THE 4SAIL MODEL ESTIMATING BIDIRECTIONAL REFLECTANCE FROM EUCALYPTUS CANOPIES

José Guilherme Fronza[1] e Flávio Jorge Ponzoni[2]

[1]Consultor ambiental na Ambientare Soluções em Meio Ambiente, SCS Qd. 07 Bloco A nº 100, Ed. Torre Pátio Brasil, sala 1025/1027, Brasília/DF, 70307-902, Brazil - guilherme.fronza@gmail.com; [2]Pesquisador na Divisão de Sensoriamento Remoto INPE Instituto Nacional de Pesquisas Espaciais - Av. dos Astronautas Sao Jose dos Campos, SP, 12227-010, Brazil - flavio@dsr.inpe.br

ABSTRACT

Scattering by Arbitrarily Inclined Leaves (SAIL) use was proposed in this work to simulate the spectral characterization from Eucalyptus sp. plantations comparing the resulting data to the bidirectional reflectance factors from orbital images. According visual comparison the differences between the WorldView 3 reflectance values and those calculated by the 4SAIL model suggest that the 4SAIL model does not take into account aspects that really participate of the canopy reflectance. In the statistical approach significant F values were calculated for the infrared region (NIR1 and NIR2) independent on the canopy level and the results to visible spectral region was performed poorly. In spite of being relatively easy to parametrize the 4SAIL model in order to calculate the canopy reflectance of some Eucalyptus plantations, at least using the WorldView 3 images converted to surface reflectance, in absolute terms the calculated canopy reflectance values calculated by the 4SAIL model were relatively different from those extracted from the WorldView 3 images.

Key words — 4SAIL, Forward Modelling, Radiative Transfer Model, Worldview-3.

1. INTRODUCTION

The forestry activities in Brazil represent importance fraction of the GNP (Gross National Product) and the paper production is the main activity followed by coal production supporting the industry. Private companies are responsible for millions of hectares occupied by Eucalyptus sp. plantations that are frequently inventoried using traditional inventory techniques, which are cost and time consuming. Methodological alternatives for logging inventory, including those based on remote sensing technology, have been asked by the Brazilian forestry sector.

The remote sensing applications on vegetation studies have been improved since quantitative approaches became frequently explored. Correlations between radiometric data from orbital images and biophysical parameters from vegetation cover have been evaluated considering both empirical (statistical/regressions) and physical approaches [1]. One of the most longstanding canopy reflectance models is the Scattering by Arbitrarily Inclined Leaves (SAIL) model that was proposed by Verhoef [2] as an improved version of the Suits model proposed by Suits [3]. Verhoef et al. [4] proposed a numerically robust and optimized version of the SAIL model called 4SAIL that permits to calculate the canopy Bidirectional Reflectance Distribution Function (BRDF) according the collecting data geometry [5]. The parametrization of any model is still a hard work depending upon the vegetation cover characteristics under study.

The objective of this work is to parametrize the 4SAIL model in order to simulate bidirectional reflectance factors from some Eucalyptus sp. plantations located in Itatinga town, São Paulo, Brazil comparing the resulting data to the bidirectional reflectance factors from orbital images toward its future inversion to estimate biophysical data from canopy reflectance.

2. MATERIALS AND METHODS

The study area was composed by Eucalyptus sp. plantations growing at the Estação Experimental de Monitoramento de Itatinga, Itatinga town, São Paulo state, Brazil. The Eucalyptus sp. stands inside the experimental area were composed by 16 different genotypes with same age. Figure 1 shows the study area localization in both the national and the regional contexts.

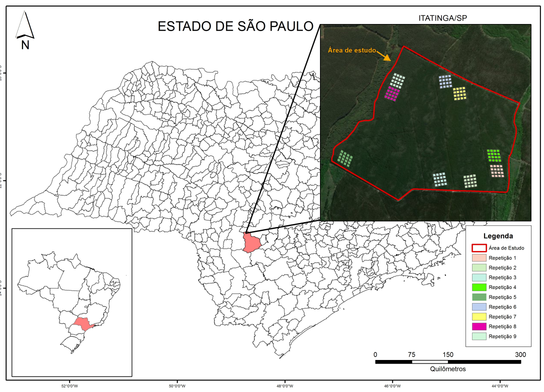

Figure 1. Study area localization.

The small color quadrats represent the spatial distribution of sample plots. There were 9 groups of 4 x 4 sample plots. Each sample plot was a 36 x 32m area in which it was planted 16 x 12 trees spaced 3 x 2 m of a specific Eucalyptus genotype. So, each group was composed by 16 sample plots and each one occupied by also 16 Eucalyptus genotypes. These genotypes were planted in 2009 being six-year-old in October of 2015 when the field campaign was performed. According Le Maire et al. [6] these genotypes presented similar structure, but different productivity levels.

A field campaign was performed from October, 19th to 23th 2015 when both biophysical and radiometric data were collected. Leaf Area Index (LAI) and Leaf Angle Distribution (LAD) were the biophysical data while leaf reflectance and transmittance and litter reflectance were the radiometric ones. The LAI and LAD data were measured and averaged for each genotype for use on 4SAIL.

The leaves spectral characterization (reflectance and transmittance) was carried out taking into account the already mentioned three crown levels: top, intermediate and bottom. Average spectra for each crown level were calculated.

Leaf and litter reflectance spectra were reduced to simulate the WorldView 3 sensor characteristics using the filter-functions provided by Digital Globe. The geometric data were stablished according a specific Worldview-3 image acquired in 10/08/2015 with zenithal solar angle of 25.9o, zenithal sensor angle of 13.5o and relative azimuth of 162.5o. At the end of the 4SAIL processing, 144 reflectance spectra were available for the comparison to the orbital WorldView 3 data.

The 4SAIL Eucalyptus sp plantations simulated data were compared to WorldView-3 data from the study area, which were collected on 10/08/2015, near the field data collection period. The WorldView 3 reflectance spectra were averaged from 130 image pixels at each genotype and sample plot. The two data set were compared by two different strategies: visually and statistically.

First, the visual strategy was based on the visual comparison between the three set of reflectance spectra (the three canopy level in-lab leaf reflectance, the 4SAIL model calculated canopy reflectance and the WorldView 3 canopy surface reflectance) from each genotype. The idea here was to evaluate the adherence between the leaf spectra, the canopy reflectance simulated by the 4SAIL model (also at each canopy level) and the canopy reflectance spectra extracted from the orbital images.

The statistical strategy included the application of linear regression models The regression significance was examined by the Fischer-Snedecor F distribution at 5% of significance.

3. RESULTS AND DISCUSSION

Figure 2 shows some typical results (just for genotypes 7, 11 and 14) achieved comparing reflectance curves obtained by the leaf spectral characterization in-lab, by the 4SAIL processing and from the WorldView 3 images per Eucalyptus genotypes.

The reflectance curves of genotypes 1, 2, 3, 4, 5, 6, 8, 9, 10, 12, 13, 15, and 16 were not showed at Figure 2 since they repeated the three patterns that will be discussed as following. Genotypes 1 and 16 presented graphics similar than those of genotype 7 showed in Figure 2. As observed, at each canopy level, leaf reflectance presented higher values at the entire spectral range evaluated (WorldView 3 spectral bands). The reflectance calculated by the 4SAIL model presented intermediate values between the in-lab leaf reflectance and those extracted from the WorldView 3 data. In the visible spectral region both leaf reflectances and WorldView 3 reflectances were relatively similar themselves in absolute terms, but extremely different in the near infrared spectral regions.

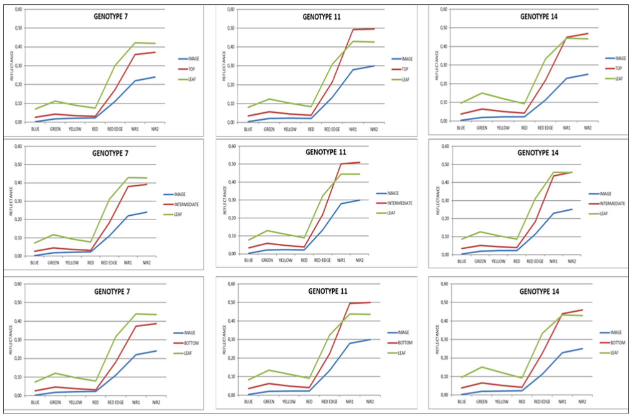

Figure 2 - Reflectance spectra simulated by the 4SAIL model, extracted from the WorldView 3 images and those calculated from the leaf reflectance spectra obtained from the in-lab spectral characterization.

Comparing leaf and 4SAIL reflectances from genotype 7 it seems that the 4SAIL would by producing coherent results since according Kumar [7] or Goel [8], canopy reflectances are frequently lower than a single leaf reflectance due to shadowing and multiple scattering phenomena, but if we assume the WorldView 3 data as a reference or “field truth” it would be considered that shadowing and multiple scattering are not perfectly taking into account by the 4SAIL model.

The reflectance values presented for genotype 11 repeated for genotypes 3, 4, 5, 6, 8, 13 and 15. Here in the visible region the reflectance values from the three different sources (leaf, 4SAIL and WorldView 3) and canopy levels presented similar positioning already described for genotype 7, but in the near infrared regions the 4SAIL model seemed to not consider the canopy shadowing or overestimate the multiple leaf scattering since the 4SAIL reflectance in NIR1 and NIR2 spectral bands presented higher values. Again the WorldView 3 data were lower that both set of reflectance data (from leaves and by the 4SAIL model).

Finally, genotypes 2, 9, 10 and 12 presented similar reflectances pattern than genotype 14 showed in Figure 2. In the visible region there were no differences comparing to the previous discussed reflectance patterns, but in the near infrared spectral bands the reflectance values from the leaves and those calculated by the 4SAIL model assumed similar values in absolute terms indicating again possible negligence of shadowing and/or multiple scattering. As observed in both previous cases, the WorldView 3 data were lower than leaf and 4SAIL reflectance values.

The 4SAIL model "understands" the canopy as a homogeneous vegetation layer not considering the leaf multiple shadowing. The differences between the WoldView 3 reflectance values and those calculated by the 4SAIL model suggest that the 4SAIL model does not take into account aspects that really participate of the canopy reflectance.

TESTS	BLUE	GREEN	YELLOW	RED	RED EDGE	NIR1	NIR2
TOP pvalue	**8,42E-01**	**1,47E-01**	**1,06E-01**	**8,99E-01**	3,25E-16	4,65E-04	7,21E-04
TOP coefB0	**8,43E-03**	**3,86E-02**	5,06E-01	1,73E-01	**2,68E-02**	9,92E-01	8,97E-01
TOP H1_B0<>1	8,61E-01	9,16E-01	2,66E-01	4,01E-01	**8,32E-09**	7,45E-02	9,88E-02
INT pvalue	**8,53E-01**	2,97E-02	**1,51E-01**	**9,48E-01**	1,49E-02	3,29E-03	3,48E-03
INT coefB0	**5,63E-03**	2,50E-01	6,34E-01	1,13E-01	6,35E-01	5,98E-01	6,28E-01
INT H1_B0<>1	8,19E-01	7,41E-02	3,63E-01	2,78E-01	2,03E-01	2,55E-01	2,96E-01
BOT pvalue	**9,26E-01**	**7,14E-02**	**2,31E-01**	**9,86E-01**	**5,50E-02**	5,71E-04	6,17E-04
BOT coefB0	**7,87E-03**	4,10E-01	7,63E-01	1,59E-01	9,83E-01	7,54E-01	7,22E-01
BOT H1_B0<>1	7,76E-01	1,50E-01	4,73E-01	3,59E-01	4,53E-01	1,24E-01	1,66E-01

Table 1 – F (Fisher-Snedecor test) values of the correlations between the 4SAIL model calculated reflectance values and those extracted from the WorldView 3 data, considering the three canopy levels.

Through the visual analysis of the reflectance spectra it is clear that in absolute terms the three sources of data produced different data. Table 1 shows the correlation coefficients between the reflectance values calculated by the 4SAIL model and those extracted from the WorldView 3 images for each canopy level and spectral bands. Here the data from the 16 genotypes were averaged.

Bold values indicate those not significant correlations at 5% of significance. The interpretation of Table 1 data is: when pvalue < 5%, the regression is significant and it is accepted the probability of the regression curve presents 45o of inclination (different of zero); coefB represents an alternative result when pvalue >=5% in which the regression intercept can be zero; and H1<> 1 evaluates if =1, or if the regression curve presents 45o of inclination.

According Table 1, significant F values were calculated for the infrared region (NIR1 and NIR2) independent on the canopy level. Figure 3 shows the linear regressions stablished from the averaged data from the 16 genotypes in the visible spectral bands.

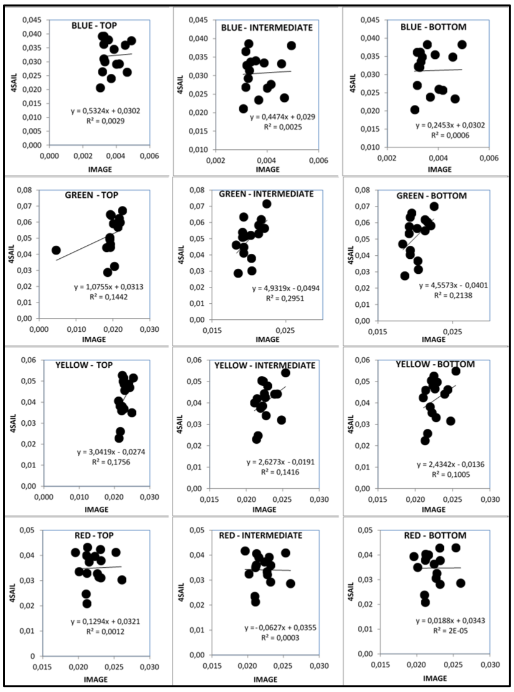

Figure 3 – Linear regressions between 4SAIL model and WorldView 3 reflectances in the visible spectral region.

As observed in Figure 2 the R2 values were low. Higher correlations have just been observed in green spectral band in both Intermediate and Bottom canopy levels suggesting that for the geometric (illumination and viewing) conditions studied here, lower portions of the canopy should be participating more intensely of the canopy reflectance in this spectral region. Figure 4 shows similar graphics specific for the red and infrared spectral bands.

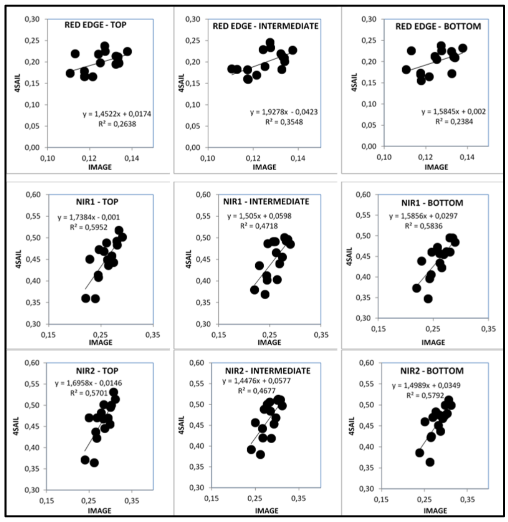

Figure 4 – Linear regressions between 4SAIL model and WorldView 3 reflectances in the red and infrared spectral regions.

Comparing these linear regressions with those calculated for the visible spectral region (Figure 3), it is clear that the correlations between the two set of reflectance data were stronger in the infrared regions. Even in the red spectral region this relationship was stronger than in the typical visible region. It was observed independent on the canopy level, indicating at least for that spectral region, that the small difference between the leaf reflectance from the three canopy levels did not influence the 4SAIL model canopy reflectance simulation.

Strongest correlations between canopy reflectance and biophysical vegetation data in the near infrared region have been reported by Ponzoni et al. [9] and Liesenberg et al. [10], studying some typical Brazilian savanna vegetation cover. Similar studies such as those conducted by Sandmeier et al [11], Galvão et al [12] and Ponzoni et al. 13] have also emphasized stronger correlations between near infrared reflectance and biophysical data from vegetation.

As the visible spectral region is characterized by lowest canopy reflectance values, it is possible that despite the 4SAIL model is properly calculating the canopy reflectance according the actual parametrization, the orbital sensor translation of the canopy radiance and its consequent conversion to canopy surface reflectance, could be generating lowest and saturated values. Thus, we had 4SAIL model canopy reflectance presenting some variations according the model parametrization versus almost constant orbital canopy reflectance, decreasing the correlation. Nevertheless, in the near infrared region the 4SAIL still continued to calculate the canopy reflectance according its parametrization, but the WorldView 3 data became more sensitive to the canopy biophysical changes increasing the correlations.

5. CONCLUSIONS

In spite of being relatively easy to parametrize the 4SAIL model in order to calculate the canopy reflectance of some Eucalyptus plantations, at least using the WorldView 3 images converted to surface reflectance, in absolute terms the calculated canopy reflectance values calculated by the 4SAIL model were relatively different from those extracted from the WorldView 3 images. Just in some rare cases (genotypes 2, 9, 10, 12 and 14) these values were closer in the near infrared region.

The correlation study indicated stronger relationship between 4SAIL calculated canopy reflectance and the canopy reflectance data extracted from the WorldView 3 images just in the near infrared region.

The actual 4SAIL version and the parametrization here adopted were not good enough to the model inversion.

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