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SURFACE SCATTERING PROPERTIES ESTIMATED FROM MODELING AIRBORNE MULTIPLE EMISSION ANGLE REFLECTANCE DATA

E. A. Guinness, R. E. Arvidson, McDonnell Center for the Space Sciences, Department of Earth and Planetary Sciences, Washington University, St. Louis, MO, 63130; and J. R. Irons, Biospheric Sciences Branch, D. J. Harding, Geophysics Branch, both at Goddard Space Flight Center, Greenbelt, MD, 20771.

Photometry has been used extensively to study the physical properties of materials exposed on the surface of planets and asteroids [e.g., 1-3]. A model that is often used in such studies is the Hapke photometric function [4]. The Hapke function has been successfully applied to laboratory bidirectional reflectance data of powdered samples [e.g., 5-6]. However, only a few studies [e.g., 7] have applied the model to terrestrial geological surfaces where the physical properties of the surface can be independently determined. In this study we apply the Hapke function to airborne bidirectional reflectance data collected over three terrestrial surfaces. The objectives of this study are (1) to test the range of natural surfaces that the Hapke model fits and (2) to evaluate model parameters in terms of known surface properties. The data used in this study are multispectral and multiple emission angle data collected during the Geologic Remote Sensing Field Experiment (GRSFE) over a mud-cracked playa, an artificially roughened playa, and a basalt cobble strewn playa at Lunar Lake Playa in Nevada. GRSFE was an experiment in which airborne remote sensing data and associated field measurements were acquired at the same time [8]. The airborne data for this study were acquired by the Advanced Solid-State Array Spectroradiometer (ASAS) instrument [9]. ASAS is a 29 spectral band (0.465 to 0.871 μm) imaging system that flies in the NASA C-130 aircraft. Seven emission angles are collected on each pass varying from 45° forward looking to 45° backward in 15° increments. Two ASAS tracks acquired during the morning of July 17, 1989 were used in this study. For the first track the aircraft flew parallel to Sun direction, which is also known as the principal plane. For the second track the aircraft flew at an azimuth of about 41° away from the principal plane. The phase angles for both tracks ranged from 20° to 97°.

Three 50x50 m sites on Lunar Lake Playa were established for modeling studies. The cobble site consisted of basalt fragments up to several tens of centimeters across sitting on silty playa sediment. The area covered by gravel and cobble size fragments ranged from 20 to 85 percent. The cobble site also contained several bushes up to 1.5 m across and 0.4 m high. The smooth playa site was a natural playa surface consisting of compacted, clay-rich sediment, 20-30 cm wide mud-cracks, a few 2-3 cm size basalt fragments, and one bush about 1 m in diameter. The rough playa site is compositionally the same as the smooth playa site. The rough playa site was artificially disturbed and roughened by driving a vehicle over the site until the playa material was churned up. The roughened surface consisted of loose powder, centimeter size clods of playa sediment, and patches of undisturbed playa. There were 6 bushes ranging from 0.4 to 1 m in diameter on the rough playa site. Radiance factors for each modeling site were computed from the 3 ASAS bands centered at 0.563, 0.649, and 0.693 μm.

Atmospheric contributions to ASAS data were evaluated by comparing ASAS data to radiances computed with the LOWTRAN-7 atmospheric scattering model and to field spectrometer reflectance measurements. LOWTRAN-7 model parameters were chosen such that the model matched optical depth values measured from the ground during the time of ASAS data collection. Optical depths ranged from about 0.06 to 0.15 over the wavelengths of the ASAS bands. The LOWTRAN model was used to predict the radiance reaching ASAS (at an altitude of 5 km above the ground) for a bright and dark surface. The atmospheric model indicates that most of the radiance reaching ASAS is from ground reflection of direct solar irradiance. The direct component comprises 76 to 82 % of the total radiance for the dark surface and comprises 84 to 86 % of the total radiance for the bright surface. There is no significant variation in the diffuse or skylight components as a function of emission angle. Measurements of the rough playa reflectance were made with a Daedalus AA440 Spectrafax field spectrometer at the time of ASAS data acquisition. The Daedalus reflectance was corrected for atmospheric attenuation on the incoming and outgoing paths using an optical depth of 0.06. The difference between the ASAS reflectance value and the corrected Daedalus value is less than the uncertainty in the absolute calibration of ASAS. This result also implies that the diffuse illumination and skylight components are of second order importance. Thus, we used ASAS reflectance data to estimate surface scattering properties without correcting for atmospheric scattering. Caution should be used in interpreting the absolute values of surface scattering parameters because the atmosphere is not fully accounted for. The estimated surface scattering parameters can be used for comparisons between the sites and to evaluate the ability of the Hapke function to model these surfaces.

The Hapke function [4] has at least five independent parameters: single-scattering albedo, average macroscopic surface roughness, width of the opposition effect, magnitude of the opposition effect, and terms defining the single particle phase function. The Henyey-Greenstein scattering function was used to model the particle phase function. The smallest phase angle in the ASAS data set was about 20°. For most materials the opposition effect is best constrained by viewing the surface with smaller phase angles [2, 4]. We found that the model fits to the ASAS data were not significantly changed by varying the two opposition effect parameters. Therefore, we concentrated on estimating the single scattering albedo, roughness parameter, and asymmetry factor of the particle phase function. Hapke parameters were estimated by minimizing the chi-square residual between the data and the Hapke fit. For the cobble and rough playa sites, a set of Hapke parameters was found that explains the variation in reflectance data from both ASAS tracks. Hapke parameters determined for these two sites are listed in Table 1, along with estimated uncertainty in the parameters. For the smooth playa site, a single set of parameters could not be found that explains the variation in ASAS reflectance data from both tracks.

The cobble and rough playa site have systematic differences in all three Hapke parameters. The rough playa site has a larger single scattering albedo than the cobble site at all three wavelengths as would be expected from the high reflectance values from the playa. The relatively high values of single scattering albedo for the cobble site are likely to be because 15 to 80 % of the surface is covered by bright silt and clay playa sediment. The Hapke roughness parameter is larger for the cobble site than for the rough playa site. There is a correlation between the size of the roughness elements and the Hapke roughness parameter for the cobble and rough playa sites, with the roughness elements being larger on the cobble site. There is no large variation in the roughness parameter as a function of wavelength for both sites. The asymmetry factor for the cobble site indicates that the particle phase function for the cobble site is slightly forward scattering. The degree of forward scattering increases with wavelength, which is consistent with trends noted by [11]. The asymmetry factor for the rough playa site is backscattering and shows no systematic variation with wavelength. The values for the rough playa site are consistent with values derived for the Moon [11]. The ASAS data for the smooth playa could not be explained with the Hapke function for the available range in lighting and viewing geometries. No unique set of Hapke parameters was found for the smooth playa ASAS data. Instead, several solutions with large differences in the Hapke parameters were found to produce approximately the same chi-square value. Solutions with near zero roughness, and weakly backscattering phase functions fit as well as solutions with a higher single scattering albedo, higher roughness values, and more strongly backscattering phase functions. ASAS data for the smooth playa show only a small change in reflectance with phase angle. An alternative interpretation for the smooth playa data is that the surface is similar to a Lambertian scatterer over the observed geometries with the reflectance only a function of incidence angle. The difference in reflectance between the two ASAS tracks is consistent with the change in incidence angle between the two tracks.

In summary, ASAS reflectance data for a cobble-strewn surface and an artificially rough playa surface on Lunar Lake Playa can be explained with the Hapke model. The cobble and rough playa sites are distinguishable by the single scattering albedo, which is controlled by material composition; by the roughness parameter, which appears to be controlled by the surface texture and particle size; and the asymmetry factor of the single particle phase function, which is controlled by particle size and shape. A smooth playa surface consisting of compacted, fine-grain particles has reflectance variations that are also distinct from either the cobble site or rough playa site. The smooth playa appears to behave more like a Lambertian surface that cannot be modeled with the Hapke function.

REFERENCES

[1] Helfenstein, P., and J. Veverka, Icarus, 72, 342-357, 1987. [2] Domingue, D., and B. Hapke, Icarus, 78, 330-336, 1989. [3] Arvidson, R., et al., J. Geophys. Res., 94, 1573-1587, 1989. [4] Hapke, B., Icarus, 67, 264-280, 1986. [5] Hapke, B., and E. Wells, J. Geophys. Res., 86, 3055-3060, 1981. [6] Mustard, J., and C. Pieters, Proc. Lunar Planet. Sci. Conf., 17th, Part 2, J. Geophys. Res., 92, Suppl., E617-E626, 1987. [7] Pinty, B., et al., Remote Sens. Environ., 27, 273-288, 1989. [8] Arvidson, R., and D. Evans, Lunar Planet. Sci., XXI, 26-27, 1990. [9] Irons, J., et al., IEEE Trans. Geosci. Remote Sensing, 29, 66-74, 1991.

TABLE 1

Modeling Site	Wavelength (μm)	Single Scattering Albedo		Roughness Parameter (degrees)		Asymmetry Parameter		Chi-square
Cobble Site								
	0.563	0.617	0.001	28.0	1.2	0.045	0.014	0.11
	0.649	0.663	0.009	31.1	1.4	0.074	0.018	0.10
	0.693	0.761	0.008	35.2	1.3	0.184	0.020	0.24
Rough Playa Site								
	0.563	0.854	0.001	20.1	0.1	-0.171	0.001	6.93
	0.649	0.898	0.001	20.4	0.1	-0.194	0.002	2.97
	0.693	0.918	0.001	21.7	0.1	-0.162	0.002	3.89

Note that the second value in the single scattering albedo, roughness parameter, and asymmetry parameter columns is the estimated uncertainty in that parameter.