Improvement of Local LOLA DTMs using LROC NAC DTMs – Example for an ESA Lunar Lander Candidate Landing Site.

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Introduction: The Lunar Reconnaissance Orbiter (LRO) mission has collected a large dataset since the start of the operational phase in June 2009. The quantity and quality of this dataset enables the science community to derive a variety of high resolution data products, such as maps and digital terrain models (DTMs). In total LRO carries 7 instruments, of which two instruments are of importance for this work: the Lunar Reconnaissance Orbiter Camera (LROC) and the Lunar Orbiter Laser Altimeter (LOLA). During the nominal 50-km altitude orbit, LROC, consisting of a Wide Angle Camera (WAC) and two Narrow Angle Cameras (NACs), imaged the lunar surface in 75 m/pxl and 0.50 m/pxl ground sampling distance respectively [1]. LOLA, a 5 spot multi-beam laser altimeter, globally measures the lunar topography with a ranging precision of +/-10 cm at a sampling rate of 28 Hz and 5 m diameter footprints [2]. With NAC and LOLA the production of high resolution polar DTMs for future lunar landing sites at a few meter pixel resolution is feasible. The European Space Agency (ESA) identified several potential landing sites in the south polar region for the Lunar Lander mission [3],[4], of which a landing site located on Connecting Ridge at 89.4649°S, 222.1027°E was used within this investigation.

Data Set: A 2,500 x 2,500 pixel NAC DTM of the Connecting Ridge (CR1) landing site extends over a 5 x 5 km area (2 m/pxl grid), see Fig. 1a. It has been derived from 10 NAC stereo image pairs, 1 m/pxl ground sampling distance, acquired within a three-week period under different solar azimuths. Compared to low-latitude targets [5], stereo processing from image data at such high latitudes is challenging due to the generally poor lighting conditions (e.g. some craters without illumination in any of the available NAC images). NAC stereo was obtained by nadir observations and along-track slews in subsequent orbits. All LOLA shots within this region amount to 106,669 shots from 876 different orbits (only data until December 2011 were considered), see Fig. 1b. An extended LOLA DTM area covers 15 x 15 km and contains 951,655 individual laser shots from 2,437 different orbits, see Fig 1d. LOLA has its highest point density at the lunar poles due to LRO's polar orbit and is independent from lighting conditions, which makes the LOLA data set ideal for polar DTMs.

Strategy: The NAC DTM, see Fig. 1a, represents the basis for this analysis. The 5 m/pxl LOLA DTM, see Fig. 1b, represents the same area as the NAC DTM. It can clearly be seen, that many tracks are offset and introduce errors in the resulting DTM. Nevertheless gaps in the NAC DTM can be resolved with LOLA. At first, the systematic displacement between the NAC DTM and the LOLA tracks was determined in order to correct for any absolute offset w.r.t. the globally cross-over corrected LOLA dataset [6]. Then each LOLA track intersecting with the NAC DTM can be individually adjusted horizontally and vertically according to the high relative accuracy of the NAC DTM [7]. The typical corrections for this CR1 site are 6 m laterally and 1 m vertically (within accuracy quoted in [6]). The resulting LOLA DTM, derived from 89,627 shots, is shown in Fig. 1c. Since all offset tracks were either adjusted or excluded according to the information from the NAC DTM, the resulting LOLA DTM now combines both, high absolute accuracy from cross-over corrections, as well as LOLA's high vertical precision, locally refined by the relative adjustment to the NAC DTM. As a next step, all adjusted LOLA tracks were used as a new reference DTM for the adjustment of LOLA tracks in the vicinity of the initial area. All LOLA tracks surrounding the NAC DTM were matched and adjusted to this reference DTM. Doing so, improvements for an area 9 times greater than the NAC DTM were achieved, see Fig. 1e. In total 917,470 LOLA shots were used.

Summary: Using a NAC DTM as a reference, we improved altimetry data from globally cross-over corrected LOLA tracks for residual horizontal and vertical displacements in a way that the resulting LOLA DTM shows no more outliers. In a second step, it was also possible to extend LOLA improvements to an area that is far larger than the initial NAC DTM.

References: [1] M.S. Robinson et al. (2010) *Space Sci. Rev., 150, 81-124*. [2] D.E. Smith et al. (2010) *Space Sci. Rev., 150,* 209-241. [3] D. De Rosa et al. (2012) *Planetary and Space Sci.*, 74, 224-246. [4] J.D. Carpenter et al. (2012) *Planetary and Space Sci., 74,* 208 – 223. [5] J. Oberst et al. (2010) *LPSC 41, #2051*. [6] E. Mazarico et al. (2012) *Journal of Geodesy, 86, #193-207*. [7] P. Gläser et al. (2010) *EPSC, p. 296*.

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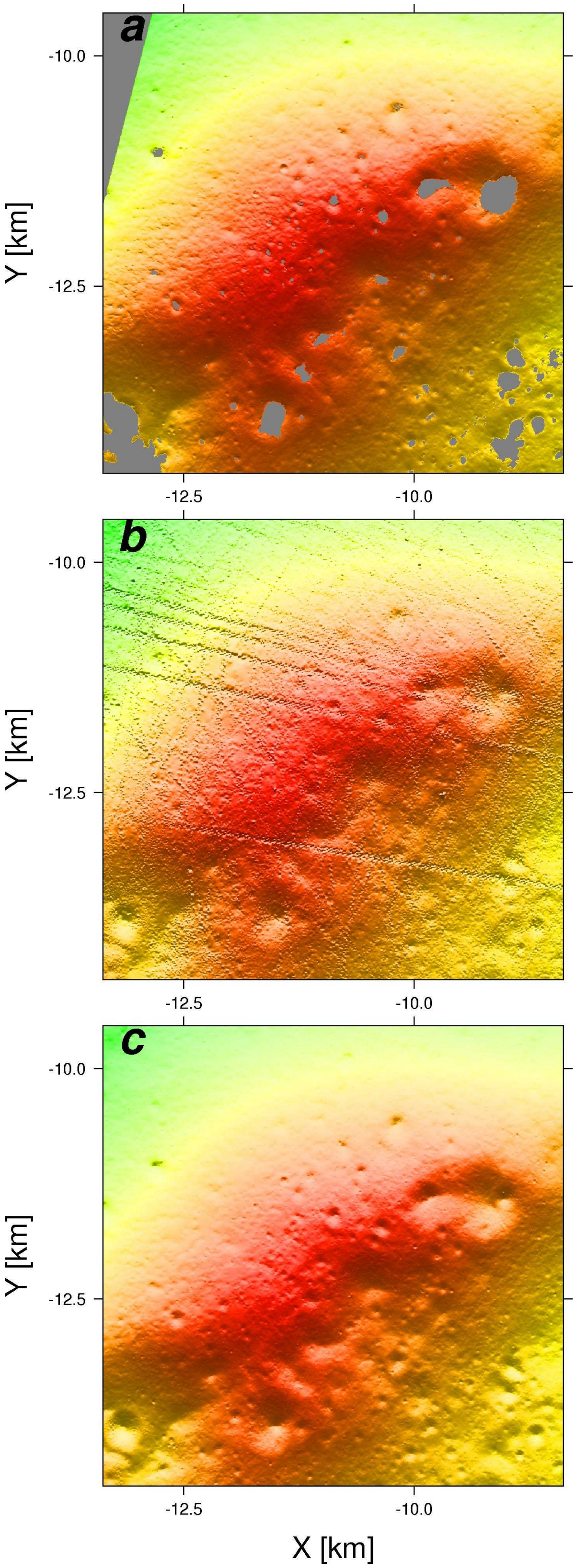
Figure 1 a-e



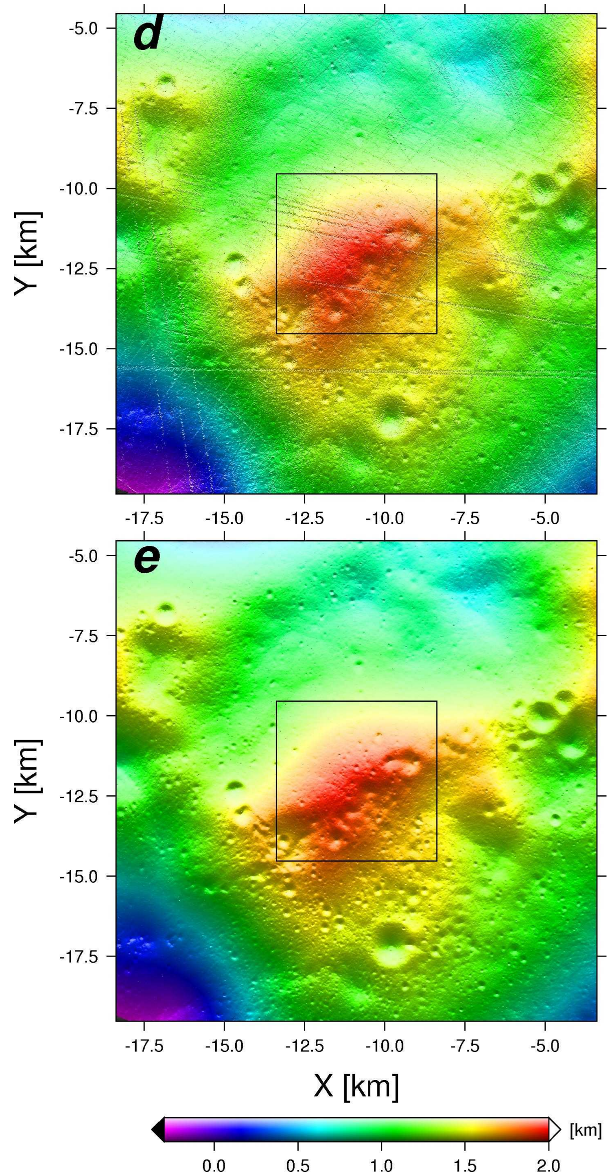


Figure 1a: 2 m/pixel NAC DTM. Areas shown in gray do not contain height information, e.g. due to shadows (craters).

Figure 1b: 5 m/pixel LOLA DTM. Offset tracks introduce errors in the DTM.

Figure 1c: 5 m/pixel adjusted LOLA DTM. All offset tracks were adjusted or canceled out.

Figure 1d: 5 m/pixel extended LOLA DTM. Offset tracks are clearly visible. The black square shows the size of the NAC DTM for comparison.

Figure 1e: 5 m/pixel extended adjusted LOLA DTM. The black square shows the size of the NAC DTM for comparison.

All plots are in stereographic projection.