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Variability of the Atlantic Forest based on the EVI index and climate variables in Cunha-SP, Brazil

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Key words:
rainfall
biome
southeast region
remote sensing

ABSTRACT
The aim of this study was to evaluate the variability of the Atlantic Forest in the municipality of Cunha-SP, Brazil, based EVI index (Enhanced Vegetation Index) and climatic variables (air temperature and rainfall). Images of MOD13Q1 product from MODIS sensor, which represent the index EVI were used. The descriptive statistics and multiple were applied to climate variables and EVI for the cycle 2007/2008 (strong La Niña event). The lowest average values of the rain were found for 2008 (171.60 mm), while the highest average rainfall was found for 2007 (187.02 mm). The vegetation behaved in a manner contrary, where the lowest average EVI index was found for 2007 (0.38), already 2008 had the highest rate (0.46), respectively. The coefficient of determination between the rainfall and the EVI in 2007 (R^2 = 0.43) higher than in 2008 (R^2 = 0.12), followed by correlation indexes in 2007 (r = 0.65) and 2008 (r = 0.34). However, both indexes were low, except correlation index in 2007. In the multiple regression analysis for the year 2007 obtained 87% correlation, while in 2008 only 27%. There is no correlation between vegetation and air temperature.

Palavras-chave:
precipitação
bioma
região sudeste
sensoriamento remoto

Variabilidade da Mata Atlântica baseado no índice EVI e variáveis climáticas em Cunha-SP, Brasil

RESUMO
O objetivo deste trabalho foi avaliar a variabilidade da Mata Atlântica no município de Cunha-SP, Brasil baseado no índice EVI (Enhanced Vegetation Index) e variáveis climáticas (temperatura do ar e chuva). As imagens do produto MOD13Q1 oriundas do sensor MODIS, que representa o índice EVI foram utilizadas. As estatísticas, descritiva e múltipla foram aplicadas as variáveis climáticas e o EVI para o ciclo 2007/2008 (evento La Niña-forte). Os menores valores médios da chuva foram encontrados para o ano de 2008 (171,60 mm), enquanto que a maior média de chuva encontrada foi para o ano de 2007 (187,02 mm). A vegetação se comportou de maneira contrária, onde a menor média do índice EVI foi encontrado para o ano de 2007 (0,38), já o ano de 2008 obteve o maior índice (0,46), respectivamente. O coeficiente de determinação entre a chuva e o EVI em 2007 (R^2 = 0,43) superior ao ano de 2008 (R^2 = 0,12), seguido dos índices de correlação em 2007 (r = 0,65) e 2008 (r = 0,34). No entanto, ambos os índices foram baixos, exceção índice de correlação em 2007. Na análise de regressão múltipla para o ano de 2007 obteve 87% de correlação, enquanto em 2008 somente 27%. Não existe correlação entre a vegetação e temperatura do ar.

Introduction

The fifth most threatened biome in the world is the Atlantic Forest. It originally covered over one million square kilometers, distributed along the Brazilian coastal region. It was reduced to less than 100,000 km^2 vegetation distributed across multiple islands of small forest fragments, separated from each other (IBAMA, 2002; RBMA, 2012, Galindo-Leal e Câmara, 2005; Gascon et al., 2000).

Brazilian biomes are threatened by human activities, particularly in agricultural production and property occupation (Aleixo et al., 2010). They are affected by the variability of regional to large-scale meteorological systems, and with influence on the increase in drought severity in some regions of Brazil (Caúla et al., 2015). Atlantic Forest and Cerrado biomes were included in the list of "hotspots" of biodiversity, ie, they have become priority regions for conservation at the global level (Myers et al., 2000).

weather effects in Brazil caused by the El Niño-Southern Oscillation (ENSO) have different impacts for cold phase (La Niña) and warm phase (El Niño). In the Mid-West and Southeast effects are few predictable and may range. Although the thermal regime can also be modified, climate anomalies of greater impact in Brazil are mainly related to rainfall. In general, anomalies of rainfall related to El Niño and La Niña affect the same Brazilian regions in the same periods of the year, but in opposite manner (Cunha et al., 2011).

Satellite images allows the acquisition of various information relevant to research related to environmental conditions, such as: obtaining and analysis of vegetation indexes (Luchiari, 2001), called spectral indexes (Miura et al., 2001) and, lastly, on deforestation and forest regeneration dynamics (Delgado et al., 2015). Zanzarini et al. (2013) indicate that such indexes are two or more spectral bands data connections assigned to the purpose of improving the association of these data with the vegetation biophysical parameters.

Goulart et al. (2015) applied some vegetation indexes in the municipality of Rio de Janeiro-RJ, and showed that the vegetation growth is correlated with climatic elements, being the rainfall and solar radiation those with greater influence. Delgado et al. (2012) in the State of Minas Gerais found high correlation of sugarcane growth results associated with rainfall in the state. Rosa et al. (2013) They claim that there is a similarity between the behavior of vegetation indexes and rainfall. The authors showed that high vegetation index values result from increased rainfall. This is due to the months of higher rain incidence coinciding with the rainy season, followed by increased temperature, and its reduction coincide with lower NDVI and EVI values in winter.

Pereira et al. (2013) showed that the orbital data such as MODIS sensor (Moderate Resolution Imaging Spectroradiometer) enable obtaining multispectral information with several space and temporal resolutions. The authors comment that beyond these multispectral information, it allow to estimate several physical, chemical and biological parameters needed in simulating the interactions between electromagnetic radiation and the objects that make up the Earth's surface.

Therefore, the aim of this study is to evaluate the variability of the Atlantic Forest in the municipality of Cunha-SP, based on the EVI index and climatic variables during the episode of strong La Niña.

Material and Methods

Municipality of Cunha – SP is located between the Serra do Mar, Bocaína and Quebra Cangalha, with a territorial extension of 1,410 km² and population of 25,000 habitants (13,000 in rural area and 12,000 in urban area), whose geographical coordinates are 23° 04’ 28” S and 44° 57’ 35” W (Figure 1) and 950 m of altitude (IBGE, 2016). The municipality is distant 235 km from Metropolitan Region of São Paulo (MRSP), being inserted into two conservation units (CU), the Parque Nacional da Serra da Bocaína and Parque Estadual da Serra do Mar (PORTAL DE CUNHA, 2015).

According to Köppen’s classification, predominant climate of Cunha - SP is “Cwa”, caracterized by altitude tropical, with rainfall in summer and drought in winner, with average temperature around 22°C (CEPAGRI METEOROLOGIA UNICAMP, 2015).

Images of MOD13Q1 sensor, from MODIS sensor TERRA, which represent EVI (Enhanced Vegetation Index) with spatial resolution of 250 m was used on the study. EVI uses wavelengths from near infrared, red and reflectance in the range of blue to indicate biome vegetative vigor. Through the canopy substrate reduction and the influence of the atmosphere, this index allows better monitoring of vegetation (Huete et al., 1997).

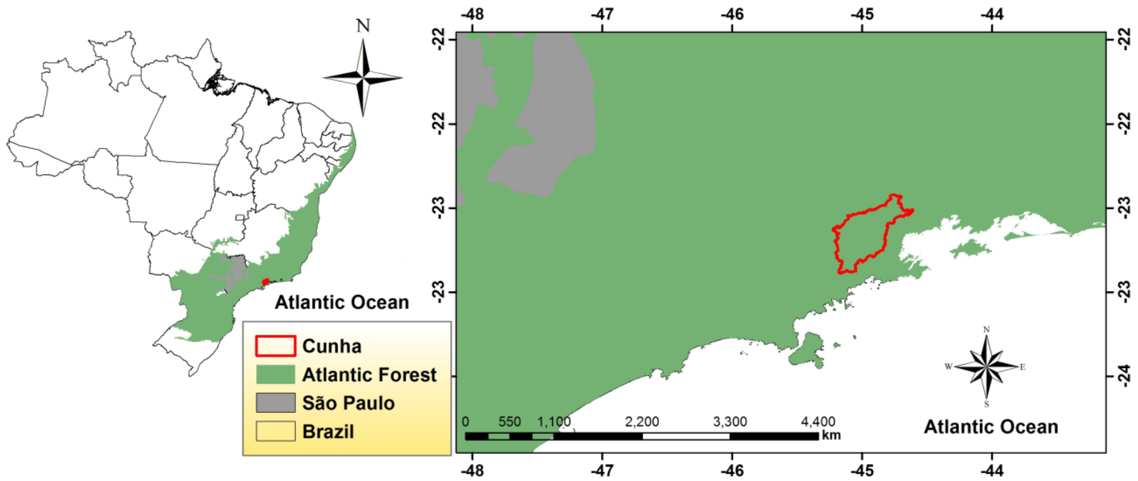

Figure 1. Geographical location of the municipality of Cunha – SP on Atlantic Forest biome.

EVI was formulated according to the combination from SAVI (Soil Adjusted Vegetation Index) and ARVI (Atmosphere Resistant Vegetation Index) (Equation 1) (Holzmann et al., 2014). Due to the reduction of canopy substrate effects and the influence of the atmosphere, the EVI allows better monitoring of vegetation, because it is an index developed to enhance the vegetation signal by optimizing sensitivity in regions with high biomass values (Jiang et al., 2008). According to Gao et al. (2000), EVI has better response to structural changes in the canopy, including LAI (Leaf Area Index), type of canopy, plant physiognomy and canopy architecture.

$$EVI = G * \frac{NIR - R}{NIR + C1 * R - C2 * B + L} \qquad (1)$$

wherein: NIV= reflectance in the near infrared; R= reflectance in red; A= reflectance in blue; C1= correction coefficient of atmospheric effects for the red band (6); C2= correction coefficient of atmospheric effects for the blue band (7.5); L= correction factor for soil interference (1); G= gain factor (2.5). Coefficients C1 and C2 can be changed according to regional conditions.

The product was obtained from the following electronic address: www.glovis.usgs.gov/. MODIS data were pre-processed with the MODIS Reprojection Tool algorithm (MRT) for transforming the HDF for GEOTIFF format and sinusoidal projection for UTM WGS 84. For the correct visualization and interpretation of the product, the images were then processed, because it is necessary converting the image digital scale. This conversion was carried out through the tool Arctoolbox, Map Algebra, Raster Calculator (Equation 2).

$$VF = ND * 0.0001 \qquad (2)$$

wherein: ND = image (MOD13Q1) and 0.0001 = transformation factor to physical value of vegetation index.

The images were extracted into the polygon of interest through the tool Arctool box, spatial analyst tools, Extract by mask. From the masks, descriptive statistics can be extracted. All data were processed in the Laboratory of Environmental Remote Sensing and Applied Climatology (LSRACA) at Universidade Federal Rural do Rio de Janeiro (UFRRJ), using licensed software ArcGIS version 10.2.1.

Descriptive and multiple statistics was applied to rainfall, temperature and EVI data set for the years 2007 and 2008. Firstly the two-year cycle was chosen, due to be characterized as La Niña event (strong) from classification adopted according to CPTEC/INPE (2015). Then, due to the passage of Front Systems (SF) on MRSP and that for the cycle was a significant increase, according to results obtained by Zeri et al. (2016), we analyzed the average, minimum, maximum, standard deviation, variance and coefficient of variation (CV). Simple linear regression (R^2) and correlation (r) between EVI, rainfall and air temperature were obtained from Conventional Weather Station (CWS), in Cunha-SP, from Instituto Nacional de Meteorologia (INMET).

To correlate and analyze the data that best explain those obtained by EVI with rainfall, we proceeded to the use of multiple regression analysis. Multiple linear regression aims to verify the existence of a functional relationship between a dependent variable Yi with two or more independent variables (X_i, i= 1, 2, ..., k). Statistical regression model is given by Equation 3.

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + ... + \beta_k X_{ki} + \varepsilon_i \quad (3)$$

The parameters β_0, β_1, …, β_k from Equation 3 are the coefficients of regression, wherein β0 is the line intercept on the ordinate axis and β_1, …, β_k is the curve of the line. The term εi represents the error associated with the distance between the observed value Y_i and the corresponding point on the model curve.

When the number of observations (n) is greater than the number of predictor variables (k), the most usual method for estimating the regression equation is the method of ordinary least squares. This method estimates the parameters of regression in order to minimize the quadratic sums of the residues (Montgomery et al., 2001).

Analysis of variance (ANOVA) is used for the significance test of regression, i.e., to verify the existence of linear relationship between predictors and predictand (Neter et al., 2004). Checking for the quality of a fitted equation may be performed using the coefficient of determination (R^2) from multiple regression, wherein $0 \leq R^2 \leq 1$ (Equation 4).

$$r^2 = \frac{SQReg}{SQT} \quad (4)$$

wherein: SQReg = Sum of regression squares; SQT = Sum of total squares.

Fitted coefficient of determination (Equation 5) is a control measure that takes into account both the variability of Yi, which is explained by the model, as the number of control variables used (Montgomery et al., 2001).

$$R^2_{aj} = 1 - \frac{n-1}{n-p}(1 - R^2) \quad (5)$$

wherein, p = number of model parameters.

Results and Discussion

Table 1 shows information about descriptive statistics of the climate variables and EVI index. The lowest average values were found for 2008 (171.60 mm), while the higher rainfall average was found for 2007 (187.02 mm). Vegetation behaviored in contrary manner, where the lowest average EVI index was verified for 2007 (0.38), since the year 2008 obtained the higher index (0.46), respectively.

Table 1. Descriptive statistics of rainfall, temperature and EVI data.

Statistics*	Rainfall (mm) 2007	Rainfall (mm) 2008	Temperature (°C) 2007	Temperature (°C) 2008	EVI 2007	EVI 2008
Average	187.02	171.60	28.06	28.33	0.38	0.46
Minimum	49.49	43.84	24.32	23.19	0.19	0.25
Maximum	360.54	387.59	30.07	32.47	0.55	0.51
SD	115.84	115.31	1.84	2.77	0.10	0.08
Variance	13420.02	13296.92	3.38	7.69	0.01	0.01
CV(%)	61.94	67.20	6.55	9.79	27.38	16.79

*CV (%): coefficient of variation; SD: standard deviation.

Coefficient of variation (CV) obtained for temperature and EVI in the years 2007 and 2008 can be considered low and indicates lower temporal oscilation of these variables over the year. Variance and standard deviation (SD) for rainfall during 2007 and 2008 can be considered high, revealing high temporal variability of these variable. The magnitude of the dispersion measurements observed in this work are in accordance with that reported by Torres et al. (2016), who observed high SD, variance and CV values for rainfall in 32 municipalities Estado de Mato Grosso do Sul.

Goulart et al. (2015) identified that the NDVI index, in 60% of the observed years, it was the index that had the highest correlation with the rainfall in the RJ compared to others. Delgado et al. (2012), at an experimental area in Triângulo Mineiro region, State of Minas Geraisshowed that the sugarcane grew only due to water availability in the region, being high the correlation with rainfall regime in the region.

Francisco et al. (2015) applied the NDVI index to Caatinga region and concluded that the absence or decrease in rainfall in this region are in an advanced process of desertification. Alvalá et al. (2009) applied the EVI and NDVI indexes to Cerrado of Amazon region and concluded that the EVI showed higher correlation with the rainfall in detecting period with lower production of leaf biomass in the land use classes. In addition, the authors report that the seasonal pattern of land use and occupation follow the rainfall patterns in the region. In a multi-temporal study of EVI images with climatic variables occurred at a natural forest and agricultural crop, Ribeiro et al. (2009) observed that green biomass accumulation represented by the maximum values found in the EVI series presents similarity to climatic variables, with greater accumulation during the summer and lower in winter.

Monthly temporal evolution of the EVI indexes for the years 2007 and 2008 is shown in Figure 2. We observed that in 2007 EVI index was higher compared to 2008 in the rainy period and lower in the dry season. There was a marked decrease in October and an increase in subsequent months. According to Zeri et al. (2016), passage of FS in October in the interior and coastal region was 3 FS (2007) and 5 FS (2008). We verified high variability in the EVI index, especially in the rainy season in both years studied. During the periods that there was an increase in the rainfall, the EVI has increased, showing a correlation with rainfall. In a recent study, Zeri et al. (2016) showed that the passage of FS in the interior and the coastal regions of São Paulo significantly increased the rainfall accumulated in the state (Figure 2).

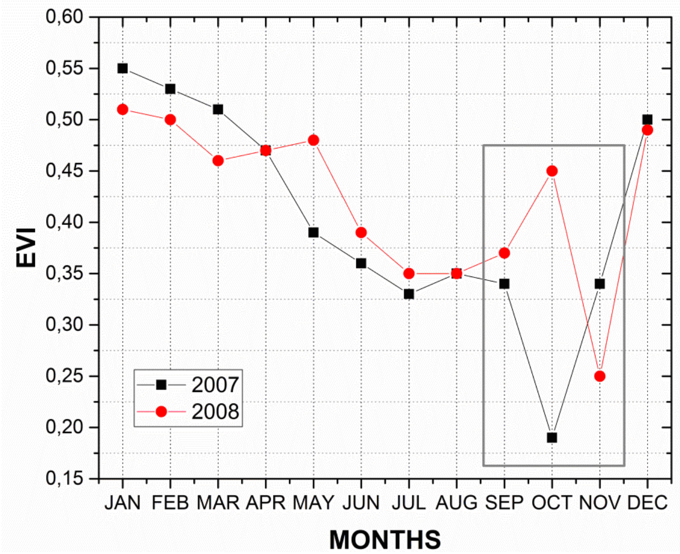

Figure 2. Monthly EVI index in 2007 and 2008 for the municipality of Cunha-SP, respectively.

The relationship between rainfall and EVI index for the study period shows that there were negative and positive trends. The coefficient of determination of the rainfall of EVI in 2007 (R^2 = 0.43) where higher than 2008 (R^2 = 0.12), as verified in Figure 3. Multiple regression for 2007 obtained 87% correlation, while in 2008 only 27% correlation (Table 2).

Correlation analysis among air temperature and EVI for the studied period showed that there was low correlation between the data for the years 2007 (R^2 = 0.16) and 2008 (R^2 = 0.024), according to Figure 4.

According to Ribeirto et al. (2015), correlating climate data with EVI in the State of Espírito Santo, they verified in florest areas highest correlations for photoperiod. However, for crops the response was another, where the variables air temperature, rainfall and relative air humidity had the higher correlations. In this study involving Atlantic Forest biome, we can to associate that the vegetation responds with greater intensity to rainfall and photoperiod.

The higher correlation between rainfall and EVI index in the year 2007 occurred because the increased rainfall on the region of Cunha-SP, due to FS action on the region, according to data collection performed by Zeri et al. (2016). According to data from CPTEC/INPE (2015) for 2007, together with La Niña also occurred EL Niño event. Cunha et al. (2011) reported that events caused by El Niño and La Niña alter the rainfall patterns in Brazil, mainly in the Southeast.

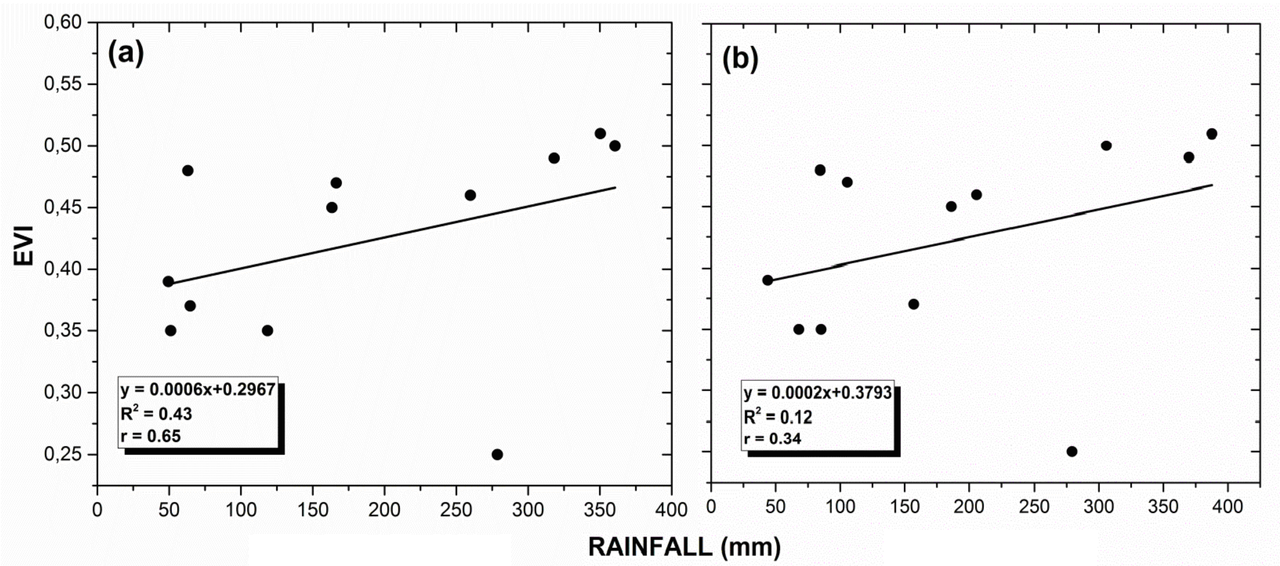

Figure 3. Regression graphs of EVI *versus* rainfall (mm) for the years 2007 (a) and 2008 (b), respectively.

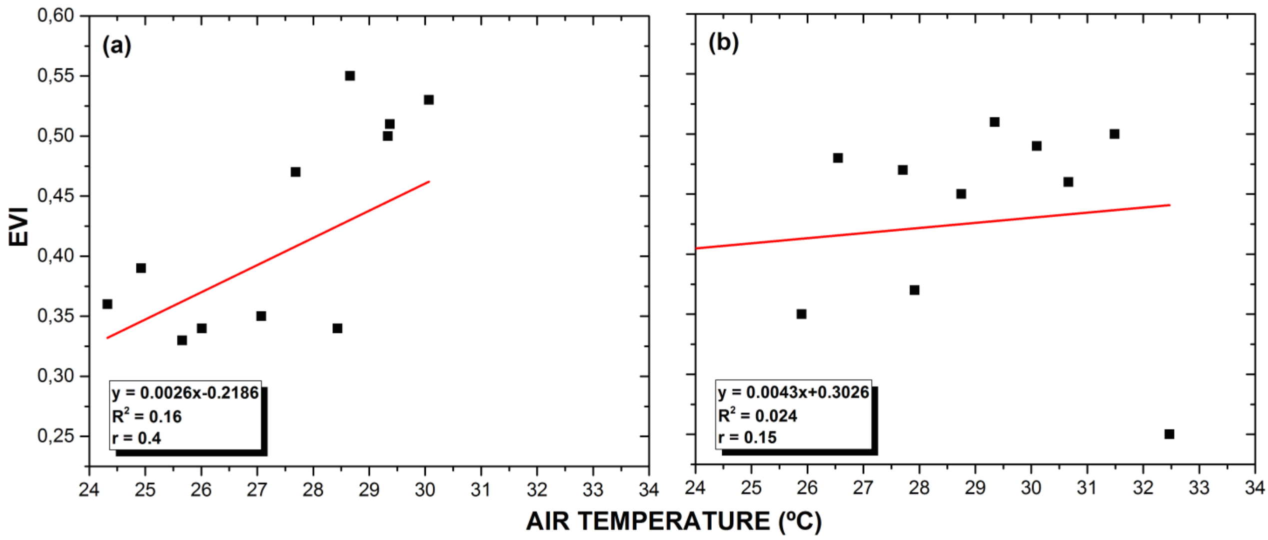

Figure 4. Regression graphs of EVI *versus* air temperature (mm) for the years 2007 (a) and 2008 (b), respectively.

Table 2. Multiple regressin of rainfall versus EVI during the strong La Niña episode for the years 2007 and 2008.

Years	β_0	β_1	R Multiple
2007	-0.057	0.0017	0.87
2008	0.349	0.0003	0.27

Conclusion

EVI index applied to Atlantic Forest increase rainfall periods, mainly with the increase of Frontal Systems passages on with increasing passage of frontal systems within and coastal environment, and it decrease in dry periods in Cunha, SP;

Regarding the climate variables, EVI index has a good sazonal correlation with rainfall in strong La Niña episodes, exception is air temperature;

It is worth mentioning that EVI index shoud be used in studies on vegetation dinamic and be estending to cases of ENOS (neutral and El Niño).

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