contribution to the IGARSS'98, Seattle 1998
International Geoscience and Remote Sensing Symposium, Copyright 1998 by IEEE

Analyzing Hyperspectral BRDF Data of a Grass Lawn and Watercress Surface Using an Empirical Model

GERHARD MEISTER[1], STEFAN SANDMEIER[2], WENGE NI[3]

[1] Universität Hamburg, II. Institut für Experimentalphysik
Mail: FB Informatik / KOGS, Vogt-Kölln-Str. 30, 22527 Hamburg, FRG
Phone: ++ 49 40 5494 2601, Fax: ++ 49 40 5494 2572, E-mail: meister@informatik.uni-hamburg.de
[2] Remote Sensing Laboratories, University of Zurich, Switzerland
Current address: NASA / Goddard Space Flight Center, Code 923, Greenbelt MD 20771
E-mail: ssandmei@pop900.gsfc.nasa.gov, http://www.geo.unizh.ch/ sandi
[3] Wenge Ni, Raytheon, STX, 4400 Forbes Blvd, Lanham, MD 20706
Phone: +1 617 794 5194, Fax: +1 617 441 1853, E-mail: ni@homer.stx.com

ABSTRACT

This paper presents results from analyzing hyperspectral BRDF data of grass lawn and watercress. The intensity of the hotspot as a function of wavelength is determined from fitting an empirical (or rather *phenomenological*) model to the data. The model consists of a lambertian, bowlshape, hotspot and forward scattering component. An analytical, theoretically derived relation between the hotspot intensity and the lambertian component is given. The intensity of the multiple scattered radiation obtained from this relation can be explained qualitatively with the surface structures of the samples.

INTRODUCTION

The Bidirectional Reflectance Distribution Function (BRDF) describes the dependence of surface reflectance on incidence and viewing angles as a function of wavelength. With hyperspectral BRDF data, the dependence of the BRDF on the 'brightness' of the surface at the respective wavelength can be studied effectively on a vegetation canopy, since the spectral albedo of vegetation varies considerably (e. g. from 0.026 to 0.43 between 500 nm and 1000 nm for a grass sample). The spectral signature affects the shape of the BRDF, because multiple scattering increases dramatically at high albedos. This paper focuses on the decrease of the hotspot relative to the albedo as multiple scattering increases.

DESCRIPTION OF DATA SETS

Data from an erectophile grass (*Lolium perenne*) and a planophile watercress (*Lepidium sativum*) surface were acquired under controlled laboratory conditions at the European Goniometric Facility (EGO) of the Joint Research Center in Ispra/Italy [1]. The angular resolution of the BRDF data is 5° and 15° in zenith and azimuth direction, respectively. The data is available from our website. In addition, a field data set of the same grass species is analyzed, measured with the FIGOS field goniometer with a resolution of 15° and 30° in zenith and azimuth, respectively [2]. All data were taken under a source zenith angle of 35° with zenith angles of reflection θ_r ranging from 0° to 75° using a GER-3700 spectroradiometer with 323 channels between 500 nm and 1000 nm.

EMPIRICAL BRDF MODEL

Four basic BRDF components are identified and fitted to the data with an empirical function: 1) hotspot 2) forward scattering 3) bowlshape and 4) lambertian component.

The forward scattering component is adopted from a specular term successfully used in similar studies [3] (see [4] for a detailed explanation of the specular term). The bowl shape is modeled as a simple linear function of the zenith angles.

To model the hotspot, we chose a simple exponential function $e^{-b_2 \cdot g}$ which has a shape very similar to a function proposed by B. Hapke [5] (g is the relative angle between viewing and illumination direction). Our function has the advantage of approaching zero in the forward scattering direction much faster than Hapke's function, which makes it easier to separate the hotspot from the forward scattering term in the inversion step. Since the decrease of reflectance from the hotspot towards larger viewing zenith angles is smaller than the decrease towards nadir, we multiplied the hotspot term with an exponential function $e^{b_1 \cdot (\theta_i \cdot \theta_r)^2}$ also used in the forward scattering component.

The resulting BRF model has the following form:

$$BRF = \pi \cdot BRDF = a_0 + a_1 \cdot (\theta_i + \theta_r) + a_2 \cdot e^{b_1 \cdot (\theta_i \cdot \theta_r)^2} \cdot e^{-b_2 \cdot g} + a_3 \cdot e^{b_3 \cdot (\theta_i \cdot \theta_r)^2} \cdot e^{b_4 \cdot \psi^2} \quad (1)$$

where ψ is the relative angle to the specular direction, see [4]. The coefficients a_i depend on wavelength, the coefficients b_i are fixed for each sample. The underlying assumption is that the shape of the hotspot and the forward scattering term are primarily determined by the geometry of the canopy, whereas the intensity of these two terms can vary with wavelength due to the change of reflectance with wavelength.

The coefficients have the following physical meaning:
a_0 = lambertian component (diffuse scattering)
a_1 = intensity of the bowlshape
a_2 = intensity of the hotspot
a_3 = intensity of the specular peak

---

[1] This research was supported by the German Research Foundation (DFG) and the Swiss National Science Foundations (NF)[2].

b_2 = width of the hotspot
For an explanation of b_1, b_3 and b_4 see [4].

Based on the assumption that the surface consists of surface patches of one reflectance only (so the background does not influence the BRDF), we derived a *physical* (not empirical) relation between a_0 and a_2:

$$a_2 = \frac{e^{-b_1\theta_i^4}}{2\pi k} \cdot (-K_1 + \sqrt{K_1^2 - 4\pi k K_0}\,) \qquad \text{with} \qquad (2)$$
$$K_0 = a_0(x-c) + a_0^2 \pi k(1-c)\,, \quad K_1 = a_0(2\pi k - c) + x$$

where $x \,\epsilon\, [0,1]$ is the areal proportion of shadowed surface patches at angles where the BRDF equals a_0 (diffuse limit), $k \,\epsilon\, [0,1]$ is the probability that scattered light will hit another surface patch, and c is a geometry factor (close to 1). x, k and c are wavelength independent quantities. The derivation of (2) and the assumptions made will be presented in a later publication.

MODEL INVERSION

We used a numerical routine from the software package 'PV-WAVE' based on the least-squares-deviation to fit the parameters of equation 1 to the BRDF data. Allowing all parameters to float freely did not yield reasonable results. So we adopted a step by step procedure.

First, we fitted parameter a_1 for the bowlshape component for each wavelength taking into account only BRDF measurements in the cross principle plane (relative azimuth φ = 90°) where the effects of the hotspot and the forward scattering term are assumed to be smallest. Then, we estimated parameters b_i (the shape-determining parameters of the hotspot and forward scattering term) from BRDF measurements in the principal plane ($\varphi = 0°/180°$, respectively), taking into account the effect of parameter a_1. For the forward scattering term, some freedom remains in the choice of b_3 and b_4. This term was designed to fit to a specular peak with a distinct maximum, but our data only shows a rise and no decline (if there is a maximum, it must be at $\theta_r > 75°$). The parameters b_1 and b_2 could be determined well, because the hotspot peak (at $\theta_i = \theta_r = 35°$) is well within the range of measured angles ($\theta_r = [0°...75°]$). For the field measurement of grass, the same coefficients b_i were used as for the laboratory measurement of grass because the angular resolution of the field measurement was much coarser.

In the final step, we fitted the parameters a_0, a_2 and a_3 to all data points.

RESULTS AND DISCUSSION

The agreement between measurements and fitted function (1) is satisfying, the mean relative deviation is only a few %, see table 1. The assumption that the shape of the hotspot does not change with wavelength was confirmed clearly for the grass laboratory sample. The coefficients b_i are given in table 1. b_1 equals 1.5 for all samples. b_2 for cress is greater than b_2 for grass, this means that cress has a sharper hotspot. The coefficients a_i are shown in Fig. 1. All 3 samples show the rising edge characteristic for vegetation at about 700 nm, see plots A-C (neglecting BRDF effects, the coefficient a_0 is approximately proportional to the albedo).

The bowlshape component described by a_1 for grass is very different from cress (plots D-F). a_1 varies only by a factor of about 2 for cress (cress has almost no bowlshape at NIR), whereas for grass, a_1 goes to zero for small a_0. Thus, a_1 for grass is roughly proportional to a_0 for $a_0 < 0.3$. For wavelengths larger than 800 nm, we suspect that the inversion routine did not distinguish well between a_1 and a_3 for cress, resulting in the negative values for a_1. However, the impact of a_1 relative to a_0 is negligible for cress for $a_0 > 0.3$.

Coefficient a_3 (plots J-L) tends to zero for small a_0 and reaches a maximum at about $a_0 = 0.25$ for grass. We don't know whether this spectral behaviour is consistent with the assumption that a_3 can be interpreted as a specular peak. If the Fresnel Reflectance of the scattering surface was constant (which is propably not the case here), a_3 would be constant. a_3 for cress is about a factor of 10 smaller than a_3 for grass.

If there was no multiple scattering (MS), we would expect the relation of a_2 (the hotspot intensity) and a_0 to be linear. Obviously, this relation is not linear (plots G-I). The reason is, that as a_0 increases, the intensity of MS increases too. MS reduces the hotspot because the shadowed components of the canopy are less dark since they are illuminated by the MS. Thus, for large values of a_0 (corresponding to high albedos) a_2 rises much slower than for small values of a_0.

For small a_0 and a_2, (2) can be transformed to $x \approx \frac{a_0}{a_0+a_2}$. x was estimated from $\frac{a_0}{a_0+a_2}$, an exact determination was not possible due to the ambiguous behaviour of $\frac{a_0}{a_0+a_2}$ for small a_0. k and c of (2) were fitted to all values of a_0 and a_2. As can be seen from the solid lines in plots G-I, (2) describes the relation of a_0 and a_2 very well. Note that (2) covers values of a_0 from 0.014 to 0.306 for grass (lab.) and 0.019 to 0.561 for cress, which is a difference of more than a factor of 20.

The coefficient k is proportional to the multiple scattered radiation. The difference of the coefficient k for grass and cress can be explained by the canopy structure: cress is a planophile canopy, not allowing much MS, whereas grass is erectophile with a lot of possibilities for MS. k for the laboratory measurement of grass is lower than k for the field measurement of grass. This is consistent with the above explanation, because the grass in the laboratory measurement has longer blades and is therefore not as erectophile as the field grass sample, and thus produces less MS. Coefficient c for the grass laboratory sample deviates significantly from 1, this may indicate problems with the application of (2) to this sample.

CONCLUSIONS

We described the BRDF of grass and cress by an empirical function, consisting of a lambertian component, a hotspot, a bowlshape and a forward scattering term. We derived a physical relation between the intensity of the hotspot (a_2) and the lambertian component (a_0). This relation is capable of describing the relation of a_0 and a_2 for grass and cress very well.

References

[1] St. Sandmeier, Ch. Mueller, B. Hosgood and G. Andreoli, 1998, Sensitivity Analysis and Quality Assessment of Laboratory BRDF Data, Remote Sensing of Environment, vol. 64, no. 2.

[2] St. Sandmeier and K.I. Itten, 1998, A Field Goniometer System (FIGOS) for Acquisition of Hyperspectral BRDF Data, IEEE Trans. of Geoscience and Remote Sensing, forthcoming article.

[3] G. Meister, A. Rothkirch, R. Wiemker, J. Bienlein and H. Spitzer, 1996, Modeling the Directional Reflectance (BRDF) of a Corrugated Roof and Experimental Verification, IGARSS 1998, Seattle.

[4] G. Meister, R. Wiemker, R. Monno, H. Spitzer and A. Strahler, 1998, Investigation on the Torrance-Sparrow Specular BRDF Model, IGARSS 1998, Seattle.

[5] B. Hapke, Theory of Reflectance and Emittance Spectroscopy, 1993, Cambridge University Press.

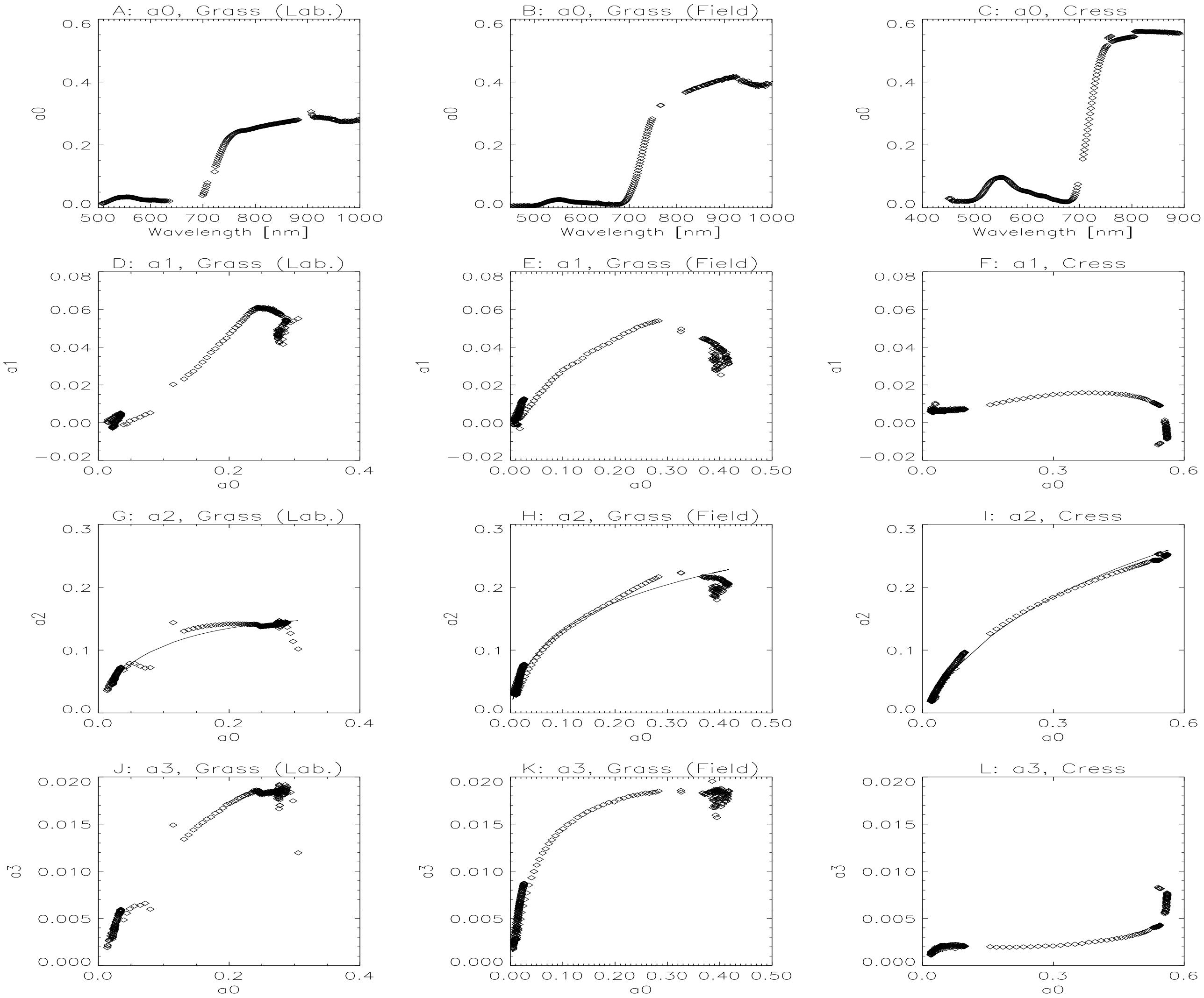

Fig.1: Wavelength dependent coefficients (rhombs) of (1) for the 3 samples as a function of wavelength (plots A-C) and a_0, respectively (plots D-L). The solid lines in plots G-I denote relation (2) using k, c and x from table 1.

Sample	b_1 [rad^{-4}]	b_2 [rad^{-1}]	b_3 [rad^{-4}]	b_4 [rad^{-2}]	k	c	x	d (red)	d (NIR)
Grass (Lab.)	1.5	1.72	4.0	0.95	0.43	0.73	0.1	0.063	0.035
Grass (Field)	1.5	1.72	4.0	0.95	0.55	0.99	0.1	0.052	0.034
Cress	1.5	2.5	4.0	0.95	0.25	1.01	0.4	0.041	0.036

Table 1: Wavelength independent coefficients and mean relative deviation d $\left(d = \frac{1}{N}\sum_{i=1,N}\frac{|BRF_i^{measured} - BRF_i^{modeled}|}{BRF_i^{measured}}\right)$.