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Influence of different rates of rainfall in the basin of the Uruguay River

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Abstract. In the state of Rio Grande do Sul, the rainfall pattern is fairly regular and precipitation is well distributed throughout the year. The aim of this study was to evaluate the spatial and temporal distribution of precipitation in the Uruguay River basin from the determination of homogeneous regions based on the rainfall pattern. Values of 47 meteorological stations of the ANA (National Water Agency) from 1975 to 2005 were used, and values of Pacific sea surface temperature were collected from the National Oceanic and Atmospheric Administration, which is based on observed anomalies for different regions' niños (1 + niño 2, 3 niño, niño 4, niño 3 + 4). From the analysis of the results it was found that the study region showed five homogeneous regions. Knowing the time series of each region, it was possible to verify the regional variability in precipitation, indicating which regions have values above and below the climatological normal, and how the different indexes influence the rainfall pattern in the region.

1 Introduction

The development of reliable methods of hydro scheme predictability and identification on a regional scale is extremely important to address deficiencies in the area and make decisions on planning and usage of those resources, whether in energy, in agricultural and even in urban areas (Melo et al., 2005). Lyra et al. (2006) determined the homogeneous regions for the state of Tachira (Venezuela) based on the seasonality of rainfall precipitation to determine the dry and wet periods in the region. Other studies relate observed precipitation with temperature, classifying the dry and wet periods, and thus defining a "normal" (precipitation data is similar to the average) of precipitation (Galvani and Luchiari, 2004).

Some authors have shown strong indications of the influence the Ninos exercise not only on the rainfall of the state of Rio Grande do Sul, but also in subtropical South America (Coelho and Ambrizzi, 2000). Some authors point out that the indexes SATL (Sea Surface Temperature of Atlantic) and SOI niños (South Oscilation Index) play an extremely influential role in the interannual variability of precipitation in the whole of South America (Sansigolo and Nery, 1998). Peak heating/cooling of the Pacific Ocean are related to anomalies in precipitation over the entire continent. As a result, this study aims to examine the influence of ocean levels on rainfall in the five homogeneous regions of the Uruguay River basin (Fig. 1).

2 Material and methods

In this study, we used monthly precipitation data on the Uruguay River basin from 47 meteorological stations of the ANA (National Water Agency) for the period from 1975 to 2005. The spatial distribution of weather stations selected for this study can be seen in Fig. 1.

To verify the grouping of homogeneous regions according to rainfall, we used the analysis of clusters, which has the advantage of reducing the space to a multidimensional measure of distance between objects. This represents a two-dimensional space, much simpler than the multidimensional space (Mardia et al., 1995). Cluster analysis seeks to group data elements based on the similarity between them. The groups are determined to obtain homogeneity within and heterogeneity among them. As a result of cluster analysis, we obtain a dendrogram, which shows the arrangement of

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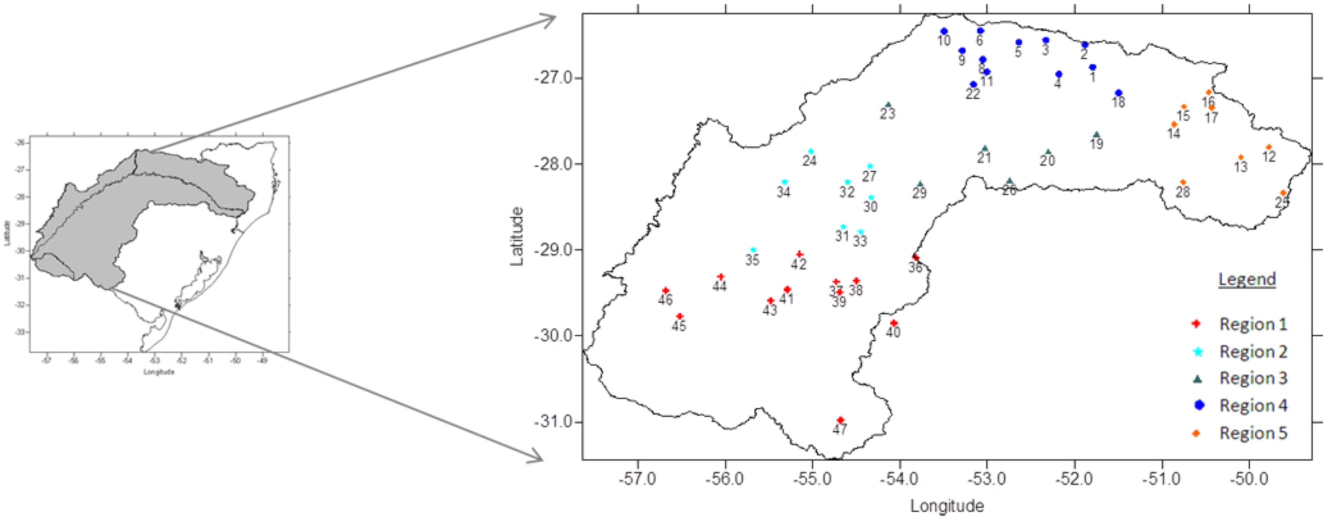

Fig. 1. Location of climatic stations of the ANA (National Water Agency) separated by homogeneous regions according to rainfall data.

objects in a distance scale. This arrangement provides only affinity between groups, not setting of any sort between them. The distances are measured and used for the representation of points of similarity in structure, representing the smallest space between two points. In this paper we used the Euclidean distance between two vectors.

After calculating the distance, the agglomerative method was used, in which each element begins representing a group and at each step a group or element is connected to another according to their similarity. In the last step, a group is formed with all the elements. For that, we used the complete linkage method, which employs the maximum distance with the tendency to form compact groups, where the noises delay to be incorporated in the groups (Fig. 1).

The rainfall variability was analyzed from the monthly series for each of the homogeneous regions. The series were divided into three categories: below normal, normal, and above normal. They were ranked from lowest to highest and divided into three stages. The series below the first threshold, which was defined from a precipitation pattern, is considered a category below normal (dry); the one above the second limit was considered above normal category (wet); and between these two limits lies the normal category (Fig. 2).

The work was divided into two stages: in the first step we analyzed the influence of *niños* in the precipitation of the Uruguay River basin, and in the second, all the indexes were correlated with the oceanic precipitation in the area.

In the first step, to interlace the indexes with the observed precipitation events of niños occurred from 1975 to 2005, we used the occurrence data of past events available at CPTEC (Center for Weather Forecasting and Climate Studies) and anomalies on the surface of the Pacific acquired from the site of NOAA (National Oceanic and Atmospheric Administration). From these data, we analyzed the rainfall observed in each of the homogeneous regions for the duration of each event.

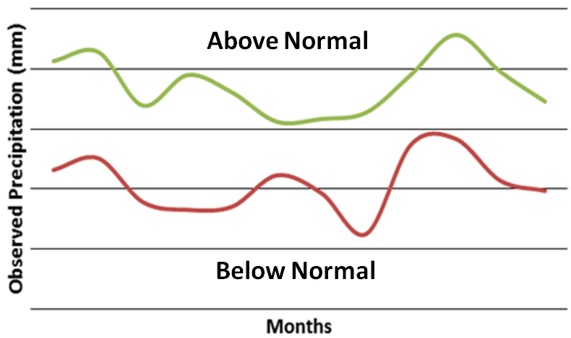

Fig. 2. Boundaries of the three categories of monthly rainfall – above normal (above the green line), below normal (below the red line) and normal (the line between green and red) – for the five homogeneous regions: Region 1 **(a)**, Region 2 **(b)**, Region 3 **(c)**, Region 4 **(d)**, Region 5 **(e)**, Mean Basin **(h)**.

To identify which are the most important climate indexes for the observed precipitation, we applied multivariate analysis using the technique of principal components (PCA). The method of principal component analysis seeks to find a new set of variables that retain the maximum variance through a linear combination of original data (Wilks, 1995). The estimated principal component is developed through information contained in the covariance matrix of the data. For the application of the technique, it is necessary to standardize the data so that the entire series will have the same magnitude of values. In this case the anomalies were calculated for each variable. The next step is to obtain the eigenvectors, which are the values that represent the weights of each variable on each component (axis) and function as correlation coefficients ranging between −1 and 1, and the eigenvalues,

Table 1. Number of stations that showed precipitation above, within and below the normal.

Precipitation	Uruguay River Basin
Above Normal	95
Within Normal	179
Below Normal	98

which represent the relative contribution of each component to the explanation of the overall data variation (Gomes et al., 2004). The number of axes or components can be equal to the number of variables, but the rear axle will contribute less to explain the data (Kent and Coker, 1992).

3 Results

With respect to the observed precipitation in the basin (Table 1), we notice that the majority of weather stations show rainfall within the normal. The number of stations with precipitation above and below normal is virtually identical, demonstrating that precipitation in this area was homogeneous.

Table 2 shows the occurrence of each *niño*, the year it occurred, its duration, and the amount of months that belongs to above normal, normal and below normal rainfall patterns. Regarding the recent ENSO events (Table 2), one can observe that the homogeneous regions of the Uruguay River basin present different precipitation. As in the 1975 event, observed in the table region one has four months with an index of observed precipitation below normal, while region two just two months. The most relevant factor in the study of the table is the influence of El Niños and La Niñas in precipitation. It may be noted that, in events of the warming of the Pacific waters, we find in certain cases a number of months with average precipitation within the normal surpassing the number of months with precipitation above normal, except for the events of 1982–1983 and 1997–1998, which are characterized as strong where precipitation values were above the climatological normal. In certain events, such as the 1990 one, it can be observed in region one there are no months with precipitation above normal, but in region four the number of months with below normal precipitation exceeds the within and above normal.

To analyze which index – SOI (Southern Oscillation Index), TNA (Northern Tropical Atlantic), TSA (Southern Tropical Atlantic) or sea surface temperatures (SST) in the Pacific Ocean – exerts a major influence on precipitation, we did a multivariate analysis of the monthly data of principal components. Table 3 shows the eigenvectors of each mode of the principal components for each homogeneous region of study. Here we can see that it takes four main components to explain 75 % or more of the variance of the observed variables and is thus concentrated in four dimensions of the information previously diluted in nine variables. The first component explains about 50 % of the total variance of the variables; the second component explains 13 % of the variance; the third and the fourth explain 10 % and 8 % of the total variables.

In Table 3, precipitation is explained by the third component in all regions. In the first region, there are anomalies in TNA as the variable that most influences the precipitation of third component, presenting an inversely proportional variation, i.e., the decrease of temperature in this region of the Atlantic results in an increase of precipitation. This influence is highly correlated, exerting sharp results on the area. In the same region, the fourth component has a small influence on precipitation, but it is interesting to note that the influence of the Pacific SST, represented by niño $1+2$ and 4, appears in the same proportion, being those inversely and directly proportional, respectively.

In regions two, three and five, the Pacific SST has great influence on precipitation with niño $1+2$ directly, and with Niño 4 in reverse. The Southern Oscillation Index (SOI) also has an important influence on precipitation in these areas, demonstrating that increased levels of air pressure that occur in the tropical Pacific precipitation directly influence the site under consideration.

In region four, the TNA is again the most influential variant, which is inversely proportional in the three components. The temperature decrease on the sea surface results in an increase of precipitation, not being as highly correlated as in region 1. Niño 3 exerts influence not so strongly, but directly proportional to this region.

4 Conclusions

In the study area, from the cluster analysis used in data belonging to values of 47 meteorological stations of the ANA (National Water Agency) for the period from 1975 to 2005, it was possible to separate it into homogeneous regions and analyze the behavior of each region. Thus, there are five homogeneous regions.

The importance of climate variables involved in the process of precipitation was evaluated using the multivariate statistical techniques Principal Components Analysis and Cluster Analysis. These techniques were applied to the data collected during 1975 to 2005 for the values of SOI (Southern Oscillation Index), TNA (Northern Tropical Atlantic), TSA (Southern Tropical Atlantic), and sea surface temperatures in the Pacific Ocean collected from The National Oceanic and Atmospheric Administration. The latter was analyzed from the last observed anomalies for different regions of niños (Niño $1+2$, Niño 3, Niño 4, Niño $3+4$). We concluded that the process of precipitation in the study area is controlled by four main components, which explain about 80 % of the variance in the data areas, the third main component being the most influential in all homogeneous regions of the

Table 2. ENSO events and their influences on the precipitation of homogeneous regions, and the amount of months that observed precipitation above normal (Ab.), within normal rainfall (N.), and below normal rainfall (Bl.)

			Region 1			Region 2			Region 3			Region 4			Region 5		
Year	Event	Duration (months)	Ab.	N.	Bl.	Ab.	N.	Bl.	Ab.	N.	Bl.	Ab.	N.	Bl.	Ab.	N.	Bl.
5	La Niña	11	3	4	4	5	4	2	1	8	2	2	7	2	3	5	3
1976–1977	El Niño	5	2	2	1	2	3	0	1	3	1	1	3	1	1	3	1
1977–1978	El Niño	5	1	3	1	0	2	3	0	3	2	0	4	1	0	3	2
1982–1983	El Niño	14	8	5	1	8	5	1	6	7	1	6	8	0	8	4	2
1983–1984	La Niña	5	1	2	2	0	5	0	1	2	2	1	2	2	1	3	1
1984–1985	La Niña	9	2	6	1	2	4	3	4	3	2	4	4	1	1	4	4
1986–1988	El Niño	17	7	7	3	1	11	5	6	7	4	4	10	3	2	10	4
1988–1989	La Niña	13	1	6	6	2	8	3	1	8	4	2	5	6	2	8	3
1990–1993	El Niño	14	0	9	5	6	4	4	4	6	4	5	3	6	4	6	4
1994–1995	El Niño	10	2	7	1	4	5	1	4	5	1	1	9	0	3	4	3
1995–1996	La Niña	5	1	2	2	1	3	1	1	2	2	2	2	1	1	3	1
1997–1998	El Niño	13	7	5	1	10	3	0	9	4	0	5	7	1	8	5	0
1998–2001	La Niña	24	3	15	6	3	16	5	6	12	6	7	11	6	4	13	7
2002–2003	El Niño	11	6	5	0	5	6	0	5	6	0	7	4	0	4	6	1
2004–2005	El Niño	6	1	4	1	2	2	2	1	3	2	1	5	0	3	2	1

Table 3. Variables that influence the main component in precipitation.

		NINO 1+2	NINO 3	NINO 4	NINO 3.4	SOI	TNA	TSA	Var. Exp (%)	Var. acm (%)
Region 1	CP 1	−0.34	−0.43	−0.38	−0.43	0.34	−0.14	−0.01	48.30	48.30
	CP 2	0.15	0.13	0.02	0.13	−0.20	−0.55	−0.70	13.43	61.73
	CP 3	0.15	0.08	−0.22	−0.02	0.06	−0.45	0.28	10.66	72.39
	CP 4	0.35	0.01	−0.35	−0.19	0.20	0.18	−0.17	8.37	80.76
Region 2	CP 1	−0.35	−0.43	−0.38	−0.43	0.34	−0.14	0.00	48.20	48.20
	CP 2	0.17	0.13	−0.01	0.12	−0.17	−0.58	−0.69	13.40	61.60
	CP 3	0.32	0.07	−0.28	−0.12	0.29	0.10	−0.01	10.82	72.42
	CP 4	−0.19	−0.04	0.29	0.08	0.04	0.47	−0.42	8.35	80.77
Region 3	CP 1	−0.34	−0.43	−0.38	−0.43	0.34	−0.14	−0.01	48.32	48.32
	CP 2	0.14	0.13	0.02	0.13	−0.21	−0.57	−0.69	13.41	61.74
	CP 3	0.30	0.11	−0.31	−0.08	0.24	−0.19	0.06	10.61	72.35
	CP 4	0.18	−0.06	−0.12	−0.15	0.21	0.61	−0.57	8.18	80.52
Region 4	CP 1	−0.34	−0.43	−0.38	−0.43	0.34	−0.14	−0.01	48.29	48.29
	CP 2	0.15	0.13	0.02	0.13	−0.20	−0.57	−0.69	13.41	61.69
	CP 3	0.24	0.09	−0.29	−0.06	0.15	−0.32	0.19	10.49	72.18
	CP 4	0.29	−0.02	−0.27	−0.18	0.20	0.35	−0.33	8.28	80.47
Region 5	CP 1	−0.34	−0.43	−0.38	−0.43	0.34	−0.15	−0.01	48.10	48.10
	CP 2	0.13	0.13	0.03	0.13	−0.21	−0.57	−0.68	13.43	61.52
	CP 3	0.35	0.09	−0.27	−0.10	0.25	−0.05	−0.10	10.83	72.35
	CP 4	−0.13	−0.04	0.25	0.05	0.09	0.54	−0.50	8.30	80.65

basin. Within this main component, the influence of the variables differs among regions. It is important to emphasize the SST in the North Atlantic, and its great influence on rainfall in the region studied, something not raised in previous works.

It can be concluded that, for this region, in years of El Niño precipitation these years do not always show values above the climatological normal, and in La Niña years the rainfall regime does not present much variation, with most months within the normal climatology. Therefore, years of extreme precipitation anomalies are not always directly linked to El Niño and La Niña.

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