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Calibrating Mars Orbiter Laser Altimeter pulse widths at Mars Science Laboratory candidate landing sites

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ABSTRACT

Accurate estimates of surface roughness allow quantitative comparisons between planetary terrains. These comparisons enable us to improve our understanding of commonly occurring surface processes, and develop a more complete analysis of candidate landing and roving sites. A (secondary) science goal of the Mars Orbiter Laser Altimeter was to map surface roughness within the laser footprint using the backscatter pulse-widths of individual pulses at finer scales than can be derived from the elevation profiles. On arrival at the surface, these pulses are thought to have diverged to between 70 and 170 m, corresponding to surface roughness estimates at 35 and 70 m baselines respectively; however, the true baseline and relationship remains unknown. This work compares the Mars Orbiter Laser Altimeter pulse-widths to surface roughness estimates at various baselines from high-resolution digital terrain models at the final four candidate landing sites of Mars Science Laboratory. The objective was to determine the true baseline at which surface roughness can be estimated, and the relationship between the surface roughness and the pulse-widths, to improve the reliability of current global surface roughness estimates from pulse-width maps. The results seem to indicate that pulse-widths from individual shots are an unreliable indicator of surface roughness, and instead, the pulse-widths should be downsampled to indicate regional roughness, with the Slope-Corrected pulse-width dataset performing best. Where Rough Patches are spatially large compared to the footprint of the pulse, pulse-widths can be used as an indicator of surface roughness at baselines of 150–300 m; where these patches are spatially small, as observed at Mawrth Vallis, pulse-widths show no correlation to surface roughness. This suggests that a more complex relationship exists, with varying correlations observed, which appear to be dependent on the distribution of roughness across the sites.

1. Introduction

Accurate estimates of surface roughness allow for quantitative comparisons of surface descriptions leading to improved understanding of formation processes, improved identification of landing site hazards and calibration of radar returns, and more accurate estimates of aerodynamic roughness used in terrain–atmosphere interactions within climate modelling (Heavens et al., 2008; Holt et al., 2008; Kreslavsky and Head, 1999, 2000; Plaut and Garneau, 1999; Shepard et al., 2001). This makes it a useful tool for studying Mars, where quantitative characterisation of terrain can help us unlock the history of surface evolution after drawing comparisons with Earth analogues. Using estimates of aerodynamic roughness, such as that in Marticorena et al. (2006), we can further our understanding of the surface conditions under which dust lifting occurs, which can lead to the formation of global dust storms that can grow from local storms within weeks, obscuring almost the entire surface of the planet (Fenton et al., 2007; Listowski et al., 2011). Our aim is to study how the pulse-width of laser altimeter backscatter shots from the surface of Mars can be used to estimate surface roughness globally at a smaller length-scales than can be derived from along-track topographic profiles alone (Neumann et al., 2003). Theoretically derived global surface roughness maps have been produced and used since this pulse-width data was first collected, however a literature search shows that the actual relationship between these pulse-widths and ‘ground-truth’ has yet to be found.

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To date, there is no commonly accepted scientific definition of planetary surface roughness, referred to simply as surface roughness, and as a result many definitions exist (Shepard et al., 2001; Kreslavsky and Head, 2000; Rosenburg et al., 2011; Kreslavsky et al., 2013). Here, it is defined *as a measure of the vertical exaggerations across a horizontal plane or profile, at a defined baseline*. It is important to understand that surface roughness is variable, and as such changes depending upon the length scale at which it is measured. This length scale is known as the baseline, and can range from centimetres to kilometres. The common methods of measuring planetary surface roughness are outlined in Shepard et al. (2001), with the chosen method often dependent on the data type and the field. Kreslavsky et al. (2013) discuss the difficulties in choosing an intuitive, which allows a researcher to interpret and compare roughness, and stable measure of surface roughness, whereby anomalously high or low elevations or slopes across a plane or a profile can significantly affect the estimated surface roughness value for that plane or profile. The measure used here is the root-mean-square (RMS) height, as defined in Shepard et al. (2001), which can be considered as unstable (Kreslavsky et al., 2013). However, experience using ICESat pulse-widths over bare-earth terrains shows this method to perform best, compared to the interquartile range, which is considered to be more stable (Kreslavsky et al., 2013).

High-resolution images (0.25 m/pixel) and digital terrain models (DTMs) (1 m/pixel) from the High Resolution Imaging Science Experiment (HiRISE) provide unprecedented views of another planetary surface, albeit at the sacrifice of spatial coverage (McEwen et al., 2007, 2010). Therefore, surface roughness at fine-scales ($\leq$ 100 m) cannot be derived globally. An alternative is to employ the Mars Orbiter Laser Altimeter (MOLA) to measure surface roughness from topographic profiles with $\approx$ 300 m along-track shot spacing and large ($\approx$ 4 km at equator) inter-track spacing (Smith et al., 2001). The primary science objective of MOLA was to produce a global elevation model that would be useful for planetary scientists to quantify topographic variation on Mars, and to quantitatively characterise the Martian landscape and the processes governing its formation and evolution (Smith et al., 1999). A secondary science goal was to characterise the terrain at finer scales by recording the time-spread of the backscatter pulse, known as the pulse-width, from which surface characteristics from within the pulse-footprint can be derived (Smith et al., 2001). Part of the reflected pulse is collected by the receiver telescope and triggers one of the four receiver channels (Smith et al., 2001) (Fig. 1). Theoretically, the pulse-width of the received backscatter pulse, once corrected for instrumental and slope effects, can be used as an indicator of surface roughness within the footprint of the pulse, which was assumed to be 170 m (Smith et al., 2001). This was thought to correspond to surface roughness estimates at 100 m baselines, however the footprint size was revised in Neumann et al. (2003) to 75 m in the production of the Slope-Corrected pulse-width

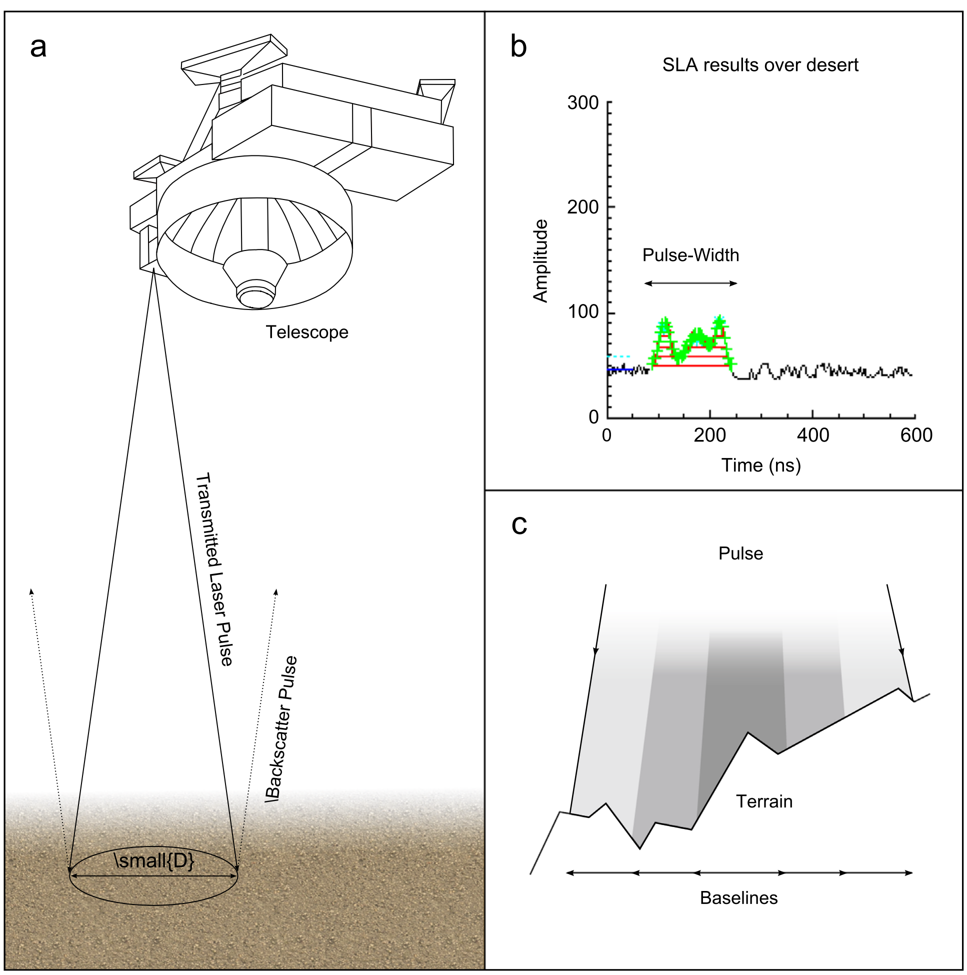

Fig. 1. (a) The MOLA instrument with an illustration of how a laser pulse diverges as it travels towards the surface of Mars before being reflected back towards the receiver telescope. (b) An example backscatter pulse over Earth desert terrain from the Shuttle Laser Altimeter (Garvin et al., 1998). Full pulse profiles are not available for Mars, instead only the final pulse-widths are available, shown by the time spread of the data plotted in the hashed region. (c) A schematic of how different pulse divergences can affect the size of roughness elements for which we have information. Smaller pulse divergence may tell us about large rocks, whereas larger divergences may tell us more about surface slope.

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