Application of photon recollision probability in coniferous canopy reflectance simulations

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Abstract

A new semi-physical forest reflectance model, PARAS, is presented in the paper. PARAS is a simple parameterization model for taking into account the effect of within-shoot scattering on coniferous canopy reflectance. Multiple scattering at the small scale represented by a shoot is a conifer-specific characteristic which causes the spectral signature of coniferous forests to differ from that of broadleaved forests. This has for long led to problems in remote sensing of canopy structural variables in coniferous dominated regions. The PARAS model uses a relationship between photon recollision probability and leaf area index (LAI) for simulating forest reflectance. The recollision probability is a measurable, wavelength independent variable which is defined as the probability with which a photon scattered in the canopy interacts with a phytonelement again. In this study, we present application results using PARAS in simulating reflectance of coniferous forests for approximately 800 Scots pine and Norway spruce dominated stands. The results of this study clearly indicate that a major improvement in simulating canopy reflectance in near-infrared (NIR) is achieved by simply accounting for the within-shoot scattering. In other words, the low NIR reflectance observed in coniferous areas is mainly due to within-shoot scattering. In the red wavelength the effect of within-shoot scattering was not pronounced due to the high level of needle absorption in the red range. To conclude the paper, further application possibilities of the presented parameterization model are discussed.

Keywords: Leaf area index; LAI; Spectral invariant; PARAS; STAR; Shoot scattering; Clumping

1. Introduction

Wide international interest and effort in developing methods for estimating biophysical parameters, such as the leaf area index (LAI), of forest canopies at stand, regional and global scales have been increasing during the recent years in several research groups and networks (e.g. Chen et al., 2002; Cohen et al., 2003; Eklundh et al., 2003; Fernandes et al., 2004; Meroni et al., 2004; Myneni et al., 2002; Nilson et al., 1999; Rautiainen et al., 2003; Stenberg et al., 2004; Weiss & Baret, 1999). In these studies, a wide range of retrieval methods and biomes have been explored, and generally the importance of ground truth validation data in the development of the algorithms has been acknowledged. Since retrieval methods have typically (or traditionally) been based on data and reflectance models designed for common broad-leaved species or agricultural crops, they are thus not optimal for boreal conditions where conifers have an important role. As coniferous forests have been observed to exhibit a different spectral behavior than other types of vegetation (e.g. Häme et al., 1997; Spanner et al., 1990; Turner et al., 1999; Zhang et al., 2002), the spectral signature of these forests is not adequately mimicked by physically based reflectance models or empirical regressions developed for other biomes. This is hypothesised to be caused by a large proportion of non-contrasting background reflectance in the visible and near-infrared (NIR) part of the spectra due the presence of mixed green understory and the heterogeneous (clumped) structure of coniferous forests. The clumped structure of coniferous forests can be characterized, for example, at two scales: single tree crowns and shoots (a group of needles bound together by a central
Using the annual shoot as the basic clumping unit has long been applied in light interception models (Cescatti, 1998; Oker-Blom & Kellomäki, 1983) as well as in more recent canopy reflectance models (Knyazikhin et al., 1998a; Knyazikhin et al., 1998b; Kuusk & Nilson, 2000; Shabanov et al., 2000) but the scattering properties of a shoot have not been fully implemented as yet.

When constructing a physically based reflectance model of a forest, four components are ultimately needed for both reflectance simulations and inversion of the model, since the bidirectional reflectance factor (BRF) of a forest is determined by illumination and viewing angles, and canopy and understory optical and structural properties. The illumination and viewing angles are known from the satellite data itself, which means that models for canopy and ground optical properties need to be developed and the relative proportion of canopy and ground (i.e. canopy cover) quantified. Typically in practical applications, emphasis is placed on determining the relationship between the biophysical parameter of interest and canopy layer scattering, and thus the ground BRF, whether formed by bare soil or a scattering understory layer, is given as input based on simplifying assumptions (if applicable measurements exist). It is also possible to use a separate reflectance model to describe the scattering of the understory layer (e.g. Kuusk, 2001). The modeling of canopy spectral properties, on the other hand, needs to be based on an understanding of the structure of the specific forest type (for example, the highly clumped structure of coniferous canopies), but still remain simple enough for use in mapping applications where a detailed set of input parameters is not available.

The aim of this paper is to present a prototype of a new simple parameterization model, PARAS, which uses the so-called photon recollision probability (Smolander & Stenberg, 2005), a spectral invariant which describes the structure of a canopy, for calculating forest stand reflectance. We also test the model in simulating reflectance of structure of a canopy, for calculating forest stand reflectance simulations and inversion of the model, since the portion of photons hitting the canopy which then escape it after one or more interactions, either to the upper hemisphere or down to the lower hemisphere.

In Monte Carlo simulations, the parameter $p$ has been shown to be closely related to LAI (Fig. 2) but fairly insensitive to solar zenith angle (Smolander & Stenberg, 2005). In other words, knowing the $p$ value of a canopy, its scattering coefficient at any wavelength can be predicted from the leaf (or needle) scattering coefficient at the same wavelength (Knyazikhin et al., 1998a, 1998b; Panferov et al., 2001; Smolander & Stenberg, 2003). In addition to LAI the parameter $p$ depends on the degree of clumping in the foliage distribution. So, for example, with the same LAI and phytoelement distribution and orientation (Fig. 1) in broadleaved and coniferous canopies, the coniferous canopies would have a higher $p$ value due to their clumped shoot structure. Clumping at different scales (hierarchical levels) in the canopy is thus reflected by different $p$-LAI relationships.

What is then the relationship between the $p$ value of a coniferous and a broadleaved canopy (Fig. 1)? Smolander and Stenberg (2005) proposed that the canopy level recollision probability for a coniferous canopy ($p_{cc}$) can be decomposed into the recollision probability within a shoot ($p_{sh}$) and the $p$ value of a leaf canopy ($p_{lc}$) with similar “effective LAI” (LAI$_{eff}$) as:

$$p_{cc}(\text{LAI}) = p_{sh} + (1 - p_{sh}) p_{lc}(\text{LAI}_{eff}).$$

Canopies with the same effective LAI have the same canopy interceptance ($i_0$) and ‘uncollided’ canopy transmission (or canopy gap fraction; $1 - i_0$). In a uniform leaf canopy (with randomly distributed leaves) LAI$_{eff}$ coincides with the true hemisurface LAI whereas LAI$_{eff}$ of a shoot canopy (randomly distributed shoots) is smaller than the hemisurface LAI.

First, Smolander and Stenberg (2003) defined the recollision probability within a shoot ($p_{sh}$) as the probability by which a photon scattered from a needle on a shoot ‘collides’ with (another needle in) the same shoot again. It was shown that this probability is linearly related to the
spherically averaged shoot silhouette to total needle area ratio \( \text{STAR} \) (a measurable characteristic, e.g. Oker-Blom & Smolander, 1988; Palmroth et al., 2002). The shoot shading factor, defined as the ratio of spherically projected shoot area to spherically projected needle area, is thus 4 \( \text{STAR} \) and it can be interpreted as the probability that a scattered photon leaves the shoot after the first interaction. Thus, \( \frac{1}{4} \text{STAR} \) is the probability that the photon interacts with another needle (or a leaf) before leaving the shoot, and we have \( p_{sh} = 1 - \frac{1}{4} \text{STAR} \).

Further, based on simulations in uniform leaf and shoot canopies, a simple exponential relationship between \( \text{LAI}_{\text{eff}} \) and canopy \( p \) was established for the leaf canopy, and the decomposition formula (Eq. (2)) was shown to hold true for the shoot canopy (Fig. 2). With this relationship between \( \text{LAI}_{\text{eff}} \) and \( p \), and information on leaf/needle optical properties \( (\omega_L) \) and shoot structure \( (p_{sh}) \), we can calculate the scattering coefficient of the shoot canopy by only measuring LAI of the stand we are interested in (Eq. (1)). (This relationship is especially applicable as the commonly used, commercial optical LAI sensors measure the effective LAI \( (\text{LAI}_{\text{eff}}) \) of a canopy, not the true hemisurface LAI.)

We now present the BRF of a forest as follows:

\[
\text{BRF} = \text{cgf}(\theta_1)\text{cgf}(\theta_2)\rho_{\text{ground}} + f(\theta_1, \theta_2)i_0(\theta_2)\frac{\omega_L - p\omega_L}{1 - p\omega_L}
\]

where \( \theta_1 \) and \( \theta_2 \) are the viewing and illumination zenith angles, \( \text{cgf} \) denotes the canopy gap fraction in the directions of view and illumination (Sun), \( \rho_{\text{ground}} \) is the BRF of the ground (which can also depend on \( \theta_1 \) and \( \theta_2 \), depending on the data available), \( f \) is the canopy scattering phase function, and \( i_0(\theta_2) \) is canopy interceptance or the fraction of the incoming radiation interacting with the canopy. (Notice that \( i_0(\theta_2) = 1 - \text{cgf}(\theta_2) \).) The canopy scattering phase function \( f \) is based on the simulations presented by Smolander and Stenberg (2005), and thus in this case is not a separate BRF model. The computation of the input \( p \) depends on whether the studied forest is broadleaved or coniferous. We call this simple semi-physical parameterization model presented here PARAS.

This is a prototype of the model which is under development and used is in this paper to study the effect of including within-shoot scattering in a forest reflectance model. Therefore, there are several aspects and approximations made that the reader should note. Currently, PARAS cannot be used only in near solar viewing direction, since hotspot behavior has not yet been built in. It also does not include crown level clumping and the associated shading patterns that this can cause on the background, since the relationship of recollision probability and LAI used in this paper is based on Monte Carlo simulations done for uniform canopies (Smolander & Stenberg, 2005). Another simplification in the model is that the first term, i.e. the ground component in Eq. (3), does not include multiple interactions of photons between the tree layer and the understory layer.
in other words photons that were reflected by the understory vegetation but did not escape the forest and were, for example, reflected back downwards by the above tree canopy. Currently, to our knowledge, there are no empirical quantifications of this, so assessing the importance of this component can be based only on simulations.

Importantly for biophysical parameter retrieval, canopy structure and optical properties are linked together by \( p \) (Eq. (1)), and thus understanding the sensitivity of canopy layer BRF to changes in \( p \) is required for planning any remote sensing applications. The contribution of the forest floor (understory) to the stand BRF (first part of the right hand side of Eq. (3)) while not explicitly a function of the recollision probability \( (p) \) is related to it through the bidirectional gap probability which is a function of LAI and \( p \). Quantification of the contribution from the vegetation below the tree canopy will be done later based on the empirical data, but first we demonstrate the sensitivity of canopy spectral reflectance to the recollision probability \( p \) (assuming the canopy to be bounded below by a black surface). Canopy BRF in the case of a black underlying surface is given by (cf. Eq. (3)):

\[
\text{BRF}_{\text{canopy}} = f(\theta_1, \theta_2) i_0(\theta_2) \frac{i_0 - p i_0}{1 - p i_0} \tag{4}
\]

where \( i_0 \) and \( p \) both increase with LAI \( \text{eff} \), but the recollision probability in addition increases with increased clumping. In Fig. 3, BRF\(_{\text{canopy}} \) normalized by \( i_0 \) is plotted as a function of \( p \) for different values of the upward scattered fraction \( f \). (Normalization by \( i_0 \) was done because \( p \) and \( i_0 \) are interrelated, and the ratio can now be interpreted as the fraction of radiation that has interacted with the medium and that is then reflected upward.) The curves show the effect of changes in the \( p \) value for the same LAI \( \text{eff} \). As \( p \) increases (from 0 to 1; however note that at given LAI \( \text{eff} \) the variation in \( p \) cannot cover the whole range), a greater fraction of the incoming radiation is absorbed and a smaller fraction reflected back into space (Fig. 3).

3. Materials and methods

3.1. Study sites and field measurements

A Scots pine (\( \text{Pinus sylvestris} \) L.) dominated study site, Puumala (61°31.6′ N, 28°42.4′ E), and a Norway spruce (\( \text{Picea abies} \) (L.) Karst) dominated site, Saarinen (62°40.9′ N, 27°28.7′ E), both located in Finland, were used in the analyses. Small areas, in other words a few management compartments, on both sites had also deciduous trees (\( \text{Betula} \) sp.). The mean height of the trees at the sites was from 3 to 26 m, which represents the typical height range of managed forests in Finland. In this paper, the sites serve as a test of the PARAS model when the important input, LAI (used for calculating the recollision probability \( p \)) and gap fractions have been measured.

The Puumala site is a 1 km \( \times \) 1 km area with a systematic 400 point grid layout (i.e. 20 parallel transects with 20 measurement points, all located 50 m from each other). The site has previously been used in several remote sensing studies as a reference site due to the extensive field work carried out in a three month field campaign in the summer 2000 and a follow-up three week campaign in summer 2001 (Rautiainen et al., 2003; Stenberg et al., 2004; Wang et al., 2003; Wang et al., 2004). The Saarinen site has a similar design in a rectangular shape (a 0.65 km \( \times \) 1.4 km grid) with 370 grid points located 50 m from each other.

Application of the PARAS model requires the canopy recollision probability \( p \) as input. Since \( p \) cannot be measured directly, but needs to be estimated from other measurements, we used the LAI–\( p \) relationships (Fig. 2) proposed by Smolander and Stenberg (2005) to compute \( p \).
from LAI measurements. LAI for the two sites was estimated from canopy gap fraction data measured by the LAI-2000 Plant Canopy Analyzer (Li-Cor Inc., Lincoln, Nebraska): Puumala was measured in June 2001 and Saarinen in August–September 2001. The LAI-2000 instrument’s optical sensor consists of five detectors arranged in concentric rings measuring radiation between 320 and 490 nm, where scattering from leaves is minimal. Canopy gap fraction in each of the five different zenith angle bands (centered at zenith angles: 7°, 23°, 38°, 53° and 68°) was calculated as the mean ratio of below- and above-canopy readings by the corresponding detector rings. Below-canopy measuring height was 1 m above the ground, so that only trees were included in the field of view. Above-canopy measurements were collected by automatic logging every 30 s in an open area located in the middle of the study site. LAI of each of the 400 plots was calculated from canopy gap fraction values averaged over 15 measurements, comprising three readings taken at each of the five different points within the plot: the plot center point, and at 6 m distance from the center point in each of the four cardinal directions (north, south, east and west). A 90° view restrictor was used on both optical sensors to remove possible sun flecks and, importantly, to exclude the operator from the field of view. Although few measurements were made under clear skies, the view restrictor was used permanently to make measurements under variable sky conditions comparable. The orientation of the above- and below-canopy sensors was similar with respect to the field of view. In the text and figures, we will denote the optical sensor based LAI estimates (calculated with the standard LAI-2000 procedure) as LAIeff.

Application of PARAS requires information on canopy gap fractions (cgf) in the viewing and illumination (Sun) directions. These data were directly available from the LAI-2000 measurements for our study sites.

3.2. Satellite data

Landsat 7 ETM images (Puumala: June 10, 2000; Saarinen: July 6, 2001) were used in the analyses. The rectified image of Puumala was provided by Boston University as part of the MODIS LAI cooperation at the site (Tian et al., 2003). The Saarinen image was rectified by VTT Technical Research Center of Finland using linear nearest neighbor sampling based on ground points. The average RMSE of the control points was about 0.5 pixels (about 15 m). Radiometric calibration was carried out in a routine way by computing from the apparent radiance the TOA (Top of Atmosphere) reflectance using as additional information the solar equivalent irradiance, the ratio of the actual sun–earth distance to the sun–earth mean distance, and the day of year (e.g. Andersson, 2000). The atmospheric corrections were carried out using the SMAC (Simplified Method for Atmospheric Corrections) algorithm of Rahman and Dedieu (1994), which enables pixelwise corrections. For the atmospheric optical thickness, a constant value of 0.1 at 550 nm was applied in the correction. The original pixel size (30 m × 30 m) was maintained in the pre-processing, and in the analyses, we used the reflectance values of the pixels in which the center points of the plots were located due to the dense network of ground truth points. The ETM3 band (630–690 nm) corresponds to the red wavelength range and the ETM4 band (760–900 nm) to the NIR range.

3.3. Application of PARAS

The PARAS model requires ultimately 5 inputs for simulating canopy BRF at a given wavelength: recollision probability \( p \), ground bidirectional reflectance factor, leaf or needle scattering coefficient and canopy transmission in the viewing and sun directions. Canopy interecetance \( (i_0) \) was calculated as \( 1 - (\text{gap fraction in the sun direction}) \). As previously mentioned, for both sites, canopy scattering was directly obtained from the recollision probability \( p \) calculated with the LAIeff – \( p \) relationships depicted in Fig. 2. The fraction of upward scattered radiation (i.e. radiation intercepted by the canopy and then reflected to the upper hemisphere) was assumed to be constant and was estimated based on simulation results from the paper by Smolander and Stenberg (2005). Needle scattering coefficients were based on values reported in literature (e.g. Panferov 2001 for Norway spruce) and ground BRFs (the ground was considered an isotropic scatterer in this study) were based on goniometric measurements made close to the Saarinen site (Peltoniemi et al., 2005). The input values are shown in Table 1.

The recollision probability for the canopies at all the plots on both study sites was computed in two ways from the measured LAIeff. First, assuming no correction for within-shoot scattering (a situation corresponding to a broad-leaved canopy i.e. \( p_{sh} = 0 \)) and then, secondly, using the within shoot correction \( p_{sh} \) (a situation corresponding to a coniferous canopy, Eq. (1) and Fig. 2). The value of \( p_{sh} \) was set to 0.44 corresponding to an average value of \( \text{STAR} 0 = 0.14 \), in agreement with empirical data for the studied species (e.g. Oker-Blom & Smolander, 1988; Palmroth et al., 2002). Within-shoot correction in the second phase was applied to plots with over 60% of the stand density composed of coniferous species. Twenty-nine plots at Puumala and 51 plots at Saarinen were deciduous and thus the shoot correction was not applied to them.

Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Red</th>
<th>NIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf/needle scattering coefficient</td>
<td>0.10</td>
<td>0.70</td>
</tr>
<tr>
<td>Ground BRF</td>
<td>0.07</td>
<td>0.20</td>
</tr>
<tr>
<td>Canopy upward scattering phase function</td>
<td>0.70</td>
<td>0.70</td>
</tr>
</tbody>
</table>
4. Results

As commonly noted, the relationships of LAI and satellite-based HDRFs (hemispherical-directional reflectance factors) at red and NIR wavelengths are typically very scattered. An important factor behind the scattering is species composition, and furthermore, the division into broadleaved and coniferous species. Our study is based on two Landsat ETM images which have undergone the same preprocessing. In order to be able to use the same input to PARAS for both sites, we need to assume that the level of HDRFs is approximately the same and that the forest canopies and their understory can be considered sufficiently similar. Both conditions were considered fulfilled even though the Saarinen site displayed slightly larger variation in HDRFs than the Puumala site (Fig. 4). However, the difference was considered small enough to make it justified to apply the same input parameters for both sites instead of performing model tuning in default of sufficient empirical data. (Please note that in the figures the BRF is an approximation of the satellite image surface reflectance obtained after atmospheric correction.)

For both study sites, red and NIR BRFs were simulated for all the plots with two methods. First, the PARAS model was applied without the within-shoot correction (Figs. 5 A and B, 6 A and B). The differences between simulated and measured (ETM) BRFs in the near-infra red wavelength were pronounced (RMSE, root mean square error for Puumala 0.068, for Saarinen 0.057), whereas in the red wavelength they were considerably smaller (RMSE for Puumala 0.010, for Saarinen 0.015). In the second phase of simulations, the within shoot correction was applied to calculating the $p$ of the canopies (Figs. 5 C and D, 6 C and D). The simulated and measured BRFs moved closer to each other in the near-infra red (RMSE for Puumala 0.040, for Saarinen 0.049). In the red wavelength the differences remained approximately the same for Puumala (RMSE = 0.010), whereas an improvement was observed for Saarinen (RMSE = 0.009). Deciduous plots can be distinguished from Saarinen in the figures (Figs. 5 and 6, c and d) as the plots which have higher BRFs than the majority of other plots. The results are a clear demonstration of the improvement the simple within-shoot scattering parameter brings to the stand reflectance simulations.

Finally, in Fig. 7, the contribution of ground (understory vegetation) reflectance from the total stand reflectance for the broadleaved and coniferous plots in Puumala and Saarinen is shown, calculated as the first term of the right hand site of Eq. (3). It illustrates that, at the same LAIeff the understory contribution is higher in coniferous canopies than in broadleaved canopies, the opposite being true for the contribution of the canopy layer (cf. Fig. 3). In other words, in a coniferous forest a larger part of the remotely sensed signal will come from the ground than in a broadleaved forest with the same LAIeff, and the difference would be even more pronounced at the same ‘true’ LAI (in which case the coniferous canopy would have smaller LAIeff than the broadleaved canopy).

5. Discussion

Several remote sensing studies have signified that coniferous canopies reflect less than broadleaved canopies, which has often been explained to be due to the grouped structure (e.g. needles into shoots, shoots into whorls or branches, branches into crowns) and high multiple scattering of coniferous forests. In coniferous canopies, further, the contribution of the forest understory has often been noted to be significant as clumping in the tree canopy layer can lead to relatively high canopy gap fractions and thus reveal a large portion of the ground to sunlight and vegetation...
However, a simple quantification (or an explanation shown to be based on the structure) of the scattering difference between these forest types had not yet been presented using empirical data. The results of this study clearly indicated that a major improvement in simulating canopy reflectance in NIR is achieved by simply accounting for the within-shoot scattering. In other words, the low NIR reflectance observed in coniferous areas can largely be explained simply by accounting for within-shoot scattering. In the red wavelength range the differences were not pronounced, possibly related to the low level of multiple scattering and high level of absorption present in the red range. Even though within-shoot scattering seems to explain a large part of the difference between broadleaved and coniferous forests, also other explanations for the optical differences should be acknowledged. For example, the absorption spectra of needles, leaves and woody material differ and can be the cause of the variation that remained unexplained in this study.

A major advantage of the method presented here is its ability to distinguish between broadleaved and coniferous canopies in optical satellite data, a problem that has persisted in several remote sensing applications. Since $p$ carries information on LAI, canopy fine and coarse geometrical features and foliage orientation, it is capable of summarizing the description of canopy structure needed for canopy shortwave radiation budget calculations. By comparing the level of simulated and measured BRFs, assuming both broadleaved and coniferous canopies, we can develop a simple algorithm for separating the canopy types. An important feature of the recollision probability is also its spectral invariance, which means that ‘tuning’ of input parameters for the model for the various input wavelength ranges is not required.

However, further investigations are still required for improving three aspects of the PARAS parameterization model. First, more research is needed to quantify the effect of clumping at larger hierarchical scales (e.g. tree crowns, Rautiainen et al., 2004; Rautiainen & Stenberg, 2005) in the canopy on the $p$–LAI relationships. Also the canopy upward scattering phase function should be parameterized in a simple and efficient way, possibly as a function of LAI.
Fig. 6. Application of the PARAS model for the Saarinen site: (A) (RMSE=0.015) and (B) (RMSE=0.057) present BRF simulations made without correcting the recollision probability $p$ for within-shoot scattering, and (C) (RMSE=0.009) and (D) (RMSE=0.049) BRF simulations made with a recollision probability $p$ that assumes within-shoot scattering.

Fig. 7. The contribution of understory to the total stand BRF (in percent) in red (A) and NIR (B) wavelengths for all the coniferous and broadleaved plots measured at the Puumala and Saarinen sites.
Finally, a better estimate of the contribution from the understory needs to be acquired, since the vegetation beneath the trees is an important source of reflectance variation between stands, as also suggested by this study. The plots at the Puuma site were more homogeneous in terms of both the tree canopy and the understory than the plots on the Saarinen site, and this can be assumed to be the cause for the wider range of the measured HDRF values for Saarinen (Figs. 5 and 6). The Saarinen site had recently undergone thinning, leaving branches and trunks with green needles on the ground. The topography of Saarinen was also relatively varying. A better fit between the simulated and measured BRFs could have been achieved through tuning of the ground component (\(c_{1}f_{1}c_{2}f_{2}\mu_{\text{ground}}\)) of the model according to the understory vegetation type (also called site type) of the plot (this information is available in standard forest data bases), but as our goal was to demonstrate the sole effect of the within-shoot scattering and since we also did not have enough ground reflectance measurements and justifications for the use of a certain ground BRF for a certain plot or site type, this approach was not applied.

Since in this preliminary study the PARAS model has indicated its potential applicability for LAI mapping purposes, our plan now is to develop the model further to an operational version functioning through a look-up table (LUT) once a sufficient empirical data base of the optical properties of boreal coniferous forests has been collected. The LUT has been planned to be created based on running of the PARAS for a multitude of boreal coniferous forest situations. In the case of Finnish forests, the LAI range that will be retrieved also falls into the most dynamic part of the \(p–\text{LAI}\) relationship (i.e. LAI < 4), further supporting the use of this parameterization. Currently, to proceed in this activity, we are collecting an extensive empirical data bank of understory BRDF (Peltoniemi et al., 2005), stand structure, gap fraction and LAI measurements which will eventually serve as the basis for the LUT. The procedure will somewhat resemble the global MODIS LAI LUT (Knyazikhin et al., 1998b) where land cover classification is used to divide vegetation pixels into six biome types which then each have their spectral properties. The difference, however, is that our model will be specifically designed for use with finer resolution data at stand scale (e.g. SPOT or Landsat) so that it can utilize the general, stand wise, relatively fine forest type classification maps, and that the focus is on coniferous regions. A problem of applying the so-called global models in Europe, and especially in Finland, is that the forested areas are typically fragmented, for instance due to high level of private land-ownership, and the moderate and coarse resolution solutions are thus not accurate enough if relatively detailed LAI mapping is desired—which, of course, depends on the goal of the activity. High resolution images together with simple physical or semi-physical models developed for local vegetation types would in general provide more reliable information which could also be used for vegetation monitoring and societal purposes. Thus, such a methodology developed in Finland could well be applicable in also other corresponding boreal areas with similar vegetation composition as long as the input LUT is adjusted (which, however, must be noted to require extensive field work).

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