

**INVESTIGATING LUNAR 2-DIMENSIONAL TOPOGRAPHIC PROPERTIES AT DIFFERENT SPATIAL SCALES USING LUNAR ORBITER LASER ALTIMETER DATA AND THE WAVELET LEADERS METHOD.** M. Lemelin<sup>1,2</sup>, M. Daly<sup>1</sup>, and A. Delière<sup>3</sup>, <sup>1</sup>Center for Research in Earth and Space Science, York University, 4700 Keele St, Toronto, On, Canada M3J 1P3, lemelin@yorku.ca, <sup>2</sup>Département de Géomatique appliquée, Université de Sherbrooke, Canada, <sup>3</sup>Department of Electrical Engineering & Computer Science, University of Liège, Belgium.

**Introduction:** The roughness of planetary bodies are commonly studied to identify smooth surfaces that would be the best landing sites candidates or to identify the geophysical processes that shaped these bodies. The Wavelet Leaders Method (WLM) is a method that allows the characterization of surface roughness both spatially and in frequency, unlike most other approaches which focus on either the former or the latter. The roughness characterization can be done in 1D using either lines of latitude or lines of longitude of data to provide information on them, or in 2D using a local spatial analysis centered on each pixel, and thus providing a more thorough analysis. The WLM allows the identification of (1) scaling regimes, (2) the mono- or multifractal behavior of the surface, and (3) the value of the Hölder exponent.

The WLM has been rarely used in a planetary science context. It has been used to characterize the roughness of Mars in 1D and in 2D using Mars Orbiter Laser Altimeter (MOLA) gridded data in [1]. It has also been used in [2] to characterize the roughness of the Moon in 1D using the Lunar Orbiter laser Altimeter (LOLA) gridded data. The 1D and 2D roughness characterization of Mars allowed the identification of a scale break, a change in the geological processes that shape the surface (e.g., craterisation), at approximately 15 km, and thus suggests that Mars has 2 scaling regimes [1]. The 2D characterization in turn exhibits the link between the scaling exponents resulting from the WLM and famous features of the Martian topography such as the smooth northern hemisphere, Hellas Planitia and Solis Planum. The results from the 1D analysis are in agreement with the results using other approaches [e.g., 3-4], while the 2D characterization of Mars was the first of its kind.

Lemelin et al. [2] used the gridded LOLA data and the WLM to characterize the 1D roughness of the Moon. They found that scale breaks occur most often at spatial resolutions of approximately 659 m/pixel, 84 km/pixel and 2,700 km/pixel, and thus that three scaling regimes are generally present at the discrete scales they investigated: 165-659 m/pixel, 1-84 km/pixel, and 169-2,700 km/pixel. The smallest scaling regime is consistent with [5] who found that, within the baselines they investigated (~17 m to ~2.7 km), competing surface processes mostly occur near 1 km. The two larger scaling regimes have not been studied previously. Lemelin et al. [2] hypothesized that the intermediate scaling regime (1-84 km/pixel) is characterized by the formation of simple and complex craters, whereas the largest scaling regime

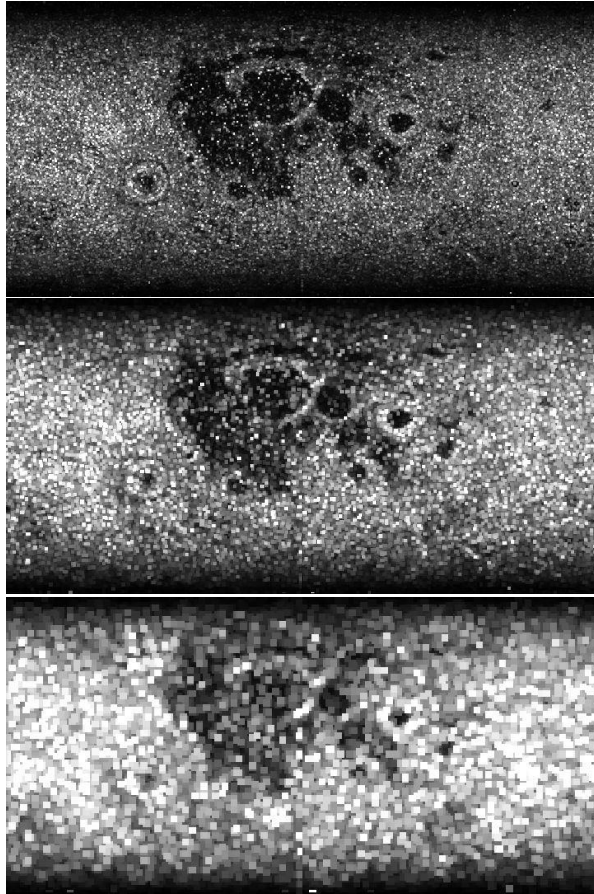
(169-2,700 km/pixel) is characterized by the formation of impact basins. At all latitudes the smallest scaling regime has a multifractal behavior, while the intermediate scaling regime has a monofractal behavior. The largest scaling regime has a multifractal behavior in the maria, and a monofractal behavior in the South Pole-Aitken basin.

In this study, we use the WLM to study the roughness of the Moon in 2D using gridded topographic data from LOLA. We first identify the scaling regimes present in the data. The fractal behavior and the Hölder exponents will be studied next.

**Dataset:** We used gridded topographic data from LOLA projected in a simple cylindrical projection (PDS3, V1.05) at 1024 ppd (or ~30 m/pixel). We downloaded individual tiles of 15° in latitude by 30° in longitude to obtain data for the whole globe, for a total of 368,640 by 184,320 pixels. As the WLM uses data of size  $2^x$  as input, we downsampled the global mosaic to 262,144 ( $2^{18}$ ) by 131,072 ( $2^{17}$ ) pixels. This corresponds to a spatial resolution of 728 ppd or ~41 m/pixel.

**Methods:** The wavelet components at various spatial scales for a given pixel are first calculated as follows. The topographic signal of pixel  $i$  and its neighbors at scale  $j$  ( $2^x$  pixels) is compared to the product of the wavelet (H) and scaling (L) coefficients of a 3<sup>rd</sup> order Daubechies wavelet, i.e., four wavelet filters: LL, HH, LH, and HL. Each of these four components have a number of  $2^{x-1}$  pixels. The HH, LH and HL components contain the high-frequency information (analogous to detrended topographic data) and are temporarily set aside for subsequent analysis. The LL component contain the low-frequency information (analogous to the topographic data) which is used as input for the subsequent comparison between the “topographic” data and the four wavelet filters at scale  $j+1$ . This process is done iteratively until there are  $2^0$  pixels left. In this study, we first focus on the analysis of the HH component.

The wavelet “leaders” at each spatial scale are then identified. To do so, the wavelet coefficients obtained at each scale are compared using a dyadic cube; the maximum absolute value of the wavelet coefficient for pixel  $i$  and its surrounding neighbors at scale  $j$  and all finer scales is the wavelet leader value retained for pixel  $i$  at scale  $j$  (Fig.1). The wavelet leaders are then used to identify (1) the scaling regimes, (2) the mono- or multifractal behavior of the surface for each pixel, and (3) their Hölder exponent.



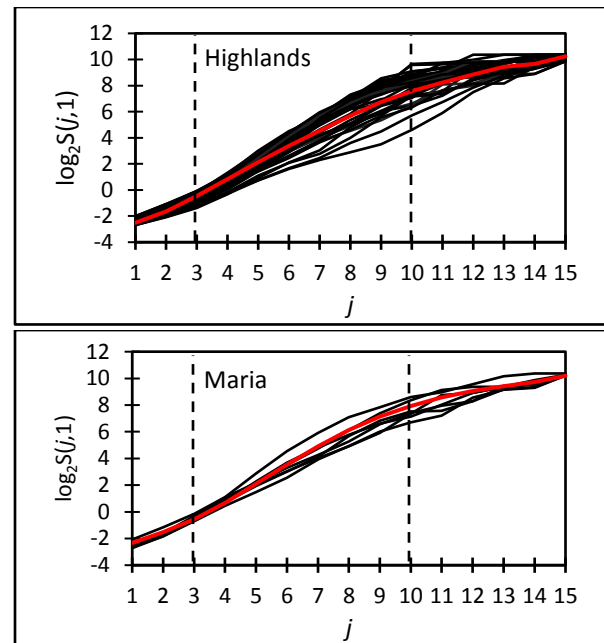
**Figure 1.** Map of the wavelet leader coefficients at different scales ( $j$ ). Top:  $j=8$  ( $2^{10} \times 2^9$  pixels, or  $\sim 11$  km/pixel). Middle:  $j=9$  ( $2^9 \times 2^8$  pixels, or  $\sim 22$  km/pixel). Bottom:  $j=10$  ( $2^8 \times 2^7$  pixels, or  $\sim 43$  km/pixel).

To identify the different scaling regimes, a random sample of 50 pixel was analyzed. For each of these pixels, we plotted  $\log_2 S(j,1)$  versus  $j$  (Fig. 2), and calculated the absolute values of the curvature on that plot, where the highest curvature values represent the likeliest scale breaks.  $S$  represents the structure function and  $j$  the scale [2]. We used the outline of the maria mapped by [6] to determine if a given pixel was located in the highlands or in the maria and investigate if the scale breaks are different for the former of the latter.

**Preliminary results:** Although they are an intermediate product of the method, the wavelet leaders coefficients indicate that the method is indeed sensitive to the roughness as they show different values in the maria versus the highlands. They also indicate that the method is less robust towards the polar region as the gridding process results in pixels having redundant value.

The analysis of the 50 random pixels suggests that scale breaks occur at  $j=3$  and  $j=10$ , in both the highlands and the maria (Fig. 2). While the scale break at the small scales ( $j=3$ ) was consistent for all sample pixels, the

scale break at larger scales varied between  $j=7-12$ , with  $j=10$  being the most frequent. These scale breaks suggest that there are 3 scaling regimes at the discrete scales investigated here:  $j=1-3$  (165-659 m/pixel),  $j=4-10$  (1-84 km/pixel), and  $j \geq 11$  ( $\geq 169$  km/pixel). These scale breaks are consistent with those found previously using the WLM 1D method [2]. The smallest scale break is consistent with the one identified by [5]. However, since the curvature cannot be calculated for  $j=1-2$ ,  $j=3$  is consistent, without surprise, in a local maximum of the function. To confirm the presence of that scale break, a local analysis with a spatial resolution higher than the one used herein ( $\sim 41$  m/pixel) should be conducted.



**Figure 2.** Plot of  $\log_2 S(j,q)$  versus  $j$  (where  $q=1$ ) for 50 random pixels across the surface used to identify the different scaling regimes. Top: 43 pixels were in the highlands. Bottom: 7 pixels were in the maria. The red line represents the average behavior on each plot.

**Future work:** The fractal behavior of the surface for each pixel, and their Hölder exponent value will be analysed next for the three scaling regimes identified. The analysis will then be conducted using all HH, LH and HL components together. This will allow a more robust characterization of the surface roughness.

**References:** [1] Delière A. et al. (2017), *PSS*, 136, 46-58. [2] Lemelin M. et al. (2018), LPSC 49, abstract #1021. [3] Orosei R. et al. (2003) *JGR*, 108, 8023. [4] Kreslavsky M. and Head J. (2000) *JGR*, 105, 26695-26711. [5] Rosenburg M. A. et al. (2011) *JGR*, 116, E02001. [6] Nelson D.M. et al. (2014) LPSC 45, abstract #2861.