SIMULATION OF FOREST RADIANCE AT TOP-OF-ATMOSPHERE LEVEL USING COUPLED RADIATIVE TRANSFER MODELS

Valérie C.E. Laurent[a,*], Jan G.P.W. Clevers[a], Michael E. Schaepman[b] and Wout Verhoef[c]

[a] Centre for Geo-Information, Wageningen University, P.O. box 47, 6700 AA Wageningen, the Netherlands - (valerie.laurent, jan.clevers)@wur.nl
[b] Remote Sensing Laboratories, Department of Geography, University of Zurich-Irchel, Winterthurerstr. 190, CH-8057 Zurich, Switzerland - michael.schaepman@geo.uzh.ch
[c] National Aerospace Laboratory NLR , Voorsterweg 31, 8316 PR Marknesse, the Netherlands - verhoef@nlr.nl

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ABSTRACT:

Three radiative transfer models were coupled to simulate forest radiances at the top-of-atmosphere (TOA) level: 1) the PROSPECT leaf model, 2) the 4SAIL2 canopy model which includes the hotspot and clumping effects, and 3) the MODTRAN atmospheric radiative transfer model. The output of the coupled model can be compared to radiances measured at satellite level.
The study area consisted of two Norway spruce stands in Eastern Czech Republic. The field data were collected in the first half of September 2006 and the CHRIS (Compact High Resolution Imaging Spectrometer) data were acquired on September 22, 2006. The coupled model was applied for the two stands, using a single set of atmospheric parameters for the four available CHRIS viewing directions.
The simulated TOA radiances were systematically too high compared to the CHRIS data, for the four viewing directions. However, the simulated spectral and directional trends matched those measured by CHRIS. After investigation, it was found that the reflectance values simulated by the coupled model at the top of the canopy (TOC) were too high and caused the TOA radiances to be too high. Further research will therefore focus on improving the simulation of the TOC reflectances.

1. INTRODUCTION

Forests are important ecosystems on Earth: they cover about 30% of the land surface, provide us with a wide range of services and have a major role in the carbon cycle. Some forest parameters (e.g. leaf area index, canopy cover, and chlorophyll content) can be used for forest monitoring or for developing biomass and climate models. These parameters can be estimated thanks to the combined use of remote sensing data and physically-based radiative transfer (RT) models. The estimation process requires inverting the RT model. However, before inverting the model, one must check that the model gives good results in the forward mode. This study therefore focussed on the forward modelling of top-of-atmosphere (TOA) radiance of forest stands. TOA level was chosen because it corresponds to satellite level and will thus avoid the atmospheric correction at later stages. This paper presents preliminary results of the study.

2. MATERIALS AND METHODS

1.1. Study area

The study area is located at the Bily Kriz experimental research site in the Moravian-Silesian Beskydy Mountains, in Eastern Czech

Republic (18.54°E, 49.50°N; altitude 936 m above sea level) (Kratochvilová et al., 1989). Two stands of montane Norway spruce (*Picea abies* (L.) Karst.) were used in this study: YOUNG and OLD2. Their characteristics are presented in table 1.

	Stand	YOUNG	OLD2
	Age (years)	28	75
	Density (trees/ha)	1436	420
4SAIL2 inputs	LAI	5.67	3.46
	fB	0.3	0.3
	D	0.7	0.9
	hot	0.05	0.05
	Leaf distribution function	Spherical	Spherical
	Cv	0.90	0.70
	ζ	0.34	0.26

Table 1. Canopy characteristics and model inputs.

1.2. Remote sensing data

One set of multi-angular data of the study area was acquired on September 22nd, 2006, by CHRIS (Compact High Resolution Imaging Spectrometer) on board of the PROBA (Project for On Board Autonomy) satellite platform. Only 4 images contained the test site area. Their acquisition geometry is shown in figure 1.

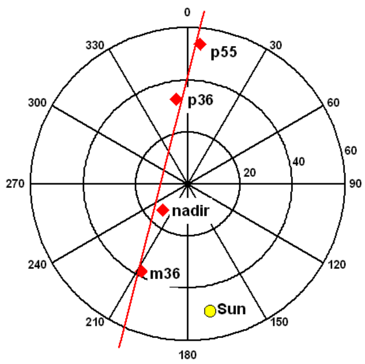


Figure 1: Polar view of the geometry of the CHRIS acquisition.

The images were acquired in CHRIS chlorophyll mode (mode 4), resulting in 18 spectral bands in the range 485-802 nm at a spatial resolution of 17 meters.

An AISA (Airborne Imaging Spectro-radiometer) Eagle image with 40 cm pixel size was acquired on September 14, 2006.

1.3. Modelling set-up

The Soil-Leaf-Canopy (SLC) model (Verhoef and Bach, 2007) was used to simulate the (TOC) reflectance of the stands. It includes:

1) a soil reflectance model which was not used in this study,
2) the PROSPECT leaf reflectance model (Jacquemoud and Baret, 1990), modified to include brown pigments (Cs) (Verhoef and Bach, 2003)
3) the 4SAIL2 canopy reflectance model which includes the crown clumping effect thanks to the introduction of two additional inputs: crown cover (Cv) and tree shape factor (ζ). 4SAIL2 allows mixing green and brown leaves in the canopy. The brown leaves can be used to simulate bark. (Verhoef and Bach, 2007).

The MODTRAN 4.1 model (Berk et al., 2003) was then used to simulate the atmospheric effects and produce TOA radiances. The DISORT algorithm was used to account for the multiple scattering in the atmosphere.

The TOC reflectances and the MODTRAN outputs were resampled to the CHRIS bands using Gaussian approximations of the sensor response functions. An interrogation technique (Verhoef and Bach, 2003) was used to calculate atmospheric gain factors from the MODTRAN output. Finally, those gain factors were applied to the TOC reflectances to produce the TOA radiances.

1.4. Field data & model inputs

The field data were collected in the first half of September 2006, during an extensive field campaign focused on estimating forest structure, leaf biochemistry and spectral properties. The spectral properties were measured with an ASD spectroradiometer coupled with a Li-Cor integrating sphere.

Background. The background was assumed Lambertian. Its signature was calculated as a weighted average of the signatures of soil, humus, litter and understory.

Green leaves. For the green leaves, the concentration of chlorophyll a and b (Cab), water (Cw), and dry matter (Cdm) were measured from the collected field samples. The value of the leaf structure parameter N was adjusted using the three wavelengths method (Jacquemoud et al., 1996) (table 2).

Stand	YOUNG	OLD2
Cab (µg/cm^2)	38.15	42.39
Cw (cm)	0.022	0.020
Cdm (g/cm^2)	0.016	0.016
Cs	0	0
N	1.77	1.67

Table 2. PROSPECT inputs for green leaf.

Bark. The bark signature was simulated using PROSPECT. The input parameters were optimized to minimize the root mean square deviation (RMSD) between the average field bark signature and the PROSPECT simulation.

Canopy. The 4SAIL2 input parameters for the two stands are presented in table 1. The effective crown LAI was obtained by averaging the LAI estimates obtained by three methods (Homolová et al., 2007). Cv was calculated from the classification of the AISA data (Lukeš, 2009). The description of the other input parameters can be found in (Verhoef and Bach, 2007).

Atmosphere. The optimization of the atmospheric parameters has not been conducted yet. It is important that the same atmospheric parameters are used for the 4 images. For this stage of the study, urban aerosols and 40 km visibility were used.

3. RESULTS

Green leaf. The reflectance and transmittance signatures simulated for the YOUNG and OLD2 stands are quite similar (figure 2). The leaf measurements were not available and could not be compared with the simulations.

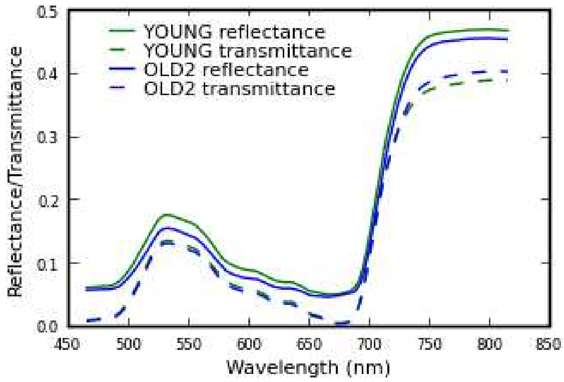


Figure 2. Simulated leaf reflectance and transmittance.

Bark. A very good agreement was obtained between the PROSPECT reflectance simulation and the measured signature (figure 3). The simulated transmittance approaches zero for all wavelengths. As expected, the best agreement was obtained with high values of N, Cdm and Cs values, no water, and low Cab.

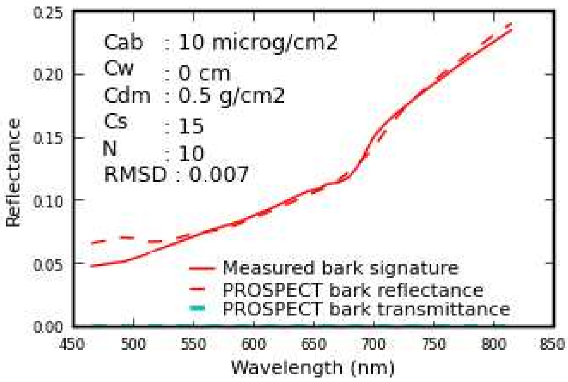
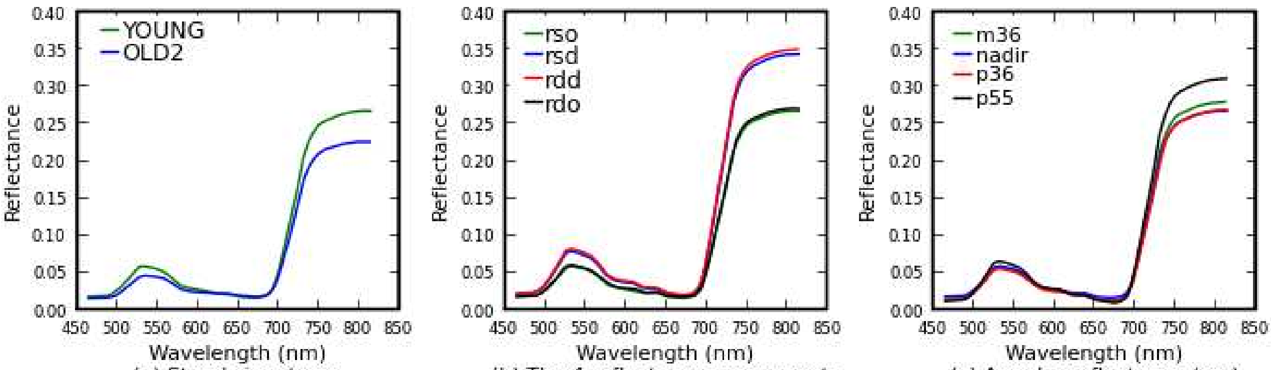


Figure 3. PROSPECT simulation compared to the reference bark reflectance signature (1nm resolution).

Top-of-canopy. The TOC output consists of four reflectance components: 1) r_{so}, bi-directional reflectance (sun-canopy-observer), 2) r_{sd}, directional –hemispherical reflectance (sun-canopy-diffuse), 3) r_{dd}, bi-hemispherical reflectance (diffuse-canopy-diffuse), and 4) r_{do}, hemispherical-directional reflectance (diffuse-canopy-observer). The obtained signatures do correspond to forest signatures (figure 4).

Top-of-atmosphere. Figure 5 shows that the overall shapes of the simulated signatures correspond quite well to that of the CHRIS data. The simulated radiance values, however, are always higher than the CHRIS radiances. A comparison of the angular profiles of simulation and CHRIS data for a few wavelengths (figure 6) shows similar profile shapes and again too high simulated values.



(a) Stand signatures (rso, nadir viewing)

(b) The 4 reflectance components for YOUNG stand (nadir viewing)

(c) Angular reflectance (rso) of YOUNG stand

Figure 4: TOC model outputs.

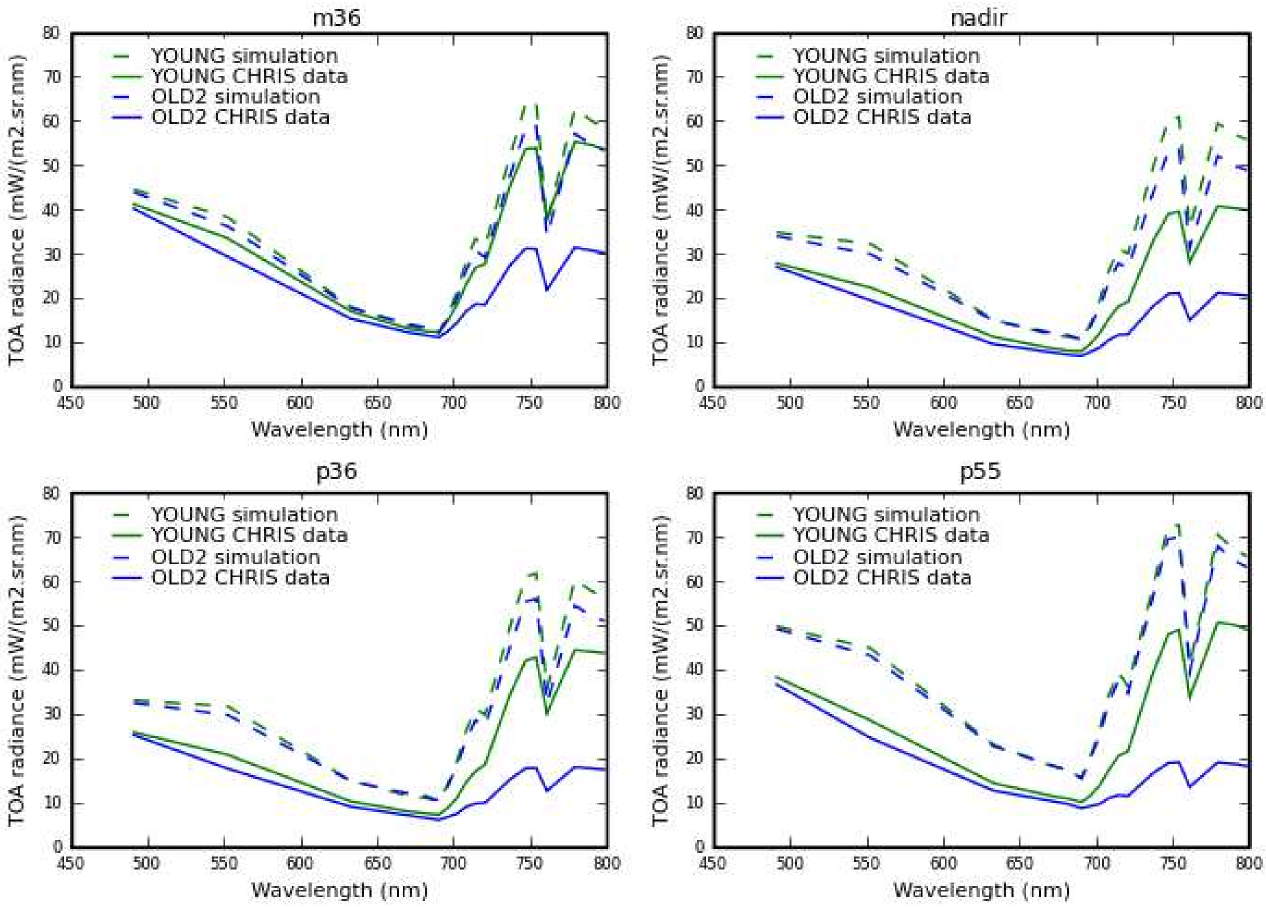


Figure 5. Comparison of TOA simulations and CHRIS signatures.

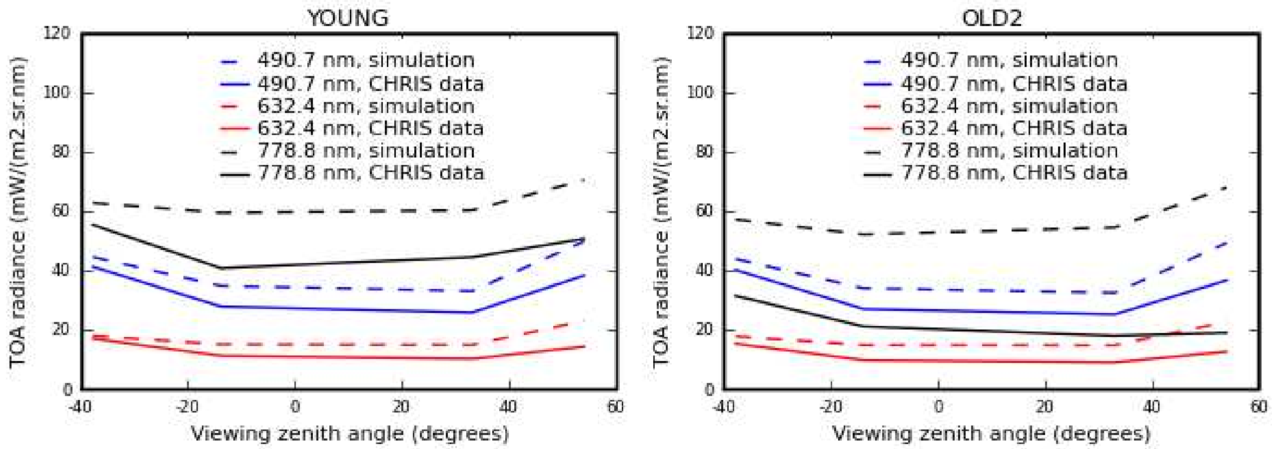


Figure 6. Comparison of the angular profiles for several wavelengths.

4. DISCUSSION

Both PROSPECT-SAIL and MODTRAN have been widely and successfully used for a large range of vegetation types and observation conditions. Since the simulations present a systematic shift which seems to be bigger where the radiance values are higher, it was decided to investigate the correctness of the calibration of the CHRIS data.

The TOC reflectances of gravel, grass and shrub targets from the AISA data, assumed to be Lambertian, were used in place of the SLC output in the modelling process. The obtained TOA signatures showed a good agreement with the CHRIS data, without a systematic shift (not shown). This tends to prove that the calibration of the CHRIS data is correct.

A good agreement was also obtained when using the AISA reflectances of YOUNG and OLD2. A comparison of the TOC simulations for the nadir view with the AISA data (figure 7) shows that SLC produces higher values than the AISA measurements. Therefore, the shift in TOA radiance values observed between CHRIS and simulated data is caused by the simulation of too high reflectance values at TOC level.

A simple investigation of SLC, varying one factor at a time, (not presented here) indicated that so far it was not possible to obtain lower reflectance values in the visible part of the spectrum simply by varying the input parameters, even when using a black background. It is therefore necessary to investigate the goodness of the simulation at the leaf level. Another explanation might be the leaf clumping at shoot level which decreases the reflectance and is not accounted for in SLC.

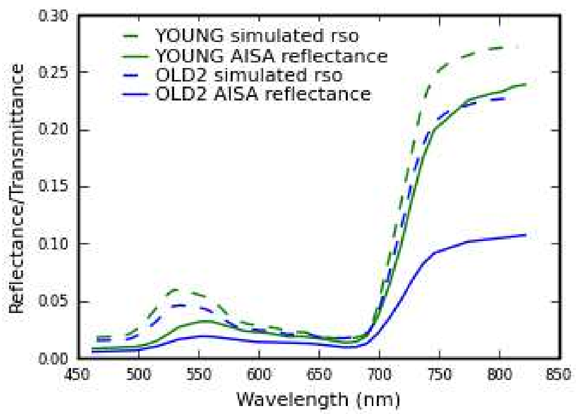


Figure 7. Comparison of the simulated and AISA TOC reflectances (nadir).

5. CONCLUSION

The aim of this study was to check whether radiative transfer models can simulate the TOA radiance of coniferous forest stands with a sufficient accuracy so as to attempt to invert the model for retrieving forest parameters in a later

stage. This study is an on-going work and preliminary results were presented.
At present, the simulations of the TOA radiances of the two forest stands do not match the CHRIS data properly: the shape of the signatures is correct, but the simulated values were shifted towards higher values. This shift appeared to be caused by too high simulations of the reflectance at TOC level. Simply adjusting canopy input parameters in SLC is not sufficient to produce lower TOC outputs and further investigation at the leaf level is required.
When better simulations are obtained at TOC level, the study will focus on optimizing the atmospheric parameters.
This study showed that input parameters at ground level greatly influence the TOA outputs. A sensitivity analysis at TOA level therefore constitutes a very interesting piece of work to carry on.

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