TOPOGRAPHIC ROUGHNESS OF THE MOON AT SCALES FROM METER TO HECTOMETER. Yuzhen Cai[1], [1]Institute of Remote Sensing and Geographical Information System, School of Earth and Space Sciences, Peking University, Beijing, China (yzcai@pku.edu.cn).

Introduction: The Moon's surface were mainly shaped by volcanism and impact cratering, and the topography displays a distinct dichotomy between maria and highlands. As a quantitative measure of topographic relief [1], surface roughness is directly related to the geologic evolution of the Moon. Recently, with the release of high-resolution laser altimetry topography data, lunar surface roughness at scales larger than hectometer were extensively studied [2, 3]. These results show that the older cratered highlands are generally rougher than the maria, as evidenced by roughness parameters like bidirectional slope, root-mean-square (RMS) height, Hurst exponent, and differential slope. Surface roughness at kilometer scales is mainly controlled by impact cratering and volcanic processes related with earlier events, whereas hectometer-scale roughness is controlled by small impacts and regolith accumulation [3]. However, surface roughness at small scales (i.e., <~50 m) and its dependence on surface processes is not studied due to the limitation of the resolution in topography data.

In this study, we investigated surface roughness of the Moon at meter to hectometer scales using the Digital Terrain Models (DTMs) from the the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Cameras (NAC). It is expected that surface roughness at meter to hectometer scales can provide important clues of the recent events resurface the Moon, such as regolith accumulation and overturn, space weathering, and rock production and break down.

Data and Methods: LROC NAC DTMs are generated from stereo images processed with photogrammetry software, with spatial resolutions from 2 to 6 m/pixel. The relative vertical precision is 0.5 to 2 times the pixel scale of NAC images, and the absolute accuracy is 2.42 m compared with Lunar Orbiter Laser Altimeter (LOLA) profiles [4]. In this study, we used 397 NAC DTMs that were released by LROC team between June 2015 to July 2017, including 136 within the maria and 261 over the highlands (see Fig. 1 for their distribution). NAC DTM covers latitudinal range of 1–2° and longitudinal range of 0.2–0.4°. For comparison with other planets, we also used meter scale laser altimetry data in Kilauea volcano on Earth and High Resolution Imaging Science Experiment (HiRISE) DTM of Mars.

In roughness mapping, we chose bidirectional slope, RMS height, Hurst exponent, absolute slope, differential slope as roughness parameters, which were used extensively in previous studies [1]. In our calculation, bidirectional slopes are calculated at a baseline of 7 m, window size for RMS height is chosen as 100 ×100 m. Hurst exponent is estimated over baselines ranging form meter to hectometer, and the breakover scale in Hurst exponent estimation is also recorded [2]. These scales are much smaller than those used in previous studies.

Results: For each DTM dataset, we calculated the three roughness parameters and obtained a map for each parameters. Fig. 1 shows the spatial distributions of the median values of bidirectional slope, RMS height, Hurst exponent, and the breakover scale. Bidirectional slope and RMS height over highlands are much larger than those in maria. Bidirectional slopes (Fig. 1a) are generally smaller than 4° over the maria, and vary from 2.6° to 24° for the highlands. RMS height (Fig. 1b) of the maria varies from 0.7 to 2 m, whereas that of the highlands are from 1.2 to 13 m. Median values of the bidirectional slope and RMS height over highlands are ~3 times as large as those of the maria (Table 1). The Hurst exponents over the maria vary from 0.77 to 0.92, and those over the highlands are from 0.75 to 0.93. Median Hurst exponents are 0.9 for both the maria and highlands. Our Hurst exponents are totally different from the Hurst exponent at baselines from hectometer to kilometer, whose median values are 0.76 and 0.95 for the maria and highlands, respectively [2].

We calculate the median absolute slope (MAS) and median differential slope (MDS) at varying baselines. NAC DTMs are used to calculate parameters at baselines 4 m–1 km, and LOLA RDR are used at baselines 0.11 to 100 km. Figure 2a shows that MAS decrease monotonously with the baseline, and the highlands show larger values than maria at all the baselines studied. Figure 2b shows that MDS of the highlands and maria show close values at a baseline of <200 m. The difference of MDS between geologic units becomes larger at baselines larger than 300 m.

Discussions: The different Hurst exponents of the maria indicate that the main geologic processes that form or modify the surface are different [1]. At meter to hectometer scales, the topographic relief might result from the small impact craters. To verify whether the small-scale roughness of lunar surface are affected mainly by small craters, we check the Hurst exponent of two types of terrains: the volcanic landform that has not been modified by impact, and the simulated cratered terrain.

Roughness caused by volcanism: To investigate the topographic roughness caused by volcanism, we compared the Hurst exponents of volcanic plains over Earth, the Moon and Mars. For various types of volcanic plains on Earth, including basalt flow, A'a, pahoehoe, and lake playa, the results show that the median values of Hurst exponents are less than 0.6 at baselines 0.01–10 m [1]. The study region of Mars is located in a young lava vent in Elysium Planitia (1.046°S, 159.745°E). The result shows that the median of Hurst exponent is less than 0.7 at 1–100 m baselines. The volcanic basalts on Earth and young lava vent on Mars have not been modified by impact, and they both show smaller Hurst exponent than lunar maria. We conclude that the Hurst exponents of volcanism features are 0.5–0.7.

The effect of impact craters: We simulate the cratered terrains with age of 1, 2, 3.5 Gyr (Figure 2), and calculate the roughness parameters. The procedure of simulation includes setting up characteristic parameters of the terrain (area, resolution and age) and the craters (number, diameter and generated time) [5,6,7].

Our results show that the bidirectional slope and RMS height show larger values within the older surface, whereas Hurst exponents have no significant difference, with equal median values of 0.88. The simulated terrain and real lunar surface show very close Hurst exponents, which prove that the Hurst exponents of cratered terrain are nearly 0.9. However, the bidirectional slope and RMS height of simulated terrains are a third of those of the real surface. We will try to consider the other meter-scale geologic processes to improve the simulation result.

Conclusions: We calculated topographic roughness of the lunar surface at scales from meter to hectometer using LROC NAC DTM data. Our results show that median values of bidirectional slope and RMS height of highlands are ~3 times larger than those of the maria. The Hurst exponents of maria and highlands are 0.9. The volcanic landforms over Earth and Mars show smaller Hurst exponents than lunar maria, with median values of 0.5–0.7. The simulated cratered terrains with different ages show close Hurst exponent with the real surface. We conclude that at small scales, the surface roughness of both the maria and highlands mainly depends on small impact craters.

References: [1] Shepard M. K. et al. (2001) *JGR, 106*, 32777–32795. [2] Rosenburg M. A. et al. (2011) *JGR-Planets*, *116*, E02001. [3] Kreslavsky M. A. et al. (2013) *Icarus*, *226*, 52–66. [4] Henriksen M. R. (2017) *Icarus*, *283,* 122–137. [5] Neukum G. (2001) *PSS*, *49*, 1507–1521. [6] Basilevsky A. T. (1976) *7th LSC*, 1006–1020. [7] Fassett C. I. and Thomson B. J. (2014) *JGR-Planets*, *119*, 2255–2271.

Table 1. Meter to hectometer scale topographic roughness statistics for lunar maria and highlands[a].

Geologic Units	Bidirectional slope (deg.)	RMS height (m)	Hurst exponent	Beakpoint scale (m)
Maria	$3.05^{+4.3}_{-2.36}$	$1.28^{+1.95}_{-1.01}$	$0.90^{+0.91}_{-0.88}$	84^{+186}_{-45}
Highlands	$8.12^{+10.46}_{-5.82}$	$3.98^{+5.24}_{-2.79}$	$0.90^{+0.91}_{-0.87}$	460^{+760}_{-220}

[a]Median values are given with 25% (after -) and 75% (after +) percentile points.

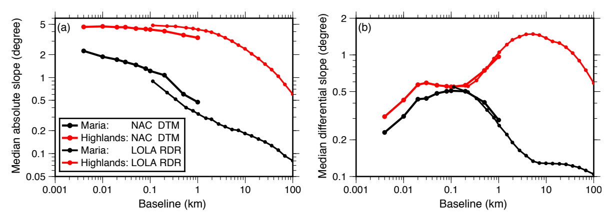

Figure 2. (a) Median absolute slope and (b) median differential slope for lunar maria and highlands.

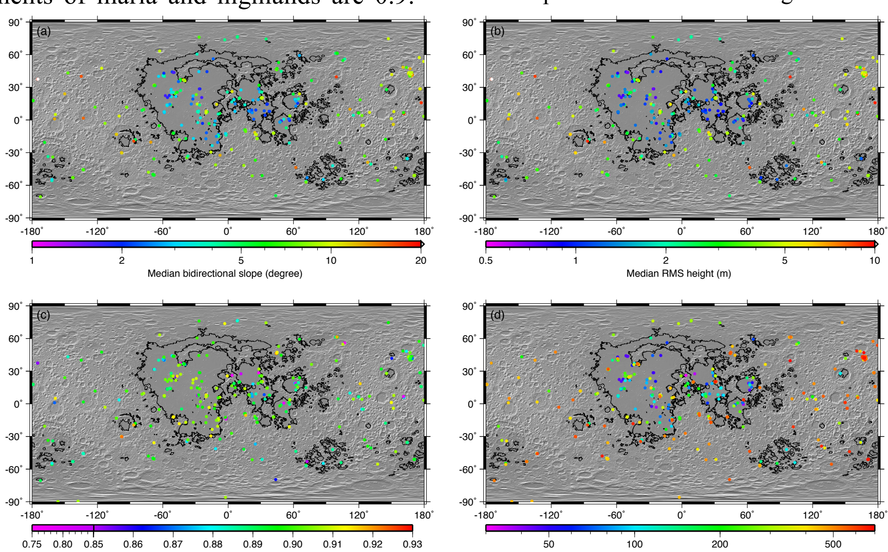

Figure 1. Median values of roughness parameters across the lunar surface: (a) bidirectional slope, (b) RMS height, (c) Hurst exponents, and (d) breakover scale.