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# Parameterization of Spectral Component Signatures for Geometric Optical Canopy Reflectance Modeling

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**Abstract** A hybrid geometric optical and radiative transfer approach is used to parameterize the four component spectral signatures (sunlit crown, sunlit background, shaded crown, and shaded background) in geometric optical reflectance models over discontinuous plant canopies. The path scattering parameters (transmittance and reflectance) are estimated using a modified version of the analytical solutions of path scattering parameters (reflectance and transmittance) for a homogeneous medium layer, which includes the effect of the canopy gaps. The spectral component signatures are functions of the transmittance and reflectance for discontinuous plant canopies, the background albedo and the proportions of incident beam and diffuse skylight. The modeled spectral component signatures show good agreement with data collected in a conifer forest in Holland, Maine. Using the parameterized spectral component signatures, estimates from Li and Strahler's geometric optical mutual shadowing model for directional reflectance over the old jack pine and old black spruce forests in the boreal ecosystem-atmosphere study (BOREAS), match well with PARABOLA measurements at different solar and viewing geometry.

**Key words** Parameterization of the spectral signatures, GO models

## 1 INTRODUCTION

Several geometric optical (GO) directional reflectance models for discontinuous plant canopies have been developed recently[1,2]. The GO models treat the forest canopy as an assemblage of three dimensional tree crowns of specified shape and size, and the directional reflectance over the canopy is the linear combination of the product of the areal proportions and the spectral signatures for four scene components: sunlit crown surface ($C$), sunlit ground surface ($G$), shaded crown surface ($T$) and shaded ground surface ($Z$).

In the GO models, field measurements for the signatures of the four components are needed. These may not be available. In fact, the signatures are the result of leaf scattering and background reflectance, and as such can be modeled based on the radiative transfer theory. However, the spectral signatures are also functions of the solar zenith angle, and canopy parameters such as crown shape, crown count density, and foliage area volume density.

One approach to parameterize the spectral component signatures is decoupling the path scattering within the plant canopy layer and the interaction of the plant canopy layer with the background surface. With the knowledge of the path transmittance and reflectance for discontinuous plant canopies and background albedo, we can parameterize the signatures easily. In a previous study[3] we have derived the analytical solutions of the path scattering parameters for a finite homogeneous medium layer. But they can not be applied for the discontinuous plant canopies due to the effect of the canopy gaps. In this study, we will modify the analytical solutions of the path transmittance and reflectance in the homogeneous medium layer for discontinuous plant canopies. And then based on the above, we will parameterize the spectral component signatures.

## 2 LIGHT SCATTERING IN A FINITE DISCONTINUOUS PLANT CANOPIES

In the study of [3], we have derived the analytical solutions of path scattering parameters (directional hemispherical reflectance, $\rho_{df}$, directional hemispherical transmittance, $t_{df}$, and spherical reflectance, $\rho_{ff}$, spherical transmittance, $t_{ff}$ for a finite homogeneous medium layer which are functions of the single scattering albedo of the medium, extinction coefficient, e.g. the projected foliage area volume density, the thickness of the layer and incident zenith angles.

For discontinuous plant canopies, the clumping of leaves into crowns results in heterogeneous canopy gaps, e.g. the between-crown gaps, and within-crown gaps. The between-crown gap probability, ($P(n=0|\theta_i)$) and within-crown gap probability ($P(n>0|\theta_i)$) have been well modeled[4]. In order to estimate the transmittance and reflectance for the discontinuous canopy layer with simple formulae, we divided the discrete canopy layer into the between-crown canopy layer, ($P(n=0)$) as shown in Fig. 1 and the within-crown canopy layer, ($P(n>0)$) as shown in Fig. 1. We assume that the canopy elements are homogeneously distributed in space within the within-crown canopy layer. The light passing through the between-crown part will be unaffected, but the transmittance and reflectance for lightps, passing through the within-crown part can be estimated by the analytical solutions of the path scattering parameters for finite homogeneous medium layer as described above.

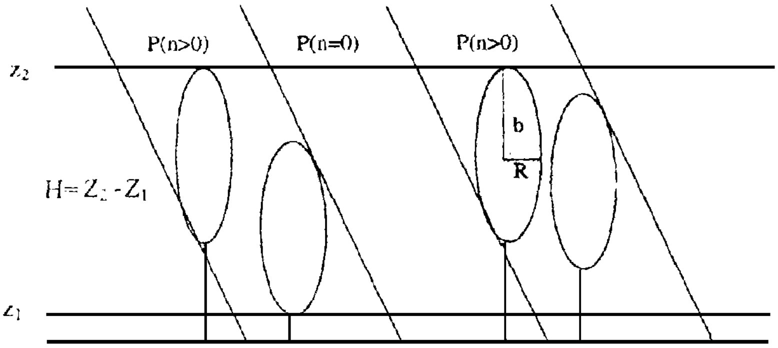

Fig. 1 Heterogeneous canopy ga between-crown gap, $P(n=0)$, and within-crown gaps, $P(n>0)$ in discontinuous canpoies

The proportions of the beam passing through the between-crown gaps and within-crown gaps are functions of solar zenith angles[4]. This leads to the volume of the between-crown layer and within-crown layer being functions of the solar zenith angles. The projected foliage area volume density, $\tau$ has to be a function of solar zenith angle within the within-crown canopy layer as:

$$\tau_d(\theta_i) = G(\theta_i)\frac{ELAI}{(1.0-P(n=0\mid\theta_i))H} \qquad (1)$$

$$\tau_f = \overline{G}\frac{ELAI}{1.0-K_{open}(n=0))H}$$

where $\tau_d(\theta_i)$, $\tau_f$ are the projected foliage area volume density, $\tau_d(\theta_i)$ is for the calculation of $T_{df}^{\infty}$ *to* and $\tau_f$ is for $T_{ff}^{\infty}$ $P(n=0|\theta_i)$ is the between-crown gap probability, can be easily calculated as function of the tree geometry, crown density, and incident zenith angle[1,2]. $K_{open}(n=0)$ is the openness factor, which is the integration of $P(n=0|\theta_i)$ over the hemisphere.

Then the directional hemispherical and spherical transmittance $t'_{df}$, $t'_{ff}$, reflectance $\rho'_{df}$, $\rho'_{ff}$ and $t'_0$ for discontinuous plant canopies can be written as:

$$t'_{df} = (t_o + t_{df})(1-P(n=0\mid\theta_i)) + P(n=0\mid\theta_i) \qquad (2)$$

$$t'_{ff} = t_{ff}(1.0 - K_{open}(n=0)) + K_{open}(n=0)$$

$$\rho'_{df} = \rho_{df}$$

$$\rho'_{ff} = \rho_{ff}$$

$$t'_o = t_0$$

Where $t_{df}$, $t_{ff}$, $\rho_{df}$, $\rho_{ff}$ and $t_0$ for homogeneous canopy layer with the modified $\tau$.

## 3 PARAMETERIZATION OF THE SPECTRAL COMPONENT SIGNATURES

In this study, the Geometric Optical Mutual Shadowing Model (GOMS)[4] was used. In the GOMS model, the signature of the shaded crown surface was assumed the same as the one of shaded background. In this study, we only parameterize the sunlit crown ($C$), sunlit background ($G$) and shaded background ($Z$).

Based on the formulae of the transmittance and reflectance for discontinuous plant canopies, the spectral signatures of the four components can be modeled as.

$$G = \rho_s \tag{3}$$

$$C = (1 - f_d)(\rho'_{df} + t'_{df}\rho_s t'_{ff}) + f_d(\rho'_{ff} + t'_{ff}\rho_s t'_{ff}) \tag{4}$$

$$Z = \{(1 - f_d)[(t_0 + t_{df})[1 - P(n = 0 \mid \theta_i)]] + f_d t'_{ff}\}\rho_s \tag{5}$$

where $f_d$ is the proportion of incident diffuse skylight, $\rho_s$ is the background albedo.

The above formulae show that $C$, $G$, $Z$ are not only the functions of the projected foliage area volume density, the incident zenith angle, but also functions of the the tree geometry, crown count density, background albedo and the proportions of incident beam and diffuse skylight.

Applying the above formulae of $C$, $G$, $Z$ to GOMS model, the bidirectional reflectance over discontinuous plant canopies can be modeled.

## 4 RESULTS AND DISCUSSION

For testing the above formulae, Fig. 2 shows the comparison of the model results and field measurement for $C$ and $Z$. The tree geometry parameters, foliage volume density, background albedo and the measured spectral component signatures are from [5]. The results show a good match of the modeled spectral signatures of sunlit crown surface and shaded background surface with the field measurement.

The foliage are very dense within crowns in the forests of Holland, Maine. In order to test the formulae of $C$, $G$, $Z$ for sparse forest with less dense foliage area volume density, we applied GOMS with parameterized $G$, $C$, $Z$ to the old jack pine and old black spruce forests in BOREAS. Fig. 3 and Fig. 4 show the comparison of the modeled bidirectional reflectance by the GOMS model geometric with the parameterized spectral component signature with the PARABOLA measurements in the SOJP and SOBS of BOREAS. The input parameters are from [4] and the ground albedo are from the measurements at 2m above the surface[4]. These figures show quite good agreement of the model results with the PARABOLA measurements on the principal plane and across the principal plane in the near infrared at all different solar and viewing zenith angles. GOMS also modeled well the bidirectional reflectance across principal plane in the red wavelengths. But GOMS model predicted less strong a hot spot than the PARABOLA measurements in the principal plane in the red spectral range especially at large solar zenith angles. The reason is due to the effect of the horizontal whorl structure in the conifer trees[4,6]. The study of [4] shows that the effect of the horizontal whorl structure in SOJP and SOBS can not be ignored in the modeling of light transmittance. The effect of the horizontal whorl structure is to allow more light to pass through the canopy to reach the ground surface, increasing the proportion of the sunlit background surface. The proportion of the sunlit background surface in the GOMS

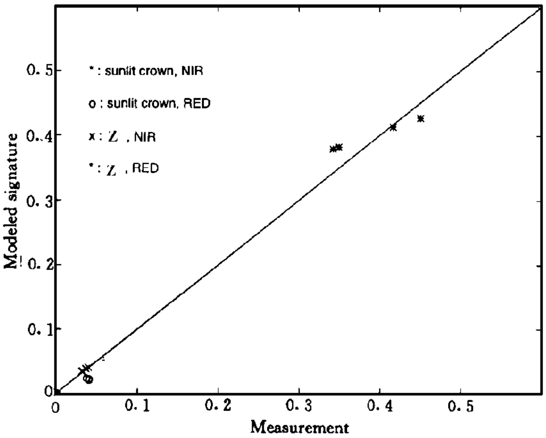

Fig. 2 Comparson of the modeled signature measurements with the field measurement in the black spruce forest in Holland, Maine, 1994

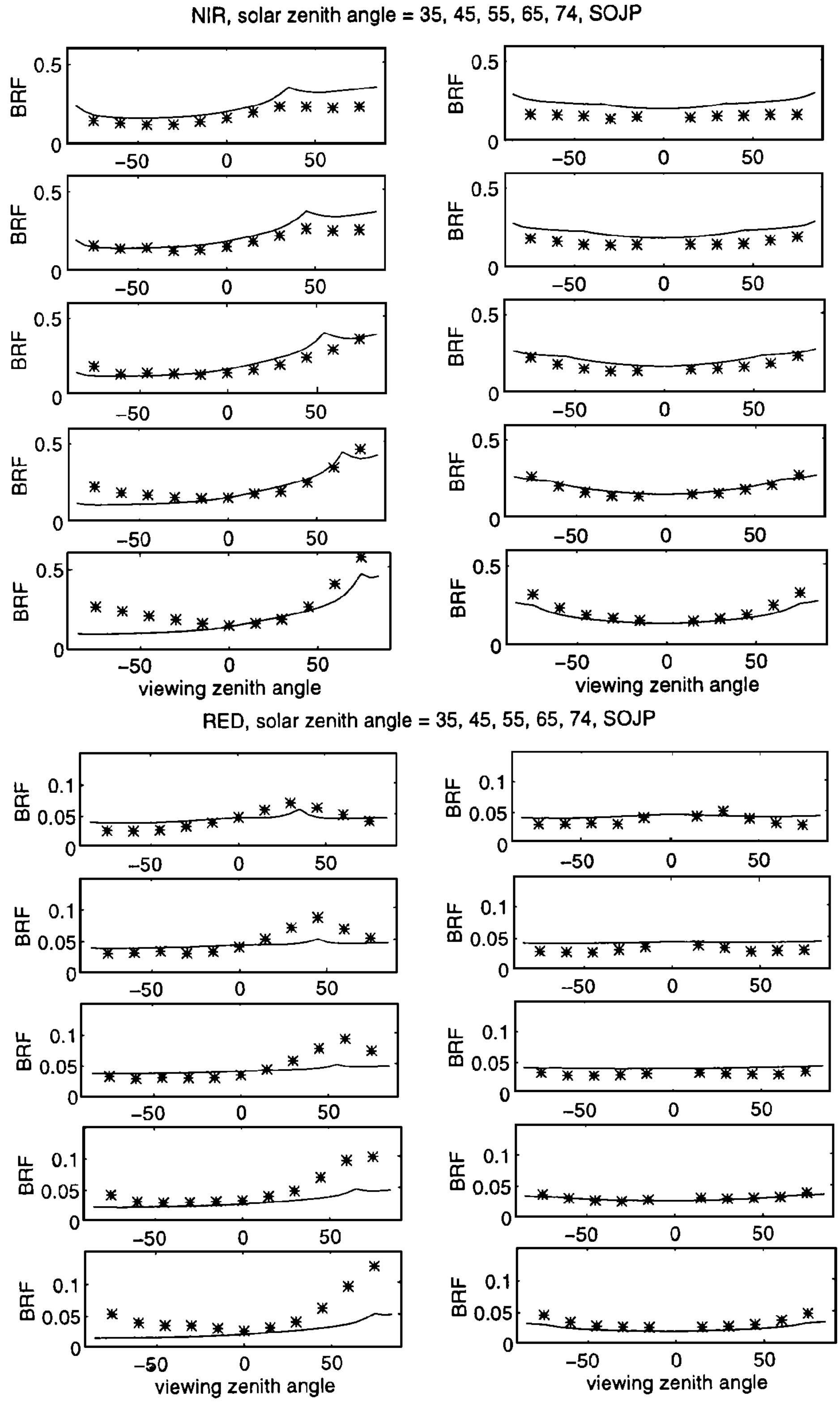

Fig. 3 Comparison of the model bidirectional reflectance factor with PARABOLA measurement in the SOJP site of BOREAS (top for NIR channel, bottom for RED channel, left is from principal plane, right is for cross plane, solid line is for model results, * is for PARABOLA measurements

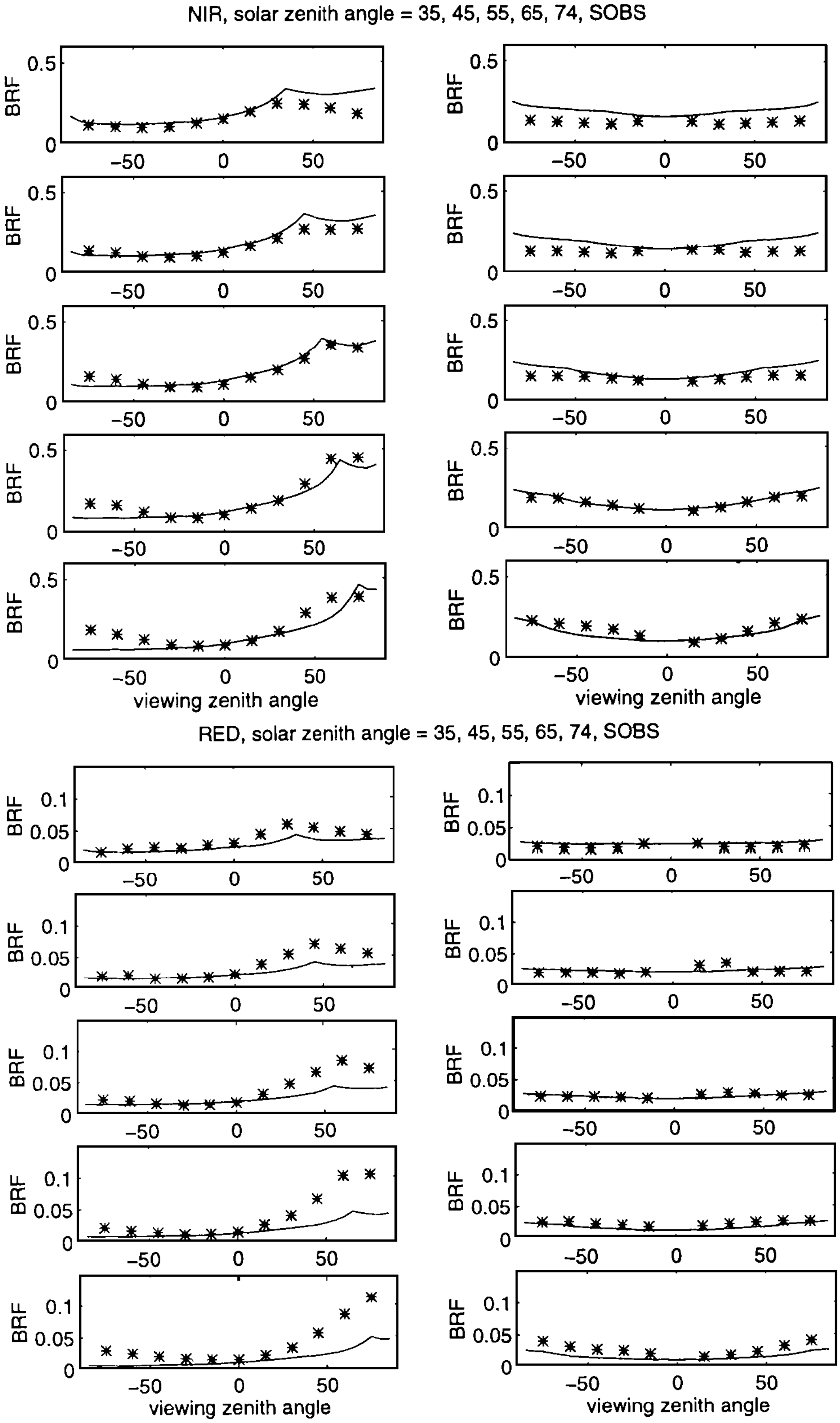

Fig. 4 Comparison of the model bidirectional reflectance factor with PARABOLA measurement in the SOBS site of BOREAS (top for NIR channel, bottom for RED channel, left is from principal plane, right is for cross plane, — is for model results, * is for PARABOLA measurements

model assumes solid tree crowns. This leads to underestimation of the areal proportion of the sunlit viewed background surface by GOMS model at hot spot cases.

The bidirectional reflectance at the hot spot is contributed only by two components: the sunlit background surface, and the sunlit crown surface. Due to the small absorption of the canopy elements in the near infrared spectral range, the signature of the sunlit crown surface is much larger than the sunlit background. The bidirectional reflectance at the hot spot in the near infrared spectral range is primarily the sunlit crown surface. This effect of underestimation of the sunlit background surface on the hot spot is not so strong.

Due to the large absorption of canopy elements in the red spectral range, the contribution from the sunlit ground surface is larger than or at least comparable to the sunlit crown surface. Underestimation of the sunlit background surface by the GOMS model will result in a weak hot spot.

Overall, the comparison of the parameterized spectral component signatures with the field measurement and the comparison of the modeled bidirectional reflectance with the parameterized spectral component signatures with the PARABOLA data in near infrared range shows the validity of the approach used for the parameterization of the spectral component signatures for the GOMS model.

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# 几何光学冠层反射建模中的光谱分量特征的参数化

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**摘　要**　该文用几何光学与辐射传输混合模型研究不连续植被冠层的几何光学反射模型的四分量（承照树冠、承照地面、阴影树冠、阴影地面）的参数化。用一个修正的均匀介质层路径散射（反射与传输）参数的解析算法估计路径散射参数（反射与传输），其中也考虑了冠层间隙的影响。光谱分量特征是不连续植被冠层的传输与反射，背景反照率，以直射光通量与天空漫射光通量比例的函数。光谱分量特征的模型与在美国缅因州 Holland 采集的针叶林数据吻合。基于 Li-Strahler 几何光学相互遮蔽模型，用参数化的光谱分量特征对老松林和老云杉林的方向反射进行估计，其结果与在不同太阳与观测方向上的 PARABOLA 测量值匹配得很好。

**关键词**　光谱分量参数化，GO 模型