Accuracy of Forest Stem Volume Estimation by TM/Landsat Imagery with Different Geometric and Atmospheric Correction Methods

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Abstract

This study aims to evaluate the accuracy in the indirect estimation of stem volume of Pinus from TM/Landsat 5 images, which were processed with different geometric and atmospheric correction methods. Regressions were used to estimate the stem volume (m³/ha), where the independent variable was the value of NDVI (Normalized Difference Vegetation Index) related to the forest sampling unit measured in the field. The surface spectral reflectance used in the NDVI calculation were obtained by four different methods: 1) geometric correction with nearest-neighbor (NN) resampling + atmospheric correction using dark object subtraction (DOS), 2) NN resampling + atmospheric correction using MODTRAN (Moderate Resolution Transmittance), 3) geometric correction with bilinear resampling + DOS, and 4) bilinear resampling + MODTRAN. The reliability of the estimates was measured by means of bias (Bias) and standard error (RMSE). Among the atmospheric correction methods, the errors were higher with DOS. Regarding the geometric correction methods, the RMSE and Bias were higher with the NN resampling. Thus, the combination of DOS + NN had the highest RMSE (62.3%) and Bias (15.9%). The best estimate was the combination of bilinear resampling + MODTRAN, with RMSE of 56.5% and Bias of 13.3%. Therefore, it was verified that different methods of geometric and atmospheric correction should be tested to improve the estimates of forest biophysical variables.

Keywords: Forest Biophysical Parameter, NDVI, Image Processing, Pixel Level

1. Introduction

Conventionally, forest inventory data has been collected primarily by means of field surveys, which is both expensive and time-consuming (HYYPPÄ et al., 2000). Alternatively, the forest attributes, including stem volume per hectare, can be indirectly estimated by means of remote sensing techniques (RIPPLE et al., 1991; ORUÉ, 2002; BERRA et al., 2012), which can potentially offer a timely and cost effective method for estimating forest characteristics (MCDONALD et al., 1998). The satellite imagery is an essential component in the development of new tools for forest management (ZAKARIA, 2010).

Since the 1970s, the use of satellite images, such as Landsat TM, for estimating continuous forest parameters, has been widely studied (MÄKELÄ and PEKKARINEN, 2004; BOYD and DANSON, 2005). A common approach is the combination of satellite image data and field data assessed from sampling plots for estimating forest variables for each pixel of the image (TOKOLA *et al*., 1996; KATILA and TOMPPO, 2001; BERRA *et al*., 2012). In this process it is usually to apply some method of geometric and atmospheric correction on the original image.

Remote sensing images are usually geometrically precision corrected to fit a selected coordinate system using, for example, ground reference points (ACKERMANN, 1996). The image and ground reference data may be coregistered most conveniently by georeferencing the image into the same coordinate system as the ground reference data (DIKSHIT and ROY, 1996). In this procedure different resampling techniques can be used.

The most commonly used resampling techniques are bilinear and nearest-neighbor (DIKSHIT and ROY, 1996), both are heuristic techniques (SHLIEN, 1979). Nearest-neighbor resampled pixels are allocated a grey-level value equal to the grey-level value of the nearest pixel in the original image (FERNEYHOUGH and NIBLACK, 1977). Bilinear resampling fits a hyperbolic paraboloid through four neighboring pixel values in the original image to estimate the resampled pixel value (CASTLEMAN, 1979).

The reflectance of the terrestrial surface "targets" is an intrinsic parameter of these targets, so in many situations, it must be used instead of the values of "gray levels" that is found in the satellite images. In order to get reflectance values, it is necessary to eliminate the atmospheric interference (GURTLER *et al*., 2005). This procedure is denominated atmospheric correction.

The atmospheric correction methods can be divided into physics, which are the most complete and based on the theory of radiative transfer, and the alternative or empirical, which are more simplified and generally assume the interference of the atmosphere as additive (FREIRE, 1996; MATHER, 1999).

The dark object subtraction (DOS) (CHAVEZ, 1988) is the empirical method most used (ANTUNES *et al*., 2003); it is perhaps the simplest and most widely used image-based relative atmospheric correction (SPANNER *et al*., 1990; EKSTRAND, 1994). The MODTRAN4 code (BERK*et al*., 2003) is one of the most widely used radiative transfer codes in accurate simulations of atmospheric radiative transfer (GUANTER, 2006). FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) is a MODTRAN4-based atmospheric correction software package (ADLERGOLDEN *et al*., 1999) that can compensate for atmospheric effects more accurately (OWOJOR and XIE, 2005).

So, for retrieve the surface spectral reflectance it is necessary to choose what set of geometric and atmospheric correction method should be used. Only after this step, a model relating the field and the image data can be fitted to perform the biophysical parameter estimation from the imagery.

The commercial forest sector has pronounced interest in this kind of estimation due the great value associated with the forests and the need for frequent monitoring. The Pinus (*Pinus elliottii* Engelm.), among the genre, has been one of the most used in commercial plantations in Brazil (FLORIANO, 2004), which is a source of wood to supply chains of major industries such as pulp and paper (CÂMARA SETORIAL DE SILVICULTURA, 2009).

In this context, the aim of this paper was to evaluate the accuracy in the indirect estimation of stem volume (m³/ha) of Pinus from TM/Landsat 5 images preprocessed with two methods of geometric and two methods of atmospheric correction. The analyses were carried out at pixel level.

2. Study Area and Methods

2.1 Study area

The study area, consisting of commercial areas of Pinus distributed over 12,000 ha, covers approximately 15 km of coastline. The area occupies a narrow strip of coastal plain on State of Rio Grande do Sul, south of municipality of Rio Grande, between the Mirim Lagoon and the Atlantic Ocean, being distributed between latitudes 32°28'30"S and 32º39'30"S and between longitudes 52º25'00"W and 52º33'00"W (Figure 1).

The regional climate, according to Köppen-Geiger classification system is humid subtropical Cfa type (MORENO, 1961). The municipality of Rio Grande presents the average air temperature of 23.1°C in summer and 13.4°C in winter and a mean annual rainfall of 1,155.6 mm (CEMETRS 2012).

The topography of the area is a rather plan all along, rising only a few meters above the sea level (~10 m). The Pinus are planted in a soil type PSAMENT.

2.2 Field data

The forest inventory data were collected during the months of September and October 2010 in young stands of Pinus, between ages 5 and 8 years old. The inventory was systematic with allocation of sampling units (S.U.) every 6 ha. Each S.U. had fixed area of 420 m² with sides proportional to planting spacing (2 x 3 m), Figure 2. The GPS Garmin Etrex Legend® was used to locate the S.U. into UTM coordinate system *datum* SIRGAS-2000. The coordinate was taken at S.U. center.

It was surveyed 111 S.U., where were measured the diameter at breast height and total tree height. With this data an allometric equation (Equation 1) was used to estimate the stem volume in m³/ha.

$$\text{Vol.} = \frac{10,000}{420} \times \sum_{i=1}^{n} g_i \times h_i \times 0.5 \qquad (1)$$

Where:

Vol.= Stemvolume (or Wood volume) per hectare (m³/ha);
10,000= 1 ha;
420= Sampling unit area (20 m x 21 m);
g_i= Basal area for the tree i;
h_i= Total height for the treei;
n = Number of trees counted within the sampling unit;
0.5 = Form factor.

2.3Imagery Data

It was used the TM/Landsat 5 image, path 221 and row 083 (the swath and width are showed in Figure 1), of September 7, 2010, which coincides with the period of the forest inventory. Firstly the image was geometrically corrected by two methods: using both the nearest-neighbor (NN) and bilinear resampling.

The georeferencing was based on 12 ground control points surveyed in the study area with a GPS Garmin Etrex Legend® set into a Universal Transverse Mercator (UTM) coordinate system, datum SIRGAS-2000 (same coordinate system and datum of the S.U.). The total RMS error of the georeferencing was 0.4 pixels. Thus, this procedure resulted in the first data set (Figure 3): 1) corrected image with NN resampling, and 2) corrected image with bilinear resampling.

Afterwards, on each one of these images was applied two methods of atmospheric correction (Figure 3): DOS and MODTRAN. The method DOS was used following methodology presented by Gurtler*et al*. (2005), which provides equations to convert the digital number (DN) values in surface Bidirectional Reflectance Factor (BRF). After, the calculation of surface BRF by radiation transfer model was carried out at ENVI FLAASH module. The FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) incorporates the MODTRAN4 radiation transfer code (ENVI, 2008).

Therefore, four sets of images with surface reflectance information were obtained by four methods: 1) geometric correction with NN resampling + atmospheric correction using DOS, 2) geometric correction with NN resampling + atmospheric correction using MODTRAN, 3) geometric correction with bilinear resampling + atmospheric correction using DOS, and 4) geometric correction with bilinear resampling + atmospheric correction using MODTRAN.

From these image sets, the spectral bands related to red (TM3) and near infrared (TM4) wavelengths were used to calculate the NDVI (ROUSE *et al*., 1973), Equation 2. The surface reflectance values needed to calculate the NDVI were extracted from the pixels which contained the S.U. geographical coordinates.

$$\text{NDVI} = \frac{\rho_{IVP} - \rho_V}{\rho_{IVP} + \rho_V} \qquad (2)$$

Where:

ρ_{IVP} = The surface reflectance from near infrared wavelength;
ρ_V = The surface reflectance from red wavelength.

Statistical differences on the NDVI values obtained by the four methods were analyzed, at first, with the repeated measure technique where the following hypothesis were tested:

H_0: the four NDVI mean values are equals.
H_1: at least one NDVI mean value is different.
Where the H_1 hypothesis was found, a Tukey test was performed.

2.4 Stem Volume Estimation

The stem volume data (m³/ha) were defined as dependent variable and NDVI data from the four sets of images entered as independent variables in the adjustment of empirical regression models to estimate the dependent variable. For each set of images was selected the best fitted model, consequently four model were adjusted.

The estimation results were checked by comparing the estimated stand volumes with the actual values based on the field inventory. The reliability of the estimates was measured by means of standard error (RMSE) and bias (Bias),Equation (2) and Equation (4) (LINDGREN, 1976). The relative RMSE ($RMSE_r$) and relative bias ($Bias_r$) were calculated as a proportion of the mean estimated value, Equation (3) and Equation (5), (MÄKELÄ and PEKKARINEN, 2004).

$$RMSE=\sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i-y_i)^2}{n}} \qquad (3)$$

$$RMSE_r=\frac{RMSE}{\bar{\hat{y}}} \qquad (4)$$

$$Bias=\frac{\sum_{i=1}^{n}\hat{y}_i-y_i}{n} \qquad (5)$$

$$Bias_r=\frac{Bias}{\bar{\hat{y}}} \qquad (6)$$

Where:

$\hat{y}_i$ = The estimate;
$\bar{\hat{y}}$= The mean of the estimates;
y_i= The observed value of y;
n= The number of observations.

3. Results and Discussion

The repeated measure technique pointed out that at least one set of the four combinations of geometric and atmospheric correction methods returned a different NDVI mean value (α=5%). With Tukey test (α=5%), the NDVI from Bilinear + DOS is equal to NDVI from NN + DOS and the NDVI from Bilinear + MODTRAN is equal to NN + MODTRAN. However, the NDVI from Bilinear + DOS is different of NDVI from Bilinear + MODTRAN and from NN + MODTRAN, even as the NDVI from NN + DOS is different of NDVI from Bilinear + MODTRAN and from NN + MODTRAN. Thus, the Tukey test pointed out that NDVI mean values were different only when the atmospheric method changed.

This suggests that the atmospheric correction method can exert more influence on the grey-level values of the original image than the geometric correction method, at least on the particular environment here defined (Figure 1).This can be explained by the different concepts involved in the methods formulation, while DOS is an empirical method and assume the interference of the atmosphere as additive, the MODTRAN is a physics method and it is based on the theory of radiative transfer (FREIRE, 1996; MATHER, 1999).

The atmospheric correction effects on spectral bands and vegetation index were studied by Latorre et al. (1998).They investigated the difference in forest NDVI values obtained from hyperspectral image (simulating the same bands of TM/Landsat 5) with and without atmospheric correction and noticed an 18% difference among the NDVI values. The authors highlight the great influence that an atmospheric correction method can exert on the original image.

Concern the two geometric correction methods don't resulting different NDVI mean values, this can be due the forest stands composition and the forest inventory's sampling design. The study area, Figure 1, has just one tree species (Pinus), which characterize a homogeneous forest, and each tree is planted in a 2 m x 3 m design (Figure 2). These facts result that trees within the stand are expected to be very similar and, as a consequence they will return a similar reflectance response on the pixels located within the stand, at least in a 30 m spatial resolution image. Besides that, the forest inventory's S.Uswere surveyed in a manner to avoid the stand borders (Figure 2). Remembering that reflectance values needed to calculate the NDVI were extracted from the pixels which contained the S.U. geographical coordinates, this means that the selected pixels were within the stands and as a result nearest-neighbor and bilinear resampling methods achieved very similar values of NDVI on these selected pixels.

The NDVI obtained from different geometric and atmospheric correction methods was then applied to estimate the stem volume of Pinus (m^3/ha). Table 1 shows the adjusted equations and its respective values of explained variation (R^2). It was verified that the best fitted equations were the power ones; the nonlinear dependency (or relationship) among the forest parameters and the spectral values were found also by Trotter *et al*. (1997) and Baccini *et al*. (2004). The equations from Table 1 are in a linear way.

The equation with the lowest R^2 and highest CV was the number 2, which combines NN + DOS. The equations number 1 and 4 have the same R^2 value. The equation best fitted (N=3) was the one that used bilinear resampling and atmospheric correction with MODTRAN (Table 1), which resulted on the lowest standard error with a relative RMSE of 56.5% (Table 2). On the other hand, the highest RMSE, 62.3%, was result of NN + DOS combination, Table 2. The biases were positive with all the different feature sets and varied from 13.3 to 15.9%. Therefore, there was overestimation in all methods.

Regard the overall accuracy of the estimates the results are similar to other studies; Reese *et al*. (2002) estimated stem volume of boreal forest with TM/Landsat 5 and SPOT 3 and the total wood volume RMSE, at the pixel level, ranged from 58% to 80% and bias ranged from -1.2 to12 m^3/ha; Hyyppä*et al*. (2000) estimating stem volume of boreal forest with TM/Landsat 5 found a standard error of 87.5 m^3/ha (56%).

Although the Tukey point out that the geometric correction methods do not produce differences on NDVI values, when using the NDVI values to estimate stem volume (Table 1 and Table 2) it can be seen that the combination of geometric and atmospheric correction methods contribute to increase or decrease the accuracy of the estimates. Park and Schowengerdt (1983) demonstrated that the mean square error between the grey-level values of the original and the resampled image is minimized using the bilinear followed by the nearest-neighbor resamplers, respectively. Similar results were observed by Shlien (1979); Results shows that pixel spectral resolution is improved with FLAASH compared to simple DOS (OWOJOR and XIE, 2005).

In practice, the difference on estimates between the equation with the highest and lowest RMSE, Table 2, was 2.34 m^3\ha (5.78%), which, at first, may seem to be a not very significant amount. However, considering the estimates on the study area, where the stand of Pinus covers approximately 4,000 ha, the difference between the stem volume estimated from the equation with the highest and lowest RMSE reaches 9,360 m^3. And taking into account the average price of wood stem in the region, 40.00 R$/$m^3$ (R$ = Brazilian reais), the amount of this difference (9,360 m^3) yields a value of R$ 374,400.00. This example, based on an economic point of view, highlighted the importance of testing different geometric and atmospheric correction methods in estimating forest wood volume with satellite images.

It is noteworthy that the results described in this paper are empirical, so cannot be said that they can be applied to other images or study areas. Furthermore, the RMSE of the estimates ranged from 56-63%, indicating the existing limitations on estimates of biophysical parameters at pixel level. However, this technique, derived from remote sensing, has the advantage of supply an estimate over the whole area.

4. Conclusion

The use of nearest-neighbor or bilinear resampling for geometric correction of the image do not result on differences on the NDVI values related to pixels located within the stands of Pinus. On the other hand, the NDVI values are different when using DOS or MODTRAN for atmospheric correction.

When the NDVI entered as independent variable on the prediction models, each set of methods presented different accuracies (RMSE and Bias).The lowest RMSE estimating stem volume of Pinus was found with the image geometrically corrected by bilinear resampling and atmospherically corrected using MODTRAN. It was demonstrated that, when considering all stands into study area, the practical difference between the estimates with the highest and lowest RMSE generates an expressive economic amount.

Therefore, the results point out that different geometric and atmospheric correction methods should be tested on studies relating spectral with biophysical data in order to improve the accuracy of the estimates over a specific area.

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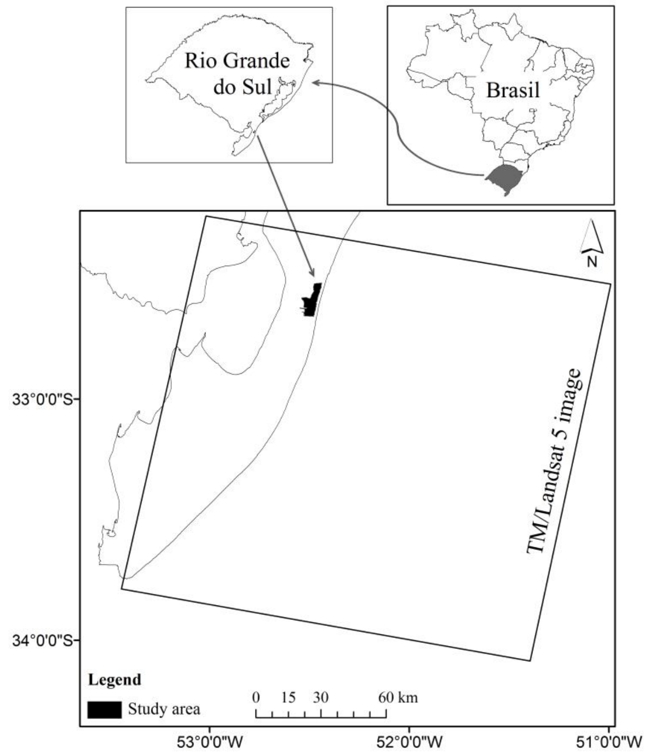

Fig. 1: Location Map of the Study Area

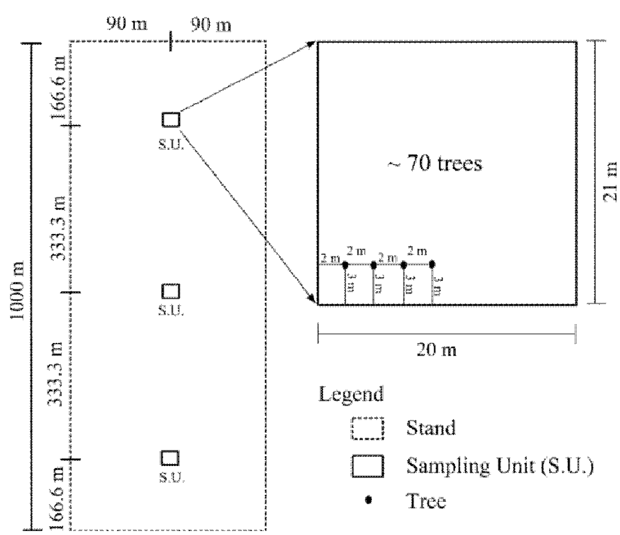

Fig. 2: Forest Inventory's Sampling Design on a Stand of Pinus

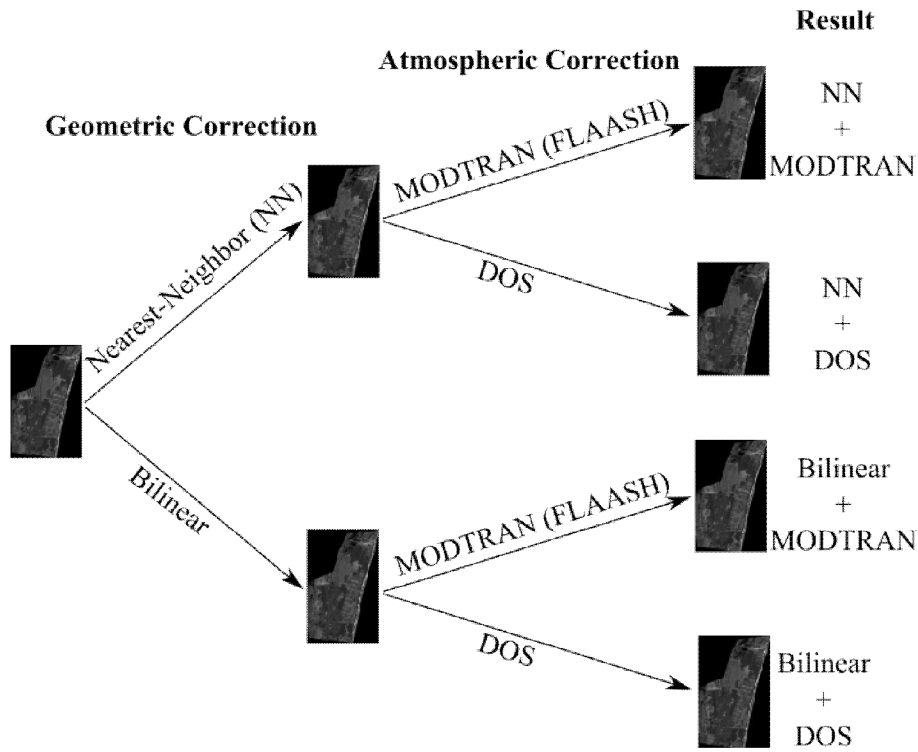

Fig. 3 – Summary of the Geometric and Atmospheric Correction Methodology Applied on a TM/Landsat 5 Images

Table 1 - Statistics of the Adjusted Equations to Estimate Stem Volume of Pinus (M^3/Ha) by NDVI Obtained from Images Corrected with Different Geometric and Atmospheric Correction Methods

N	Predictor	Estimates	p-value	CV%	R^2
1	Intercept BILINEAR + DOS	5.41 8.81	8.47E-48 9.31E-17	16.18	0.57
2	Intercept NN + DOS	5.31 7.97	5.61E-47 1.68E-15	16.75	0.54
3	Intercept BILINEAR + MODTRAN	6.21 3.27	1.16E-42 5.15E-18	15.62	0.60
4	Intercept NN + MODTRAN	5.99 2.89	2.25E-42 1.00E-16	16.19	0.57

Where: N= equation number; p-value= value of the probability *p*; CV%= coefficient of variation in percentage; R^2 = coefficient of determination.

Table 2 - Errors of the Pinus Volume Estimates Using Different Geometric and Atmospheric Correction Methods for Extract the Spectral Features

Feature sets	RMSE		Bias	
	m^3/ha	%	m^3/ha	%
BILINEAR + DOS	31.01	59.52	7.85	15.07
NN + DOS	32.21	62.29	8.23	15.92
BILINEAR + MODTRAN	29.87	56.51	7.08	13.39
NN + MODTRAN	30.78	58.92	7.70	14.75