NEW HIGH RESOLUTION POLAR TOPOGRAPHIC PRODUCTS FROM THE LUNAR ORBITER LASER ALTIMETER (LOLA). M. K. Barker[1], E. Mazarico[1], D. E. Smith[2], X. Sun[1], M. T. Zuber[2], G. A. Neumann[1], J. W. Head[3]. [1]Solar System Exploration Division, NASA Goddard Space Flight Center 8800 Greenbelt Rd. Greenbelt, MD 20771 michael.k.barker@nasa.gov, [2]Dept. of Earth, Atmospheric and Planetary Sciences, MIT, 77 Massachusetts Ave. Cambridge, MA 02139, [3]Dep. Earth, Env. & Planet. Sci., Brown Univ., Providence, RI, 02906, USA.

Introduction: The Lunar Orbiter Laser Altimeter (LOLA) onboard the Lunar Reconnaissance Orbiter (LRO) has collected nearly 7 billion measurements of surface height with a range precision of 10 cm and an absolute horizontal and radial accuracy of less than 10 m and 1 m, respectively [1,2]. This dataset forms the geodetic reference for locating data collected with LRO instruments, and other lunar datasets, as well. The ability of laser altimeters like LOLA to obtain global measurements independent of solar illumination conditions provides an advantage over passive imaging, particularly at high latitudes where such imaging is hindered by shadows. Hence, LOLA topographic products are a valuable tool for polar science and exploration particularly with new NASA human and robotic missions to the south pole in development. Here we present results of ongoing work to update LOLA polar topographic products focusing on high-priority landing sites. These products will include improved digital elevation models (DEMs) and slope maps, as well as, for the first time, surface height uncertainty estimates, and will be made available on the Planetary Data System (PDS) LOLA data node website, https://imbrium.mit.edu.

Improved DEMs: We focus on the 4 most illuminated sites near the south pole [3]. Figure 1 shows a close-up of one such site on the rim of Shackleton Crater. A 5 meters-per-pixel (mpp) resolution is a natural choice given LOLA's 5 meter spot size in the nominal 50 km altitude mapping orbit. Approximately 10% of the pixels in this region have at least one ground return, and the rest are interpolated with a continuous curvature surface [4]. Despite the high positional accuracy

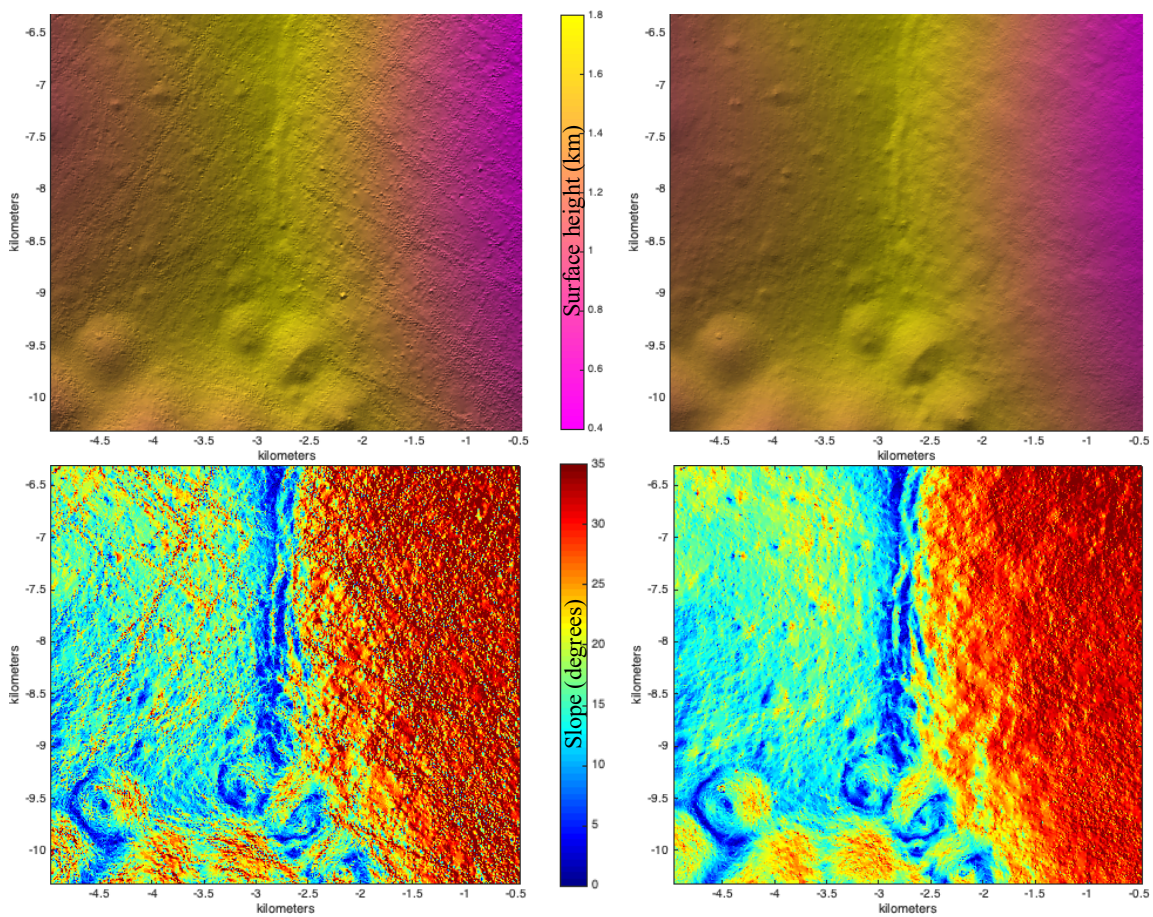

Figure 1- Hillshaded LOLA DEM (top) and slope map (bottom) of Shackleton crater's rim in stereographic projection at 5 mpp. Original version archived at the PDS (left) and after applying track adjustments (right).

of the LRO orbit reconstruction, some tracks are still visible. Such artifacts can be removed by adjusting the tracks to a reference DEM produced by, e.g., stereo images acquired with the LRO Narrow Angle Camera [5]. However, the LOLA data near the poles are dense enough to provide their own reference DEM for this purpose [6]. We use an iterative process in which we remove a randomly selected small fraction of the nadir-pointing tracks from the DEM, adjust each of the missing tracks to the resulting "reduced" DEM in the along-track, cross-track, and radial (ACR) directions, and repeat until all tracks have been adjusted. The whole process is repeated a second time starting from a new DEM computed with the best-fit track adjustments just found. Additional cleaning is achieved by excluding tracks and individual returns with abnormally high residuals. The resulting DEM and slope map after two iterations (Fig. 1, right column) are significantly cleaner than the originals (Fig. 1, left column).

Height Uncertainty: The surface height uncertainty is of particular interest for landing site studies since it can directly impact illumination conditions [7], and, therefore, site selection, traverse planning, and solar panel placement. We developed a Monte Carlo approach to estimate the height uncertainty in these LOLA DEMs due to orbital errors and interpolation errors. For the orbital errors, a set of 1000 random realizations of the data are created by perturbing all the tracks in the ACR directions. The perturbations are normally distributed with standard deviations $\sigma_A/\sigma_C/\sigma_R$ = 7/7/0.5 m, commensurate with the typical orbit reconstruction errors [2]. The root-mean-square (RMS) difference between the perturbed and original DEMs gives an estimate of the DEM height uncertainty, σ_Z, due to orbital errors in the vicinity of filled pixels. A distance-weighted smoothing within a radius of 30 m fills in most remaining empty pixels (Figure 2). As expected, σ_Z is correlated with slope, θ, and can be broadly approximated by the relation,

$$\sigma_Z \approx \sqrt{{\sigma_R}^2 + \left(\frac{\sigma_{AC}}{1.4}\tan\theta\right)^2}.$$

Thus, on flat surfaces, σ_Z is limited by radial orbit errors and bottoms out at ~0.5 m whereas on highly sloped surfaces it is limited by horizontal orbit errors and is typically several meters on Shackleton's wall.

The interpolation error for a given empty pixel is expected to depend on slope, roughness, gap size, and distance to nearest filled pixel. We can only reliably estimate the interpolation error where there is data, and must therefore extrapolate to nearby gaps. The gap mask is shifted by a random amount and overlaid on the filled pixels, which are then interpolated and differenced with their true height values. This is repeated 1000 times to fully sample the gap distribution. The RMS difference between the interpolated and true values gives an estimate of the interpolation uncertainty (Figure 3). On flat surfaces, this is of similar magnitude as the uncertainty due to orbital errors whereas on highly sloped surfaces the orbital errors tend to dominate.

References: [1] Smith, D. E. et al. (2017) *Icarus*, 283, 70. [2] Mazarico, E. et al. (2018) *P&SS*, 162, 2. [3] Mazarico, E. et al. (2011) *Icarus*, 211, 1066. [4] Wessel, P. et al. (2019) *Geoch., Geophys., Geosys.*, 20, 5556. [5] Gläser, P. et al. (2013) *44th LPSC*, 1719, 1967. [6] Zuber, M. T. et al. (2012) *Nature,* 486, 378. [7] Mazarico, E. et al. (2020) *this meeting*.

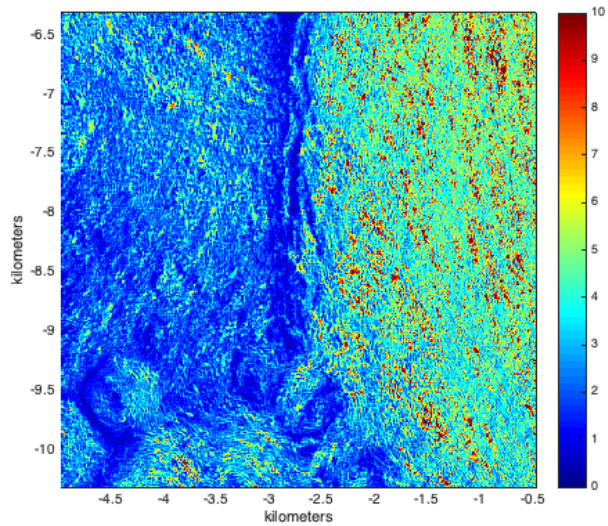

Figure 2-Estimated RMS surface height uncertainty (in meters) due to orbital errors.

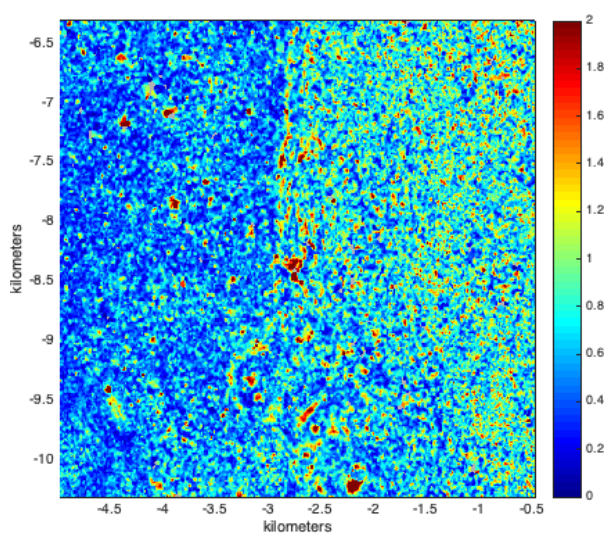

Figure 3-Estimated RMS surface height uncertainty (in meters) due to interpolation. Note the change in color scale from Figure 3.