Variation of satellite estimated LAI due to the impact of the ground vegetation cover

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Abstract - The contribution of the understorey vegetation to the spectral reflectance from the top of a forest canopy was investigated by the use of a forest canopy reflectance model. Detailed field data, i.e. forest leaf area index (LAI), tree structural parameters like the height, diameter and crown length of the trees, and the composition, distribution and reflectance of the forest floor, was collected for some common forest types in southern Sweden and used as input data to the model. Results verify that the impact of the understorey to LAI estimates is of major importance and varies with both the understorey distribution and the forest properties.

Keywords: Canopy reflectance models, forest, LAI, NDVI, understorey vegetation, vegetation parameters

1. INTRODUCTION

The leaf area index, or LAI, defined as half the total leaf area per unit ground surface area (Chen and Black, 1992), is an important biophysical parameter when modelling processes involved in the exchange of energy and matter between the geosphere, biosphere and the atmosphere. Remote sensing enables satellite measured reflectance values to be related empirically to LAI (Eklundh et al. 2003), a method that has been widely applied although both the atmosphere and the ground vegetation may have large impacts on the retrieved correlations. Another drawback is the site and scene dependency on the empirical relationship.

Physically based radiative transfer models simulate the canopy reflectance (Jacquemoud et al. 2000; Kuusk and Nilson 2000) and could be used for estimating forest vegetation parameters like the forest LAI. For a successful separation between the forest LAI and the ground vegetation LAI, the model requires some detailed information about the ground vegetation characteristics.

The aim of this paper is to examine the understorey vegetation for some common forest types in southern Sweden and to determine what influence the ground vegetation could be expected to have on satellite estimated LAI values.

2. THE MODEL

A forest reflectance and transmittance model, FRT (Kuusk and Nilson, 2000), calculates the angular distribution of the reflectance for a given solar direction from 400 to 2500 nm. It includes both geometrical-optical and radiative transfer properties. The input parameters consist of both traditional stand structural parameters common in forest inventory and information about the forest LAI, leaf angle distribution parameters and crown dimensions. Additionally, the following stand-alone sub models are incorporated:

* PROSPECT (Jacquemoud and Baret, 1990), a leaf model that simulates the reflectance of a single leaf using information about the chlorophyll-, water- and dry matter- content as well as the structure of the leaf.

* ACRM (Kuusk 2001), produces reflectance values of the ground vegetation separated into two layers. The PROSPECT model is incorporated in both layers as well as parameters describing the size and angle of the leaves and parameters used for the calculation of the soil reflectance spectrum.

* 6S (Vermote et. al 1997) is used to calculate the incident radiative fluxes using information about aerosol data, visibility and the Ångström turbidity factor.

* MCRM (Kuusk, 1995) produces spectra of the ground vegetation in the same manner as ACRM, but treats the forest floor as one layer instead of two.

3. SITE DESCRIPTION AND FIELD DATA

The study area is located in southern Sweden, 55°45 N and 13°30'E. In total, 20 stands were investigated in the vegetative season of 2003 and sorted after tree species in order to ease the modelling procedure: 8 beech- (*Fagus sylvatica*), 5 oak- (*Quercus robur*),1 birch- (*Betula spp.*) stands , 4 spruce- (*Picea abies*) and 2 pine- (*Pinus sylvestris*) stands. All stands had a varying degree of ground vegetation cover, where the species were separated into five major classes: grasses, herbs, ferns, mosses and small bushes.

The water content, the dry weight and the specific leaf weight, (defined as dry weight per unit leaf area), were estimated separately for each species, including leaves from both the upper and lower parts of the trees, (Eriksson et al. 2005). The reflectance of the leaves was measured using an ASD spectrometer at 325-1075 nm. The measurements were performed in a dark isolated room using a halogen photo lamp as the only light source, to prevent illumination variations. The instrument was held at the normal from the leaf position and the halogen lamp at a zenith angle of 45°, focusing on the leaf. The white reference reflectance was achieved using a reference plate (spectralon), having nearly lambertian properties.

The ground cover was classified into the five major vegetation classes found in the stands using a grid square of 0.5 m^2. The square was laid out every three meters along a 30 m long transect centred over the mid-point of the stands, forming 10 samples to be averaged to represent the mean vegetation cover in each stand. The reflectance of the squares was measured using an ASD spectrometer, the field of view covering the 0.5 m^2 area and the view direction held at nadir. The white reference reflectance was achieved using a reference plate (spectralon).

All tree structural parameters used in the model, like stem density, tree height, trunk diameter and crown were averaged from measurements of several trees within each stand. The branch area index (BAI) was retrieved from former measurements (Eklundh et al. 2003).

LAI was estimated using the instrument LAI-2000 (LI-COR, Inc. 1992). No corrections for clumping and stem influence was performed on the LAI values included in the analysis, since these two components seem to cancel each other out in forest stands of the characteristics investigated here (Eriksson et al. 2005). Table 1 shows some information of the character of the forest stands.

Table A. Ranges of the forest structural parameters.

Tree specie	Tree density (trees ha^{-1})	Forest LAI (m^2/m^2)
beech	200-640	3.0-5.3
oak	180-670	1.9-5.1
birch	370	2.5
spruce	370-910	2.5-3.9
pine	320-370	1.8-2.0

4. MODEL ESTIMATES

Model parameters relating to leaf properties (content of water, chlorophyll and dry matter and the leaf structural parameter) was modelled by the leaf model PROSPECT, using leaf reflectance from 94 deciduous leaves (11 birch-, 30 oak- and 53 beech leaves) as input. Since the area of one conifer needle is too small to fit into the field-of-view of the spectroradiometer, a number of needles were packed tightly to form six layers of needles to be measured by the spectroradiometer. For the deciduous leaves, the water content and dry weight were measured and used as fixed parameters in the model. The refraction indices provided by the model were used. Measured and modelled reflectance values were compared individually for each leaf.

The model uses 4 parameters with information about soil spectra, classified after Price (1990). In forests growing in southern Sweden, the soil layer is seldom seen since the forest floor is covered by senescent leaves/needles. For the retrieval of the soil parameters, the MCRM model was indirectly inverted using spectra of none or small (<3%) amounts of vegetation, fixing all parameters except those describing the soil characteristics. These soil parameters were then used in all further analysis as fixed values. Spectra of senescent conifer needles was obtained from Lang et al. (2002). The modelled spectra corresponded well to data and showed a difference in spectra related to cover type, conifer needles showing higher- and beech leaves showing lower reflectance values, as seen in Fig.1.

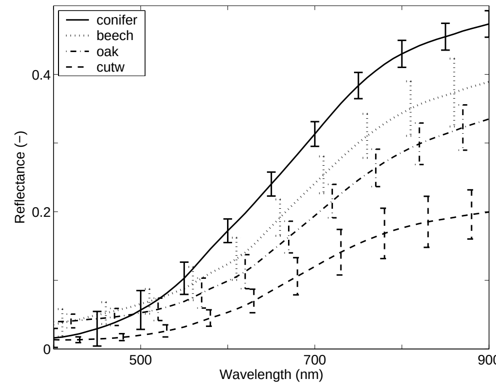

Figure 1. Modelled spectra of senescent leaves/needles for the retrieval of soil parameters, the error bars showing standard deviations of all simulations within each specie.

5. RESULTS AND DISCUSSION

To study how reflectance spectra and LAI estimations vary due to the ground vegetation cover, MCRM was run in inverted mode, using reflectance spectra as input data, and letting the model produce LAI values while most of the other parameters were held constant or within restricted lower and upper limits, defined from PROSPECT simulations and literature values. The reflectance spectra used were all retrieved from squares restricted to one vegetation class. The model fitted the parameters successfully as measured and modelled spectra agreed and the shape of the spectral curves corresponded to the degree of vegetation cover. In Fig. 2, different fractions of grass spectra are shown, the other vegetation types having a similar appearance, not shown here.

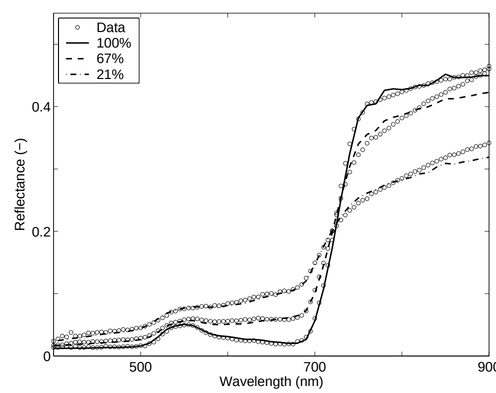

Figure 2. Measured (dots) and modelled (lines) spectra of grass vegetation.

Model estimations of LAI were compared to the vegetation cover degree and to Eq, 1 (Kuusk et al. 2004):

$$W = 1 - \exp(-\frac{G_0 L}{\mu_0}) , \quad (1)$$

where W is the fraction of vegetation ground cover, L is LAI, G_0 is the geometry factor, the Ross-Nilson G-function (here assumed to 0.5) and $\mu_0 = \cos(0) = 1$ is the cosine of the view angle, $\theta = 0$ for the vertical view. LAI was modelled by MCRM for homogenous spectra and ACRM for heterogeneous spectra, plotted against the estimated fraction cover in percent in Fig. 3.

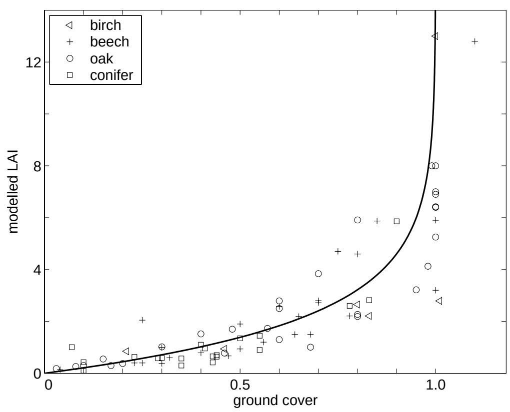

Figure 3. The relationship between vegetation cover degree and modelled LAI.

Since the relationship between the coverage degree and modelled LAI corresponded well with the curve of Eq. 1, the ground vegetation cover degree was transformed into LAI using the Ross-Nilson formula, and used as input parameters in all continuous simulations. The Ross-Nilson G function works well for all species studied here, but may work even better if G_0 is modified according to species.

Theoretically, both the influence and the distribution of the understorey vegetation depends on the density of the forest, an open forest allowing more sunlight to pass through the foliage than a closed canopy. This was verified by the data, when comparing forest LAI to the cover of ground vegetation in the stands, as seen in Fig. 4.

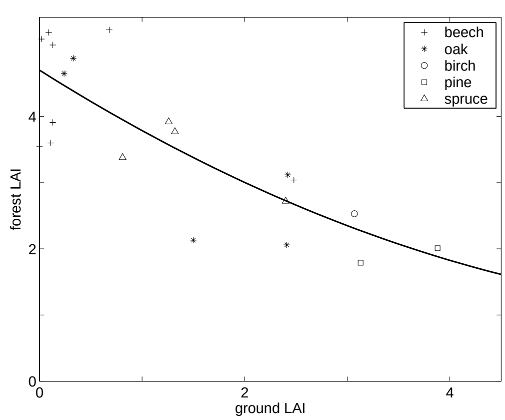

Figure 4. Comparison between forest LAI and ground LAI, transformed from the vegetation cover degree.

The significant quadratic relationship ($r^2 = 0.67$) that was established can be used for estimating the influence of the understorey on reflectance data measured from above the canopy.

A preliminary study of the oak stands was performed to see to what extent the ground vegetation influenced LAI retrieved from the top of the canopy reflectance data. As a first step, the reflectance from the top of the canopy was modelled for one sparse stand (measured forest LAI = 1.9) and one dense stand (measured forest LAI = 5.1) . All parameters were fixed using the individual measurements from each of the stands. In total, three runs were performed in each stand, altering the ground vegetation parameters between the minimum, maximum and average understorey vegetation LAI found within the stands. A comparison between the stands showed a distinct difference in the appearance of ground vegetation, the sparse stand having an understorey vegetation variation of 32-100% while the understorey vegetation of the dense stand only varied between 0-38%.

When comparing the reflectance spectra from the two stands, (Fig 5a and 5b), one can distinguish more pronounced vegetation characteristics in the spectra of the dense stand than of the sparse stand, the dense stand showing lower values in the green and higher values in the red and NIR regions. Another difference between the stands is that the spectra from the sparse stand are diverging more than the spectra of the dense stand, especially in the NIR region.

To evaluate the possibility to retrieve forest stand LAI estimates from the model without any prior information about the ground vegetation, the model was run in inverted mode using modelled reflectance values (six wavelengths in order to represent the Landsat TM bands, (486, 570, 660, 840, 1675 and 2215 nm) as input. LAI of the ground vegetation was retrieved using the quadratic function in Fig. 4.

The difference between the modelled LAI values from the minimum and maximum reflectance spectra within the stands give an indication of the extent to which forest LAI retrieved from satellite reflectance values could be expected to vary depending on the fraction of ground cover. In the sparse stand, the modelled forest stand LAI value varied between 1.52 and 3.3, the measured forest stand LAI being 1.9. This value fits within the lower part of the range of the modelled LAI-values. The overestimation of LAI is partly due to the choice of input values related to ground vegetation characteristics, the function-fitted ground cover LAI being a bit below the measured ground cover LAI in the stand.

In the dense stand, the modelled LAI value varied between 4.86 and 5.03, the measured forest stand LAI being 5.1. Here, the range was much more narrow, and the measured LAI did not fit into the range of the modelled LAI. The reason for the underestimation of the dense stand is the opposite compared to the sparse stand. Here, function-fitted ground cover LAI exceeds the measurements of ground cover LAI.

Since most of the parameters used in the model were collected from real measurements, the effect of the forest density on both the understorey vegetation cover degree and its influence on the canopy reflectance spectra could be considered.

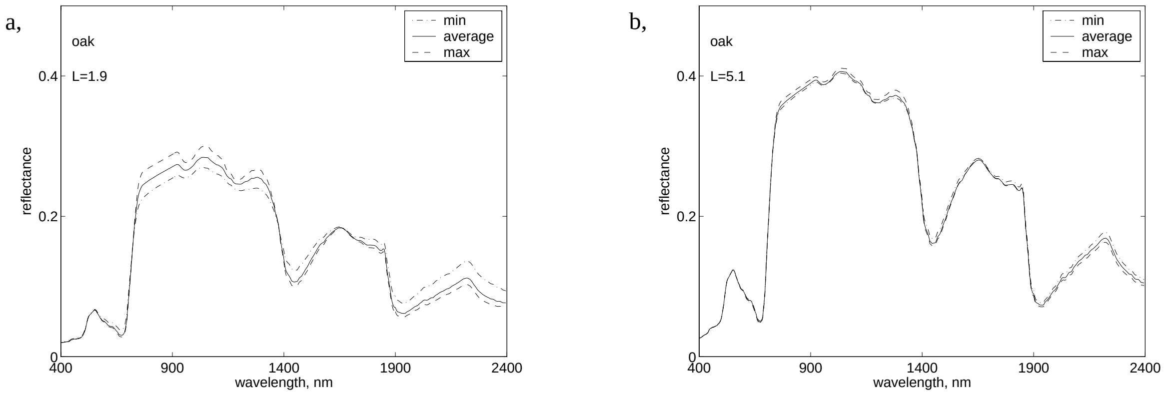

Figure 5. Reflectance spectra from the top of the canopy for, a, one sparse oak stand and, b, one dense oak stand, altering the ground vegetation between minimum, average and maximum cover degree found in the stands.

6. CONCLUSIONS

The ground vegetation may have a significant influence on forest vegetation parameters derived from satellite reflectance values, depending on the density of the leaves in the forest (LAI). This was found by using a radiative transfer model to simulate reflectance spectra from the top of the canopy.

Model simulations and measured spectra of the ground vegetation agreed well, both when using homogenous spectra (using MCRM designed for one vegetation layer) and heterogeneous spectra (using ACRM designed for two vegetation layers).

The relationship between modelled LAI values and the fraction of ground coverage agreed well with the G-function, relating vegetation cover degree to LAI. Ground LAI (derived from the G-function) was inversely related to forest LAI (r^2=0.67). This relationship allows an estimation of the contribution of the ground vegetation which was also tested here.

The results indicate that the influence of the ground cover on dense oak stands (LAI around 5) is minor (within 0.3 units) while the influence on sparse stands (LAI around 2) is major (within 2 units).

The future work will involve a deeper examination of the variation of LAI values modelled from satellite data, including more stands and other tree species.

7. REFERENCES

Chen, J.M., and Black, T.A.1992. "Defining leaf area index for non-flat leaves", Plant Cell Environ. 15.

Eklundh, L. Hall, K. Eriksson, H. Ardö, J. and Pilesjö, P. 2003. "Investigating the use of Landsat thematic mapper data for estimation of forest leaf area index in southern Sweden", Can. J. Remote Sensing. 29:3.

Eriksson, H., Eklundh, L., Lindroth, A. 2005. "Estimating LAI in deciduous forests", Agric. For. Meteorol., 91.

Jacquemoud, S. and Baret, F. 1990. "PROSPECT: A model of Leaf Optical Properties Spectra", Remote Sens. Environ. 34:75-90.

Jacquemoud, S. Bacour, C. Poilvé, H. and Frange, J.-P. 2000. "Comparison of Four Radiative Transfer Models to Simulate Plant Canopies Reflectance: Direct and Inverse Mode", Remote Sens. Environ. 74:471-481.

Kuusk, A. 1995. "A Markov chain model of canopy reflectance", Agric. For. Meteorol. 76.

Kuusk, A. 2001. "A two-layer canopy reflectance model", J. Quantitative Spectroscopy & Radiative Transfer. 71.

Kuusk, A. Lang, M. and Nilson, T. 2004. "Simulation of the reflectance of ground vegetation in sub-boreal forests", Agric. For. Meteorol. 126.

Kuusk, A., and Nilson, T., 2000. "A Directional Multispectral Forest Reflectance Model", Remote Sens. Environ. 72.

Lang, M., Kuusk, A., Nilson, T., Lükk, T., Pehk, M., Alm, G., 2002. "Reflectance spectra of ground vegetation in sub-boreal forests", Web page: http://www.aai/bgf/ger2600/ from Tartu Observatory, Estonia.

LI-COR, Inc. 1992. "LAI-2000 plant canopy analyzer operating manual", LI-COR, Inc., Lincoln, Nebr.

Price, J.C., 1990. "On the information content of soil reflectance spectra", Remote Sens. Environ. 33.

Vermote, E. F., Tanré, D., Deuze, J. L., Herman, M., and Morcrette, J. J. 1997. "Second simulation of the satellite signal in the solar spectrum, 6S –an overview", IEEE Trans. Geosci. Remote Sens. 35.