THE ROUGHNESS OF THE MARTIAN SURFACE: A SCALE DEPENDENT MODEL. M. K. Shepard, E. A. Guinness, and R. E. Arvidson, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130.

In the coming decade, several lander missions to Mars are planned (e.g., MESUR Pathfinder, MESUR). One of the dangers facing planners of these missions is the rough topography observed at both Viking Lander sites. Both landing sites are ubiquitously covered with meter-scale boulders. Objects of this size pose obvious threats to soft landers, especially at Mars where the distance from Earth causes prohibitive time lags between the transmission of commands and feedback from the spacecraft. An obvious solution is to scout for a "smooth" site prior to the landing. However, the best resolutions realizable on current and future missions (i.e., Mars Observer) are on the order of several meters. Even at this scale, boulders of 1-2 meters in size are unresolvable. Additionally, the amount of time and spacecraft resources required to search even a small area of the planet are unrealisitic given other mission objectives. An alternative is to determine the "roughness" of the surface at a subpixel scale using bidirectional reflectance observations. Much larger areas of the planet can be searched and much of the search can easily be automated.

The morphology of the martian plains observed by the Viking Landers is physically simple. The surface is covered with a layer (approximately flat lying) of aeolian sediment from which numerous outcrops of bedrock and boulders protrude. This morphology, while simple, will be difficult to characterize from orbit using traditional bidirectional reflectance models (i.e., Hapke (1)) for two reasons. First, modeling the surface as facets with gaussian or exponential slope distributions is not realistic given the morphology described above. Second, the roughness parameter is an "average" of the roughness at scales ranging from the wavelength of light being scattered to the pixel size of the observation (2). Thus, there is no definite scale of roughness that can be extracted from the Hapke roughness parameter. Using the concepts of geometric and boolean models developed by several workers (3,4,5) we have developed a model for the bidirectional reflectance of a surface morphology comparable to that observed at the Viking Lander sites. The model assumes that the surface is flat layer of sediment partially covered by rock, similar to the model of Christensen (6). The model is capable of extracting the proportion of boulders, a measure of the average boulder aspect ratio, and a quantitative estimate of average boulder size. The reflectance of each pixel is modeled as the linear sum of three endmembers: surface, boulder, and shadow, weighted by the observed fraction of each endmember. The bidirectional reflectance of each endmember is assumed to be Lambertian for simplicity, although more complex functions could be used. The reflectance of a pixel made up of these endmembers is then:

$$r = A_b*r_b + A_s*r_s + A_{sh}*r_{sh} \qquad \text{(eq. 1)}$$

where r is the radiance factor as defined by Hapke (7), A_b is the fractional area of the pixel area covered by boulders, r_b is the radiance factor of the boulder material, A_s and r_s are the corresponding quantities for the surface not covered by boulders or shadows, and A_{sh} and r_{sh} are the values for the area covered by shadow. The sum of the areas is forced to 1.0. Utilizing the work of Strahler and Jupp (6), we derived the following expression for A_s:

$$A_s = \exp -[\ A_m(1+hwr*\tan(i)) + A_m(1+hwr*\tan(e)) - O(i,e,\Delta\o)\ ] \qquad \text{(eq. 2)}$$

where

A_s = fractional area of visible and illuminated surface

$A_m = -\ln(1-A_b)$, here called the model area of boulders

hwr = the height to width ratio of the boulder, e.g., 1.0 for a sphere or cube

i = incidence angle, e = emission angle

$\Delta\phi$ = relative azimuth between incidence and emission vectors

$O(i,e,\Delta\phi)$ = the fractional overlap between viewing and illumination shadows.

Equation (2) assumes that the boulders are randomly placed on the surface and that no two boulders overlap. Assuming values for the radiance factor of the surface, shadows, and boulders, the average height-to-width ratio (hwr) of boulders, and the proportion of the surface covered by boulders, it is possible to solve for the proportion of the surface in shadow and in sunlight from equation (2) and the radiance factor of the pixel from equation (1) for any illumination and viewing geometry. Given a minimum of 2 observations of the same area under different lighting and viewing geometries, it is possible to solve for hwr and A_b simultaneously in a least squares solution. Given observations from at least three more viewing geometries, it is theoretically possible to also solve for r_b, r_s, and r_{sh}. The utility of equation (2) has been confirmed with computer simulated surfaces.

Currently, the model assumes a unimodal distribution of boulders. To determine the average size of the subpixel boulders requires multiple pixels of an area in which each pixel can be assumed to be covered by approximately the same number and size of boulders. Qualitatively, one can reason that the smaller the boulders are with respect to the pixel, the smaller the variance in radiance factor from pixel to pixel. Similarly, the larger the boulder size with respect to the pixel, the greater the interpixel variance. Again, computer simulations confirm this reasoning.

The model was tested on a terrestrial surface analogous to the martian plains - a portion of the Lunar Lake playa, Nevada, approximately half covered by cobble size basalt fragments (8). This area was one of several sites extensively studied during the Geologic Remote Sensing Field Experiment (GRSFE) (8) and was imaged by the Advanced Solid-State Array Spectroradiometer (ASAS) (9). ASAS is an airborne instrument which acquires multiple emission angle observations of the surface and has pixels 4.25 m in size (cross-track). Data were acquired at incidence angles of 17°, 18°, 61°, and 65°. The data considered here were taken at a wavelength of 0.65 μm. The radiance factors of the endmembers were independently known from other ASAS and portable spectrometer measurements. Atmospheric effects were ignored in this study based upon results from earlier work (10). Model results for cobble surface cover are within 10% of the best estimates of surface cover made by ground observations. Additionally, the model indicates that the average basalt cobble size is < 5% of the pixel size and that the average height-to-width ratio (hwr) is < 0.5, both in excellent agreement with ground observations. Current and future work involves applying this model to high resolution images obtained by the Viking orbiters and later by the Mars Observer Camera.

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