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# Computer Simulations of Differing Radiation Regimes on Aspen Trees

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Abstract: LAI (leaf area index) and LAD (leaf angle distribution) are two important parameters determining vegetation canopy structure. In computer simulations of vegetation canopies, these two parameters are the controlling parameters that render the 3D vegetation scene. In this paper, a computer graphics method, Modified Extended L-system (MELS), is used to render an architecturally realistic leaf canopy (grass) and tree canopy (aspen), that are based on measured structure data of typical grass and aspen trees. A radiosity-graphics combined model (RGM) is then used to calculate the radiation regime of the simulated 3D realistic structure scene, including canopy directional reflectance and spectrum in visible and NIR regions. Two aspen tree scenes are simulated: one where the underlying surface is soil and another where the underlying surface is grass and soil. Then, distributed characteristics of canopies BRF (bi-directional reflectance factor) for the two kinds of scenes are analyzed. However, for realistically structured trees, the radiosity method cannot simulate a large-scale scene because there are too many variables to be processed, so one solution is to simplify the tree crown, making it possible to simulate the canopy BRF at a larger scale. So, we conclude that computer simulations can obtain the radiation regime of forest canopies with some kinds of underlying surfaces, making computer simulation a good way of providing directional reflectance.

Key words: bidirectional reflectance factor (BRF); radiosity; computer simulation; GOMS
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## 1 INTRODUCTION

About 30% of the Earth is covered by land, much of which is vegetated. Terrestrial vegetation impacts climate by playing a key role in various processes, such as energy, mass, and momentum exchanges. The basic premises for optical remote sensing of vegetation are that the solar radiation received by a remotely located sensor (e.g. on a satellite) upon interaction with the vegetation canopy carries the spectral signature of the canopy, and that this spectral signature can be deciphered to obtain information of interest. Physics-based methods for the assessment or monitoring of vegetation parameters (e.g. structural and biophysical characteristics) have progressively become more attractive since they are better-suited for many current large-scale applications, than traditional used statistical techniques. The parameters of interest vary with different areas of application, such as with production ecology, global change monitoring, and climate models; however, for all applications, good models of the shortwave radiation budget of vegetation canopies are needed to interpret the remotely sensed signal. The shortwave radiation budget T describes how the fractions of radiation absorbed by or scattered from the canopy to the underlying soil and understory or back into space (canopy reflectance or albedo) are related to the structural and optical properties of the canopy and background. Vegetation characterization

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and classification are important issues in remote sensing of vegetation and ecological research. Correctly discriminating vegetation types to the species level is often required in agriculture, forestry, and range resources management[1].

The leaf area index (LAI) is a key parameter in models describing the exchange of matter and energy flow between the vegetation and the atmosphere. LAI and LAD are the important parameters determining vegetation canopy structure. In our computer simulation of vegetation canopies, the two parameters are the controlling parameters to render the 3D vegetation scene. The 3D scene model takes advantage of the radiosity method and computer graphics techniques. The RGM consists of two major modules: a modified extended L-systems (MELS)[2] method to generate a realistic 3D scene; and a radiosity-graphics combined method (RGM) to simulate the radiation regime based on the realistic 3D structure scene. This model takes into account the 3D architecture of the canopy, and fully incorporates multiple scattering, shading, and mutual shadowing effects, including the hotspot effect. The model also calculates the radiation regime of the canopy. The model outputs include the canopy bidirectional reflectance factor (BRF), that is used in this study. Fig. 1 is the flow chart describing the simulation of canopy BRF, using the method above.

In this paper, MELS is used to render the architecturally realistic structure scene, such as leaf canopy (grass) and tree canopy (aspen), based on their measured structure data. Then the simulated structure

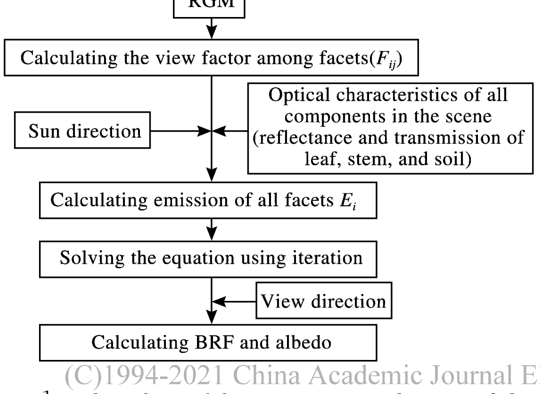



Fig. 1 Flow chart of the computer simulation model of combined radiosity

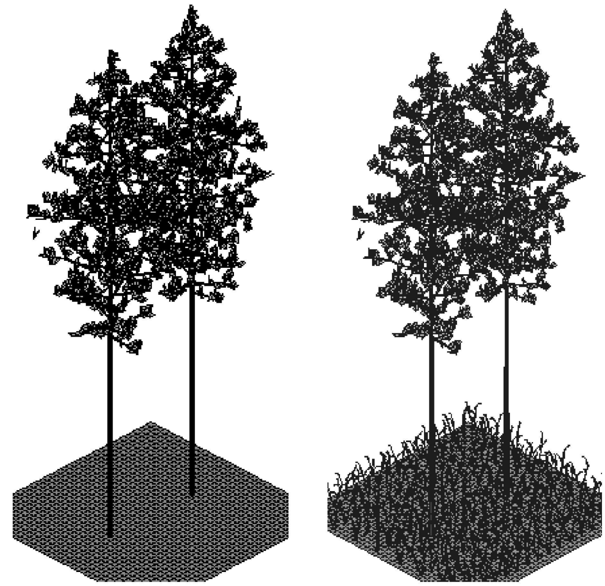
scene is used as the input parameters in RGM[1,3] and the radiation regime of the vegetation canopies is calculated, including canopy spectrum and its directional reflectance in visible and NIR regions. For aspen trees, two scenes are rendered: (1) aspen trees with underlying soil, and (2) aspen trees with underlying soil and grass. Then, we used the RGM model to simulate the canopy radiation regime and to analyze the differences between the two canopy types. However, the numbers of surfaces are more complex in the forest structure, making it difficult to simulate canopy BRF with the radiosity method. One idea is to simplify the structure of tree crowns, considering the sunlit and shaded surfaces. Last, the simulated results are compared with that of the realistic scene, to see if its accuracy meets our study requirements.

In addition, in order to simulate large scale scenes, such as one pixel TM image, the structure of the simulated object must be simplified. In this paper, we simulate simplified aspen trees, and compared the results to realistically structured scenes.

## 2 THE REPRESENTING OF VEGETATION SCENES

Effectively and efficiently representing realistic structures of vegetation is a prerequisite to study the radiation regime of vegetation canopies, from which the spectral reflectance at different scales can be simulated. It is also necessary to transform the structural parameters of the vegetation into ecological variables. So, it is important to render 3D vegetation scenes accurately. The algorithms to render artificial vegetation are based mostly on two computer graphics methods: fractals and Lindenmayer systems (L-systems). In this paper, we use the extended L-systems (ELSYS); the basic idea of this method is to define complex objects by successively replacing parts of complex objects with parts of simple objects, using a set of rewriting rules or productions, compiling them, saving the structures to the text files, and finally displaying realistic plant models. Thus, for any vegetation species, based on its botanical frame structure, one can generate a plant with minimal measurement inputs, such as leave area index (LAI), plant height and foliage element size. In this study, in order to generate aspen trees many parameters have been measured, such as total height, stem diameter, crown horizontal and vertical diameters, leaf size, and leaf spatial distributions. Two scenes are generated: aspen trees with underlying soil and aspen trees with underlying soil and grass. In the program to render these two kinds of scenes, LAI and aspen height are the important controlling parameters. So, canopy spectrum and its directional reflectance can be simulated for different growth phases, namely for different LAI and different tree heights. Analysis of the results of the two scenes indicates that the underlying surfaces have a great effect on canopy BRF.

Experiments performed in Shandong province, in the northern part of China, identified forests and wheat in May, 2005. Field-measured data, including aspen tree structure parameters, and airborne data were obtained in the May 2005 experiment. This experimental data is used in the present study. With the help of field-measured morphological parameters, and of field photographs, aspen trees scenes are generated using the MELS program. Fig. 2 is the rendered scene used to simulate canopy reflectance. Fig. 2(a) is the simulated scene of aspen trees that have soil underlying



(a) aspen (b) aspen and grass

Fig. 2 The 3D simulation scene of aspen and the mixed scene of aspen and winter wheat

them, where LAI is 1.26. Fig. 2(b) is the simulated scene of aspen trees that have soil and grass underlying them (Fig. 3), where LAI is 1.52. The entire scene, consisting of plants and soil, is composed of triangle- and quadrangle-shaped surfaces. We measured reflectivity and transmittance properties by integrating sphere and ASD spectroradiometer, selecting four wavebands as shown in Table 1.

Table 1 The optical properties of components in scenes

| | Wavelength/nm | 446 | 557 | 671 | 867 |
|---|---|---|---|---|---|
| Soil | Reflectivity | 0.0506 | 0.1455 | 0.1880 | 0.5624 |
| | Transmittance | 0.0 | 0.0 | 0.0 | 0.0 |
| Leaf | Reflectivity | 0.0537 | 0.1220 | 0.0702 | 0.5143 |
| | Transmittance | 0.095 | 0.081 | 0.033 | 0.4324 |
| Bark | Reflectivity | 0.1368 | 0.20 | 0.2215 | 0.5434 |
| | Transmittance | 0.0 | 0.0 | 0.0 | 0.0 |
| Grass | Reflectivity | 0.07913 | 0.14279 | 0.07361 | 0.47712 |
| | Transmittance | 0.01109 | 0.08633 | 0.01142 | 0.46115 |

## 3 SIMULATION OF THE RADIATION REGIME WITH RGM MODEL AND THE EFFECT OF UNDERLYING SURFACE ON THE CANOPY BRF

Radiosity is the radiation flux density leaving a surface element. The radiosity equation (1) states a rigorous energy balance requiring the total radiation flux leaving any surface element i to be equal to the sum of its emitted and reflected flux originating from all other surfaces. The radiosity method is based on 3D realistic structure scenes, that are spatial entities composed of spatial triangle- or quadrangular-shaped surfaces (Fig. 4). Radiation regimes of the rendered scene are simulated based on the energy transfer

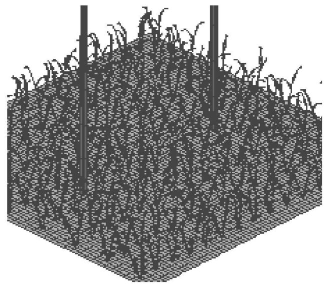


Fig. 3 The underlying surface of the mixture scene

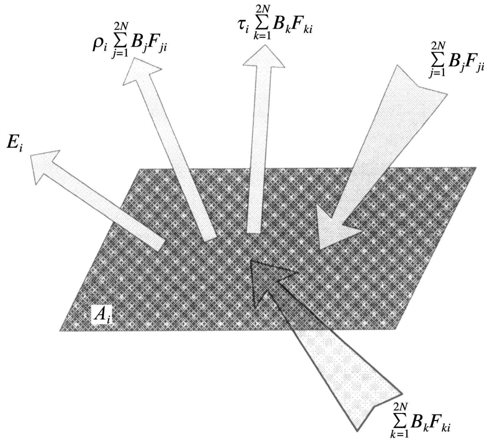



Fig. 4 Radiosity relations for a surface patch[5]

among surfaces. In this method, the Sun is considered as important source of energy, where sunlit facets are the starting points to transfer scene energy. The radiosity method is capable of describing the radiative effects due to the discrete nature of leaves and stems (e.g. shading and clumping). The solar irradiance on each individual leaf can also be computed. Such data is of very importance to analyzing photosynthesis, nutrient and another biochemical transport mechanisms within realistic plants. As long as the plant architecture can be satisfactorily described by surfaces with given orientation, the radiosity equation can provide a valuable complement to the RT description of the radiation field in vegetation canopies. So, a combination of the radiosity method with MELS provides a powerful tool to study radiation regimes in a heterogeneous 3D-structured vegetation scene[5].

$$B_i = E_i + \chi_i \sum_{j=1}^{N} B_j F_{ij} \quad (1)$$

$$\chi = \begin{cases} \rho_i & \text{if } (\vec{n}_i \cdot \vec{n}_j) < 0 \\ \tau_i & \text{if } (\vec{n}_i \cdot \vec{n}_j) > 0 \end{cases} \quad (2)$$

where $B_i$ is the radiosity on surface element i, defined as the total radiation flux density leaving that surface. $E_i$ is the surface emission, $\rho_i$ the reflection coefficient, and $F_{ij}$ is the view factor that specifies the fraction of radiant flux leaving another surface j that reaches the surface i.

In order to analysis the characteristics of the two different scenes, a simulated experimentation is done with the same conditions. In the process of simulating the radiation regime of the rendered scenes, we define solar zenith angle to be 45° and solar azimuth angle to be 180°, where the field of view (FOV) is 10° and where the view zenith ranges from −65° to 65°. We also use the optical properties of components, such as soil, tree leaf, bark, and grass leaf, shown in Table 1. The size of the simulated scenes is 4.0m × 4.0m. Fig. 5 compares the results of the canopy BRF distribution with changing view zenith angles between the two scenes in the visible regions (blue, green, and red bands), and with NIR region in the principle plane where the view azimuth is aligned with the solar azimuth, but where the view zenith varies. From Fig. 5, it can be seen that the differences between the two scene canopy BRF are bigger in both the visible and NIR region, and the canopy BRF of the aspen trees that have soil underlying them is smaller than BRF of trees that have soil and grass underlying them at almost every view zenith angle. In order to analyze their differences, the normal differences are calculated. The normal difference is defined as the difference normalized by the summation of the two canopies BRF in every band, shown by equation (3).

$$nd = (r_{max} - r) / (r_{max} + r) \quad (3)$$

where nd is the normal difference; $r_{max}$ is the canopy BRF of the mixed scene of aspen and grass; and r is the canopy BRF of the aspen scene. Fig. 6 shows the normal difference distribution with the change of view zenith angles of the two aspen trees scenes at visible and NIR regions in the principle plane. In Fig. 6, it can be seen that the trend of these normal difference values are in accordance with those in the visible regions (blue, green and red bands), but are different in NIR regions. In visible regions, from the backward view direction to the forward direction, the stream first decreases, then increases, and at the hot spot

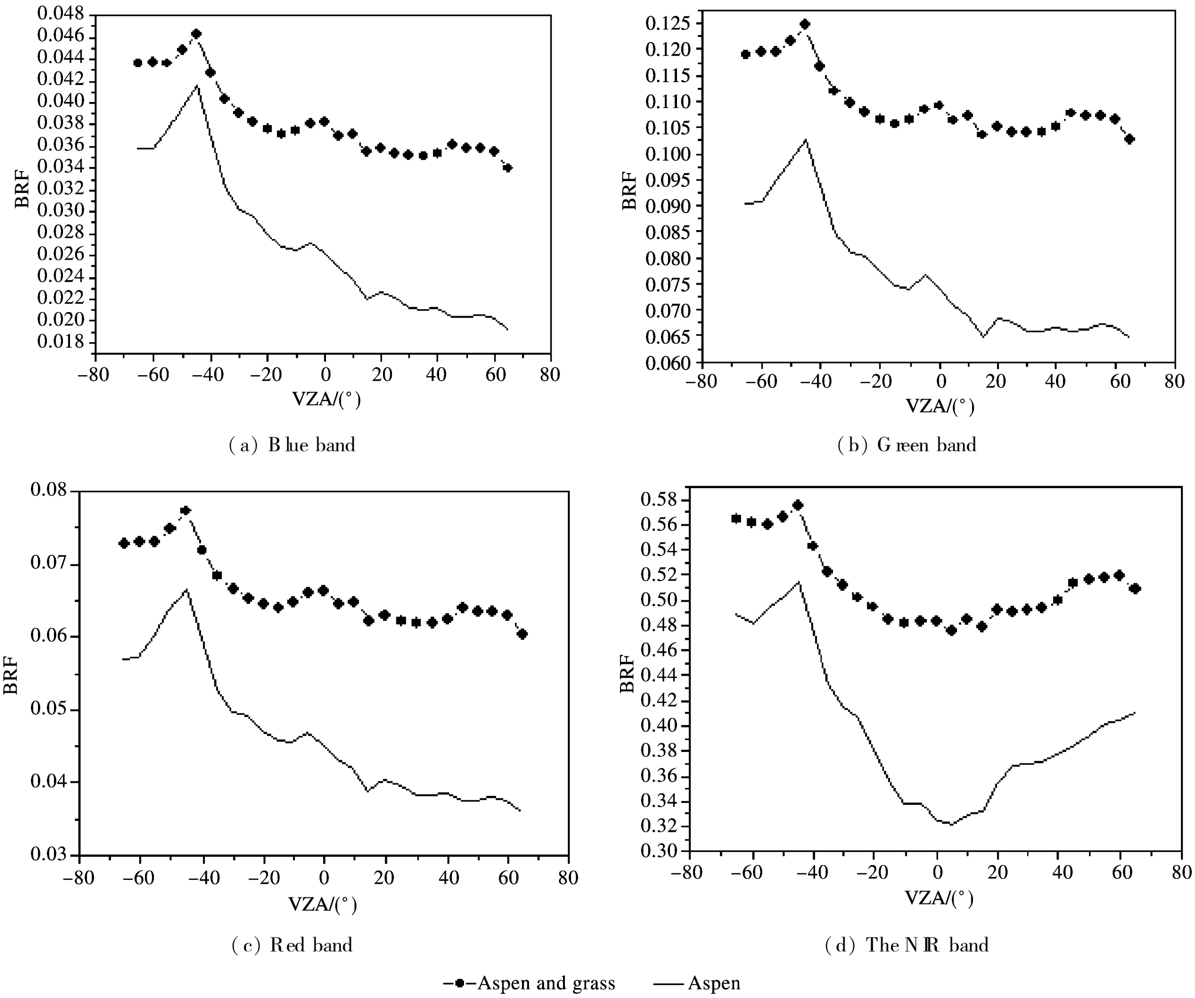



Fig. 5 Comparison of BRF distribution with view zenith angles between the aspen scene and the mixture scene in the visible and NIR regions in the principle plane

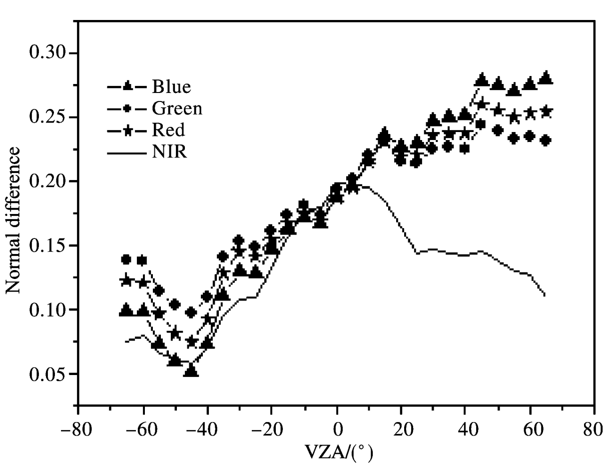


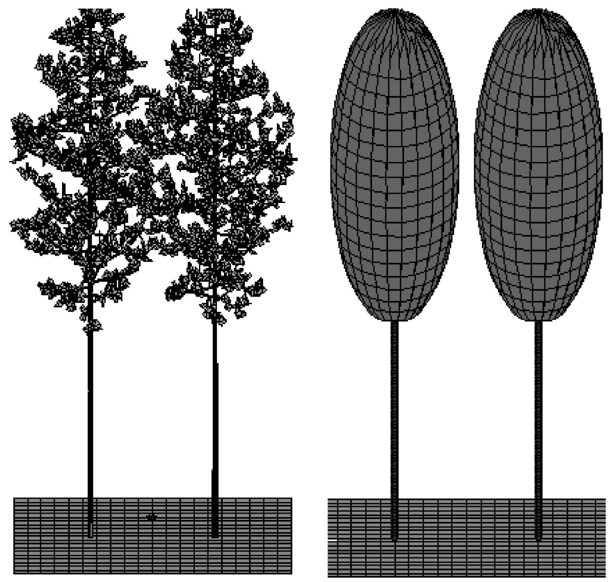

Fig. 6 The normal difference distribution with view zenith angles between the aspen scene and the mixture scene in the visible and NIR regions in the principle plane

view direction; there is an inflexion; that is the differences are smallest at the hot spot. In the NIR regions the lowest point is the same as in the visible bands but the highest is at nadir. In general, the normal differences in the NIR region are smaller than those in the visible regions at every view zenith angle. All components in the scene (i. e. leaf, bark, stem, grass and soil) contribute to the canopy BRF, where the optical properties are especially important. If we change their optical properties, the results also change to some degree, so in this study, the analysis is based on the optical properties shown in Table 1. The hotspot is the result of single scattering, and in Fig. 5, it can be seen that the normal difference in hotspot direction is the smallest, so the single scattering in the mixed scene increases the least. On the other hand, the effect of the multiple scattering is greater in both the visible and NIR regions. Evidently the grass is part of the underlying surface that enhances the multiple scattering in the mixed scene of aspen trees and grass. But in the NIR region, the multiple scattering is the main contributor to canopy BRF and the LAI of the grass is so small that its effect on the whole multiple scattering is small. In the nadir view direction, the influence of the underlying surface is large, so its normal difference is the largest; however, because view zenith angle is bigger, the effect is weak, and the multiple scattering of tree leaves is the dominant contributor to the canopy BRF.

Based on this analysis, we conclude that the effect of the underlying surface on the canopy BRF is great for both visible and NIR bands and it cannot be ignored when studying the radiation regime of the forest. Considering the effect of the kinds of underlying surface, it is possible to enhance the classification of vegetation.

## 4 SIMPLIFYING THE SCENE STRUCTURE

Bigger forest scenes have more complex structures because there are more surfaces to render in the 3D realistic structure scene. However, the radiosity method is limited in the number of facets that can be used as input, so the number of surfaces facets must be reduced. In this study, the main idea is to abstract the tree crown and to simplify the surfaces of the scene. We abstracted the characteristics of the aspen tree crown as an ellipsoid as shown in Fig. 7. Fig. 7(a) is the realistic aspen tree, Fig. 7(b) is the simplified tree and its optical properties shown in Table 2. The simplified scene almost reduces by ten times the number of surfaces making-up the realistic structure scene, saving calculating time and memory space. Thus, we can use radiosity method to simulate the larger scale scenes. The key is to provide values for the surfaces of the ellipsoid crown. In this test, we use the concept of the gap probability model[4] in the simplified model, and simulate the sunlit surfaces and shaded surfaces based on the direction of the Sun. FAVD is taken as the control to provide the optical properties of the surfaces. In the simplified scene, after photons come into the scene, there are some kinds of interactions. First, some photons will collide with absorbed surfaces, and the energy will disappear.



(a) Realistic scene (b) Simplified scene

Fig. 7 The realistically structured scene and the simplified scene

Table 2 The optical properties of the components in the scenes

| Components | Optical Properties | Visible | NIR |
|---|---|---|---|
| Leaf | Reflectance | 0.122 | 0.5143 |
| | Transmittance | 0.081 | 0.4324 |
| Transmitted Leaf | Reflectance | 0 | 0 |
| | Transmittance | 1 | 1 |
| Absorbed Leaf | Reflectance | 0 | 0 |
| | Transmittance | 0 | 0 |
| Soil | Reflectance | 0.10775 | 0.22015 |
| | Transmittance | 0 | 0 |
| Shaded soil | Reflectance | 0 | 0 |
| | Transmittance | 0 | 0 |
| Bark | Reflectance | 0.200 | 0.5434 |
| | Transmittance | 0 | 0 |

Secondly, some photons will meet the leaf surfaces, so some will reflect out of the tree canopy directly (i.e. single scattering), and some will be transmitted into the crown. The transmitted photon may be transmitted to the underlying surface or interact with other surfaces. Thirdly, some photons will pass through directly through gaps in the tree crown to collide with the underlying surface. Then after the interaction of photons and the underlying surface, some photons will enter the tree crowns again, and continue their interactions with other surfaces.



Fig. 8 is a larger version of the simulated scene of the simplified aspen tree. The size is 27m × 27m and LAI

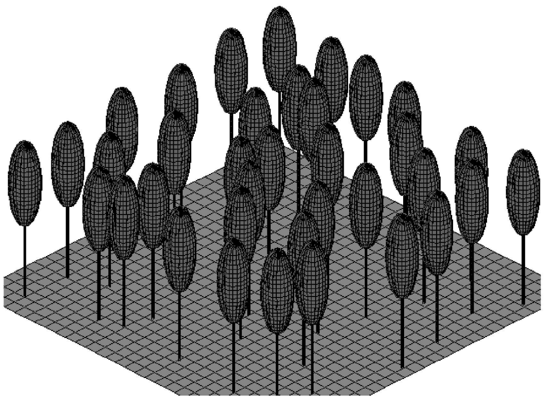


Fig. 8 The simplified scene in large scale

is approximately 3.1. The simplified tree height is 9.2m, and the vertical diameter and horizontal diameter of the ellipsoid crown are 2.25m and 1.4m respectively. The simplified aspen trees are distributed randomly in Fig. 8. This random distribution more closely duplicates nature. We defined simulated conditions: solar zenith and azimuth are 45° and 180°, respectively, the field of view (FOV) is 10° and view zenith ranges from −65° to 65°. We compared the computer simulated results with the results generated by GOMS model[6] to validate our computer results. The GOMS model represents forest canopies as a collection of discrete crown entities casting shadows onto the background and/or other tree crowns. Crowns have been modeled as ellipsoids. For the GOMS model, lambda, brratio and hbratio are the important structure parameters. Lambda is the density of the simulated ellipsoid crowns in the scene; brratio is the ratio of the vertical radius of the ellipsoid crown to the horizontal radius; and hbratio is the ratio of the height of trees to the vertical radius. The structural and optical properties for the visible and NIR bands of the simulated scene are shown in Table 3.

Fig. 9 illustrates the comparisons of the canopy BRF distribution with the view zenith angles of the computer simulated simplified scene and the results for the GOMS model. The simplified results are in accord with the results of GOMS model. However, there are some differences, especially in the visible band, for the larger view zenith angles in the forward direction. Perhaps this is because that the optical characteristics of the simplified crown structure in the NIR band are more accurate than the ones for the visible bands, or because in the visible bands, the characteristics of the underlying surface for computer simulated simplified scene are not as similar to the GOMS model. Future research plans include our intention to modify the optical characteristics chosen for the visible bands. However, this research supports our contention that it is possible to use the radiosity method to simulate large-scale scenes, that can be considered as a forward model to produce the directional reflectance of

Table 3 The optical properties of the components in the scenes

| | | | |
|---|---|---|---|
| Structural Parameters | lambda | 0.08 | |
| | brratio | 3 | |
| | hbratio | 2.6 | |
| | htdif | 0.01 | |
| Optical Parameters | | visible | NIR |
| | Rg | 0.10 | 0.15 |
| | RC | 0.09 | 0.46 |
| | RZ | 0.015 | 0.05 |

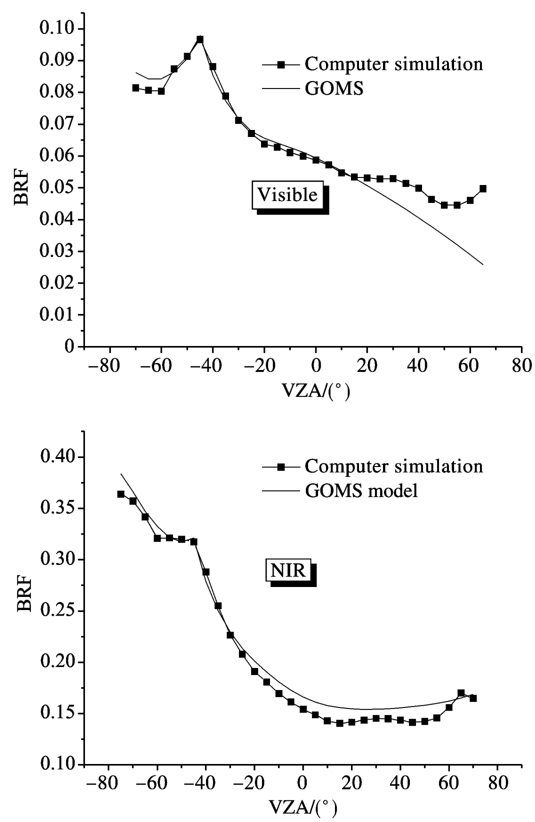



Fig. 9 Comparison of the results of BRF distribution with view zenith angles between computer simulation and GOMS in the visible and NIR regions in the principle plane

larger scale scenes for future research.

## 5 DISCUSSION

The canopy structures in nature are so complex that the precise modeling of canopy BRF of vegetation can rarely be completely solved. Great effort is being devoted to finding more effective methods to address this problem, such as the radiosity method. Using this method, more accurate canopy BRF can be obtained based on simulated realistic natural vegetation scenes. In this paper, using aspen trees as an example, bidirectional reflectance is simulated for aspen trees that have soil underlying them and trees that have soil and grass underlying them.

We can draw some conclusions from our study. Computer simulations can obtain the radiation regime of forest canopies for some kinds of underlying surfaces. Therefore, computer simulations are proven to be an effective means of providing directional reflectance. Using the simulated data, we can analyze and classify measured data, such as field-data and airborne data. According to the computer-simulated results, the reasons for errors in image classification can be analyzed. In addition, our study of the simulating simplified structures indicates that bidirectional reflectance can be calculated using the radiosity method at a lager scale. However, because vegetation displays a wide variety of shapes, our simplified simulation should be modified to adapt to more types of vegetation.

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# 基于真实白杨林地场景冠层辐射特性的计算机模拟


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**摘　要：** 叶面积指数(LAI)和叶倾角分布(LAD)是决定植被冠层结构的重要参数。在计算机模拟植被冠层，两个参数是植被三维真实结构生成的重要控制因子。本论文中，结合计算机图像学理论，基于实验的地面实测结构参数数据利用可改写的扩展 L-system方法生成草以及白杨树的真实三维场景。RGM(A radiosity-graphics combined model)模型是基于辐射度方法的计算机模拟模型，利用此模型来计算生成的三维场景可见光及近红外波段的冠层辐射特性，如冠层波谱以及方向反射特性等。在本研究中，模拟了两种不同下垫面的白杨林地：(1)下垫面只有土壤的白杨树场景；(2)下垫面包括土壤和草的白杨树。在特定的场景组分光学特性下，模拟得到两种情况的主平面冠层 BRF(bi-directional reflectance factor)，并对两者的差异进行了分析。可以看出，下垫面对冠层 BRF的影响不可忽视。但是，由于白杨林地结构的复杂，大尺度的场景中必须由成千上万个面元组成，因此辐射度方法不能模拟大尺度的真实结构场景。为了拓展辐射度方法应用范围，根据白杨树树冠的特点，将其抽象为椭球体，从而减少场景组成面元个数，满足了辐射度方法的要求。并结合几何光学模型的思想，在对椭球体面元赋值加入了间隙率；并考虑了整个树冠的承照面以及阴影面的差异，模拟大尺度林地冠层 BRF且与 GOMS模型结果符合的很好。通过以上研究，可以看出计算机模拟为遥感研究获取多角度数据信息提供了一种很好的手段。




**关键词：** BRF; 辐射度；计算机模拟；几何光学模型