CONTROLLED POLAR MOSAICS OF THE MOON FOR LMMP BY USGS. E. M. Lee, L A. Weller, J. O. Richie, B. L. Redding, J. R. Shinaman, K. Edmundson, B. A. Archinal, T. M. Hare, R. L. Fergason, and the Astrogeology Science Center programming team, U. S. Geological Survey (2255 N. Gemini Dr, Flagstaff, AZ 86001, elee@usgs.gov)

Introduction: The geometrically controlled polar averaged mosaics shown in Figure 1 and Figure 2 were produced in support of the Lunar Mapping and Modeling Project (LMMP) [1,2], developed to support the Constellation Program (CxP), by team members of the Astrogeology Science Center. The Lunar Reconnaissance Orbiter (LRO) spacecraft acquired high resolution images (~0.5 m/pixel) with the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) instruments [3]. The Lunar Orbiter Laser Altimeter (LOLA) [3] team released a global Digital Elevation Model (DEM) and higher resolution polar DEMs in polar stereographic projection in March 2011 which was the base for the ground control points. The polar mosaic coverage includes 85.5° to 90° latitude north and south, and 360 degrees of longitude at 1.0 m/pixel resolution resulting in final mosaics that are 273,051 lines by 273,051 samples in size. These are the largest geodetically controlled lunar or planetary mosaics (70 GBytes) ever produced by the USGS Astrogeology Science Center.

In order to handle the large volume of data it was necessary to improve the existing ISIS software and hardware. New software development in ISIS3 included conversion to binary control networks and modification to existing programs so they could handle the new format and large control network files. The enormous disk space needed to store the data also led to purchasing new hardware that utilized cluster computing methods and storage space.

The primary focus was to geometrically control the NAC images and to create controlled mosaics showing as much information in the shadowed areas as possible. Emphasis was not necessarily placed on producing a cosmetically perfect product. In order to create a product with minimal shadow artifacts, a secondary averaged mosaic was also created. The averaged mosaics have misregistration in some areas that appear as double features. These were not corrected due to time limitations. The mosaics were validated against the LOLA DEM for accuracy.

Source data: The LROC NAC images from LROC Science Operations Center (SOC) [4] were used to create the mosaics. The LRO LOLA Reduced Data Record (RDR) based on LRO PDS Release 5, March 2011 was used to measure ground points and to project images to polar stereographic projection. For LROC NAC images, reconstructed SPICE kernels were provided by Goddard Space Flight Center for LRO, and additional reconstructed SPICE kernels provided by the LOLA team based on their cross-over analysis. The LROC team from Arizona State University also provided corrected SPICE kernels to USGS, and preliminary lists of images for both poles.

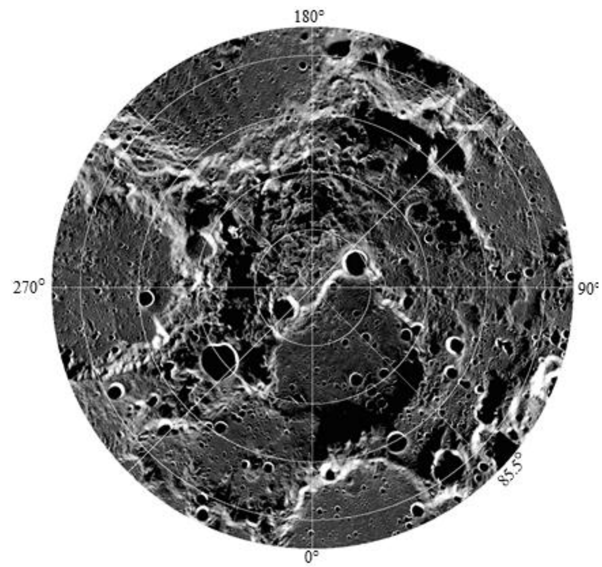

Figure 1. North Pole mosaic

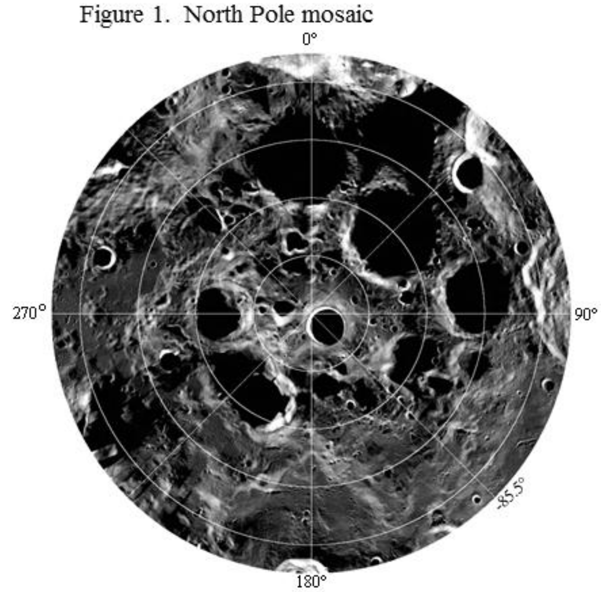

Figure 2. South Pole mosaic

A majority of the images in the mosaic are from the primary or nominal phase, and occasionally from commissioning and science phase to fill gaps. Poor quality images and those with poor geometric information were eliminated from processing.

Software and Hardware: The Integrated Software for Imagers and Spectrometers (ISIS) version 3.2.1 software package [5] was used to ingest and radiometrically calibrate the images, create and evaluate control networks, and generate and review mosaics. The intensive processing requirements for one mosaic required additional hardware to be set up as a compute cluster that could run multiple jobs, in addition to allocating 60 TB of disk space. The enormous amount of control points (North Pole – 340,142 , South Pole – 527,756) in the control network files, and large number of images (North Pole - 3,682, South Pole - 3,827) also led to major software development in order to improve efficiency. Extensive work was done in converting control networks normally stored in ASCII format to a binary format. All programs dealing with control networks had to be modified to deal with the binary format. Existing interactive tools also had to be modified to handle the massive file sizes. Many of the existing programs were improved as a result of encountering the limitations at various phases of processing the data.

Processing: The raw images were ingested and radiometrically calibrated. The NAC images are captured as left and right pairs, so control points between each pair were collected first. Next, the outer perimeter of each left-right pair was seeded with tie points and additional control measures from other overlapping images added to all the tie points. An interactive ISIS3 program (qnet) was used to collect the ground points and record the latitude, longitude, and radius based on the polar 10 m/pixel DEMs. The ground source file generated from V1.05 LOLA DEMs scaled to 10 m/pixel with a bounding box encompassing the entire set of NAC images included in the mosaics. The following are polar stereographic projected V1.05 LOLA DEMS that were used:

"LDEM_75S_30M_radius_Mar2011.cub"
"LDEM_875S_5M_radius_Mar2011.cub"
"LDEM_75N_30M_radius_Mar2011.cub"
"LDEM_875N_5M_radius_Mar2011.cub"

Most ground control points were assigned apriori precisions of 100 m in latitude and longitude and 20m in radius, and adjusted as needed by the analyst. Only a limited number of ground points were constrained due to the lack of features visible in more than one image. The final control networks consisted of 2,102,373 measures for North Pole and 3,363,623 measures for South Pole. Bundle adjustments (jigsaw) were performed for each network. Analysts identified bad measures based on residual error analysis, and deleted or corrected the measures. The bundle adjustment for each network was repeated until an acceptable solution was reached. We solved for spacecraft (i.e. camera) orientation (direction and twist), and the spacecraft position.

After the bundle adjustment, the camera pointing and position was updated and the images processed further to deal with the shadows. Since the goal was to show information in the shadowed areas, a cutoff pixel value was set to 0.0007 density number (DN) after evaluating DN values in different shadowed areas. The input images were masked so all pixels less than the cutoff value were set to invalid pixels. The remaining salt and pepper type pixels were deleted, and the jagged edges smoothed. Finally, the processed images were cropped down to show only the area containing valid data in order to minimize disk space usage. The cropped images were projected to a polar stereographic projection at 1 m/pixel.

Each pole was broken into 103 tiles for ease of processing on the compute cluster. Two mosaics were created for each tile. The first contained a mosaic of each projected image in the first band with the filename stored in the second band. The second band was used to track and identify which image a particular valid pixel in the mosaic came from. The second mosaic contained averaged pixel values where more than one image overlapped a pixel location. The averaged mosaic provided a more aesthetically pleasing product especially along image boundaries.

Validation: The mosaicked tiles were compared against a hill shade file of the LOLA DEM for accuracy, and checked for offsets between adjacent images. The mosaics met the LMMP requirement of acceptable horizontal accuracy within 100 meters of the LOLA data. The final mosaic consists of all the individual tiles mosaicked into a single file with a single band showing only the image information converted to 8 bit by saturating 0.2% of the data at the low and high end of the histogram.

Summary: We have made major improvements in our software and hardware, and in our ability to process large volumes of data. Each mosaic produced by USGS will be available through the LMMP portal web site [6].

References: [1] Nall, M., et al. (2010), LEAG #3024; [2] Noble, S.K., et al. (2009), LEAG #2014. [3] Chin, G., et al. (2007) Space Science Reviews, volume 129, issue 4, pp.391-419. [4] https://lrocsoc.ser.asu.edu/ [5] http://isis.astrogeology.usgs.gov/UserDocs/index.html. [6] http://lmmp.nasa.gov.