TOPOGRAPHIC MODELS FROM THE LUNAR ORBITER LASER ALTIMETER (LOLA) IN SUPPORT OF TERRAIN RELATIVE NAVIGATION AT THE MOON

Michael K. Barker[1], Erwan M. Mazarico[1] and Carolina I. Restrepo[1] [1]NASA/GSFC, 8800 Greenbelt Rd., Greenbelt, MD 20771

Abstract.

The LOLA instrument onboard Lunar Reconnaissance Orbiter (LRO) has collected nearly 7 billion globally-distributed measurements of surface height with a vertical precision of ~10 cm and accuracy of ~1 m. The LOLA dataset is used by the community as the geodetic framework for aligning datasets from LRO and other lunar missions. Here we describe ongoing work to update and improve LOLA topographic products to support TRN and landing side studies in the south polar region of the Moon.

Introduction. In preparation for sending humans to the lunar south pole, it is important to have the most detailed and accurate topographic maps possible. These are critical inputs to many aspects of mission design and site selection, such as locating subsurface volatiles, mapping traversable terrain, assessing sun and earth visibility, and making maps for terrain relative navigation (TRN). We need to know the topography both outside and within permanently shadowed regions on lander-relevant scales of ~1-5 m. Imaging-based techniques (stereo-photogrammetry and shape-from-shading, SfS) face challenges in polar regions due to the extreme shadowing conditions found there. Given their active ranging capabilities, laser altimeters like LOLA can see into the shadows, but gaps between ground tracks and individual laser spots require interpolation and increase uncertainties in the resulting topographic models. Also, small errors in the LRO orbit reconstruction (~ few meters horizontally & ~0.5 m vertically [1]) can cause streaky artifacts in a LOLA digital elevation model (LDEM). Also, isolated noise returns (~1% of total) can appear as spurious "flag-poles" or "pot-holes". These artifacts become more apparent at higher LDEM resolution (pixel scales less than ~20 m/pix) and can pose a challenge to TRN and detailed landing site studies. Here we summarize recent [2] and ongoing work [3] to update and improve the LDEM products to support NASA science and exploration at the Moon.

Data Analysis. LOLA is a time-of-flight laser altimeter operating with a firing rate of 28 Hz and a cross-shaped, 5-spot footprint on the surface canted by 26° from the along-track direction to optimize coverage overlap [4]. From the nominal mapping altitude of 50 km, the cross-track spacing between each profile is 12 m with an along-track spacing of 57 m between each measurement in a profile. Each laser spot footprint has a diameter of 5 m, suggesting a natural minimum pixel scale of 5 m/pix for the LDEM products. Most artifacts in the LDEMs can be removed by adjusting the LOLA tracks to a reference DEM, such as those produced by stereo or SfS using LRO Narrow Angle Camera images [5,6,7]. Due to gaps between tracks and individual laser spots, a 5 m/pix LDEM has a fill factor of only ~10% near the south pole (i.e., roughly 10% of 5 m pixels have data while the rest are interpolated). However, the LDEM still contains enough information to act as the reference allowing the track adjustment process to produce a vastly cleaner LDEM with fewer artifacts. Updating the 5 m/pix LDEM in this way yields a product that is more useful for TRN, landing site studies, and as a constraint to higher-resolution DEMs from stereo and SfS. A major advantage of this process is that it enables realistic estimates of LDEM height uncertainties due to range error, orbital errors, interpolation, and sub-pixel sampling.

Error Analysis. Detailed TRN and landing site studies may require knowledge of the spatially varying LDEM height errors. The LDEM errors can be considered to have a data component, due to orbital errors and interpolation, and a geologic component, due to natural terrain variations. We can take advantage of the self-similarity of lunar topography to generate simulated terrains with approximately the same statistical properties as the real terrain. In total, 100 such clones are generated for each LDEM. These form a statistical ensemble with approximately the same error properties as the data. Such a Monte Carlo approach is analogous to that used in the analysis of the Gravity and Interior Laboratory (GRAIL) lunar gravity field [8]. The clones allow us to explore the effects of orbital error and interpolation uncertainties on surface height without having to compute the full error-covariance matrix of the entire LDEM, which would be computationally prohibitive. The resulting cleaned LDEMs and clones are available to the community at the NASA/GSFC Planetary Geodynamics Data Archive https://pgda.gsfc.nasa.gov/.

References.

[1] Mazarico, E. et al. (2018) *PSS*, 162, 2, https://doi.org/10.1016/j.pss.2017.10.004. [2] Barker, M. K. et al. (2020) *PSS*, 203, 105119, https://doi.org/10.1016/j.pss.2020.105119. [3] Restrepo, C. I. et al. (2022) AIAA SciTech Forum, San Diego, CA & Virtual, https://doi.org/10.2514/6.2022-0356. [4] Smith, D. E. et al. (2017). *Icarus*, 283, 70, https://doi.org/10.1016/j.icarus.2016.06.006. [5] Henriksen, M. R. et al., (2017) *Icarus*, 283, 122, https://doi.org/10.1016/j.icarus.2016.05.012. [6] Beyer, R. A. & Alexandrov, O., (2018) *E&SpS*, 5, 652, https://doi.org/10.1029/2018EA000390. [7] Gläser, P. et al. (2018) *PSS*, 162, 170, https://doi.org/10.1016/j.pss.2017.07.006. [8] Lemoine, F. G. et al. (2014) *GRL*, 41, 3382, https://doi.org/10.1002/2014GL060027.