UPDATE ON HIGH-RESOLUTION GEODETICALLY CONTROLLED LROC POLAR MOSAICS. Brent Archinal[1], Ella Lee[1,2], Lynn Weller[1], Janet Richie[1], Ken Edmundson[1], Jason Laura[1], Mark Robinson[3], Emerson Speyerer[3], Aaron Boyd[3], Ernest Bowman-Cisneros[3], Robert Wagner[3], Ara Nefian[4], [1]USGS, Astrogeology Science Center (2255 N. Gemini Drive, Flagstaff, AZ 86004; barchinal@usgs.gov); [2]Retired; [3]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287; [4]NASA Ames Research Center, Moffett Field, Mountain View, CA 94035.

Introduction: We are continuing our effort to create geodetically controlled high-resolution (1 m/pixel) Lunar Reconnaissance Orbiter (LRO) [1] narrow angle camera (NAC) [2] polar mosaics of the lunar north and south polar caps, poleward from 85° latitude. The final products of this effort will include controlled mosaics of all useful and useable images and “illumination” controlled mosaics made every 10° of solar longitude. Such products are critical for the identification, evaluation, extraction, and use of lunar resources related to illumination, including the availability of sunlight, solar power, or the presence of permanently shadowed regions that may harbor cold trap resources.

Similar mosaics previously generated under the Lunar Mapping and Modeling Project (LMMP) [3] contained a smaller image set, and were not optimized to create separate mosaics showing solar illumination changes. Coverage was limited to 85.5° poleward [4], but now extends to 85°, an increase in coverage of 23%. Problems with the control network, used to create the previous mosaics, have been addressed. In addition, image tie-pointing methods and network solution parameterization are improved.

Illumination Mosaics: There will be 36 mosaics for the north and south poles, at every 10° of solar longitude. We are evaluating whether to make averaged mosaics and/or mosaics with the best illuminated images shown in front of other images. Note that doing averaged mosaics (see Figure) is only possible when the images are controlled to the sub-pixel level, thus allowing images to be co-added, increasing the signal-to-noise ratio in low light conditions and showing all areas ever illuminated while the images were collected.

With 148 possible mosaics at 1 m/pixel, 32 bits/pixel, each mosaic is ~86 GB for a total volume of ~13 TB. The final mosaics and updated geometry information (SPICE [5]) will be archived to the Planetary Data System (PDS).

These mosaics will provide many benefits for science, engineering, exploration, and for supporting future mapping and global lunar reference frame improvement efforts. The high resolution and accurate registration properties will be useful for identifying small scale permanently shadowed regions (lunar cold traps) or areas of lengthy solar illumination (ideal sites for future exploration [6]), targeting observations by future missions (e.g. [7]), detailed surface characterization and landing site assessment [8], geological and resource mapping, and change detection.

Other Benefits: This work also helps improve capabilities for the development of further large controlled mosaics, as well as provide information on what critical tools will need to be developed in advance of such work [9]. These products can be used to characterize the precision and accuracy of a priori LRO SPICE data and possibly to provide further geometric calibration of the LROC and LOLA instruments. The updated SPICE (orientation, or C kernel) data could be used to improve the LRO Lunar Orbiter Laser Altimeter (LOLA) [10] results. For example, improved orientation data would allow for a new type of “crossover” adjustment of LOLA data with controlled simultaneous NAC images.

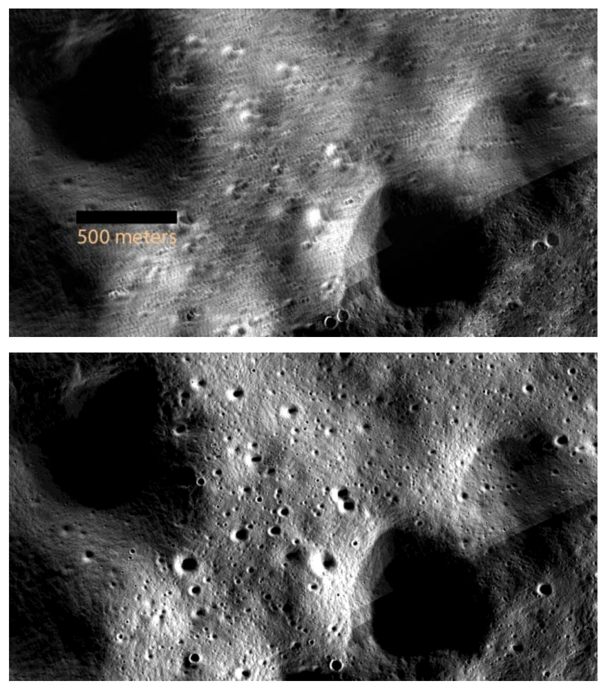

Figure: Area (at 85.°588N, 123.°159E) in north polar cap showing 7 images (top) in an uncontrolled averaged mosaic vs. (bottom) a controlled averaged mosaic. Note blurring and doubling of some features in the top image with offsets up to 165 m. The scale is 7.5 m/pixel.

Current Solution Statistics: Control solutions are being performed with the USGS ISIS software package [11] and in particular the *jigsaw* application [12]. We have completed preliminary control network solutions for both poles. Images not used have been tracked for future use, or for possible manual work to update an area of interest. The south pole network has not yet been constrained (controlled to ground in absolute coordinates) while the north pole network is constrained to LOLA data at 18 points (resulting in a higher maximum residual). The following table shows the current network results:

Current Solution	North Pole	South Pole
Images	9,688	18,963
Points	386,873	1,638,727
Measures	3,064,199	13,745,057
Std. Dev. (pix.)	0.31	0.65
Max. resid. (pix.)	7.27	4.99

Technical Problems Encountered: Numerous problems have been encountered but they have been largely addressed. Problems include a) manual checking of high residual tie points; b) manual measures needed to be added for some "island" images (i.e. with few areas of illuminated overlap with other images) including 26 images in the north; and c) some images have not been successfully controlled because they are blank (532 in the north), or they are part of an island and the images do not overlap. We are also still assessing the best way to winnow out bad data near the edges of images and in shadows that caused, and are still causing, black line artifacts in the previous LMMP best-resolution "image on top" mosaics, as well as for averaged mosaics.

Comparison to Other Networks: Due to the significant increase in the number of images used, these networks are substantially larger than the original LMMP networks, and in terms of the total number of control points and measures, comprise one of *the largest solar system control networks ever done, possibly including terrestrial networks*. Only a final global THEMIS IR controlled mosaic [13] is likely to exceed these networks in size in the next several years. Current large planetary networks are listed in the table here:

Body	Name/reference	Images	Points	Measures
Moon	ULCN 2005 [14]	43866	272931	546126
Moon	LMMP North Pole USGS [4]	3682	340142	2102373
Moon	LMMP South Pole USGS [4]	3827	527756	3363623
Mercury	USGS Messenger (Pers. Comm.)	60281	555120	6599703
Mars	USGS Themis IR [13]	13496	1578113	6069647
Moon	North Pole (this work)	9688	386873	3064199
Moon	South Pole (this work)	18963	1638727	13745057

Ground Control: We have looked at several possibilities for providing absolute horizontal and vertical control of these networks. Testing has just been completed using NASA Ames routines that match illuminated LOLA track data to images [15]. These algorithms were successfully developed for matching between track data and Apollo Metric camera images and are now working to do matching to NAC images. We are about to install this software at USGS and create tools to use the matching information for comparison with or in our network solutions. We will redo our solutions with the LOLA tie point information constrained appropriately to the accuracy of the LOLA track data, thus providing a significant amount (thousands of points) of absolute constraints to the LOLA reference frame.

Plans: This year we plan to finish the initial full north and south pole solutions, create preliminary averaged mosaics and test 10° illumination mosaics, and derive LOLA-based control points for comparison. In 2016, we will complete final solutions tied to LOLA points, make final mosaics, archive products to the PDS, and document the work with a journal article.

Future Needs: This work serves as a reminder of the need for developing cartographic processing tools for even larger mosaics. Examples are the global THEMIS IR work or the likely global coverage of the Moon at 2 m/pixel with LROC images – with *a need to possibly control well over 1 million NAC images* – as opposed to the ~28,000 images processed here. Previous recommendations [9] regarding the need for doing NASA cartography planning and developing such tools still stand.

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