

**How reliable are surface roughness estimates from planetary laser altimeter pulse-widths? An assessment using MOLA and LOLA pulse-width data.** W. D. Poole<sup>1</sup>, J.-P. Muller<sup>1</sup> and S. Gupta<sup>2</sup>, <sup>1</sup>University College London – Mullard Space Science Laboratory, Holmbury St. Mary, Dorking, RH5 6NT, UK, <sup>2</sup>Department of Earth Science and Engineering, Imperial College London.

**Introduction:** Pulse-widths from both the Mars Orbiter Laser Altimeter (MOLA) and the Lunar Orbiter Laser Altimeter (LOLA) have been used to derive theoretical relationships between planetary surface roughness and pulse-widths within the laser footprint [1][2]. By studying the surface at LA footprint scales using these pulse-widths it was hoped that surface information could be extracted at significantly finer scales than could be derived using the elevation of each pulse at the pierce-point alone. This would then aid planetary scientists in the selection of landing sites, comparison of surface formation and evolution processes and the calibration of radar scattering.

For each set of pulse-widths, the aim was to establish the baseline at which they are best correlated to surface roughness and slope, and then find the relationship between the pulse-widths and surface roughness and slope. This was done by comparing the pulse-width values to the roughness and slope values, as measured from high-resolution digital terrain models (DTMs), at different baselines. A more reliable global surface roughness map could then be derived for each of the planetary bodies, which would then be available to be used in scaling, and landing site selection studies.

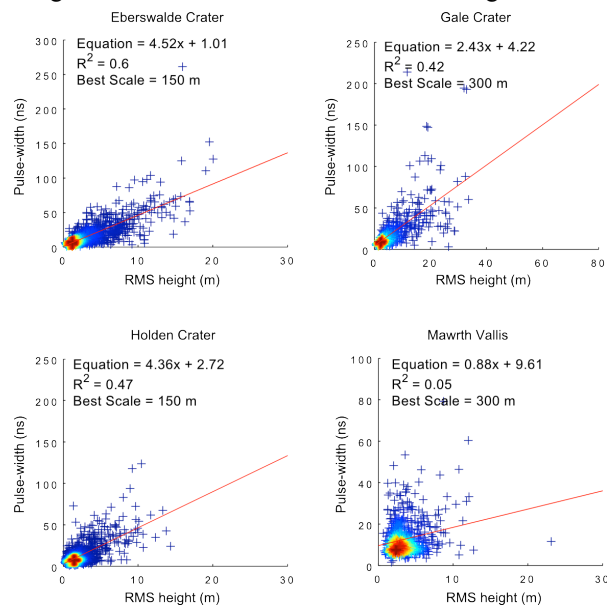
**Methods:** In the case of the MOLA instrument the along-track pulse separation is 300 m, with an average inter-track spacing of 4 km at the equator [3], however the pulse footprint is believed to be  $\approx 150$  m [3], which was later revised to 75 m [1]. The pulse-width data used here is a corrected version derived by [1]. In contrast, the LOLA instrument has a 5 spot (X pattern) laser pulse set-up, with each spot separated by 25 m, and shots spaced 50 m apart in the along-track direction. Inter-track spacings can be over 1 km at the equator. However, the laser pulse is thought to be approximately 5 m in diameter. The LOLA pulse-widths used here come from the LOLA RDR query tool on the Planetary Data System (<http://pds.nasa.gov/>).

The pulse-widths from each of the instruments were compared to surface roughness and slope estimates from high-resolution DTMs. For Mars these DTMs were derived from HiRISE (1 m/pixel) [4] and CTX (18 m/pixel) [5] cameras on board Mars Reconnaissance Orbiter. For the comparison of LOLA pulse-widths, the DTMs used were derived from LROC-NAC images at 2 m/pixel [6]. The DTMs were initially checked for quality through inspection of hillshaded images and checking for the pits and troughs that can

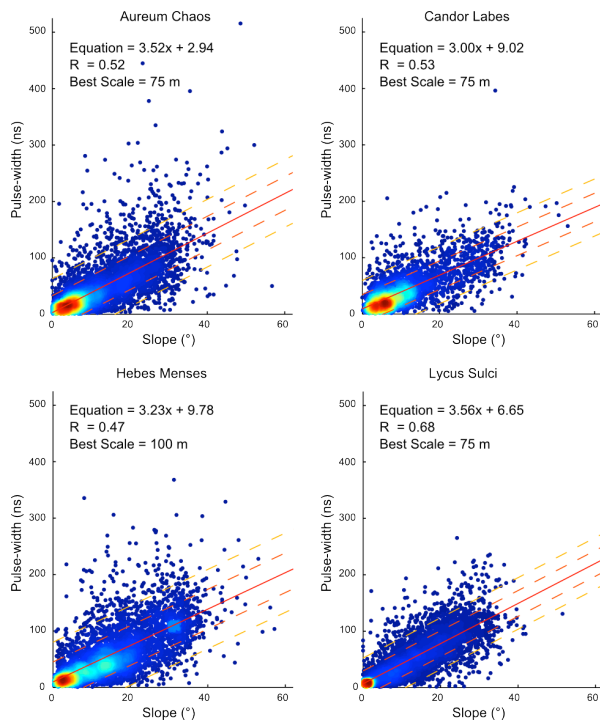
occur during DTM production. Surface roughness and slope maps were then produced at various baselines, from which values were extracted at the pierce point of the pulse and compared to pulse-width values. The baseline at which the pulse-widths best respond for each of the surface characteristics was then found by comparing the R-squared value of the fit of determination of the results from each of the baselines.

Surface roughness maps were produced using RMS height [7], calculated within a circular window with a diameter equal to each of the baselines. The slope maps were produced from DTMs which have been resampled to each of the baselines, and slopes measured from these using the maximum slope between a cell and each of its eight neighbors.

**Results:** Initially, the Mars investigations used the HiRISE DTMs only, as the MOLA pulse-widths were expected to be sensitive enough to respond to features which might pose a problem to landing and roving on a surface, and only the HiRISE DTMs could identify. This investigation focused on the final four candidate landing sites of the NASA Mars Science Laboratory (Curiosity), and are the only locations with sufficiently extensive HiRISE coverage required to collect enough MOLA data points. Only three of the four sites showed reasonable correlations, with pulse-widths over Mawrth Vallis showing no correlation as the individual roughness elements here have low coverage and are



**Figure 1. Results from the final four MSL candidate landing sites using MOLA pulse-widths and HiRISE DTMs.**



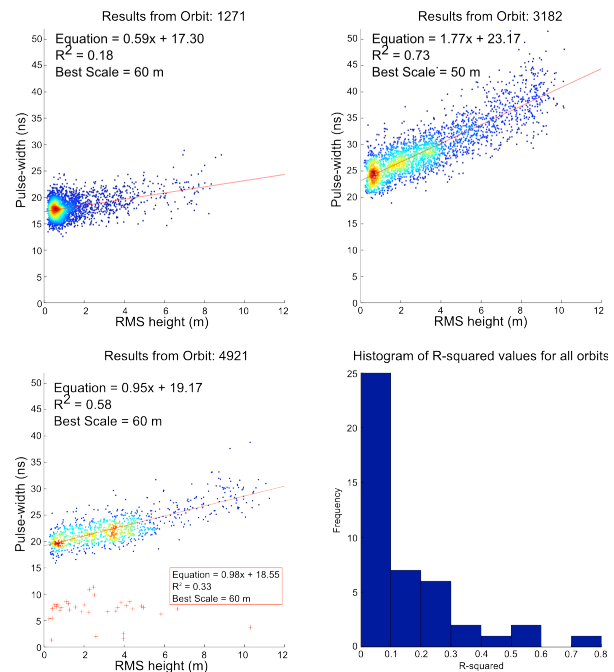
**Figure 2.** Results from very rough Martian terrain comparing MOLA pulse-widths to surface slope from CTX DTMs.

therefore not correctly detected due to the large pulse footprint of MOLA (Fig 1). All sites showed poor correlations between pulse-widths and slope.

In the second part of the investigation, we examined whether MOLA pulse-widths could detect roughness over much rougher terrain (Fig 2). In this case, CTX DTMs were used as these offered extensive coverage in areas with low HiRISE coverage whilst also maintaining a resolution with high enough resolution for reliable comparisons to be made. Chaos terrain, chasmata, and terrain on the NW flank of the Olympus Mons aureole were all analysed. Over rough terrain, the pulse-widths respond to slope as well as roughness, despite being already corrected for 1 km across- and along-track slope. The results from 3 of the 4 sites show that the pulse-widths respond to 75 m baseline slopes, and 300 m baseline surface roughness. The R-squared values are higher than those observed in the initial investigation, and suggest that to correctly calibrate the pulse-widths, rough terrain is required.

The final investigation studied how LOLA pulse-widths responded to surface roughness and slope (Fig. 3). As this instrument is more recent, and the laser footprint considerably smaller, it was expected that this instrument would yield better correlations between pulse-widths and surface roughness and slope, and at baselines useful for landing and roving site selection.

Many of these orbits reveal poor pulse-width values, whilst others reveal similar or, more often, lower



**Figure 3.** Showing a range of plots comparing LOLA pulse-widths and surface roughness for individual orbits from DTMs near Mons Gruithuisen Gamma.

correlations than those from the MOLA investigations. The baselines at which the best correlations occur are significantly larger than the 5 m pulse footprint, whilst slope correction techniques, as used in [1], were also applied to the data without success. The baselines at which the best correlations occur are on the order of 40 to 60 m for surface roughness and 20 m for slope. These baselines are similar to those which can be derived from the 5 spot elevation data. They are therefore not useful for the objectives of landing site selection. As observed here, and other study sites, the LOLA dataset contains many orbits of poor pulse-width data, whilst many of the better orbits are very noisy.

**Conclusions:** (1) These studies show that current planetary laser altimeter pulse-width datasets cannot be used to reliably infer surface roughness at resolutions higher than inter-spot spacings and not at the laser altimeter footprint scale. (2) The fact that MOLA pulse-widths over rough terrain are correlated to 300 m baseline roughness is likely to be due to the contribution from 75 m baseline slopes to surface roughness at baseline, rather than a direct relationship between pulse-widths and roughness at this baseline.

**References:** [1] Neumann *et al.* (2003) *GRL*, 30(11), pp 1561. [2] Smith *et al.* (2010) *GRL* 37, L18204. [3] Smith *et al.* (2001) *JGR* 106(E10), pp 23,689-23,722. [4] McEwen *et al.* (2007) *JGR* 112, E05S02. [5] Malin *et al.* (2007) *JGR* 112, E05S04. [6] Robinson *et al.* (2010) *Space Sci. Revs.* 150, pp 81-124.