HIGH RESOLUTION LUNAR DIGITAL ELEVATION MODELS WITH SHAPE-FROM-SHADING. T. E. McKenna1,3, S. Bertone2,3, M. K. Barker3, E. Mazarico3, 1Southeastern Universities Research Association (thea.mckenna@nasa.gov), 2University of Maryland College Park, 3NASA Goddard Space Flight Center (GSFC), Code 698.

Introduction: High resolution digital elevation models (DEMs) are an important data product needed for lunar geological science and human and robotic exploration. Previous stereophotoclinometry efforts have been central to operations for OSIRIS-REx [1, 2, 3]. High resolution DEMs are also beneficial to Artemis campaign planning. Stereophotogrammetry is routinely used to create high resolution lunar DEMs [4], using images from the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC). However, extreme illumination conditions make it challenging to obtain high-quality stereo pairs in the polar regions, leading to a relative lack of stereo-based DEMs there. In contrast, the photoclinometry, or shape-from-shading (SfS), technique can utilize available images with fewer observational geometry restrictions to produce DEMs at a pixel scale close to the native resolution of the images. To that end, we utilize the SfS tool within the Ames Stereo Pipeline (ASP) [5] to produce 1 m/pix DEMs of high-interest sites within the south polar region, based on LROC NAC images and starting from recently updated polar DEMs from the Lunar Orbiter Laser Altimeter (LOLA). Here, we present results for one site in particular, Cabeus “Exterior Wall 1”, referred to as NPA [6]. We take a 1x1 km box centered on the coordinates 87°S, 289°E for SfS processing.

Although NPA was not selected as one of the 13 Artemis III candidate landing sites, we chose it as a “stress-test” case for the processing methods because it has lower illumination than other sites yet still has proximity to permanently shadowed regions (PSRs), as seen in Figure 1b. PSRs are of interest as they may contain cold-trapped volatiles such as water which are valuable resources for a sustained human presence on the Moon. An accurate modeling is important to quantify surface characteristics such as elevation, slope, and roughness near PSRs to assess the viability of potential landing sites, plan traverses, and determine high-priority science activities [7, 8].

Method: We use 25 NAC images and an a priori 5 m/pix resolution LOLA DEM [9] in conjunction with the ASP SfS tool to derive our 1 m/pix DEM. We embedded ASP routines within an automated python pipeline for ease of use [10]. All usable images overlapping the chosen region are calibrated, map-projected onto the a priori LOLA DEM (Figure 1a), and bundle-adjusted to improve image alignment using ASP tools. The subsequent image selection process prioritizes spatial coverage of the region and Sun azimuthal range over the set of images. Images with less than 5% illumination are removed. The final selection of images is then registered to the LOLA DEM to account for any global translations that occurred during the bundle-adjustment steps. Images are then passed to SfS, along with the LOLA DEM. SfS uses the observational geometry and the measured light intensity in the images to infer terrain slope and hence topography.

Results: The resulting 1 m/pix resolution DEM from SfS processing is shown in Figure 1c. The SfS DEM captures many details not seen in the LOLA DEM, including many meter-scale craters. However, several artifacts similar to steep ridges are still visible in the SfS DEM. We show the artifacts in simulated images and find them to be related to shadowed regions in the images (Figures 1d, 1e). These may arise from SfS approximating the Sun as a point-source, resulting in less accurate topographic reconstruction on shadow edges [5]. NPA does not receive as much illumination as most Artemis III candidate landing regions, as seen in the average illumination over one lunar cycle shown in Figure 1f. Finally, Figures 1g and 1h show reconstructed slope and roughness over the region, where the latter is derived from the slope-detrended standard deviation of neighboring surface heights, following [9].

Conclusion: The SfS technique is a useful method to produce high resolution DEMs from existing LROC NAC images for human and robotic exploration, as well as for advancements in geomorphological studies. We have processed the NPA region as a “stress-test” example of SfS’s capabilities. We will apply the technique to other sites. Ongoing improvements target the treatment of shadow boundaries, refining the image selection process and their fine bundle-adjustment, as well as extending the validation and assessment of the final models.

Acknowledgements: LROC images and LOLA DEMs were retrieved from the Planetary Data System and NASA GSFC Planetary Geodesy Data Archive.

Figure 1. (a), (c), (f)-(h) are 1x1 km maps of NPA. (a) shows the a priori LOLA DEM with the hillshade in greyscale and the elevation in color. (b) shows a map of the lunar south pole region with PSRs in orange contour, Artemis III candidate landing regions in blue rectangles (QuickMap), and NPA indicated in pink. (c) is the SfS DEM product with the hillshade in greyscale and the elevation in color. (d) and (e) show the same image footprint, where (d) is the real NAC image and (e) is the corresponding simulated image using the SfS DEM. Red ellipses show artifacts in (e) not present in (d). (f) is an average illumination map of NPA over one lunar day with a red-dashed box indicating the location of (d) and (e). (g) is a slope map derived from (c). (h) shows the roughness of (c), defined here as the standard deviation of height residuals about a plane fit to a 3x3 pix moving window.