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Temporal analysis of rainfall and vegetation index using satellite images in Pernambuco State

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Abstract

The development of this work aimed, analyze and interpret the temporal standards of precipitation and NDVI in the Pernambuco state (Brazil). We used monthly average data of rainfall and NDVI obtained by Terra/MODIS satellite image, with spatial resolution of 1km, for the period from 2003 to 2013. We applied the Principal Components Factorial Analysis method to determine the variability seasonal standard variables. The results showed that the technique applied to the temporal analysis of precipitation explained 84.61% (CPs) of the data variance, and to NDVI the temporal analysis explained 90.21% (3 CPs). Altogether, we observed that the vegetation index is proportional to the amount of rain of the region and that the vegetation takes a while after the rainfall to develop.

Keywords: NDVI, MODIS, rainfall.

1. Introduction

Pernambuco is located in east-central Northeast of Brazil, dependent on weather conditions the quantity and distribution of rainfall. Across the state, rainfall decrease in east-west direction and, to a lesser extent, in the south-north direction. So there are three climate variations in Pernambuco: prevailing humid tropical climate in the coastal and forest zone where the rainfall varies between 700 and 2000 mm/year, sub-humid tropical climate that prevails in the arid zone, with rainfall volumes between 600 and 1000 mm/year and, finally, semi-arid, predominantly tropical climate in the hinterland and San Francisco, corresponding to 70% of Pernambuco territory that has a rainfall average of 600 mm/year. The annual average temperatures recorded for the territory range from 26 °C to 31 °C (ATLAS PERNAMBUCO, 2003).

The variability of precipitation and the temperature state is related to topography and vegetation and are also influenced by weather systems that interact with each other, give the characteristics peculiar state. The coastal vegetation of Pernambuco shows that mangroves are found in the areas in which they occur contact between sea water and rivers. The plants that inhabit mangroves have adapted to overcome the adverse conditions; the forests are predominantly represented by large trees, evergreens, such as mahogany and sucupira. In agreste, hinterland and San Francisco region, the predominant vegetation is the caatinga due to the dry climate of the region, and the vegetation denser agreste and reaching a larger size. The swamps of altitude, located within the Caatinga area, are disjunctions of coastal forest, occupying the upper levels of the hills and slopes to windward (ALMANAQUE ABRIL, 2012). Precipitation is a major component climate and its variability throughout the year directly affects the composition of the vegetation in a given region (Lexer et al., 2002). With the advancement of technology, observation of vegetation condition has been made through high-resolution remote sensors which are able to identify, monitor and map areas of vegetation across the globe. According to Huete et al. (2002), vegetation indices are set to designate the properties of vegetation and provide spatial comparisons and reliable time the earth's photosynthetic activity and changes in canopy structure, and allows the monitoring of seasonal variation, interannual phenological and biophysical parameters of vegetation long term.

From the spectral reflectances of the visible channel (VIS) and near infrared (IR) gives the Vegetation Index Normalized Difference (NDVI) which is an indicator of the amount of green biomass degree of growth and development of plants (Jense, 2009). From the combination of these reflectance spectral bands is possible to get contrast in relation to the different targets of the surface and to map the vegetation of a particular area or region. The vegetation behavioral changes are gradual over time and result in a gradual change in spectral reflectance of the vegetation, enabling growth detect possible problems and distinguish different types of vegetation.

Researchers around the world has been developing studies to better understand the relationships between vegetation and precipitation using remote sensing techniques. Srivastava et al. (1997) used the remote data to study the relationship between NDVI and total seasonal precipitation and sweating in the state of Karnataka (India), Nicholson and Farrar (1994) showed in their studies for Africa, that the variation of NDVI is more related to soil water storage capacity than the own rainfall. Braga et al. (2003) applied the Factor Analysis Principal Components in the NDVI temporal series to determine the response time of vegetation to rainfall in northeastern Brazil. Wang et al. (2010) used NDVI data from the MODIS sensor and the Loess Plateau rainfall data in China and applied ACP to determine the development of the vegetation cover. The results show that precipitation has a dynamic similar to the spatial pattern of NDVI. Sousa (2014) used monthly NDVI data from NOAA and MODIS satellites in the 2010s to find a relationship with rainfall in the state of Paraiba. The results showed that correlations are higher in drier months than in the rainy season.

Studies show a strong spatial or temporal relationship between climate and NDVI in seasonal and interannual time scales for a given period (Wang et al., 2001; Chen and Pan, 2002; Ji and Peters, 2003; Zhang, 2003; Piao et al., 2004; Mennis, 2006). Wang et al. (2003) examined temporal responses of NDVI to precipitation and temperature over a period of nine years (1989-1997) in Kansas. The NDVI images were obtained by NOAA/AVHRR. The results showed that there was a weak negative correlation between temperature and NDVI. The relationship between precipitation and NDVI is strong and predictable when viewed in the appropriate spatial scale. In this study was used monthly data from NDVI and rainfall for the period 2003 to 2013. Given the volume of data to be handled, it was decided to use a statistical technique that is able to reduce the initial set of NDVI data obtained by sensors with less loss of information possible. It has used the method of Factor Analysis Principal Components (PCA) (Richaman, 1986; Wilks, 2006). This technique was introduced in meteorology and climate research initially Lorenz (1956) which called the empirical orthogonal function. It has since been successfully employed by researchers worldwide (Gutman and Ignatov, 1998; Braga, 2000; Braga et al., 2003; Amanajás and Braga, 2012).

In this context, the work presented, aimed to improve previous studies for the state of Pernambuco, using statistical techniques of factor analysis Principal Component because this technique allows get and set the temporal patterns of variables (NDVI and rainfall) as well as spatially identify regions of the same behavior, associating them with weather systems that operated in the area during the study period.

2. Materials and methods

2.1 Study area

Pernambuco is among 7°15'45" and 9°28'18" south latitude and between 34°48'35" and 41°19'54" west longitude, limiting with the states of Paraíba, Ceará, Piauí, Bahia, Alagoas and east with the Atlantic Ocean. It covers an area of 98,149,119 km², distributed in 185 municipalities, with the estimated population of 9,277,727 inhabitants (IBGE, 2014). Figures 1 and 2 show, respectively, the location of Pernambuco state on the map of Brazil and the state of vegetation.

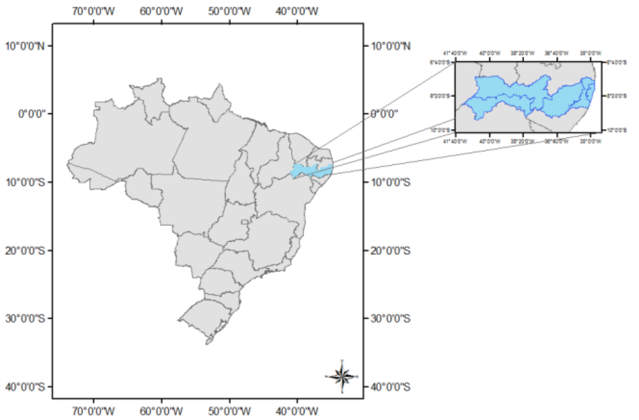

Figure 1 – Pernambuco state the location on the map of Brazil. Headlines appear the mesoregions.

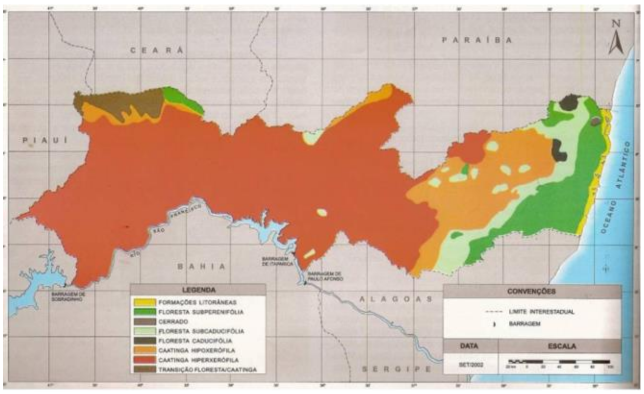

Figure 2 – Map of Pernambuco types of vegetation.

2.2 Rainfall Data

Were used in 81 weather stations rainfall data distributed throughout the state of Pernambuco from 2003 to 2013, obtained from Pernambuco Water and Climate Agency website - PWCA. The relief of Pernambuco (Figure 3) is moderate, much of the state is below 600m. It consists of three types of relief:

Coastal Lowlands, Plateau of Borborema and Country Depression. In the coastal state, the relief is almost all the average sea level. The Coastal lowlands, is nothing more than a coastal plain of sedimentary origin and altitude between 0 and 10m, with increasing altitude as moves away from the coast. Between the Zona da Mata and Agreste, is the Borborema Plateau, with an average altitude of 600m, from 1000m at the highest points. It is observed that the altitude decreases the Hinterland to San Francisco, forming an area of relative depression (compared to the Plateau of Borborema). The Sierra Araripe, which is on the border with Ceará, has an altitude of about 800m.

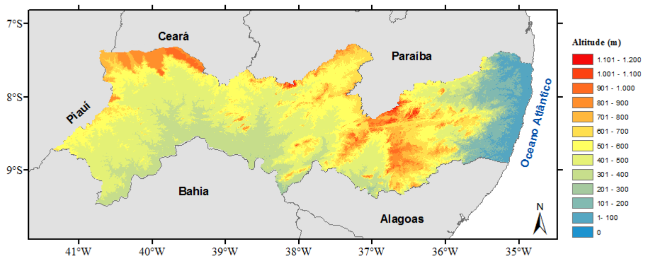

Figure 3 – Relief (meters) from the state of Pernambuco (Miranda, 2005).

The rainfall from one location can be enhanced or reduced according to the terrain characteristics. Figure 4 shows the total annual rainfall average for the period 2003-2013 in the state of Pernambuco. The highest rates are seen in the state of coastline, with values greater than 1800mm. While, the lowest values are observed in the San Francisco region and in the hinterland, with values less than 600 mm.

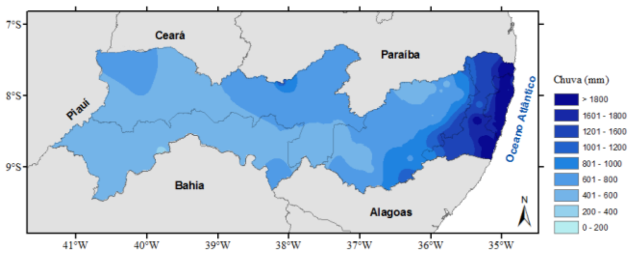

Figure 4 – Spatial distribution of total average annual precipitation (mm) in the state of Pernambuco, period 2003-2013.

2.3 NDVI data from Terra/MODIS

NDVI is a model resulting from the combination of reflectance levels in satellite images, the near infrared (0,725 - 1,10 μm) and the visible (0,58 - 0,68 μm). Soon, the NDVI is determined by the following equation:

$$NDVI = \frac{(NI - VIS)}{(NI + VIS)} \quad (1)$$

NDVI values range between -1 and 1, where areas with vegetation cover are linked to positive values of vegetation index. Materials that reflect more in the portion of red compared to the near infrared (clouds, water and snow) have negative NDVI. Bare soils and rocks reflect both visible and near infrared almost the same intensity, so that your NDVI reaches close to zero (Rizzi, 2004).

The MODIS NDVI product, specifically MOD13A3 product, with spatial resolution of 1 km, for the period 2003-2013, was acquired in the REVERB / NASA website at http://reverb.echo.nasa.gov/. This product is in the form HDF (Hierarchical Data Format) and is converted to the format .IMG.

Products are arranged in so-called mosaic “tiles”. The state of Pernambuco is located in tiles h13v09 e h14v09 (Figure 5).

Table 1 shows the NDVI product with the correction factor to be applied to convert the data. For this, the product multiplied by the correction factor MOD13A3. Moreover, the tiles were pooled and images were placed on the projection lat/lon WGS84 with the aid of software designed for extracting information from digital images. Thus, the images processed, extracted NDVI value for each pixel.

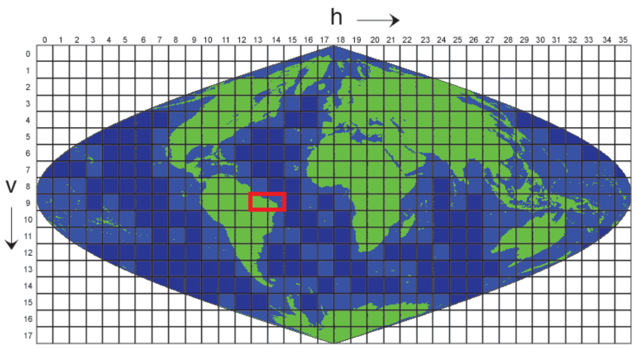

Figure 5 – Tiles MODIS sensor, especially the tiles where is the state of Pernambuco.

Table 1- Product MODIS and specifications.

Product	**Description**	**Multiplicative Factor**	**Aditional Factor**	**Resolution (spatial and temporal)**	**Unit**
MOD13A3	NDVI	0,0001	-	1 km^2 monthly	Dimensionless

Source: LP DAAC (2012)

2.4 Factor Analysis in Principal Components

The Principal Component Analysis (PCA) was developed by Pearson (1901). It is defined as a technique to reduce the number of variables of the data set, identifying the default correlation or covariance between them, and generating a smaller number of new variables.

For PCA, it takes a matrix of original data X p variables for n individuals in order to obtain a variance and covariance matrix S by:

$$S = \frac{1}{n}.X.X^t \quad (2)$$

Where X is the array with values centered, Xt the transposed matrix n is the number of individuals. The R correlation matrix will equal the array of variance and covariance, then:

$$R = S = \frac{1}{n}.X.X^t \quad (3)$$

The R matrix is a symmetric matrix and positive correlation dimension (pxp) Diagonalizable by an orthogonal matrix A, called base change eigenvectors, thus:

$$D = A^{-1}.R.A = A^t.R.A \quad (4)$$

Where D is the diagonal matrix and A^{-1} is the inverse of the matrix A. As the base change matrix for a new reference system consisting of the eigenvectors of R, the principal components (PC) U1, U2, ... , Up, are obtained by linear combinations of eigenvectors of the transpose

(A^t) and the observation matrix (X) standard, as described below:

$$U = A^t . X \quad (5)$$

To estimate Xi n-th local values, is used:

$$X_i = a_{j1}U_1 + a_{j2}U_2 + \cdots + a_{jk}U_k + \cdots + a_{jp}U_p \quad (6)$$

Where a_{ij} is the set of X of eigenvalues in descending order of the most significant eigenvalues of a_k in A.

The percentage of variance explained of the eigenvalues in descending order is given by:

$$\%Var(X) = \frac{\sum_{i=1}^{n} \lambda_i}{\sum_{j=1}^{n} \lambda_j} \quad (7)$$

In this study the rotated eigenvectors was employed (Varimax) by presenting better explanatory power of the factors. The correlation between the i-th original variable and the i-th main component is:

$$Coor(X_i Z_j) = a_{ij} . \sqrt{\lambda_i} \quad (8)$$

Being, a_{ij} j-th element of the i-th eigenvector and λi the i-th eigenvalue. For this analysis we used a suitable statistical software.

3. Results and discussion

3.1 Temporal analysis of precipitation

Table 2 contains the percentage of variance explained for the first two common temporal rotated factors that explain 84.61% of the total variance of the series and truncated second criterion Kaiser (Mingoti, 2005).

Figure 6 shows the first two rotated factors of rainfall. The first time common factor of the precipitation that explained 51.26% of the total variance of the data, shows high correlations above 0.7 in the months from April to October. The spatial distribution associated with this factor (Figure 7a) shows that the largest contribution (scores) greater than 1.5 range from the Recife metropolitan area to the south of Pernambuco Forest Zone. Negative values lower than -1 are observed in the State of the Wild. It is observed in the arid zone marked a transition zone that separates the rainfall regime of the west and east of the state. Possibly the rains associated with this pattern are the result of the Eastern systems operating in Pernambuco those months. According to Braga (2000) the rainfall totals more influenced by easterly disturbances occur in the months of May and June.

Table 2 - Sequence of eigenvalues and the contribution (%) to the total variance of the rotated monthly average data of rainfall in the state of Pernambuco.

Components	Eigenvalues			Rotated charges		
	Total	Variance (%)	Accumulated (%)	Total	Variance (%)	Accumulated (%)
1	7,19	59,89	59,89	6,15	51,26	51,26
2	2,97	24,73	84,61	4,00	33,36	84,61
⋮	⋮	⋮	⋮			
12	0,01	0,07	100,00			

Factor 2 (Figure 6), which explains 33.36% of the total variance of the series of rainfall, has high correlations above 0.80 in the months from December to March. Analyzing the spatial pattern of the second factor (Figure 7b), contributions are observed above 1 in the North Coast and Hinterland (Sierra Araripe). Smaller contributions are observed in Pernambuco hinterland, and to a lesser extent, in the central region in the valley of San Francisco and a portion of the Zona da Mata and Agreste of the state. This second factor shows the rains from the ITCZ and VCAS that predominate in the region in the months of summer and fall.

According to Gan and Kousky (1986) observed that the VCAS in tropical latitudes are formed in the Atlantic Ocean, between the months of November and March, most often between the months of January and February.

Already Uvo (1989) who made a very detailed study of the ITCZ in the Pernambuco region that receives the influence of the ITCZ is the Hinterland. In this area, the rainy season is from January to June, and features maximum amounts of rainfall in March and April, months in which the ITCZ acts more intensely (Melo, 1997).

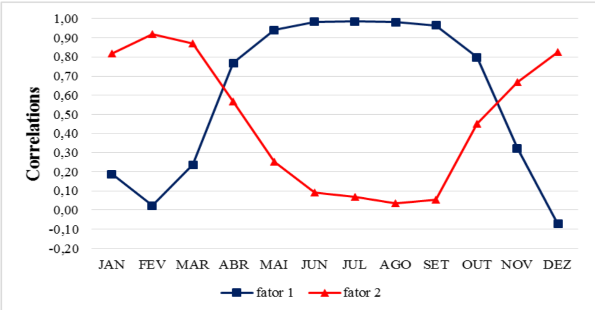

Figure 6 – Rotated factorial loads (correlations) for the two common factors of rainfall that explain 84.61% of the total variance (51.26% + 33.36%) in the state of Pernambuco.

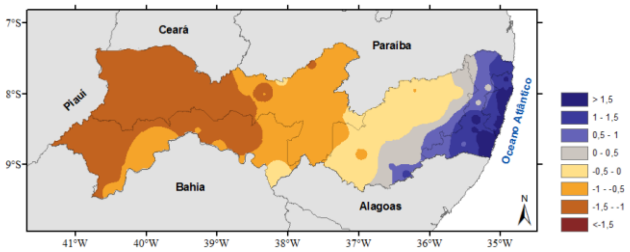

Figure 7a – Spatial pattern to the first common factor (scores) of precipitation in Pernambuco

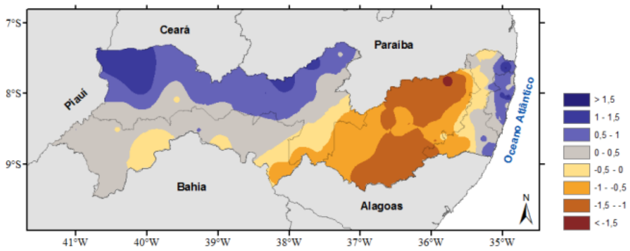

Figure 7b – Spatial pattern to the second common factor (scores) of precipitation in Pernambuco.

3.2 Temporal Analysis of NDVI

In Table 3, the explained variance is observed, in percent, for the first three common temporal rotated factors that explain 90.21% of the total variance of the series and cut second criterion Kaiser.

Following are analyzed and discussed the results of the application of the PCA for the NDVI temporal series for the state of Pernambuco. The first factor that explains 57.26% of the total variance of the series, presents significant correlation (>0.8) in the months from May to December (Figure 8). The spatial distribution associated with this common factor presents contributions in excess of 1.5 in the Coast, the Jungle Zone and small nuclei in Agreste (swamp altitude). From 37.0° longitude contributions descrescem toward the interior of the state, with less than -1.5 values in the extreme southwest (Figure 9a). The vegetation response in the east is associated to the type of vegetation (irrigated agriculture and Atlantic Forest), as well as the performance of east systems.

Table 3 - Sequence of the eigenvalues and the contribution (%) to the total variance of the rotated monthly average of NDVI data in the state of Pernambuco.

Components	Eigenvalues			Rotated charges		
	Total	Variance (%)	Accumulated (%)	Total	Variance (%)	Accumulated (%)
1	6,99	58,22	58,22	6,87	57,26	57,26
2	2,69	22,40	80,62	2,70	22,48	79,74
3	1,15	9,58	90,21	1,26	10,46	90,21
…	…	…	…			
12	0,00	0,04	100,00			

The second common factor explains 22.48% of the total variance of NDVI data and has high correlation greater than 0.8 in the months February to April (Figure 8). The pattern of this factor shows high contributions greater than 2 in the central-northern region of the Wild in isolated nuclei in the Hinterland, around 37 ° W and in the southern coast (Figure 9b). In the other regions of the state the negative contributions are less than -0.5.

Furthermore, the third common factor explains 10.46% of NDVI data and has the largest positive correlation only 0.8 in January (Figure 8). The spatial configuration of this factor (Figure

9c) shows the greatest contributions of the NDVI, greater than 1.5, in southeastern coast and the Forest Zone, and southwest of the state. This factor may be associated with VCAS that operate mainly in the southwest and even the breeze systems in the east. In the other regions, the contributions are less than -1.0, suggesting the driest region this month.

Regarding the response of vegetation to the occurrence of rain, Barbosa (1998) noted that the best correlation was found between total precipitation of two consecutive months with the NDVI of these last two months. Braga et al. (2003) observed that the vegetation of savanna reaches maximum force value in just a month after large volumes of rain.

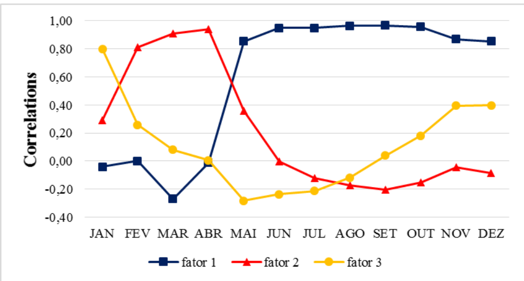

Figure 8 – Rotated factorial loads (correlations) for the three common factors of NDVI that explain 90.21% of the total variance (57.26% + 22.48% + 10.46%) in the state of Pernambuco.

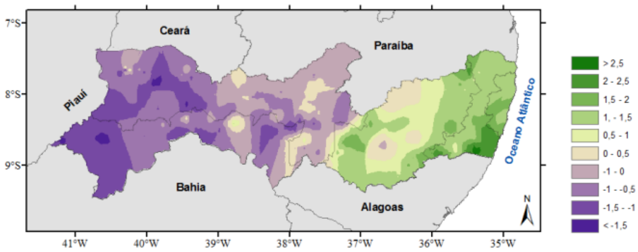

Figure 9a – Spatial pattern to the first common factor (scores) of NDVI in Pernambuco.

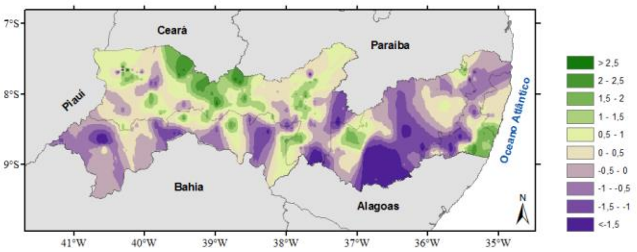

Figure 9b – Spatial pattern to the second common factor (scores) of NDVI in Pernambuco.

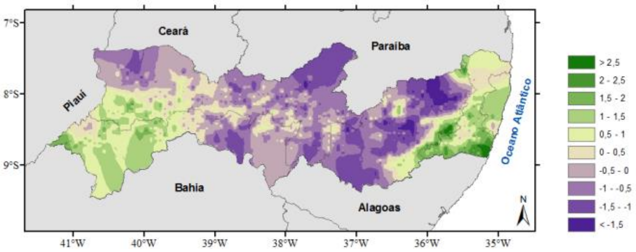

Figure 9c – Spatial pattern for the third common factor (scores) of NDVI in Pernambuco.

4. Conclusions

The first monthly common factor in these 11 years studied, showed high correlations rainfall occurred from April to October in the eastern part of the state, while for the NDVI were higher from May to December in the same region. This shows that after the rains, vegetation takes a while to develop. In the first factor, the rains are associated with the systems East and in the case of the second common factor, high rainfall correlations were from November to March, while the NDVI was higher from February to April and is associated with the ITCZ and VCAS.

The results from the application of principal component analysis to the time of rainfall and NDVI series allowed to define spatial patterns and temporal correlations of the variables, identifying the behavior of the same and the performance of meteorological phenomena on different time scales, adding some studies conducted in the state.

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