.; GUERREIRO, S. B.; BLENKINSOP, S.; LI, X. F.; FOWLER, H. J. Increases in summertime concurrent drought and heatwave in Eastern China. **Weather and Climate Extremes**, v. 28, p. 100242, 2020.

LIEBMANN, B.; VERA, C. S.; CARAVALHO, L. M. V.; CAMILLONI, I. A.; HOERLING, M. P.; ALLURED, D.; BARROS, V. R.; BA'EZ, J.; BIDEGAIN, M. An observed trend in central South American precipitation. **Journal of Climate**, v. 17, p. 4357–4367, 2004.

LIMBERGER, L.; ELY, D. F. Régions homogènes de précipitation dans l'État du Paraná (Brésil) en lien avec la température de surface de la mer. In : Colloque de l'Association Internationale de Climatologie, 32, 2019, Thessalonique. **Anais [...],** 2019. p 493-498.

LÓPEZ-MORENO, J. I.; VICENTE-SERRANO, S. M.; MORÁN-TEJEDA, E.; LORENZO-LACRUZ, J.; KENAWY, A.; BENISTON, M. Effects of the North Atlantic Oscillation (NAO) on combined temperature and precipitation winter modes in the Mediterranean mountains: observed relationships and projections for the 21st century. **Global Planet Change**, v. 77, n. 1, p. 62-76, 2011.

MANN, H. B. Nonparametric tests against trend. **Econometrica: Journal of the Econometric Society,** 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.; JONES, R.; ALVES, L. M.; VALVERDE, M. C. Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. **International Journal of Climatology**, v. 29, n. 15, p. 2241-2255, 2009.

MENDONÇA, F. A. (org.) **Os Climas do Sul:** em tempos de mudanças climáticas globais. Jundiaí, Paco Editorial, 2014.

MENDONÇA, F. A. Aquecimento global e suas manifestações regionais e locais: alguns indicadores da região Sul do Brasil. **Revista Brasileira de Climatologia**, v. 2, p. 71–86, 2006.

MENDONÇA, F. A. **O Clima e o Planejamento Urbano de Cidades de Porte Médio e Pequeno.** Proposição Metodológica para Estudo e sua Aplicação à Cidade de Londrina/Pr. 1994. Tese (Doutorado em Geografia Física) - Universidade de São Paulo, São Paulo, 1994.

NASCIMENTO JÚNIOR, L. **As chuvas no Paraná**: variabilidade, teleconexões e impactos de eventos extremos. 2013. Dissertação (Mestrado em Geografia) - Universidade Estadual Paulista, Presidente Prudente, 2013.

NOBRE, C. A.; MARENGO, J. A.; SELUCHI, M. E.; CUARTAS, L. A.; ALVES, L. M. Some Characteristics and Impacts of the Drought and Water Crisis in Southeastern Brazil during 2014 and 2015. **Journal of Water Resource and Protection**, v. 8, p. 252-262, 2016.

OLIVEIRA, P. T.; E SILVA, C. S.; LIMA, K. C. Climatology and trend analysis of extreme precipitation in subregions of Northeast Brazil. **Theoretical and Applied Climatology**, v. 130, n. 1-2, p. 77-90, 2017.

OTTO, F. E.L.; COELHO, C. A.; KING, A.; COUGHLAN de PEREZ, E.; WADA, Y.; van OLDENBORGH, G. J.; HAARSMA, R.; HAUSTEIN, K.; UHE, P.; van AALST, M.; ARAVEQUIA, J. A.; ALMEIDA, M. W.; CULLEN, H. Factors other than climate change, main drivers of 2014/15 water shortage in southeast Brazil. **Bulletin of the American Meteorological Society**, v. 96, n. 12, p. 35-40, 2015.

PEDRON, I. T.; SILVA DIAS, M. A.; de PAULA DIAS, S.; CARVALHO, L. M.; FREITAS, E. D. Trends and variability in extremes of precipitation in Curitiba–Southern Brazil. **International Journal of Climate**, v. 37, n. 3, p. 1250-1264, 2017.

PINHEIRO, G. M. **Variabilidade têmporo-espacial da pluviosidade na bacia do Alto Iguaçu.** 2016. Tese (Doutorado em Geografia) - Universidade Federal do Paraná, Curitiba, 2016.

SANGIOLO, C. A.; KAYANO, M. T. Trends of seasonal maximum and minimum temperatures and precipitation in Southern Brazil for the 1913–2006 period. **Theoretical and Applied Climatology,** v. 101, n. 1-2, p. 209-216, 2010.

SEN, P. K. Estimates of the regression coefficient based on Kendall's tau. **Journal of the American Statistical Association**, v. 63, n. 324, p.1379-1389, 1968.

SILVA, I. R. **Variabilidade sazonal e interanuais das precipitações na região Sul do Brasil associadas às temperaturas dos oceanos Atlântico e Pacífico**. 2001. Dissertação (Mestrado em Meteorologia) - Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2001.

SMITH, T. M.; REYNOLDS, R. W. A global merged land air and sea surface temperature reconstruction based on historical observations (1880-1997). **Journal of Climate**, v. 18, p. 2021-2036, 2005.

SOUSA, P. **Estudo da variabilidade da precipitação no estado do Paraná associado à anomalia da TSM no oceano Pacífico.** 2006. Dissertação (Mestrado em Geografia) – Universidade estadual de Maringá, Maringá, 2006.

STOCKER, T. (Ed.) **Climate change 2013**: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press: In Press, Cambridge, 2014.

STOTT, P. A.; CHRISTIDIS, N.; OTTO, F. E.; SUN, Y.; VANDERLINDEN, J. P.; van OLDENBORGH, G. J.; VAUTARD, R.; von STORCH, H.; WALTON, P.; YIOU, P.; ZWIERS, F. W. Attribution of extreme weather and climate-related events. **WIRES Climate Change**, v. 7, n. 1, p. 23-41, 2016.

TEIXEIRA, M. D. S.; SATYAMURTY, P. Trends in the frequency of intense precipitation events in southern and southeastern Brazil during 1960–2004. **Journal of Climate**, v. 24, n. 7, p. 1913-1921, 2011.

TERASSI, P. M. B.; GALVANI, E. Identification of Homogeneous Rainfall Regions in the Eastern Watersheds of the State of Paraná, Brazil. **Climate**, v. 5, n. 3, p. 1 - 13, 2017.

TRENBERTH, K. E.; FASULLO, J. T.; SHEPHERD, T. G. Attribution of climate extreme events. **Nature Climate Change**, v. 5, n. 8, p. 725-730, 2015.

WOLD, H. Nonlinear Interative Parcial Least Squares (NIPALS) modelling : some current developments. In: KRISHNAIAH, P. R. **Multivariate Analysis** – III. New York : Academic Press, p. 383 – 407, 1973.

ZANDONADI, L. **As chuvas na bacia do Paraná:** aspectos temporais, espaciais e rítmicos. 2009. Tese (Doutorando em Geografia) - Universidade Estadual Paulista "Júlio de Mesquita Filho", Rio Claro, 2009.

ZANDONADI, L.; ACQUAOTTA, F.; FRATIANNI, S.; ZAVATTINI, J. A. Changes in precipitation extremes in Brazil (Paraná River basin). **Theoretical and Applied Climatology**, v. 123, n. 3-4, p. 741-756, 2016.

ZAVATTINI, J. A.; BOIN, M. N. **Climatologia Geográfica** : teoria e prática de pesquisa. Campinas : Editora Alínea, 2013.