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BIDIRECTIONAL REFLECTANCES OF THREE SOIL SURFACES AND THEIR CHARACTERIZATION THROUGH MODEL INVERSION

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ABSTRACT

Spectral bidirectional reflectances were measured over three natural soil sites using a specially designed radiometer called the PARABOLA. Two of the sites were bare soils and the third had a sparse cover of desert scrub. The reflectances were strongly non-Lambertian for all three surfaces but with markedly different patterns. The measured data were fitted with a quasi-physical reflectance model in which the surface backscattering and forwardscattering are separately formulated. A soil reflectance characterization was obtained by assessing the contributions of the forward, backward and Lambertian components. This three-parameter characterization produced a satisfactory fit to the measured reflectances, and appears promising to provide a basis for soils categorization.

KEYWORDS: bidirectional reflectance, modeling, anisotropy, soil

INTRODUCTION

A unique two-axis scanning-head field radiometer, called the PARABOLA (Deering and Leone, 1986), has been used to measure the directional incoming and outgoing spectral radiances for a variety of earth surface types. Our study involves characterizing the bidirectional reflectances for three relatively simple surface types: two bare soils and a third surface with soil similar to one of the bare soils but with a sparse plant canopy. We then express the bidirectional reflectance patterns in terms of three soil reflectance components from inversion of a quasi-physical model. The goal herein is 1) to evaluate and characterize the nature of the bidirectional reflectance variations and 2) develop an approach to simple radiometric surface categorization for soils, both bare and with sparse vegetation.

SITE CHARACTERISTICS AND FIELD INSTRUMENTATION

The two bare soil surfaces studied are a naturally occurring dune sand and an alkali

flat in the White Sands desert (<250 mm annual precipitation) of New Mexico. A dune sand flat, whose surface is composed of sand-sized, nearly pure gypsum (hydrous calcium sulfate) crystals and is characterized by uniform ripples formed by wind action, was selected for the measurements (Fig. 1a and 1b). These ripples are, in effect, transverse "micro-dunes", which averaged approximately 10 cm from crest to crest and approximately 1-2 cm from crest to trough.

The alkali flat examined occurs within a vast non-vegetated expanse (32 km long) of the Tularosa Basin along the predominantly windward side of the White Sands dune formation. The alkali (or gypsum) flat's surface microtopography is coarse-textured and is composed of a stabilized crust with patches of a darker coloration.

The third surface type is a low-scrub community that lies within a semidesert grassland area in Ward County in west Texas (Fig. 1c). With a long history of overgrazing, the vegetation cover consisted primarily of scattered clumps of a low growing Rough Coldenia subshrub species (*Coldenia hispidissima*) mixed with several other scrub species and grasses of a similar stature. The 10-15 cm tall, grayish-woody shrub had some green leaves and the vegetative clumps occupied less than 15 percent of the surface area.

The Portable Apparatus for Rapid Acquisition of Bidirectional Observations of the Land and Atmosphere, or PARABOLA instrument has been described in detail by Deering and Leone (1986). The PARABOLA is a battery-powered, two-axis scanning head three-channel (0.650-0.670, 0.810-0.840, and 1.620-1.690 μm , respectively), motor-driven radiometer that enables the acquisition of radiance data for almost the complete (4π) sky- and ground-looking hemispheres in 15° instantaneous field-of-view (IFOV) sectors in only 11 s. The instrument was operated at 4.5 m above the ground surface.

THE SURFACE BIDIRECTIONAL REFLECTANCE MODEL

The bidirectional reflectance model specifies separately the contribution of the soil and from the plants. The reflectance of bare soil, R_s , is given as:

$$R_g = (1-f) \frac{r(\sin z - z \cos z) + t[(z-\pi)\cos(z-\pi) - \sin(z-\pi)]}{4(\cot\theta_o + \cot\theta_v)} + fr_o \quad (1)$$

where z is the azimuth with respect to the solar principal plane ($z = 0$ corresponds to forwardscattering in the principal plane), θ_o is the solar zenith angle and θ_v is the view zenith angle. The model is quasi-physical, as it describes a surface consisting of a Lambertian fraction, f , with reflectance r_o and a

predominant in backscattering, while the transmittance is predominant in forwardscattering. R_g represents the reflection from the soil unobscured by plants. The soil characterization is by three components: fr_o , $(1-f)r$ and $(1-f)t$.

The contribution of the plants is described by the same model of vertical cylinders or randomly oriented facets

$$R_p = \frac{r_p(\sin z - z \cos z)}{4(\cot\theta_o + \cot\theta_v)} \quad (2)$$

where r_p is the plant material reflectance. This model (Otterman and Weiss, 1984) was based on observations of desert-scrub vegetation in the Sinai (Otterman, 1981). The above expression for R_p represents a dense field of vertical cylinders. For a finite density, given by projections of cylinders per unit area on a vertical plane, the contribution is multiplied by $1 - \exp[-s(\tan\theta_o + \tan\theta_v)]$. The effects of soil obscuration and soil shadowing by the plants are expressed by $\exp[-s(\tan\theta_o + \tan\theta_v)]$. The combined reflectance R_c of plants/soil is thus:

$$R_c = R_g \{\exp[-s(\tan\theta_o + \tan\theta_v)]\} + R_p \{1 - \exp[-s(\tan\theta_o + \tan\theta_v)]\} \quad (3)$$

RESULTS

Reflectance Measurements

The measured bidirectional reflectances are presented in Figure 2. The patterns are quite different for the three soil surfaces, with the backscattering predominant for the alkali flat and for the desert scrub, but forwardscattering is dominant for the dune sand flat. There is considerable solar zenith angle dependence for the dune flat in the forwardscatter direction. For the desert scrub the solar zenith angle dependence is especially pronounced in the backscatter direction at large viewing zenith angles. Because the measurements at the White Sands were made in November, the range of solar zenith angles available was quite limited; theoretically, from 90° up to a solar noon position of about 52° . Measurements at the Texas site on September 14, however, were possible up to 29° .

The near-infrared ($0.826 \mu\text{m}$) reflectances (not presented here) followed, for all three surface types, very similar patterns of anisotropy to those in the red band, with typically 5-10% higher (absolute) values than the red reflectances. The shortwave infrared ($1.658 \mu\text{m}$) reflectances, on the other hand, were generally 10-20% lower (absolute) and exhibited somewhat stronger anisotropy than the red band.

Model Results

The quasi-physical bidirectional reflectance model specifies separately the contribu-

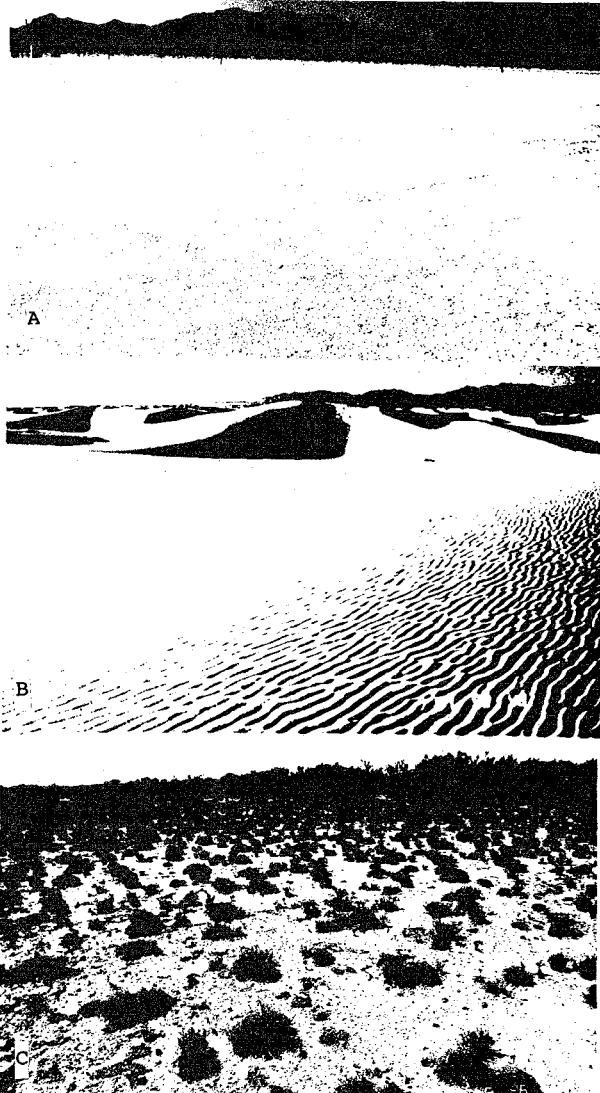


Figure 1. Photographs of the three alkali soil sites examined: a) alkali flat, b) dune sand flat and c) desert scrub site.

fraction $1-f$ of randomly-located vertical facets with facet-reflectance r and facet transmittance t . The reflection from such facets is equivalent to that from thin vertical cylinders, as described by Otterman and Weiss (1984). The facet reflectance is

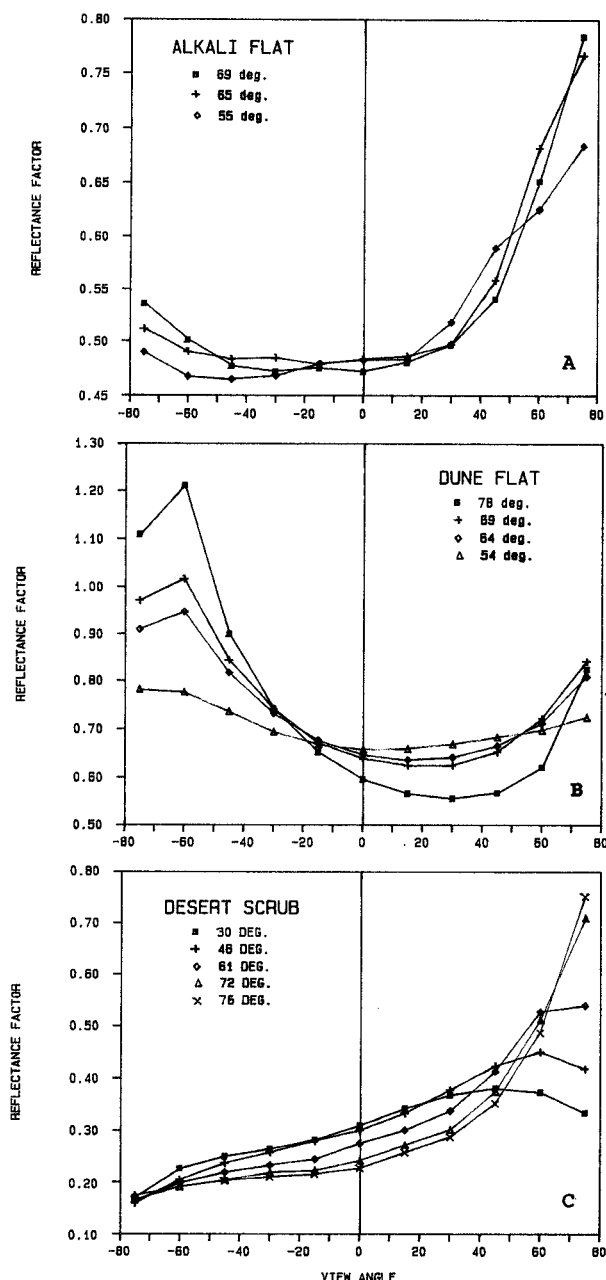


Figure 2. Red spectral band ($0.662\mu\text{m}$) reflectances in the solar principal plane at several solar zeniths for the alkali flat (a), dune sand flat (b), and the desert scrub (c) surfaces. Negative view angles are forwardscatter.

tion from the soil and from the plants. The enhanced anisotropy (both forwardscattering and backscattering) at large solar zenith angles that we observed is appropriately described by our model by $\cot \theta_0$ that appears in the denominator. The parameter values presented in Table 1 quantify the essential differences between the three surface types in terms of the Lambertian, backscatter, and

forwardscatter model components. The Lambertian component values for the alkali flat, dune sand and desert scrub surfaces remain essentially unchanged with solar zenith angles

Table I. Model inversion for each of the three soil surfaces made with approximately 55 observations from all view zenith angles $<70^\circ$ on one side of the solar principal plane, including the solar principal plane.

θ°	fr.	(1-f)r	(1-f)t
DUNE SAND FLAT			
69°	0.62	0.14	0.32
54°	0.64	0.09	0.19
ALKALI FLAT			
69°	0.41	0.26	0.09
55°	0.44	0.30	0.05
DESERT SCRUB			
72°	0.29	0.62	0.06
46°	0.31	0.59	0.00

and typify the general magnitude of the reflectances at nadir. Thus, at the higher sun elevation examined the dune sand had the highest value at 0.64, the alkali flat was somewhat less at 0.44 and the desert scrub was the lowest at 0.31. The consistency of these three parameter values over a wide range of solar zenith angles is illustrated for the desert scrub type in Table 2 for both the red and near-infrared spectral bands.

The ratio of the backscattering component to the forwardscattering component is one indicator of the anisotropy. For the desert scrub the backscatter was larger than the forwardscatter by at least a factor of ten

Table II. Model inversion for the desert scrub surface over a wide range of solar zenith angles for the red and near-infrared spectral bands.

θ°	fr.	(1-f)r	(1-f)t	s
0.662 μm (RED)				
29.9°	.31	.56	.00	.155
46.0°	.31	.59	.00	.135
61.0°	.29	.62	.04	.125
72.0°	.29	.62	.06	.120
0.826 μm (NEAR-IR)				
29.9°	.38	.55	.04	.125
46.0°	.39	.62	.02	.125
61.0°	.37	.60	.02	.100
72.0°	.33	.54	.04	.070

over the wide range of solar zeniths examined. The alkali flat ratio was lower and varied with solar zenith angle; with ratio factors of 2.8 and 6.6 for 69° and 55°, respectively. The same ratio for the dune sand, with its strong specular reflectance, resulted in fractional ratio values of 0.43 and 0.47 (69° and 54°, respectively); and thus was much less dependent on solar zenith angle. Red and near-infrared spectral bands yielded similar

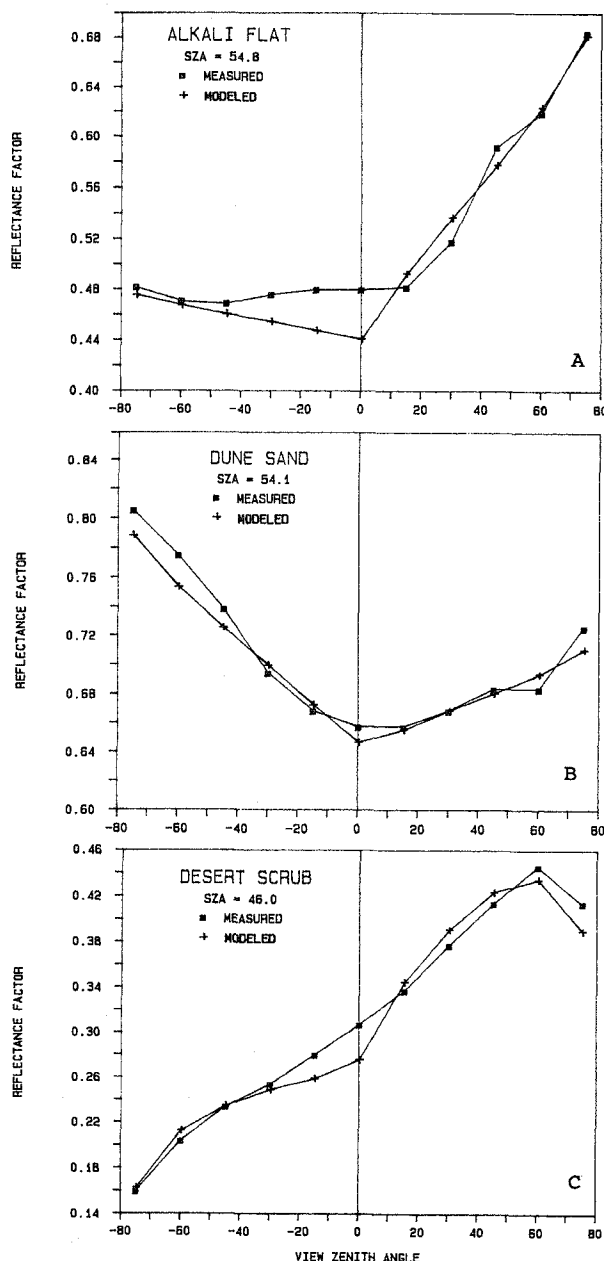


Figure 3. Measured and modeled bidirectional spectral reflectances at $0.662 \mu\text{m}$ for the a) alkali flat, b) dune sand and c) desert scrub surfaces for the nominal 50° solar zenith angle.

ratio values, although the Lambertian component was more variable with solar zenith angle for the near-infrared than for the red spectral band.

The correspondence of model-derived values of red spectral band bidirectional reflectance factors to measured values is presented for the solar principal plane in Figure 3. The curves compare very well for the dune sand and desert scrub surfaces, but show an appreciable deviation from the alkali

flat at the nadir and near-nadir forwardscatter viewing directions. With the considerable variety of curve shapes, the comparability is quite encouraging. Our model appears to provide a simple and very useful descriptive tool for directional reflectance analysis.

DISCUSSION AND CONCLUSIONS

The measured reflectances represented in our field program showed very strong non-Lambertian characteristics. The patterns of directional reflectance were sharply different for the two bare soils. The presence of sparsely placed plants on a relatively smooth soil also exhibits strong anisotropy, with plant shadowing affecting the anisotropy in a special way -- reducing the reflectance at large view zenith angles. For the desert scrub alkali soil site the ratio of the backscattering component to the forwardscattering component was larger by at least a factor of ten. The alkali flat ratio was somewhat lower and depended on solar zenith angle. The same ratio for the dune sand, with its strong specular reflectance, was close to 0.5 and was only slightly dependent on solar zenith angle. Red and near-infrared spectral bands yielded similar ratio values, although the Lambertian component was more variable with solar zenith angle for the near-infrared than for the red spectral band.

With only three surface parameters, the model inversion provides a satisfactory description of the surface spectral reflectance characteristics. The only significant departures from the modeled and the measured reflectances occurred in the vicinity of the nadir direction. Therefore, specifying the three anisotropy components (back scattering, forwardscattering, and Lambertian), appears to be a suitable approach to the characterization of soil type from the point of view of bidirectional reflectance patterns. Some refinement of the model might be appropriate, and additional bare soil and sparsely-covered soil surface measurements will be made to further develop and validate this approach.

One important value of the model is that relatively minor changes in this quantitative characterization occur when the solar zenith angle changes. It is anticipated that based on this characterization useful but simple radiometric surface categorization for soils, both bare and with sparse vegetation, may be developed.

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