

**REGIONS OF INTEREST: AVAILABILITY OF AND ACCESS TO LROC NAC DATA PRODUCTS.** M. R. Henriksen<sup>1</sup>, M. R. Manheim<sup>1</sup>, J. M. Walsh<sup>1</sup>, C. P. Harris<sup>1</sup>, M. S. Robinson<sup>1</sup> and the LROC Team<sup>1</sup>, <sup>1</sup>School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603 ([mhenriksen@ser.asu.edu](mailto:mhenriksen@ser.asu.edu))

**Introduction:** The Lunar Reconnaissance Orbiter Camera (LROC) has been in orbit since July 2009 and the LROC team has released over 1.9 million Narrow Angle Camera (NAC) images with illuminated Moon as of 31 Dec. 2020. Many of these images were sequenced to enable creation of high-resolution cartographic reduced data records (RDRs), including digital terrain models (DTMs), regional controlled mosaics (CMs), and photometric sequences (PSs). These RDRs enable landing site analysis as well as a wide variety of scientific investigations. They are radiometrically corrected and photogrammetrically controlled products and are globally distributed, covering a variety of features of interest to the lunar community. As well as the PDS products themselves, the LROC team has created supplementary shapefiles, map sheets, and 3D models derived from NAC RDR products.

**Product Overview:** Products derived from LROC NACs provide accurate topographic and photometric data at some of the highest resolutions available for the Moon. This makes them valuable resources with many applications, as shown in **Table 1**.

**Table 1:** Common applications for NAC data products

Potential Use	NAC Data Product		
	DTM	CM	PS
Morphologic Investigations	✓	✓	
Photometric Analyses	✓	✓	✓
Crater-counting studies		✓	
Hazard assessment for traverses and landing ellipses (slope maps and highest-resolution imagery)	✓	✓	
Line-of-sight communication and illumination analyses	✓		

LROC NAC DTMs are made from geometric stereo (GS) observations at a 2-5 m pixel scale and have average accuracies within 10 m horizontally and 1 m vertically [1]. The DTMs are controlled to LOLA altimeter shots converged with the GRAIL GRGM900C gravity model [2,3]. In the Sept. and Oct. 2020 RDR releases to the NASA Planetary Data System (PDS), we made several improvements to the existing NAC DTM products. Scale and Offset values were added to the PDS keywords for a majority of the orthophotos so that users can convert back to I/F values for photometric analysis. In addition, new color-shaded relief maps and new color slope maps were generated using a color palette that is more comprehensible for those with color vision deficiency [4]. Two versions of the color-shaded relief

maps were released: one with a continuous color gradient and one with discrete elevation bins customized for each individual product to show terrain variation [5,6].

CMs are made at the native NAC pixel scale and usually consist of 2-5 NAC image pairs taken on subsequent orbits that provide consistent lighting across the map area [7]. These sets of images, which have been specifically targeted for mosaics of features of interest, are referred to as feature mosaics (FMs). Controlled using ISIS3 jigsaw, offsets are < 20 m horizontally, with the overall sigma0 of the mosaic < 1 and nearly all point residuals < 1 pixel [7]. As of the June 2020 RDR release to the PDS we provide residuals plots to help users evaluate the CMs. Two versions are available: a standard residuals plot containing all individual points and a residuals plot binned by 0.1 degrees.

NAC PSs consist of up to 100 NAC images with a wide range of phase angles (0° - 115°) co-registered to a NAC DTM [8]. Ground points for each image are tied individually to the DTM and are not allowed to move in order to avoid warping of the images [8]. Backplanes for local emission, incidence, and phase angle are provided for each NAC image in the series.

In addition to these improvements to the NAC data products themselves, all the LROC RDRs were updated with references and more detailed descriptions in their PDS labels, detailed readme files containing relevant processing and interpretation information (now co-located with the PDS products in the archive), and browse products (low-resolution preview images; links found in the readmes). The RDR archive documentation has also been extensively updated to reflect the current processing methodology and archive structure [9].

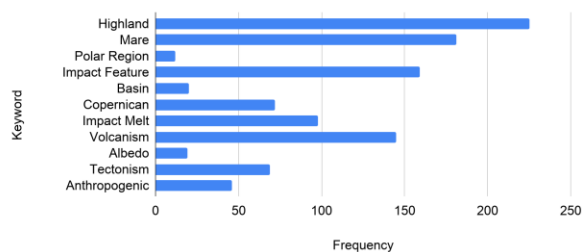
As of the Dec. 2020 PDS release, there are 530 NAC DTMs, 4466 GS observations, 387 CMs, 1398 acquired FMs, and 9 released PSs with another 51 PSs currently being acquired and processed (it takes several years to acquire a complete PS).

The PSs are centered around the equator, as the small axial tilt of the Moon makes acquiring the full range of phase angles difficult at poleward latitudes. However, the rest of the NAC products and observations targeted for NAC products are distributed globally. **Table 2** shows the numbers of acquired FM sequences and GS observation sets, as well as the derived CMs and DTMs, divided into 30° bins of latitude and 60° bins of longitude. In general, the products are more numerous closer to the equator. This is at least partially because the latitude-longitude bins near the equator cover more area. In addition, lighting conditions are more frequently ideal closer to the equator.

**Table 2:** NAC targeted observations and derived data products in 30° bins of latitude and 60° degree bins of longitude. Each table is colorized in 5 shades with the darkest bins being the most populous (based on FM/GS frequency).

FMs (CMs)						
Lon: Lat:	0-60	60-120	120-180	180-240	240-300	300-360
60 - 90	4(1)	13(10)	10(2)	4(1)	3(3)	9(3)
30 - 60	45(10)	57(25)	32(5)	33(5)	40(1)	48(20)
0 - 30	119(63)	77(9)	67(25)	72(14)	59(9)	109(63)
-30 - 0	39(12)	50(1)	53(13)	61(8)	81(25)	67(19)
-60 - -30	17(1)	26(3)	47(9)	58(6)	20(0)	22(3)
-90 - -60	20(5)	1(4)*	16(2)	8(0)	8(1)	3(3)
GS (DTMs)						
Lon: Lat:	0-60	60-120	120-180	180-240	240-300	300-360
60 - 90	22(4)	30(3)	18(1)	7(0)	3(1)	22(4)
30 - 60	173(10)	208(21)	161(35)	183(4)	196(17)	202(41)
0 - 30	230(69)	133(17)	164(22)	170(18)	123(6)	243(72)
-30 - 0	131(35)	166(1)	156(9)	149(3)	194(10)	133(37)
-60 - -30	95(7)	183(11)	254(22)	272(17)	206(21)	107(4)
-90 - -60	22(3)	10(0)	34(0)	34(1)	17(0)	15(0)

\*Rarely, CMs are made from images other than targeted FMs.



**Fig. 2:** Numbers of NAC DTMs associated with major keywords (note that many DTMs have multiple tags).

NAC products also cover a variety of sites of interest from both geological and engineering perspectives. The NAC DTMs have been tagged with 28 relevant keywords to help users identify features of interest, such as anthropogenic objects, various geologic landforms, and general regional characteristics. Unsurprisingly, a majority of the DTMs cover scientifically-important features, including 159 impact-related DTMs and 145 DTMs related to volcanism (**Fig. 2**). The keywords can

be found in the NAC DTM readmes as well in the NAC DTM shapefile.

In addition to the products themselves, shapefiles containing footprints for all the NAC RDR products and acquired observations are available for download through the LROC PDS archive ([http://wms.lroc.asu.edu/lroc/rdr\\_product\\_select](http://wms.lroc.asu.edu/lroc/rdr_product_select)), as well as via Quickmap and Lunaserv [9,10,11]. These are a few of the many tools enabling users to identify what NAC data products are available and to easily locate them. For more information, refer to [12].

Extra (non-PDS) products such as ISIS3 cube files, map sheets, posters, and 3D models are available on the LROC Downloads page (<http://lroc.sese.asu.edu/archive/downloads>). Sets of regional map sheets are available for a few key sites, including the Apollo landing sites, using NAC-scale topography and imagery. These maps include contour lines derived from NAC DTMs and supporting imagery including Wide Angle Camera context maps and NAC obliques. 3D models of common lunar geological features like craters, rilles, mountains, and more are available as STL files compatible with 3D printers; some are also available as 3D puzzles. These products can be particularly beneficial for education and public outreach.

**Current Efforts:** NAC DTM, CM, and PS production is ongoing to support scientific goals and future exploration [13]. We are working to improve users' ability to locate needed data products by also tagging the PSs and CMs with relevant keywords. We are also working on providing more absolute accuracy information for the CMs, and on providing updated SPICE data derived from the CMs.

NAC oblique images are taken at large slew angles (>55°) and are specially processed to remove parallax distortion. We are currently working on releasing these to the RDR archive, as well as providing an accompanying shapefile to facilitate their location.

**References:** [1] Henriksen, M.R., et al. (2017) *Icarus* 283:122-127. [2] Mazarico, E., et al. (2013) *LPSC XLIV*, Abs. 2414. [3] Lemoine, F.G., et al. (2014) *Geophys. Res. Letters*, 41, 3382–3389. [4] Brewer, C. A. et al. (2003) *Cartogr. Geogr. Inf. Sci.* 30(1), 5-32. [5] Eisemann, M., et al. (2011) *Intl. Wkshp. on Visual Analytics*. [6] Henriksen, M. R. et al. (2019) *PDW4*, Abs. 7066. [7] Klem, S. M., et al. (2014). *LPSC XLV*, Abs. 2885. [8] Martin, A. C. et al. (2019). *LPSC L*, Abs. 2752. [9] LROC RDR SIS. (2020). [http://pds.lroc.asu.edu/data/LRO-L-LROC-5-RDR-V1.0/LROLRC\\_2001/DOCUMENT/RDRSIS.PDF](http://pds.lroc.asu.edu/data/LRO-L-LROC-5-RDR-V1.0/LROLRC_2001/DOCUMENT/RDRSIS.PDF) [10] ACT-REACT Quickmap. <https://quickmap.lroc.asu.edu/> [11] Estes, N.M., et al. (2013) *LPSC XLIV*, Abs. 1719. [12] Henriksen, M. R. (2017) *PDW3*, Abs. 7019. [13] Manheim, M. R. et al. (2020) *Lunar Surface Sci. Wkshp.*, Abs. 5155.