Mercator, Fortaleza, v. 22, e22030, 2023. ISSN:1984-2201

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ARTICLE

# EFFECT OF OROGRAPHY ON RAINS THROUGH THE ANALYSIS OF CLIMATE INDEXES IN THE WESTERN PLATEAU REGION OF PAULISTA

https://doi.org/10.4215/rm2023.e22030

Santos, B. C. [a*] - Sanches, R. G. [b] - Neves, G. Z. F. [c]
Souza, P. H. [d]

(a) PhD in Environmental Engineering Sciences
**ORCID:** https://orcid.org/0000-0001-8218-6803. **LATTES:** http://lattes.cnpq.br/3575388027991557.
(b) PhD in Environmental Engineering Sciences
**ORCID:** https://orcid.org/0000-0003-2471-5070. **LATTES:** http://lattes.cnpq.br/2395726310692375.
(c) PhD in Environmental Engineering Sciences
**ORCID:** https://orcid.org/0000-0002-3952-8238. **LATTES:** http://lattes.cnpq.br/7502283592528073.
(d) PhD in Environmental Engineering Sciences
**ORCID:** https://orcid.org/0000-0003-0399-9123. **LATTES:** http://lattes.cnpq.br/1955052278935490.

**Article history:**
Received 17 December, 2020
Accepted 8 Obtober, 2023
Published 25 October, 2023

**(*) CORRESPONDING AUTHOR**
**Address:** Department of Hydraulics and Sanitation, University of São Paulo, São Paulo, 05508-010, SP, Brazil.
**E-mail:** phsouza31@hotmail.com

## Abstract

The present research analyzed the effect of relief on the variability and extremes of rainfall in the central portion of the state of São Paulo, using 31 surface rainfall gauges. For this, it applied the methods of filling gaps (Regional Weighting), rainfall classification (Rain Anomaly Indexes) and precipitation indexes (Rclimdex). Through the methods used, it was verified that the pluviometric variability showed in the admitted parameters of normality with about 17% of the years, in the wet parameters about 18% of the years and in the dry parameters about 15% of the years of the historical series of 1979 -2017. In addition, it was found that among the thirty-eight years of the historical series, the year 1983 was the wettest and the year 2014 the driest. As these were two distinct representative years (wet and dry) of rainfall, it was noted through the rainfall indexes, they showed the strength of the orographic effect in the intensification of rainfall in volume and number of extreme days in the higher regions located in the southern portion of the study area. Therefore, due to the altitude that manifests itself associated with a sharp altimetric difference that establishes a high slope, which the central region of the state of São Paulo has, its morphological characteristics play an important role with the process of intensification of the rains, mainly in the years rainy.

**Keywords:** Precipitation; Rainfall anomaly index; Extreme years; RClimdex; Relief.

## Resumo / Resumen

### EFEITO DA OROGRAFIA NAS CHUVAS POR MEIO DA ANÁLISE DE ÍNDICES CLIMÁTICOS NA REGIÃO DO PLANALTO OCIDENTAL PAULISTA

A presente pesquisa analisou o efeito do relevo na variabilidade e nos extremos das chuvas, na porção central do estado de São Paulo, utilizando 31 postos pluviométricos de superfície. Para isso, aplicou os métodos de preenchimento de falhas (Ponderação Regional), classificação das chuvas (Índices de Anomalia de Chuva) e índices de precipitação (Rclimdex). Por meio dos métodos utilizados, verificou-se que a variabilidade pluviométrica mostrou nos parâmetros admitidos de normalidade com cerca de 17% dos anos, nos parâmetros úmidos cerca 18% dos anos e nos parâmetros secos cerca de 15% dos anos da série histórica de 1979-2017. Além disso, verificou-se que entre os trinta e oito anos da série histórica, que o ano de 1983 foi o mais chuvoso e ano de 2014 o mais seco. Por tratar-se de dois anos representativos distintos (úmido e seco) de pluviosidade, notou-se por meio dos índices de chuva, evidenciaram a força do efeito orográfico na intensificação das chuvas em volume e número de dias extremos nas regiões mais elevadas localizadas na porção meridional da área de estudo. Portanto, em razão da altitude que se manifesta associada a um acentuado desnível altimétrica que estabelece uma declividade elevada, que a região central do estado de São Paulo possuí, suas características morfológicas cumprem um papel importante com o processo de intensificação das chuvas, principalmente nos anos chuvosos.

**Palavras-chave:** Precipitação; Índice de anomalia de chuva; Anos extremos; RClimdex; Relevo.

### EFECTO DE LA OROGRAFÍA SOBRE LAS LLUVIAS A TRAVÉS DEL ANÁLISIS DE ÍNDICES CLIMÁTICOS EN LA REGIÓN DEL MESETA OCCIDENTAL DE PAULISTA

Esta investigación analizó el efecto del relieve sobre la variabilidad y los extremos de las precipitaciones, en la parte central del estado de São Paulo, utilizando 31 estaciones pluviométricas de superficie. Para ello aplicó los métodos de llenado de vacíos, clasificación e índices de precipitación. A través de estas aplicaciones se verificó que la variabilidad de las precipitaciones de los años de la serie histórica 1979-2017 mostró normalidad en los parámetros aceptados en alrededor del 17%, en los parámetros húmedos alrededor del 18% y en los parámetros secos alrededor del 15%. Además, se encontró que entre los treinta y ocho años, el año 1983 fue excepcionalmente el más húmedo y el año 2014 fue el excepcionalmente más seco. Al tratarse de dos años distintos representativos (húmedo y seco) de precipitaciones, se observó la influencia del efecto orográfico en la intensificación de las precipitaciones en volumen y número de días extremos en las regiones más altas ubicadas en la porción sur del área de estudio. Por lo tanto, debido a la altitud que está asociada a un pronunciado desnivel altimétrico que establece una alta pendiente, que tiene la región central del estado de São Paulo, sus características morfológicas juegan un papel importante en el proceso de intensificación de las lluvias, especialmente en los años lluvioso.

**Palabras-clave:** Precipitación; Índice de anomalías de lluvia; Años extremos; RClimdex; Alivio.

# INTRODUCTION

Rain has its temporal and spatial variations arising from climate fluctuations, as they contribute to the delimitation of atmospheric patterns and help, due to the severity of the impacts caused by extreme events, with the planning of economic activities.

The analysis of rainfall variability on a regional scale, especially in the tropical climate, has rainfall as the input of water volume through the supply of water resources on the surface, making any atmospheric change that affects the rainfall pattern, reducing its volume or distribution to the surface, a throughout the year. (RIBEIRO et al, 2014).

Even though the atmosphere has been presented throughout human history as a domain of regularity, it is in a process of reordering and changes, due to human actions that permanently modify its composition, on a local scale, such as the change in land use that contributed to the change promoted in the surface albedo.

Unfortunately, this situation causes serious problems for the population and ecosystems established in a given area, which is not prepared to deal with the consequences of extreme events that result in downpours (SANCHES et al., 2018) and floods (ABREU et al., 2017) and drought (SETH et al., 2015).

As rains derives from atmospheric phenomena that interact with the earth's surface through the exchange of heat and humidity (GOUVEA et al., 2018), any change that promotes this reordering in its habituality way can cause a regional and local reorganization of precipitation that comes to redefines its spatial and annual distribution, as well as extreme trends in its daily volume (ALVES et al., 2010; SANCHES et al., 2022).

Therefore, understanding the temporal and spatial behavior of precipitation in tropical areas is extremely relevant, considering its impact on urban and rural dynamics and, thus, on strategic planning. From the same perspective, orography is a factor that can contribute to this process triggered by the atmosphere, presenting spatial influences through the regional particularities of each topographic and altimetric surface.

Paying attention to the severity of this situation, which is being established with a new climatic pattern of extreme events on different parts of the planet, the present study sought to verify the orographic effects on the precipitation pattern during the 38-year historical period (1979-2017) in central region of the state of São Paulo, southest of Brazil.

# METODOLOGY

## CHARACTERIZATION OF THE STUDY AREA

The study area has approximately 9,151.7 km² and is partially inserted within the Corumbataí Environmental Protection Area (APA), integrating a total of 17 municipalities in São Paulo. The region has undergone a major transformation in geographic space in the last 35 years, in particular the conversion of pastures to sugarcane monoculture, due to the characteristics of the soil and climate and also due to the strategic position that the region has for activities agricultural (BUENO et al., 2022).

In geomorphological terms (Figure 1) of the State of São Paulo, the area is located between the transition of the Western Plateau, formed in a large area of smooth relief composed of hills, low hills and mountains, with an average altitude of approximately 900m and the Paulista Peripheral Depression, presenting a predominantly hilly and smooth relief, as well as isolated hills and mountains with levels of approximately 600 meters above sea level. (ROSS; MOROZ, 1996).

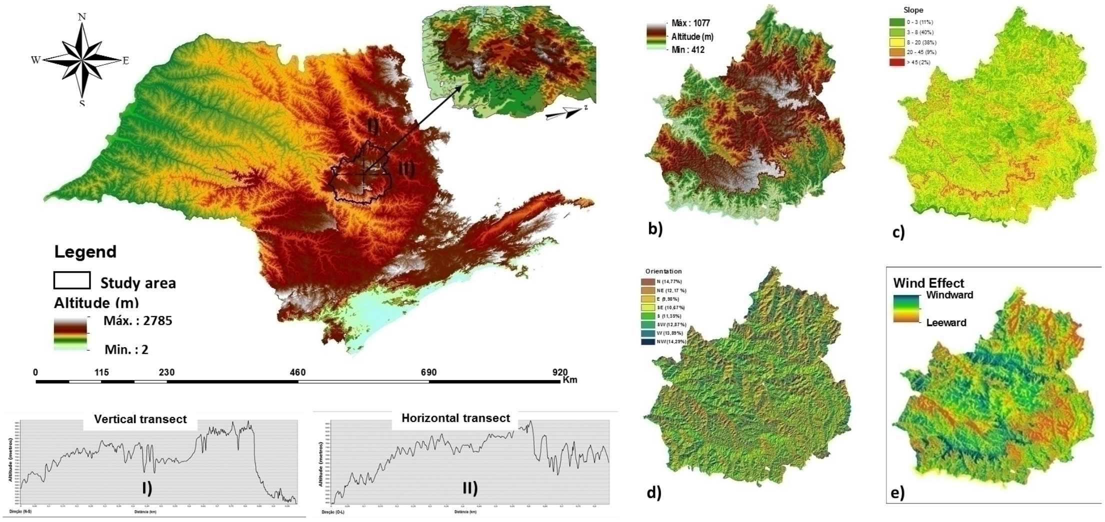


Figure 1 - (a) Location of the study area over the hypsometric map of São Paulo and the transects (I and II) of the relief, represented by the white dashed lines, in the vertical profile in the N-S direction and the horizontal profile in the W-E direction. (b) Digital elevation model; (c) Slope of the land; (d) Orientation of the slopes; (e) Orientation of the windward (damp) and leeward (dry) slopes. Source: Prepared by the authors.

Other geomorphological characteristics are the slope, the orientation of the relief slopes and the orientation of the windward and leeward slopes. The mountain located in the southern part of the map presents relevant morphological particularities due to its altitude of 1100 meters at its maximum peak, longitudinal extension in the East-West direction, steep slope above 45% and orientation of the scarps facing the South, North and East. Therefore, this formation has a high permeability coefficient, favoring infiltration, which occurs mainly in the Guarani Aquifer recharge region.

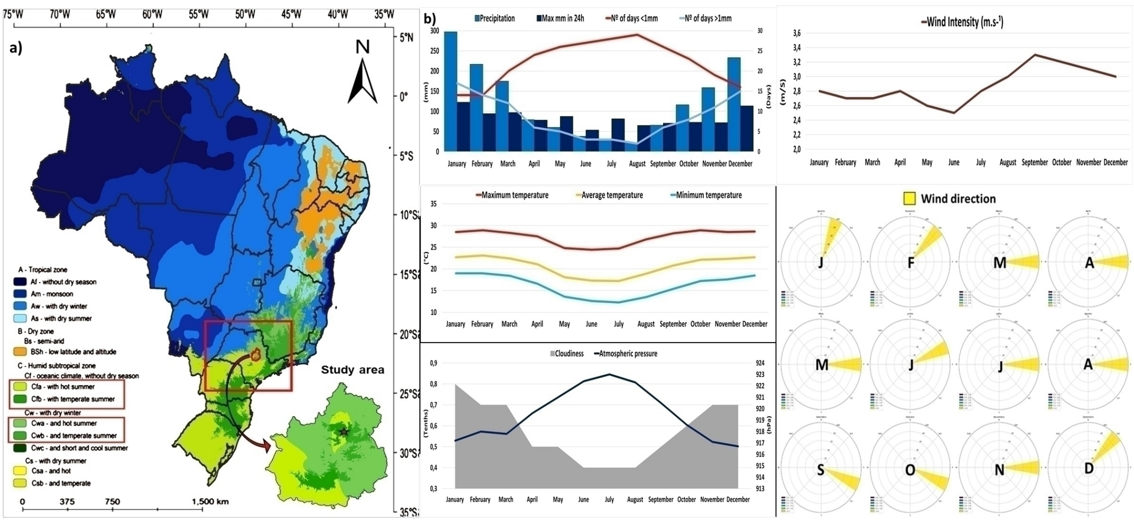


Figure 2 - (a) Location of the study area in the State of São Paulo within the Köppen climate classification for Brazil; (b) Climatological normal of São Carlos-SP (1991-2020). Source: Adapted from Alvares (2013) and INMET (2020).

Among the climate types in Brazil (Figure 2a), according to the Köppen classification, the study area has the Cwb climate type (ALVARES, et al., 2013). According to Monteiro (1973), the climate pattern in the region represents an important characterization in the rainfall regime, which is seasonally divided into two periods, with a wet season (October to March) and a dry season (April to September). This represents an important characterization in the climate pattern, as demonstrated by the climate elements (temperature, air humidity, precipitation, consecutive wet and dry days, atmospheric pressure, cloudiness, wind speed and direction) presented in Figure 2b.

Monteiro (1973) reports that, as it is a plateau region, on the edge of the São Paulo Western Plateau, where the Cuestas relief is found, there are higher sections that contribute to a slight increase in the amount of precipitation due to orographic effect. For Tavares et al. (1985), there is a contrast in the border strip of the São Paulo Western Plateau between the north and south fronts of the Cuestas. This is due to the variation in annual insolation received in each of them, with the southern escarpment being colder and more humid than the northern one.

The atmospheric pattern of rainfall in the study area is associated with the dynamic interaction between tropical and extratropical atmospheric systems, controlled by the advance of polar frontal systems on the South American continent (Figure 3), which changed the configuration of SACZ episodes (South Atlantic Convergence Zone) and, therefore, generating conditions of atmospheric instability and high volumes of precipitation over the Center-South region of Brazil (REBOITA, et al., 2012; FERREIRA; REBOITA, 2022).

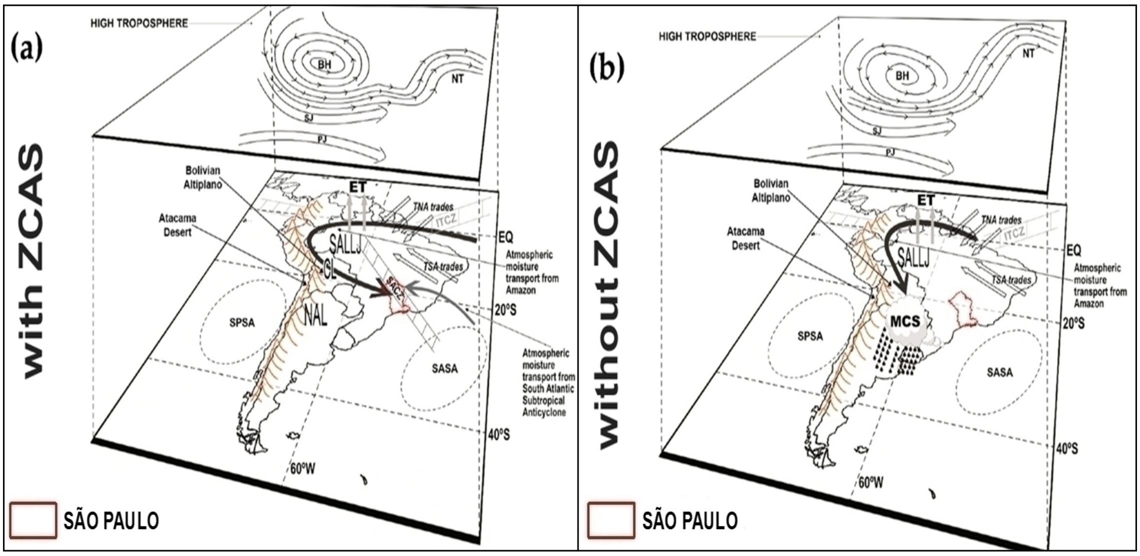


Figure 3 - Scheme of important atmospheric circulation features over the South American region, considering events with (a) and without (b) ZCAS over the state of São Paulo. Source: Adapted Ferreira & Reboita (2022).

Therefore, this pattern represents an important and punctual aspect of seasonal variation in the distribution of rainfall, in view of the pattern of regional atmospheric circulation that makes up the studied area, in view of the eventuality of a tendency for exceptional episodes to occur in the region (SANCHES, 2022; SANTOS, et al., 2020 and 2021).

Therefore, rainfall verified through records contained in specific rainfall stations is the main strategy for understanding and outlining their links, such as frequency, peaks of variance and significance, among other statistical aspects, and their observations spatially and temporally.

## SELECTION AND PROCESSING OF RAINFALL DATA

To carry it out, the research selected and used 31 pluviometric stations containing daily data with historical series spanning 38 years (1979-2017). The data was collected on the Hidroweb online platform of the National Water Agency (ANA) and on the website of the Integrated Agrometeorological Information Center (CIIAGRO), linked to the Department of Agriculture and Supply of the state of São Paulo.

After data acquisition, the information obtained was compiled and the daily precipitation data was quantitatively processed, followed by the organization of tables and graphs on annual, monthly and daily time scales using Microsoft© Excel 2016 software.

The next stage dealt with the process of monthly filling the gaps in the data of the stations that showed failures, for this, a method was used (regional weighting) capable of estimating precipitation values in stations with data gaps. (BERTONI & TUCCI, 2009).

Equation 1 presents the regional weighting method.

$$Px = \frac{1}{3}\left(\frac{Pz}{Pzm} + \frac{Py}{Pxm} + \frac{Pw}{Pwm}\right).Pxm$$

Where Px is the station with gaps to be filled and Pz, Py and Pw are the stations with data available in the same time interval, in the vicinity of station Px. The variables Pxm, Pzm, Pym and Pwm are the average precipitation values for each station.

## ANALYSIS OF HISTORICAL RAINFALL SERIES (1979-2017)

For the analysis of rainfall, it was initially decided to establish representative classes of the total annual rainfall, for the purpose of individualizing the rainfall stations and the years representing the exceptional rhythm, which are rainier or drier in relation to the usual precipitation pattern.

In order to verify the rainfall temporal variability in the region, the RAI method (Rainfall Anomaly Indices) proposed by Rooy (1965) and adapted by Freitas (2005) was applied. This method is expressed in the formula (Equation 2):

$$IAC = 3\left[\frac{(N-\bar{N})}{(\bar{M}-\bar{N})}\right] \quad \text{(Anomalias positivas)}$$

$$IAC = -3\left[\frac{(N-\bar{N})}{(\bar{X}-\bar{N})}\right] \quad \text{(Anomalias negativas)}$$

Where N is the average annual precipitation, corresponding to the year generated from the RAI (mm), N average precipitation of the historical series (mm), M represents the ten highest precipitations of the historical series (mm) and X the average of the ten lowest rainfall in the historical series (mm). Anomalies with positive values are considered above average and negative values below average.

Using the values found, the rainfall regime was classified, according to the classes shown in Table 1.

| Rainfall Anomaly Index (RAI) Methodology | | |
|---|---|---|
| **Classification** | **Rainfall Standards (Acronyms)** | **Detour (+) or (-)** |
| **Rainy Years** | Extremely rainy (ER) | > +4 |
| | Very rainy (VR) | +2 a +4 |
| **Normal Years** | Rainy (R) | 0 a +2 |
| | Normal (N) | 0 |
| | Dry (D) | 0 a -2 |
| **Dry Years** | Very dry (VD) | -2 a -4 |
| | Extremely dry (ED) | < -4 |

Table 1 - Rain Anomaly Index – rainfall classification RAI. Source: adapted from Freitas (2005).

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## ANALYSIS OF EXTREME WET AND DRY YEARS

After classifying the years, two exceptional standard years (rainy and dry) were selected to assist in understanding regional rainfall and its interaction with the relief within the delimited studied area.

Currently, applications of climate indices for observing rainfall data stand out, such as the RClimdex script (HAYLOCK et. al., 2006; SANCHES et al., 2018; STEPHENSON et. al., 2014; ZHANG; YANG, 2004) which highlights the analysis of rainfall using different precipitation indices (Table 2).

| Index (Identification) | Index name | Definition | Observed Unit |
|---|---|---|---|
| **RX1day** | Maximum rainfall accumulated in 1 day | Maximum rainfall accumulated in a single day | **mm** |
| **RX 5 days** | Maximum accumulated rainfall in 5 days | Maximum accumulated rainfall in five consecutive days | **mm** |
| **CDD** | Consecutive dry days | Maximum number of days in which rainfall < 1 mm | **days** |
| **CWD** | Consecutive wet days | Maximum number of days when rainfall ≥ 1 mm | **days** |
| **Rnn*** | Rainy days above *nn* millimeters | Number of days above *nn* millimeters of rain | **days** |

* Admitted $RR_{ij}$ as the daily amount of precipitation on day *i* in period *j*. Thus, *nn** represents any reasonable value of daily precipitation, where the number of days is added, being: $RR_{ij} \geq nnmm$

Table 2 - Methodologies used to analyze precipitation data (Climatic Index in RClimdex). Source: adapted from Zhang and Yang (2004).

The indices are calculated using rainfall data referring to the maximum value accumulated in a single day of rain (RX1 day), the maximum value accumulated in 5 consecutive days of rain (RX5 days), the maximum number of consecutive dry days (CDD), the maximum number of consecutive wet days (CWD) and the number of days above pre-established values based on outlier detection (*Rnnn**).

Among the indices used, *Rnn* stands out for its function of representing the number of days above a defined value, highlighting its possibility of adjustments to base values, that is, being able to assign a reference value for intense or extreme events to precipitation values.

In this way, the determination of the *nn** value of rainfall with anomalous behavior was carried out using outliers. According to Chrun, Cukier and Sneeringer (2008), the determination of the outlier can be understood by an assessment of the evolution and identification of exceptional behaviors in historical data series, identifying them from the average and using (+/-) three or four standard deviations per limit (Equation 3).

$$\left\{ x_i : x_i > \bar{x} + t * \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n}} \right\}$$

The determination of such intense and extreme rainfall values presupposes the identification of abnormal situations or outliers in the data series (SANCHES et al., 2018). For the present study, the value RX46 mm (number of days above 46 mm of rain) was determined for the present study. According to Sanches (2022), the calculation of the RX46 mm index expresses atypical rainfall in relation to daily precipitation, that is, the daily outliers found within the historical period (1979-2017) of the selected rainfall stations.

After the results obtained, the information was interpolated using the IDW method (Interpolation by Inverse Distance Weighting). This method can spatially estimate a value for a given location that does not present information, by calculating the weighted average of neighboring samples by the inverse of the distance between the point to be interpolated within a neighborhood (FARIAS; FRANCISCO; SENNA, 2017). In this way, maps were generated in a GIS system to spatially visualize the effect of relief on the spatial distribution of rainfall in the central region of the state of São Paulo.

# RESULTS

## *ANALYSIS OF THE CLASSIFICATION OF ANNUAL RAINFALL*

Next, Figure 4 summarizes the total frequency of precipitation classes, in the period 1979-2017 for the 31 selected stations. The graph at the bottom of Figure 4 (a) shows the variability of annual rainfall deviation values in relation to the historical average (1968 mm). Among the years, 1983 was the year with the largest deviations and 2014 recorded the smallest deviations between the period 1979-2017.

Among the thirty-eight years of data, the classifications of annual rainfall in relation to the average (1468 mm) show that around 17% of the years were usual (N), 45% between the dry classes (D, VD and ED) and 38% between the humid classes (D, VR and ER).

The histogram in Figure 4 (b) in the lower right corner, presents the number of occurrences of rainfall classes, and the maps in Figure 4 (b) spatially display the frequency distribution of rainfall classification, among the thirty-one stations of rainfall surface. Note in the histogram in Figure 4 (b), a frequency of years in the class considered Drought (D) greater than that of Normal (N). In relation to the extremely dry (ED) and rainy (ER) classes, there is a greater recurrence of the ER class than of the ED throughout the historical series (1979-2017).

In order to visualize the spatial distribution of frequency classes, the maps show the locations where the greatest or least number of occurrences (between 0 to 11) of the seven categories (N, D, R, VD, VR, ED and ER) are concentrated rainfall for the study area. It is noted, within the usual class (N), that the central-south portion was the one that presented a greater recurrence within the average, mainly around the northern edge of Serra de Itaqueri and in the northernmost portion, it was noted a smaller occurrence of years within the rainfall pattern.

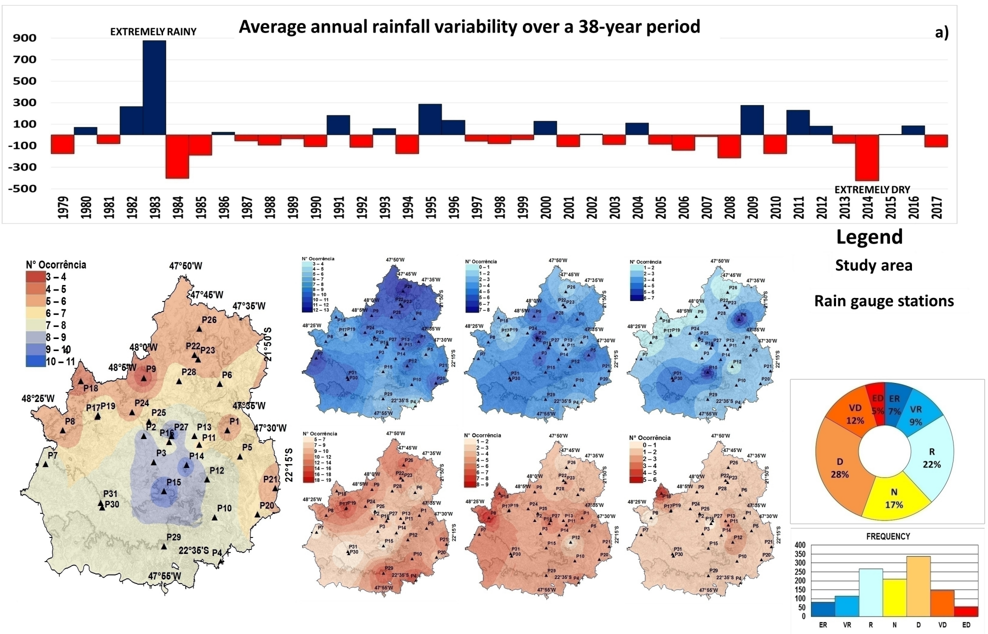


Figure 4 - a) Annual rainfall variability in the period 1979-2017. b) Spatial distribution of the number of occurrences of rainfall classes (ER, VR, R, N, D, VD and ED) of the Rain Anomaly Index (RAI) in the study area. Source: Prepared by the authors.

For the humid classes, the north and southwest portions had a more recurrent frequency of rainy years. On the other hand, the dry classes, the southwest and southeast portions show a recurring periodicity of years below the average. Finally, the extreme years (rainy and dry) showed a greater occurrence of rainy extremes in the surroundings of the mountain located to the south and a greater occurrence of dry extremes in the northwestern portion of the study area.

## ANALYSIS OF THE EXTREME YEARS OF 1983 (RAINY) AND 2014 (DRY)

From the identifying the extreme years of 1983 (rainy) and 2014 (dry) in the historical series (1979-2017), it was possible to compare rainfall differences in the study area to verify the influence of relief in different extreme years.

In Figure 5, the maps and graphs display the results comparing using the PROCTOT (a), CDD (b), CWD (c), RX1 day (d), RX5 days (e), and RX46 mm (f) indices of the rainfall distributed for the extreme rainy year of 1983 and the extreme dry year of 2014. It can be seen in the graph in Figure 5 (a), that the annual rainfall accumulation (PRCTOT) in relation to the average presented extremely different values.

In spatial terms, the maps show higher accumulations in the central-southern portion, in relation to the lower areas in the southeast for the year 1983. On the other hand, the year 2014 recorded extremely lower values, mainly in the central- north and east of the map. However, the southern portion of the map recorded volumes slightly higher than the rest of the study area, although still remaining below average.

In relation to consecutive dry days (CDD), the year 1983 indicated a shorter drought in the central-southern portion, varying between 30 and 40 days, and in the central-northern portion, between 40 and 50 days. For the year 2014, the dry period of consecutive dry days was below 45 days for most of the study area. Only the central region of the map showed a longer period of drought with a total of 70 days.

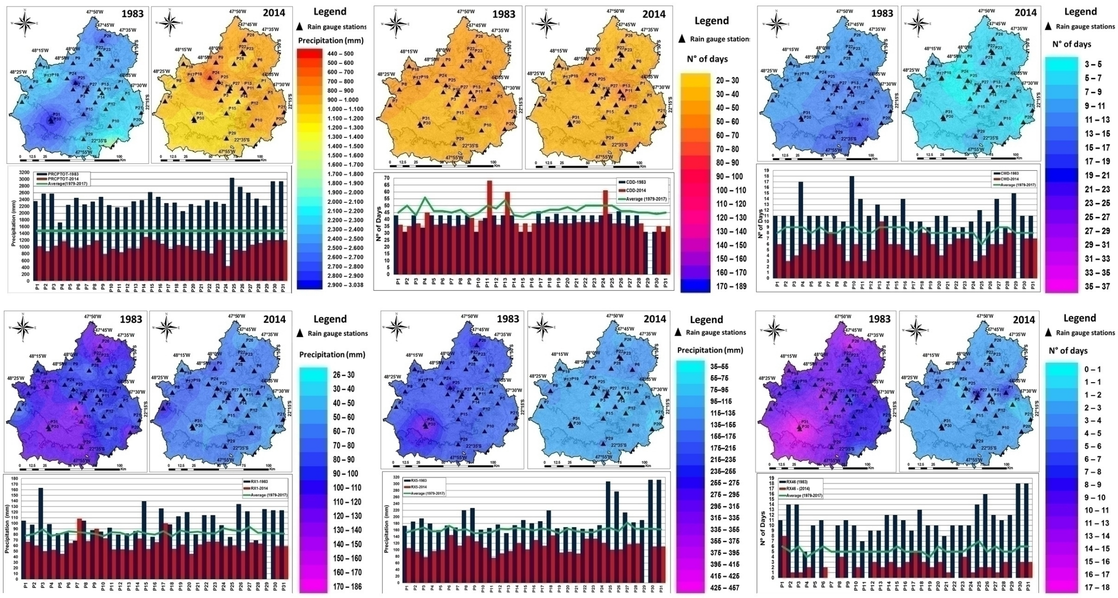


Figure 5 - Spatial distribution of rainfall in the extreme wet year of 1983 and the extreme dry year of 2014. Source: Prepared by the authors.

On the other hand, consecutive wet days (CWD) had greater continuity in the southeastern portion of the map, when compared to the central and peripheral areas, for the year 1983. These southeastern areas are located over the domain of the Peripheral Depression in the transition or close to the edge of

Serra de Itaqueri. Therefore, the natural barrier exerted by the relief must influence regional circulation, causing the formation of clouds and subsequently orographic rains, which consequently result in an increase in the number of wet days during SACZ events.

For the year 2014, consecutive wet days (CDD) occurred below 11 days for the study area. It was observed on the map that areas to the northwest showed shorter periods of rainy days and some isolated portions recorded longer periods. Again, the highest values of humid days occurred in areas influenced by orography (altitude and slope).

For the maximum accumulated precipitation in a day (RX1) for the year 1983, it was observed spatially that the highest accumulations occurred in the northern and southern areas of the map. The central-southern region once again exhibited differentiated conditions due to orographic barriers when compared to the low-lying areas, with an intensification of rainfall over a twenty-four-hour period. For the RX1 day in the year 2014, it was observed that the accumulated values over 24 hours were below 70 mm in a large part of the study area. However, regions in the western part of the map had accumulations of up to 110 mm in a single day, while the remaining areas located in the central-south and east had values below 50 mm.

For the accumulated rainfall over five days (RX5), it was observed that in 1983, the distribution of rainfall was homogeneous throughout the study area, with the exception of the southern portion, which showed higher values. On the other hand, the accumulated precipitation over five days in 2014 recorded lower values for a significant portion of the study area and, in some regions, had relatively insignificant accumulated values.

Finally, the days with extreme precipitation above 46 mm showed that in 1983 there was a higher occurrence of days with extreme precipitation in the central-southern and northern areas of the map, where the highest altitudes are located. On the other hand, the southeastern portion, which has lower altitudes, had fewer days of extreme rainfall. In the year 2014, there were days with extreme precipitation below 8 days. It is noticeable on the map a nearly uniform behavior in the number of extreme days (2 to 3) for the entire study area and a decrease (0 to 2) for the central and eastern portion of the map, however, some isolated areas recorded slightly more than 3 days.

Among the isolated points, the Central-Eastern region stands out, as it alone experienced the highest number of extreme rainfall events exceeding 46 mm in approximately 8 days. The western portion of the map also recorded a moderately significant number of extreme days, around 5 days. Taking this information into account, it can be observed that in dry years, the occurrence of extreme rainfall is almost negligible, with episodes lasting a maximum of 3 days when compared to rainy years. In rainy years, the occurrence of extreme rainfall substantially increases the number of days above 46 mm, especially in regions where the presence of topography is notable.

# DISCUSSION

The occurrence of intense rainfall, even under the influence of the relief, tends to be concentrated during the spring-summer period (October-March), where the passage of atmospheric systems triggers the formation of instability and contributes to the occurrence of extreme precipitation events. on shorter time scales.

According to Houze (2012), orographic precipitation is intrinsically a transient phenomenon and tends to occur during the passage of a pre-existing meteorological disturbance, and precipitation rates can vary substantially during the course of a single storm, according to changes in the synoptic conditions acting. along the day.

In a comparative way and synthesizing the results of the analyzes for the atypical years of 1983 (rainy) and 2014 (dry), the atmospheric circulation was clearly different in both years, especially during the first half of the year, reproducing a discrepant hydroclimatic dynamic and denoting a process that resulted in intense rains in the summer of 1983 and, in a marked and prolonged drought in 2014.

According to Santos et al., (2020), the humid year of 1983 presented a summer associated with successive frontal passages, which resulted in humid, essentially cloudy and/or overcast types of weather, with frequent and abundant rain in exceptional volumes for the area. of study. On the other hand, in the dry year of 2014, the intense presence of tropical air masses in the summer resulted in stable types of weather and long sequences of dry days, which are uncommon at this time of year.

It is noteworthy that frontogenetic atmospheric phenomena also contribute to the configuration of SACZ episodes, which can act over several days and, thus, interact with the local orography in seed-feeder intensification (Figure 6). For Houze (2012) and Roe (2005), the effect happens when pre-existing large-scale clouds at higher levels "seed" as they pass over the relief with more precipitation, "feeding" the development of new cloud cover at lower levels. of the land. Therefore, precipitation produced from the seeding cloud adds additional moisture when it falls through the feeding cloud, either by coalescence or by edge, and thus precipitation is increased over the relief.

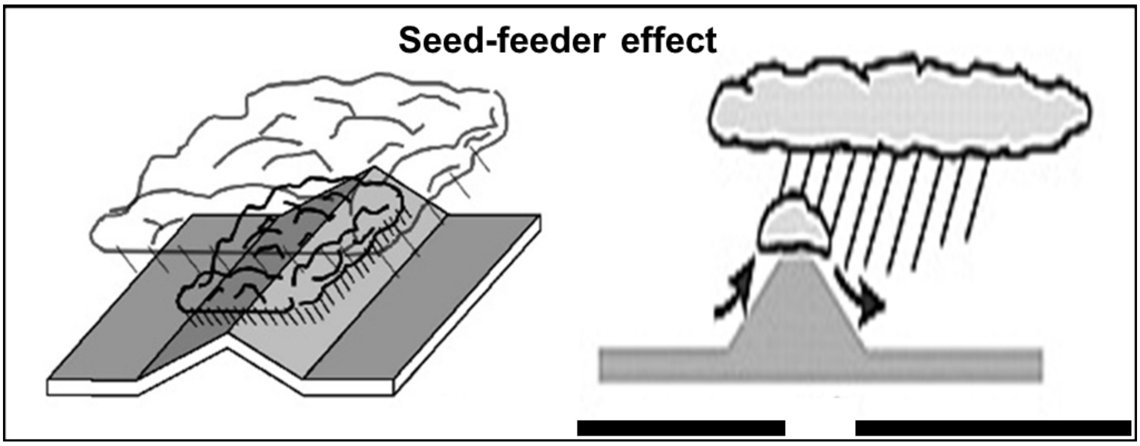


Figure 6 – "Feeder-seeder" or seed-feeder orographic effect. Source: Adapted from Roe (2005) and Houze (2012).

Therefore, the action of frontal systems and SACZ episodes distributes a volume of precipitation throughout the study area that unifies the climatic description of the rains. However, the orography favors a particularity due to the extra contribution it provides in specific portions where the relief is striking within the study area (SANTOS, 2021).

Therefore, observing the maps, it was possible to verify that in regions where the relief has a significant slope and altitude, rainfall rates are higher, compared to regions with flatter relief. In view of this, as these are two distinct representative years (wet and dry) for the historical series (1979-2017), it is understood that the greater rainfall in these elevated regions in relation to the others, both in 1983 and in 2014, possibly indicated the influence of the orographic effect on high precipitation volumes (HOUZE, 2012; ROE, 2005).

# CONCLUSIONS

The use of the Rain Anomaly Index (RAI) method for the annual classification (from 1979 to 2017) of the temporal behavior of rainfall and climate indices (RClimdex) for the analysis of the extreme years of 1983 (rainy) and 2014 (dry), proved to be efficient and capable of demonstrating the influence of the orographic effect in the study area.

The difference in the spatio-temporal distribution of precipitation was confirmed due to the restricted influence of the orographic effect in some parts of the study area, after using the Rain Anomaly Index (RAI) for the adopted historical series. Furthermore, the CDD, CWD, RX1 day, RX5 days and RX46 mm indices, when applying RClimdex, highlighted the strength of the orographic effect in intensifying rainfall, especially in the southern portion of the study area.

Given this, it is possible to state that some parts of the relief that are present in the study area, considering their extension, elevation and slope, play a fundamental role in the process of intensifying rainfall, especially during years with greater rainfall.

Based on these analyses, it is important to highlight that understanding extreme years of rainfall (floods or droughts), which have the power to cause serious disruption to people's quality of life and the performance of economic activities, must be included as part of public policies measures to mitigate the possible impacts that the hydroclimatic system in the central region of the state of São Paulo may face in atypical climatic years.

Therefore, it is essential that public authorities are aware of the results of these analyzes to develop efficient strategies for planning and preventing natural disasters. Such strategies must include measures to monitoring and controls areas most prone to floods and landslides, as well as the implementation of education policies and awareness among the population about the risks associated with extreme weather events.

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## Author's Affiliation

Santos, B. C. - Researcher at the Federal University of São Carlos, Brazil
Sanches, R. G. - PhD in Environmental Engineering Sciences from the São Carlos Engineering School (EESC) of the University of São Paulo (USP) in the area of Applied Climatology
Neves, G. Z. F. - Professor at the University of São Paulo, Brazil
Souza, P. H. - Professor at the Federal University of Alfenas, Brazil

## Authors' Contribution

Santos, B. C. - The author contributed to the elaboration, realization and manipulation of the data and writing.
Sanches, R. G. - The author contributed to the elaboration, realization and manipulation of the data and writing.
Neves, G. Z. F. - The author contributed to the elaboration, realization and manipulation of the data and writing.
Souza, P. H. - The author contributed to the elaboration, realization and manipulation of the data and writing.

MERCATOR

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## Editors in Charge

Alexandra Maria Oliveira
Alexandre Queiroz Pereira