Accuracy of forest stand volume estimation by Landsat TM imagery with different geometric and atmospheric correction methods

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Abstract

Stem volume of Pinus elliottii were estimated from Landsat TM data with different methods of geometric and atmospheric correction. 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 sampling unit measured in the field. The 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.

Keywords: Stem volume, geometric correction, atmospheric correction, 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.

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). A common approach is the combination of satellite image data and field data assessed from sample plots for estimating forest variables for each pixel of the image (Tokola *et al*., 1996; Katila and Tomppo, 2001).

Remote sensing images are usually geometrically precision corrected to fit a selected co-ordinate 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 process 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 is a MODTRAN4-based atmospheric correction software package (AdlerGolden *et al*., 1999) that can compensate for atmospheric effects more accurately (Owojor and Xie, 2005).

Therefore, the overall objective of this paper was to evaluate the accuracy in the indirect estimation of stem volume (m^3/ha) on a Landsat 5 TM image preprocessed with two methods of geometric and two methods of atmospheric correction. The analyses were carried out at pixel level.

2. Materials and methods

2.1 Study area and field data

The study area is located between the coordinates (32°41'36"S; 52°32'27"W) and (32°32'33"S; 52°23'04"W); with prevalence of sandy soils. The regional climate is type Cfa, of the Köppen classification (Moreno, 1961).

The forest inventory data were collected during the months of September and October 2010 on pole stands of *Pinus elliottii*, aged 5-8 years. The inventory was systematic and each Sampling Unit (S.U.) had an area of 420m² (70 trees). In the S.U. center was taken the geographic coordinate.

Allometric equations were used to determine the stem volume per hectare.

2.2 Imagery data

It was used the Landsat-5 TM images, path 221 and row 083, of September 7, 2010, which coincides with the period of the forest inventory.

Firstly the image was geometrically corrected by two methods: using the nearest-neighbor (NN) resampling and bilinear resampling.

The georeferencing was based on 12 ground reference 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 0.40 pixels. Thus, this procedure resulted in the first data set: 1) corrected image with NN resampling, and 2) corrected image with bilinear resampling.

In the sequence, on each one of these images was applied two methods of atmospheric correction: 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).

Thus, four sets of images with surface BRF information were obtained by four methods: 1) geometric correction with NN resampling + atmospheric correction using DOS model, 2) geometric correction with NN resampling + atmospheric correction using MODTRAN model, 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, as suggested by Rouse *et al*. (1973). The BRF values needed to calculate the NDVI were extracted from the pixels which contained the S.U. geographical coordinates.

2.3 Stem volume estimation

The stem volume data (m^3/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.

The estimation results were checked by comparing the estimated stem 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) (Lindgren, 1976). The relative RMSE (RMSEr) and relative bias (Biasr) were calculated as a proportion of the mean estimated value (Mäkelä and Pekkarinen, 2004).

3. Results and discussion

Table 1 shows the result of the regression analysis. It was verified that the best fitted equations were the power ones; the nonlinear dependency 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 the linear way.

Table 1: Statistics of the adjusted equations to estimate stem volume of *P. elliottii*.

N	Predictor	Estimates	p-value	CV%	R²
1	Intercept	5.41	8.47E-48	16.18	0.57
	DOS+BILINEAR	8.81	9.31E-17		
2	Intercept	5.31	5.61E-47	16.75	0.54
	DOS + NN	7.97	1.68E-15		
3	Intercept	6.21	1.16E-42	15.62	0.60
	MODTRAN + BILINEAR	3.27	5.15E-18		
4	Intercept	5.99	2.25E-42	16.19	0.57
	MODTRAN + NN	2.89	1.00E-16		

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

The model with the lowest R^2 and highest CV was the number 2, which combines NN + DOS. The models number 1 and 4 had the same R^2 value. The model best fitted (N=3) was the one that used bilinear resampling and atmospheric correction with MODTRAN.

The lowest standard error on pixel-based volume estimation was achieved using bilinear resampling and MODTRAN, which relative RMSE was 56.5%. 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%. Thus, there was overestimation in all methods.

Table 2: Errors of the *Pinus elliottii* volume estimates using different geometric and atmospheric correction methods for extract the spectral features.

Feature sets	RMSE		Bias	
	m³/ha	%	m³/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

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 Landsat 5 TM and SPOT 3 and for total wood volume RMSE, at the pixel level, ranged from 58-80% and bias ranged from -1.2 to12 m³/ha; Hyyppä *et al*. (2000) estimating stem volume of boreal forest with Landsat 5 TM found a standard error of 87.5 m³/ha (56%).

Some authors studied the effects of methods for geometric correction and atmospheric correction separately; 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); Latorre *et. al*. (1998) investigated the difference in forest NDVI values obtained from hyperspectral image with and without atmospheric correction and noticed a 23% difference among the NDVI values.

In practice, the difference on estimates between the model with the highest and lowest RMSE was 2.34 m³\ha (5.78%), which, at first, may seem a not very significant result. However, considering the estimates on the study area, where the stand of *Pinus elliotti* cover approximately 4,000 ha, the difference between the stem volume estimated from the model with the highest and lowest RMSE reaches 9,360 m³. And taking into account the average price of stem in the region, R$ 40.00 m^{-3}, the amount of this difference (9,360 m³) yields a value of R$ 374,400.00.

The economic value related to estimates obtained by different methods of geometric and atmospheric correction highlighted the importance of testing these methods in estimating forest volume with satellite image.

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.

4. Conclusion

Both the atmospheric correction and geometric correction methods influence the accuracy of estimates.

The lowest RMSE estimating stem volume of *Pinus elliottii* was found using NDVI from the image geometrically corrected by bilinear resampling and atmospherically corrected using MODTRAN.

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