Calibration of the MOLA Laser Pulse Spread for Interpretations of Surface Roughness

Peter Saiger[1,2], Jürgen Oberst[1], Marita Wählisch[1]
1) German Aerospace Center, Berlin-Adlershof, Germany (Juergen.Oberst@dlr.de)
2) University of Potsdam, Institute of Geography, Geomatics Section, Potsdam, Germany

Introduction. The Mars Orbiter Laser Altimeter (MOLA) on the Mars Global Surveyor (MGS) spacecraft has operated from 1999 to June 30, 2001. Though the instrument's main goal was to measure the topography of the planet, the characteristics of the MOLA Laser pulse returning from the surface can also be used to study the surface roughness and the 1.064 µm reflectivity of Mars. In this paper, we report about progress in the understanding and calibration Laser pulse spread for quantitative interpretations of surface roughness.

Laser Pulse Spread. Following the classical altimeter principle, the MOLA transmitter is based on a longitudinally pumped ND:YAG laser with 40/50 mJ pulses at 2.5 ns pulse duration, operating at 10 Hz. The returning pulse is received by a small telescope. Digital filtering is used for pulse detection and pulse shape measurements. Following Abshire (2000), the following parameters contribute to the received width of the Laser signal, σ_r:

- Transmitted Pulse Width: σ_x
- Receiver Pulse Response: σ_f
- Curvature of Wave Front: $\sigma_{curv} = 2R_m/c * \tan(\gamma)^2$
- Surface Slope : $\sigma_{slope} = 2R_m/c * \tan(\gamma) \tan(\theta)$
- Surface Roughness: $\sigma_{roughness}$

where R_m is the laser one-way range, c is speed of light, γ is Laser beam spread, and $\tan(\theta)$ is the surface slope with respect to the incident beam. Note that the beam curvature term typically becomes very small and can be neglected. Assuming that these contributions can be modelled by Gauss-shaped functions, we obtain the variance of the pulse shape:

$$\begin{aligned}\sigma_r^2 &= \sigma_x^2 + \sigma_f^2 + \sigma_{roughness}^2 + \sigma_{curv}^2 + \sigma_{slope}^2 \\ &= \sigma_x^2 + \sigma_f^2 + \sigma_{roughness}^2 + \\ &\quad 4\,(R_m/c)^2\,[\,\tan(\gamma)^4 + \tan(\gamma)^2 \tan(\theta)^2\,]\end{aligned}$$

(compare with Abshire's paper, eq 4, where roughness is not directly included). Data on transmitted pulse width σ_x and receiver pulse response σ_f. are available from ground calibrations. Then, from the measured pulse width σ_r, a corrected pulse width σ_{corr} (sigopt), may be computed

$$\begin{aligned}\sigma_{corr}^2 &= \sigma_r^2 - \sigma_x^2 - \sigma_f^2 - \sigma_{curv}^2 \\ &= \sigma_{slope}^2 + \sigma_{roughness}^2\end{aligned}$$

which, can be interpreted in terms of both, surface roughness, and slope (Fig. 1).

Calibration of Laser Pulse Width. A lower limit of the surface slope is typically known from shot-to-shot range measurements along the altimeter track. Alternatively, in this work, we extract the surface slope from MOLA gridded topographic data. Hence, the effect of surface slope can be subtracted from the observed pulse spread, with pulse spread due to surface roughness remaining. However, our analysis shows that the observed pulse spread is significantly smaller than what is predicted by the above equations for the measured surface slopes. Following the reasoning of Neumann et al., (2001), we interpret this in terms of the unknown "effective" Laser beam spread and Laser spot size on the ground. By comparison of observed pulse spread with estimated slopes, this "effective beam spread" can be measured and pulse spread be calibrated. We estimate that the pulse width (for most MOLA tracks we analyzed) is smaller than nominal by approx. a factor of 2, in agreement with previous analyses, Fig. 2 (Neumann et al., 2001). Following a calibration, the slope effect can be removed from the pulse spread data, which can then be interpreted in terms of surface roughness (Fig. 3). We wish to caution and point to evidence that "effective beam spread" may differ in different MOLA tracks. This is an issue, we are still investigating.

References:

Abshire, J.B. et al., Mars Orbiter Laser Altimeter: Receiver and performance analysis, Applied Optics, Vol. 39, No. 15, 2000.

Neumann, G.A., J.B. Abshire, O.Aharonson, J.B. Garvin, X. Sun, and M.T. Zuber, Mars Orbiter Laser Altimeter pulse width measurements and footprint-scale roughness, Geophys. Res. Lett., 30(11), 2003.

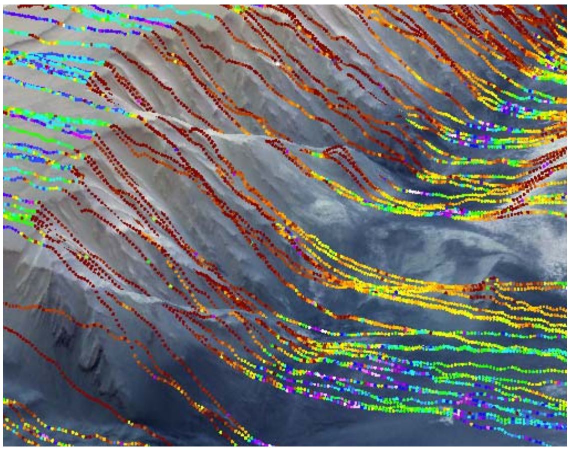

Fig. 1: MOLA Laser profiles across the cliffs of Valles Marineris. The color codes represent the Laser pulse spread. Green and blue indicate small – brown colors represent large pulse spread. Note the correlation of Laser pulse width with terrain slopes. In the background, an oblique terrain view based on HRSC images (HRSC = High Resolution Stereo Camera) is shown.

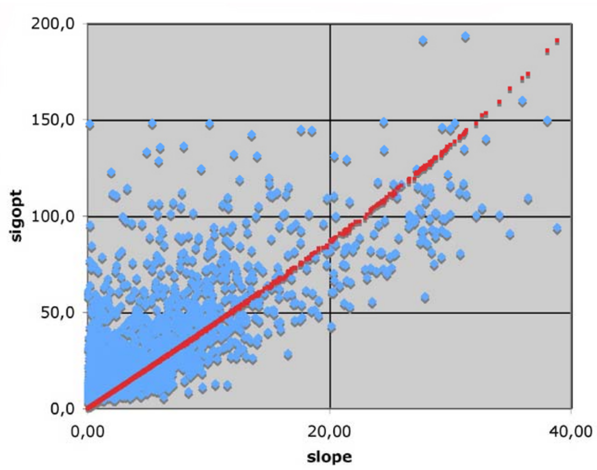

Fig. 2: Slopes (in deg) along the MOLA tracks vs. measured Laser pulse spread (in ns). The blue symbols show the measured pulse spread, whereas the red symbols mark the predicted pulse spread on the basis of known slopes and Laser beam divergence. The data suggest that the Laser spot size is smaller than nominal by a factor of approx. 2.

Fig. 3 (below): Surface roughness in an area north of Tempe Terra computed after calibration of MOLA pulse width for “effective spot size”. Note erroneous data in some tracks.