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Relationship Between Canopy and Leaf Spectral Response In Savanna

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R E S U M O

O sensoriamento remoto e imagens digitais são técnicas que tem o potencial de ajudar nas analises dos ecossistemas terrestres em escala espacial. É conhecido que o monitoramento de floresta é mais preciso quando se conhece as características estruturais do ecossistema em diferentes escalas espaciais. Relacionar as medidas obtidas com sensoriamento remoto e em campo é sempre um desafio uma vez essas relações sempre envolvem erros. Uma das dificuldades na obtenção de estimativas de parâmetros e variáveis biofísicos da vegetação com sensoriamento remoto é a resolução espacial das imagens que é baixa e isso complica a relação entre dados regionais, locais e de detalhe. Assim , este estudo tem como objetivo avaliar a similaridade e a correlação existente entre a reflectância do dossel a da folha e propor um modelo que melhore as estimativas das características biofísicas da folha. Foi usado analise de cluster teste t, correlação de Pearson e regressão. Os resultados foram satisfatórios e mostraram que são significativas as diferenças entre a reflectância na folha e dossel em Caatinga para um nível de significância de 0,01. O modelo desenvolvido pode ser usado com alta significância para imagens do IKONOS.

Palavras-chave: floresta seca, interação folha dossel, reflectnacia, analises de cluster, regressão.

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A B S T R A C T

Remote sensing and digital images are techniques that have the potential to assist in the analysis of terrestrial ecosystems in spatial scale. It is known that a forest monitoring is more accurate when you know the ecosystem features at different spatial scales. Relate measurements with remote sensing and obtained in the field (scales of detail) is challenging since several physical interference (biotic and abiotic) can provide errors in these relationships. One of the difficulties in obtaining estimates of parameters and vegetation biophysical variables with remote sensing are the spatial resolution is often low and this complicates the relationship between the regional data, location and detail. Thus, this study aims to evaluate the similarity and the correlation between canopy reflectance and leaf and propose a model that improves the estimates in leaf scale. We used cluster analysis, t-test, Pearson correlation and regression to analyze the similarity between samples, the degree of correlation and regression finally adopted for the model. The results were quite satisfactory and showed that there are significant differences between the reflectance in the leaf and canopy in Savannah for a significance level of 0.01. The model developed here can be using with high significance for high spatial resolution images such as IKONOS.

Keywords: dry ecosystems, canopy and leaf interactions, reflectance, cluster analysis, regression.

1. Introdução

Analyses of various biophysical and biochemical factors affecting plant canopy reflectance have been carried out over the past few decades, yet the relative importance of these factors has not been adequately addressed. A combination of field and modeling techniques were used to quantify the relative contribution of leaf, stem, and litteroptical properties (incorporating known variation in foliar biochemical properties) and canopy structural attributes to nadir-viewed vegetation reflectance data (Asner 1998a).

Many ecological processes (e.g., species growth, invasion, competition, facilitation, mortality) are dictated by existing spatial conditions (i.e., both biotic and abiotic) and lead to the generation of new spatial conditions. Hence, Pattern and process are perpetually intertwined. In order to understand how nature works, ecologists must be able to classify patterns and develop process-based spatial explicit models that can produce observed patterns at multiples scales (Drake and Weishampel 2000).

Canopy architecture plays fundamental roles in the land-atmosphere interactions, yet quantification of canopy architecture using optical sensors in an open canopy remains a challenge. Savannas are spatially heterogeneous, open ecosystems, thus efforts to quantify canopy structure with methods developed for homogeneous, closed canopies are prone to failure.

Savannas are globally important ecosystems of great significance to human economies (Sankaran et al. 2005). Savannas exist in water-limited regions, which force tree canopies open and heterogeneous (Eagleson and Segarra 1985), (Ryu and Science 2010). The open canopy structure allows grass to co-dominate in the savannas by occupying different niches in space and time. The co-dominance of trees and grass defines the functions and metabolisms in the savanna ecosystems (Higgins, Bond, and Trollope 2000);(House et al. 2003). However, how to quantify canopy architecture and how to monitor structure, function, and metabolism in savanna ecosystems remains challenging.

The term "savanna" has a wide range of meanings among biogeographers, sometimes referring to flat and open land-scapes, and other times referring to the vegetation that characterizes that landscape (Eagleson and Segarra 1985). Savanna is curious vegetation state characterized by the coexistence of grasses and trees. Although the exact ratio of grass to tree varies considerably with savanna type, the physiognomy of savanna remains clearly distinct from that of grassland and forest. Most authors, would agree that a complex web of factors, notably, water, herbivory, fire, soil texture and nutrients, influences the balance between grass and trees in savanna (Higgins, Bond, and Trollope 2000). Given this complexity, the question of how grasses and trees coexist over such a wide range of climate, edaphic, biogeographic and historical conditions is intriguing so intriguing that it has been referred to as the "savanna problem" (Higgins, Bond, and Trollope 2000).

Thus, studies that will contribute to the understanding of this ecosystem have been increasingly frequent and interest of the scientific community worldwide. One alternative of obtaining fast and low-cost data on ecosystems has been the remote sensing. Remote sensing and digital images are techniques that have the potential to assist in the analysis of terrestrial ecosystems in spatial scale. It is known that a forest monitoring is more accurate when you know the ecosystem features at different spatial scales. Relate measurements with remote sensing and obtained in the field (scales of detail) is challenging since several physical interference (biotic and abiotic) can provide errors in these relationships. One of the difficulties in obtaining estimates of parameters and vegetation biophysical variables with remote sensing is the spatial resolution that often is low and this complicates the relationship between the regional data, local and detail (in situ).

Conditions for accurate monitoring of surface flows within regional scales are useful in planning and managing water resources, in agricultural productivity forecasts and numerical weather prediction. Biophysical quantities derived from images with bands in the electromagnetic spectrum include vegetation indices, albedo and leaf area index, which may be related to the efficiency of light use by the plant community and, therefore, are valuable elements in the carbon assimilated by vegetation, water balance and energy balance between the surface and atmosphere, (Bonan 1995). In addition, satellite images in bands of green and red spectral provide estimates of leaf chlorophyll content (Cab), which is an important indicator of the physiological conditions of the plants.

The advantages of using remote sensing for monitoring terrestrial ecosystems have been well documented in Brazil (B. B. Silva et al. 2013), (Galvíncio, Pimentel, and Mendonça 2012), (Pereira, França, and Galvincio 2012), (L. G. da Silva and Galvincio 2012) and (Galvíncio et al. 2011) and exterior, (Wang et al. 2012), (Liu et al. 2011), (Ryu and Science 2010), (Yilmaz, Hunt, and Jackson 2008) and (Bonan 1995).

Models based on physical processes proved to be a promising alternative to describe the transfer and interactions of radiation inside the canopy based on physical laws and thus provide an explicit connection between the biophysical variables and canopy reflectance.

To date, there are few studies using high spatial resolution satellites to estimate the chlorophyll content of the plant. This difficulty occur due the estimates obtained to present date are unreliable, many underestimate the values of chlorophyll content and consequently all other estimates that use this data. It is believed that these underestimates occur due to differences in reflectance between the canopy and leaf. Thus, this study aims to evaluate the similarity and the correlation between canopy reflectance and leaf and propose a model that improves the estimates in leaf scale.

2. Methods

2.1. Study area

The spatial location of the research sites under study is in the municipalities of Petrolina and Serra Talhada in the state of Pernambuco, Northeastern Brazil, Fig. 1.

Fig. 1. Spatial location of the municipalities Serra Talhada and Petrolina in Brazil.

2.2. Field data

Data were collected on a grid 500 x 500 meters, which corresponds to an area of 250,000 m2 per site. A total of two sites, one in Serra Talhada and another in Petrolina. Each site was divided into a grid of 5 x 5 or 25 sampling points. In 30 samples were obtained reflectance data, corresponding to 15 and 15, canopy and leaf, respectively. These data varied temporally and spatially correspond to days: 05/19/2011, 06/14/2011 to 06/16/2011, 03/15/2012 to 05/17/2012, 11/22/2012, November/28 and 29/2012, 02 and 03 of the April of 2013, Long Term Ecological Program-LTER, sites, in Brazil PELD, obtained in Petrolina and Serra Talhada.

2.3. IKONOS satellite data

The IKONOS satellite data were acquired for the PELD, site 22, (http://www.ufpe.br/sercaatinga). The data were delivered in a geo-registered, UTM projection with 11-bit radiometric resolution.

The image used data corresponding to 08/26/2008, with azimuth 49.7925, 60.79709 elevation and time of satellite passage: 13: 13

GMT. The IKONOS satellite sensor has a spatial resolution of 1m. This image covers the area of the site 22 of PELD in Petrolina. The area located in savanna (Caatinga) preserved of the Embrapa Tropical semiarid, with coordinates (09 º 09 'S latitude and 40 º 22' W longitude), Fig. 2.

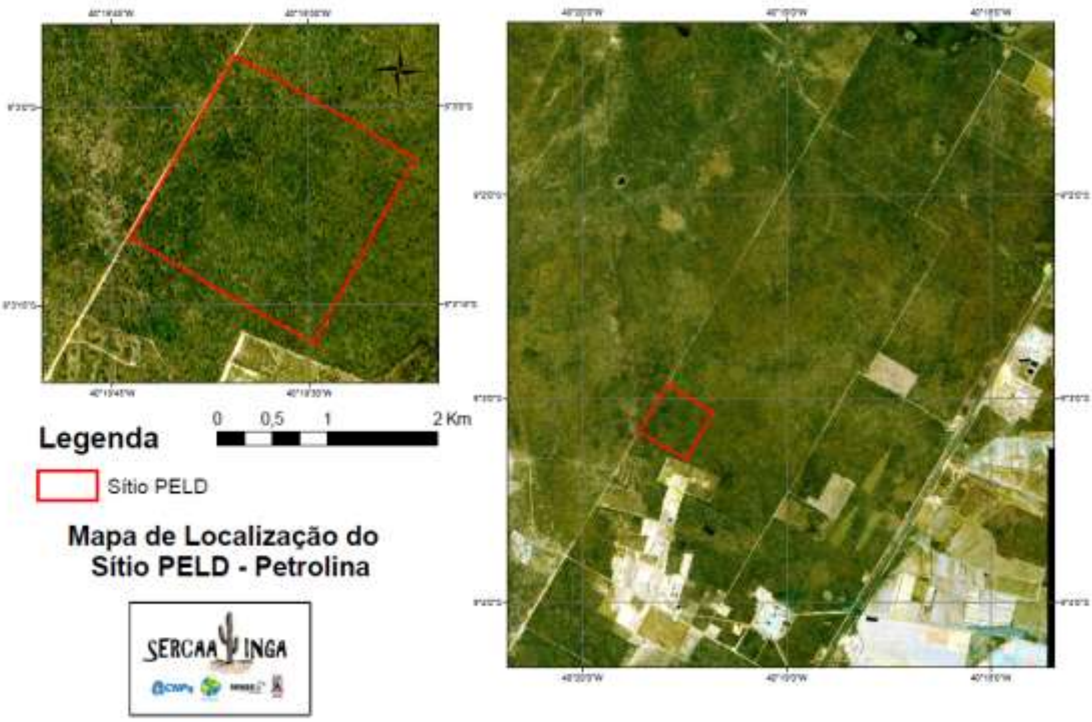


Fig. 2. IKONOS Image, site 22, PELD, Petrolina-PE.

2.4. Spectral reflectance data

Spectral reflectance was measured between 336 and 1045 nm with a spectral resolution of 1 nm, covering visible and near-infrared portions of the electromagnetic spectrum. Fieldspec HandHeld (ASD, Boulder, USA) fitted with a fiber optic probe having a 25° field of view was used. The spectroradiometer was optimized using reference white plate.

2.5. Cluster analysis

Methods were used for cluster analysis was Ward, the method of partial correlation was Pearson and linear regression method.

The Ward method is also called "Minimum Variance". In this method the formation of groups is by maximizing homogeneity within groups. The sum of squares within groups is used as a measure of homogeneity. That is, the Ward method attempts to minimize the sum of squares within the group. The groups formed in each step are the result of group solution with the smallest sum of squares.

2.6. T-test

The two-sample t-test for testing whether differences exist between two population means was adopted in this study to determine difference between canopy and leaf reflectance. Numerous studies have shown that the two- sample t test is robust to considerable departures from its theoretical assumptions (that both samples come at random from normal populations with equal variances), especially if the sample sizes are equal or nearly equal (Boneau, 1960; Cochran, 1947; Posten et al., 1982; Zar, 1996). We tested the research hypothesis that the means of the leaf and canopy indices for each species were different, i.e., Ho: μ1 = μ2 versus the alternative hypothesis, H1: μ1 ≠ μ2, where μ1 and μ2 are the means of leaf and canopy reflectance, respectively. The t values were calculated using Eq. 1.

$$t = \frac{\overline{X_1} - \bar{X}_2}{\sqrt{\frac{sd_1^2}{n_1} + \frac{sd_2^2}{n_2}}} \qquad (1)$$

where, $\overline{X_1}$ *and* $\bar{X}_2$, sd_1 and sd_2 and n1 and n2 represent the means, standard deviations and sample sizes of the leaf and canopy data, respectively.

2.6. Correlation and regression

To learn how similar grouped data are was used to the partial correlation analysis of Pearson.

We used linear regression to develop a model to better estimate the reflectance in leaf using reflectance on the canopy. This model is suggestion for estimate in spatial scale smaller than 3 meters or area smaller than $9m^2$.

2.7. Image analysis

2.7.1 Radiometric calibration of the IKONOS

The radiometric calibration of satellite sensors IKONOS can be obtained by Equation 2:

$$L_\lambda = \frac{10^4 DN_\lambda}{Coef_\lambda BandaWith_\lambda} \qquad (2)$$

where DN_λ is digital number in band $_\lambda$ and Coef $_\lambda$ e Bandawith $_\lambda$ are the coefficient of calibration in band $_\lambda$, Table 1.

Table 1 – Radiometric calibration coefficient of by band.

Wavelength (μm)	Calibration coefficient	Band with$_\lambda$	Esunλ (Wm^{-2} μm^{-1})
Band 1 (0,45 – 0,52)	728	71,3	1930,9
Band 2 (0,51-0,60)	727	88,6	1854,8
Band 3 (0,63 – 0,70)	949	65,8	1556,5
Band 4 (0,76 – 0,85)	843	95,4	1156,5
Pan	161	403	1375,8

2.7.2. Reflectance

The reflectance was estimated by Equation 3

$$L_\lambda = \frac{\pi L_\lambda d^2}{ESUN_\lambda CosZ} \qquad (3)$$

where L_λ is spectral radiance in band$_\lambda$, $ESUN_\lambda$ is spectral irradiance of each band at the top of the atmosphere (Wm^{-2} μm^{-1}, Table 1), Z is solar zenith angle and d^2 is square of the average distance Earth-Sun and was estimated by:

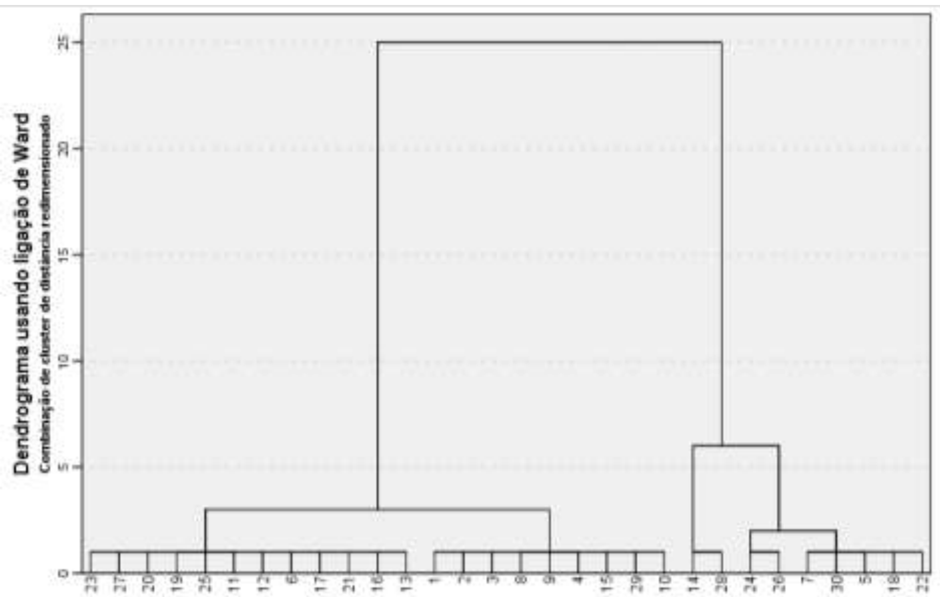
$$d_r = 1 + 0{,}033\cos(DSA2\pi / 365) \qquad (4)$$

where, DSA represents the day of the year sequential and *cos* is rad. The mean value year (d_r) is 1 (one). This value d_r can fluctuate between 0.97 and 1.03.

3. Results and discussion

3.1 Cluster analysis and t-test

In dendrograma (Fig. 3) the point of canopy are (1, 2, 3, 6, 8, 12, 13, 15, 17, 19, 21, 23, 25, 27 e 29) and point of leaf are (4, 5, 7, 9, 10, 11, 14, 16, 18, 20, 22, 24, 26, 28, 30). Note that the data were grouped into two groups sharply. Group 1 - refers to the measures in the canopy and Group 2 - the measurements taken in the leaves. Thus, it is suggested that the reflectance measurements of leaf and canopy are not similar.



1, 2, 3, 6, 8, 12, 13, 15, 17, 19, 21, 23, 25, 27 e 29 – canopy
4, 5, 7, 9, 10, 11, 14, 16, 18, 20, 22, 24, 26, 28, 30 – leaf
Fig. 3. Dendrograma of point of canopy and leaf.

Applying the t-test on the samples from the canopy and leaf was obtained significant differences between samples with significance level 0.01, ie a confidence interval of 99%. Note that this study show significant differences between canopy and leaf. Similar results was obtained in (Cho et al. 2008) when analyses the sensibility between hyperspectral index in different scales, canopy and leaf.

3.2. Correlation and regression analysis

Correlation was obtained between the samples of the canopy. The correlations between the samples were always greater than 0.80 with a significance level of 0.05. Ie, the data collected in the canopy are highly correlated.

Knowing that the data obtained in the canopy and those obtained on the sheet are not similar, we sought to examine the degree of correlation between the data obtained in the canopy and leaf, Fig 4. Note that there is a high correlation between the data obtained in the leaf and canopy determination coefficient equal to 0.96. So you can make an estimate reflectance in leaf using the canopy reflectance and thus improve estimates of the different spectral indices in detail scale (leaf). Fig 4 shows the equation y = 1.5766 +0.0037 x, where x is the spectral reflectance in the canopy and y is the spectral reflectance of the sheet. It is suggested that this equation is used for images with high spatial resolution, such as IKONOS, Quickbird, Worldview, Geoeye, etc.. For medium and low resolutions (Landast, NOAA, MODIS, etc.) the error in estimating leaf reflectance may increase due to interference of various environmental factors and atmospheric.

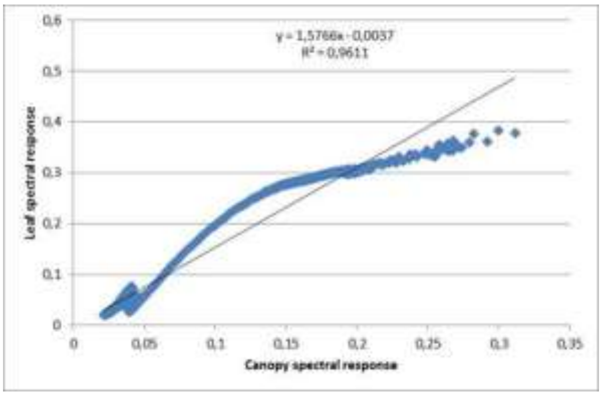


Fig. 4. Relationship between canopy and leaf reflectance.

3.3. Application of the model developed in the IKONOS image

Model was applied to the IKONOS image and the reflectance was estimated. In that new image were analyzed 10 points in site 22 of the LTER in Petrolina. The data of reflectance obtained in the canopy and estimated using the model developed here to leaf are shown in Table 2. Note that the increase in the reflectance value between the canopy and the leaf is around 35%. Ie, the estimated values of leaf reflectance in the visible (green and red) are greater than 0.10 or 10%. This result confirms the literature because shows that the reflectance of a leaf in the visible (green and red) is always greater than 10%. For the near infrared spectral response pattern of a green leaf varies around 0.3 or 30%. In the green region reflectance is of around 15%. Thus, it is suggested that the model developed here will improve estimates of spectral indices when using images with high spatial resolution.

Table 2. Reflectance in 10 points of dense forest in the savanna, site 22, Petrolina-PE, LTER-Long Term Ecological Program, using IKONOS imagery.

Band	Canopy	Leaf (Model)	Increase (%)
2 green	0.08	0.12	34,64
3 red	0.07	0.11	34,33
4 near infrared	0.16	0.25	35,61
2 green	0.09	0.14	34,81
3 red	0.09	0.15	35,17
4 near infrared	0.14	0.23	35,55
2 green	0.10	0.15	35,06
3 red	0.10	0.16	35,58
4 near infrared	0.14	0.22	35,34
2 green	0.09	0.14	34,78
3 red	0.09	0.15	35,09

4 near infrared	0.14	0.21	35,51
2 green	0.09	0.15	35,09
3 red	0.10	0.16	35,40
4 near infrared	0.13	0.20	35,64
2 green	0.09	0.15	35,09
3 red	0.10	0.16	34,81
4 near infrared	0.14	0.22	35,29
2 green	0.09	0.15	34,86
3 red	0.10	0.17	34,93
4 near infrared	0.15	0.23	35,52
2 green	0.08	0.13	34,58
3 red	0.09	0.14	34,50
4 near infrared	0.13	0.20	35,60
2 green	0.09	0.14	35,21
3 red	0.10	0.15	35,06
4 near infrared	0.14	0.22	35,71
2 green	0.09	0.14	34,53
3 red	0.09	0.15	34,89
4 near infrared	0.14	0.22	35,34

The results of this study revealed systematically higher near infrared (NIR) and visible (V) reflectance's at the leaf scale than at the top-of the canopy. The higher leaf V and NIR reflectance may be explained by the effect of multiple scattering caused by leaf stacking since the leaf reflectance were measured in situ, (Cho et al. 2008). Blackburn (1999) showed that the NIR and to a lesser degree, the visible reflectance increases with leaf stacking. He equally argues that the spectral reflectance properties of background materials and areas of shadow can have large influence upon that of the whole canopy even when there is complete canopy.

It is known that the reflectance is the primary data obtained from satellite images and case presents error in data in your measurement / calibration, all other products derived this increase noise, as vegetation indices (NDVI –Normalized Difference Vegetation Index, SAVI- Soil Ajusted Vegetation Index.), Leaf Area Index (LAI), chlorophyll index (TCAI-Transformed chlorophyll Absorption Index and MCAI - Modified Chlorophyll Absorption Index) index physiology (PRI Phorochemical Reflectance Index) index structure (IPVI- Infrared Percentage Vegetation Index) and energy balance and water balance estimated were accumulated errors.

Scientist around the world have sought to improve the estimates of the different products estimated with remote sensing, (Liu et al. 2011), (Elmore and Craine 2011), (Cho et al. 2008), (Danson and Bowyer 2004), (Asner and Warner 2003), (Eamus, Hutley, and O'Grady 2001), (Drake and Weishampel 2000), (Asner 1998b) and (Knyazikhin et al. 1998), But improving the differences between the estimates of canopy reflectance and leaf virtually nonexistent.

The quantification of clumping effects at the ecosystem scale, which has been overlooked in most remote sensing products, reflectance, is crucial to obtain the correct information of ecosystems.

4. Conclusions

The model developed in this study may be used to improve the estimates of reflectance and indices spectral in leaf with high spatial resolution images, such as images IKONOS.

This study reinforces the importance of developing models to better to estimate the reflectance in scale of detail (leaf) since there are no similarities between the reflectances in the leaf and canopy but a high statistical correlation.

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