

# COMPARING THREE CANOPY REFLECTANCE MODELS WITH HYPERSPECTRAL MULTI-ANGULAR SATELLITE DATA

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### ABSTRACT:

Studies that compare modelled reflectances with satellite-measured reflectances for different wavelengths and view angles are still rare. We compared model outputs from three different canopy reflectance models (SLC, FRT and INFORM) with satellite measured reflectances (Chris/PROBA). Comparison of the simulated directional reflectances reveals general agreement but also some differences among the models. In general, the radiative transfer models produce signatures comparable to measured ones for spruce and beech forest of different age and canopy structure.

## 1. INTRODUCTION

Among various methods, physically based radiative transfer models have proved to be a promising alternative to estimate biophysical vegetation attributes. However, the existence of many canopy reflectance models with different levels of complexity makes it difficult to choose the most appropriate model for a given application. Intensive research has been done on comparing different models in predicting canopy bidirectional reflectance (Jacquemoud et al., 2000; Bacour et al., 2002; Pinty et al., 2004) but studies that compare modelled reflectances with satellite-measured reflectances for different wavelengths and view angles are still rare. The objective of this study is to evaluate the performance of three canopy reflectance models SLC (Soil-Leaf-Canopy; Verhoef & Bach, 2007), FRT (Forest Reflectance and Transmittance; Kuusk & Nilson, 2000) and INFORM (Invertible Forest Reflectance Model; Schlerf & Atzberger, 2006; Atzberger, 2000) in the direct mode and to compare the model outputs with hyperspectral and multi-directional canopy reflectances from Chris/PROBA images.

## 2. METHODS

### 2.1 Canopy reflectance models

The three models SLC, FRT, and INFORM simulate the bi-directional reflectance of forest stands between 400 and 2500 nm as a function of leaf attributes, canopy attributes, and external parameters. A forested scene is divided into four components: sunlit tree crowns, sunlit ground, shaded crowns, and shaded ground.

*INFORM* is a combination of the PROSPECT leaf model (Baret and Fourty, 1997), the SAILH radiative transfer model for

homogeneous canopies (Verhoef, 1984; 1985) and the semi-empirical forest model FLIM (Rosema et al., 1992). In INFORM (and in opposition to FLIM), crown transmittance in observation and sun direction, crown reflectance at infinite crown depth and the background reflectance are computed using the SAILH+PROSPECT models.

*SLC* is an integrated model consisting of a modified Hapke (1981) soil BRDF model, a robust version of PROSPECT, and a modernised canopy model 4SAIL2 (a hybrid two-layer version of SAILH which contains elements from FLIM (crown clumping), GeoSAIL (Verhoef and Bach, 2003; vertical leaf color gradient) and SAIL++ (Verhoef, 2002; numerical robustness)). In contrast to INFORM, SLC applies a clumping modulation to all (in total: 11) optical properties of the canopy layer.

*FRT* is a forest stand model built on an early forest reflectance model by Nilson & Peterson (1991). It incorporates PROSPECT, the radiative transfer model 6S and the two-layer understory reflectance model MCRM2 (Kuusk, 2001). Crown shapes are modelled as rotation ellipsoids or as cones, optionally with a cylinder in the lower part. Leaves and branches are uniformly distributed in the crown and spherically oriented. Several tree classes of different size and/or species are possible. The soil reflectance is modelled by Price' vectors (Price, 1990).

### 2.2 Satellite data and field measurements

Chris/PROBA images were acquired at Idarwald test site (Germany) on 5 September 2005 in mode 1 (411-1004 nm) at five observation angels (-44°, -33°, -5°, +28°, and +44°). The sun zenith angle during the sensor overpass was 44° and the relative azimuth angle between sun angle and observation angle

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was 50° (Figure 1). All five images were geocoded to the local reference system using image-to-image registration and resampled to the nominal ground resolution at nadir view (34 m). The images were radiometrically corrected to top-of-canopy reflectance assuming standard atmospheric parameters.

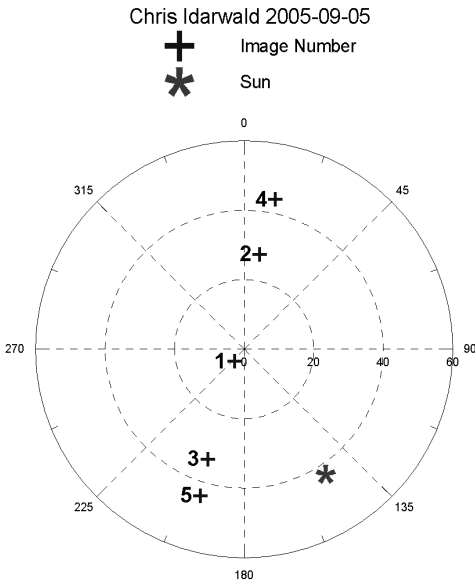


Figure 1: Observation and sun geometry of Chris/PROBA images acquired over Idarwald test site on 05/09 2005

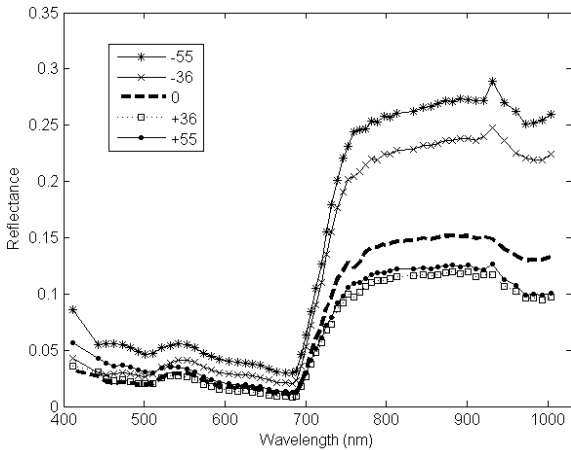


Figure 2: Bi-directional Chris/PROBA spectral reflectances of spruce stands after image radiometric correction. Each curve corresponds to the average signature of 15 stands (60 pixels in total). Beech stands exhibit similar directionality.

Two weeks after the image acquisition, an extensive field campaign was conducted and the canopy structure of altogether 28 forest stands (15 plots of Norway spruce (*Picea abies* L. Karst.) and 13 plots of Beech (*Fagus sylvatica*)) was measured. In each forest stand, a plot of 30x30 m<sup>2</sup> size was established and its central position determined using a hand-held GPS device. Measured attributes include leaf area index (LAI, measured

with Li-Cor LAI-2000), crown diameter (CD), tree density (SD), crown cover (COcr), canopy height (TH), and percent coverage of understorey vegetation (COus).

### 2.3 Model parameterisation

We identified three typical stands for each species (Table 1): young, medium, and old stands. Young stands (20-30 years; before thinning) typically have small tree crowns, many trees and relatively large canopy LAI, whereas old stands (> 80 years) are usually thinned out and therefore show lower LAI values and larger crowns.

At first, for all of the six stands, an average hyperspectral signature was extracted from the four nearest pixels surrounding the GPS-measured plot location in each Chris/PROBA image. The angular variations of the spectral signatures of spruce stands is illustrated in Figure 2.

Type	Age	ID
Spruce	21	83
Spruce	42	109
Spruce	131	301
Beech	40	8
Beech	84	243
Beech	122	245

Table 1: Selected forest stands. Age = stand age in 2005 (years), ID = forest stand identification

ID	CD	TH	SD	LAIc	LAI <sub>s</sub>	COcr	CO <sub>us</sub>
83	1.75	7.9	5000	5.1	7.25	80	30
109	4.30	15.2	689	3.8	6.00	70	70
301	6.60	35.4	211	3.9	7.71	35	40
8	3.03	13.2	3022	6.1	6.59	85	10
243	5.70	24.8	467	3.4	4.80	50	10
245	7.85	25.2	233	4.3	6.29	35	20

Table 2: In situ measured canopy properties. CD = crown diameter (m), TH = tree height (m), SD = stem or tree density (/ha), LAI<sub>c</sub> = canopy leaf area index (Li-Cor LAI-2000), LAI<sub>s</sub> = single tree leaf area index (LAI<sub>c</sub>/COcr), COcr = crown cover (%), CO<sub>us</sub> = cover of understorey vegetation (%), visually estimated)

	Spruce	Beech
N	3.0	1.5
Cab	70	50
Cw	0.02	0.02
Cm	0.025	0.015
ala	65	50
hot	0.02	0.04

Table 3: Leaf properties and species specific canopy properties. N = leaf structure parameter, Cab = chlorophyll a+b content (µg/cm<sup>2</sup>), Cw = equivalent water thickness (g/cm<sup>2</sup>), Cm = dry matter content (g/cm<sup>2</sup>), ala = average leaf angle (°), hot = hot spot parameter

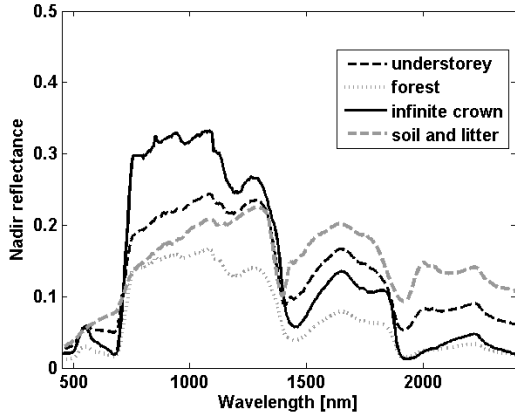


Figure 3: INFORM simulations of a spruce canopy in nadir direction (stand 301).  $R_{\text{soil}}$  (soil and litter) = scaled HyMap spectrum,  $R_{\text{understorey}} = R_{\text{soil}} +$  understorey vegetation (LAI=0.5),  $R_{\text{infinite}} =$  Tree crown LAI = 15,  $R_{\text{forest}} =$  Forest canopy reflectance

To allow comparison of modelled and measured reflectance, the models were parameterised to a large extent using the ground truth information that had been measured in the respective forest stands. Ground truth was available for the most important structural canopy parameters (Table 2). Leaf properties and certain canopy properties that have not been measured in the field (Table 3) were fixed to species specific default values or were slightly optimised through comparing INFORM model outputs with Chris reflectances. All models used a similar background spectrum (Figure 3, black dashed line named understorey). Specification of the sun and viewing geometry was matched to the image acquisition (section 2.2). Using the stand type specific canopy attributes and the illumination and viewing geometries of the Chris/PROBA overpass, the canopy reflectance was modelled using the three radiative transfer models.

In FRT, additional input parameters had to be defined. The following input parameters were computed from measured values: crown length (m), trunk diameter (m), total dry leaf weight (DLW, kg/tree), chlorophyll-% of DLW, water-% of DLW, dry matter-% of DLW, among others. For the following input parameters default values were used: shoot shading coefficient, refraction index ratio, shoot length, Markov parameter, among others. Cones (spruce) and ellipses (beech) were assigned to approximate crown shape.

### 3. RESULTS

Comparison of the directional reflectances simulated by FRT, SLC, and INFORM reveals general agreement but also some differences among the models. In general, the models produce signatures comparable to measured ones for spruce and beech forests of different age and canopy structure.

The pronounced bowl shape in the red waveband of the Chris/PROBA data (Figure 4) is not followed by the models; they rather produce a straight line. Possibly, in the atmospheric correction of the satellite data, the value for the aerosol optical thickness should have been higher, yielding lower reflectances in the red, and thus less of a bowl shape.

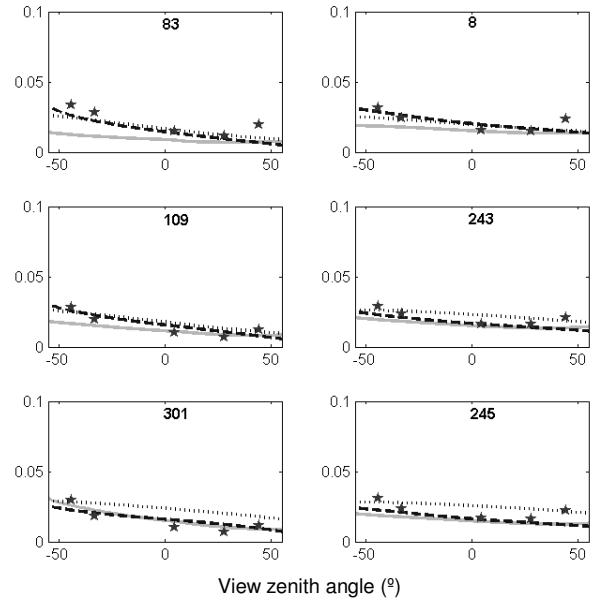


Figure 4: Measured and simulated bi-directional reflectances in the red (670 nm) for spruce forests (left) and beech forests (right) labelled with the respective stand ID. Grey line = FRT, black dashed line = INFORM, black dotted line = SLC, black stars = Chris/PROBA.

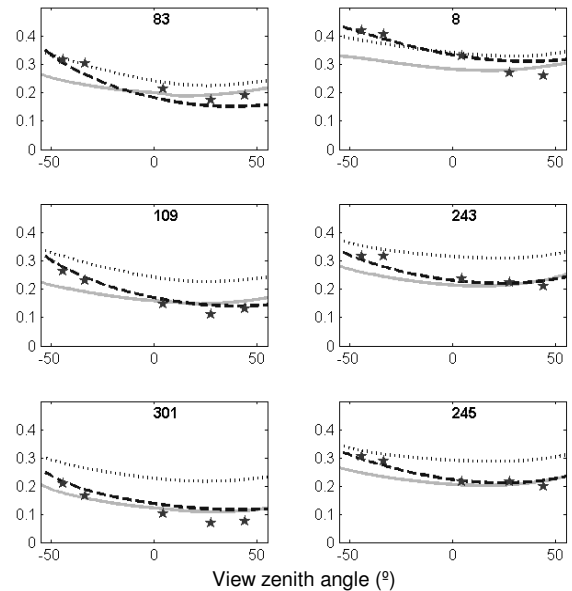


Figure 5: Directional reflectances in the NIR (780 nm) for spruce forest (left) and beech forest (right) labelled with the respective stand ID. Grey line = FRT, black dashed line = INFORM, black dotted line = SLC, black stars = Chris/PROBA.

FRT underestimates red reflectances of young forest stands at large negative viewing angles whereas model outputs of SLC and INFORM are pretty similar to the measured ones.

In the NIR (Fig. 5), differences are more pronounced than in the red. SLC overestimates NIR reflectance for older stands, in particular spruce but also beech. Approximating the Chris/PROBA reflectance curves with SLC for those stands would be possible when a darker background is used or woody material is included. Similar to the red domain, FRT underestimates NIR reflectances at large negative viewing angles. FRT and SLC in general show a relatively low directional variability in the NIR compared to the INFORM model whose outputs better approximate the measured reflectances.

In this study, parameters that were not measured (e.g.  $\alpha$ ,  $C_m$ ) were optimised using INFORM; SLC and FRT had to follow INFORM in those parameter which partly explains why INFORM shows the best results. In the NIR, FRT performs slightly better than SLC as it has additional free parameters that were modified to approximate the satellite measured reflectances.

#### 4. CONCLUSIONS

This is one of the first studies that compare modelled reflectances with satellite-measured reflectances of forest canopies for different wavelengths and view angles. The results are promising, as there is a general agreement between modeled and measured spectra. Most of the differences among the models can be explained by the inherent model structure or by the way the models were parameterized. The results of this research represent an important step towards model development, understanding of radiative transfer in canopies and subsequent model inversion.

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