JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, E02001, doi:10.1029/2010JE003716, 2011

Global surface slopes and roughness of the Moon from the Lunar Orbiter Laser Altimeter

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Received 23 August 2010; revised 3 November 2010; accepted 15 November 2010; published 3 February 2011.

[1] The acquisition of new global elevation data from the Lunar Orbiter Laser Altimeter, carried on the Lunar Reconnaissance Orbiter, permits quantification of the surface roughness properties of the Moon at unprecedented scales and resolution. We map lunar surface roughness using a range of parameters: median absolute slope, both directional (along-track) and bidirectional (in two dimensions); median differential slope; and Hurst exponent, over baselines ranging from ~17 m to ~2.7 km. We find that the lunar highlands and the mare plains show vastly different roughness properties, with subtler variations within mare and highlands. Most of the surface exhibits fractal-like behavior, with a single or two different Hurst exponents over the given baseline range; when a transition exists, it typically occurs near the 1 km baseline, indicating a significant characteristic spatial scale for competing surface processes. The Hurst exponent is high within the lunar highlands, with a median value of 0.95, and lower in the maria (with a median value of 0.76). The median differential slope is a powerful tool for discriminating between roughness units and is useful in characterizing, among other things, the ejecta surrounding large basins, particularly Orientale, as well as the ray systems surrounding young, Copernican-age craters. In addition, it allows a quantitative exploration on mare surfaces of the evolution of surface roughness with age.

Citation: Rosenburg, M. A., O. Aharonson, J. W. Head, M. A. Kreslavsky, E. Mazarico, G. A. Neumann, D. E. Smith, M. H. Torrence, and M. T. Zuber (2011), Global surface slopes and roughness of the Moon from the Lunar Orbiter Laser Altimeter, *J. Geophys. Res.*, *116*, E02001, doi:10.1029/2010JE003716.

1. Introduction

[2] As signatures of surface evolution processes acting over geologic time, surface slopes and slope distributions provide important clues to the morphologic history of a planetary surface in terms of both formation and modification mechanisms. Moreover, the comparison of surface regions based on quantitative measures of roughness and its scale dependence is a powerful tool for interpreting the relationships between geologic and topographic units and their origins and has been successfully employed for various planetary bodies, including Earth [e.g., *Morris et al.*, 2008; *Neumann and Forsyth*, 1995; *Smith and Jordan*, 1988], Mars [e.g., *Aharonson et al.*, 2001; *Orosei et al.*, 2003; *Kreslavsky and Head*, 2000], and Venus [e.g., *Sharpton and Head*, 1985]. Attempts to study surface roughness on the Moon have spanned the decades between the Apollo era and the present [*Daniels*, 1963; *Moore and Tyler*, 1973; *Yokota et al.*, 2008], yet to date no comprehensive study of surface slopes and slope distributions has been possible at high resolution and across many scales.

[3] The Lunar Orbiter Laser Altimeter (LOLA) began collecting data in late June 2009, after the successful entry into orbit of the Lunar Reconnaissance Orbiter (LRO) [*Smith et al.*, 2010a; *Zuber et al.*, 2010]. With a ground track configuration consisting of five illuminated spots on the surface arranged in a cross pattern (Figure 1), LOLA allows for determination of slopes at multiple baselines, both between pairs of spots within each laser shot and between sequential shots. The high vertical precision (10 cm), accuracy (~1 m), and high density (~57 m along-track spacing) of LOLA measurements permit an unprecedented opportunity for quantitative morphologic characterization of the lunar surface relevant to current and past surface processes as well as to future lunar landing site selection. For comparison, the Mars Orbital Laser Altimiter operated with a vertical precision of ~1.5 m, a spatial accuracy of ~100 m (including pointing errors), and an along-track spacing of ~300 m [*Smith et al.*, 2001].

2. Topography Data

[4] LRO maintains a nearly circular, 50 km polar orbit that scans all longitudes of the Moon each month. We use

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0148-0227/11/2010JE003716