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TRENDS AND EXTREME EVENTS IN AIR TEMPERATURE AND PRECIPITATION IN GOIÁS, BRAZIL

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ABSTRACT

Climate change is unequivocal, widespread, accelerating, irreversible and without historical precedent, with extreme climatic events recorded in all regions of the planet, causing adverse impacts in the environmental, economic and social spheres. The aim of this research was to detect climate change trends and identify extreme events and in the The study aimed to identify climate trends and extreme weather events in the state of Goiás, using air temperature and precipitation indices from a 45-year time series (1980 to 2024), based on daily data recorded by seven conventional weather stations of the National Meteorological Institute, located in Goiânia, Jataí, Pirenópolis, Aragarças, Formosa, Posse and Ipameri. To this end, indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI), linked to the World Meteorological Organization (WMO), were used. Seventeen indices were calculated with the R software, using the Rclimdex extension. For the precipitation-related indices, the data show a negative trend with high statistical significance in only a few stations. In the case of the temperature-related indices, there is a positive trend with high statistical significance at all the stations analyzed, which shows an increase in maximum and minimum temperatures over the time series analyzed. This study demonstrates significant warming trends and increasing climate extremes in Goiás, reinforcing the need for evidence-based adaptation and mitigation measures to enhance resilience and promote sustainable development under a changing climate.

Keywords: Climate Change, Global Warming, Climate Trends, Climate Indices, Rclimdex.

INTRODUCTION

Understanding the variability and changes in climatic parameters is of paramount importance, as it forms the basis for environmental diagnostics and prognostics. Such insights are critical for guiding the planning of human activities and mitigating or preventing undesirable losses and damages.

The Intergovernmental Panel on Climate Change (IPCC, 2021) is categorical in stating that global climate change is a reflection of human actions, pointing out that these changes are widespread, accelerated, irreversible and without historical precedent. The same organism further underscores the increasing frequency, intensity, and severity of extreme weather events worldwide, often associated with extreme temperature anomalies (e.g., heat or cold waves), intense rainfall episodes, or prolonged droughts.

Recent decades have witnessed record-breaking heatwaves in Europe, Asia, North America, and other regions, as well as increasingly severe precipitation events, prolonged droughts, and compound extremes affecting ecosystems, infrastructure, food production, water resources, and human health.

Among the most significant recent examples are the extreme heatwaves recorded in Europe, China, and the United States during 2023, when temperatures exceeded historical records in several regions – including the registration of 52.2°C in Sanbao (Xinjiang, China) – according to the China Meteorological Administration (CMA). Initially, 2023 was declared the hottest year on record since measurements began in 1850 (WMO, 2024). However, 2024 surpassed this record, becoming the first year to exceed 1.5°C above pre-industrial levels (COPERNICUS, 2025).

At the same time, extreme precipitation events have become more frequent and destructive in many parts of the world, causing floods, landslides, and substantial economic losses. Conversely, prolonged droughts have affected extensive areas of South America, Africa, Europe, and western North America, compromising water availability, agricultural production, and energy generation.

In South America, and particularly in Brazil, the effects of climate variability and change have become increasingly evident through both temperature and precipitation extremes. In the winter of 2022, a cold air mass led to record-low temperatures in the Midwest and Southeast regions of Brazil, with minimum temperatures recorded at 4.9°C in Brasília (DF), 7.0°C in Cuiabá (MT), 7.6°C in Belo Horizonte (MG), and 7.8°C in Goiânia (GO). In turn, a heatwave in 2023 resulted in record-high temperatures, including 44.8°C in Araçuaí (MG) and 44.2°C in Cuiabá (MT), according to data from the National Institute of Meteorology (INMET).

Also, notable examples include the extreme rainfall events in Northeast and Southeast Brazil in 2022 and in Rio Grande do Sul in 2024, which resulted in hundreds of fatalities and displaced thousands of individuals. In contrast, severe droughts have affected extensive areas of the North, Northeast, and Central-West regions, notably during the Amazon droughts of 2005, 2010, and 2023–2024, the prolonged Northeast drought between 2012 and 2017, and the widespread drought that impacted Central Brazil during 2020–2021, causing substantial impacts on water resources, agriculture, energy production, navigation, and ecosystem functioning.

While extreme weather events are not novel phenomena unique to recent years in Brazil (ARTAXO, 2014, 2020; MARENGO, 2009; MARENGO, CARDONA, MARTINEZ, 2022), the current global climate crisis is characterized by their increased recurrence, intensity, duration, and severity. These events disproportionately affect countries, communities, and ecosystems, with greater impacts on those that are more vulnerable or sensitive (MARENGO et al., 2009).

In this context, the Central-West Region of Brazil warrants particular attention due to its economic reliance on agriculture and livestock. These sectors are highly susceptible to fluctuations in temperature and precipitation extremes, which can lead to reduced agricultural productivity, crop failures, and livestock mortality (CASSOL; BOHNER, 2012). Beyond economic losses, climatic irregularities and anomalies also impact water availability, affecting food production, domestic water supply, and hydroelectric power generation. This, in turn, exacerbates challenges related to food, water, and energy security (RODRIGUES, 2017).

The IPCC (2021) projects that the Brazilian Midwest will experience a trend toward higher temperatures, reduced relative humidity, and altered precipitation patterns. This projection is supported by scientific studies conducted in the state of

Goiás (NEVES, 2018; DEUS; NASCIMENTO, 2021) and the broader Central-West Region (ALMEIDA, 2012; SANTOS et al., 2023). Thus, the general objective of this study is to identify climate trends and extreme weather events associated with air temperature and precipitation indices across seven weather stations in the state of Goiás, using a 45-year time series (1980–2024). The analysis employs standardized indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI), affiliated with the World Meteorological Organization (WMO).

It is hoped that this work will corroborate the climate change scenarios projected by the IPCC for the state of Goiás and elucidate trends and occurrences of climatic extremes in the seven selected locations, which represent diverse climatic typologies: Goiânia, Jataí, Pirenópolis, Aragarças, Formosa, Posse, and Ipameri. The findings aim to provide a scientific foundation for the formulation of public policies and strategic planning to address the climate crisis in the region.

METHODOLOGY

LOCATION AND BRIEF CHARACTERIZATION OF THE STUDY AREA

The area under study refers to the state of Goiás, located in the Central-West Region of Brazil, covering an area of 340,242 km² - which represents approximately 4% of the national territory. Specifically, the study focuses on seven municipalities within Goiás where conventional weather stations are situated. These stations were selected due to their extensive and consistent time series data: Goiânia, Jataí, Pirenópolis, Aragarças, Formosa, Posse, and Ipameri (Figure 1).

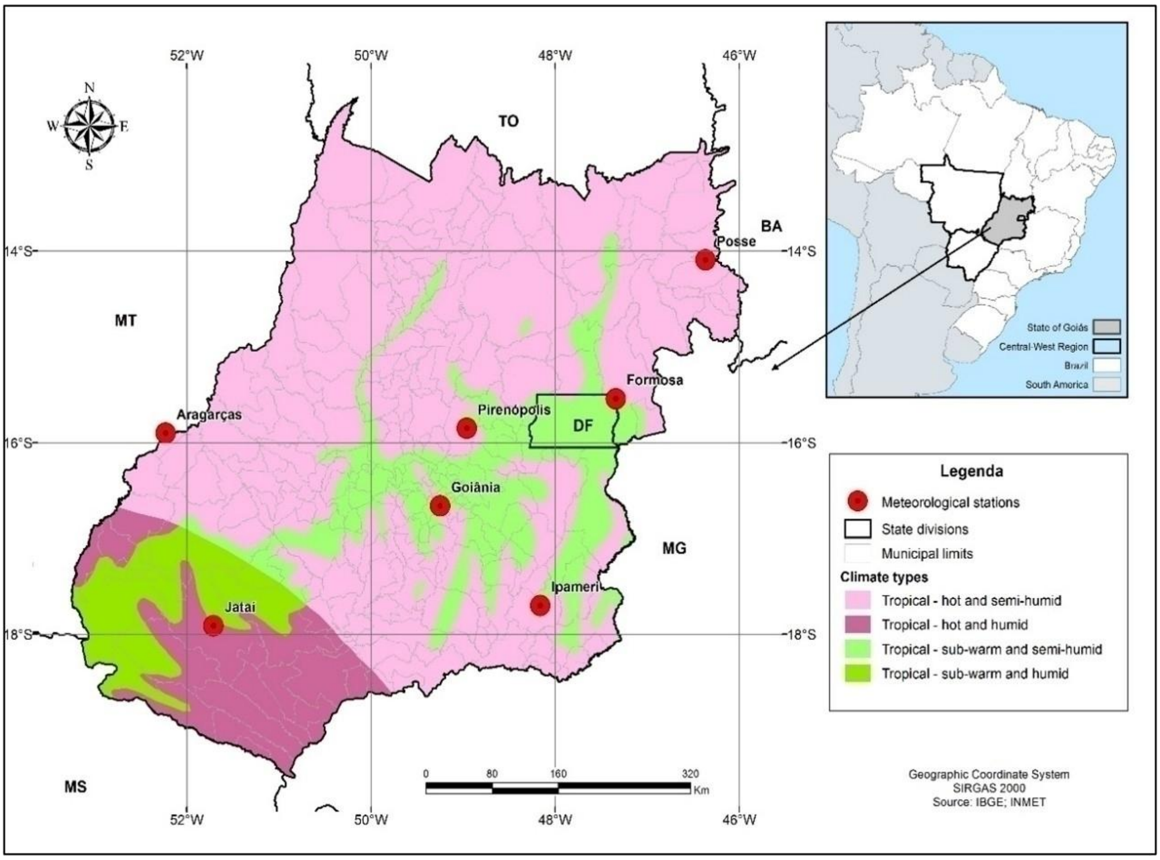

Figure 1 – Location, climate types, and selected stations in the state of Goiás. Source: authors, according to the Koppen-Geiger (1961) climate classification system.

As noted by Nimer (1979), the study region exhibits an average annual temperature of 22°C and average of annual precipitation between 1,550 mm and 1,750 mm, with a dry season lasting four months, typically from May to August. In turn, based on 105 ANA rainfall stations and 47 INMET climate stations, Cardoso, Marcuzzo, and Barros (2014) report an average annual temperature of 23.4°C for the area in question, with higher values in the northwest region, reaching an average of 27°C. The authors report an average annual precipitation of 1,500 mm, ranging from 1,000 to 2,800 mm.

According to the most recent data, based on the 1991-2020 climate norms calculated by INMET for the stations used in the study (Table 1), the highest average annual temperature is recorded in Aragarças (26°C), and the lowest in Formosa and Jataí (22.8°C) – due to the influence of the continental climate, altitude, and latitude, respectively.

Station	Average Annual Temperature (°C)	Lowest monthly average minimum temperature (°C)	Highest monthly average maximum temperature (°C)	Average Annual Precipitation (mm)	Length of the dry season (months)
Posse	24.4	17.8 (julho)	32.5 (setembro)	1,345.5	5
Formosa	22.8	14.6 (julho)	30.8 (setembro)	1,339.4	5
Aragarças	26	15.5 (julho)	36.5 (setembro)	1,450.9	5
Pirenópolis	23.3	14.2 (julho)	33.7 (setembro)	1,725.9	5
Goiânia	24.5	14.8 (julho)	34.0 (setembro)	1,667.3	5
Jataí	22.8	11.6 (julho)	33.4 (setembro)	1,593.3	3
Ipameri	22.9	13.1 (julho)	31.8 (outubro)	1,481.8	5

Table 1 – Annual and monthly averages of mean, maximum, and minimum temperatures, as well as precipitation and the duration of the dry season. Source: climate norms calculated by INMET (1991/2020).

As illustrated in Figure 1, the predominant climate typology in Goiás is a hot and semi-humid tropical climate, characterized by average temperatures exceeding 18°C throughout the year and a dry period of 4 to 5 months – according to the Koppen-Geiger (1961) climate classification system. This condition is reflected in the weather stations located in Posse, Formosa, Aragarças, Pirenópolis, and Goiânia. Additionally, a hot and humid tropical climate typology is observed in the study area, with only 3 dry months, as exemplified by the Jataí station.

Furthermore, a sub-hot tropical climate is present in the region, characterized by average temperatures between 15°C and 18°C in at least one month of the year. In the study area, this typology is primarily associated with semi-humid conditions (with 5 dry months), as represented by the Ipameri meteorological station. However, the sub-hot tropical climate can also occur under humid conditions (only 3 dry months), although this subtype is not represented by any of the selected stations in this investigation.

According to Campos et al. (2002), Luiz (2012), Neves (2018; 2019), and Nascimento and Oliveira (2020), the region's climate is influenced by physiographic characteristics and the interaction of atmospheric systems of equatorial and tropical origin, with occasional incursions of polar systems. These dynamics result in two well-defined seasons: a hot and rainy spring/summer, driven by the dominance of the continental Equatorial mass and the South Atlantic Convergence Zone, and a milder and drier autumn/winter, influenced by the Atlantic Tropical mass and continentalized polar air incursions.

METHODOLOGICAL PROCEDURES

To conduct this study, daily precipitation and air temperature data (maximum and minimum) were obtained from seven conventional weather stations managed by the National Institute of Meteorology (INMET) and located in the state of Goiás (Formosa, Posse, Aragarças, Pirenópolis, Goiânia, Jataí, and Ipameri).

A common time series spanning 45 years (1980–2024) was used for all stations, corresponding to 16,437 daily records. Although conventional weather stations typically provide longer and more consistent data series, some gaps were identified. The maximum proportion of missing data was 10.6% for maximum temperature (Ipameri), 7.6% for minimum temperature (Formosa), and 2.8% for precipitation (Aragarças). These percentages are within the range generally considered acceptable in climatological studies (WMO, 2017).

In addition, the calculation of climate indices allows missing observations to be coded as −99.9 and includes a quality-control procedure to assess the potential influence of missing data on the results (ZHANG; YANG, 2004). So, considering the low proportion of missing values, no data infilling procedures were applied in order to preserve the original variability of the series and avoid artificial homogenization that could affect the derived climate indices.

To detect climate trends and extreme weather events, indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI), affiliated with the World Meteorological Organization (WMO), were utilized. These indices are designed to measure and detect variability and changes in climate parameters through standardized metrics, enabling global-scale observation and comparison (KARL, NICHOLLS, GHAZI, 1999). A comprehensive description of the indices can be found in the full workshop report (PETERSON et al., 2001) or its summary (PETERSON, 2005).

The standardized ETCCDI/WMO indices are widely used in scientific literature at various scales. In Brazil, studies have been conducted for the entire country

(SALVIANO; GROPPO; PELLEGRINO, 2016; PENEREIRO; MESCHIATTI, 2018; REGOTO, et al., 2021; COELHO et al., 2023), as well as for specific biomes LMEIDA, et al., 2016; JOSEPH. SOUZA. SABINO, 2021; SILVA et al., 2019; LUIZ-SILVA et al., 2025), regions (ALMEIDA, 2012; COSTA et al., 2020; SANTOS et al., 2023; SANTOS et al., 2024), and Federal Units (REBELLO, et al., 2008; SANTOS, et al., 2009; SILVA et al., 2015; SILVA, MONTENEGRO, SOUZA, 2017; CASTELHANO; PINTO, 2022; LUIZ-SILVA; OSCAR-JUNIOR, 2022), in addition to numerous local-scale studies.

Among the 27 indices proposed by ETCCDI/WMO, 19 were selected for this study: 11 related to air temperature and 8 to precipitation, as detailed in Table 2. The data were organized in Excel spreadsheets and processed using the Rclimdex extension in the R program, following the recommendations of Zhang and Yang (2004) and Zhang et al. (2005).

To assess statistical significance, linear trends are calculated using the least squares method (slope) were considered significant if they exceeded the standard error of estimate (STD). Trends with p-values below 0.05, as determined by the Student’s t-test, were classified as highly statistically significant, while those with p-values between 0.05 and 0.1 were considered moderately significant, following the approach suggested by Santos et al. (2009).

It is worth noting that, although linear regression based on least squares is the standard approach adopted in the ETCCDI/RClimDex framework, it can be sensitive to outliers, deviations from normality, and serial correlation. Therefore, future studies could complement the analysis by using nonparametric approaches, such as the Mann-Kendall test and the Theil-Sen slope estimator, due to their greater robustness to non-normality, autocorrelation, and outliers.

Acronym	Name	Description	Unit
TXx	Highest Maximum Temperature	Maximum value of daily maximum temperature	°C
TXn	Lowest Maximum Temperature	Minimum value of daily maximum temperature	°C
TNx	Highest Minimum Temperature	Maximum value of daily minimum temperature	°C
TNn	Lowest minimum temperature	Minimum value of daily minimum temperature	°C
TX10p	Cold days	Percentage of days in which the maximum daily temperature was below the 10th percentile	%
TX90p	Hot days	Percentage of days in which the maximum daily temperature was above the 90th percentile	%
TN10p	Cold nights	Percentage of days in which the minimum daily temperature was below the 10th percentile	%
TN90p	Hot nights	Percentage of days in which the minimum daily temperature was above the 90th percentile	%
WSDI	Duration of hot periods	Annual count of days with at least 6 consecutive days in which the maximum daily temperature was above the 90th percentile	days
CSDI	Duration of cold periods	Annual count of days with at least 6 consecutive days in which the minimum daily temperature was below the 10th percentile	days
DTR	Diurnal temperature range	difference between temperature maximum and minimum	°C
RX1day	Maximum amount of precipitation in 1 day	Maximum volume of precipitation in one day	mm
RX5day	Maximum amount of precipitation in 5 days	Maximum precipitation volume in five consecutive days	mm
R10mm	Days with heavy precipitation (>10mm)	Number of days in a year with precipitation greater than 10 mm	days
R20mm	Days with intense precipitation (>20mm)	Number of days in a year with precipitation greater than 20 mm	days
R40mm	Days with very intense precipitation (>40mm)	Number of days in a year with precipitation greater than 40 mm	days
CDD	Consecutive Dry Days	Maximum number of consecutive days with precipitation less than 1 mm	days
CWD	Consecutive Wet Days	Maximum number of consecutive days with precipitation greater than 1 mm	days
PRCPTOT	Total Precipitation	Total annual precipitation	mm

Table 2 – List of climate indices used. Source: authors.

RESULTS AND DISCUSSIONS

The values of the climate trend indices for the seven selected stations in the state of Goiás, based on the period from 1980 to 2024, are presented in Table 3. For the temperature-related indices, a predominance of positive trends (indicating an increase) was observed, with high statistical significance across all stations for the highest and lowest maximum temperatures (TXx and TXn), highest and lowest minimum temperatures (TNx and TNn), and diurnal temperature range (DTR).

Indices / Stations		Aragarças	Pirenópolis	Goiânia	Posse	Formosa	Jataí	Ipameri
TXx	Highest Max. Temperature	**0.097**	**0.102**	**0.107**	**0.088**	**0.069**	**0.079**	**0.098**
TXn	Lowest Max. Temperature	**0.048**	**0.084**	**0.074**	**0.024**	**0.066**	**0.052**	**0.09**
TNx	Highest Min. Temperature	**0.041**	**0.040**	**0.074**	**0.056**	**0.08**	**0.037**	**0.045**
TNn	Lowest Min. temperature	**0.015**	**0.018**	**0.058**	**0.009**	**0.034**	**0.005**	**-0.007**
TX10p	Cold days	-0.369	-0.633	-0.416	-0.426	-0.412	**-0.232**	-0.32
TX90p	Hot days	0.692	0.889	0.802	0.607	0.57	0.599	0.646
TN10p	Cold nights	0.087	-0.299	-0.564	-0.187	-0.349	-0.314	-0.298
TN90p	Hot nights	0.130	0.495	0.625	**0.352**	0.701	0.471	0.462
WSDI	Duration of hot periods	0.424	0.598	0.811	0.309	0.36	0.630	0.559
CSDI	Duration of cold periods	-0.066	**-0.072**	-0.483	-0.227	-0.223	-0.068	-0.084
DTR	Diurnal temperature range	**0.055**	**0.047**	**0.010**	**0.033**	**0.013**	**0.016**	**0.036**
RX1day	Precipitation in 1 day	0.103	-0.256	0.283	-0.421	0.032	0.054	0.171
RX5day	Precipitation in 5 days	-0.559	-0.829	0.056	-0.512	-0.871	-0.292	0.168
R10mm	Days with heavy precip.	-0.174	-0.187	-0.122	-0.299	-0.279	-0.197	-0.191
R20mm	Days with intense precip.	-0.071	-0.021	-0.058	-0.188	-0.141	-0.093	-0.006
R40mm	Days with very intense precip	**-0.030**	**0.000**	**0.031**	**-0.067**	**-0.036**	**0.016**	**-0.022**
CDD	Consecutive Dry Days	0.630	0.574	1.132	0.543	0.795	0.321	0.238
CWD	Consecutive Wet Days	**0.002**	**0.008**	**-0.001**	**-0.060**	**-0.075**	**-0.058**	**-0.093**
PRCPTOT	Total Precipitation	**-6.620**	-2.849	**-0.720**	**-8.786**	**-7.656**	**-4.703**	**-3.551**

Table 3 – Trend detection indices for selected stations in Goiás for the period from 1980 to 2024. Source: authors, based on data stations and calculations carried out in RClimDEX. Note: positive trends in green and negative trends in red, and high statistical significance in dark gray (p-value < 0.05) and good statistical significance in light gray (p-value between 0.05 and 0.1).

The indices for hot days (TX90p) and hot nights (TN90p) also exhibited positive trends (increase), with good statistical significance in most locations, except for the Aragarças and Formosa stations, where no significance was observed. The hot period duration index (WSDI) showed a positive trend but lacked statistical significance in all studied locations. These findings align with the global scenario of rising temperatures (IPCC, 2021) and are consistent with previous studies for the state of Goiás (Almeida, 2012; Neves, 2018; Hofmann et al., 2021, 2023; Santos et al., 2023; Silva and Nascimento, 2021), Brazil (Regoto et al., 2021), and the South American continent (Skansi et al., 2013).

Conversely, the indices for cold days (TX10p), cold nights (TN10p), and cold periodo duration (CSDI) displayed negative trends (decrease), with good statistical significance in most locations. This suggests a reduction in the frequency of colder days and nights, consistent with findings by Santos et al. (2006), Nascimento, Santos and Barros (2011), and Luiz (2012) for Goiânia, and Almeida (2012) and Santos et al. (2023) for the broader Central-West Region.

Regarding precipitation-related indices, negative trends (reduction) predominated for the maximum 5-day precipitation (RX5day), days with precipitation exceeding 10 mm (R10mm), 20 mm (R20mm), and 40 mm (R40mm), consecutive wet days (CWD), and total annual precipitation (PRCPTOT). The R40mm, CWD, and PRCPTOT indices showed high statistical significance, while R10mm and R20mm exhibited good significance across all stations. In contrast, the consecutive dry days (CDD) index showed a positive trend at all stations, and the maximum 1-day precipitation (RX1day) index increased in five of the seven locations, though neither trend was statistically significant.

These precipitation trends are consistent with findings by Alexander et al. (2006) for much of the globe, Salviano, Groppo, and Pellegrino (2016) for over 70% of Brazil's territory, and Santos et al. (2006), Penereiro and Meschiatti (2018), Santos et al. (2023), and Neves et al. (2024) for the state of Goiás. The results indicate a concerning scenario: a reduction in annual precipitation totals, fewer days with rainfall (whether consecutive or not), and a shorter wet season. This aligns with IPCC projections for the Central-West Region and is supported by studies such as Skansi et al. (2013), Almeida (2012), Marcuzzo, Oliveira and Cardoso (2013), Neves (2018), and Santos et al. (2023).

Analysis of the time series based on ETCCDI/WMO indices also highlights extreme temperature events. As shown in Figure 2, the highest maximum temperature (TXx) recorded was 43.3°C at the Aragarças station in October 2020, followed by 42.0°C in Jataí and 41.2°C in Goiânia during the same month and year. These values exceed previous records for the study area (NASCIMENTO, LIMA, CRUZ, 2019; DEUS, NASCIMENTO, 2021), underscoring the breaking of temperature records year after year. Extreme maximum temperatures were also recorded in 2024 at the Pirenópolis and Posse stations, a year marked as the hottest since records began and the first to exceed 1.5°C above pre-industrial levels (COPERNICUS, 2025).

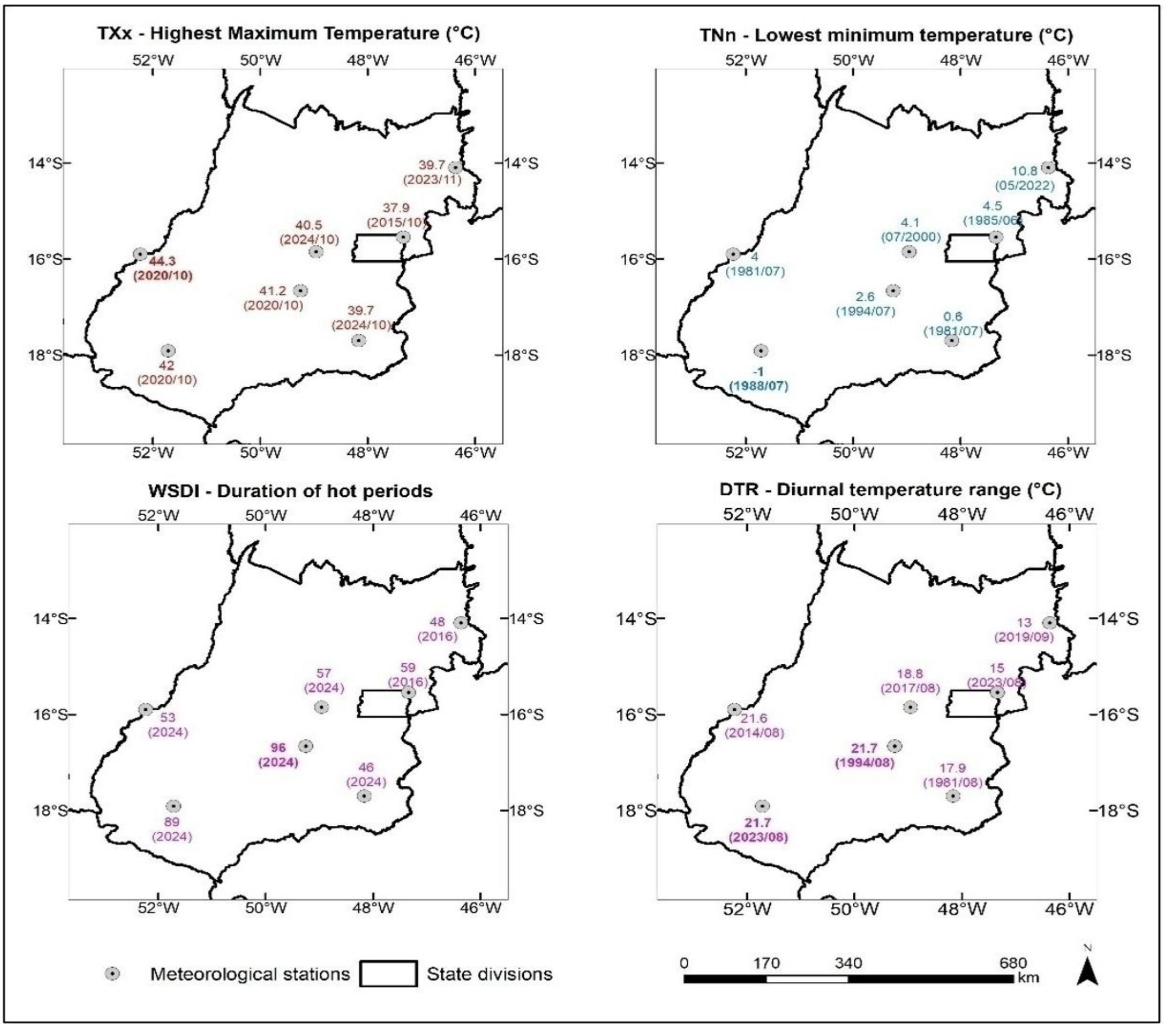

Figure 2 – Spatial variation of extreme events from 1980 to 2024 for some indices associated with air temperature (TXx, TNn, WSDI and DTR). Source: authors, based on INMET data processed in RClimDEX.

The lowest minimum temperature (TNn) records were -1.0°C in 1988 at Jataí, 0.6°C in 1981 at Ipameri, and 2.6°C in 1994 in Goiânia. The first and last locations, situated in the southwest and southeast portions of Goiás, respectively, are more susceptible to incursions of polar air masses, as noted by Nascimento (2016) and Neves (2019). Such low temperatures pose significant risks to agricultural crops, livestock, and human health, particularly for vulnerable populations such as the elderly, children, and those with chronic illnesses (FENNER, SILVA, GURGEL, 2009; MENDONÇA, 2005).

Heatwaves were another notable extreme event, with a record duration of 96 days in Goiânia in 2024. Similar records were observed in Jataí (89 days), Aragarças (53 days), Pirenópolis (57 days), and Ipameri (46 days) during the same year. These prolonged heatwaves, attributed to the influence of the El Niño phenomenon, pose serious health risks, including increased cardiovascular and respiratory mortality, particularly among vulnerable groups such as the elderly, pregnant women, and individuals with chronic conditions (MASSELOT et al., 2023; ROMANELLO et al., 2024). Furthermore, there is a great risk of dehydration, especially as the period is dry and associated with lower levels of relative humidity.

High diurnal temperature ranges (DTR) were also observed, particularly at the end of winter and beginning of spring. Record DTR values included 21.7°C in Goiânia and Jataí and 21.6°C in Aragarças, recorded in August of 1994, 2023, and 2014, respectively. Such fluctuations can exacerbate health risks and impact agricultural productivity.

The maps in Figure 3 illustrate extreme values of maximum 1-day precipitation (RX1day), with notable records of 174 mm in Posse (1994), 167 mm in Pirenópolis (1989), and 151 mm in Jataí (2005). Even more alarming were the extreme 5-day precipitation events, with records of 390 mm in Pirenópolis, 358 mm in Aragarças, and 245 mm in Goiânia.

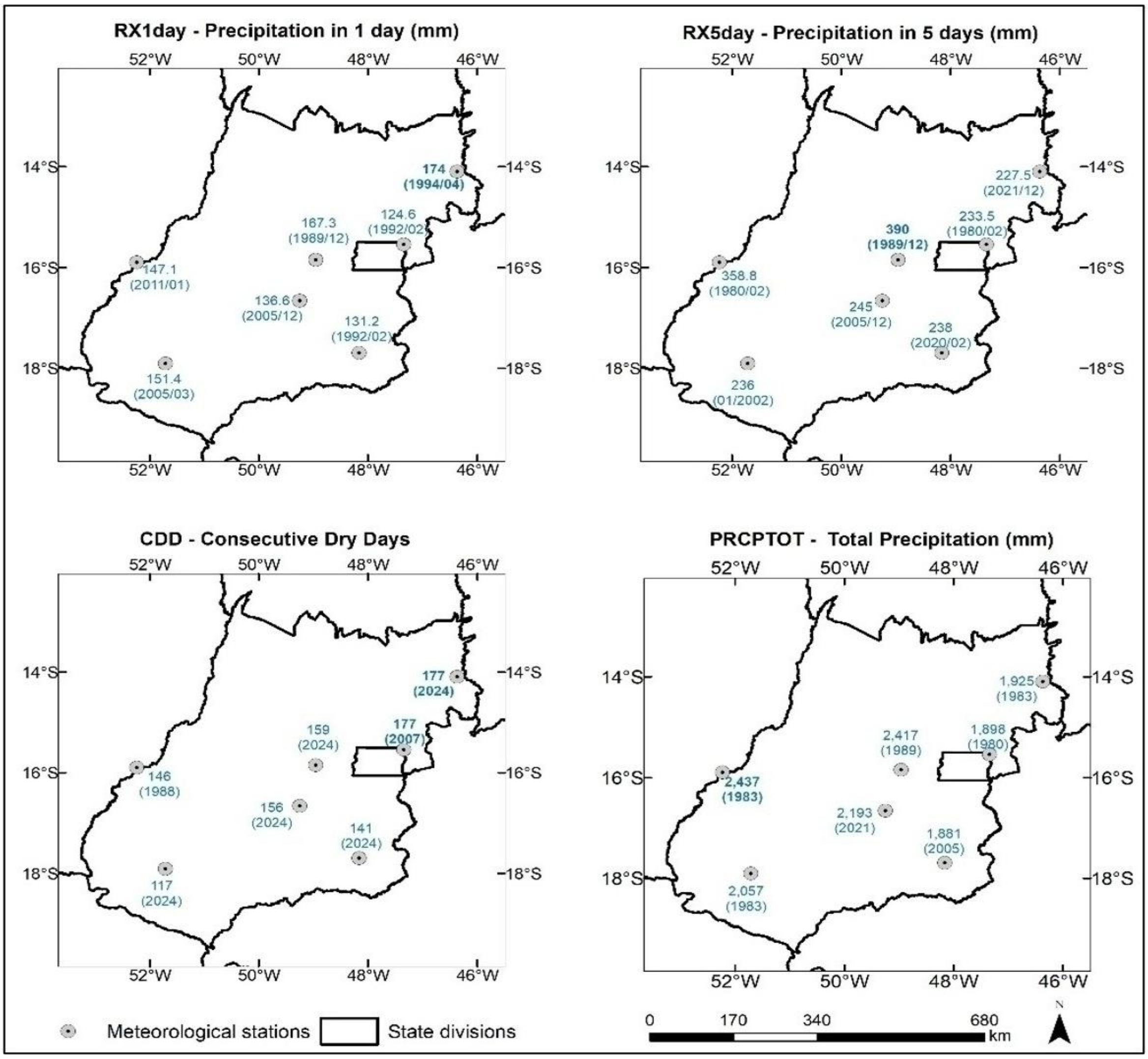

Figure 3 – Spatial variation of extreme events from from 1980 to 2024 for some indices associated with precipitation (RX1day, RX5day, CDD and PRCPTOT). Source: authors, based on INMET data processed in RClimDEX.

These intense precipitation events have led to recurring urban flooding, as highlighted by Rego and Barros (2014) and Luiz and Romão (2019) for Goiânia (Figure 4-A). Deus and Nascimento (2016) also documented the impacts of extreme rainfall in smaller cities, such as Pirenópolis (Figure 4-B), a tourist destination in Goiás.

Figure 4 – Flooding recorded in the cities of Goiânia (A) and Pirenópolis (B) following extreme rainfall events. Source: (A): https://opopular.com.br/cidades/chuva-forte-causa-estragos-em-goiania-veja-fotos-e-video-1.3125219 and (B): https://opopular.com.br/cidades/defesa-civil-de-pirenopolis-alerta-para-risco-de-desabamentos-e-recomenda-fechamento-de-cachoeiras-1.2384903

The occurrence of extreme precipitation events in the study area is often linked to the performance and intensity of atmospheric systems, such as the South Atlantic Convergence Zone and the continental equatorial mass, influenced by atmospheric teleconnections like the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (Nascimento, Lima, & Cruz, 2019; Silva & Carpenedo, 2021; Alves, Cabral, & Nascimento, 2022).

The maximum annual value of consecutive dry days (CDD) reached 177 days in Posse and Formosa, followed by 159 days in Pirenópolis and 156 days in Goiânia. Such prolonged dry periods, lasting up to five or six months, severely impact water, food, and energy security (Hoff, 2011; Mariani et al., 2016). Annual precipitation (PRCPTOT) records included 2,437 mm in Aragarças (1983), 2,417 mm in Pirenópolis (1989), and 2,193 mm in Goiânia (2021).

The northeastern portion of Goiás, where Posse and Formosa are located, historically receives lower precipitation due to topographic barriers that hinder the entry of rain-producing atmospheric systems (NASCIMENTO, 2016; NEVES, 2019). In contrast, Aragarças, Pirenópolis, and Goiânia are situated in areas less affected by such barriers.

The dry season in the study area is primarily influenced by the dominance of the Atlantic Tropical Mass during autumn and winter, which brings high temperatures, atmospheric stability, and a lack of precipitation (SERRA; RATISBONA, 1942; MONTEIRO, 1951). However, in particularly dry years, the absence of rainfall for three or more consecutive months is common, often exacerbated by atmospheric teleconnections such as ENSO and PDO (NASCIMENTO; COSTA, 2020; ALVES, CABRAL, NASCIMENTO, 2022).

The results of this study align with the broader scientific literature and IPCC projections, indicating a hotter and drier climate for the study area, with increased intensity and recurrence of extreme temperature and precipitation events. These findings underscore the urgent need for adaptive strategies to mitigate the impacts of climate change on agriculture, water resources, and public health in the state of Goiás.

CONCLUSIONS

The application of climate indices has proven highly effective in identifying trends in meteorological variables across selected weather stations in the state of Goiás. The analysis revealed a clear and statistically significant pattern of increasing temperatures, as evidenced by positive trends in the highest and lowest maximum and minimum temperatures (TXx, TXn, TNx, and TNn) and the diurnal temperature range (DTR). These findings align with global observations of rising temperatures and underscore the intensification of warming trends in the region.

In contrast, precipitation-related indices predominantly exhibited negative trends, particularly in the number of days with heavy (R10mm), intense (R20mm), and very intense (R40mm) rainfall, consecutive wet days (CWD), and total annual precipitation (PRCPTOT). While the trends for PRCPTOT, CWD, and R40mm were statistically significant, other indices showed good but not high significance. This suggests a shift toward drier conditions, albeit with variability across the study area.

The study also highlighted extreme climatic events recorded over the 45-year period (1980–2024), including: a highest maximum temperature of 44.3°C in Aragarças (2020); a lowest minimum temperature of -1.0°C in Jataí (1988); a maximum 1-day precipitation of 174 mm in Posse (1999), a record of 177 consecutive dry days in Posse and Formosa, and a total annual precipitation of 2,437.9 mm in Aragarças (1983).

These findings are consistent with the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC, 2021), which emphasizes unprecedented global warming and the increased frequency and intensity of extreme weather events. For the Central-West Region of Brazil, the IPCC projects further temperature increases and potential alterations in precipitation patterns, though the latter lacks consistent statistical significance in this study.

While this study provides valuable insights into climate trends and extremes in Goiás, further research is needed to deepen our understanding of these phenomena. Future studies should a) conduct more granular analyses of specific indices to identify localized trends and impacts; b) investigate the socioeconomic and environmental repercussions of rising temperatures and changing precipitation patterns; and c) explore the role of atmospheric teleconnections, such as ENSO and PDO, in driving extreme events in the region.

Finally, the findings of this study underscore the urgent need for proactive measures to address the impacts of climate change in Goiás. By integrating scientific knowledge with practical adaptation and mitigation strategies, the state can enhance its resilience to climate variability and ensure sustainable development for future generations.

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AUTHOR'S CONTRIBUTIONS

Silva, G.C. - The author contributed to the elaboration, realization and manipulation of the data and writing.

Nascimento, D.T.F. - The author contributed to the elaboration, realization and manipulation of the data and writing.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

RESEARCH DATA AVAILABILITY

All the data supporting the results of this study were published in the article itself.

USE OF AI

No Artificial Intelligence tools were used.

BIBLIOGRAPHIC REFERENCES

ACOSTA, Alberto. O bem viver: uma oportunidade para imaginar outros mundos. Tradução de Tadeu Breda. São Paulo: Autonomia Literária, Elefante, 2016.

ACSELRAD, Henri. Justiça ambiental e construção social do risco. Desenvolvimento e Meio Ambiente, Curitiba, n. 5, jan./jun. 2002.

ADAMI, Rose Maria. Rio Criciúma: o rio que a cidade escondeu – significados e representações na paisagem. Criciúma: UNESC, 2015.

ALEXANDRE, Nadja Zim. Diagnóstico Ambiental da Região Carbonífera de Santa Catarina: degradação dos recursos naturais. Revista Tecnologia e Ambiente, Criciúma, v. 5, n. 2, jul./dez. 1999.

ALIMONDA, Héctor. Descolonizar la naturaleza: por una ecología política latinoamericana. Textos reunidos de Héctor Alimonda 1982-2017. Compilación de Facundo Martín, Gabriela Merlinsky y Felipe Milanez. Prólogo a cargo de Facundo Martín, Gabriela Merlinsky y Felipe Milanez. 1ª ed. Ciudad Autónoma de Buenos Aires: CLACSO, 2025.

AMORIM, Celeste Dias; CESTARI, Luis Artur de Santos. A cartografia e a racionalidade ambiental: em busca da superação da racionalidade instrumental. Práxis Educacional, Vitória da Conquista, v. 17, n. 48, 2021. DOI: 10.22481/praxisedu.v17i48.9168.

ARÁOZ, Horacio Machado. El extractivismo y las raíces del “Antropoceno”. Regímenes de sensibilidad, régimen climático y derechos de la Naturaleza. Direito e Práxis, Rio de Janeiro, v. 14, n. 01, 2023.

ASSUNÇÃO, Viviane Kraieski de et al. O sofrimento social nas narrativas de sujeitos afetados pela mineração de carvão no sul do estado de Santa Catarina. In: MENEZES, Carlyle Torres Bezerra de et al. (Orgs.). Impactos do carvão mineral nas pessoas e na natureza. Criciúma: EdiUnesc, 2024.

BOURRIAUD, Nicolas. Estética Relacional. São Paulo: Martins Fontes, 2009a.

BOURRIAUD, Nicolas. Formas de vida: a arte moderna e a invenção de si. São Paulo: Martins Fontes, 2011.

BOURRIAUD, Nicolas. Pós-produção: como a arte reprograma o mundo contemporâneo. São Paulo: Martins Fontes, 2009b.

BRASIL. Decreto nº 20.089, de 9 de junho de 1931. Autoriza a Cia de Navegação Lloyd Brasileiro e a Estrada de Ferro Central do Brasil a contratarem, em nome do Governo, com as companhias nacionais de mineração de carvão, por preço e prazo que combinarem, toda a produção de carvão nacional disponível. Diário Oficial da União, Rio de Janeiro. Disponível em: https://www2.camara.leg.br/legin/fed/decret/1930-1939/decreto-20089-9-junho-1931-519084-publicacaooriginal-1-pe.html. Acesso em: 14 jan. 2026.

BRASIL. Decreto-Lei nº 2.667, de 3 de outubro de 1940. Autoriza o fomento às empresas nacionais de mineração de carvão pelo Governo da União e autoriza obras e instalações necessárias para facilitar e baratear o transporte do carvão nacional. Diário Oficial da União, Rio de Janeiro. Disponível em: https://www2.camara.leg.br/legin/fed/declei/1940-1949/decreto-lei-2667-3-outubro-1940-412620-publicacaooriginal-1-pe.html. Acesso em: 14 jan. 2026.

CAROLA, Carlos Renato. Progresso, tecnologia e insensibilidade ambiental socioambiental: a extração do carvão na primeira metade do século XX (1880-1950). In: CAROLA, Carlos Renato (Org.). Memória e cultura do carvão em Santa Catarina: impactos sociais e ambientais. Santa Cruz do Sul: EDUNISC, 2010.

CAROLA, Carlos Renato; DASSI, Nilso. Era uma vez o rio Mãe Luzia… Criciúma: EDIUNESC, 2014.

COSTA, Luciano Bedin da. Cartografia: uma outra forma de pesquisar. Revista Digital do Laboratório de Artes Visuais, Santa Maria, v. 7, n. 2., 2014.

DELEUZE, Gilles; GUATTARI, Félix. Mil platôs: capitalismo e esquizofrenia. V. 1. Tradução de Aurélio Guerra Neto e Célia Pinto Costa. Rio de Janeiro: Editora 34, 1995.

ENGEPLUS. Prefeitura esclarece retirada de placas da praça. Criciúma, 2 dez. 2015. Disponível em: https://engeplus.com.br/noticia/cultura/2015/prefeitura-esclarece-retirada-de-placas-da-praca. Acesso em: 19 jan. 2026.

HARAWAY, Donna. Antropoceno, Capitaloceno, Plantationoceno, Chthuluceno: fazendo parentes. Tradução de Susana Dias, Mara Verônica e Ana Godoy. ClimaCom, Campinas, ano 3, n. 5, 2016.

HARAWAY, Donna. Ficar com o problema: fazer parentes no Chthuluceno. São Paulo: n-1, 2023.

JUNG, Leandro. Meios. Mutatis Mutandis: quando a arte se propõe a pensar o que tem de ser mudado [Fotografia]. Criciúma, 2025.

KOTHARI, Ashish et al. Pluriverse: A Post-Development Dictionary. Nova Delhi: Tulika Books, 2019.

KROGH, Katrine; JENSEN, Ole B.; FRANDSEN, Anne Kathrine; HANSEN, Majken Kirkegaard. Framing artistic practices through new materialism to ensure multispecies futuring in the built environment. Futures, Amsterdam, v. 166, n. 2, 2025.

LOPES, Rosana Peporine; SANTO, Eder Luiz; GALATTO, Sérgio Luciano. Mineração de carvão em Santa Catarina: geologia, geoquímica e impactos ambientais. In: MILIOLI, Geraldo; SANTOS, Robson dos; CITADINI-ZANETTE, Vanilde (Coord.). Mineração de carvão, meio ambiente e desenvolvimento sustentável no sul de Santa Catarina: uma abordagem interdisciplinar. Curitiba: Juruá, 2009.

MENEZES, Carlyle Torres Bezerra de et al. Transição energética justa, ecológica e inclusiva e a reconversão socioambiental da região carbonífera sul catarinense. In: MENEZES, Carlyle Torres Bezerra de et al. (Orgs.). Impactos do carvão mineral nas pessoas e na natureza. Criciúma: EdiUnesc, 2024a.

MENEZES, Carlyle Torres Bezerra de; GONÇALVES, Elizabeth Marley Brusch; VIEIRA, Simoni Daminelli; MARTINELLO, Eduardo Fernandes. A revitalização de rios urbanos e a governança das águas: possibilidades e desafios na região sul de Santa Catarina, Brasil. In: SELVA, Vanice Santiago F. et al. (Orgs.). Água, gestão, territórios e sustentabilidade. 1. ed. Ananindeua: Itacaiúnas, 2024b.

PASSOS, Eduardo; KASTRUP, Virginia; ESCÓSSIA, Liliana (Orgs.). Psicologia Social: a cartografia como método de pesquisa. Petrópolis: Vozes, 2009.

PACHECO, Adilson. “Daniele Zacarão - é interessante sua proposta. Ela também provoca dupla interpretação - a inércia das autoridades e ao mesmo tempo chama atenção da população. Infelizmente a região de Criciúma como toda região carbonífera pagou e paga um alto preço pelo desenvilvimento sem planejamento e degradação ambiental…” [Comentário em: 3ª SOU]. In: LABORATIVO. 3ª SOU - Rio Criciúma: instruções para escuta por Daniele Zacarão. Facebook, 30 nov. 2015. Disponível em: https://encurtador.com.br/gvib. Acesso em: 8 mai. 2026.

PORTO-GONÇALVES, Carlos Walter. Da geografia às geo-grafias: um mundo em busca de novas territorialidades. In: CECEÑA, Ana Esther; SADER, Emir. (Orgs.). La Guerra Infinita: hegemonía y terror mundial. Buenos Aires: CLACSO, 2002.

RANCIÈRE, Jacques. A partilha do sensível. 2ª ed. São Paulo: Ed. 34, 2009.

RANCIÈRE, Jacques. O espectador emancipado. São Paulo: Editora WMF Martins Fontes, 2012.

SACHET, Celestino. Quem é Celestino Sachet? (Biografia Sentimental). Yumpu Publicações, s/d. Disponível em: https://www.yumpu.com/pt/umdedodeprosa.cce.ufsc.br. Acesso em: 27 jan. 2026.

SOUZA, Marcelo Lopes de. Ecologia-Mundo, Rapina Ambiental e Zona de Sacrifício: provocações a partir da (semi) periferia. In: MITIDIERO JÚNIOR, Marco Antônio et al. (Org.). A Geografia que fala ao Brasil, XIV Encontro Nacional de Pós-Graduação e Pesquisa em Geografia. Marília: Lutas Anticapital, 2021.

TSING, Anna. O cogumelo no fim do mundo: Sobre a possibilidade de vida nas ruínas do capitalismo. Tradução de Jorge Menna Barreto e Yudi Rafael. São Paulo: n-1 edições, 2022.

ZACARÃO, Daniele. Rio Criciúma: instruções para escuta. SOU – Semana de Ocupação Urbana, Laborativo, Criciúma, 2015.