Applications of the 4-Scale Radiative-Transfer Model in the Remote Sensing of Boreal Forests.

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ABSTRACT

Remote sensing of forested regions depends greatly on the sun and view geometries under which images are taken. A forest canopy radiative-transfer model based on detailed tree architecture named "4-Scale" [1] has been used in recent years to study the influence of boreal forest properties such as leaf area index (LAI), crown size, branches architecture, tree grouping, etc, on the bidirectional reflectance of different canopies. This paper presents updated results using the latest version of the model that contains a new multiple-scattering scheme that depends on the crown architecture as well as the spatial distribution of the trees. New simulations of ground-based PARABOLA and airborne POLDER reflectances in the red and near-infrared bands are shown, and the mechanisms controlling NDVI directionality will be discussed. The use of 4-Scale for directional corrections of airborne CASI data will also be shown. These results have implications on inversion techniques based on the shadow and sunlit proportions for the retrieval of LAI.

INTRODUCTION

The 4-Scale model developed by Chen and Leblanc [1] and Leblanc *et al*. [2] uses forest canopy architectural properties to simulate the bidirectional reflectance distribution function (BRDF). The model considers different scales at which the foliage is distributed: the non-random crown spatial distribution, the crown shape, and the foliage distribution inside the crown as branches and leaves (or shoots for conifers). 4-Scale has been used to study the directionality of NDVI due to different forest structural and optical properties [3] and for correcting BRDF effects on images from the Compact Airborne Spectrographic Imager (CASI) that has a field of view of ± 17.5 degrees. The model reflectance (ρ) is calculated by associating reflectivities of the sunlit and shaded trees crown (R_T and R_{ZT}) and background (R_G and R_{ZG}) to the four proportions of the scene viewed:

$$r = R_T \cdot P_T + R_G \cdot P_G + R_{ZT} \cdot Z_T + R_{ZG} \cdot Z_G \qquad (1)$$

where P_T and P_G are the probabilities of seeing the sunlit crown and ground, respectively, and Z_T and Z_G are the probabilities of seeing the shaded crown and ground, respectively. In previous versions, constant multiple-scattering factors were used, introducing errors since the amount of multiple-scattering changes with variations in canopy structure. The new version of the model implicitly computes the multiple scattering, based on canopy architecture, is presented here. New simulations of POLDER and PARABOLA are showed along with CASI BRDF corrections and simulation. Implication of different canopies attributes influence on the retrieval of LAI is also discussed.

MULTIPLE SCATTERING: SHADED CROWNS

Shaded crown components can receive light from three sources: the sky, the ground, and from the surrounding foliage. For simplicity, we assume that the foliage contribution comes only from other sunlit crowns. The second order of light reflected by the shaded foliage is then

$$R_{ZT}^{(2)} = R_T (F_{TT} R_T + F_{GT} R_G + F_{ST} f_D) \qquad (2)$$

where F_{TT} is the view factor for other crowns from an infinitesimal elemental area on the shaded crown side; F_{GT} is the view factor for the ground; F_{ST} is view factor for the sky; R_T is the foliage reflectivity; and R_G is the background reflectivity; and f_d is the fraction of diffuse light compared to the total sky irradiance (direct sun + diffuse light). Adding higher orders of scattering gives the total light reaching the shaded foliage in the following form after summation of the order series to infinity:

$$R_{ZT} = R_{ZT}^{(2)} / (1 - R_T) \qquad (3)$$

MULTIPLE SCATTERING: SHADED BACKGROUND

The background receives second order light from the sky and the canopy. Similar to the shaded foliage, the shaded background is

$$R_{ZG} = R_{ZG}^{(2)} / (1 - R_G) \qquad (4)$$

where

$$R_{ZG}^{(2)} = R_G(F_{TG}R_T + F_{SG}f_D) \,, \qquad (5)$$

F_{TG} is the tree view factor for the ground surface and F_{SG} the sky view factor for the ground surface. The factors are calculated in the model from the canopy gap fraction. The diffuse light is also added to the sunlit components in the final reflectance calculation. These simple equations capture the major mechanisms controlling the multiple scattering in forest canopies.

APPLICATIONS

In previous works [1][2] the 4-Scale model results have been successfully compared with PARABOLA and POLDER measurements of different boreal forests. The model was also used to study the NDVI directionality [3] based on the canopies attributes, but since the multiple-scattering factors used red and NIR bands were fixed, errors in the NDVI changes with parameters such as LAI and large SZA were expected. Fig. 1 shows the new (namely version 3.0) and old (version 2.5) simulations of the BOREAS Old Black Spruce (OBS) site.

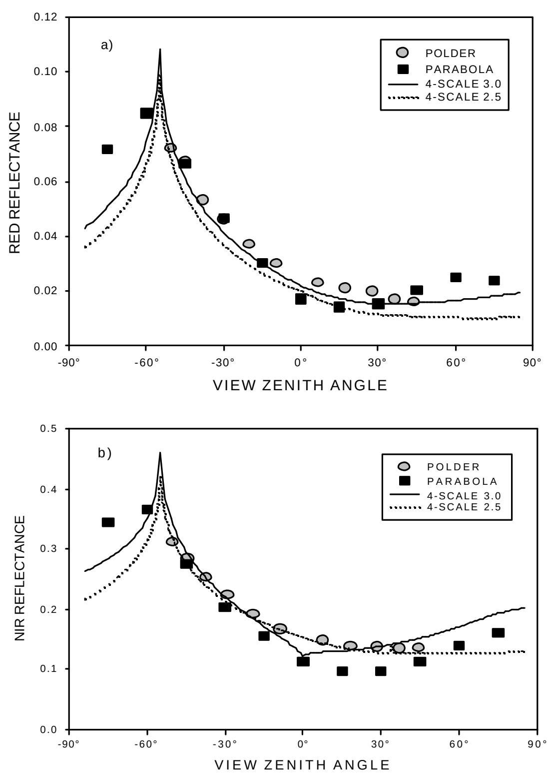

Fig. 1 Comparison between the POLDER, PARABOLA and 4-Scale v. 2.5 and 3.0 for the BOREAS Old Black Spruce (OBS) site for a) the red and b) the near infrared band, respectively.

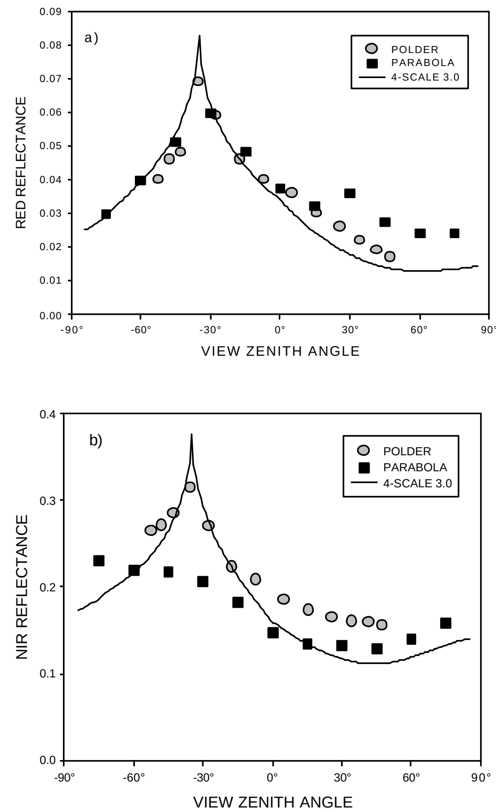

Fig. 2: 4-Scale simulations of POLDER and PARABOLA data of the BOREAS Young Jack Pine site for a) the red and b) the near infrared band, respectively.

The model captures well both the hot spot and the "bowl" shape of the BRDF. Previously, the model had some problems in simulating the BRDF at large solar zenith angles. The new multiple-scattering scheme allows a better simulation as seem in Fig. 1b for the near infrared band. Overall both simulations are good, but the multiple scattering scheme with consideration of the effects of canopy architecture eliminates the need in the old version to set multiple-scattering factors (or the reflectivities of shaded components), and it is expected to work better for numerical simulations involving a wide range of canopy conditions.

Fig. 2 shows new simulations for the BOREAS Old Jack Pine site. The model captures very well the important features in the angular variation. Fig. 3 shows how we applied 4-Scale to CASI image analysis. The model was used to simulate the red and NIR band reflectances at different SZA and VZA to find correction factors to bring the images to a common geometry. Once corrected, the relationship between NDVI and LAI is greatly improved (with R^2 increased from 0.19 to 0.69) (Fig.3).

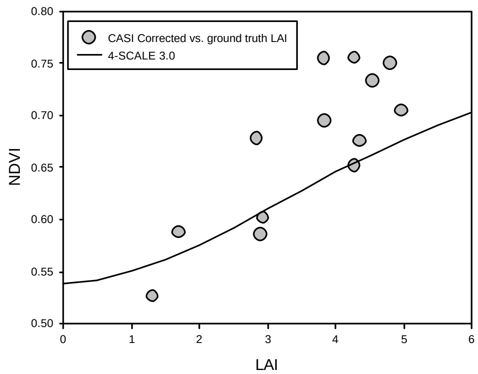

Fig. 3 NDVI taken form red and near infra-red CASI data corrected with 4-Scale along with a simulated NDVI-LAI curves that increase the LAI by adding trees and increasing the size of the crown.

Also shown is a NDVI-LAI curve simulated with 4-Scale. For this simulation, the model uses parameters from the BOREAS OBS tower site. Many of the sites have different canopy conditions (stand density, etc) that could cause the discrepancy between the model and the data, indicating the importance of canopy architecture. In a previous study [3], 4-Scale was used to investigate the effect of several biophysical parameters on the NDVI. The effect of using the constant multiple-scattering factors at different sun angles on NDVI simulations can be seen in Fig. 4, where it is compare with the new multiple-scattering scheme. The two curves are similar in shape, but the constant multiple-scattering factors gave larger values at all solar zenith angle. These results demonstrate that the dependence of NDVI on SZA reported by Leblanc *et al*. [3] was basically correct.

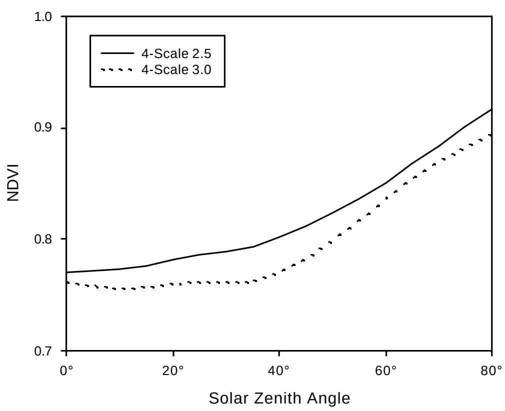

Fig. 4: Simulation of the effect of the sun zenith angle on the NDVI a nadir view for a young jack pine stand.

The NDVI variation with LAI can be explained by the increase of shaded area seen by the viewer because of the different multiple-scattering effects in the red and NIR bands [3]. NDVI-LAI relationship can vary greatly from species to species, and it also depends on the understorey. Hall et al. [4] showed relationships between shadows and biomass of black spruce canopies.

CONCLUSION

A new multiple-scattering scheme is developed for the 4-Scale model. It improves the modelling of forest canopies and also eliminates the need to use shaded component reflectivies. The model is now more reliable for a wide range of canopy conditions and view and illumination angles.

The model code and a Windows NT/95 version are available on request

REFERENCES

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