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Modeling forest canopy closure using vegetation index

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Abstract.
The use of remote sensing to estimate forest structure has been largely tested but few researches have related such information about canopy closure in tropical forests in steep slope. This work aims to analyze the potential employ of vegetation index and sunlight radiation to generate a predictive model of canopy closure in the Ribeira Valley, south of the São Paulo State – Brazil. The canopy closure data were obtained from Spherical Densiometer in 52 sample points. The sun radiation (AIF) was obtained using TOPODATA image and literature equations. Thus, canopy closure and AIF information were related to NDVI, EVI and LAI, obtained from LANDSAT-TM and ALOS-AVNIR images. The results showed: a) field canopy closure facing to the North, East and West presented a tendency to have higher canopy closure then points facing to the south; b) the field canopy closure ranged from 0.58 to 0.97 c) and the annual illumination factor (AIF) ranging from 0.28 to 0.66 ; d) all three indexes showed lower determination coefficients when compared with image bands alone; e) two spatial resolution images were tested using 30 m (TM) and 10 m (ALOS); the lower pixel size did not result in better canopy closure estimation; f) the use of topographic correction on the TM images did not resulted in better model explanation of canopy closure, comparing it with models that use AIF; g) the blue ALOS band and TM7 Landsat band models explained, about 27% and 30% of the variation in observed canopy closure, respectively.

Keywords: remote sensing, canopy closure, topography, ecology, sensoriamento remoto, fechamento de dossel, topografia, ecologia.

1. Introduction

The use of remote sensed data to estimate forest features has been widely tested (Freitas et al. 2005; Lu, 2006; Lei et al., 2012; Coulston et al. 2012). The measurement of forest structure at landscape scale can provide information of how the vegetation is affected by environmental gradients. The modeled sun radiance over steep slope regions obtained by the annual illumination factor (AIF) may be used to evaluate the responses of the vegetation due to sunlight spatial patterns (Valeriano, 2011). In addition, the canopy closure information is an indicative of the spatial distribution of the canopy gaps across forest patches (Lima and Gandolfi, 2009).

The physical interaction between sun radiation and forest structure results in different patterns of sunlight reflectance. Thus, satellite Vegetation Index (VI) can serve as indicators of various biophysical vegetation parameters such as leaf area, percentage green cover, green biomass and absorbed photosynthetically active radiation (Sellers, 1985; Asrar et al., 1984; Goward and Huemmrich, 1992; Huete et al., 2002). The leaf area index (LAI) is also an important indicator of forest structure (Duchemin et al., 2006). Although a wide range of approaches has been tested for modeling forest structure using remote sensing data, few researches have used satellite data to produce information about canopy closure in tropical
forests. In this context, this work aims to analyze the potential employ of some remote sensed indexes and AIF to generate a predictive model of canopy closure in steep slope tropical forests.

2. METHODS

2.1. Study Area

The field data survey took place in the mountainous portion of the Ribeira Valley (Latitude 24°33’ S and Longitude 48°39’ W), south of São Paulo State, Brazil (Fig. 1). The area consists on a series of steep ridges ranging from 200 m to 600 m in elevation. Climate is humid sub-tropical, with hot summers and drought absence. The mean annual temperature is over 21°C and rainfall is very abundant, totaling up to 1500 mm annually. The vegetation is defined as Ombrophilous tropical forest, which has elevated number of species and complex structural forest canopy layers (Guilherme et al., 2004; Marques et al., 2009).

The Ribeira Valley comprises the biggest continuous forest patches of the Brazilian Atlantic Rain forest, part of the Atlantic Forest Biosphere Reserve (Ribeiro et al. 2009). This forest area remains mainly due to unfavorable occupation conditions, such as rugged relief, high slope, poor soil and elevated moisture (Aidar, 2000). The region has been used for subsistence production by small farmers in slash and burn agriculture system (Adams, 2000; Peroni and Hanazaki, 2002). This management practices resulted in a heterogeneous forest mosaic compounded by different forest regrowth stages.

2.2. Vegetation inventory data

Vegetation data from 52 sample points were collected during November 2010 in an area of about ~15,000 ha. The sampled points were systematically distributed considering vegetation index, terrain slope and aspect range. Then, they were proportionally spread over two forest succession stand, namely, initial secondary forest class (tree height lower than 10 m) and advanced secondary forest/primary forest class (tree height higher than 10 m).

The forest canopy closure was estimated using a spherical densiometer (Lemmon, 1956; Knowles et al., 1999; Englund et al., 2000; Suganuma et al., 2008). This instrument consists of a concave mirror with a view angle of 60°. In each sampled point, the spherical densiometer was placed in horizontal position at breast high. The portion of the sky covered by the canopy was then computed. The canopy closure data obtained from the spherical densiometer was registered with digital pictures, in order to eliminate the observer subjectivity to score canopy closure by a visual analysis. The pictures were then converted into binary images (Fig. 2) using Sidlelook software (Nobis, 2005). The software algorithm...
detects the border between pixels representing the sky and the vegetation, defined by the maximum contrast between them (Nobis and Hunziker, 2005). Finally, the number of black and white pixels was counted with Idrisi Andes® software, giving the canopy closure percentage (from 0 to 1).

Figure 2. Spherical densiometer images used to estimate field canopy closure. Black color = canopy leaves; white color = opened sky.

2.3. Annual Illumination Factor

The annual illumination factor (AIF) represents the angle between the solar beam and the normal line from the ground. It is estimated from average values of daily and monthly illumination factor angles and illustrates the mean illumination conditions considering the sunlight radiation during the year (Valeriano, 2011). The primary source of topographic data to calculate the AIF was the digital elevation model (DEM) obtained from the TOPODATA database (http://www.dsr.inpe.br/topodata). The TOPODATA derives from the Shuttle Radar Topography Mission (SRTM-3) available from the United States Geological Survey (http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/) and refined to a resolution of 30 m (Valeriano & Rossetti 2008).

2.4. Satellite data pre-processing

LANDSAT-TM data (November 2010) and ALOS-AVNIR (March 2010) provided the spectral data used as independent variables for the development of the regression model to estimate canopy closure. The satellite data were converted to surface reflectance and adjusted for atmosphere effects (Chaves 1996). The topographic correction was employed only to the TM data. The ALOS images were not topographically corrected due to pixel size differences comparing to the TOPODATA image.

The TM and ALOS images were processed to produce indexes (vegetation index and leaf area index). The indexes are dimensionless and provide information about the amount and condition of the vegetation (Huete et al., 1994; Huete et al., 1999). These indexes are based on the rate between data from different spectral range, which can reduce multiplicative noise (illumination differences, cloud shadows, atmospheric attenuation, and topographic variations) present in multiple bands (Huete et al., 2002). They do not require assumptions or any additional information than the measurements themselves, resulting in simplicity in the data analysis (Huete et al., 1999). The indexes used to evaluate its relation with the canopy closure were: normalized difference vegetation index (Rouse et al., 1974), leaf area index (Duchemin et al., 2006), and enhanced vegetation index (Huete et al., 1994; Huete et al., 1997), estimated by the following equations:

\[ NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}} \]  \hspace{1cm} (eq. 1)

\[ LAI = \frac{1 - \log(NDVI)}{-0.54} \]  \hspace{1cm} (eq. 2)

\[ EVI = G \left( \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + C_1 \times \rho_{red} - C_2 \times \rho_{blue} + L} \right) \]  \hspace{1cm} (eq. 3)
where NDVI is normalized difference vegetation index; LAI is leaf area index; EVI is the enhanced vegetation index; \( \rho \) is atmospherically corrected surface reflectance, \( L_1 \) (value = 1) is the canopy background adjustment, \( C_1 \) (value = 6) and \( C_2 \) (value = 7.5) are the coefficients of the aerosol resistance term (it uses the blue band to correct for aerosol influences in the red band) and \( G \) (value = 2.5) is a gain factor.

2.5. Modeling approaches

The relationship between AIF and canopy closure was tested using Pearson correlation test. Afterward, the canopy closure was modeled with a linear regression analysis. The modeling was elaborated with field forest data from the 52 points as the response variable and Landsat TM (TM1, TM2, TM3, TM4, TM5, TM7), ALOS-AVNIR-2 (Alos1, Alos2, Alos3, Alos4) and AIF data as explanatory variables. All possible models were tested for normality using the Shapiro-Wilkes normality test. Model’s fitness was evaluated using an adjusted R-squared (\( R^2 \)) and root mean square error (RMSE). The RMSE test compares the ground truth with the modeled data. In this validation procedure, we randomly selected 70% of the total data set of 52 field points 100 times. In each selection, we obtained the RMSE comparing the remained 30% field canopy closure values with the values estimated by the models. Then, we evaluated the reliability of each model by the mean of the 100 RMSE values.

3. Results

The AIF ranged from 0.28 to 0.66 and presented a mean value of 0.51 (SD = 0.09). As for the field canopy closure, values founded ranged from 0.58 to 0.97, with a mean of 0.81 (SD = 0.08). No significant differences (\( \rho \> 0.05 \)) of canopy closure values between the two analyzed forest succession stands (initial secondary forest and advanced secondary forest) were detected. However, the field canopy closure of sampled points facing to the North, East and West showed a tendency to have higher values then points facing to the south (Figure 3). We also found a tenuous positive increase between the AIF and canopy closure (\( \rho > 0.05 \)) (Figure 4).

![Figure 3. Scatterplot between canopy closure and aspect (degree).](image)

![Figure 4. Scattering plot between canopy closure and annual illumination factor.](image)

3.1. Modeled canopy closure and prediction accuracy

The use of topographic corrected TM images did not improve the performance of the models in estimating canopy closure. On the other hand, the modeled canopy closure exhibited better results when the annual illumination factor was included in the modeling steps, with either TM (Fig. 5) or ALOS (Fig. 6) images. Concerning the indexes, all three (EVI, NDVI and LAI) resulted in lowers determination coefficients when compared with the satellite image bands alone. The performance of the TM and ALOS images were similar, regarding its differences on the spatial resolution. The EVI from both the TM and ALOS images showed lower R-squared values in comparison with the other index. The two models used to predict the canopy closure, namely TM 7/annual IF and ALOS1/annual IF, showed
the highest determination coefficient ($R^2 = 0.30$ and $R^2 = 0.27$, respectively; Figure 8). Despite the statistical significance of the relation between the observed values and the predictions, the R-squared values were low. Canopy closure RMSE of 0.071 and 0.070 by using the models from ALOS and LANDSAT, respectively, were found. Considering the range of 0.58 to 0.97 of field canopy closure it represents 22% of error.

Figure 5. R-squared for the estimated canopy closure using ALOS images.

Figure 6. R-squared for the estimated canopy closure using TM images.

Dark grey bars = modeling using annual illumination factor; grey bars = modeling without Illumination Factor; white bars = modeling with topographically corrected images and without Illumination Factor. ** = $p \leq 0.05$.

Figure 8. Scatter plot of observed versus predicted values of canopy closure of the best models: Alos1/annual IF (A) and TM-7/annual IF (B) data.

4. Discussion and Conclusions

The high topographic heterogeneity on the study area determines the incident pattern of the sunlight over the steep slopes. The canopy closure showed similar pattern between initial and advanced forest succession stands. This forest structure similarity throughout the forest regrowth indicates that Atlantic Rain Forest areas rapidly develop a closed canopy structure and that the light availability for the sub-canopy is reduced at the initial forest succession stage. However, this paper found a tendency of higher field canopy closure values on mountainside facing north, east and west. Moreover, there was a positive relation, although not as evident, between canopy closure and AIF, suggesting an increase in foliage biomass due to the elevation of the annual sunlight availability. The incident sunlight is a major determinant of microclimate conditions, mainly controlling environment temperature and water availability (Ful and Rich et al., 2002), besides representing a primordial factor to the photosynthesis process. Thus, the well-defined difference of canopy closure among the ground aspect can be partially explained by the annual sunlight availability, but also by others micro-scale environmental conditions not controlled on the present study, such as soil type, human management and species composition.
In continuous forest areas, the stratification and the canopy structure result in higher variability in the near infrared than in red reflectance, which determines a worst performance of the NDVI comparing to EVI. Thus, it is expected a feasibility on the canopy closure estimation by using the EVI. However, we did not find good canopy closure estimation using any of the remote sensed indexes, including the EVI. Anaya et al. (2009) found no significant relation between EVI and tropical forest biomass. According to the authors, the small range of the EVI in tropical forest reduces its performance to evaluate forest structure. In addition, the saturation of the satellite signal is also a problem to the premise of precise relation between the three tested indexes and the forest structure. The good performance of Landsat TM band 7 can be partially explained by its relation to some soil components. This wavelength has been used to discriminate geological formation of rocks (Jensen, 2011). The seventh band presents high reflection in hydroxyl ion and carbonate minerals ( Gül et al., 2012), elements expected in regions of karst topography such as the study area. Therefore, the greater the amount of soil not cover by vegetation, the bigger will be the reflection on band 7.

The model explanation of about 27% and 30% of the variation in observed canopy closure by using blue ALOS band and TM7 Landsat band, respectively, are similar with results obtained by Lei et al. (2012). These low levels of agreement can be explained in part by the complexity of tropical forest, with high local variations in species and layer composition. Higher model agreements are reported in studies with less biodiversity and structural complex forests (Carreiras et al., 2006; Joshi et al., 2006). The use of topographic correction on the TM images did not resulted in better model explanation of canopy closure comparing with models that use the AIF. The topographic corrections are attenuations of the topographic distortions on the images and may shows limitations on reducing all topographic effects (Song and Woodcock, 2003). Two spatial resolution images were tested using 30 m (TM) and 10 m (ALOS), nevertheless the lower pixel size do not result in better canopy closure estimation. Alternatively, the use of images with higher spectral (narrow bands) and higher radiometric resolutions might ensure more accurate results (Levesque and King, 2003; Sampson et al., 2003; Chubey et al., 2006; Falkowski et al., 2009).

5. References.


