

Rainfall diagnosis in different time scales in Maranhão using the wavelet transform

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Received 20 April 2016; accepted 04 May 2016

Abstract

This study aims to make a diagnostic analysis of seasonal and annual precipitation in different scales of time and relate them to atmospheric mechanisms that operate in different regions of the Maranhão State. For this we applied the methodology of Wavelet Transform (WT) the climatological series of rainfall in different homogeneous regions. The result of applying the WT to climatological series of rainfall has highlighted the different scales time, years that occurred heavy rains in the regions and show the dominant time scales and their interactions with smaller scales (seasonal, semiannual) and relate the variability of precipitation with major weather systems that operate in the state.

Keywords: Rain, time series, time scale.

1. Introduction

Most of Brazil's Northeast region is characterized as semi-arid, with high spatial and temporal variability of precipitation and high evaporation rate. Rainfall is a determining meteorological variable in defining water conditions of a region, which has great variability in the tropical region. The rains are directly connected to the local convection, which is characterized by the convergence of moist air at low levels of the troposphere, the result of low pressure near the surface, either due to differential heating of this surface, or the action of purely dynamic character of transient phenomena. The convection in the tropics is essentially controlled

by the general circulation of the atmosphere, large-scale phenomenon resulting from complex interactions between the surfaces of the planet, in particular the distribution of continents and oceans with uneven supply of solar energy, topography and vegetation cover (Molion and Bernardo, 2002).

In general, the mechanisms that govern the rainfall regime in the Northeast region are: Events El Niño-Southern Oscillation (ENSO); Sea Surface Temperature (SST) in the Atlantic Ocean basin, trade winds, Pressure at Sea Level (PSL) Andreolli and Kayano (2006); Intertropical Convergence Zone (ITCZ) over the Atlantic Ocean cold fronts, and Upper Tropospheric Cyclonic Vortex (UTCV).

Knowledge of the role of weather systems and the frequency in which they may affect the seasonal and annual variability of rainfall in a given region is of fundamental importance in agricultural planning, water and a socioeconomic region. In the last times new mathematical and statistical techniques have been developed and introduced in the scientific literature, in order to provide subsidies for the characterization of non-linear atmospheric regimes linked to the nature of the meteorological variables and the environment (Weng and Lau 1994; Vitorino et al . 2006; Braga et. al. 2014). Recently, Oliveira et al. (2015) used the wavelet transform and the Student's t-test to statistically prove the significant difference between the mean values of various meteorological variables during active and inactive phases of the Madden-Julian Oscillation (MJO) in the eastern Amazon. The results showed that weather variables influenced by convection (longwave radiation, average temperatures and maximal insolation) showed differences between each phase of MJO, at a significance level of 95% or higher.

Faced with the above considerations, the purpose of this study is to analyze the variability of precipitation in different time scales, in rainfall homogeneous regions of Maranhão State using the Transform Wavelet of Morlet in analysis time - range of energy scalograms for the period 1972-2013.

2. Materials and methods

Study area

The study area comprises the State of Maranhao, located in northeast Brazil, whose land area of 331,983.293 km², bordered to the north by the Atlantic Ocean to the south and southwest by the State of Tocantins, to the east by the State of Piaui and the West State of Pará, as shown in Figure 1. Due to its geographical position, it presents transition area characteristics, ie; north state processes the passage of northeastern climate domain to the eastern Amazon, and Brazil Central in the south-southwest portion (Atlas do Estado do Maranhão, 2002).

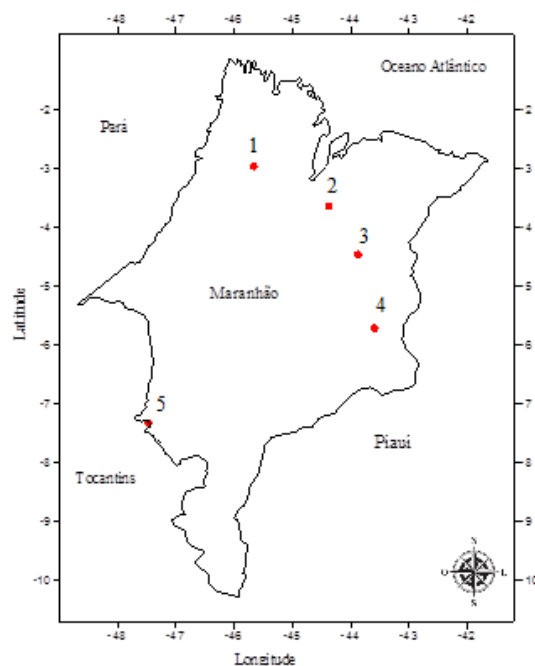


Figure 1 - Location of five of rainfall stations (Monção - 1, Cantanhede – 2, Codo – 3, Buriti Bravo - 4, Carolina - 5).

The state is not in the polygon of droughts, since it has well-defined climatic conditions, although the spatial and temporal distribution of rainfall is very irregular. In the northern coastal strip and Northwestern State the average annual total exceeding 1900 mm, reaching the lowest values in the South Central region, which is the driest part of the state. The climate of Maranhão is characterized as tropical and humid equatorial, average annual temperatures are above 24 ° C (Menezes, 2009; Birth, 2014).

Rainfall data

Were used stations precipitation monthly

rainfall series belonging to the homogeneous regions of the State, namely: Monção (Alto Turi) (-2.95 ° S -45.66 ° W) north, Cantanhede (-3.63 ° S , -44.37 ° W) in the northern part, Codó (-4.45 ° S -43.87 ° W), Buriti Bravo (-5.70 ° S -43.58 ° W) to the east and Carolina (-7.32 ° S -47.46 ° W) to the south, in the 1972-2013 period (Figure 2).

These data were obtained from the meteorological laboratory at the Universidade Estadual do Maranhão (UEMA) and Agência Nacional de Águas (ANA). Selected a period to submit the lowest number of failures and they had a common observation period.

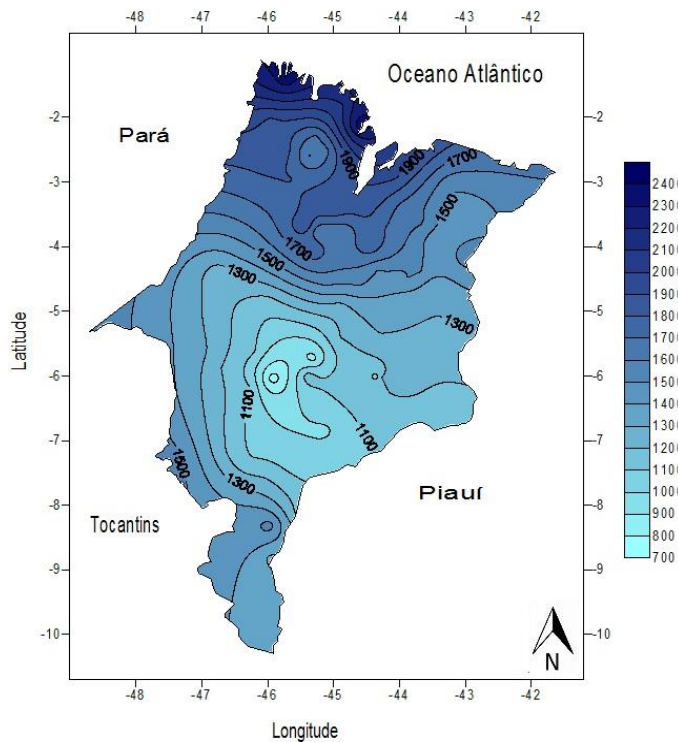


Figure 2 - Variability of total average annual precipitation in the period from 1972 to 2013 in the state of Maranhão.

Due to the large territory, its north / south and east / west are influenced by different atmospheric systems that depend on the time of year (Andreolli and Kayano, 2006; Souza and Cavalcanti, 2009; Menezes, 2009).

Wavelet Transform

The methodology used in this study is wavelet transformed, we attempted to make a multiresolution signal analysis of rainfall in multiscale occurred in the state.

Basically wavelets are localized in time (or scales), which are suitable for analyzing non-

stationary signals, containing transience (Torrance and Compo, 1998).

The WT emerged in its continuous form with the work of Morlet and Grossman in the 1980. The wavelet term refers essentially to a set of functions in the form of small waves generated by translations $\psi(t) \rightarrow \psi(t+1)$ and escalations $\psi(t) \rightarrow \psi(2t)$ a wavelet function base $\psi_0(t)$, that has finite energy, ie a beginning and an end, this function is fully able to dilate or compress and called wavelet-mother (BLAIN and Kayano, 2011; Morettin, 1999).

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

With $a, b \in \mathbb{R}$ and $a \neq 0$, and \mathbf{a} the expansion factor and \mathbf{b} the translation factor. The parameter \mathbf{a} determines the frequency of oscillation and the length of the wavelet and \mathbf{b} translation parameter determines its offset position.

The factor $\frac{1}{\sqrt{a}}$ It is called normalization constant energy of each daughter wavelet, so that together maintain the same energy as the main wavelet $\Psi(t)$, i.e., the sum of the energies of all daughter wavelets. The equation of daughter wavelets can be expressed by (Bolzan, 2006):

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

With $j, k \in \mathbb{R}$ and $j \neq 0$, begin \mathbf{j} the factor dilation and \mathbf{k} translational factor.

The Wavelet Transform involves a "linear" operation that can be used in the analysis of nonstationary signals to extract information from variations in their frequency, and to detect structures located in time or space.

For a function to be called wavelet base, represented by, it must satisfy the following properties:

1st Property: The integral of the function must be zero, ie:

$$\int_{-\infty}^{+\infty} \Psi_0(t) dt = 0 \quad (3)$$

This condition is known as a condition of "admissibility".

2nd Property: The wavelet function must have unitary energy, ie:

$$\int_{-\infty}^{+\infty} |\Psi_0(t)|^2 dt = 1 \quad (4)$$

The properties described above are equivalent to say that $\Psi_0(t)$ is squared and integrated, or that the wavelet function belongs to the set of square integrable functions $L^2(\mathbb{R})$ within the set of real numbers \mathbb{R} .

This work is applied to wavelet base "Morlet", which has a good representation of nonstationary signals obtained from nature, such as symmetrical or not, and presents a smooth or abrupt time variation.

The Morlet function is given by the following expression:

$$\Psi(t) = e^{iw_0 t \varepsilon} e^{-\frac{t^2}{2}} \quad (5)$$

representing a wave modulated by a Gaussian envelope. Where the parameter t (dimensionless) refers to the period or time range studied and w_0 (adimensional) the signal frequency.

You can then vary the "scale" of wavelet changing its width. This is the real advantage of wavelet analysis. Morlet waves have a high frequency while gaussian have low frequency. For the determination of short or long cycles modifies the wave type for Morlet or Gaussian, respectively.

3. Results and discussion

The following will be analyzed and discussed the results of the application of wavelet transform (WT) the monthly time series of precipitation selected within the five homogeneous areas previously determined by cluster analysis (Figure 3). The determination of precipitation in homogeneous regions was made by agglomerative method of Ward (1963) applied to the main

common factors temporal and spatial scores of monthly and annual rainfall.

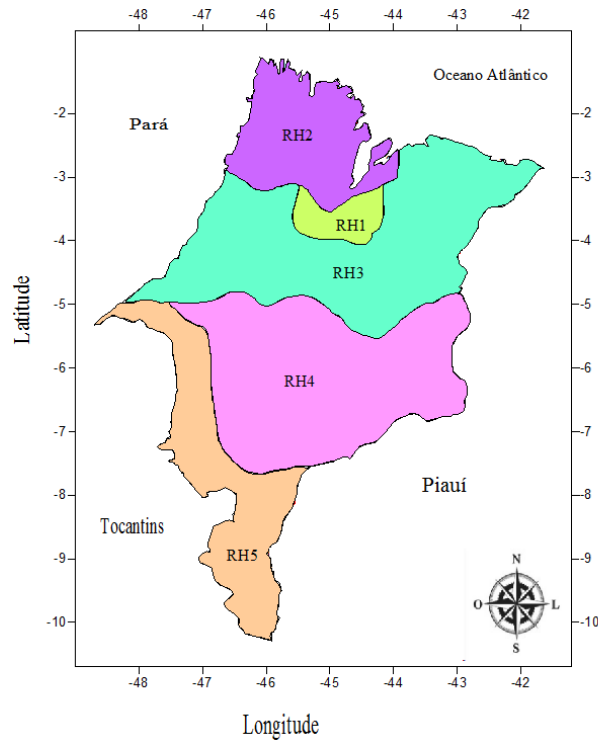


Figure 3 - Homogeneous Regions precipitation to the Maranhão State from the analysis grouping Ward of the main factors common spatial and temporal scores.

The colored areas on the scale of the Wavelet Power Spectrum (WPS), the black and red colors correspond to the standard variances (higher energy). The closed contours are significant to the 95% confidence level continuous curve in the shape of "U", which represents the cone of influence. In the Global Wavelet Spectrum (GWS), the values are significant at the 95% the right of the dashed curve.

The homogeneous region one (RH1) in Figure 3, located in the north central region of the State is considered the town of Cantanhede. Note that the dominant scale is annual, the maximum intensities of energy in the WPS precipitation occur in the years 1973/1974, 1984-1986, 1988,

1991, 1998, 2004, 2008 and 2009. In recent years, there is an intense energy associated with the annual scale, with very few interactions with intraseasonal and semiannual scales (Figure 4b). In the years 1973/1974, 1984/1985 and 2008 precipitation maxima coincide with La Niña years. It is observed also swings the scales of 4 and 8 between 1988-1992. In Figure 4d, corresponding to average per scales powers or variances (ASPV), it is seen that in the range of 0.25-2 years, some maxima are observed, and are associated with higher variance of the data in this time scale, some of these peaks coincide with increased rainfall in the Northeast in the years that occurred event "La Niña".

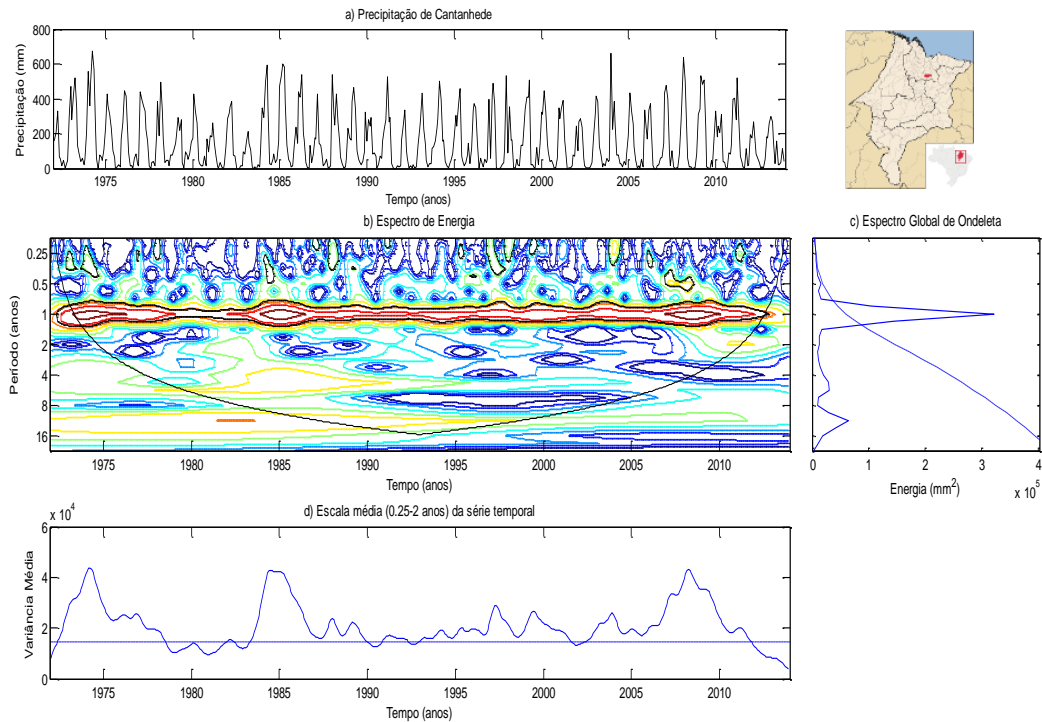


Figure 4 - a) Time series of precipitation; b) wavelet energy scalogram; c) global spectrum to the town of Cantanhede; d) Average per scales of power or variance.

For the town of Monção (Alto Turi) located north of the state is part of the homogeneous region two (RH2). It may be noted that the dominant scale is also annual, the maximum intensity of energy in WPS precipitation occur in 1974 and 1977 1985/1986, 1996 and 2007 were years of occurrence of La Nina years and transition phenomena between ENSO (Figure 5b). In the annual scale relationships exist with the smaller scales associated with the precipitation peaks exceeding 500 mm in years 1985/1986 and 700 mm in 2007 (Figure 5a), which can be confirmed in Figure 5d showing the wet years when power it is maximum. They are still observed some less significant peaks in the time scale of 2 to 4 years in the 1980s and 2000.

The homogeneous region three (RH3) represented by the town of Codó, WPS and GWS annual scale is striking, with higher energy intensity in the years 1984 to 1989, 1995, 1999/2000, 2003/2004 and 2008/2009 (Figure 6a). In most of these years, there was very subtle form of interactions with the semi-annual scale in the years 1984-1989 (Figure 6b), with rainfall height of 400 mm, these maximum precipitation can also be seen in ASPV, indicating that they were rainy years, which are found the largest energy and the variance on this time scale. In scalogram was evident nuclei higher energy associated with the timescale of two to four years, very significant in the decade 1980-2000.

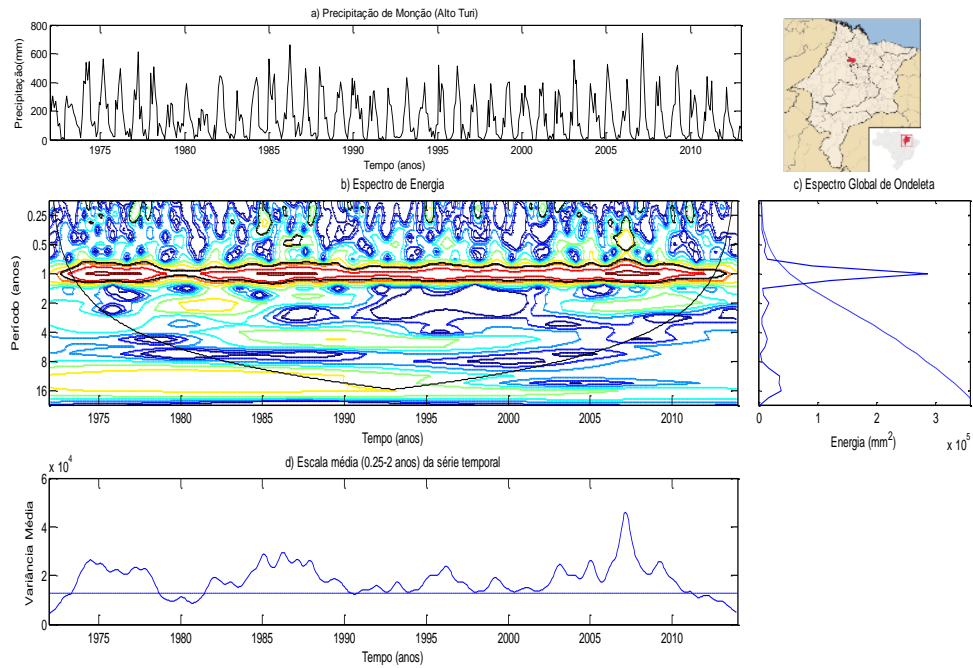


Figure 5 - a) Time series of precipitation, b) wavelet energy scalogram, c) global spectrum to the town of Monção, d) Average per scales of power or variance.

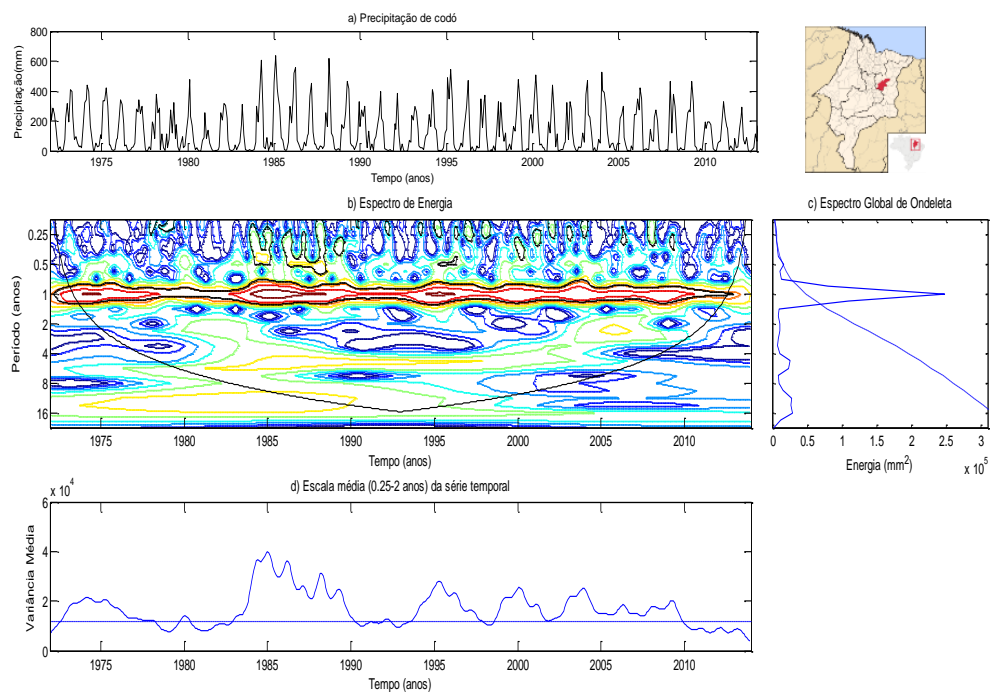


Figure 6 - a) Time series of precipitation b) wavelet energy scalogram, c) global spectrum to the town of Codó, d) Average per scales of power or variance.

The overall spectrum of the wavelet energy for the town of Buriti Bravo, homogeneous region four (RH4), located in the region East of the State is also marked by the annual cycle in this region the highest above 500 mm rainfall are recorded in 1984 / 86, 1989, 1997 and 2004 occurred in La Niña years and years transition between El Niño and La Niña (Aragão, 1998). In the annual scale relationships exist with the smaller scales associated with the highest precipitation peaks

(Figure 7a). There is a strong interaction in the range of 4 years in 1984-1986.

Figure 7d represents the Average per Scales Powers or Variances (ASPV), the average power in the band 0.25-2 years also shows the dry and wet years; i.e., when power in this band decreases considerably, this means a dry year and when the power is maximal means a wet year. In the years 1984-1986, 1989/90, 1996/97, 2004 and 2009, the rainfall is greater and cause increased power in this band.

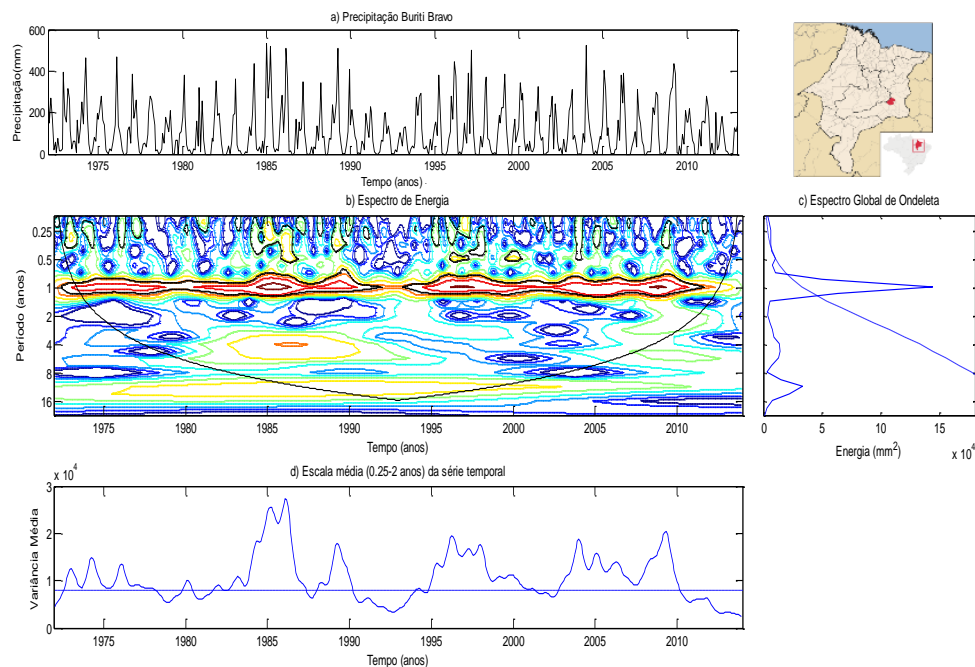


Figure 7 - a) Time series of precipitation; b) wavelet energy scalogram; c) global spectrum to the town of Buriti Bravo and d) Average per scales of power or variance.

The Global Wavelet Spectrum of precipitation to the town of Carolina, the homogeneous region five (RH5), also presents annual dominant scale there is maximum precipitation peaks in the years 1973, 1982/83, 1986/87 were years of El Niño, showing that the rains in this region of the State do not suffer influence of the event. Other maximum peaks in time series of rainfall occurred in the years 1973, 1982/83, 1987, 2004 and 2005 (Figure 8a). The WPS and GWS show the annual domain and a few

interactions with both the seasonal scale and semi-annual (Figure 8b and 8c). It also exhibits a peak of little significance between 4-8 years. As studies to Maranhão due to its geographical position to the south and southwest have Amazon features with more intense rains from November to April and are associated with UTCV, SACZ and Fronts (Kousky, 1988; Nascimento, 2014).

Figure 8d there is greater variance in the band 0.25-2, and has more power in the years

1982, 1983, 2004 and 2005 interactions between

scales cause an increase in energy in this band.

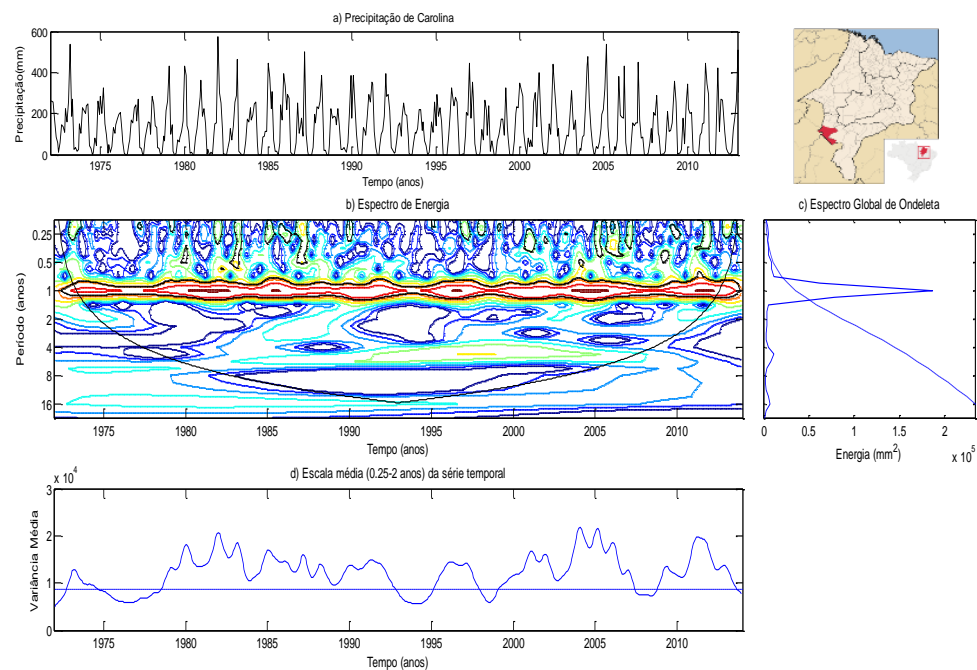


Figure 8 - a) Time series of precipitation, b) wavelet energy scalogram, c) global spectrum to the town of Carolina, d) Average per scales of power or variance.

In summary the applied methodology allowed to detect oscillations present in variable and check the behavior on different time scales at each point. The results of the Wavelet Transformed (WT) for the selected stations showed that the application of the methodology in precipitation shows that the overall Global Wavelet Spectrum is most striking in the annual cycle. Also observed were complex interactions of fluctuations in time scales, intraseasonal, semiannual, annual and biennial, there were peaks in the ranges between 4-8 years, but may be overlooked because of lack of statistical significance, because they are outside the cone of influence and the connection of the maximum and minimum peaks of rain with performance of various weather systems, such as ZACS, ITCZ, UTCV (Gan and Kousky, 1986; Nascimento, 2014). These results corroborate in part to work done by Braga et al. (2014) to the Paraíba State and Nascimento (2014) to Maranhão State. The authors also showed that the energy of rain

wavelet showed relations between the monthly scale, intra-seasonal, semi-annual, annual, where the interactions between weather systems in different meteorological scales that act in the production of rain (ITCZ, ENSO, VCAS), for example.

4. Conclusions

The Wavelet Transform applied to the climatological precipitation series was able to decompose the signal on multiple time scales and show that the construction of the series is part of complex interactions of fluctuations on different scales. Wavelet energy of rain was evident the relationship between seasonal ranges, semiannual and annual and interactions between weather systems that work for the production of high rain rate in different regions of the State. As allowed out on different scales time years heavy rains occurred in the regions, showing the dominant time scales and their interactions with smaller

scales (seasonal, semiannual), showing how the State suffers intense variability in rainfall patterns.

Acknowledgments

The authors thank the Agência Nacional de Águas (ANA) for granting the data. As well as the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for granting master's scholarships.

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