**TOPOGRAPHY OF THE LUNAR POLES AND APPLICATION TO GEODESY WITH THE LUNAR RECONNAISSANCE ORBITER.** Erwan Mazarico[1,2], Gregory A. Neumann[2], David D. Rowlands[2], David E. Smith[1,2], and Maria T. Zuber[1]. [1] Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139 (mazarico@mit.edu); [2] Planetary Geodynamics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771.

**Introduction:** The Lunar Orbiter Laser Altimeter (LOLA) **[1]** onboard the Lunar Reconnaissance Orbiter (LRO) **[2]** has been operating continuously since July 2009 **[3]**, accumulating ~5.4 billion measurements from 2 billion on-orbit laser shots. LRO's near-polar orbit results in very high data density in the immediate vicinity of the lunar poles, which are each sampled every ~2h. With more than 10,000 orbits, high-resolution maps can be constructed **[4]** and studied **[5]**. However, this requires careful processing of the raw data, as subtle errors in the spacecraft position and pointing can lead to visible artifacts in the final map. In other locations on the Moon, ground tracks are sub-parallel and longitudinal separations are typically a few hundred meters. Near the poles, the track intersection angles can be large and the inter-track spacing is small (above 80° latitude, the effective resolution is better than 50m).

Precision Orbit Determination (POD) of the LRO spacecraft **[6]** was performed to satisfy the LOLA and LRO mission requirements, which lead to a significant improvement in the orbit position knowledge over the short-release navigation products. However, with pixel resolutions of 10 to 25 meters, artifacts due to orbit reconstruction still exist. Here, we show how the complete LOLA dataset at both poles can be adjusted geometrically to produce a high-accuracy, high-resolution maps with minimal track artifacts. We also describe how those maps can then feedback to the POD work, by providing topographic base maps with which individual LOLA altimetric measurements can be contributing to orbit changes. These 'direct altimetry' constraints improve accuracy and can be used more simply than the altimetric crossovers **[6]**.

**Iterative geometric adjustment:** The algorithmic concept of the geometric adjustment is to find the optimal displacement to be applied to each LOLA track to minimize its misfit with a base map grid created from all the other tracks. This is performed for all the tracks in the dataset, and iterated until convergence. We find empirically that with well-sampled regions and with the roughness of the Moon topography typical of planetary surfaces, the risk of non-convergence is not warranted. Given the large number (~8,000) of LOLA tracks to be sequentially adjusted, it is not reasonable to create one base map for each track (excluding only that one track). Instead, we perform the misfit minimization by 'mission phase' (about one month),

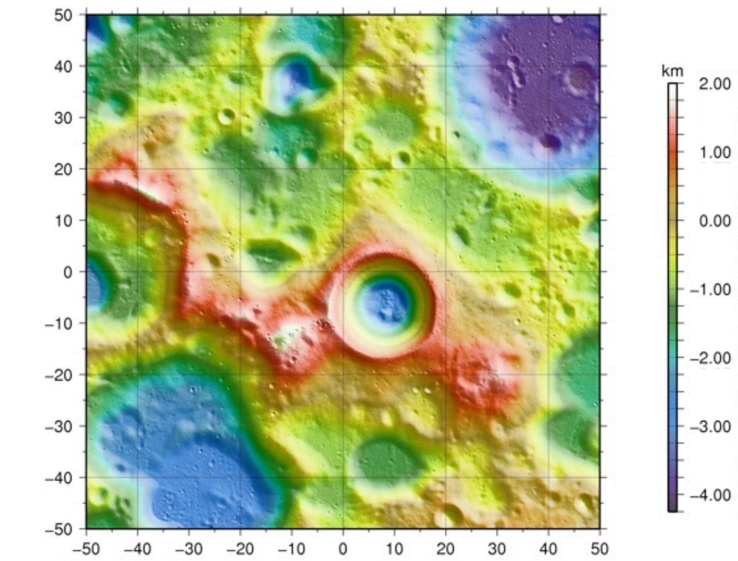


**Figure 1.** Topographic map of the lunar South Pole region, in stereographic projection (axes are in kilometers). Original resolution is 10 meters per pixel.

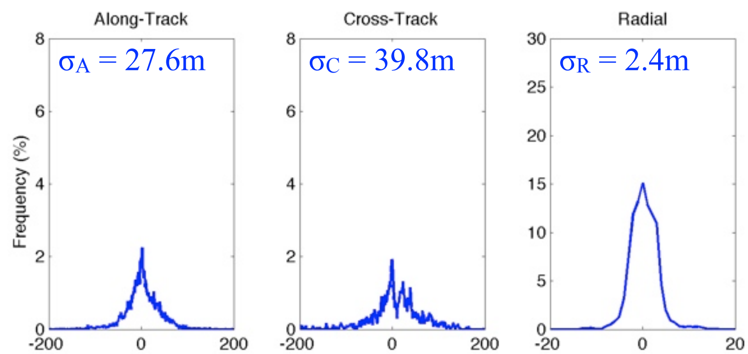


**Figure 3.** Histograms of the adjustments (1-m bins) that were applied to the LOLA tracks originally geolocated with navigation orbits, in order to best fit the final (drift-corrected) map.

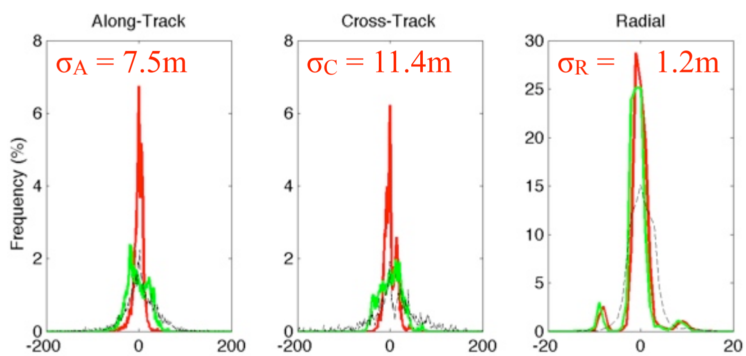


**Figure 3.** Histograms of the displacements (1-m bins) minimizing the mistfit of the LOLA tracks geolocated from LOLA orbits and topographic basemaps. Green indicates the immediate post-fit adjusted map, while red uses the additional drift correction.

with all the tracks in that phase adjusted on a common base map that excludes them.

Because of the large number of mission phases (28), we first perform the adjustment a small number of phases together (about 6). Once reasonably converged, we progressively add other phases. Once fully iterated, the whole dataset is used to construct the 'adjusted' map. However, in its current form, the geometric adjustments are performed at each iteration on a per-track basis, with no overall control of the map 'position'. It is thus possible, as more iterations are performed and as new mission phases contribute, for the map barycenter to drift from its dynamic position. Even though that 'drift' is small (comparable to one pixel of the base map resolution), and does not affect the scientific exploitation of the high-resolution maps [5], we correct this drift by forcing the map barycenter to match the original barycenter obtained from POD (**Fig. 1**).

**Geodetic implications:** Dynamically-referenced seamless high-resolution topographic models can also be advantageous to geodetic applications.

*Orbit quality assessment.* Figures **2** and **3** show the adjustments that need to be brought to the navigation and LOLA POD Team orbits reconstructions in order to minimize each track's misfit to the adjusted maps. This gives an absolute assessment of their accuracy. We can see that the LOLA orbits represent a significant improvement over the navigation solutions in all directions, and that the overlap analysis of **[6]** yielded realistic estimates of the orbit accuracy. We note that the drift correction is critical to such assessment (**Fig. 3**).

*Geodetic constraints.* The base map can also be used as 'ground truth' when integrating altimetric range measurements in the orbit reconstruction. Whereas altimetric crossovers (previously used for LRO by **[6]**) rely on two intersecting profiles, any laser bounce point in the map region can act as a constraint to the trajectory. Given a spacecraft state and altimeter pointing parameters, a round-trip ray path can be computed which intersects the topographic base map (**Fig. 4**). The residual between the calculated range to that bounce point and the actual LOLA measurement can then be minimized in the POD process. Advantages are that a large number of 'direct altimetry' measurements are available for use (the number of altimetric measurements), unlike crossovers, and their temporal separation is uniform (one orbital period). This allows short arcs (typically 2.5 days with LRO) to benefit from altimetric constraints, in contrast to crossovers which necessitate arcs longer than two weeks. However, these measurements can only be used at the poles where adjusted maps can be constructed at high resolution from the LOLA dataset. Analysis is ongoing, but orbit changes are appreciable (**Fig. 5**).

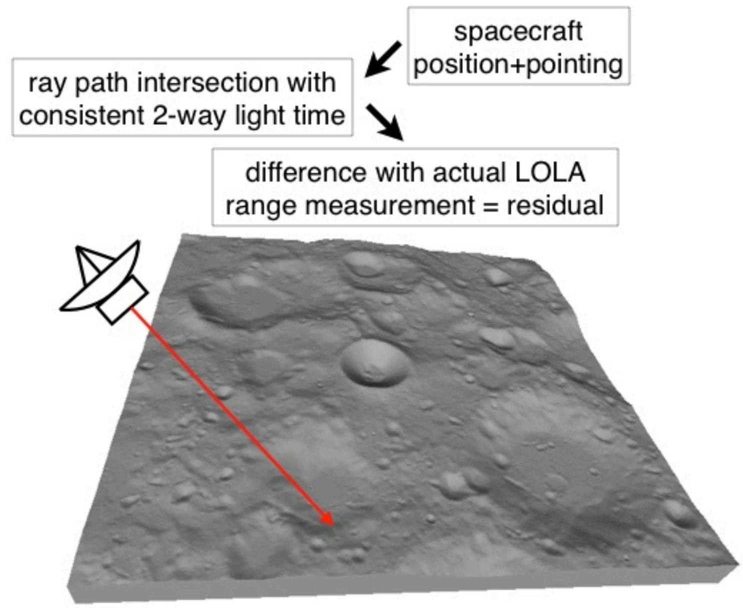


**Figure 4.** Schematic of the 'direct altimetry' measurement concept.

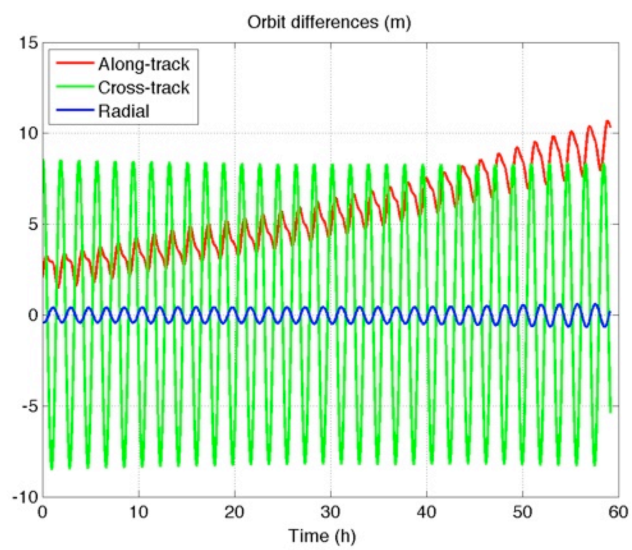


**Figure 5.** Orbit differences in short LRO arcs induced by the use of 'direct altimetry' measurements during the POD convergence.

**References:** [1] Smith D.E. et al. (2009) *Space Sci. Rev.*, *105*; [2] Chin G. et al. (2007) *Space Sci. Rev., 129*; [3] Smith D.E. et al. (2010), *Geophys. Res. Lett.*, 37, L18204; [4] Smith D.E. et al. (2011) *LPS XLII*, 2350, ; [5] Zuber M.T. et al. (2012) *Nature*, submitted; [6] Mazarico E. et al. (2011) *J. Geodesy*, in press.