GEODETICALLY CONTROLLED PRODUCTS: CRITICAL TO THE SUCCESS OF ARTEMIS AND A SUSTAINED HUMAN PRESENCE ON THE MOON. R. L. Fergason[1], B. A. Archinal[1], K. A. Bennett[1], M. T. Bland[1], L. R. Gaddis[1], D. M. Galuszka[1], B. M. Redding[1], J. Richie[1], L. Weller[1], E. Lee[1,2], and M. Rosiek [1,2]. [1]U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ, USA, rfergason@usgs.gov. [2]Retired.

Motivation: Geodetically controlled products, including controlled mosaics and Digital Terrain Models (DTMs), provide accurate and consistent basemaps that enable and enhance the science and exploration that could be performed by human crews on the lunar surface and they facilitate communication between engineers and scientists [1]. The use of consistently controlled base products encourages scientific collaborations by aiding strategic planning of data acquisition, supporting the production of geologic maps [2], enabling the accurate and reliable assessment of resources [3,4], and facilitating cross-discipline investigations. A consistent basemap also allows for more accurate integration of data from different instruments, such as visible wavelength images and radar [5,6], and ultimately can maximize the scientific return of lunar science investigations supported and enabled by Artemis.

Reliable geodetically controlled products will specifically benefit both Phase 1 and Phase 2 of NASA's Artemis program. During Phase 1, these consistent and accurate products will enable NASA to safely land human beings on the lunar surface near the Moon's south pole and facilitate successful operations. These maps also benefit Phase 2, as the same map products should ideally be used both by humans on the lunar surface and by the ground crew and scientists with whom they are communicating to minimize miscommunications and ensure efficient and accurate transfer of vital, potentially life-saving, information.

Existing USGS ASC Products: The USGS Astrogeology Science Center (ASC) has produced accurate photogrammetrically corrected mosaics and DTMs using data from the Lunar Reconnaissance Orbiter Camera (LROC) and the Apollo panoramic cameras for the Lunar Mapping Modeling Project (LMMP) [7-9] and as part of research supported by the NASA Lunar Science Institute [NLSI]. In addition, the ASC has developed geodetically controlled LRO Mini-RF S-band monostatic radar mosaics of both lunar poles in two look directions, as well as smaller mosaics of Chandrayaan-1 Mini-SAR data [5].

Controlled mosaic for the South Pole and Malapert Massif region: As part of the LMMP effort, we used the Integrated Software for Imagers and Spectrometers (ISIS) [10] software package to create and evaluate control networks and resulting mosaics for the lunar south polar and Malapert Massif region using LROC Narrow Angle Camera (NAC) images (Fig 1). We generated control networks using automatic image-to-image tie point methods and sub-pixel registration (with human oversight) along with bundle adjustment software [10]. These networks were then tied to an illuminated model of Lunar Orbiter Laser Altimeter (LOLA) data. The resulting polar mosaics were orthorectified using gridded LOLA topography, and the Malapert Massif mosaic was orthorectified using the corresponding LROC stereo derived DTM. This methodology resulted in a control network and an orthorectified product that has broad applicability and is tied to the LOLA reference frame.

Figure 1. LROC NAC South Pole mosaic covering the region of -90° to -85.5° derived as part of the LMMP project. RMS errors are 93 m in latitude, 57 m in longitude, 164 m in radius. The resolution of the original mosaic is 1 meter per pixel.

DTM and slope maps for the South Pole and Malapert Massif region: High-resolution DTMs provide critical information regarding the topography of the surface for both scientific investigations and evaluation of engineering criteria for safe landing. The ASC developed the methodology to generate DTMs using LROC NAC images using the commercial software system SOCET SET® from BAE Systems [11]. SOCET SET® uses matching software to correlate features in each image and uses the known camera orientation to determine topography. We then performed manual editing as required to correct errors and remove artifacts (determined by visual inspection) from the automated matching process, which significantly improves the quality of the DEM. Detailed procedures, as now being carried out by the LROC science team, have been documented [12].

As part of our LMMP work, a DTM, orthoimage mosaics slope map, and confidence map were generated of the Malapert Massif area using images with solar illumination from both the north and the south (Fig. 2). As part of the NLSI work, a DTM and related products were generated for the south pole and Shackleton crater [13]. These products constitute the highest resolution mapping products available for the lunar south pole.

A history of landed-mission support: Through these efforts, and similar efforts for other planetary bodies, the ASC has developed community-leading expertise in solving challenging photogrammetric problems through the development of innovative methods for controlled products [14,15], DTM generation [e.g.,16-18], and DTM and orthoimage mosaic generation [19]. We provide not only our products, but our methods, software and techniques, to the community, who then use these tools to create additional high-quality products [e.g., 12].

We have supported landing efforts through the generation of photogrammetric products for over 40 years (since the Viking landing on Mars for a total of 9 successfully landed missions) and understand through decades of experience how to generate products that meet the often-conflicting needs of both the science and engineering communities.

Ongoing work: The ASC has recently developed a sensor model for the Kaguya Terrain Camera (TC) instrument and is generating a controlled mosaic for the Apollo 15 landing site area [20] and plans to evaluate the south pole TC data for use in a controlled product generation later this year [21]. We have also developed procedures to rigorously control LROC NAC images with simultaneously collected LOLA track data and are investigating the quality of the derived results. Additionally, no new Artemis architecture capabilities or crew would be necessary to improve existing controlled products or to generate new products, although if new or additional images of the lunar surface were obtained from Artemis, those data could be photogrammetrically processed to enable an improved product.

Acknowledgements: References to commercial products are for identification purposes and do not imply an endorsement by the U.S. Government. Funding for this work has been provided by the NASA LRO PS, LMMP, NLSI, LASER, PDART the NASA-USGS PSDI Interagency Agreement.

References: [1] Archinal, B.A. et al. (2016) *LPS VLII*, Abs. #2377. [2] Skinner et al. (2020) *Lun. Surf. Sci. Work.*, this conference. [3] Keszthelyi L. et al. (2019) *Lun. ISRU Work.*, Abs. #503 [4] Keszthelyi L. et al. (2020) *LPS LI*, submitted. [5] Kirk R. F., et al. (2015) *LPS VLI*, Abs. #2507. [6] Patterson, W. G., et al. (2019) *LPS L*, Abs. #2861. [7] Noble et al. (2009) LEAG Meeting. [8] Rosiek, M. R. et al. (2012) *LPS XLIII*, Abs. #2343. [9] Lee, E. M. et al. (2012) *LPS XLIII*, Abs. #2507. [10] Edmundson K. L. et al. (2012) *ISPRS Annals,* I-4, 203-208. [11] Miller S. B. and Walker A. S. (1993) *ACSM/ASPRS Annual Conv.*, *3*, 256–263. [12] Henriksen, M. R. (2017) *Icarus 283*, 122, doi 10.1016/j.icarus.2016.05.012. [13] Rosiek, M. R., et al. (2013) *LPS XLIV*, Abs. #2583. [14] Fergason, R. L. et al. (2019) 4th *PDUW*, Abs. #7059. [15] Bland, M. T. et al. (2019) 4th *PDUW*, Abs. #7048. [16] Kirk, R. L. et al. (1999) *JGR*, 104(E4), 8869-8887. [17] Kirk, R. L. et al. (2008), *JGR*, 113, doi:10.1029/JE003000. [18] Fergason, R. L. et al. (2017), *SSR*, doi: 10.1007/ s11214-016-0292-x. [19] Fergason, R. L. et al. (2020) *LPS XXXIII,* Abs. #2020. [20] Gaddis, L. et al. (2019), 4th *PDUW*, Abs. #7044. [21] Gaddis et al. (2020) *Lun. Surf. Sci. Work.*, this conference.

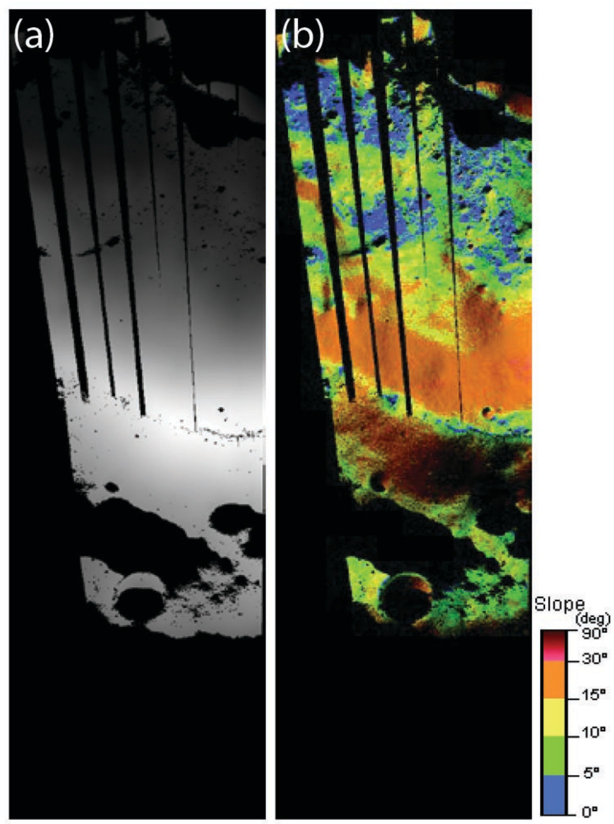

Figure 2. (a) DTM (with high areas bright and low areas dark) and (b) slope map of the Malapert Massif region. The absolute horizontal position accuracy of the DTM, as derived from SOCET SET triangulation root mean square errors, is 0.2 meters in X; 0.1 meters in Y, and 0.1 meters in radius.