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Variability of BRDF with Land Cover Type for the West Central HAPEX-Sahel Super Site

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Abstract -- The issue of Bidirectional Reflectance Distribution Function (BRDF) spatial variability on the landscape and its linkages to surface characteristics has received little attention. Data sets such as those collected by the Advanced Solid-State Array Spectroradiometer (ASAS), an airborne imaging spectroradiometer with along-track pointability, are ideal for such investigations. ASAS data collected during the Hydrologic and Atmospheric Pilot Experiment (HAPEX-Sahel) near Niamey, Niger were analyzed to address spatial variability with land cover type, the effects of scale on the directional reflectance trends, and how well a simple BRDF model accounted for the principal plane reflectance trends. A hypothesis was also tested that critical elements of the BRDF of the land cover types, as captured by the terms of a simple model, could be scaled up to the BRDF of the full scene using a linear mixture model.

INTRODUCTION

Several recent studies have noted a linkage between Bidirectional Reflectance Distribution Functions (BRDF) and land cover as measured by satellite systems at coarse spatial resolution (e.g. [1]). Although there also exists a substantial body of local plot-level BRDF data [2], it is as yet unclear what the contribution of multiple landscape components is to the BRDF observed by current or future satellite remote sensing systems at coarse spatial scales. In many cases the bidirectional signal is considered as "noise" and attempts are made to remove or attenuate it. However, this signal is both spectrally and temporally variable, and appears to be related to the structural attributes of terrestrial surfaces such as leaf area index, leaf angle distribution, and soil brightness and roughness [2,3,4,5]. Thus, it is reasonable to expect that the additional information contained in the bidirectional signal should be useful in improving either global classification schemes or biophysical parameter retrieval from satellite remote sensing systems.

In this study, we have used aircraft bidirectional data at full spatial resolution and "degraded" to satellite resolution to examine the variability of the BRDF with landscape components of the West Central Super Site (WCSS) of the Hydrologic and Atmospheric Pilot Experiment (HAPEX-Sahel) [6] near Niamey, Niger. Specific objectives were to: 1) examine the variability of principal plane reflectance trends as a function of land cover, 2) assess the performance of a simple empirical model in describing these trends, and 3) determine if the BRDF of lower spatial resolution imagery could be described by a linear function of the higher resolution BRDFs.

DATA AND METHODS

The Advanced Solid-State Array Spectroradiometer (ASAS) [7] was used to collect airborne multidirectional, multispectral data in the solar principal plane over the HAPEX WCSS from an altitude of approximately 4750 m above ground level on September 3, 1992. The solar zenith angle at the time of measurement was 36° and the ground-measured aerosol optical thickness at 550 nm was 0.237. For HAPEX, ASAS provided spectral data for 62 spectral bands centered from 420 nm to 1037 nm and for 10 view zenith angles (70, 60, 45, 30, and 15 degrees forward along track, nadir, and 15, 30, 45, and 55 degrees aft). Because several spectral bands were significantly affected by instrument noise, only data for 33 spectral bands, from approximately 505 nm to 841 nm, were used. Imagery for 7 out of the 10 view zenith angles was available for this data set. The nadir spatial resolution was approximately 3.2 by 3 meters covering 1.5 by 1.1 Km for the full image.

The ASAS off-nadir imagery were co-registered to within one pixel to the nadir imagery through the use of ground control points and a nearest neighbor resampling routine. Principal component analysis of the nadir spectral data was performed to reduce the spectral information from the 33 useable bands to 10 principle components channels which were used in an unsupervised classification. Six distinct land cover classes were identified on the classified imagery as old age fallow/bushland, intermediate age fallow, young age fallow/grassland, bare laterite/continental terminal deposits, bare dark soil/sparse millet and bare sandy soil/sparse millet. The classes represented approximately 12, 29, 19, 5, 13 and 23 percent, respectively, of the whole image.

Mean and standard deviations for spectral digital counts were extracted from each view angle image for the 33 spectral bands, for each land cover class, and for the entire image. Radiometric resolution factors which were supplied with the data were used to calculate at-sensor radiance values in $W/m^2/\mu m/sr$. The radiances were input to the 6S radiative transfer model [8] with a tropical standard atmosphere, a continental aerosol model, and the ground-measured aerosol optical thickness to obtain atmospherically corrected at-ground bidirectional factors. A simple empirical BRDF model [5] was then fitted to the signatures for each cover type and the coefficients were retained for analysis. This model describes the Bidirectional Reflectance Factor (BRF) at a particular view direction as:

$$BRF = a\theta_v^2 + b\theta_v \cos(\phi_v) + c \quad (1)$$

where θ_v is the view zenith angle in radians, ϕ_v is the relative view azimuth angle and a, b, c are coefficients derived through least-squares regression analysis. Briefly, the a coefficient describes the general curvature of the BRDF, b provides a linear dependence on view zenith which interacts with the first term to fit more variable surface shapes, and c is the minimum reflectance for the particular BRDF [4,5].

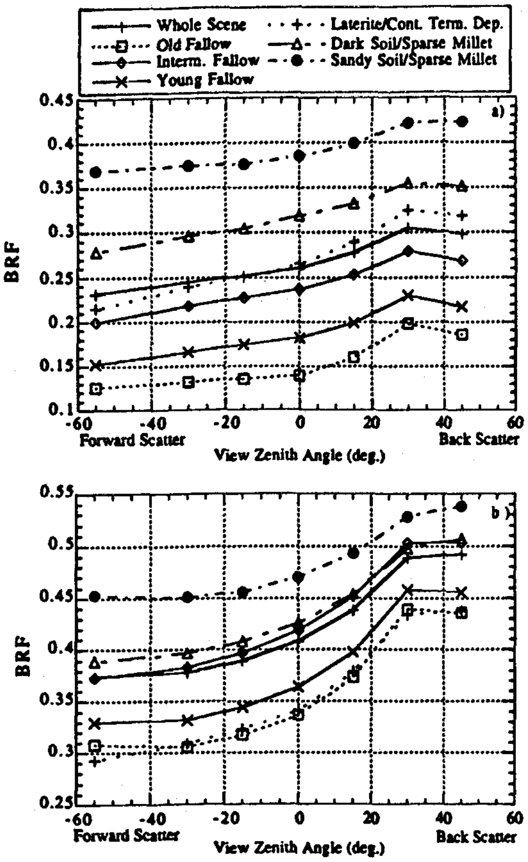

Fig. 1) ASAS Bidirectional Reflectance Factors (BRF) as a function of view zenith angle at: a) 676 nm and b) 800 nm.

RESULTS AND DISCUSSION

Fig. 1a and 1b show the BRFs for each of the land cover classes and for the whole image as a function of view zenith angle for ASAS spectral bands 27 (676 nm) and 39 (800 nm). The trends here are consistent with results seen in other soil-dominated canopies at similar illumination angles: strong back scattering peak values decreasing to minimum values in the extreme forward scatter direction [2]. These trends are mainly associated with viewing a greater proportion of shadows as the view zenith angle moves towards the forward scattering direction [2]. Also, the BRFs for each cover type are distributed about those for the whole scene, indicating that the full scene BRFs may be a combination of the sub-scene BRFs. A cursory examination of these plots also reveals that the curvatures for the BRFs are greater in the near-infrared (NIR) than in the visible wavelengths.

After application of eq. (1) to the curves for each spectral band, we have a quantitative way of describing this curvature, shown in Fig. 2a-2c. In general, the performance of the model in fitting and describing the trends associated with each of the BRDF distributions was very good, with a minimum r^2 value of 0.87 for the old fallow class at 697 nm. The a coefficients of the model, describing the general curvature of the BRDF, increased from negative values at 505 nm, meaning a convex curvature, to greater positive values, with concave curvatures, in the near-infrared (Fig. 2a). The a values for the old fallow class were the greatest for almost all the spectral bands, indicating an influence of the denser vegetation cover present for this class, a trend also seen in [4]. The bare sandy soil/sparse millet class also had large values of this coefficient in the visible but not as great in the near-infrared as the old fallow or young fallow classes. The a coefficients for the other classes generally showed little change over the visible or near-infrared wavelengths but were more variable in the NIR portion of the spectrum.

The b coefficients increased almost linearly with wavelength for all classes, indicating that the difference between the backscattering peak and the minimum value in the forward direction was greater in the NIR than in the

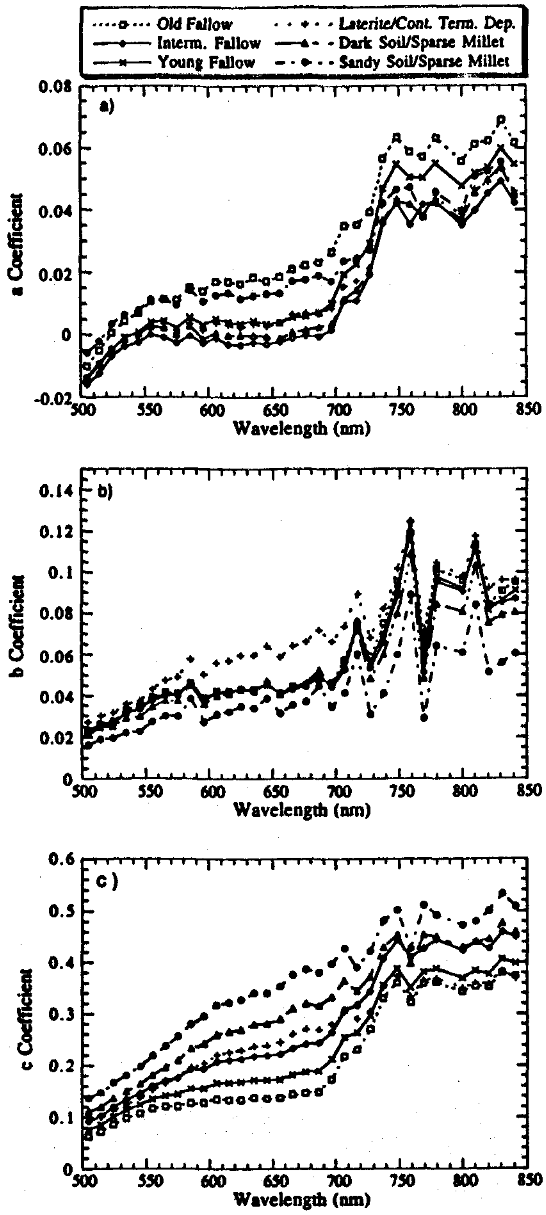

Fig. 2a,b,c) The three coefficients of eq. (1) vs. wavelength.

visible (Fig. 2b). The bare laterite/continental terminal deposits class was found to have the most "extreme" BRDF. The bare sandy soil /sparse millet class had the smallest b values for all wavelengths, presumably because of the strong multiple scattering by the soil particles and the large overall reflectance values at all view zenith angles. A more thorough analysis of this coefficient is currently ongoing.

Fig. 2c shows the minimum reflectances for each distribution (c coefficient) which were found for all classes

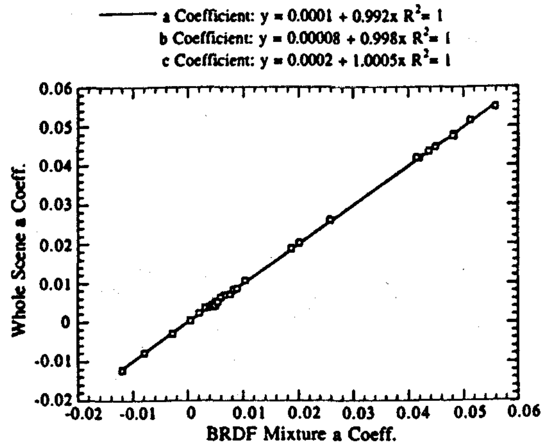

Fig. 3) The a coefficient for the whole scene vs. The a coefficient for a linear mixture model of subscene a coefficients. Also included are linear regression equations for all three coefficients.

and for this 36 degree illumination angle to be typically at 30 or 55 degrees in the forward scattering direction. These curves also show the strong effect of soil background materials for the reflectance factors of each of the land cover classes represented here, even for the more vegetated fallow classes.

Finally, we compared the coefficients for the whole scene with a linear mixture model of the coefficients for the land cover classes such that:

$$W = \sum_{i=1}^{6} p_i k_i \qquad (2)$$

where W is the a, b or c coefficient for the whole scene, p_i is the area percentage of each cover class (i) and K_i is the a, b or c coefficient for each cover class. These show very strong agreement for all three coefficients (Fig. 3), suggesting that bidirectional signals at the coarse scale are a mixture of those at the finer scale, and that this relationship is nearly perfectly linear.

CONCLUSIONS

The results from this analysis indicate that: 1) the bidirectional signal of different land cover types is variable both spectrally and spatially, 2) these signals are well described by a simple empirical model, 3) the signal for the whole scene, as described by the coefficients from the simple model, appear to be a mixture of the signals for each of the land cover classes, as described by the same coefficients. However, a more rigorous test of the mixture model approach using two independent data sets such as ASAS at two altitudes over a target is required.

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