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Temporal space variability for precipitation in the state of Pernambuco

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Abstract

This study aims to make a diagnostic analysis of rainfall at different time scales in the rainfall homogeneous regions of the state of Pernambuco and associate them with weather systems operating in the region. The state was divided into three geographical regions (HR) of rainfall regime, according to Ward's clustering method. In each RH applied to Wavelet Transform (TO) time series of 1995-2015 precipitation. The results showed that in all regions the dominant scale is annual. It is also observed the interaction with the semi-annual and seasonal scales mainly in RH2 and RH3 regions. The TO showed that high levels of rainfall in the regions are associated with different weather systems.

Keywords: Time series, homogeneous regions, wavelet.

1. Introduction

Precipitation is characterized as the return of the condensed steam to the soil, which transformed into droplets with sufficient size to break the force of gravity and fall, and the distribution during the annual cycle is quite irregular (Ometto, 1981). Thus, in turn the precipitation is most important meteorological variable for the tropics. Most of the Northeast region of Brazil is characterized as semi-arid, with great spatial and temporal variability of precipitation and high rate of evaporation.

The state of Pernambuco is located in the center-east of the Northeast of Brazil, has climatic conditions dependent on the amount and distribution of rainfall. Throughout of the State, rainfall decreases in the East-West direction and, to a lesser extent, in the South-North direction. There are at least three systems that produce precipitation in Pernambuco, namely: the Intercropical Convergence Zone (ITCZ), East Undulatory Disorders (DOL) and High Level Cyclonic Vortices (VCAN) (Souza et al., 2004).

The cluster analysis aims to discover the complex nature of the multivariate relationships between the data investigated. The classification of the variables into homogeneous groups and the identification of their common characteristics make possible a better knowledge and prediction of the phenomenon in question. The Transform of Ondeletas is an important tool in the analysis of non-stationary signals, allowing identifying the main dominant scales in a time series and its evolution (Torrence and Compo, 1998).

Lately numerous works have been developed, using more reliable techniques to study the spatial and temporal variability of meteorological variables. Note, for example, the studies by Nery et al. (1998), who studied the rainfall of the States of Alagoas, Pernambuco and Sergipe, and correlated with their physical attributes, grouping them, using multivariate analysis to generate the homogeneous groups.

Keller et al. (2005) who used the technique of hierarchical grouping analysis with the objective of delimiting homogeneous regions in Brazil, using as analysis variables the temporal distribution of drought periods and precipitation frequency distributions. The results allowed identifying 25 pluviometrically homogeneous zones throughout the Brazilian territory, contributing to climatic studies of risks in agriculture.

Oliveira et al. (2015) used the Student's t test to statistically prove the existence of a significant difference between the mean values of various meteorological variables during the active and inactive phases of the Madden-Julian Oscillation (OMJ) in the Eastern Amazon. We used the wavelet transform to identify 14 cases of MJO occurrence, which the analyzes were performed. The analysis showed that the variables influenced by the convection, such as long wave radiation, mean, maximum and sunshine temperatures, showed differences between each phase of the MJO, at 95% confidence levels or higher.

Costa (2016) applied the wavelet transform (TO) to the rainfall series in homogeneous regions, in the State of Maranhão and in the SST areas of the Equatorial Pacific. The application of TO in rainfall shows that the global spectrum of the wave energy is more marked in the annual cycle for all stations representative of the homogeneous regions studied, and that in addition to the annual scale there are also interactions with the seasonal, intrasazonal, semi-annual, biannual and decadal. For the SST of the Equatorial Pacific, the annual scale is more intense in the eastern sector of the ocean, decreasing in the east-west direction, where the decadal scale becomes more pronounced.

In view of the above, the objective of this work was to apply TO the temporal series of precipitation to evaluate the variability of the same in different time-frequency scales in the state of Pernambuco and associate them with the atmospheric systems operating in the region.

2. Materials and methods

The study area corresponds to the state of Pernambuco. Situated in the center-east of the Northeast region. It has an area of 98,281 km^2. It is limited, in the North, with Ceará and Paraíba; To the South with Bahia and Alagoas; To the East, with the Atlantic Ocean and to the West with Piauí. It occupies an area of 98.149,119 km², distributed in 185 municipalities (IBGE, 2014). Figure 1 below shows, respectively, the location of the state of Pernambuco on the Brazilian map.

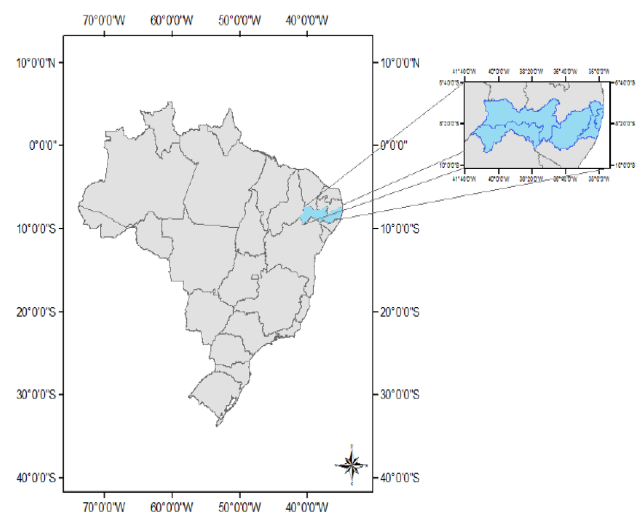

Figure 1 - Location of the state of Pernambuco on the map of Brazil.

Monthly precipitation data were analyzed in (mm), for the period 1995-2015, from 92 pluviometric stations distributed in the State of Pernambuco. These data were obtained from the website of the Pernambuco Agency for Water and Climate - APAC (2016).

Cluster Analysis (AA)

The Cluster Analysis (AA) is a method that consists in dividing a multidimensional system in groups, in each of which the individuals who present greater similarity between themselves and dissimilarity between groups meet (Wilks, 2006). The grouping criterion used in this study was that of Ward (1963). This grouping criterion proposes that at any stage of the partition, the loss of information resulting from the clustering can be measured by the sum of the squares of the deviations (SQD) of each point, to the mean of the groups to which it belongs (Everett, 1974).

$$SQD = \sum_{i=1}^{n} X_i^{\,2} - \frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2 \quad (1)$$

Where X_i is the number of individuals belonging to the ith group.

The distance used to measure the similarity or dissimilarity between the individuals (stations), Si and Sj, was at Euclidean distance. The Euclidean distance between two individuals xi and xj is given by:

$$d(x_i, x_j) = |x_i - x_j| = \left[\sum_{k=1}^{n} P_i (X_{ik} - X_{jk})^2\right]^{\frac{1}{2}} \quad (2)$$

Where x_{jk} represents the monthly values of the locations xi and xj and Pi is the weight associated with each individual.

Wavelet Transform (TO)

The TO emerged in its continuous form with the works of Morlet and Grossman in the 1980s (Morettin, 1999). The term wavelet refers basically to a set of functions with the form of small waves generated by translations $\psi(t) \rightarrow \psi(t+1)$ and escalations $\psi(t) \rightarrow \psi(2t)$ Of a base wave function $\psi_0(t)$. Which has finite energy, that is, a beginning and an end, this function is fully capable of dilating or compressing and called the mother wave (Blain and Kayano, 2011; Braga, 2014; Oliveira et al., 2015).

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\,\psi\left(\frac{t-b}{a}\right) \quad (3)$$

With a, b $\in \mathbb{R}$ e $a \neq 0$, being **a** the factor of dilation and **b** the factor of translation. The parameter **a** determines the oscillation frequency and the length of the wave and the translation parameter **b** determines its displacement position.

The factor $\frac{1}{\sqrt{a}}$ is called the energy normalization constant of each wave-daughter, so that together they maintain the same energy of the main wave $\psi(t)$, that is, the sum of the energies of all the wandering daughters. The equation of the wifes-daughters can be expressed by (Bolzan, 2006):

$$\psi_{j,k}(t) = \frac{1}{\sqrt{2}}\,\psi\left(\frac{t-k}{j}\right) \quad (4)$$

With j, k $\in \mathbb{R}$ e $j \neq 0$, where **j** is the expansion factor and **k** is the translation factor.

In this work will be applied the base wave of "Morlet", which has an excellent representation of non-stationary signals obtained in nature, such as symmetry, or not, and exhibits a mild or abrupt temporal variation.

The Morlet function is given by the following expression:

$$\Psi(t) = e^{i w_0 t} e^{-\frac{t^2}{2}} \quad (5)$$

Which represents a wave modulated by a Gaussian envelope. Where the parameter t (dimensionless) refers to the time period or time scale studied and w_0 (dimensionless) at the frequency of the signal.

In the case of an atmospheric wave signal, the Morlet wave is one of the most adequate functions to provide an understanding of precipitation patterns due to its good frequency resolution (Daubechies, 1992; Oliveira et al., 2015).

3. Results and discussion

In order to obtain the delimitation of the homogeneous regions of the precipitation, the group method of Ward (1963), from the matrix of the most expressive spatial and temporal common factors. The application of the method to the data matrix resulting from the monthly ACP made it possible to subdivide the State of Pernambuco into three homogeneous regions (RH) from the point of view of the precipitation regime (Figure 2).

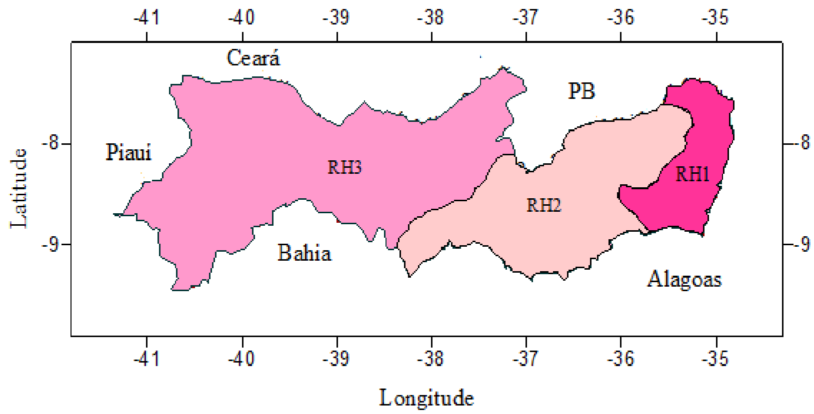

Figure 2 - Regionalization of precipitation from the spatial and temporal factors defined by the Ward method for the state of Pernambuco.

The application of TO to the monthly rainfall series in RH showed the oscillations present in the variable and allowed to detect the behavior in the different time and frequency scales in each region.

In RH1 covering the coast and the forest zone, whose annual average total rainfall is over 1500 mm, presents the highest rainfall indices in the May, June and July quarter. According to Braga (2000), the highest rainfall ratios in RH1 occur from May to June due to the occurrence of east waves and breeze systems, which occur frequently in this area. In Figure 3b, TO shows the dominant annual scale in practically the whole series, especially in the decade of 2000, where the maximum energies of the global energy spectrum (EPG) (orange hue) associated with the annual scale are found. The EPG configuration of RH1 behaves differently from other regions with pluviometric heights of over 300 mm (Figure 3a) in the years 2000, 2001 (La Ninã), 2004, 2005 (El Niño), 2011 and 2012 (La Niña), which coincide with energy interactions associated with the monthly and intrasazonal scale. There are also interactions on the biannual scale and 4 years in the 2000/2002 e 2012 (scale related to the ENSO cycle), agreeing with the peaks of variance observed in Figure 3c.

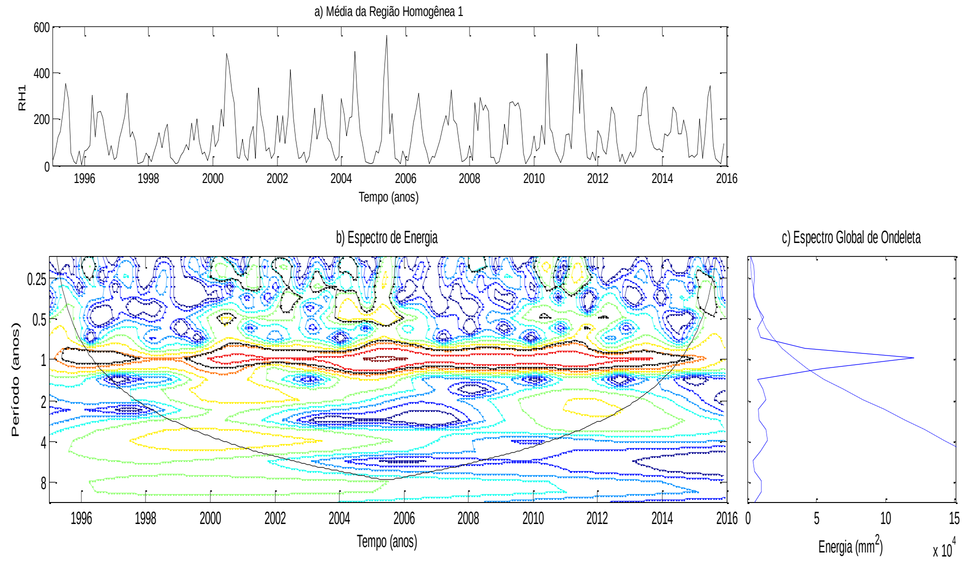

Figure 3 - a) Time series of precipitation, b) Wandering energy scalgram, c) Global spectrum, for average of RH1.

For RH2, which comprises the State Agreste, the highest rainfall levels also occur in the May, June and July quarter. In this region the dominant scale is the annual, but with less intensity than RH1. The greatest energies in the EPO occur in the years of 2004, 2005, 2010 and 2011 (Figure 4a). In addition to the annual scale, there are interactions between the intrasazonal and semi-annual scales (Figure 4b), agreeing with the peaks of variance observed in Figure 4c. In 2010 (year of La Nina occurrence), the rainfall in the rainiest months exceeded 200 mm (Trenberth, 1997).

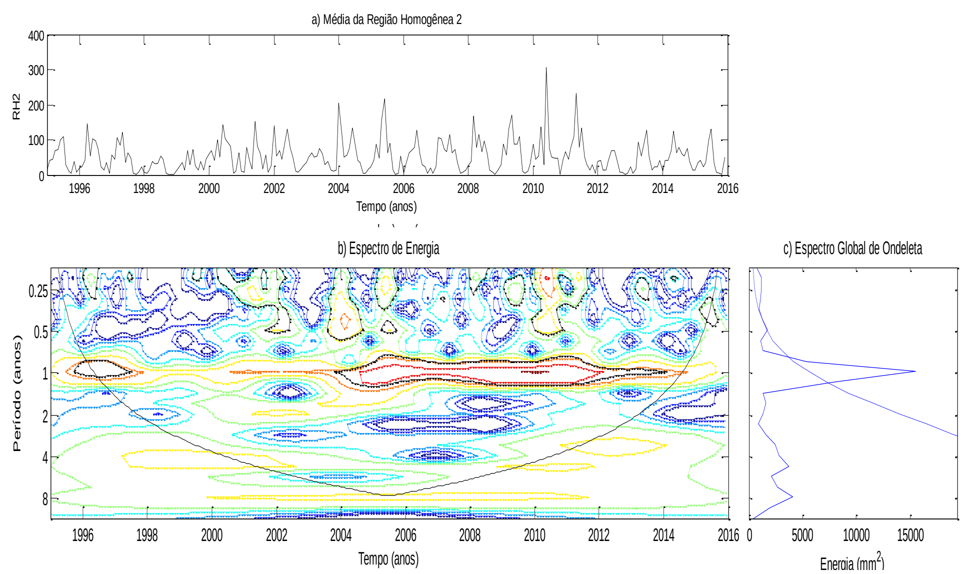

Figure 4 - a) Time series of precipitation, b) Wandering energy scalgram, c) Global spectrum, for Average of RH2.

RH3 covers the hinterland and the region of São Francisco which corresponds to the driest areas of the State, presents the highest rainfall rates during the summer in the January, February and March quarter extending until the month of April, in the months of March and April the ZCIT acts of more intense form.

It can be seen in Figure 5b of the EPO that the dominant cycle is the annual one, with less intensity in the years 1998 to 2003, and presents interaction with lower scales in the years 2001/2002, 2004/2005 and 2008 to 2010, agreeing with the peaks of variance observed in Figure 5c. It is observed in the time series a peak of more than 400 mm Figure 5a, associated with the annual scale and relations with the lower scales were observed, which caused high precipitation, year of El Niño, evidencing that the rains in the region this year were not influenced by the event.

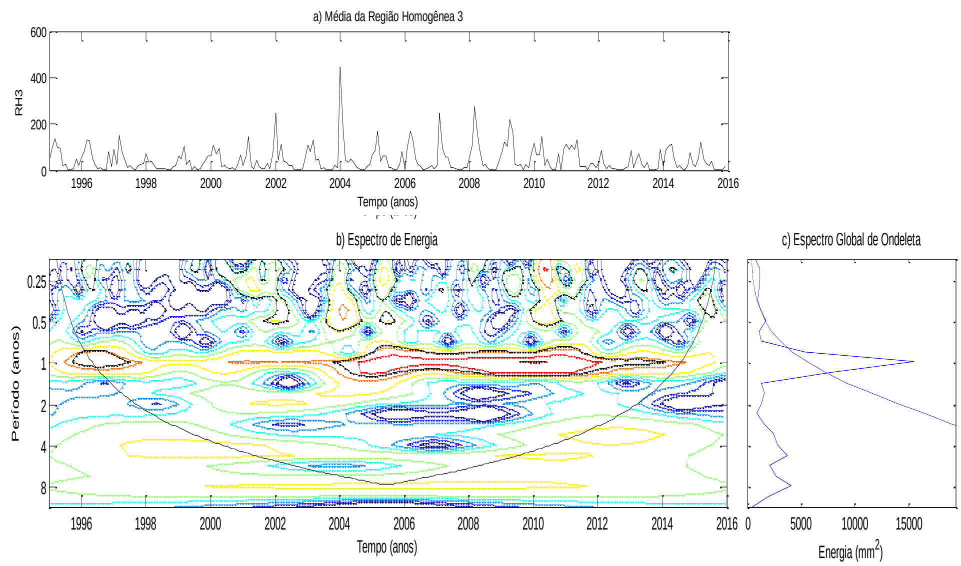

Figure 5 - a) Time series of precipitation, b) Wandering energy scalgram, c) Global spectrum, for Average of RH3.

It is observed that the two regions (RH2 and RH3) over the years present similar behaviors, but with different pluviometric heights, although the oscillation of the signal occurs in a similar phase. In these regions the most important precipitations are associated with the displacement of the ITCZ to the South and the performance of the VCAN in the summer (Gan and Kousky, 1986; Uvo, 1989).

4. Conclusions

Ward's agglomerative method provided the division of the state of Pernambuco into (3) areas of homogeneous precipitation regimes. This allowed us to prove through the technique of cluster analysis the general characteristic of the state of Pernambuco in relation to precipitation. In summary, this technique of multivariate analysis is an important tool, since it is able to show the existence of different regions with higher or lower water potential, which may help in the agricultural zoning of the region.

The TO applied to the climatological series of precipitation was able to decompose the signal at multiple time scales and show that the construction of the series is part of complex interactions of oscillations at different scales. The energy of the wavy of the rain made clear the relations between the intrasazonal, semiannual, annual and biannual scales, being also seen peaks in the scales between 4-8 years. It can be noticed the connection of maximum and minimum rain peaks with the performance of the different meteorological systems, such as: ZCIT, Eastern Disturbances and VCAN that act in the production of high rainfall indices.

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