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ANALYSIS OF TEMPORAL PRECIPITATION VARIABILITY IN THE STATE OF SANTA CATARINA - BRAZIL

Análise da variabilidade temporal de precipitação no Estado de Santa Catarina - Brasil

Análisis de la variabilidad temporal de la precipitación en el Estado de Santa Catarina - Brasil

André Francisco Pugas
Federal Institute of Santa Catarina
squallafp@hotmail.com

Ariana Pereira Barboza da Silva
Federal Institute of Santa Catarina
arianaveida@gmail.com

Eliseo Breda da Silva
Federal Institute of Santa Catarina
eliseo.breda.silva@gmail.com

Helena Pures Roldão
Federal Institute of Santa Catarina
helena.pures@gmail.com

Mario Francisco Leal de Quadro
Federal Institute of Santa Catarina
mquadro@ifsc.edu.br

Adriano Vitor
Federal Institute of Santa Catarina
adriano.vitor@ifsc.edu.br

Michel Nobre Muza
Federal Institute of Santa Catarina
michel.muza@ifsc.edu.br

Abstract: Precipitation studies are commonly related to the geomorphology and atmospheric circulation of a specific region, primarily due to the instability of these systems that are directly influenced by the elevation and/or slope of mountains and their proximity to the coastal environment. Therefore, the objective of this study is to analyze precipitation anomalies that occurred in the state of Santa Catarina and identify trends in the State's rainfall pattern. Thus, historical series totaling 15 years of pluviometric data in 24 municipalities of the State were used. Based on these data, moving averages for 50-day periods were analyzed, and precipitation corresponding to the 95th percentile was selected, representing the 5% rainiest days for each season of the year. After this analysis, a result of 70% of cases with a downward trend, 19% of cases with an upward trend, and 11% of cases without trend in precipitation patterns in the four seasons of the year was obtained. The results, in general, demonstrated spatial and temporal variability in precipitation in the State, with most cases showing that, on days with higher rainfall intensity, precipitation volume has decreased over the years. However, in some coastal and high-altitude regions, a historical increase in pluviometric indices was observed.
Keywords: Precipitation. Santa Catarina. Anomalies. Trends.

Resumo: Os estudos de precipitação são comumente relacionados à geomorfologia e a circulação atmosférica de uma determinada região, principalmente pela instabilidade desses sistemas que são influenciados diretamente pela elevação e/ou inclinação das montanhas e pela sua proximidade com o ambiente litorâneo. Por isso, o objetivo deste trabalho é analisar as anomalias de precipitação que ocorreram no estado de Santa Catarina e encontrar tendências no padrão de chuvas do Estado. Deste modo, foram utilizadas séries históricas que totalizam 15 anos de dados pluviométricos em 24 municípios do Estado. A partir desses dados, foram analisadas as médias móveis para períodos de 50 dias e selecionadas as precipitações relativas ao percentil 95, chegando-se aos 5% dos dias mais chuvosos para cada estação do ano. Após esta análise, obteve-se um resultado de 70% dos casos com tendência descendente, 19% dos casos com tendência ascendente e 11% dos casos sem tendência nos padrões de precipitação nas quatro estações do ano. Os resultados, em geral, demonstraram que há variabilidade espacial e temporal da precipitação no Estado, sendo que na maior parte dos casos, evidenciou-se que, nos dias com maior intensidade de chuvas, o volume de precipitação tem diminuído com o passar dos anos. Todavia, em algumas regiões litorâneas e de altitudes elevadas verificou-se aumento histórico nos índices pluviométricos.
Palavras-chave: Precipitação. Santa Catarina. Anomalias. Tendências.

Resumen: Los estudios de precipitación suelen estar relacionados con la geomorfología y la circulación atmosférica de una región específica, principalmente debido a la inestabilidad de estos sistemas que son influenciados directamente por la elevación y/o inclinación de las montañas y su proximidad al entorno costero. Por lo tanto, el objetivo de este trabajo es analizar las anomalías de precipitación que ocurrieron en el estado de Santa Catarina y encontrar tendencias en el patrón de lluvias del estado. De este modo, se utilizaron series históricas que totalizan 15 años de datos pluviométricos en 24 municipios del estado. A partir de estos datos, se analizaron las medias móviles para períodos de 50 días y se seleccionaron las precipitaciones correspondientes al percentil 95, llegando al 5% de los días más lluviosos para cada estación del año. Después de este análisis, se obtuvo un resultado del 70% de los casos con tendencia descendente, 19% de los casos con tendencia ascendente y 11% de los casos sin tendencia en los patrones de precipitación en las cuatro estaciones del año. Los resultados, en general, demostraron que hay variabilidad espacial y temporal en la precipitación en el estado, y en la mayoría de los casos se evidenció que, en los días con mayor intensidad de lluvias, el volumen de precipitación ha disminuido con el paso de los años. Sin embargo, en algunas regiones costeras y de altitudes elevadas, se observó un aumento histórico en los índices pluviométricos.
Palabras clave: Precipitación. Santa Catarina. Anomalías. Tendencias.

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1. INTRODUCTION

Climate variability is a topic that has been gaining prominence worldwide, as its effects influence global activities. The impact of climate is perceived through the anomalous variation of climatological elements such as radiation, temperature, atmospheric pressure, and evapotranspiration (GOTARDO et al., 2018).

With recent analyses from the World Meteorological Organization (WMO) and the Intergovernmental Panel on Climate Change (IPCC), the results have reached alarming data regarding global climate change. The latest IPCC report, with data updated until the year 2021, depicts that the planet's climate scenario is rapidly worsening, and measures to mitigate these issues are of extreme urgency. According to the World Meteorological Organization reports, global warming is progressing at a rate of 2.5°C to 3°C, exceeding the target of limiting the increase to 1.5°C, as established by the Paris Agreement. An increase of 1.1°C in the global average temperature has been observed over the last decade. (IPCC, 2021; WMO, 2022).

With the pronounced change in the planet's temperature, pressure patterns, wind, and atmospheric systems also undergo alterations, which can lead to climatic anomalies in all regions of the world. As an example, precipitation, one of the most important climatic variables, requires fundamental studies in this context for proper planning regarding urban structures and other population needs. In recent years, the frequency of extreme precipitation events has been increasing, with greater intensity and duration, favoring natural disasters such as floods and severe droughts in various regions of Brazil (IPCC, 2021; MARENGO et al., 2011; WMO, 2022).

In this context, precipitation influences the environment and its components in various ways, as highlighted by Barcellos et al. (2020). For example, the lack of rain over a long period of time in a certain region can cause an imbalance in an ecosystem and lead to significant economic losses for the region. Similarly, excess rainfall, either due to recurrent events or abnormal volume for a specific region, can result in soil deterioration, impaired capacity for drainage in pluvial and fluvial systems, leading to urban flooding, and consequently, various environmental and urban community impacts, as well as damage to public and private assets (PBMC, 2016).

Excessive rainfall, combined with the lack of soil permeability in urban centers, is the main cause of floods because urban areas cannot handle the volume, leading to overflowing drainage channels and causing various issues. Similarly, when associated with rivers or regions with large watersheds near urban centers, the impacts can be more significant. In such cases, floods may reach larger proportions (CEPED, 2016).

Similarly, the state of Santa Catarina and the southern region of Brazil, which have a large part of their economy tied to agribusiness, are deeply influenced by these climatic variations. Meteorological characteristics, such as the distribution and intensity of rainfall, are crucial for determining favorable or unfavorable periods for agricultural and livestock production. This scenario emphasizes the relevance of the study by Cera and Feraz (2015), which addresses the influence of climate on the region's primary economic activities, highlighting the need for adaptive strategies to face such climatic challenges.

Therefore, knowledge and monitoring of rainfall patterns are of great relevance for the management and development of containment measures and/or possible solutions to mitigate potential impacts. In this context, the present study aims to analyze climatic variability and identify possible temporal trends in precipitation in the state of Santa Catarina. This will be achieved by analyzing data from meteorological stations available in the study area, as well as identifying any climatic anomalies that occurred during this period.

2. LITERATURE REVIEW

2.1. Meteorological systems that affect the State of Santa Catarina

The climate in Santa Catarina is influenced mainly by the proximity of the South Atlantic anticyclone, combined with geomorphological factors that determine heat and moisture balances, as well as local factors (VICTORIA et al., 2007). The topography of Santa Catarina is quite diverse and plays a crucial role in determining the precipitation patterns, which vary from region to region in the state.

The main meteorological systems present and influencing extreme weather events such as storms, gusts, hail, and floods in the southern region of Brazil are: **(i) general synoptic-scale systems** like Frontal Systems, Extratropical Cyclones (EC), Low-Level Jets (LLJ), South Atlantic Convergence Zone (SACZ), and South Atlantic Subtropical (SAH) and South Pacific Subtropical Highs (SPH); (ii) **followed by maritime systems affecting the coast**, such as the Brazil and Malvinas currents; El Niño Southern Oscillation (ENSO) and Pacific Decadal

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Oscillation (PDO); (iii) **and mesoscale convective systems** like the Squall Line (SL), Mesoscale Convective Complexes (MCC), and convective storms (REBOITA et al., 2010; Orlanski (1975).

2.1.1 General synoptic-scale systems

Frontal systems are composed of a center of low atmospheric pressure, a cold front, and a warm front. Thus, the system forms as one of the fronts (cold or warm) advances over the other, meaning the front can also be defined as a transition zone between warm and cold air (REBOITA et al., 2010).

According to Back et al. (2012), in the summer, the influence of cold fronts is greater over the Atlantic Ocean; in the fall, they penetrate further into the continent, and in winter, with the continent colder, air masses from higher latitudes become more important in the distribution of precipitation in the Southern Region. Although the average number of monthly incursions is the same, in winter, cold fronts have a more continental influence.

This increase in the occurrence on days with intense precipitation can cause socio economic losses associated with floods, inundations, and landslides. Another strong influence on precipitation on the coastal Santa Catarina is the so-called "eastern winds" (lestadas), which are formed from low-pressure systems that remain for a period ranging from hours to days, east of the coastline over the ocean, causing high rainfall rates (BACK et al., 2012; MONTEIRO, FURTADO, 1995; MONTEIRO, 2001).

Cyclones, according to Hakin (2003), are low-pressure atmospheric systems that operate in regulating temperature between the poles and the equator. In the southern hemisphere, they move clockwise. In southern Brazil, extratropical cyclones are more common because they occur at middle latitudes and are related to masses of polar origin (BJERKNES; SOLBERG, 1922).

The High-Level Jets, or Jet Stream, are named for a strong and narrow current along a horizontal axis, caused by wind shear in the upper troposphere, with maximum wind speeds between 140 to 300 km/h. High-Level Jets can still be characterized as subtropical and polar (World Meteorological Organization – WMO). As for Low-Level Jets, they are characterized by vertical winds in the lower troposphere with average maximum speeds above 10 m/s (CAMPOS; SANTOS, 2007).

The Low-Level Jets (LLJ) are active globally, but in the southern region of Brazil, the Jet is called JBNAS (South American Low level Jets) and is responsible for transporting moisture from the Amazon Basin and the Tropical Atlantic southward (CAMPOS; SANTOS, 2007). According to Marengo and Soares (2002) and Doswell (1991), Jets are significant regulators of the precipitation regime as they destabilize the atmospheric system through interaction with other systems and local topography.

The South Atlantic Convergence Zone (SACZ) is defined by a band or stationary mass of cloudiness and precipitation oriented from northwest to southeast from the Amazon region to the southwest of the South Atlantic Ocean, which can result in a change in the rainfall pattern of the affected region (KOUSKY, 1988; QUADRO, 1994; CARVALHO et al., 2004).

The combination of various meteorological systems, such as the differential heating in the ocean-atmosphere system, the Low-Level Jets (LLJ) that transport humidity from the Amazon to the Southeast and South regions, the moisture transported from the South Atlantic Ocean by the South Atlantic Subtropical Anticyclone (SAH), among other systems, also favors the formation of the SACZ.

The subtropical anticyclones SAH and SPH are centers of high atmospheric pressure that form according to latitude and are originated by the Earth's general atmospheric circulation. Subtropical anticyclones form near the 30° latitude and are derived from the Hadley cell and are responsible for various weather conditions in the southern region of Brazil (ITO; AMBRIZZI, 1999).

In Brazil, the SAH system is responsible for a significant portion of the weather conditions. The position and direction (displacement) of this system directly influence the precipitation regime and meteorological events in this region (REBOITA et al., 2010).

According to Quadro et al. (2012), it establishes that the South Atlantic Subtropical Anticyclone (SAH) also contributes to humidity in the summer months, although less effectively than the humidity coming from the Amazon system. In Santa Catarina, SAH is the main driver of winds in the eastern quadrant, which, according to the author Rodrigues (2011), favors the precipitation pattern in the region.

2.1.2 Maritime Systems

Santa Catarina has already experienced many natural disasters, some of them linked to Maritime Circulation (Lestadas). According to Haas (2002), the major flood in Tubarão in March 1974, the flood in December 1995 in Greater Florianópolis, supported by the 2008 flood in the North Coast and Lower Itajaí Valley, were caused by rains with winds from the east quadrant.

The effect of maritime circulation favors the transport of moisture from the sea to the continent and the action of east winds, resulting in the formation of low and medium clouds in coastal regions, sometimes with associated rain and without electrical discharge. This persistent weather condition can vary from a few hours to a week but typically lasts 2 to 3 days and is characterized as "Lestada."

Haas (2012) stated that "Lestadas" are generally very strong, with warm and shallow clouds, long-lasting, and modulated by the relief and/or local circulation when they reach the continent. The intensity of the rain varies depending on the conditions of maritime circulation and other atmospheric systems in action. The region's orography is decisive in intensifying the conditions of rain associated with the wind flow from maritime circulation. When encountering the walls of the Serra Geral, the orographic barrier causes the moist air to rise, favoring voluminous stratiform precipitation.

Storms, which originate from various meteorological phenomena, are among the events that cause the most significant risks and impacts to society. This includes intense precipitation, strong winds, and hail. According to CEPED/UFSC (2013), the Civil Defense of Brazil recorded that, from 1991 to 2012, 77% of the storms associated with strong winds occurred in the Southern region, affecting more than 4 million people, directly or indirectly. These extreme rainfall events are often influenced by large-scale phenomena, such as El Niño and La Niña, which are characterized, respectively, by the anomalous warming and cooling of the waters in the central and eastern Equatorial Pacific Ocean.

The ENSO (El Niño-Southern Oscillation), which combines the effects of El Niño and La Niña with the Southern Oscillation Index (SOI), can significantly alter global climatic patterns. This variation in sea-level pressure between the Central Pacific (Tahiti) and the West (Darwin/Australia) plays a crucial role in weakening or intensifying the trade winds over the

Equatorial Pacific Ocean, thus impacting the frequency and intensity of storms in various regions, including the Southern region of Brazil.

This anomalous variation of components (El Niño/La Niña and SOI) shows two opposite phases of ENSO, which on average has a periodicity of four to seven years and an average duration of twelve to eighteen months (CERRA, FERRAZ, 2015). Due to a change in temperatures, which generated negative to positive anomalies in the mid-1970s, researchers suggested that this may be associated with planetary-scale phenomena such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). According to Minuzzi (2017), the occurrence of the El Niño Southern Oscillation (ENSO) is seen as a driver of climatic anomalies in various regions of the globe, especially in precipitation.

The southeast coast of Brazil is influenced by the Brazil Current (CB), Falkland Current (CM), and their confluence (Brazil-Malvinas Confluence). Sea Surface Temperature (SST) is a fundamental component for understanding the interaction between the atmosphere and the ocean, as its exchanges define different temperature gradients that will directly influence the climate and, especially, the hydrogeological regime of the region (CATALDI et al., 2010).

In the study by Cataldi et al. (2010), results showed that SST anomalies in the BC-Malvinas region played an important role because, after synoptic analysis of several simulated and observed mean fields, it was identified that, with the observation of positive SST anomalies in the BC-Malvinas region, transient low-pressure systems passing near this region would intensify. As a consequence, there would be ascending air anomalies over the South Atlantic, resulting in a descending anomaly over the Southern Region of Brazil, and thus leading to the appearance of another ascending anomaly over the Southeast Region and a descending anomaly over the Northeast Region.

Ultimately, this alteration in the wave-like pattern of vertical atmospheric circulation leads to a decrease in precipitation in the Southern Region of Brazil due to the presence of this subsiding air anomaly, and creates favorable conditions for the formation of the South Atlantic Convergence Zone (SACZ) over the northern part of the Southeast Region. This entire process of anomaly in the vertical structure of the atmosphere can vary according to the time of year, the intensity and persistence of SST anomalies, and primarily the presence of large-scale or global-scale forcings, such as the presence of phenomena like ENSO.

2.1.3 Meso-scale systems

Meso-scale Convective Systems (MCSs) are composed of a cluster of convective clouds and exhibit an area of continuous precipitation that can be partially stratiform and partially convective. These systems can have various shapes (HOUZE, 1993; MACHADO & ROSSOW, 1993). Furthermore, these systems can be classified as: Squall Lines (SLs), which have a linear shape (HOUZE, 1993); Mesoscale Convective Complexes (MCCs), which have a circular shape (MADDOX, 1980); or SCM, representing irregular shapes (HOUZE, 1993).

In the southern region of Brazil, MCSs are responsible for a significant portion of surface precipitation and, consequently, are important for the region's climatic regime. Generally, these systems move eastward in winter and from southwest to northeast in the summer season, and their average lifespan varies from 6 to 36 hours (ANABOR, 2004).

2.1.4 Topography and its relationship with precipitation

Precipitation is one of the meteorological elements that can have a significant influence on environmental conditions, exhibiting large spatial and temporal variations (COAN et al., 2014). According to Gotardo et al. (2018), rainfall is one of the most important forms of precipitation within the hydrological cycle. However, its occurrence or lack thereof is related to meteorological and climatic phenomena of great relevance.

According to Alves and Silveira (2018), the characteristics of the topography are important for the climatic definition of a particular region, as high-altitude and steep-sloped terrains form a physical barrier to atmospheric systems. The authors also highlight that the following four attributes of topography play a role: (i) the position or general arrangement of the relief; (ii) the orientation and shape of slopes; (iii) the slope gradient; and (iv) the altitude.

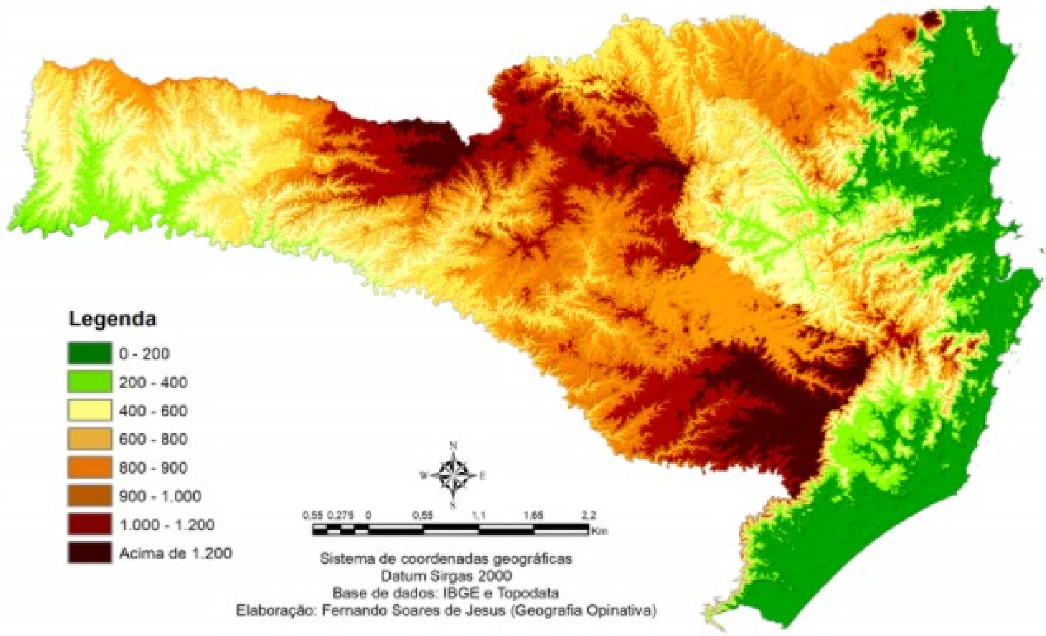
In the coastal region of Santa Catarina, the intensity of precipitation is related to the instability of the meteorological system that generates rainfall, as well as the height, slope of mountains, and intensity of local maritime circulation (RODRIGUES, 2015). According to Alves and Silveira (2018), understanding the factors that influence precipitation in cities built on steep terrain with significant slope variation is of great importance, as certain events (such as extreme rainfall events) can in turn generate structural problems with a significant impact on cities.

For example, flooding is one of the main impacts of rainfall in the state of Santa Catarina. Flooding occurs in this region due to the volume and regularity of precipitation, resulting in increased river flows and the inability of the soil and urban drainage systems to absorb it (CEPED, 2016). When associated with steeper topography, water flows more intensely, resulting in flooding in lower-lying areas.

According to Back et al. (2012), in the state of Santa Catarina, precipitation is lower in the coastal plain, and the highest rainfall values are observed near the slope of the Serra Geral. In the narrow coastal area of Santa Catarina, the highest rainfall occurs in the summer, while the lowest values are usually recorded in the winter and, to a lesser extent, in the autumn. These differences can be attributed to the differential influence of air masses in the southern region of the country, directly affecting the frequency and intensity of rainfall.

Figure 1 shows the topography of Santa Catarina, which is characterized by a pronounced zonal variation in altitude. The coastal areas are predominantly flat, while the central region of the state, in the plateau, is characterized by elevations exceeding 1,200 meters in height.

Figure 1 -Altimetric characterization based on the relief of Santa Catarina.



Source: Jesus (2013).

2.1.5 Other Global Influences

The increase in deforestation in the Amazon in recent years and the alarming changes in the planet's temperature and regional and global climate may be associated with the declining trends in precipitation patterns in Santa Catarina, which accounted for 70% of the cases studied.

Several studies show that the increase in deforestation has led to a decrease in humidity in the Amazon region. As a consequence, the moisture brought by winds from northern Brazil to the South is reduced. Based on this, rainfall patterns across Brazil are impacted. However, this trend will not only affect Brazil, as confirmed by studies indicating that these climatological and environmental changes and consequences will have effects on both local and global scales (DURIEUX et al., 2003; D'ALMEIDA et al., 2007; DAVIDSON et al., 2012; COSTA & PIRES, 2010; IPCC, 2021).

The study of the effects of El Niño and La Niña is generally introduced as a consequence of the increase or decrease in global rainfall patterns. In southern Brazil, it affects the entire rainfall pattern and consequently the state of Santa Catarina, altering atmospheric pressure and influencing the wind pattern responsible for bringing moisture to the southern region of Brazil.

During El Niño episodes, high-level jets such as the Subtropical Jet and the Polar Jet may be affected in their position and intensity. These wind currents have a direct impact on regional atmospheric circulation and can influence the transport of moisture to southern Brazil. Depending on the intensity of these events, patterns can change dramatically. When the PDO occurs together with ENOS events, they intensify this entire process.

3. MATERIALS AND METHODS

The construction of the database for this study was defined based on the databases listed in **section 3.2**, with available data totaling up to 15 years of study. From the data, it was possible to assess precipitation patterns in the state of Santa Catarina, based on the principles of moving average analysis in relation to the 95th percentile, to obtain possible trends in precipitation patterns using the top 5% of days with the highest precipitation volume in this series.

Failures present in the series were discarded without any treatment. According to the statistical approach, it is not necessary to manipulate the data for the entire phenomenon (that is, the entire historical period); it is sufficient to obtain a consistent sample, and the conclusions are projectable to the population without loss of generalization.

The moving average is one of the techniques used in the analysis of time series, where the sequence of data is observed at regular time intervals, with the aim of smoothing out strong fluctuations that can distort the results. Particularly in the case of historical precipitation series, where large variations are common, its use is beneficial (BACK et al., 2017).

It should be noted that the main objective of this study is to analyze the variability and trends of precipitation in the state of Santa Catarina, using observational data spanning up to 15 years. We emphatically emphasize that the focus is on identifying variable patterns and emerging trends in precipitation, and not on the extensive climatic characterization of the region.

Climatological characterization, which generally requires a longer analysis period, is not the main focus of this work. Instead, emphasis is placed on understanding how precipitation has varied over the available period, with the aim of identifying recent and significant trends.

Although some regions addressed in this study have shorter historical series, the validity of the analysis is reinforced by the use of consolidated statistical techniques. The sampling of data from various institutions and diverse locations contributes to a more comprehensive and representative analysis. Despite variations in the duration of the historical series, the application of established statistical methods such as moving averages and percentile 95 analysis allows for an effective assessment of precipitation variability and trends. Such statistical techniques are particularly beneficial for smoothing out strong oscillations and highlighting underlying patterns, which is fundamental in time series of precipitation.

Similarly, this study is distinguished by the exclusive use of observational data, avoiding the use of reanalyses or climate modeling. The choice of real and observable data ensures a concrete basis for statistical analysis, providing a direct and unmediated view of climatic patterns. At the same time, the use of methodologically validated and robust statistical resources ensures the reliability and relevance of the conclusions drawn from the study.

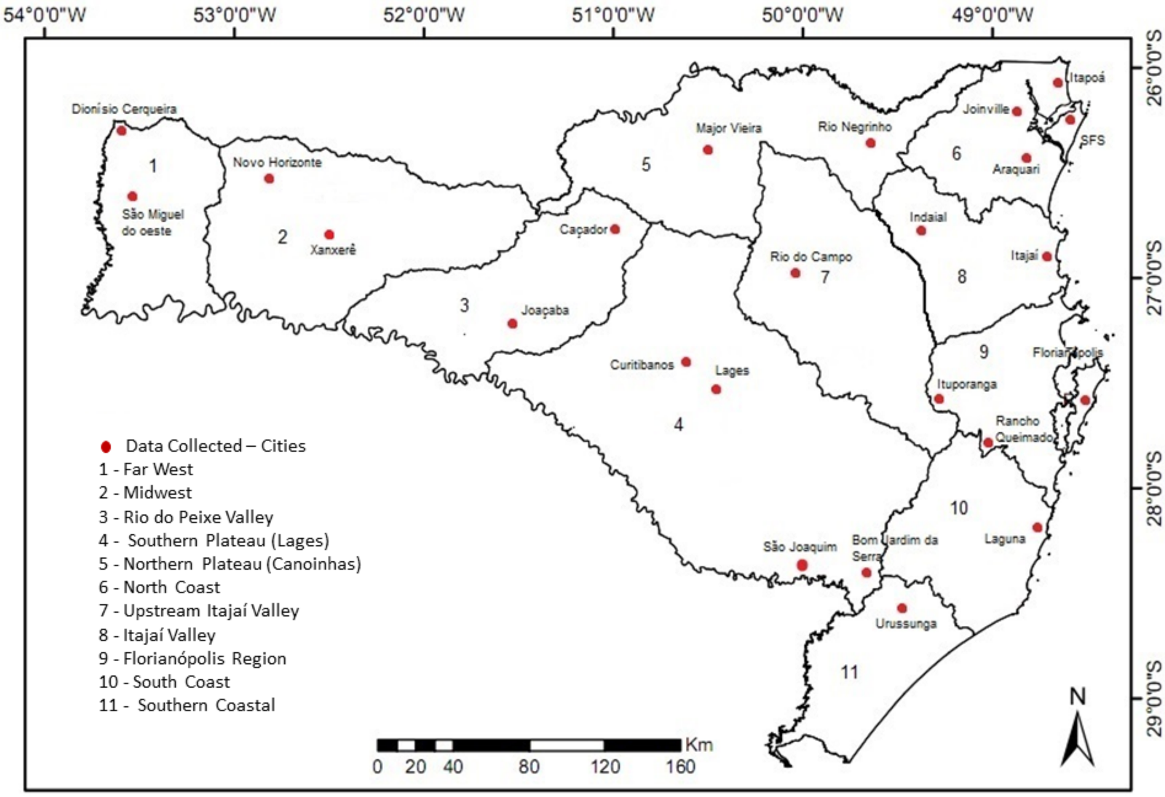
While the research has strong statistical-methodological rigor, it is important to indicate the inherent limitations of this study. One of them is the dependence on data provided by monitoring institutions, which implies that the extent and integrity of the historical series are beyond the control of the researchers. This limitation is recognized and accepted as part of the nature of working with observational data and conjectures proposed through methods and statistical tests.

3.1. Study area

The study area of this work comprised the 11 mesoregions of the state of Santa Catarina (Figure 2): Far West, Midwest, Rio do Peixe Valley, Southern Plateau (Lages), Northern Plateau (Canoinhas), North Coast, Upstream Itajaí Valley, Itajaí Valley, Florianópolis Region, South Coast, Southern Coast, according to the meteorological division of the State Civil Defense (2021) and the division of the study by Back et al. (2017).

From the mesoregions, a total of 24 pluviometric stations were selected in different municipalities. Thus, the entire state of Santa Catarina was included in this analysis. The locations of the municipalities according to their coordinates and the time series period for each analyzed pluviometric station are shown below (Figure 2).

Figure 2 -Location of the 11 mesoregions of the state of Santa Catarina and the location of the 24 municipalities for the collection of data from the pluviometric stations (The municipalities are described in Table 1).



Source: Revised by the author cited in Back et al., 2020.

3.2. Data collection

For this study, data provided by the meteorological stations of the Center for Weather Forecast and Climatic Studies (CPTEC), the National Water Agency (ANA), the National Institute of Meteorology (INMET), the National Center for Monitoring Alerts and Natural Disasters (CEMADEN), and the Center for Environmental Resources and Hydrometeorology Information of Santa Catarina (EPAGRI/CIRAM) were used. Historical series were obtained from the year 2006 to the year 2020, totaling 15 years of pluviometric data, as described in the data availability table (Table 1).

To obtain the results of this study, an analysis was conducted considering 24 municipalities and taking into account the time series according to the seasons (spring, summer, autumn, and winter), thus totaling 96 trend scenarios. The analysis periods correspond to a total maximum time series of 15 years of pluviometric data, covering the periods from 2006 to 2020, according to the data availability in the respective stations, as described in Table 1.

Table 1- Location of the 24 municipalities of the meteorological stations and composition of the analyzed time series period.

MUNICIPALITY	LONGITUDE	LATITUDE	ALTITUDE (approximate)	HISTORICAL SERIES PERIOD
Araquari	-48,99°O	-26,35°S	9m	01/07/2007 a 31/12/2020
Caçador	-51,01°O	-26,78°S	920m	01/04/2008 a 30/06/2020
Curitibanos	-50,58°O	-27,27°S	987m	01/03/2008 a 30/06/2020
Dionísio Cerqueira	-53,61°O	-26,19°S	830m	01/06/2008 a 30/06/2008
Florianópolis	-48,82°O	-27,38°S	3m	01/02/2003 a 30/06/2020
Indaial	-49,23°O	-26,34°S	64m	01/08/2006 a 30/06/2020
Itajaí	-48,87°O	-26,33°S	2m	01/07/2010 a 30/06/2020
Itapoá	-48,84°O	-26,30°S	18m	01/07/2007 a 30/06/2020
Ituporanga	-49,61°O	-27,37°S	370m	01/04/2008 a 30/06/2020
Joaçaba	-51,51°O	-27,16°S	522m	01/10/2007 a 30/06/2020
Joinville	-48,79°O	-26,24°S	4m	01/07/2007 a 31/12/2007
Lages	-50,32°O	-27,29°S	916m	01/12/2014 a 30/06/2020
Laguna	-48,60°O	-28,18°S	2m	01/06/2008 a 30/06/2020
Major Vieira	-50,33°O	-26,24°S	786m	01/03/2009 a 30/06/2020
Bom Jardim	-49,63°O	-28,33°S	1245m	01/07/2007 a 30/06/2020
Novo Horizonte	-52,83°O	-26,44°S	710m	01/10/2008 a 30/06/2020
Rio do Campo	-50,13°O	-26,92°S	570m	01/04/2008 a 30/06/2020
Rancho Queimado	-49,01°O	-27,67°S	810m	01/06/2016 a 30/06/2020
Rio Negrinho	-49,52°O	-26,25°S	790m	01/04/2008 a 30/06/2020
São Francisco do Sul	-48,98°O	-26,25°S	1m	01/07/2007 a 31/12/2007
São Joaquim	49,99°O	-28,30°S	1360m	01/05/2008 a 30/06/2020
São Miguel do Oeste	53,51°O	-26,45°S	720m	01/04/2008 a 30/04/2020
Urussanga	49,32°O	-28,51°S	49m	01/06/2008 a 30/04/2020
Xanxerê	52,40°O	-26,86°S	800m	01/04/2008 a 30/04/2020

Fonte: Compiled by the authors (2023).

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3.3. Data processing and analysis

The collected data were processed using the Matlab and Minitab software with functionality that allows appropriate statistical treatment. Initially, daily precipitation moving averages were analyzed based on historical series. Subsequently, their variations were examined and classified into frequency or recurrence classes. Finally, the precipitation trends were determined by municipality/region.

From these results, extreme events were identified, and then the data were determined based on the quantile technique, adopting the 95th percentile. Then, the 95th percentile was calculated for a 50-day moving average, identifying the top 5% of the rainiest days for each season (summer, winter, fall, and spring). To establish the seasons, only the months corresponding to each season were considered (December to March; June to September; March to June; and September to December).

Changes in precipitation due to climate change have led to a significant increase in extreme drought and rainfall events (COSTA et al., 2015). Therefore, it is essential to use tools that allow the verification of climatological trends and/or variations. According to Santos and Portela (2007), the Mann-Kendall test is a non-parametric test (Mann, 1945; Kendall, 1975), recommended by the World Meteorological Organization (WMO), for assessing trends in time series of environmental data.

The statistical test is based on:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign\,(\times_i - \times_j)$$

Where: xj represents the estimated data from the sequence of values, n is the length of the time series, and the sign (xi - xj) is -1 for (xi - xj) < 0, 0 for (xi - xj) = 0, and 1 for (xi - xj) > 0. The Mann-Kendall test is commonly used to assess trends in time series of environmental data with high efficiency.

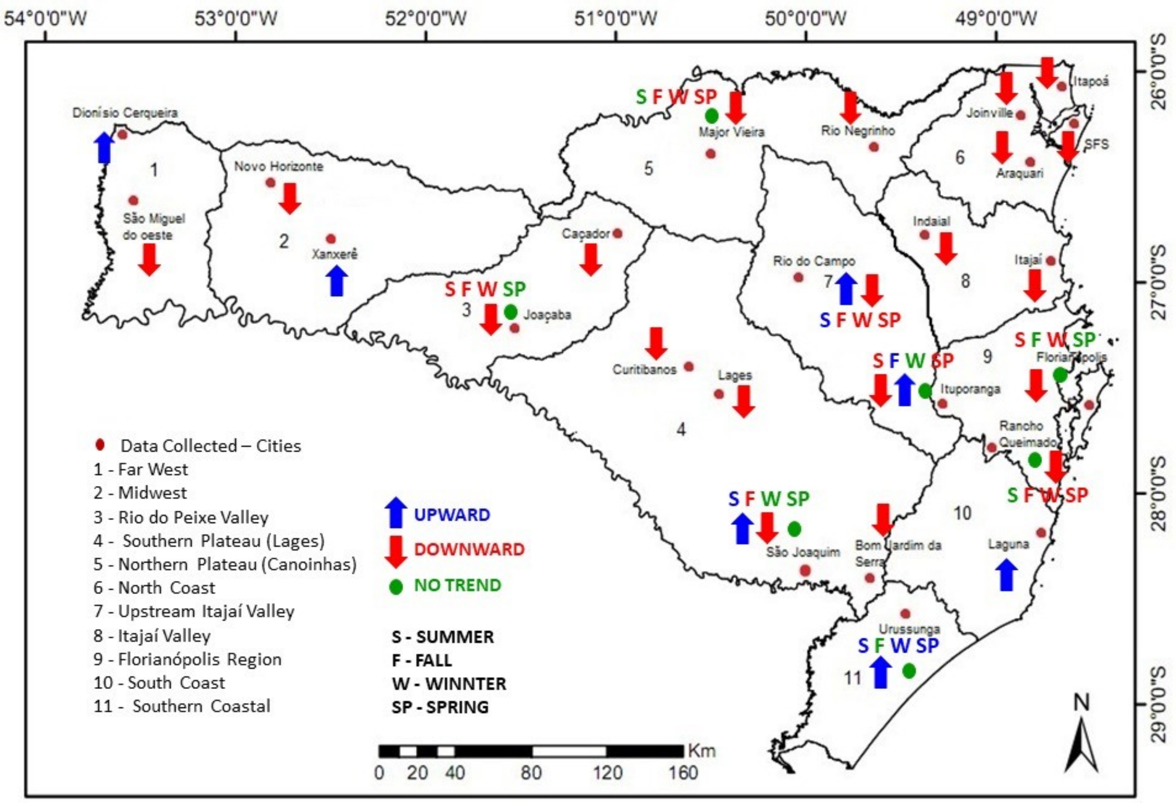
According to Salviano et al. (2016), the method is based on either rejecting or not rejecting the null hypothesis (H0) that there is no trend in the data series, using a significance level (α). In this two-sided test, a significance level of 5% was considered, meaning that the null hypothesis of no trend was rejected when the p-value was lower than the α level.

Therefore, the significance level can be interpreted as the probability of committing a Type I error (rejecting H0 when it is true).

3. RESULTS AND DISCUSSION

From the survey, the following results were obtained regarding precipitation patterns in the four seasons: a descending trend was observed in 70% of cases (67 cases), an ascending trend was observed in 19% of cases (18 cases), and no trend was observed in 11% of cases (11 cases), as seen in Figure 3.

Figure 3 -Result of the trend pattern for the 24 Meteorological Stations in the 11 mesoregions during the analyzed time series period. *Arrows without station information indicate that all stations had the same pattern*.



Source: Compiled by the authors (2023).

Through the results obtained from the Mann-Kendall test, the majority of the analyzed municipalities show significant trends, with a predominant **descending trend** (70%). This means that in the top 5% of rainy days, the trend is for less rainfall. In Table 2, for example, we can visualize the obtained results of precipitation trends on the rainiest days for each season of the year, in each of the 11 mesoregions analyzed, based on the 50-day moving average of precipitation, using the 95th percentile.

Table 2- Trend of extreme rainfall by season of the year. *Null (100%) indicates a trend of both increase and decrease.

Classification	Mesoregion	Summer	Autumn	Winter	Spring
1	**Far West**	Null (100%)*	Null (100%)*	Null (100%)*	Null (100%)*
2	**Midwest**	Null (100%)*	Null (100%)*	Null (100%)*	Null (100%)*
3	**Rio do Peixe Valley**	Decline (100%)	Decline (100%)	Decline (100%)	Decline (66%) Null (33%)
4	**Southern Plateau (Lages)**	Decline (66%) Increase (33%)	Nulo (66%) Decline (33%)	Decline (66%) Null (33%)	Decline (66%) Null (33%)
5	**Northern Plateau (Canoinhas)**	Decline (50%) Null (50%)	Decline (100%)	Decline (100%)	Decline (100%)
6	**North Coast**	Decline (100%)	Decline (100%)	Decline (100%)	Decline (100%)
7	**Upstream Itajaí Valley**	Null (100%)*	Null (100%)*	Declínio (50%) Null (50%)	Decline (100%)
8	**Itajaí Valley**	Decline (100%)	Decline (100%)	Decline (100%)	Decline (100%)
9	**Florianópolis Region**	Decline (50%) Null (50%)	Decline (50%) Null (50%)	Decline (100%)	Decline (50%) Null (50%)
10	**South Coast**	Increase (100%)	Increase (100%)	Increase (100%)	Increase (100%)
11	**Southern Coast**	Increase (100%)	Increase (100%)	Increase (50%) Null (50%)	Increase (100%)

Source: Compiled by the authors (2023).

From the analysis of the results, despite the predominance of the descending trend in the data, indicating a decrease in rainfall recurrence in the top precipitation days over the years, confirming a decrease in rainfall for these regions in the state of Santa Catarina. However, the opposite trend of decrease was diagnosed in certain locations. In these places, the results suggest an increasing trend in precipitation over the years. This phenomenon occurred in the summer season in mesoregion 4 (Southern Plateau) and for all seasons in mesoregions 10 (South Coast) and 11 (Southern Coast).

According to the results, there was a notable variation in the rainfall pattern within the state of Santa Catarina. Similar to the studies by Back et al. (2012), Reboita et al. (2010), and Antunes and Constante (2016), which identified that rainfall is lower in the coastal plain, and the highest rainfall values are observed near the slope of the Serra Geral and at high latitudes. For example, the municipalities of São Joaquim, Dionísio Cerqueira, and Xanxerê demonstrated ascending patterns in rainfall trends over the years.

It can be observed that in coastal regions, such as Laguna and Urussanga, there is an upward trend pattern in their rainfall indices, only in winter for Urussanga the pattern showed the absence of trends. The cities are located in the southern coastal and far southern coastal sectors, which are directly adjacent to the mountainous region of the State, representing a mountainous area with elevations close to 1000m. High altitudes near the coastal environment (moisture accumulation) can influence the rainfall pattern in this region, causing orographic rainfall that can be added to the rainfall pattern from other systems, as well as the "lestadas" that occur and directly influence coastal regions.

The coastal region of Santa Catarina, according to Nimer (1971), shows a not-so-high and poorly distributed rainfall height, which presents a significant difference between the more and less rainy periods. The rainiest period occurs in the summer months, and the driest in winter, representing a characteristic seasonal rhythm of tropical climate regions, a factor linked to proximity to the ocean. Therefore, patterns of upward trends in the summer season can be observed in the municipalities of Rio do Campo, São Joaquim, Urussanga, Laguna, Xanxerê, and Dionísio Cerqueira.

According to Back et al. (2012), in the narrow area of the Santa Catarina coast, the maximum rainfall occurs in the summer, while the minimum index is most often recorded in winter and, secondarily, in autumn, as observed in municipalities near the Santa Catarina coast such as Urussanga and especially in Ituporanga, which showed an upward trend only in autumn. Typically, when the SACZ (South Atlantic Convergence Zone) is influencing the Southern Region of Brazil, pronounced rainfall patterns occur in the northern region of Santa Catarina, leading to flood events that are characteristic of many periods in this region (QUADRO et al. 2012; DEFESA CIVIL, 2022).

In mountainous regions, such as the municipalities of Rio Campo and São Joaquim, the upward trend was found in the summer, and this can be understood through the research of Degola (2013). The author was able to identify month by month (in the period from 1989 to 2010) that the latitudinal variation and the central pressure of the SAH (Subtropical South Atlantic High) showed a seasonal behavior. In latitudes further north, higher pressures were obtained in winter months, and in latitudes further south, higher pressures were in summer, resulting in higher rainfall indices. Quadro et al. (2012) also described the SAH as responsible for bringing humidity in the summer months along with moisture from the Amazon region.

Considering all seasons, the SAH may have influenced the upward patterns in the municipalities of Laguna and Urussanga, which experienced an increase in rainfall patterns over the years, and Ituporanga, which showed upward averages in the fall. This result supports the work of Rodrigues (2011), which describes that the SAH is responsible for the winds in the eastern quadrant that bring moisture to the region.

These constant wind belts that occur at subtropical latitudes are of great importance to this region. Ito and Ambrizzi (1999), who analyzed the SAH from 1977 to 1996 in the southern region of Brazil using reanalysis data for the months of June, July, and August (winter), showed that the greatest longitudinal displacements occurred throughout the month of July and on some days at the beginning and end of August. A slightly greater latitudinal displacement among the three months was observed in August. In general, winter data showed null or declining trends, meaning that in winter, the SAH may be influencing the decrease in rainfall trends in the state, in contrast to summer, which tends to cause an increase in certain regions.

It can be observed in the municipalities of Dionísio Cerqueira, Laguna, and Xanxerê a pattern of upward trend in all seasons over the years, meaning that over the years in the rainiest periods, it is raining increasingly. The high altitudes of Dionísio Cerqueira and Xanxerê and the proximity to the ocean in the municipality of Laguna may be the main reasons for the increased precipitation in these regions. According to the study by Baptista, Severo (2018), between the western region and the Santa Catarina Plateau where Dionísio Cerqueira and Xanxerê are located, the annual total precipitation compared to the coast is higher, between 1,900 and 2,000 mm (West) and between 1,600 and 1,700 mm (Santa Catarina Plateau).

However, these are regions with precipitation levels significantly higher compared to other areas.

Considering the annual climatology of precipitation, in the study by Baptista and Severo (2018), it is observed in the extreme northeast of Santa Catarina an average rainfall between 2,600 and 2,700 mm. Considering this climatological regime, the northern coast of Santa Catarina has shown patterns of declining precipitation over time. In other words, even with a steep drop in altitude compared to the coastal plain, which promotes orographic rainfall due to the abrupt wind displacement, the intensity of rainfall over the years has still decreased.

Other systems may also be associated with this pattern of uneven distribution in the state of Santa Catarina, such as LLJs, which is also responsible for transporting moisture from the Amazon Basin and tropical Atlantic to the southern region of Brazil, as well as SPH. According to authors like Reboita et al. (2010 and 2012) and CAMPOS, SANTOS (2007), this system is the main atmospheric system influencing the precipitation regime over the southern and southwestern regions of South America. It brings moisture from other regions to the south, acting as a driving force for precipitation in the Santa Catarina region.

These authors also describe that the maximum annual precipitation in the southwestern region occurs in winter, while the minimum occurs in summer. In the southernmost part, precipitation is relatively uniform throughout the year. However, most regions showed patterns of decreasing precipitation throughout the seasons, especially in summer and autumn for some regions. For the majority of regions, the precipitation pattern in winter was either descending or without a clear trend.

The Mesoscale Convective Systems (MCSs) can be responsible for a significant portion of observed surface precipitation in the summer in Rio do Campo, São Joaquim, Urussanga, Laguna, Dionísio Cerqueira, and Xanxerê, causing an increase in precipitation patterns (from southwest to northeast). In winter, in São Joaquim and Ituporanga, this influence is neutral in the patterns (with a tendency of eastward winds in Santa Catarina).

With a series of climatic records worldwide (IPCC and WMO), the increase in intense climate events such as extratropical cyclones is being increasingly documented in the state. However, in most regions, a clear relationship with the increase or decrease in trend patterns was not found. On the other hand, the effect of changes leading to drought can be concerning, with a 70% downward trend, especially in a state that is highly productive in various agricultural products. In the long term, this pattern may have a significant impact on production.

Studies conducted by Freitas and Oliveira (2017) indicate that the State of Santa Catarina, especially in the western region, failed to demonstrate a statistically significant relationship between drought and dry periods and phenomena such as El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), or Antarctic Oscillation (AAO). However, atmospheric blocking events emerged as a phenomenon related to drought and dry periods, considering the climatic and meteorological analysis of the dynamics of air masses and atmospheric systems in the western region of Santa Catarina.

The state of Santa Catarina is characterized by diversity in its landscapes and the existing processes that affect the region. Thus, it can be understood that the systems do not operate in isolation but rather interact together. Therefore, the topography of the state's region, in conjunction with atmospheric and meteorological systems, shapes the precipitation pattern across the entire state.

In a more detailed examination of precipitation in the region, it was possible to observe significant spatial and temporal variability, as it was noted that on days with the highest intensity of rainfall, the total volume of precipitation has decreased over time. This phenomenon may be intrinsically linked to global climate changes, which affect atmospheric patterns in various ways.

Climate change, driven by factors such as the increase in greenhouse gas emissions and changes in land use, can alter atmospheric circulation patterns and moisture distribution. This can result in changes in precipitation patterns, such as an increase in the frequency of extreme rainfall events interspersed with longer periods of drought. Such changes in climatic patterns not only affect the amount of rain but also its intensity and temporal distribution, which can also have significant implications for agriculture, water resource management, and urban planning in Santa Catarina.

In studies such as Nimer (1971), Back (2012), and Gonçalves and Back (2018), which investigated precipitation patterns in the Southeast (SE) region of Brazil, it can be compared that the results of this research are similar to those of the SE region, where there is an increase in rainfall in the summer, no trend in the spring, and a reduction in the fall and winter. This leads to a decrease in the regularity of precipitation distribution throughout the year.

4. CONCLUSION

In general, there was observed a predominance of decreasing trend in the precipitation volume on the rainiest days in Santa Catarina, which indeed explains the increasingly frequent occurrences of drought in the state. For the few regions where an ascending trend was observed, this is mainly related to being high-altitude regions or in the far southern coastal areas. The occurrence of climatic phenomena such as SAH, MCSs, SACZ, LLJs, as well as ENOS, PDO, and other influences from marine complexity that alter coastal climates, are responsible for shaping the rainfall pattern in the state, and other systems may indirectly influence these processes.

However, this study aimed to understand the variability of rainfall trends in the state, without more detailed and significant studies of their potential causes. Nevertheless, it can be understood that MCSs and LLJs, combined with the marine system bringing moisture to the state, and other systems responsible for the distribution and trapping of moisture within the state, play a role in this pattern.

Santa Catarina features diverse terrains, and as a consequence, precipitation patterns exhibit natural variability. The combination of various influencing systems in the distribution of the state's rainfall pattern, as demonstrated by this study, shows spatial and temporal variability. Moreover, there is a predominant pattern of decreasing trends in precipitation, which may be directly related to global climate changes.

Changes in precipitation, such as annual reductions, can have a significant impact on economic activities in general, particularly affecting agribusiness and electricity generation. In Brazil, hydropower plays a major role in the energy matrix. The current reality includes experiencing a water crisis, leading to the operation of thermal power plants, resulting in a significant increase in energy costs and affecting other sectors of the economy. It is crucial to emphasize the importance of monitoring and conducting further studies to determine the cause-and-effect relationships of precipitation patterns in the state.

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