The Surface Roughness of the Moon from Diviner Infrared Observations. P. O. Hayne[1], O. Aharonson[1,2], J. L. Bandfield[3], B. T. Greenhagen[4], and D. A. Paige[5], [1]Geological and Planetary Sciences, California Institute of Technology (phayne@gps.caltech.edu), [2]Weizmann Institute of Science, [3]Earth and Space Sciences, Univ. of Washington, [4]NASA – Jet Propulsion Laboratory/Caltech, [5]Earth and Space Sciences, UCLA.

Introduction: Slopes and roughness present a unique record of geologic processes on planetary surfaces, including impact melting and ejecta emplacement, regolith processing, and mare volcanism [1,2]. Recently, Rosenberg et al. [3] presented maps of lunar surface slopes and roughness parameters at a range of scales from ~17 m to 2.7 km using laser ranging data from the Lunar Orbiter Laser Altimeter (LOLA) onboard the Lunar Reconnaissance Orbiter Spacecraft (LRO). Thermal infrared measurements by the Diviner instrument on LRO can also be used to derive slopes on a range of scales, potentially filling in gaps in our knowledge of roughness properties, especially at the smallest scales where steep slopes dominate. We used Diviner measurements to constrain and map surface roughness globally, and examined the properties of two specific geologic features in greater detail: the Reiner Gamma "lunar swirl" and a prominent "Diviner cold spot" surrounding a fresh equatorial impact crater [4].

Methods and Dataset: Because the daytime lunar surface is near radiative equilibrium, slopes effectively determine local temperatures. A distribution of slopes therefore leads to a distribution of temperatures, which we model as a Gaussian characterized by a root-mean-square (RMS) slope [5]. We model the effects of self-shadowing and hard shadows using the statistical functions of [6], and assume a shadow temperature of 150 K, though the results are insensitive to this parameter for daytime temperatures $T > 250$ K.

Diviner measures surface thermal emission in seven spectral channels from ~7 – 400 μm [7], each with a different wavelength of peak sensitivity. A mixture of temperatures within each detector's ~250-m footprint leads to differences in brightness temperatures among the channels ("anisothermality"), which can be inverted using the forward model, to obtain an estimate of RMS slope at the sub-pixel scale. Figure 1 shows the variation in the (channel 3) – (channel 6) brightness temperature difference as a function of RMS slope.

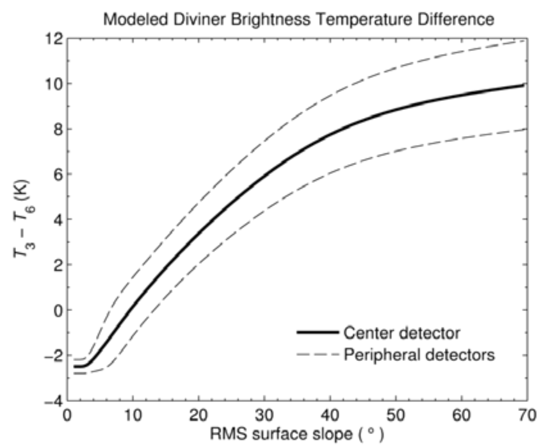
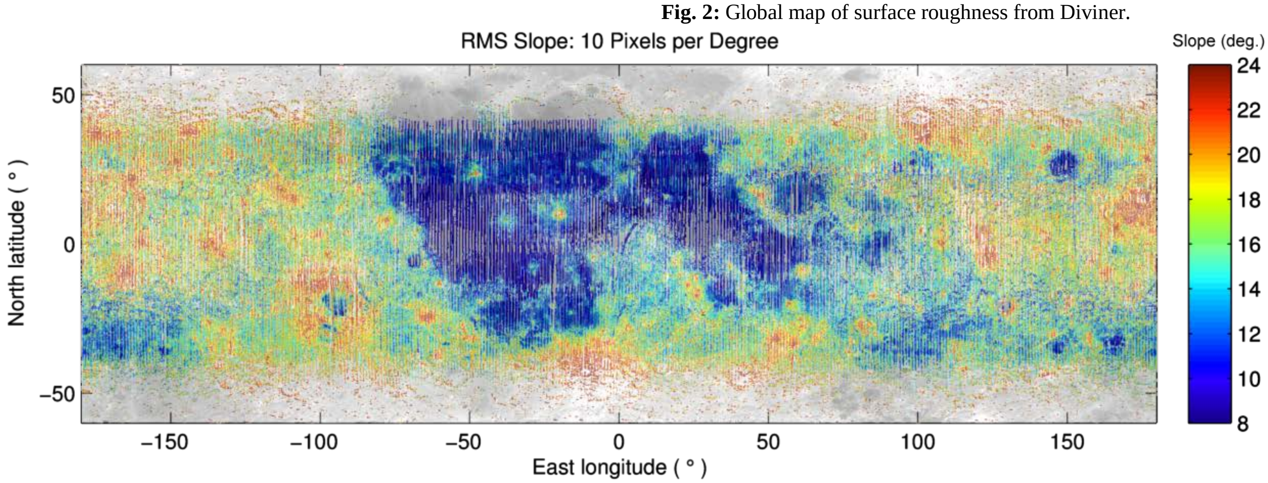


Fig. 1: Simulated Diviner brightness temperature difference as a function of RMS surface slope.

Results: We derived surface slopes for all latitudes between 60°S and 60°N at a scale of 1/10 degree, or ~3 km at the equator, using brightness temperature differences between 7.8 and 13.5 μm (Fig. 2). The usual highlands/maria dichotomy is present, as well as a variety of interesting smaller scale features. Fresh craters are especially prominent, both in the highlands and the maria.

Fig. 2: Global map of surface roughness from Diviner.



The surface roughness statistics for the 3-km spatial scale are shown in Fig. 3. Mode values for RMS slope in the maria (~11°) and highlands (~18°) bracket the peak of the overall distribution (~16°), which is dominated by the rougher highlands terrain by area.

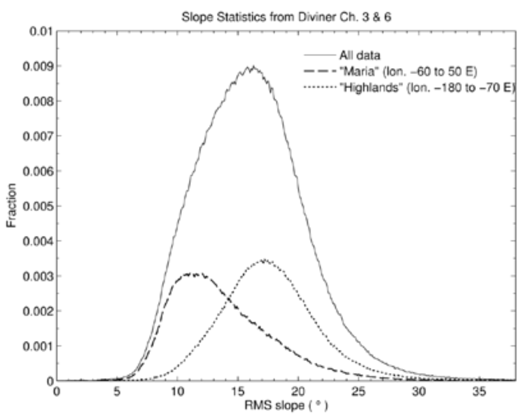


Fig. 3: Distribution of surface roughness (RMS slope) for latitudes ±60°N.

Lunar swirls are anomalous features of ambiguous origin, characterized by high albedo and curvilinear geometry [8], with a distinct composition measured by Diviner [9]. Diviner roughness maps clearly show enhanced surface roughness associated with one of the most prominent of these features, Reiner Gamma, providing an important constraint on its formation mechanism. Compositional constraints suggest deflection of the solar wind by local magnetic anomalies [9], but the roughness enhancement may require an alternative or complementary mechanism.

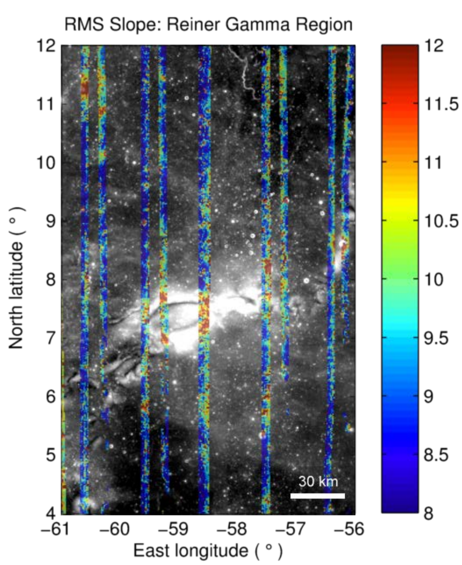


Fig. 4: Reiner Gamma surface roughness with clementine 750-nm albedo (grayscale).

We also investigated the surface roughness within a Diviner "cold spot" – ray-like features of anomalously low thermal inertia surrounding some fresh impact craters [4]. Fig. 5 shows that no significant signature is seen outside of the proximal (blocky) ejecta blanket, though a slight roughness enhancement of ~1-2° RMS is consistent with the data. In fact, another nearby fresh crater (~158°E) shows a much more pronounced roughness enhancement, probably due to rocks and boulders in its own ejecta blanket.

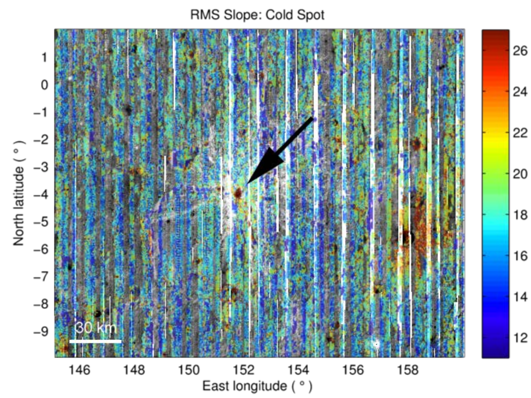


Fig. 5: Surface roughness in the vicinity of a Diviner cold spot surrounding a fresh impact crater (arrow), with Diviner nighttime regolith temperature (inverted grayscale).

Conclusions: At least one lunar swirl (Reiner Gamma) shows a distinct enhancement in surface roughness, which must be reconciled with proposed formation mechanisms. The anomalous thermal behavior of Diviner cold spots, on the other hand, does not appear to be related to surface roughness. Surface roughness maps derived from Diviner data readily distinguish fresh craters (probably due to blocky, unprocessed ejecta), suggesting the potential for dating terrain based on roughness. Finally, the Diviner surface roughness maps will be essential in correcting near-IR spectra for thermal emission, especially as it pertains to mapping the distribution of OH/H_2O on the lunar surface [10].

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