ADJUSTMENT OF MOLA LASER ALTIMETER TRACKS TO HRSC PHOTOGRAMMETRIC STEREO DTMs USING EVOLUTION STATEGY. K. Willner[1], K. Gwinner[1], A. Stark[1], S. Elgner[1], H. Hussmann[1] ;[1]German Aerospace Center (DLR), Institute of Planetary Research, Planetary Geodesy, Rutherfordstr. 2, 12489 Berlin, Germany (Konrad.Willner@dlr.de).

Introduction: The laser altimeter data of Mars Global Surveyors (MGS) Mars Orbiter Laser Altimeter (MOLA) [1] instrument provide a dense global network of laser shots with unprecedented height precision for planet Mars. The conversion of the measured time-of-flight of returned laser pulses into planetary radii (i.e. 3D coordinates of points at the surface), however, requires knowledge of spacecraft trajectory and the instrument's orientation in space. Limited knowledge of these extrinsic parameters leads to inconsistencies between the nominal ground profiles obtained, as observed in the original (not adjusted) MOLA mission data record e.g. in the form of height differences between overlapping ground tracks (i.e. at cross-over points), and occasionally leads to substantially offset outlier profiles. Such discrepancies have been strongly reduced in the final mission data products by applying adjustment techniques to minimize cross-over residuals [2]. Yet, when compared to external digital terrain model (DTM) products of similar resolution such as HRSC Mars quadrangle DTMs [3], single MOLA tracks still show considerable variability in terms of height differences, i.e. their co-registration with the external DTM is of variable quality. A possible explanation for this may be attributed to inherent limitations of the cross-over optimization techniques applied. Determining height differences at cross-overs always implies some degree of interpolation between data points, as the laser ground spots rarely are ideally coincident. Furthermore, the adjustment involves a parametric approximation of the altimetry profiles that does no longer depend on relevant original parameters of the observational equations, such as spacecraft position and attitude.

We present a method to effectively and accurately co-register MOLA profiles to existing Mars half-quadrangle DTMs which allows to increase the accuracy of the coregistration of the single laser tracks while providing similar internal a-posteriori cross-over accuracies as the archived final MOLA data record. The method allows to derive improvements to the extrinsic observation parameters directly and applies Evolution Strategy (ES) techniques for parameter optimization.

The High Resolution Stereo Camera (HRSC) on ESA's Mars Express (MEX) [4] spacecraft provides a unique data set to derive a global DTM by means of stereo photogrammetry for Mars [3], at substantially improved spatial resolution. However, optical images of a dust-covered, atmosphere-bearing planet like Mars contain a considerable amount of areas with poor image texture and clouds or hazes, which means that gaps in the DTM are unavoidable in many regions. Complementing the HRSC DTMs with accurately co-registered MOLA-tracks will therefore provide the most comprehensive and best resolved global data product currently achievable for Mars

Methods: For the joint analysis of image and laser altimeter data, deterministic minimization techniques (a least-squares approach) are usually applied that require the derivation of a complete functional formulation of the problem. However, the level of functional dependencies is raised with each additional data set, instrument type, spacecraft, etc. and, consequently, the number of parameters to be estimated increases such that this approach is becoming increasingly error-prone the more complex the dependencies become. Here, the approach is altered to combine all the information of imaging and laser altimeter data sets in a single joint optimization procedure and solve for a parameter vector that can be used to define a cost or quality function which still does depend on the original observation data. We make use of Evolution Strategy (ES) techniques [5,6] that have their strengths in solving large parameter vectors for a given problem. Using this approach, the problem is reduced to providing comprehensive but separate modules, implementing the observational equations for each data source, and to formulating a suitable quality function which needs to include dependencies of all unknown parameters. Here we modelled a parameter vector that estimates the components of the bore-sight vector of MOLA as well as orbit shifts along-track, cross-track and in height for each segment of a laser track. Segments are defined as sections of the laser data that reach from North Pole to South Pole without large data gaps in between. The segmentation is applied as the optimization of the parameter vector is performed on the basis of an equatorial HRSC half-quadrangle DTM. All laser data points outside the DTM area will still inherit the parameter optimization. Hence the segments are tailored to only cover half a hemisphere to minimize the distance to the reference DTM and thus the potential increase of errors with increasing distance to the reference DTM region. Furthermore, laser data gaps will terminate the segment as it is uncertain why a data gap might have occurred.

The ES randomly creates a number of parameter vectors and tests the quality of all these child vectors based on the defined quality function. Here we derive the root-mean square of all height differences at the shifted (according to the parameter vector) laser shot locations and the DTM heights. The child vector with the lowest RMS determined will become the seed for new random child vectors. We apply an ES-CMA [4] procedure in our implementation as this variant has the capability to self-adjust the search distances applied and thus provides highly reliable convergence properties.

Results: ES-based adjustment of MOLA tracks was applied using two existing equatorial HRSC DTM half-quadrangles (MC-13E and MC-21E) and the laser track segments intersecting these quadrangles. The quality of the adjustment has been evaluated by visual inspection of gridded DTM data products generated from the adjusted tracks (Fig. 1) and by analyzing the consistency of the results in terms of height residuals at cross-overs. For comparison, the corresponding values have also been derived for the original (not adjusted) MOLA profiles and for the crossover-adjusted profiles published by the MOLA instrument team. Inspection of gridded DTM products is mainly sensitive to the detection of outlier tracks (see Fig. 1). In this respect, we note that these quite commonly do occur among the original MOLA, but also still appear in the crossover adjusted version. The ES adjustment, which allows for improving the extrinsic observation parameters directly, apparently allows for the most reliable integration of outlier tracks, although they cannot be eliminated completely over the full area of the quadrangle. A similar evaluation can be based on the comparison of average absolute residual height differences at cross-overs. While these amount to 4.44 m initially, i.e. before any corrections to the nominal profile solutions, and to 4.58 m in the crossover-adjusted version of profiles [6], an average residual height difference of only 2.78 m is achieved with ES-adjusted profiles. Outlier tracks are difficult to identify during cross-over analysis. Hence, it is instructive to consider the same values also after applying a global 3σ-blunder elimination to the height differences. The corresponding values then are to 3.48 m (nominal case), 2.93 m (cross-over adjusted), and 2.09 m (ES-adjusted).

From these encouraging initial results, we conclude that the ES-method performs very well with respect to the reliability and the accuracy of the parameter optimization. As the method inherently establishes a high-quality co-registration between MOLA and the reference DTM, the results are considered also very promising with respect to future joint HRSC/MOLA DTMs. Current investigations are addressing the performance of the method in other example areas of Mars and the potential influence of distance to the reference area on the accuracy of the solution.

Acknowledgments: The authors thank the HRSC Experiment team at DLR, Institute of Planetary Research, Berlin as well as the Mars Express Project teams at ESTEC, ESOC, and ESAC for their successful planning and acquisition of data as well as for making processed data available.

References:

[1] Smith, D. E. et al. JGR 106, 23689-23722 (2001). Doi:10.1029/2000JE001364
[2] Smith, D. E. et al. NASA PDS (2003). MGS-M-MOLA-5-MEGDR-L3-V1.0.
[3] Gwinner, K. et al. PSS 126, 93-138 (2016). Doi: 10.1016/j.pss.2016.02.014
[4] Jaumann, R. et al. PSS 55, 928-952 (2007). Doi:10.1016/j.pss.2006.12.003
[5] Hansen, N. 75-102 (Springer Berlin Heidelberg, 2006).
[6] Rechenberg, I. Evolutionsstrategie 94. Vol. 1 (Frommann-Holzboog, 1994).

Figure 1: Color-coded and shaded display of gridded digital terrain model from MOLA profiles of different processing levels (subset of DTM at 463 m/post resolution covering quadrangle MC-13). Left: original MOLA tracks with nominal orientation data. Center: cross-over corrected profiles [2]. Right: MOLA tracks adjusted to HRSC DTM using the Evolution Strategy method. Note different contribution of outlier tracks. For fine-scale differences concerning height accuracy please refer to text.