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A BDRF Model for Forests

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Abstract Existing forest reflectance models[1−3] have already demonstrated their ability to be used to interpret remotely sensed data on forests in the nadir view direction. With the appearance of new possibilities to measure the multiangular reflectance characteristics, the interest to simulate forest reflectance in any view direction has increased. The cited models are capable to produce the angular distribution of reflectance, too, however, this possibility has been little used so far. Below some results of simulation of angular distribution of reflectance by the model described in [2] are presented.

Key words BDRF, The angular distribution of reflectance

1 MODEL DESCRIPTION

The basic ideas of the forest bi-directional reflectance factor (BDRF) model remain the same as in the previous nadir view version:

1. calculations are made for a homogeneous forest stand;
2. trees in the stand are divided into size and species classes; in each class the trees are identical;
3. tree distribution pattern is described by the relative variance of stem number;
4. crowns are modelled as ellipsoids of rotation or cones + cylinders;
5. foliage orientation is assumed to be spherical;
6. reflectance factors of the first-order scattering and multiple scattering are calculated separately with the algorithms of different precision; in calculating the first-order-scattered radiation on tree crowns and background the central role is played by analytically evaluated bi-directional gap probabilities in the sun and view directions;
7. multiple scattering on tree crowns and background is calculated by means of a rough two-stream approximation;

So far only a part of the potential of the forest canopy reflectance model has been used, since it has mainly been applied for the nadir view direction. In addition, there have been problems with the algorithm of the reflectance model that needs determination of the common parts of crown projection areas simultaneously in two directions - a geometrically simple but computationally inconvenient task. Now, the algorithm was extended to any view direction in the principal plane.

The BRDF of a homogeneous forest stand $R(\Omega, \Omega_o)$ is presented as the sum of following four components[2].

$$R = R^1_{CR} + R^1_{GR} + R^M_{CR} + R^M_{GR} \tag{1}$$

where

R^1_{CR} is the reflectance factor caused by the first-order scattering on tree crowns;

R^1_{GR} is the reflectance factor caused by the first-order scattering on backgound (ground and field layer vegetation or soil);

R^M_{CR} and R^M_{GR} are the reflectance factors caused by multiple scattering within the forest stand, while for R^M_{CR} the last scattering act should occur on tree crowns and for R^M_{GR} on background. All components in (1) are symmetrical functions of the incident radiation direction $\Omega_o = (\Theta_o, \Phi_o)$ and view direction $\Omega = (\Theta, \Phi)$, where Θ_o is the zenith angle of incident radiation direction, Φ_o the incident radiation azimuth, Θ the view nadir angle, Φ the view azimuth.

The following expressions are used to evaluate the first component in sum (1):

$$R^1_{CR} = \sum_{i=1}^{m} R^1_{CRi} \tag{2}$$

$$R^1_{CRi} = \frac{N_i c_i}{\cos\theta_0 \cos\theta} \iiint_{V_i} u_i \Gamma_i(\Omega_0 \to \Omega) \cdot P_{ooi}(x, y, z) dx dy dz \quad (3)$$

Here, the trees of the stand are divided into m size or species classes, N_i being the stem number (trees/m^2) of ith class, u_i the foliage area volume density (1/m), Γ_i the phase function of the canopy medium, p_{ooi} the bi-directional gap probability from a point (x, y, z) within the tree crown simultaneously in the view and incident radiation directions, V_i is the spatial region corresponding to the crown, c_i is the tree distribution pattern parameter calculated as $c_i = \ln GI_i / (GI_i - 1)$, where GI_i is the relative variance of the number of trees in the ith class on the plot of size equal to the average crown projection area at 45°.

For the second component in sum (1) we have

$$R^1_{GR} = b_{GR} p_{oo}(z = 0, \Omega_o \to \Omega) \quad (4)$$

b_{GR} being the ground vegetation reflectance factor and p_{oo} the bidirectional gap probability for the ground level. The third and fourth components of sum (1) are calculated by means of the two-stream approximation of the radiative transfer equation for the multiple scattering.

The set of input parameters needed to run the model includes the set of routine forest inventory parameters (tree height, breast-height diameter, stem number). Other structural parameters (crown length and radius, tree distribution pattern parameter, leaf and branch area indices, clumping index of leaf spatial distribution) should be determined by special measurements or via regressions on known inventory parameters. The set of optical parameters includes: leaf reflectance and transmittance, branch and trunk bark reflectance, ground vegetation reflectance factor.

2 SOME EXAMPLES OF SIMULATION RESULTS

A series of numerical experiments has been made to study the effect of key forest parameters (canopy closure, mean tree height, crown length, tree height variance, needle area index, ground vegetation type) on angular dependence of BDRF in a few pine-dominated forest stands in Estonia. The needed stand structural input parameters were obtained from DBH measurements on 40×50 m sample plots and by detailed measurement of 12 sample trees on each plot. Tree distribution pattern parameter was derived from the respective visual canopy and crown closure measurements. Needle and bark optical properties were the same as described in [4]. Ground reflectance factors were measured by a four-channel field radiometer, the spectral channels corresponding approximately to Landsat TM bands TM1, TM2, TM3 and TM4.

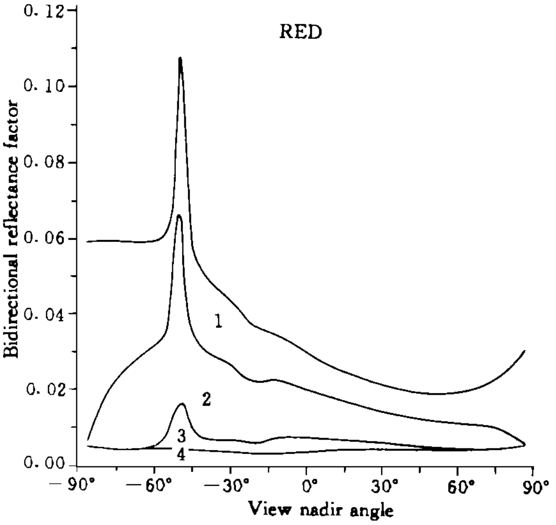
In Fig. 1a and 1b the role of different reflectance components from Eq. 1 are shown. Trees in the studied stand were divided into three size classes that may be interpreted as the dominating, dominated and suppressed. The main structural characteristics of the stand are given in Table 1.

Table 1 Description of the 35-year-old pure scots pine stand structure. medium site class (3)

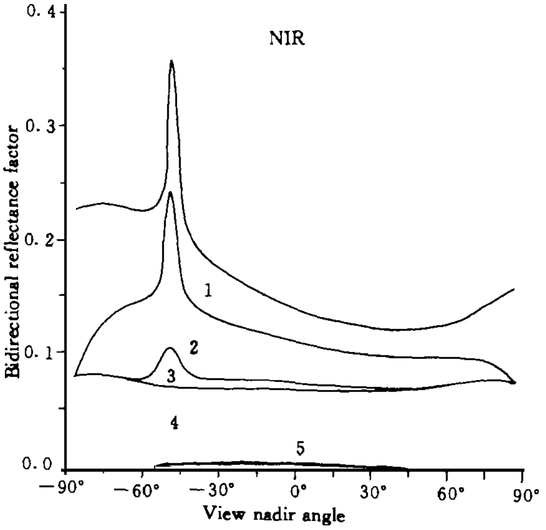
Parameter \ size class	dominating	dominated	suppressed
stem number (m^{-2})	0.0425	0.2200	0.0475
tree height (m)	10.4	8.1	6.2
crown length (m)	5.3	3.6	2.0
crown radius (m)	1.36	1.01	0.55
breast-height diameter(cm)	10.9	7.4	4.4
one-sided needle area index	1.30	2.35	0.07
contribution to total crown closure	24.8%	70.7%	4.5%

Since the canopy closure of this stand is rather high (77.8%), the influence of ground layer is quite small. In spite of the fact that the dominated trees form most part of the total canopy closure, the contributions of dominating and dominated tree crowns in the first-order-scattering component are comparable. Note the different behavior of contribution of the highest and medium size classes at larger view angles: at very large view angles only tops of the highest trees are seen. In the near infrared the role of multiple scattering on tree crowns is significant.

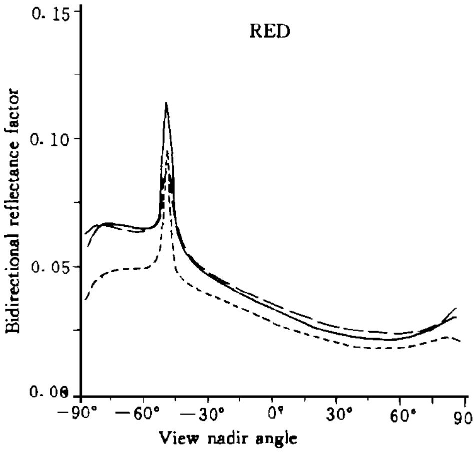
In Figs. 2a and 2b the shapes of the BDRF



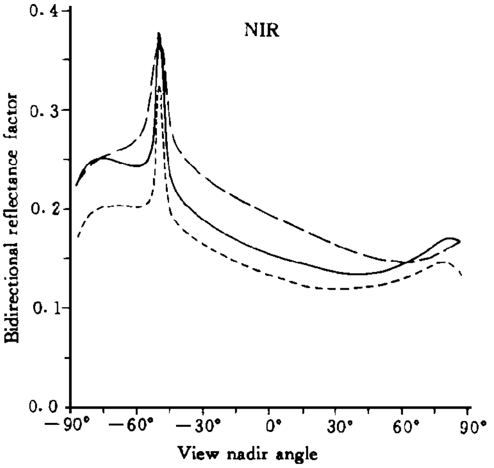
Fig· 1a The angular distribution of BDRF in the principal plane of a 35-year-old Scots pine forest· Contributions of different components forming the reflectance factor are shown: 1 - first order scattering on dominating tree crowns, 2 - first-order scattering on dominated tree crowns, 3 - first-order scattering on background, 4 - multiple scattering from tree crowns· Contributions of the first-order scattering on suppressed tree crowns and multiple scattering from the background are negligible· Red region of the spectrum (TM3)· Solar zenith angle 49.6 degrees



Fig· 1b BDRF in the principal plane of a 35-year-old Scots pine forest· Contributions of different components forming the reflectance factor are shown: 1 - first order scattering on dominating tree crowns, 2 - first-order scattering on dominated tree crowns, 3 - first-order scattering on background, 4 - multiple scattering on tree crowns, 5 - multiple scattering from background· Contribution of the first-order scattering on suppressed tree crowns is negligible· Near infrared region of the spectrum (TM4)· Solar zenith angle 49.6 degrees



Fig· 2a Comparison of the BDRF curves for three different Scots pine stands· 35-year-old stand of medium site quality (full line), 31-year-old stand of the highest site quality (dotted line) and a 80-year-old sparser stand growing on an infertile bog (dashed line)· Canopy closures of the stands are respectively 77% (medium), 97% (fertile) and 51% (infertile)· Red region of the spectrum (TM3)· Solar zenith angle 49.6 degrees



Fig· 2b Comparison of the BDRF curves for three different Scots pine stands· 35-year old stand of medium site quality (full line), 31-year-old stand of the highest site quality and of complete canopy cover (dotted line) and a sparser stand growing on an infertile bog (dashed line)· Near infrared region of the spectrum (TM4)· Solar zenith angle 49.6 degrees angular curves are compared for three different pure Scots pine stands. The BDRF angular distribution curves for stands of medium and highest density appeared not to differ much in shape. For the sparse stand, there is a considerable effect of background reflectance that can especially be noted in the NIR region. Ground vegetation of this stand had a rather high reflectance factor in the NIR (0.24).

An attempt was made to estimate the effect of differentiation in size on the BDRF distribution. Calculations were made considering three or four different size classes in contrast to an equivalent stand with all trees of the stand of only one size. As a rule, the more is the differentiation of size among trees of the stand, the less is the reflectance factor in all directions except for the hotspot direction and very inclined view directions. The main reason for such effect is the increase of shade in the visible crowns in more size-distributed stands. This explains why in the hotspot direction the influence of the number of size classes was small.

3 CONCLUSIONS

The results of model experiments conducted show that in the principal plane, in addition to the solar elevation, the angular shape of BRDF of forests is influenced by the same main driving factors that determine the forest reflectance in the nadir view direction. The angular distribution of the first-order scattering components in Eq. 1 are much determined by the (bi-directional) gap fractions in solar and view directions. The latter depend on canopy closure, leaf and branch area indices, crown length/diameter ratio, leaf clumping index. In addition, the shape of the angular distribution of the first-order-scattering BDRF on tree crowns is much influenced by the leaf reflectance/transmittance ratio and leaf surface refractive index. The angular reflectance distribution of ground vegetation and the amount of radiation transmitted to the forest floor have more effect for sparser stands and cases with large reflectance contrast between crown (leaf) and background (ground and field layer + soil). The angular dependence of the multiple scattering components as simulated by this model is relatively insignificant.

On the opposite to the solar position side (see Fig. 1 and Fig. 2), there is a region of view angles (45°—60°), where the sensitivity of BDRF on forest structural parameters is rather weak. The sensitivity of BDRF on different structural characteristics of forests must be taken into account when trying to carry out inversions of the model.

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一种森林的BDRF 模型

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摘　要　已有的森林反射模型[1－3]已经显示了其用于解释天顶方向观测到的森林遥感数据的能力。随着新的测量多角度反射特征的可能性的出现，大大地增加了在任意观察方向上模拟森林反射率的兴趣。上述模型也具有产生反射率方向分布的能力，但迄今仅有少量的应用。该文论述采用 Nilson 和 Peterson[2]模拟模型的反射率方向分布的结果。

关键词　BDRF，反射的角度分布