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Relationship between the rainfall index for Southern Brazil and the indexes of the Tropical Pacific and the Tropical Atlantic Oceans

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ABSTRACT. The proposed study verified the possible influences of sea surface temperature (SST) anomalies in the equatorial Pacific and the tropical Atlantic on the rainfall in the southern region of Brazil. The rainfall stations used have monthly data for the period from 1977 to 2015 and are distributed throughout that region. Monthly TSM anomalies in the Niño 3.4 and Niño 1 + 2 areas, the Southern Oscillation Index and the Monthly Tropical South Atlantic Temperature Index were also used, from the database provided by the Climate Prediction Centre. The results show the association of precipitation in the South region with variations in sea surface temperature in the Tropical Pacific Ocean and, to a lesser extent, with sea surface temperatures in the Tropical South Atlantic Ocean.

Keywords: correlations; rainfall; anomalies; el niño-southern oscillation.

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Introduction

Oceans cover most of our planet and due to the high thermal capacity and circulation, they can absorb, store and transport heat (Rahmstorf, 2002). Through ocean circulation, this energy is distributed between different latitudes and depths, modulating the configuration of their surface layer, including temperature (Garrison, 2014). The Sea Surface Temperature (SST) is an indispensable force for climate variations and interaction between the ocean and the atmosphere interferes with temperature and rainfall on continents (Bjerknes, 1969, Lau, 1997, Clarke, Church & Gould, 2001). Oceans play an extremely important role for the earth's climate (Garrison, 2014).

Despite having known climatology on the rainfall variability in each region, there are several processes with different scales that affect the monthly rainfall average and contribute to the generation of anomalies. Many of these events are associated with external variables (such as SST anomalies), which contribute to rainier or drier years in relation to normal years. SST anomalies are important forces for atmospheric circulation variations that will affect rainfall over continental regions, so that greater understanding of such configurations is necessary to have better planning and management by sectors affected by rainfall variabilities.

In the Pacific Ocean, the El Niño-Southern Oscillation (ENSO) phenomenon climatic causes periodic variations and fluctuations on an inter-annual scale in South America, especially in the Amazon, in the northeastern region (Kousky, Kayano, and Cavalcanti, 1984, Kayano, Rao, and Moura, 1988, Araújo & Brito, 2011) and in the Southern region of Brazil, (Rao and Hada, 1990). Rainfall variability in these areas has been associated with SST anomalies of the Equatorial Pacific Ocean, which, in the positive phase (El Niño), favors the increase in rainfall over the Southern region, while in the negative phase (La Niña), contributes to reduce these rains, sometimes below the historical average in that same region (Andreoli, Kayano, Guedes, Oyama, & Alves, 2004).

There are several indexes used to monitor the tropical Pacific, all based on SST anomalies calculated in each region. Anomalies are usually calculated over a base period of 30 years. The Niño 3.4 index is the most used to define El Niño (EN) and La Niña (LN) events. Other indexes are used to characterize the unique nature of each event. The numbers of the Niño regions 1, 2, 3 and 4 correspond to the labels assigned to the tracks of ships that cross these regions. The Niño 1 + 2 region is the smallest and most eastern of the Niño regions and corresponds to the coastal region of South America, where El Niño was recognized for the first time by local populations. This index tends to have the highest variance of Niño indexes, compared to the other sectors analyzed. Niño 3.4 anomalies can be considered as representing the average equatorial SST, across the Pacific, from the data line up to the South American coast. The Niño 3.4 index normally uses a continuous average of five months and El Niño or La Niña events are defined when Niño 3.4 SST exceed +/- 0,4 °C for a period of six months or more (Nobre & Shukla, 1996).

In this sense, the aim of this work was to associate several Tropical Pacific indexes, as well as south Atlantic anomalies, with rainfall anomalies in the Southern region of Brazil to verify the possibility of rainfalls in the Southern region being associated with sea temperature variations in the tropical Pacific and south tropical Atlantic.

Rao and Hada (1990) showed that rainfall variability in the extreme south of the Brazil is quite significant and that some global anomalies in behavior atmospheric pressure can influence the precipitation field in this region. Berlato, Fontana, and Gonçalves (1992) found that the interannual variability of rainfall is the main factor in the fluctuation of agricultural production in the Southern region of the country.

Most of Paraná and central-eastern Santa Catarina have a unimodal annual precipitation cycle, with a single maximum in the summer rainy season, indicating subtropical summer monsoon regimes. In Rio Grande do Sul, the annual cycles of precipitation are, for the most part, bimodal and even trimodal, with precipitation concentrated in the quarters of August, September, and October (Grimm, 2009).

According to Nery (2005), studying the Southern region of Brazil and its dynamics is very complex and requires a close look at the different systems that operate in this region. Many explanatory dynamics of heavy rains or even the lack of rain, of the thermal amplitude in this region, have their origins far from this area of Brazil. Systems such as the Mesoscale Convective Complexes, for example, operating mainly in spring and summer, in addition to the South Atlantic Convergence Zone (SACZ), also operating from September/October to March/April, are important for the climatic dynamics of the study area.

Another very important event in the climate dynamics of the Southern region is the El Niño-Southern Oscillation (ENSO) a phenomenon linked to the warming (cooling) of the waters of the Tropical Pacific Ocean, causing the El Niño (La Niña) phenomena. This phenomenon normally causes a significant increase in rainfall in the study area, as occurred in 1982/83 and 1997/98. During the 1982-83 ENOS episode, the Southern region was affected with above-normal rainfall during the month of July (Nery, 2005). Rao and Hada (1990) found significant correlations between precipitation anomalies and the Southern Oscillation Index (SOI) during spring. Grimm (1992), analyzing this relationship from indications of the green functions of a barotropic model based on the vorticity equation, suggested differentiated relationships between ENSO events and rainfall in Southern Brazil, in winter (positive rainfall anomalies) and summer (negative rainfall anomalies).

Material and methods

Rainfall data from the Southern region of Brazil obtained through the HIDROWEB website from the National Water Agency (ANA) were analyzed. The study period was from 1977 to 2015, using 65 rainfall series, which were selected considering the best spatiality and possible distribution of stations in the study area. The errors and flaws identified in the series underwent a thorough analysis and were manually corrected, so that the flaws and gaps found were replaced or filled in by data from nearby stations, with superior quality (Figure 1).

The best spatial and temporal distribution that could analyze some ENSO events in the study area was prioritized.

When analyzing a database, one of the main challenges for the analyst was to summarize information collected. In many cases, when there are many observations, it may be of interest to create groups. Within each group, elements must be like each other and different from elements within the other groups.

Cluster analysis consists of a method that aims to group elements, components and objects (Hair, Black, Babin, Anderson, and Tatham, 2009), as well as locations (Gonçalves, Blanco, Santos, Oliveira, and Pessoa, 2016), based on their characteristics or attributes (Hair, Black, Babin, Anderson and Tatham, 2009), generating similar and homogeneous elements in one group, but distinct from elements of other groups. In this study, two cluster analysis techniques (one hierarchical and one non-hierarchical) were used to determine homogeneous municipalities. In principle, the application of a hierarchical technique aims to carry out an exploratory process; subsequently, it makes it possible to use a defined number of clusters in the non-hierarchical technique. Initially, the Ward's hierarchical method was used to define groups. This technique has the particularity of forming a two-dimension diagram, which can also be called dendrogram or tree diagram.

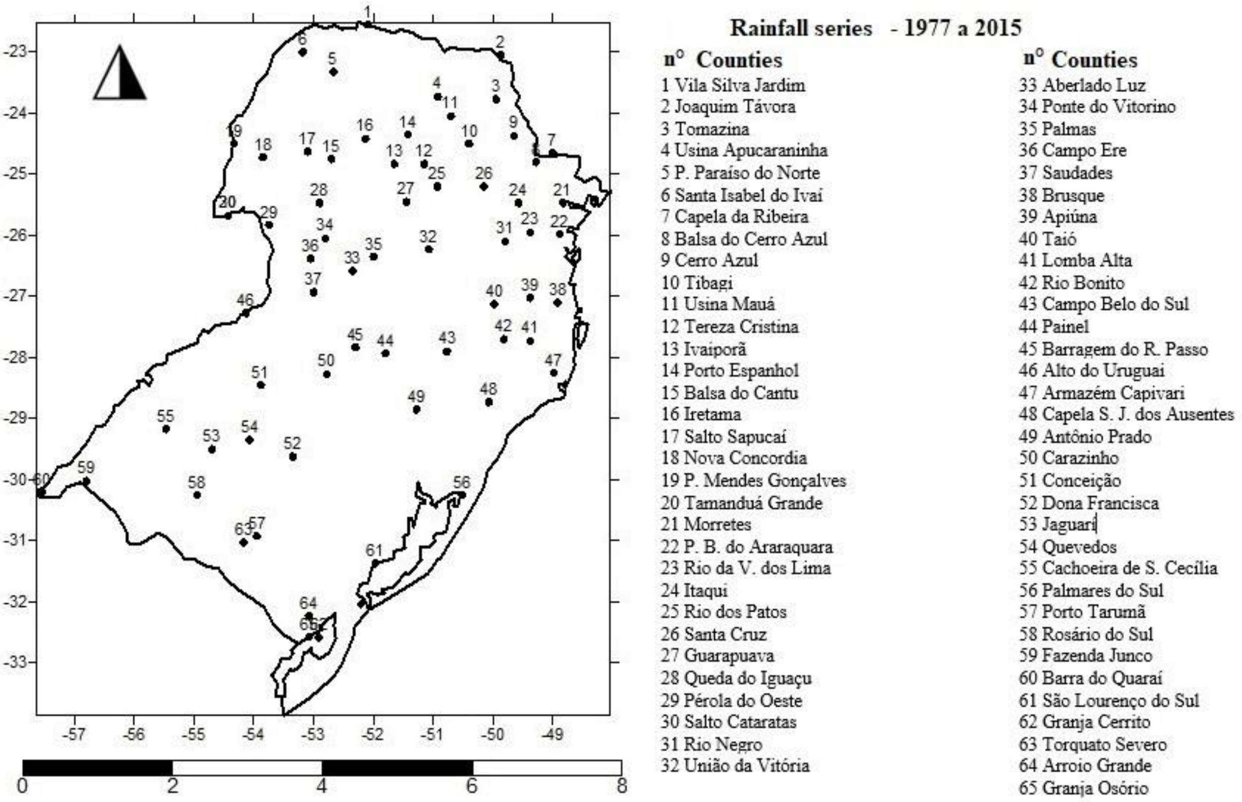

Figure 1. Spatial distribution of rainfall stations used in this work.

The rainfall index used in this work was that of Moreno, (1994):

$$IPP = \frac{(pp - PP)}{PP}$$

On what *IPP* is the rainfall index, *pp* is the total monthly rainfall value and *PP* is the average rainfall of the analyzed period.

One of the methods most used in Statistics to investigate the relationship between variables is the multiple regression model. Regression can also be defined as a statistical methodology that studies the relationship between two or more variables (Naghettini & Pinto, 2007).

According to Montgomery and Runger (2003), a regression model that contains more than one "regressor" is called a multiple regression model, the term linear is used because the equation is a linear function of unknown parameters β_0, β_1, β_2, and β_n. In the regression analysis, the data were subjected to normality tests. The assumption of normality is the one, according to which we assume that a set of data follows a normal distribution.

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_n X_n + \varepsilon$$

On what: *Y* dependent variable; X_i independent variables; β_i estimator parameters and ε random error of the model. The random error is characterized as a continuous random variable independently distributed, with null mean and constant variance over the values of the model variables. Variable *Y* is also defined as a random variable and X is a normal variable. This initial assumption around ε is, according to Montgomery and Runger (2003), important for the estimation of the regression line. The regression model is commonly expressed in the form of matrix notation.

The rainfall index was correlated with the other indexes (Pacific and Atlantic), with the rainfall index being used without lag and with lag of up to eight months.

Table 1 shows events classified according to CPTEC / INPE, and it is possible to observe events that were more intense and their duration.

The El Niño-Southern Oscillation events analyzed in this work were: 1979/1980, 1982/1983, 1987/1988, 1991/1992, 1997/1998, 2003/2003, 2006/2007 and 2008/2009.

Table 1. Periods of occurrence of El Niño and La Niña events.

Start of El Niño event		End of event (months)	Start of La Niña event		End of event (months)
Sep.68	Mar.70	19	Jul.70	Jan.72	19
Apr.72	Mar.73 ***	12	Jun.73	Jun.74 **	13
Aug.76	Mar.77 **	8	Sep.75	Apr.76 **	20
Aug.79	Jul.80 **	12	Set.84	Jun.85	10
Apr.82	Jul.83 ***	16	May.88	Jun.89 **	14
Aug.87	jul.88 **	12	Sep.95	Mar.96	7
Mar.91	Jul.92 ***	17	Jul.98	Jun.00 *	24
Feb.93	Sep.93 *	8	Jul.00	Feb.01	8
Jun.94	Mar.95 *	10	Aug.07	Jul.08	12
Apr.97	Jun.98 ***	15	Aug.10	Jul.11	12
Apr.02	Mar.03 **	12			
Aug.06	Jul.07 **	12			
Aug.09	Jul.10 **	12			
Aug.15	Jul.16 ***	12			

Source: National Institute of Space Research

Results and discussion

The dissimilarity measure used was the Pearson distance r and, for the composition of clusters, the Ward's method was used. The cutoff was made at a height of 1.5 on the dissimilarity axis (or linking distance), which resulted in the composition of four groups, Figure 2.

Based on the dendrogram, it can be observed in the Figure 3 that the first group (leftmost group, according to the cutoff) was composed of 13 rainfall series (this group was called G4, located further south of the study area), representing 19 % of the total series; group 1 (G1), located in the north / northwest of the Southern region included 21 rainfall series, representing 31% of the total rainfall series; group 2 (G2), composed of 14 rainfall series, representing approximately 24% of the total rainfall series, and group 3 (G3), consisting of 16 rainfall series, representing 25% of the total series analyzed.

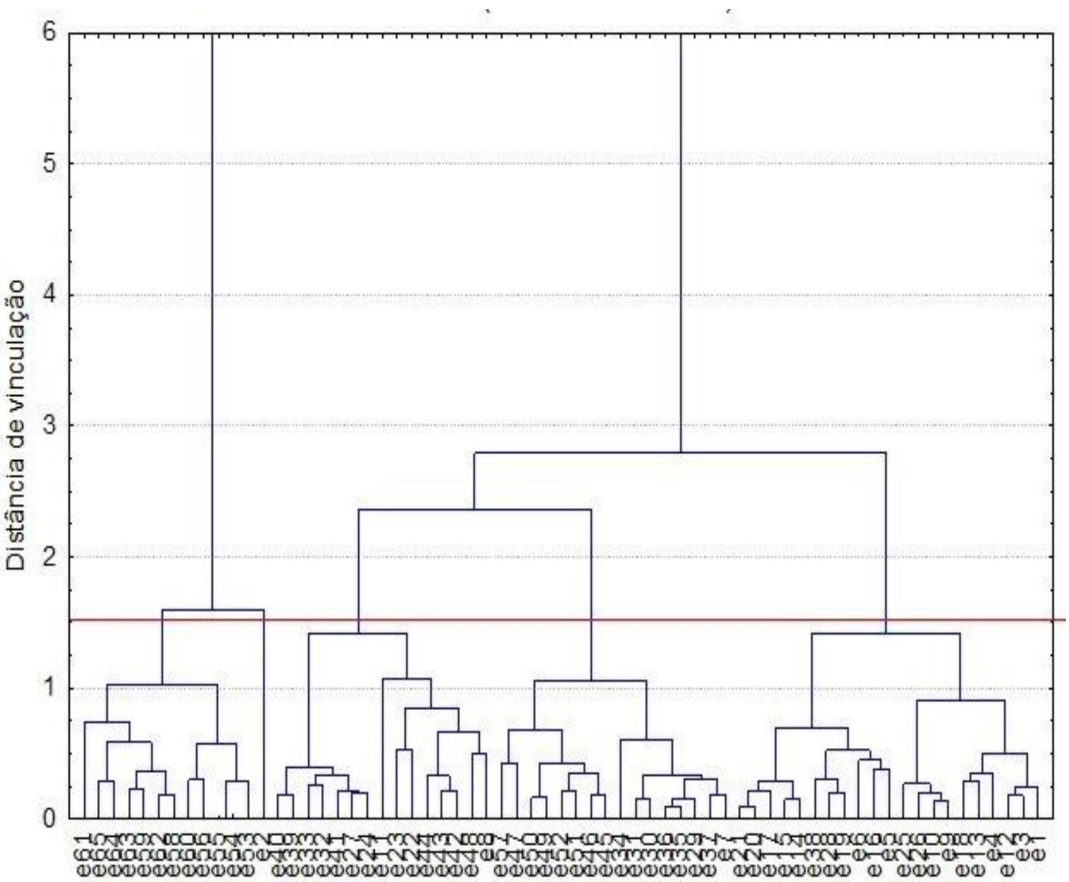

Figure 2. Dendrogram built from multivariate analysis (cluster analysis).

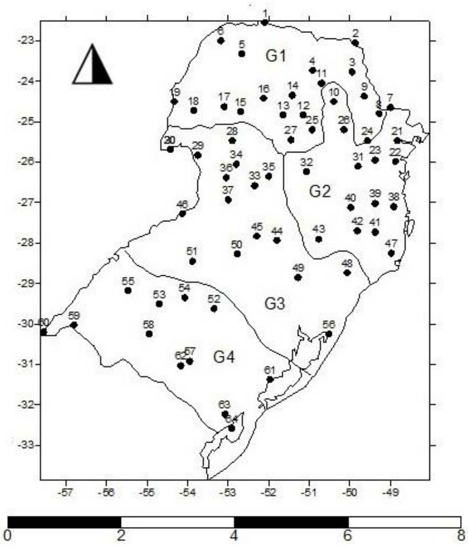

Figure 3. Classification of homogeneous areas based on cluster analysis.

Some dynamics are important to understand variations in temperatures, precipitation, among other meteorological elements, in the Southern region. For example, the cyclogenesis on the coast of Santa Catarina that is associated with the thermal gradient, as well as the depressions due to the meeting of the heated waters of the Brazilian ocean current with the currents of the Malvinas, causing a thermal gradient, often causing of intensification of cold fronts moving over this region. And, an area of intense convective activity, producing extra tropical cyclones and, particularly, a possible hurricane, with significant economic damage in the region last year. In this way, to study the climatic dynamics of the Southern region of Brazil requires an analysis of these events, in addition to the issue of continentality, maritimely, for example, which are local effects, generating regional climates within each area studied (Nery, 2005).

In the Southern region of Brazil, precipitation is, in general, well distributed throughout the year, with high rainfall totals. The totals are even higher in the west of Southern Brazil on the border with Paraguay. In this sense, precipitation in that region is influenced by different atmospheric systems throughout the year, that is, frontal systems, cyclones, Mesoscale Convective Complexes, the Lines of Instability, persistent elongated convective systems, cyclonic eddies at high levels, and breeze circulations (Reboita, Krusche, Ambrizzi, and da Rocha, 2012).

Cyclones are also important systems in the climatic dynamics of the study area. The coast of the Southern region and the extreme south of Brazil, on the border with Uruguay, are frequently affected by these systems that cause strong winds, precipitation, and temperature reduction. A case worth mentioning is the cyclone that occurred in the first week of May 2008 which in a single day caused above average rainfall for the month in Porto Alegre (Reboita, Iwabe, da Rocha, and Ambrizzi, 2009).

Figure 4 shows the average rainfall value for the analyzed period. It can be observed that the highest average rainfall is found between states of Paraná and Santa Catarina, located in southwestern Paraná and northwestern Santa Catarina, with value of 2.000 mm. The lowest average values are found in the northern Paraná and in Southern Rio Grande do Sul.

The Paraná state it's located at north of the Southern region, mostly inserted in G1 (Figure 3), and below the Tropic of Capricorn (cuts its extreme north), thus being a subtropical region influenced by climatic dynamics differentiated, in addition to being influenced by events. The state is included among those that stand out in agricultural production Brazilian. Considering that its economy depends on this production, one must highlight the importance of rainfall as a regulator of agricultural production in Paraná. This state is characterized, from the climatic point of view, as a region transition between tropical and subtropical climates. The passage of cold fronts is frequent in this state, causing temperature decline during the months of May to August, with the possibility of late frost, in September. In winter, seafaring avoids the excessive cold in the eastern part of the state. That's why negative temperatures are much more common on the western side of the state, even in low-lying counties like Foz do Iguacu. Small snowfalls occur from time to time (Nery & Siqueira, 2020).

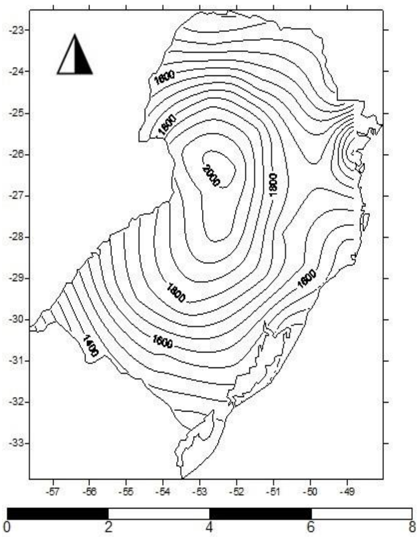

Figure 4. Average rainfall values in the analyzed period.

During the summer, according to Monteiro and Furtado (1995), predominate in the state of Santa Catarina, mostly inserted in G3 (Figure 3), air masses with centers of tropical and equatorial origins, that is, with these characteristics, like the Continental Equatorial (mEc), Atlantic Tropical (mTa) and eventually Tropical Continental (mTc). In winter, the passage of the Atlantic Polar Front (FPA) precedes the arrival of the Atlantic Polar Mass (mPa), which, respectively, cause frontal rainfall and of temperature and humidity, displacing the tropical masses towards the center and north of the country. Mention is also made of the influence of orography on the formation and distribution of rainfall, more common between the months of September and March, in view of the atmospheric circulation of winds from northeast direction, humid, fed by the Atlantic Tropical Mass that is positioned over the South Atlantic. These winds face the Serra Geral escarpment and form orographic rains. Convective rainfall, typical of the hottest months of the year, should also be recorded (Ana & Back, 2019).

Siqueira and Nery (2020) studied the spatial distribution of trends in rainfall in the state of Paraná and observed that positive trends are present mainly between the west and east of the state, denoting an increase in precipitation in these regions. The trends were predominantly positive, showing a very similar distribution pattern in the periods, that is, there is an increase in rainfall, both in the wet period (with more irregular rainfall) and in the dry period, with more regular rainfall.

According to Siqueira and Nery (2020), the spatial variations of the wet period are due to the action of mechanisms responsible for the formation of rainfall in the Southern region of Brazil, since this region, according to Grimm (2009), presents great contrasts in the regime of precipitation, with a very clear transition: in the north, the typical monsoon regime dominates, with the rainy season starting in spring and ending in early autumn, resulting in large differences between summer and autumn. uniform rainfall throughout the year. In the wet period, Mesoscale Convective Complexes, local heating and SACZ are frequent and responsible for a large part of the total precipitation. In the dry period, there is greater penetration of fronts in Paraná, causing stratiform and more homogeneous rainfall in the study area.

In Santa Catarina state, the increase in totals and peaks rain directly imply landslides on slopes, floods, agricultural losses, outbreak of urban environmental problems, transmission of diseases and even loss of life. Those events are responsible for large economic losses and high social costs (Ana & Back, 2019).

Figures 5 and 6 show the values of anomalies for the years 1982 and 1983, years considered to have occurred one of the most intense El Niño events in the world. It should be highlighted that the temperature of the tropical Pacific Ocean was 6 °C above the climatological normal in this ocean, in the occurrence of this event.

It can be observed that the values of anomalies were positive both in 1982 (Figure 5) and in 1983 (Figure 6). However, the values of positive anomalies were very marked in 1983, with rainfall values of 1.000 mm (central part of the Southern region of Brazil) above the climatological average for the analyzed period.

The El Niño-Southern Oscillation phenomenon (ENOS) is one of the main modes of global climate variability to scale interanual and periodicity from 2 to 7 years (Trenberth 1997). Once an ENOS event is established this affects the global atmospheric circulation causing anomalies in precipitation and temperature in different places on the planet, such as in South America (AS). In general, an EN event is responsible for the increase in precipitation in the south of the Brazil and drought in the Amazon and northern coast of north and northeast regions of Brazil, while opposing conditions are recorded in events of LN (Cai et al., 2020).

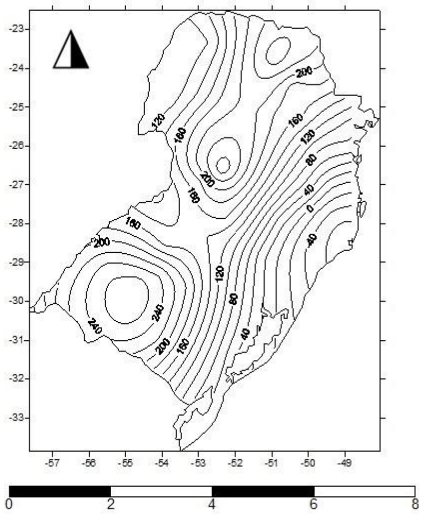

Figure 5. Rainfall anomalies for the year 1982.

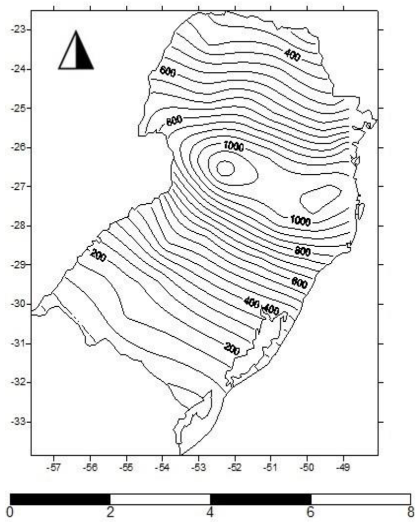

Figure 6. Rainfall anomalies for the year 1983.

The 1982-83 El Niño was distinguished from others not only by its intensity, duration, and global climatic effects, but also by its abnormal initial development. This early development was associated with a very low southerly wobble index and anomalously strong westerly low-level winds in the western Central Equatorial Pacific (Rasmusson and Wallace, 1983).

Apparently, the onset of the 1982-83 event was not preceded by a period of anomalously strong easterly winds at sea level along the equator, whose abrupt weakening around November coincides with the weakening of the surface anticyclone in the Pacific southeastern subtropical, as observed for other El Niño phenomena (Kousky et al., 1984). Furthermore, it is possible that the 1982-83 El Niño was driven by the weakening of the surface cyclone in the Pacific. Thus, in addition to presenting very particular characteristics of development, the 1982-83 event caused the most extreme climatic anomalies of the 20th century across the globe, many of them characterized by droughts or very intense rains with disastrous socioeconomic impacts for most areas affected (Kayano and Moura, 1986).

Kayano and Moura (1986) spatialized the deviations of precipitation in relation to the mean, normalized by the mean, for South America, for the quarters June-August 1982 to June-August 1983. The results showed that the Northeast of Brazil, and even the Amazon region were affected by severe droughts, while northern Argentina, Paraguay, Uruguay, part of Bolivia and part of Southern Brazil were affected by heavy rainfall. According to these authors, in the Southern region of Brazil and surroundings, heavy precipitation occurred in almost every month from July 1982 to September 1983, with the highest incidence of rain occurring in the months of May and July 1982.

Figure 7 shows the spatial distribution of anomalies for the year 1997, where anomalies with marked variability and positive values are observed throughout the southern region of Brazil. The highest values can be observed to the west of the study area. Figure 8 shows anomalies of the year 1998. In this year, values of anomalies were higher compared to the previous year, the year of the beginning of the ENSO 1997/1998 event.

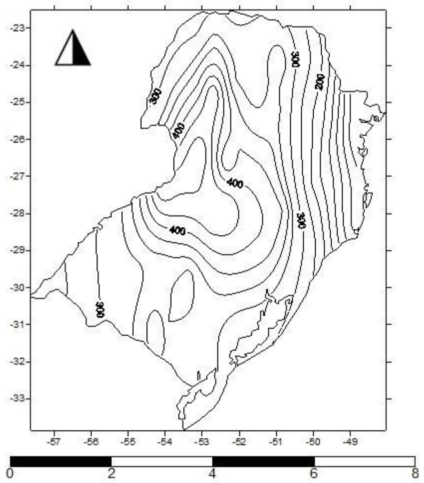

Figure 7. Rainfall anomalies for the year 1997.

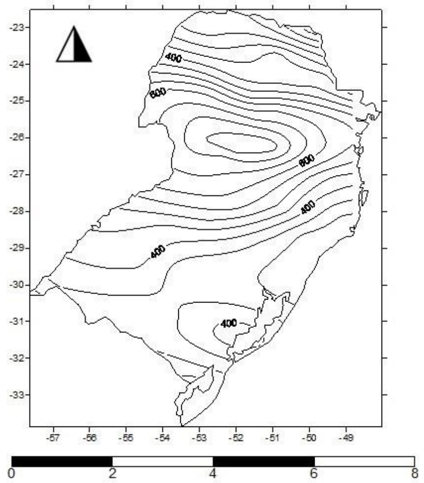

Figure 8. Rainfall anomalies for the year 1998.

On the 1997 El Niño event, surface temperatures of the sea, in the Eastern Tropical Pacific, are the largest observed since the 1950, sea surface temperature in the so-called Niño 3 region (90°-150°W, 5°N-5°S) exceeded 3,0 °C. No other event, including the 1982/83 event, surpassed this value. However, said episode is slightly less intense than the 1982/83 one, based on the anomalies achieved during the entire event. Comparison with other El strength indicators Niño, including the wind and pressure fields, paint a similar picture: the 1997 El Niño is close in magnitude to that of 1982/83 (Cunha, 1997), which can be observed from the similarities between the isolines in Figures 5 and 6, with those in Figures 7 and 8, indicating a similar anomalous pattern for the two episodes in the southern region of Brazil.

Even so, it is important to emphasize that, despite the similarities, the impacts of each El Niño event are diferente, depending on the evolution of each episode. Despite this, much of what happened in 1997 resembles the past in 1982, at a level worldwide. In both 1982 and 1997, drought hit Indonesia, with forest fires. A Drought also affected Mexico and Central America in 1982 and 1997. Likewise, in both years the hurricane season in the western Atlantic and Caribbean Sea was less active. However, there is a big difference between 1982 and 1997 when compared with regard to the tropical storms in the western Pacific. In the past (1982/83) several tropical storms hit the western Pacific, unlike what happened in 1997 (Cunha, 1997).

Figure 9 shows the distribution of anomalies in the study area. It is possible to observe values above 900 mm of rainfall anomalies, that is, it rained another 900 mm above the climatological average in northwestern Paraná. It is also possible to observe marked spatial variability, with values below 300 mm of rainfall anomalies in southeastern Rio Grande do Sul. The 2015 event started in May, when conditions for El Niño formation were fulfilled. The event was one of the three largest events ever recorded on the planet, only compared to the 1982/83 and 1997/98 events.

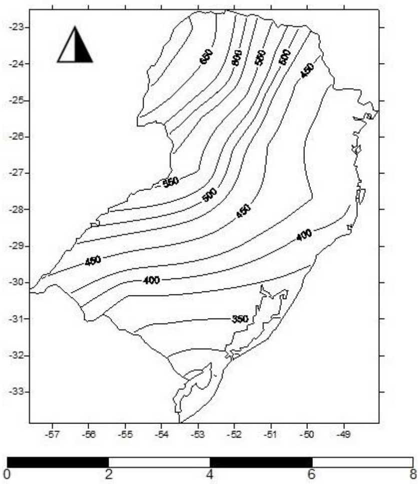

Figure 9. Rainfall anomalies for the year 2015.

In general, the Southern region of Brazil is more consistent when considering scope and anomalies in response to El Niño and La Niña phenomena than most other regions. And, under the influence of Mesoscale Convective Complexes in the region, El Niño/La Niña effects occur more consistently in spring (Rao and Hada, 1990). The 2015-16 event was an example that followed these characteristics. The 2015-16 El Niño was a case where initially the largest water temperature anomalies were located in the Central Pacific region (El Niño Modoki), but as it strengthened, it started to behave a little more like an El Niño canonical (major anomalies in the eastern Pacific region). During the period between June 2015 and March 2016, precisely when the 2015-16 El Niño phenomenon was most active, temperatures and rainfall were above average in most months in the Southern Region, which is expected for a strong pattern of El Niño. In Santa Catarina, it rained more than the normal in 8 of the 10 months of that period, based on data provided by the National Institute of Meteorology (INMET).

The only two months of the 2015-16 El Niño period in which rainfall remained below average in Santa Catarina were August 2015 and January 2016, partly due to atmospheric blocking and the more southerly positioning of the Subtropical Jet during these months. But even with a drier August, the winter was, in general, rainier than normal across the region. In July 2015, heavy and constant rains hit southern Brazil, affecting more than 25.000 people in 108 municipalities in the region. In Paraná, 21.000 people were affected, in Rio Grande do Sul, 1,700 were left homeless, and in Santa Catarina, more than 2.000 were affected by the rains. In some locations, it rained more than twice as expected for the entire month in just a few days. Due to lack of information in most rainfall series, it was not possible to analyze the 2015/2016 event.

Table 2 shows the multiple regression performed for group 1. It can be observed that the rainfall index (IPP1) for this study area was significantly correlated with the temperature index of the tropical Pacific Ocean (El Niño sector 3.4), but it can also be observed that in some years, they were also correlated with the southern oscillation index (SOI), with El Niño (sector 1 + 2) and eventually with the temperature index of the tropical southern Atlantic Ocean (TSA). In some years, lags occurred in up to five and six months (1987/1988 and 2009/2010, respectively) and in others without lags (1979/1980 and 1982/1983). It is also possible to observe that, for this group, the years 1987/1988 did not present significant correlation, which demonstrates that the El Niño event does not act homogeneously in the analyzed area but presents rainfall values generally above the climatological average in the entire southern region.

Table 3 shows the multiple regression for El Niño events referring to group 2. This group showed marked correlations for El Niño, sector 3.4 of the tropical Pacific Ocean and some significant correlations with temperature index of the tropical Atlantic Ocean (TSA), with El Niño 1 + 2 (western coast of South America) and with the southern oscillation index, although inversely, that is, positive rains associated with negative southern oscillation index.

In terms of the behavior of atmospheric fields, the Southern Oscillation Index (SOI) reflects the anomalies of surface pressure via differences in pressure between Tahiti in the Central Pacific, and Darwin, Australia. In years when surface pressure is high in Darwin and low in Tahiti, IOS is negative (El Niño episode); conversely, when surface pressure is low in Darwin and high in Tahiti, IOS is positive (da Cunha et al., 2011).

Table 2. Multiple regression analysis applied to the tropical Pacific Ocean and tropical South Atlantic Ocean indexes, in relation to the rainfall index for southern Brazil. IPP1 represents the rainfall index calculated for group 1 in the southern region of Brazil; PDO - Pacific Decadal Oscillation Index; SOI - Southern Oscillation Index; EN 1 + 2 - EL Niño of sector 1 + 2 (coast of South America) and EN 3.4 - temperature index in sector 3.4 of the tropical Pacific. Values in bold represent significant correlations.

PERIODS	IPP1	PDO	SOI	EN 1+2	EN 3.4	TSA
1979/1980	SDef	-0,44	0,21	0,29	0,61 *	-0,07
1982/1983	SDef	-0,40	-0,66 *	-0,05	0,71 *	0,51 *
1987/1988	Def5	-0,34	0,17	-0,50	-0,50	0,24
1991/1992	Def3	0,31	0,10	0,21	0,50 *	-0,36
1997/1998	Def4	-0,24	-0,15	0,52 *	0,39	0,36
2002/2003	Def2	0,27	-0,36	0,12	0,83 *	-0,69 *
2006/2007	Def2	-0,27	-0,44	0,73 *	0,81 *	-0,12
2009/2010	Def6	-0,47	0,68 *	-0,52	-0,40	-0,18

Table 3. Multiple regression analysis applied to the tropical Pacific Ocean and tropical South Atlantic Ocean indexes in relation to the rainfall index for southern Brazil.

PERIODS	IPP2	PDO	SOI	EN 1+2	EN 3.4	TSA
1979/1980	Def2	-0,35	0,12	0,12	-0,10	0,63 *
1982/1983	SDef	0,53 *	-0,09	0,59 *	0,00	0,20
1987/1988	Def2	0,48	-0,37	0,61 *	0,68 *	-0,37
1991/1992	SDef	0,23	-0,13	0,46	0,57 *	0,27
1997/1998	Def1	0,04	-0,61 *	0,46	0,63 *	0,57 *
2002/2003	Def2	-0,02	-0,40	-0,05	0,71 *	-0,78 *
2006/2007	Def2	-0,20	-0,11	0,46	0,53	-0,53
2009/2009	Def2	0,22	-0,71 *	0,42	0,78 *	-0,25

When the IOS is strongly positive, cooler than normal waters appear in the central and eastern part of the equatorial Pacific Ocean. This cold episode is called La Niña and implies climatic anomalies generally inverse to those of the warm episode, called El Niño. another aspect of the atmosphere that is disturbed during the El Niño period is a north-south circulation cell, of the Hadley type, which intensifies and ends up influencing the jet stream, which these are very strong winds that blow from the west at an altitude of around 10,000 m. The intensified jet stream determines blockages in the atmosphere, causing the cold fronts to become semi-stationary over the extreme south of Brazil, causing the excessive rainfall observed during the El Nino years, for example than happened in 1997/1998 (da Cunha et al., 2011).

Table 4 shows the multiple regression for group 3 between rainfall index and tropical Pacific Ocean indexes and temperature index of the tropical Atlantic Ocean. Significant correlations showed values referring to the oscillation index (inverse correlations) and for El Niño 1 + 2 and sector 3.4, predominantly. Marked correlations predominated for the correlations without lag or with one-month lag.

Table 4. Multiple regression analysis applied to the tropical Pacific Ocean and tropical South Atlantic Ocean indexes in relation to the rainfall index for southern Brazil.

PERIODS	IPP3	PDO	SOI	EN 1+2	EN 3.4	TSA
1979/1980	Def1	0,02	0,12	0,38	0,00	0,67 *
1982/1983	SDef	0,54 *	-0,03	0,59 *	-0,04	0,14
1987/1988	Def1	0,29	-0,13	0,42	0,46	-0,18
1991/1992	SDef	0,19	0,11	0,50 *	0,49	-0,29
1997/1998	Def1	0,13	-0,62 *	0,46	0,66 *	0,39
2002/2003	SDef	0,27	-0,32	0,33	0,68 *	-0,35
2006/2007	Def3	0,20	-0,43	0,45	0,29	0,19
2009/2009	Def1	0,32	-0,63 *	0,77 *	0,69 *	-0,29

Table 5 shows the multiple regression analysis for group 4. It can be observed that the rainfall index (IPP4), for this study area, was significantly correlated with the tropical Pacific Ocean (sector 3.4) in some events, sector 1 + 2 of the tropical Pacific Ocean, also having some relevance, for events that occurred in 1979/1980 and 1982/1983. It can also be observed that there was no index that predominated over the others in a clear way. Both PDO and SOI showed significant correlations to explain rainfall in group 4, associated with temperature anomalies or, in the case of SOI, pressure in the tropical Pacific Ocean.

Table 5. Multiple regression analysis applied to the tropical Pacific Ocean and tropical South Atlantic Ocean indexes in relation to the rainfall index for southern Brazil.

PERIODS	IPP4	PDO	SOI	EN 1+2	EN 3.4	TSA
1979/1980	SDef	0,28	-0,20	0,62 *	-0,40	0,34
1982/1983	Def3	0,14	-0,17	0,70 *	0,59 *	0,23
1987/1988	SDef	0,33	-0,57 *	0,42	0,52 *	-0,35
1991/1992	Def4	-0,63 *	-0,30	0,08	0,53 *	-0,05
1997/1998	Def6	-0,26	0,66 *	-0,44	-0,34	0,41
2002/2003	Def1	-0,73 *	0,20	-0,26	0,30	-0,61 *
2006/2007	Def8	-0,01	-0,32	0,43	0,46	0,44
2009/2009	Def5	0,51	-0,30	0,40	0,48	-0,30

The analysis of the tables, based on the results provided by the indices, makes it possible to identify significant variability in rainfall in the Southern region, associated with sea surface temperatures in the Tropical Atlantic and Equatorial Pacific Oceans. In general, there is an increase in rainfall in the study area, especially when these indices are correlated with the anomalies identified in the Pacific Ocean. The phenomenon El Niño-Southern Oscillation (ENOS) interferes with the climatic characteristics of the circulation general. The tropical Pacific Ocean undergoes anomalous warming of waters, generally cold on the east of that ocean. This warming causes changes in the large-scale circulation of the atmosphere, causing climate anomalies in various regions of the globe (Webster, 1981, Wallace & Gutzler, 1983). The intensities and phases of the Southern Oscillation have usually been measured through indices called indices of the Southern Oscillation (IOS), which are derived from meteorological parameters (pressure at sea level, temperature, wind, and precipitation) observed in the neighborhoods of OS action centers. Among these, an index based on differences in normalized (monthly and seasonal) pressure anomalies at the level of the sea between Tahiti and Darwin, which is negative during hot episodes of OS, has been touted as a great indicator of the state of the Southern Oscillation (Trenberth, 1984).

Conclusion

Rainfalls in the southern region of Brazil suffer external influences, with El Niño events having strong influence on these values. It is notorious that there were greater rainfalls in the study area due to the occurrence of these events. Even so, this increase in rainfall is not homogeneous throughout the area, with some areas presenting significantly higher rainfall values compared to other areas within the region under study. In general, there is excessive rainfall in the years of El Niño and drought in La years Nina. The extreme phases of the Southern Oscillation (El Niño and La Niña) cause significant changes in historical and zonal precipitation totals in the Southern Region of Brazil, with spring being the season that most suffers the impacts of El Niño, with more frequent and intense rains, while in La Niña springs are drier.

Another issue is that each occurrence of ENSO events presents different rainfall variability in areas generated by the multivariate analysis, what it means the Southern region of Brazil as a whole. Another issue is that each occurrence of ENSO events presents different variability in the areas generated by the multivariate analysis, that is, in the Southern region of Brazil as a whole. The results showed that both ENSO and the indices of the Tropical Pacific and Tropical Atlantic oceans influence the dynamics of precipitation in the study area, mainly associated with increased precipitation. Of the two oceans analyzed, the Tropical Pacific is the ocean that showed the greatest correlation with increased rainfall in the analyzed area.

Oceans are warmer at certain times. This warming is associated with the internal dynamics of the planet Earth. The Atlantic Ocean, for example, has been warmer on the Brazilian coast, although the Pacific Ocean is colder due to the influence of La Niña. La Niña's response is different from other times, where both oceans are colder; that is when La Niña gives a negative response, and it rains less in southern Brazil.

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