LUNAR SOUTH POLE DIGITAL ELEVATION MODELS FROM LUNAR RECONNAISSANCE ORBITER NARROW ANGLE CAMERA.
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Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) consists of one Wide Angle Camera (WAC) for synoptic multispectral imaging and two Narrow Angle Cameras (NAC) that provide high-resolution images (0.5 to 2.0 m pixel scale) of key targets. LROC was not designed as a stereo system, but can obtain stereo pairs through images acquired from two orbits (with at least one off-nadir slew). Off-nadir rolls interfere with the data collection of the other instruments, so during the nominal mission LROC slew opportunities are limited to three per day [1].

This abstract describes a methodology of Digital Elevation Model (DEM) generation from LROC stereo pairs over the lunar south pole and provides a comparison to the Lunar Orbiter Laser Altimeter (LOLA) 5 m DEM [2]. Previously we described DEM generation for the Lunar Mapping and Modeling Program (LMMP) [3, 4]. The methodology was updated to include registration of the LROC NAC images to the LOLA DEM and LOLA track data. Also, the SOCET SET (®BAE Systems) [5] sensor model was updated to accommodate images that crossed the pole, and other software modifications were made to map images that were captured while the spacecraft was rotating. Because of the shadows in the polar region, we used images that were collected at four different times and tied those datasets together.

Image datasets: The LROC NAC images were acquired in four groups from 2010: 21 SEP, 23 SEP, 4 OCT, and 11 OCT. In Figure 1, the four different LROC NAC image groups are shown. Shadowed areas were eliminated in Figure 1. In order to tie these groups together, extra image tie points were used around the rim and wall of Shackleton crater and along ridge lines where the images went into shadows. The images were controlled within each group and then as a complete group.

Registration to LOLA: For our LMMP mapping we registered the images to the LOLA tracks. In the polar area, there are so many LOLA tracks that we were unable to handle them all as a single group. We initially registered to the LOLA grid and used those points as Z control points. We then selected patches of LOLA tracks to use for XYZ control. Tie points were used to tie images together with no constraint on the XYZ location. The distribution of these points is shown in Figure 2. The XYZ system we used was a south Polar Stereographic projection.

The registration process provides a Root Mean Square Error (RMSE) between a LOLA track point and where we identified the location on LROC NAC images. The RMSE-X value was 14.8 m and the RMSE-Y value was 10.1 m for 106 XYZ control points. The RMSE-Z of 4.6 m combines the 106 XYZ and 1008 Z control points.

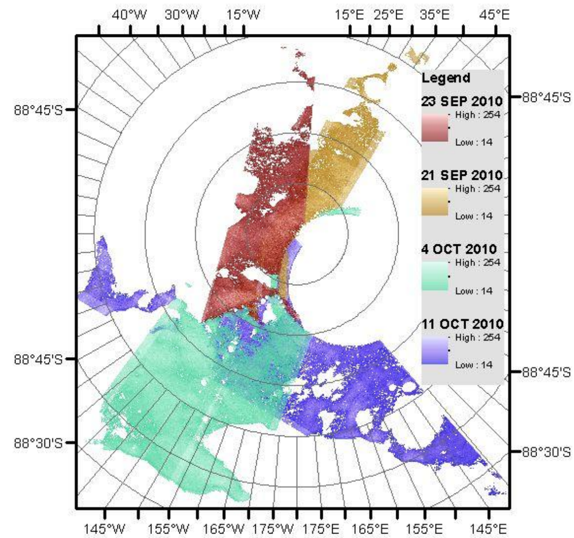

Figure 1 – LROC NAC images

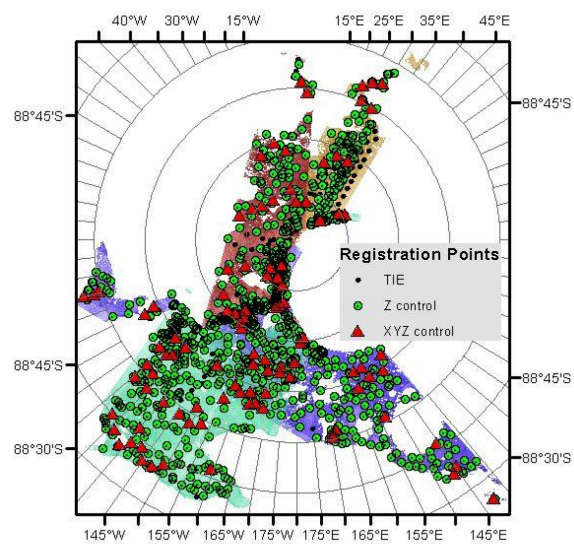

Figure 2 – Registration points.

The range of the difference in X was between -26.9 and 20.1 m, in Y the range was between -56.0 and 23.6

m and in Z the range was between -9.5 and 8.5 m for the XYZ points. For the Z points the range of the difference in Z was between -29.1 and 35.0 m. The XYZ points were based on LOLA track points and Z control points were based on the LOLA grid data. Because the gridded data have interpolated points, the larger range of the Z control points shows the errors of gridded data compared to the track data.

Sensor model and software update: SOCET SET's generic pushbroom sensor model failed when determining the time an image line was obtained for images that crossed the poles. We therefore replaced its interpolation method with the more robust "Brent's Method," a root-finding algorithm [6].

Mapping with images acquired while the spacecraft was rotating was accomplished by supplying quaternions at an adequate interval that captures the rotation, to the sensor model. Quaternions describe the sensor pointing, and if not supplied, the sensor model will calculate default quaternions based on *one* instance of the sensor pointing, which is insufficient if the sensor pointing is not held reasonably constant. As a by-product, these quaternions also allow for a straightforward import of images into SOCET SET without the need to preprocess for boresight sample locations, image binning and mirrored (flipped) images.

Comparison of LROC NAC DEM to LOLA Grid: Sixty-six LROC NAC images were used on this project. This resulted in 57 stereo models that provided DEMs and were used to merge into a single DEM. The final merged DEM has 66,588,910 points and covers 1,065 sq km. Some differences in elevation were found in the seams between the stereo models: mostly on the order of 1 or 2 m but some were up to 5 m. The seams were smoothed during editing. Also, the seams were noticeable where a DEM from one stereo model filled the shadows of another stereo model. We used a shadow masking program to remove areas in the stereo model that were in shadow. We are in the process of editing the edges of the shadows where some erroneous data remain.

Looking at the initial LROC NAC DEM the difference to the LOLA grid DEM has a mean difference of -0.6 m and a standard deviation of 5 m. The range is between -618.2 and 2343.1 m. We looked at a few of the points with large differences and they are either due to spikes in the LOLA DEM or on the edges of shadows in the LROC NAC DEM. We will need to examine these points further and determine which points need to be edited within the LROC NAC DEM and which points are spikes in the LOLA DEM. Most of the differences between the LROC NAC DEM and the LOLA grid are within 50 m (99.9787%).

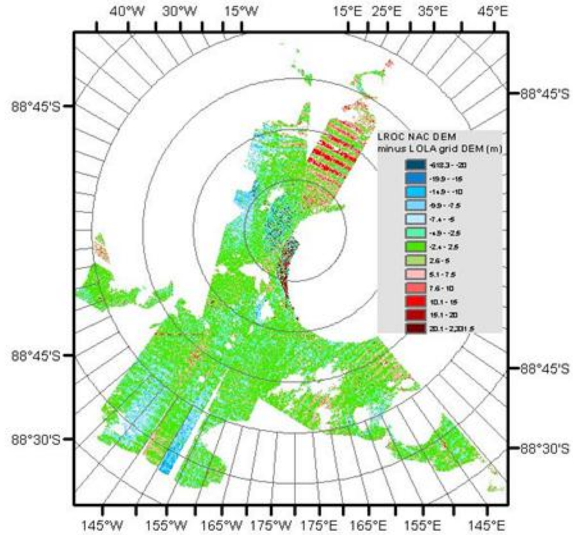

Figure 3 – Difference map between the LROC NAC DEM and the LOLA DEM

The major differences are along the rim and wall of Shackleton crater. This is where many LOLA tracks cross over and they are slightly offset. There are a few LOLA tracks that appear to be outliers and can be seen as streaks in the difference map.

The other noticeable features in Figure 3 are rolling bands or stripes. These are most likely caused by motion in the sensor that is not being properly modeled. There are other potential reasons for the visible rolling bands in the difference map: 1.) The spacecraft is transitioning between light and shadow and spacecraft motion is caused by adjusting for this change; 2.) The spacecraft motion is recorded at 10 Hz but the SPICE data are available at 5 Hz so sufficient information on the motion is not available; 3.) The camera model needs to be upgraded further to handle and solve for the dynamic motion.

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