USGS DIGITAL TERRAIN MODELS AND MOSAICS FOR LMMP. M. R. Rosiek, E. M. Lee, E. T. Howington-Kraus, R. L. Fergason, L. A. Weller, D. M. Galuszka, B. L. Redding, O. H. Thomas, R. A. Saleh, ,J. O. Richie, J. R. Shinaman, B. A. Archinal, and T. M. Hare, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ, 86001, mrosiek@usgs.gov.

Introduction: The Lunar Mapping and Modeling Program (LMMP) [1] is a NASA-funded effort initiated in 2007 to create useful cartographic products from past and current lunar datasets. The primary initial objective was to support exploration missions by making Lunar Reconnaissance Orbiter (LRO)-derived products useful and accessible to the Constellation Program (CxP) [2]. LRO Principal Investigators and relevant activities were funded at NASA Ames Research Center, Army Cold Regions Research & Engineering Laboratory, NASA Goddard Space Flight Center (GSFC), NASA Jet Propulsion Laboratory and the United States Geological Survey (USGS). These groups have made a wide range of products including digital terrain models (DTMs), orthomosaics, hazard/lighting maps, and data access/visualization tools [3]. Here we describe the USGS LMMP products, including extensive cartographic products and the web portal service.

Sites: USGS made 1.5 or 3.0 m gridded DTMs and 0.5 m orthomosaics for 20 of the 50 CxP regions of interest using LRO Narrow Angle Camera (NAC) images (~0.5 m/pixel resolution). Additionally, 3 or 5 m DTMs and 1 or 1.5 m image orthomosaics for 3 sites were produced from digitized Apollo Panoramic images. The requirement was to produce DTMs covering at least a 10 by 10 km region (100 sq. km) with a goal of covering 20 by 20 km (400 sq. km), and an orthomosaic for a 40 by 40 km region (1,600 sq. km). The DTMs and othomosaics were geodetically controlled using Lunar Orbiter Laser Altimeter (LOLA) spot elevation measurements (based on LRO Planetary Data System (PDS) release 5 March 2011). The Apollo Panoramic DTMs are lower resolution, but cover a larger area at each site (3,276 ± 718 sq. km) than the DTMs produced using the LRO NAC images (558 ± 175 sq km). The Apollo Panoramic orthomosaics cover the same area as the Apollo Panoramic DTMs and the LRO NAC orthomosaics cover a larger area (1,433 ± 123 sq km) than the LRO NAC DTMs.

Source material: LROC NAC images were provided by the LROC Science Operations Center [4]. Apollo Panoramic images were obtained from the Arizona State University [5]. LRO LOLA Reduced Data Records were available through the web [6]. The Apollo Panoramic DTMs were initially controlled to the Unified Lunar Control Network 2005 (ULCN 2005) [7] and later readjusted to the LOLA track data. NAC smithed SPK SPICE kernels from the LOLA team cross over analysis were used where available. Otherwise GSFC reconstructed SPICE data (CKs and SPKs) were used. At the time the Apollo Panoramic images were processed there were no SPICE data available so the image support data were obtained from National Space Science Data Center. These data consisted of microfilm recordings of the computer printouts that recorded the Apollo mission.

Coordinate system and precision: All products are in the lunar mean Earth/polar axis coordinate system [8] and the preliminary global reference frame of the LOLA track data and DTMs (release date specified above). The absolute accuracy of these products is limited by the accuracy of the LOLA data used for control and orthorectification. The expected vertical precision of a DTM derived from LROC NAC stereo images varies from ~40 to 100 cm and Apollo Panoramic stereo images varies from ~50 to 120 cm.

Software and algorithms: *ISIS 3.2.1:* The Integrated System for Imagers and Spectrometers (ISIS) USGS [9] is used for image ingestion, radiometric calibration, tie pointing, photogrammetric control, orthoprojection, and creation of mosaics, all using geometric camera models.

SOCET SET ®BAE: SOCET SET is a commercial software package with photogrammetry capabilities [10]. For DTM production, ISIS was used to radiometrically calibrate the LROC NAC images and compute SOCET SET keyword values for the line scanner sensor model. Raw image files and keywords were then imported into SOCET SET where images were tied to each other and controlled to LOLA track data. Automatic DTM extraction was done using stereo matching. DTM quality control and editing were done manually. Completed DTMs were transferred from SOCET SET back into ISIS. This DTM was combined with LOLA-derived DTMs to allow for the creation of orthomosaics.

Products: In addition to the above described DTMs and orthomosaics, four other DTM-derived products are provided: slope maps, hill shade maps, shaded relief maps, and confidence maps (based on SOCET SET "figure of merit" information). All four of these products cover the same area as the DTM. The orthomosaic covers a larger area than the DTM (40 x 40 km, source images allowing), hence the need for the combined LRO NAC-LOLA DTM described above. The primary released file format is GeoTIFF.

Validation process: The main validation step is the comparison between LOLA track elevation values and the DTM elevation values. Validation begins during the triangulation process. As LOLA track points are selected and aligned to geomorphic features in the images, the triangulation results report the root mean square error (RMSE) for the horizontal and vertical agreement between the latitude, longitude, and elevation values. The alignment between the images and LOLA tracks can be evaluated visually. Horizontal alignments of the mosaics were validated by visually comparing the mosaics to hillshaded images of the DTMs for the same areas. This process results in a horizontal alignment between the DTM and the LOLA data at about the 20 – 30 m level. The reported horizontal error of the LOLA data is 20 m [11]. The SOCET SET control net was exported to ISIS so the orthomosaics would align with the DEM. This network was augmented with auto measured points for images used to fill the 40 by 40 km area needed for the orthomosaic.

After the DTM was edited and visually inspected, it was exported from SOCET SET, converted into an ISIS cube file, and then converted to final product formats with GDAL. Then the final DTM product was displayed in ArcMap along with the LOLA track data that cover the DTM. Each LOLA track point was intersected with the DTM and the elevation value of the DTM was recorded. The difference between the DTM elevation value and the LOLA track point was calculated. The vertical agreement between the 20 LROC NAC DTMs and the LOLA track data is within -8.2 ± 3.4 and 8.5 ± 3.8 m at the 95% confidence level. For the three Apollo Panoramic DTMs, the vertical agreement is within -71.3 ± 9.5 and 77.1 ± 25.9 m at the 95% confidence level. The higher error for the Apollo Panoramic DTMs was caused by controlling first to the ULCN 2005 control net and then aligning to the LOLA data. At the time the Apollo Panoramic DTMs were created, LOLA data were not available.

Summary: LMMP products will soon be available at the LMMP Portal [12]. These include very large high resolution DTMs and orthomosaics of close to 50 key sites on the lunar surface, and high resolution controlled polar mosaics. These products constitute an important initial step in processing LRO datasets and should greatly facilitate the exploration and study of these significant lunar sites.

References: [1] Nall, et al. (2010), LEAG #3024; Noble, et al. (2009), LEAG #2014. [2] Connolly (2006), available at http://www.nasa.gov/pdf/163092main_constellation_program_overview.pdf. [3] Archinal, (2010), AGU #P53D-1549. [4] http://www.lroc.asu.edu. [5] http://apollo.sese.asu.edu. [6] http://ode.rsl.wustl.edu/moon/indextools.aspx. [7] Archinal,et al., (2006), USGS, Open-File Report 2006-1367. [8] Archinal, et al. (2011), Cel. Mech. & Dyn. Ast., doi 10.1007/s10569-010-9320-4; LRO & Lunar Geodesy and Cartography Working Group (2008), http://lunar.gsfc.nasa.gov/library/LunCoordWhitePaper-10-08.pdf.[9] Anderson et al., (2004) LPSC #2039. [10] Miller, S. B., and Walker, A. S. (1993), ACSM/ASPRS Annual Conv. 3, 256–263; Miller, S. B., and Walker, A. S. (1995), Z. Phot. Fern. 63(1), 4–16. [11] Smith, D. E., et al., (2011), LPSC #2350. [12] http://lmmp.nasa.gov.

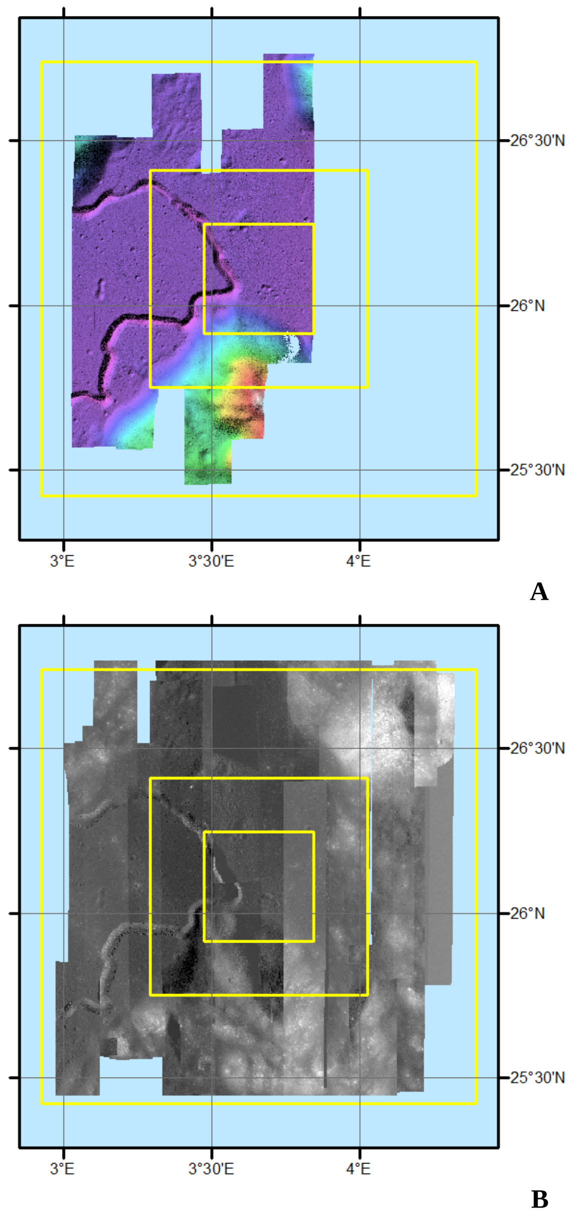

Figure 1 – The top image (**A**) shows the color-hillshaded DTM for the Apollo 15 site. The yellow boxes show the 10, 20 and 40 km bounding areas. The bottom image (**B**) shows the orthomosaic for the same site. Both images are in equirectangular projection.