SURFACE ROUGHNESS, OPTICAL SHADOWING, AND RADAR BACKSCATTER;

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The topography of natural surfaces at scales of a few meters or less is commonly referred to as roughness. These variations in height and slope, their magnitude, and the changes in structure as a function of scale length are of fundamental importance to interpretation of geologic emplacement regimes and subsequent modification. For most planetary studies and many terrestrial situations, no in situ observations of the ground are available, and remote sensing data are used to infer the nature of the terrain. For optical, infrared, and microwave measurements, surface roughness and its scale-dependence have a large impact on the brightness, polarization, angular scattering properties, and wavelength-dependence of reflected energy. The link between surface roughness and specific remote sensing properties for many types of observations, however, remains elusive. We focus here on the nature of roughness and its scale-dependence for terrestrial rocky surfaces, and the effect of such changes on optical shadowing and radar backscatter.

Topographic Data. In this work, we analyze the roughness behavior of ten lava flow sites on Kilauea Volcano, Hawaii. Topographic profiles at 25-cm horizontal spacing (80-120 m in length) form the basis for the analysis. These ten sites fall within an area of the volcano for which calibrated AIRSAR data have been collected, permiting a direct comparison between roughness statistics and radar echoes at varying incidence angles and polarization [1,2]. Using methods described in [3], we calculated the variogram function for each profile, and found that all sites exhibit self-affine (fractal) properties at horizontal scales below about ~5 m. Fractal dimensions for the sites range from 1.3 to 1.7, which represents significant variability in the distribution of roughness as a function of scale. A fractal dimension of 1.5 corresponds to ordinary Brownian (random-walk) statistics. Parameters such as rms height or rms slope are often used to describe surfaces in radar or optical scattering/shadowing models. These parameters are strongly coupled to the horizontal scale at which they are calculated, leading to confusion in comparing values produced in different field experiments. Self-affine behavior for the variations in surface height means that we can predict the change in rms height or rms slope as a function of scale size, so only one value of the parameter is needed to "anchor" the entire function. Such a two-component descriptor (i.e., rms height at a reference scale and the fractal dimension) may be a more robust method of characterizing natural terrains.

Optical Shadowing. There are an insufficient number of optical observations of the above topographic sites to determine the amount of shadowing present. However, the ability to quantitatively describe the sites using a fractal dimension and rms slope at a given scale allow us to synthesize statistically identical surfaces on a computer. These synthetic surfaces can then be illuminated and viewed from a variety of geometries using ray tracing techniques, thereby providing a way to calculate shadowing functions for these or any other self-affine surfaces. We compared the shadowing functions derived by various authors [4,5,6] to such synthetic surfaces and found that only the Hapke [6] shadowing or S-function accurately predicted the amount of surface in shadow at any given illumination angle. However, the Hapke S-function was only valid for ordinary Brownian surfaces (profile fractal dimension, $D = 1.5$) and the corresponding

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value of the Hapke roughness parameter, $\overline{\theta}$, was given by

$$tan(\overline{\theta}) \approx (0.7)\,tan(\theta_0) \tag{1}$$

where $\tan(\theta_0)$ is the rms slope at the smallest resolvable scale of the synthetic surface. It can be shown that both of these results are consistent with the Hapke [6] model assumptions. Further, it can be demonstrated that equation (1) is consistent with both of the current interpretations of $\overline{\theta}$: (1) as an integral measure of surface roughness [6,7]; and (2) as representative of the roughness at the smallest scales on a planetary surface [8].

Radar Scattering. We compared the radar backscatter strength from the ten sites to their derived topographic statistics. In general, the cross-polarized linear (HV) component provides the simplest measure of diffuse radar scattering, with little contribution from large single-scattering facets or slopes. The AIRSAR system collects data at three radar wavelengths (6, 24, and 68 cm), which permits analysis of the changes in apparent (radar-perceived) roughness with differing length scale. At each wavelength, the HV backscatter cross section scales with the rms height at some reference value (we used 1 m), with a rolloff in echo strength at the highest roughnesses. This rolloff marks the point at which the surface appears entirely diffuse in its scattering properties; further increases in roughness do not affect the angular distribution of echo power. The ratio of echo power between wavelengths is also correlated with rms height, showing that the change in perceived roughness with illuminating wavelength can also be linked to measured surface statistics. Based upon our exploration of wavelength-dependence of radar echoes, we suggest the use of a new composite parameter to describe both topographic and radar roughness - the normalized rms slope, s_{RMS}. Essentially, s_{RMS} is a measure of the rms slope of a surface at the scale of the wavelength or ruler being used. For 24 cm radar, it is the rms slope of the surface measured from 24 cm profiles. We have found that, within the observational uncertainties, the HV backscatter component is directly (although not linearly) proportional to s_{RMS}. This may provide a powerful new way of directly estimating the rms slope of a planetary surface from radar backscatter alone, and a means of comparing radar backscatter from platforms using different wavelengths.

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