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Surface roughness from MOLA backscatter pulse-widths

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Abstract

The time-spread of backscatter laser altimeter pulses, known as pulse-widths, are thought to be capable of being used to infer variations in topography within the footprint of the laser pulse. Here, Mars Orbiter Laser Altimeter (MOLA) pulse-widths have been compared to surface roughness and slope, as measured from high-resolution digital terrain models (DTMs), over different terrains in order to understand how this dataset can be used in the selection of landing and roving sites, and in inferring surface formation and evolution. The results are varied, and suggest that pulse-widths do not respond consistently to variations in terrain. The results show that over Mars Science Laboratory (MSL) candidate landing sites, the pulse-widths can be used as a rough estimate of surface roughness at baselines much larger than the footprint of the pulse. Over much rougher terrain, these pulse-widths respond best to footprint scale slope, which suggests that an additional slope correction for 75 m baselines slopes is required to infer finer scale roughness. However, this is shown not to be the case, as correcting the pulse-widths for 75 m slopes at the MSL candidate sites, and detrending the DTM data, produced poorer results.

1. Introduction

Surface roughness is an important surface property when considering landing site selection, calibration of radar returns, and modelling interactions between the surface and the atmosphere in general circulation models [1]. However, measuring global surface roughness at fine scales using traditional methods involving elevation data is not currently possible given the low DTM coverage (≈38% for HRSC (≥50 m/pixel), <1% for HiRISE (≥1 m/pixel)) [2]. An alternative is to use the time-spread of backscatter laser altimeter pulses which, once corrected for background slope, are thought to provide information of the height variations within the pulse footprint [3, 4]. The MOLA pulse footprint is thought to be ≈75 m, however it is unknown at which baselines the pulse-widths respond to surface roughness and slope [4].

This work explores the relationship between MOLA pulse-widths and surface roughness and slope as measured from high-resolution DTMs, to effectively calibrate the pulse-width data at locations where high-resolution DTMs are available. The work is split into two parts, which varied only in terrain and DTM source: Part 1 studied the final four MSL candidate landing sites using HiRISE data (Eberswalde, Gale, Holden, and Mawrth); Part 2 used much rougher terrain and CTX DTMs (Aureum Chaos, Candor Chasma, Hebes Chasma, and Lycus Sulci). By calibrating this global dataset, it was hoped that more candidate landing and roving sites could be identified as well as potential correlations between surface roughness and geologic features [5].

2 Method

For *Part 1*, HiRISE orthorectified image and DTM data was downloaded from the Planetary Data System (PDS). For *Part 2*, CTX stereo pairs were identified over rough terrain, from which DTMs were produced using ISIS 3 and SOCET SET®, as outlined in [6]. These datasets were then coregistered to HRSC nadir images, which were coregistered to MOLA, following the hierarchal scheme employed by [7].

Surface roughness and slope maps were then produced at different resolutions from the DTM data, where surface roughness is given as:

$$\xi = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(z\left(x_i\right)-\bar{z}\right)^2\right]^{\frac{1}{2}}, \qquad (1)$$

where n is the number of points sampled, $z(x_i)$ is the elevation at point x_i, and $\bar{z}$ is the mean of z of all the sample points within the window. Slope was measured using the maximum slope between a pixel, and its eight neighbours. Slope and roughness values were then extracted from each of the maps at each MOLA pulse location and plotted against pulse-width for each baseline individually. The best correlated baseline for both slope and roughness was then found for each location by identifying the highest R-squared value when fitted with a linear line-of-best-fit.

The MOLA pulse-widths used in this study are from [4]; pulses which are thought to record cloud height, or affected by dust scattering have been removed. The raw pulse-width values have been used, and subsequently corrected for slope, as well as the corrected pulse-widths produced in [4].

3 Results

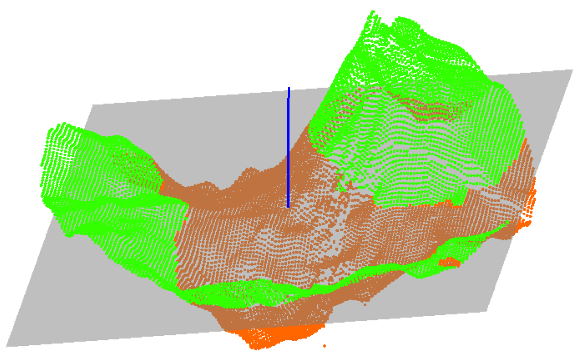

Figure 1: An example of extracted data from within a pulse footprint, with a plane fitted to the data (grey), and the normal to this plane (grey). Data which plots above this plane is shown in green, and below in orange. Part 1 effectively responds to the height variations within a pulse footprint, Part 2 responds to the angle of the plane. The pulse-widths do not respond to surface roughness once the effects of the background slope (i.e. the plane) have been removed.

Part 1: Results showed that MOLA pulse-widths responded to surface roughness at baselines of 150-300 m where roughness features were spatially much larger than the pulse footprint. At these sites, much poorer correlations were observed when pulse-widths were compared to slope. Where this was not the case, like at Mawrth Vallis, no correlation was observed between surface roughness, or slope, and pulse-widths.

Part 2: R-squared values observed over the rougher terrain were similar when pulse-widths were compared to both surface roughness and slope, and were typically larger than observed in *Part 1*. However, the baselines at which the highest R-squared values were observed was very different. The slope baselines were 75-100 m (≈ footprint scale), whereas the surface roughness baselines were 300-400 m, similar to *Part 1*. It is likely that over these terrains, the pulse-widths are actually responding to slopes at 75-100 m baselines, which is affecting surface roughness at much larger baselines, hence the correlation between surface roughness and pulse-widths.

Making additional 75 m baseline slope corrections to the raw pulse-widths over the MSL sites (i.e. applying the findings of *Part 2* to *Part 1*), and detrending the DTM data to remove the effects of the background slope, did not improve the results. Instead the observed R-squared values were much poorer, which suggest that fine scale roughness can not be derived from the MOLA pulse-widths.

4 Conclusion

MOLA pulse-widths have been shown not be capable of estimating fine scale surface roughness. Instead a more complex relationship exists, whereby the response is very much dependent on the scale of the roughness features within the terrain. Where roughness features are small, such as MSL candidate sites, the pulse-widths respond to surface roughness at baselines of 150-300 m. Where roughness elements are much larger, the pulse-widths appear to respond directly to slope at footprint scales (≈75 m), and indirectly to surface roughness at much larger baselines. However, making additional corrections to the pulse-widths to account for this slope did not improve results.

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