

Analytical study for multi-scale topographic roughness on airless bodies: estimation for the small-scale features on Phobos

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Surface roughness is a key geomorphological variable describing topography variation with respect to the horizontal scale. Topographic roughness of solar system bodies is a surface remnant that is the result of the evolutionary history of surface regolith environment, and has proven to be a useful tool for geological studies. Simultaneously, topographic roughness is one of the few predominant parameters for remote sensing observations determining optical reflectance (e.g., Hapke 1984), surface thermal emissivity, (e.g., Bandfield et al., 2015), and radar scattering (e.g., Fa et al., 2011). The parametric analysis for multi-scale topographic roughness has been conducted and provides unique knowledge for the remote sensing analysis (e.g., Kreslavsky et al., 2013; Cai & Fa, 2020), however, the roughness of millimeter- to centimeter-scales, which is particularly important when observing the shallow subsurface, remains inaccessible due to limited observational data. Hence, in this study, we conduct an analytical study to estimate the small-scale topographic irregularities on airless bodies from larger-scale surface roughness. We particularly focus on the small-scale topographic roughness on Phobos, which is the target body for JAXA's Martian Moons eXploration (MMX) mission.

We conduct the multi-scale topographic analysis for several airless bodies, which have different gravitational environments. Particularly, we focus on the areas where DTMs of a wide range of scales from mm to km exist and evaluate the scale dependency for the roughness properties. Surface roughness is quantitatively analyzed by the 2D Power Spectral Density and other roughness parameters. The results of the Power Spectral Density analysis show that the topographic features of the lunar millimeter- to centimeter-scale roughness have the same trend for the lunar surface in the meter to 100-meter scales, however, other small bodies have completely different types of spectral density. We also analyze the meter-scale topographic irregularities on Phobos to estimate the small-scale topographic irregularities. Due to the limited resolution of the DTM, we utilize the high-resolution regional DTM on the specific area near the Stickney crater (Takemura et al., 2021). Based on the analysis of scale dependence in other airless bodies, we establish the millimeter-to-centimeter roughness models for the surface of Phobos. This research develops one of the key techniques for the estimation of the small-scale topographic irregularities for remote sensing, and more specifically, leads the safe landing and rover operations for future the MMX mission.

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