

Update On High-Resolution Geodetically Controlled LROC Polar Mosaics

by

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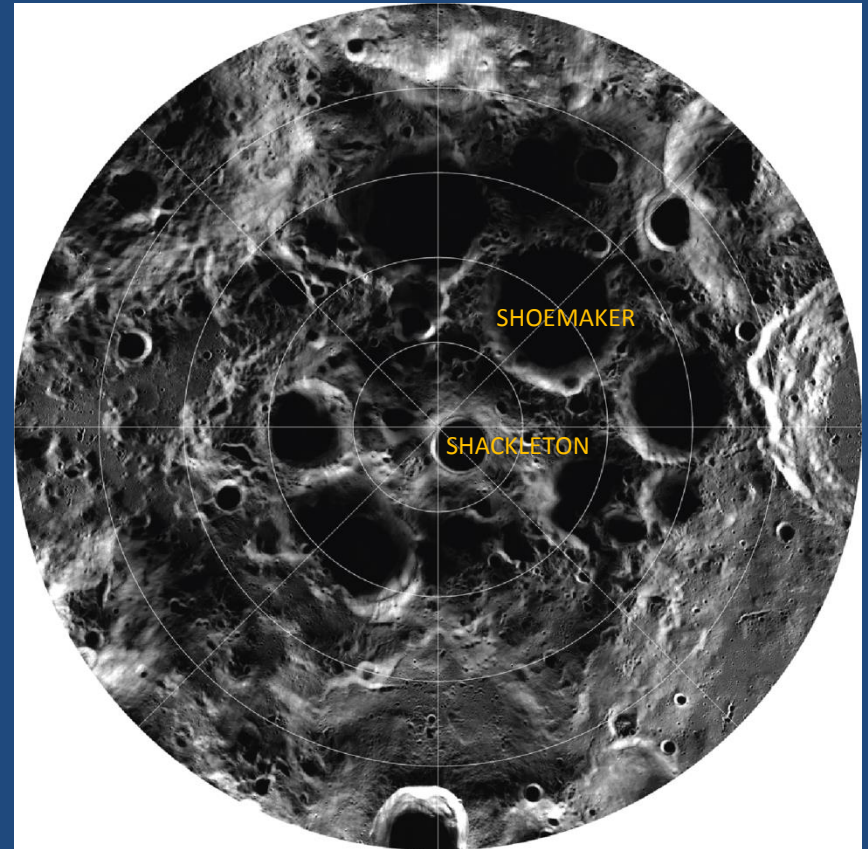
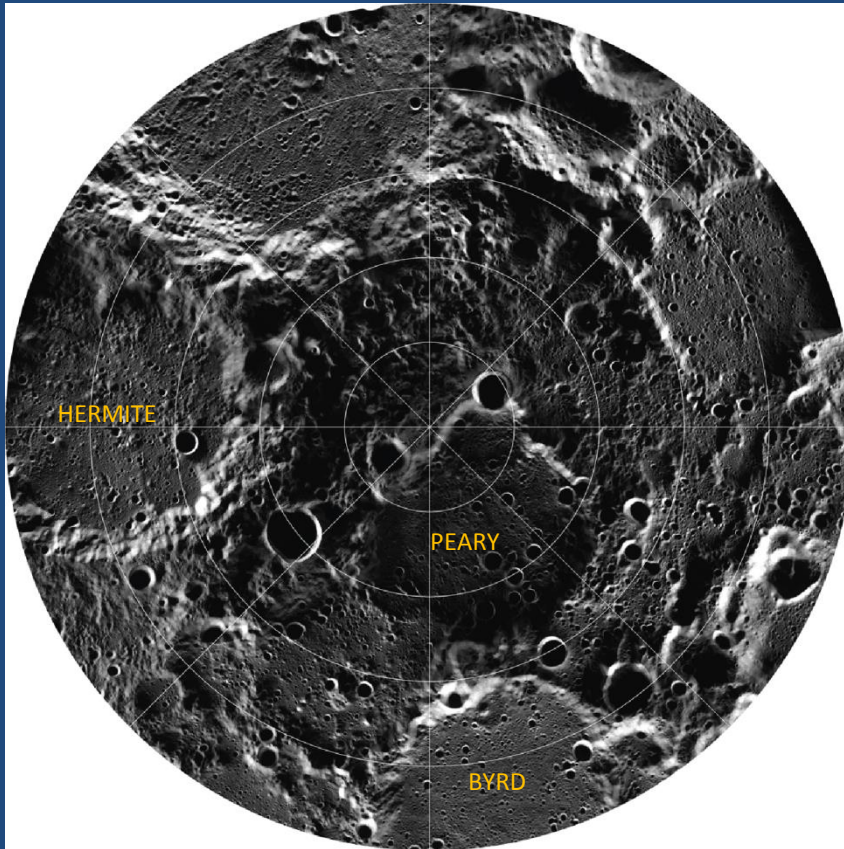
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Outline

- Current status of mosaics
- Products/Benefits
- Use for solar illumination mapping
- Registration examples
- In progress – controlling to LOLA
- Addressing LEAG questions
- Summary

Current Mosaics

North and South poles to 85° latitude



Shown at 280 m/pixel, derived from 3 m/pixel. Final version to be at 1 m/pixel. Averaged images, projected on LOLA topography. Polar stereographic projection. Grid shows 1° of latitude and 45° of longitude. North has 0° longitude at bottom (toward Earth) and south has 0° longitude at top. These may be the *largest controlled planetary mosaics ever made*, in both number of original image pixels and numbers of tie points and measurements.

Solution Statistics

Comparison of Large Solar System Control Networks					
Body	Network/Mosaic Name	# images	# points	# measures	Reference(s)
Moon	ULCN 2005	43,866	272,931	546,126	Archinal et al., 2006. (USGS OFR)
Moon	LMMP North Pole (USGS)	3,682	340,142	2,102,373	Lee et al., 2012. Pole to 85.5°d, LROC NAC.
Moon	LMMP South Pole (USGS)	3,827	527,756	3,363,623	Lee et al., 2012. Pole to 85.5°d, LROC NAC.
Mercury	(USGS MESSENGER)	60,281	555,120	6,599,703	Personal communication, L. Weller.
Mars	(USGS THEMIS DAY IR)	24,721	980,010	4,221,165	18 of 28 tiles, test merge. Pers. Comm., L. Weller.
Mars	(USGS THEMIS NIGHT IR)	14,980	925,358	4,278,516	13 of 28 tiles, test merge. Pers. Comm., L. Weller.
Moon	North Pole	9,688	386,873	3,064,199	This work
Moon	South Pole	18,962	1,638,726	13,745,031	This work
Moon	Both poles	28,650	2,025,599	16,809,230	This work

Polar Mosaic Solution Residual Information		
	(pixels)	
	North	South
Mean:	0.46	1.08
Std Deviation:	0.31	0.65
Median:	0.39	0.97
Mode:	0.25	0.79
Skew:	0.70	0.50
Maximum:	7.27	4.99
Note: 1 pixel ~= 1 meter		

What and Why?

- Products
 - north and south polar averaged mosaics, from $\pm 85^\circ$ to $\pm 90^\circ$ latitude; 1 and 10 m/pixel versions
 - mosaics (x 2) using all useful images
 - mosaics (x 72) using images from every 10° of solar longitude
 - images (all) with Updated geometry
 - data products (all?) archived to the PDS
 - USGS ISIS software improvements
 - ARC software for LROC NAC to LOLA track matching
 - summary paper
- Benefits
 - identifying small scale permanently shadowed regions (lunar cold traps) or areas of lengthy solar illumination
 - ideal sites for future exploration
 - providing detailed surface characterization and landing site assessment
 - providing base for geological and resource mapping and change detection studies
 - eliminating the need for each user to register multiple images at random (polar) sites
 - improving tools for tie-pointing and photogrammetric control
 - characterizing LRO SPICE data precision, accuracy; instrument boresight offsets
 - allowing for improvement of LOLA track relative positions



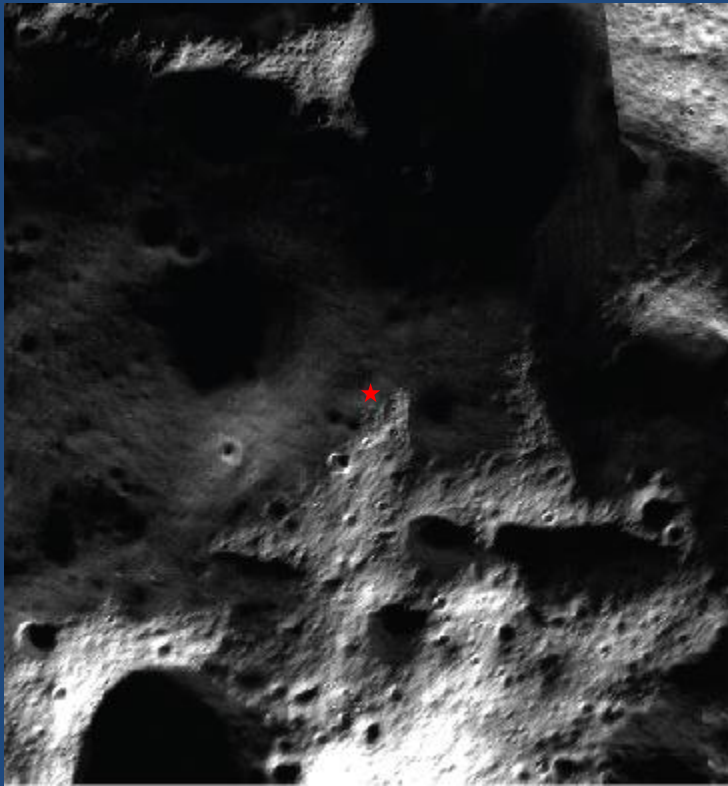
Example Solar Illumination Mosaics - Movie

South pole –
Shackleton Crater at
center (20 km dia.),
0° longitude up

All images used in
first frame of movie.
Then, solar longitude
of 0-10°,
incrementing to 80-
90°

North Pole

Before / After control (example 1)



Mosaicked at 10 m/pixel; 3.6 x 3.9 km shown; red star is north pole

Before / After control (example 2)



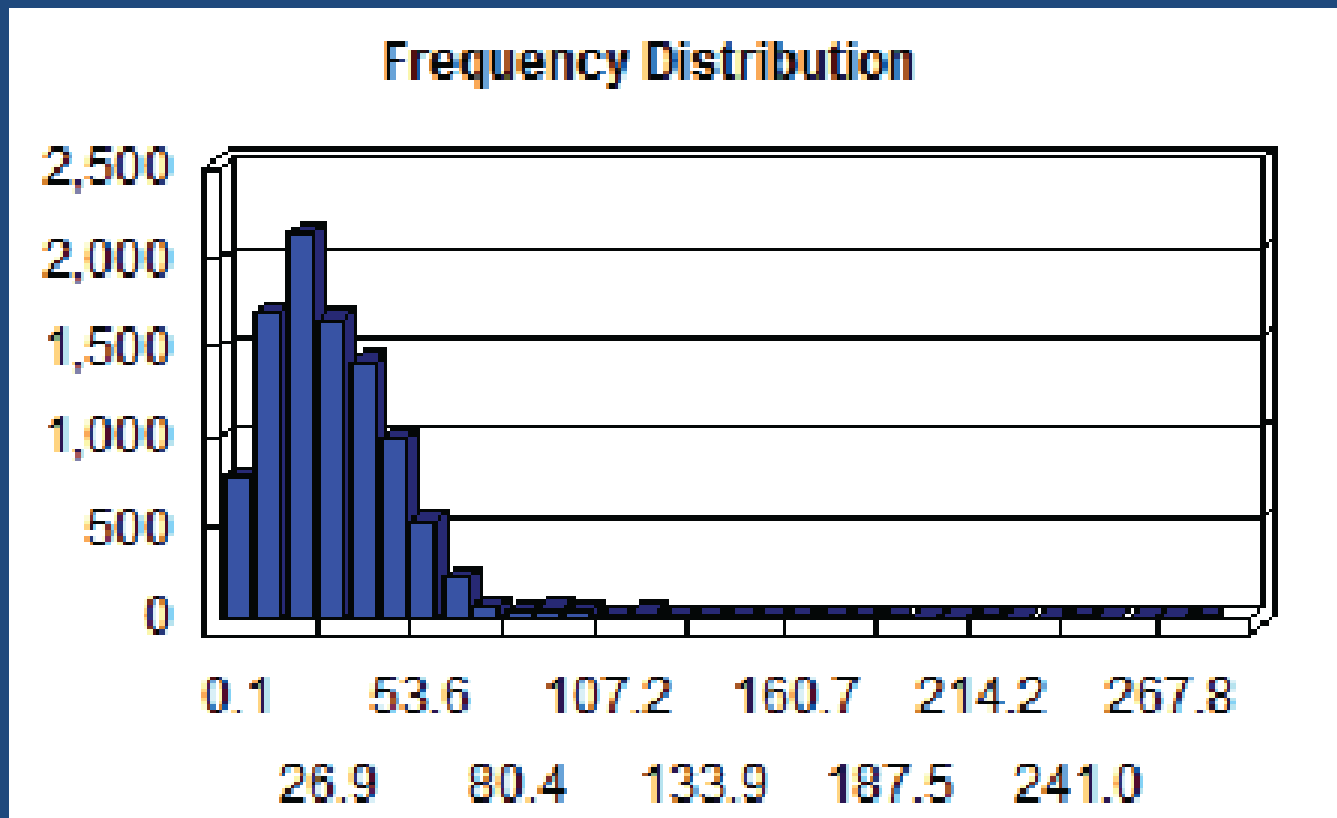
An area (latitude 85.6° north) before and after (upper and lower) control of 7 images, and shown at a resolution of 7.5 m/pixel. Largest shifts are 165 m.



SNR can be increased with averaged mosaics, but only with controlled / registered images

Histogram of Image Movement

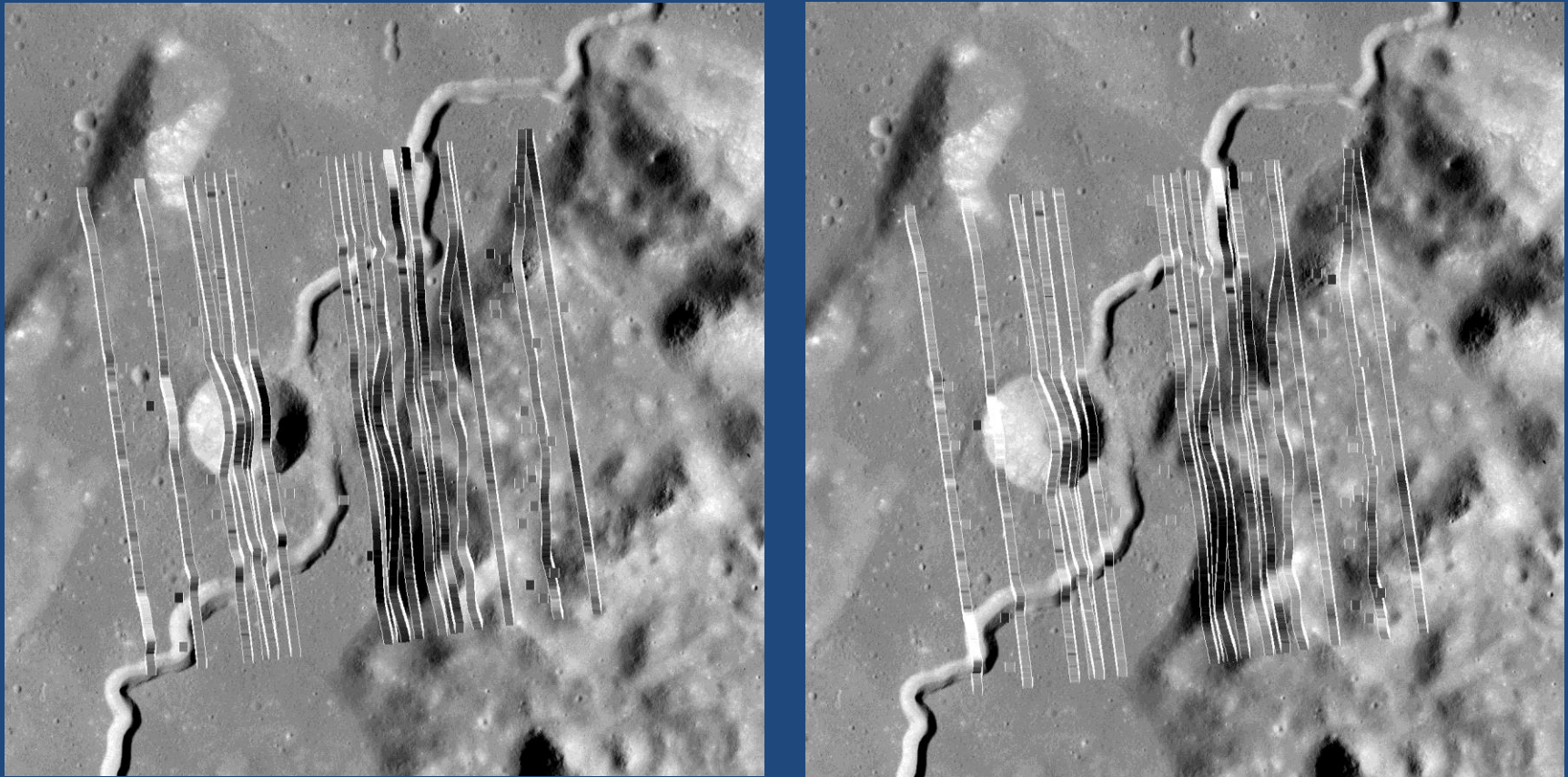
Movement after control in meters; 9,688 images



Mean total movement of 32 m \pm 21 m, with a maximum outlier of 281 m. North pole mosaic, tied to LOLA ground points in 16 locations. Movements currently reflect: a) errors in the a priori SPICE (CK and SPK) data; and b) insufficient control to LOLA. Need to improve on the latter in order to investigate the former.

Controlling to LOLA Tracks

Before / After matching



- Example is a portion of Apollo Metric image 15-1134, with Hadley Rille.
Attempting to use now with LROC NAC images. See Nefian et al. (2014) *LPS XLVI*, #1679
- *May also be able to improve relative position of LOLA tracks* -> improved local LOLA topography; perhaps eventually global improvement?

Addressing LEAG Meeting Goals & Themes

“What is our current understanding of the location ... of the resources?”

- This study involves developing products for determining polar locations as well as it can currently be done – providing base maps for all polar studies, including ISRU, engineering, and science; other existing and new data will need registered to these products
- Providing ground truth data for “resources” such as permanently shadowed areas and areas of lengthy illumination

“What new technologies are required to make these measurements and answer these questions ...?”

- Better mapping technology is needed to map the entire Moon and to handle other missions
- E.g. tie pointing, large photogrammetric solutions, photometric modeling, photoclinometry improvements, sensor models

“What could be the next mission ...?”

- Next steps, missions/instruments
 - Orbital high resolution (e.g. multi-spectral) mapping for resource identification
 - Future mission/instrument to measure landing site scale topography for entire Moon
 - For planning landings and surface operations at any location
 - For registration and photometric correction of multispectral data for deriving resource mapping at high resolution

Summary

In the works:

- Developing 1 m resolution controlled mosaics of north and south polar caps of the Moon with LROC NAC images
- Developing mosaics using all useable images, as well as creating changing Illumination mosaics
- Working with control to LOLA data having completed relative control to subpixel precision

Usability:

- The data products will be useful for locating permanently shadowed and lengthy solar illumination areas, mission operations, and registration of other datasets

Target Completion Date:

- Late 2016

Acknowledgements

This effort is funded by the

- NASA Lunar Advanced Science and Exploration Research (LASER) program,

and builds on earlier funding from the

- LRO Participating Scientist Program, and
- Lunar Mapping and Modeling Project.

We also acknowledge the tremendous work and effort by LRO mission and LROC and LOLA personnel, without which this work would not be possible.

Backup

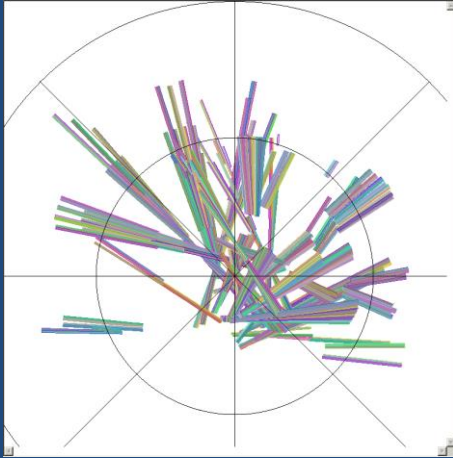
Solution Statistics

LMMP vs. Current

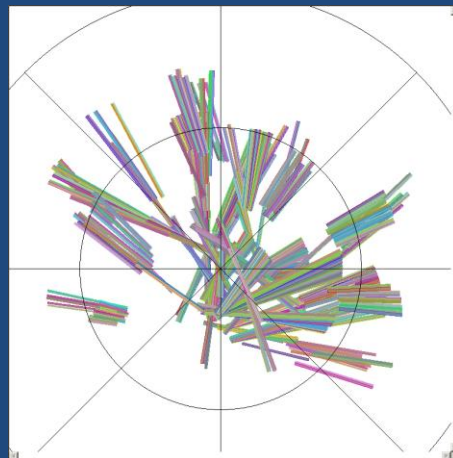
Polar Mosaic Solution Input Information						
	North pole		South pole		Total	
	LMMP	current	LMMP	current	LMMP	current
Images:	3,682	9,688	3,827	18,962	7,509	28,650
Points:	340,142	386,873	527,756	1,638,726	867,898	2,025,599
Measures:	2,102,373	3,064,199	3,363,623	13,745,031	5,465,996	16,809,230
Constrained points (so far):	18	16	16	0	34	16

Example Solar Illumination Footprint Plots

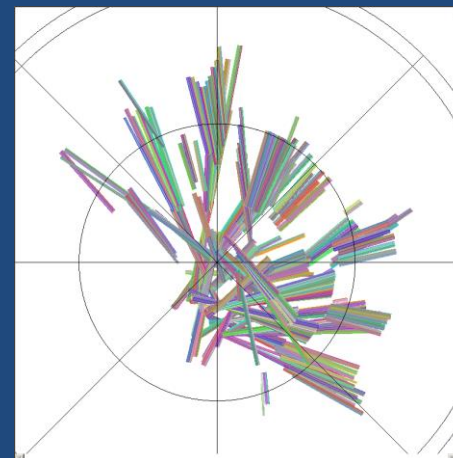
South pole; 10-20° to 80-90°



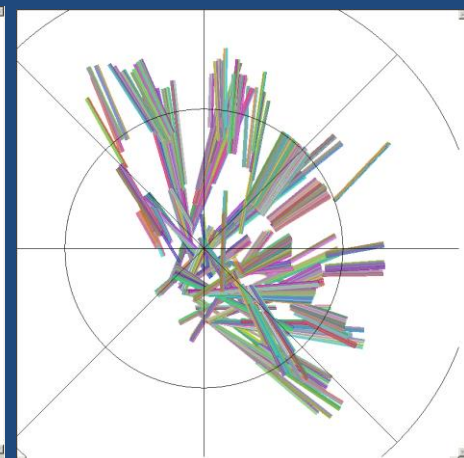
10°-20°



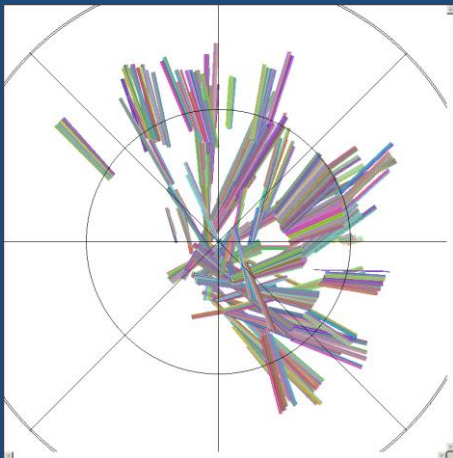
20°-30°



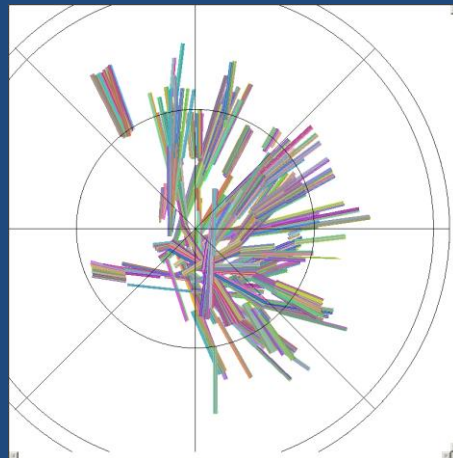
30°-40°



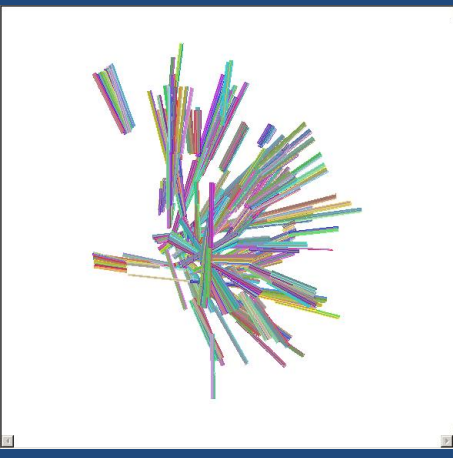
40°-50°



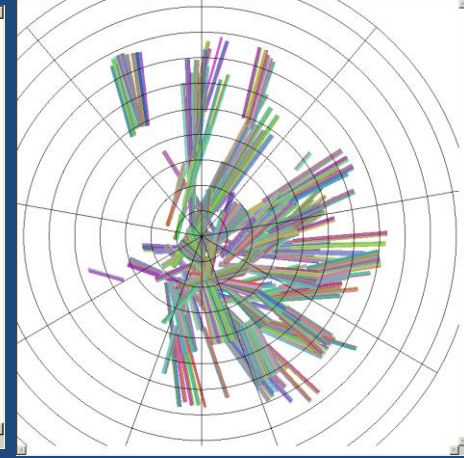
50°-60°



60°-70°

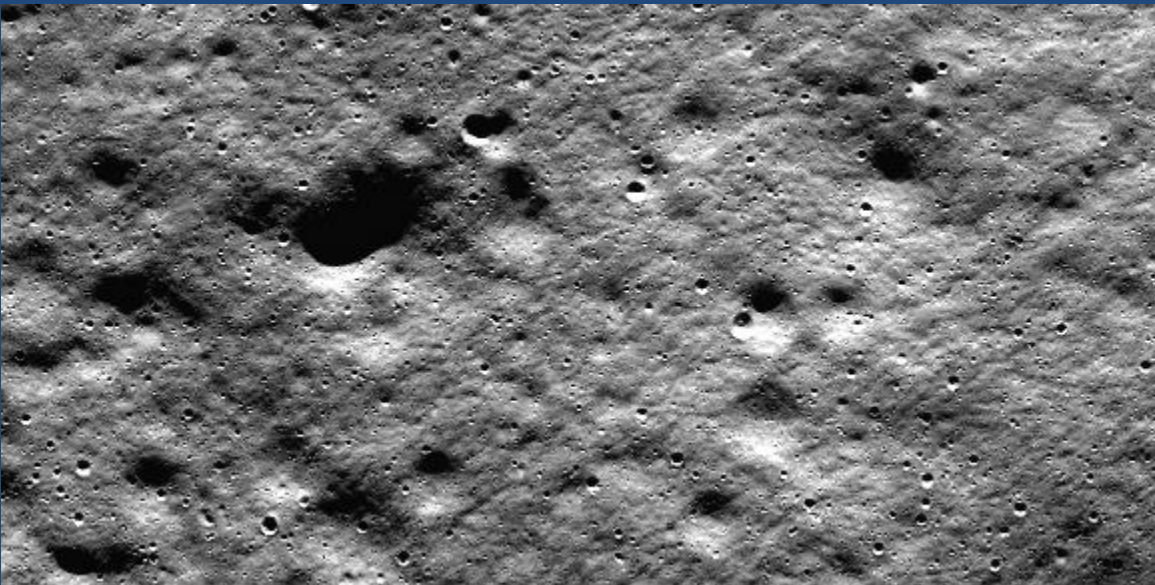
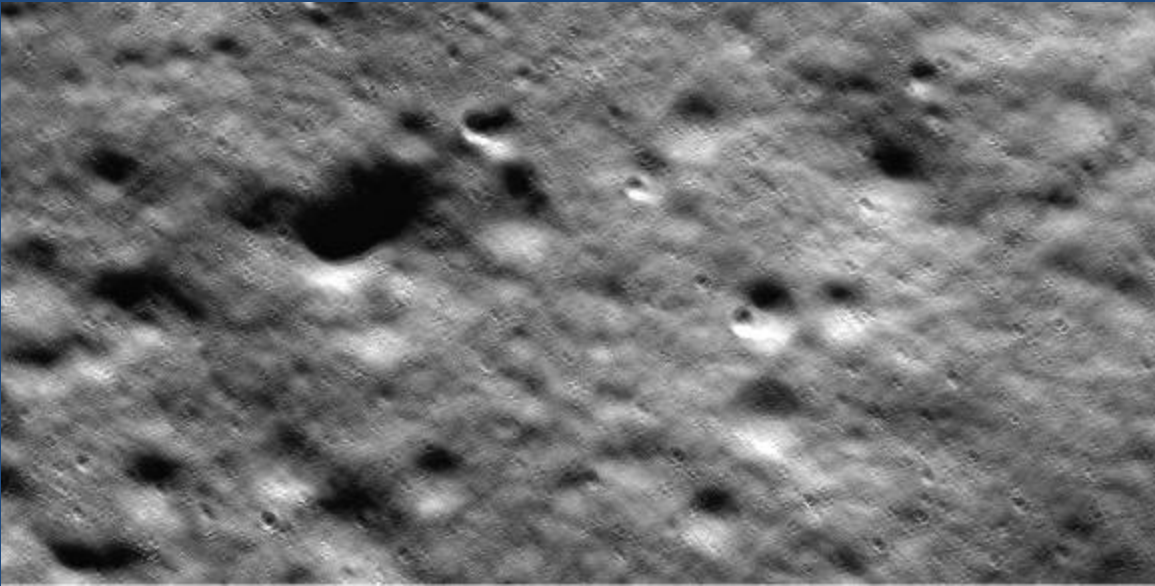


70°-80°



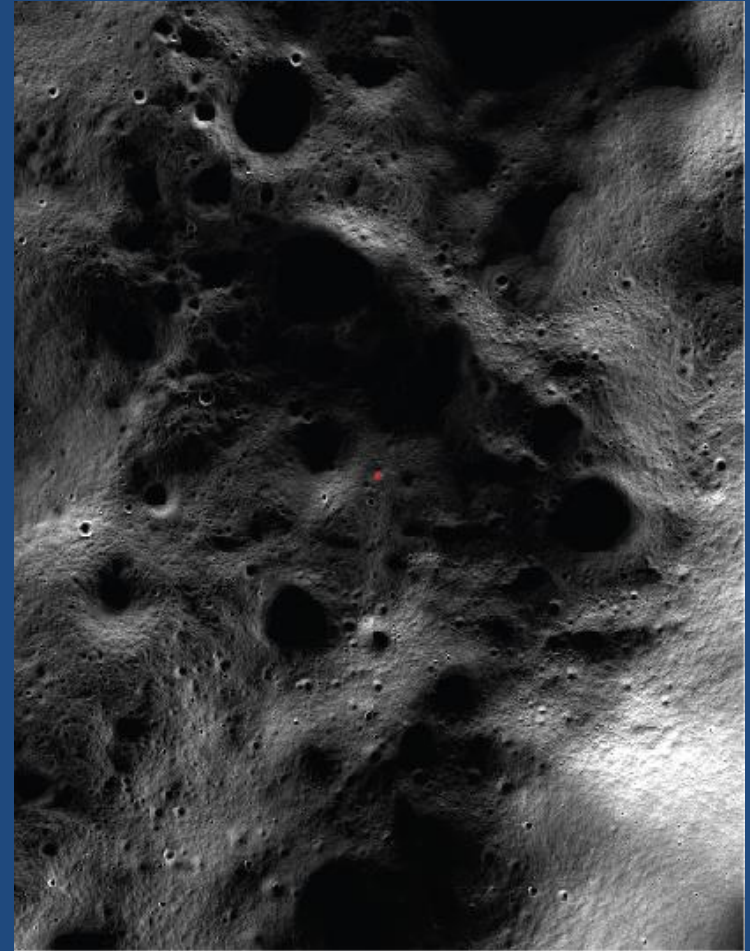
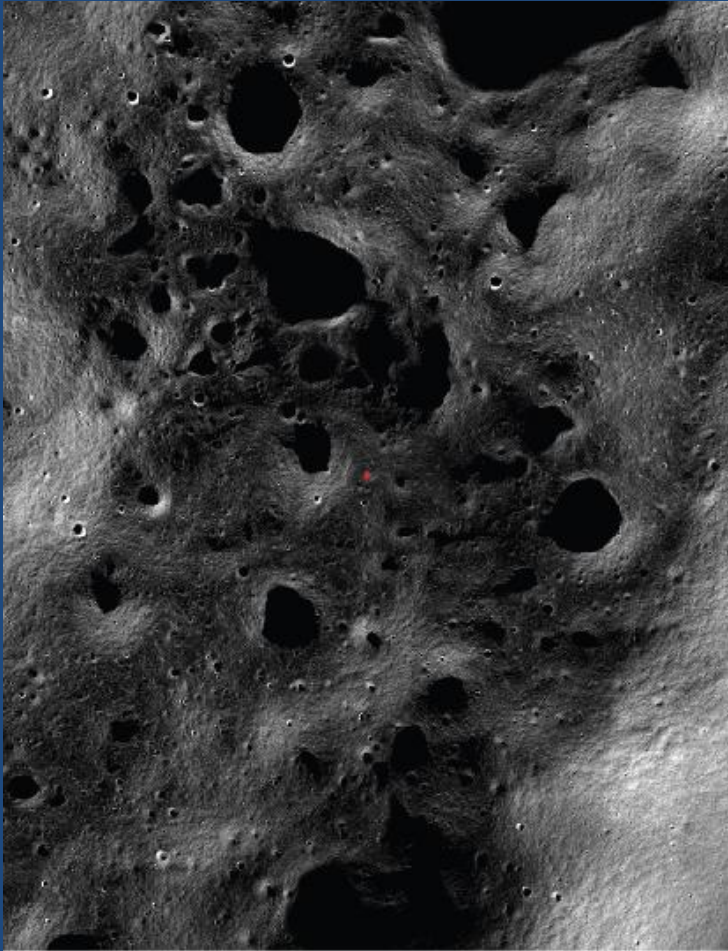
80°-90°

Before / After control (example 3)



Improvement in the area of the south pole, from 9 images total. Again, the resolution is 7.5 m/pixel. The area covered is 3.4 x 1.7 km.

What to do with low SNR (portions of images?)



Comparison of LMMP mosaic (left) to current mosaic (right), at 11 m/pixel, covering 11.4 x 5.7 km. The red dot is the north pole. The central region here was shown previously. The oddly sharp edges to features in the left image are due to automatic removal of low SNR portions of images in the averaged LMMP mosaic. The darker areas in the right image are due to the lack of such editing and the averaging of many dark images in the current mosaic. Which is best?

Addressing LEAG Meeting Goals & Themes

(long version)

- “What is our current understanding of the location and characteristics of the resources?”
- “What measurements are critical for ISRU, engineering, and science?”
 - This study is developing products for determining polar locations as well as it can currently be done – providing base maps for all polar studies, including ISRU, engineering, and science; other existing and new data will need registered to it
 - Providing ground truth data for “resources” such as permanently shadowed areas and areas of lengthy illumination
- “What new technologies are required to make these measurements and answer these questions ...?”
 - To do entire Moon and to handle other missions, better mapping technology
 - E.g. tie pointing, large photogrammetric solutions, photometric modeling, photoclinometry improvements, sensor models
- Next steps, with current data
 - Finish (start?) processing existing data; Apollo, Clementine (UV), Kaguya (TC, MI, SP), Chandrayaan-1 (TMC, M³), global LROC NAC, etc.
 - Allow comparison of multiple datasets at best possible resolution
 - Better processing of color data for (mineralogical) resource identification and location
- “What could be the next mission ...?”
- Next steps, missions/instruments
 - Orbital high resolution e.g. multi-spectral mapping for resource identification
 - Future mission/instrument to measure landing site scale topography for entire Moon
 - For planning landings and surface operations at any location
 - For registration and photometric correction of multispectral data for deriving resource mapping at high resolution