Lunar Reconnaissance Orbiter Camera Permanently Shadowed Region Imaging – Atlas and Controlled Mosaics. E. Cisneros, A. Awumah, H.M. Brown, A.C. Martin, K.N. Paris, R.Z. Povilaitis, A.K. Boyd, M.S. Robinson and the LROC Team, Arizona State University, School of Earth and Space Exploration, PO Box 873603, Tempe AZ, 85287-3603 ecisneros@asu.edu.

Introduction: The Lunar Reconnaissance Orbiter (LRO) spacecraft entered lunar orbit in June of 2009 [1]. One area of scientific interest for the Lunar Reconnaissance Orbiter Camera (LROC) team includes permanently shadowed regions (PSRs) [2]. While not designed to image within shadowed regions, the LROC Narrow Angle Camera (NAC) can obtain useful images with long exposure observations of PSRs at times of maximum secondary illumination [3].

Acquisition of NAC PSR observations has been iteratively optimized over several campaigns to maximize signal-to-noise ratio (SNR) and pixel scale, resulting in a comprehensive dataset that has been systematically reviewed [4]. A total of 6,864 individual PSR observations have been collected since the start of the mission, with 531 new NAC PSR images acquired since 1 January 2016. An atlas of NAC observations of PSRs larger than 10 km^2 has been compiled to facilitate analysis. The atlas includes a context mosaic of each PSR, associated metadata, and comments regarding features of interest. Images with insufficient SNR (1,162 NAC images) were excluded from the atlas.

Observation Artifacts: The LROC NAC is designed to image illuminated terrain on the Moon, while the PSR imaging campaign is designed to investigate the reflectance inside of photon-starved shadowed regions utilizing secondary illumination reflected from nearby Sun-facing topographic facets. The increased exposure time (20x to 80x) leads to pixel smear and elongated pixels in the along track direction, and thus reduced image resolution compared to typical NAC images (10–40 m/pixel vs. 0.5–2 m/pixel). The low illumination levels (typically 50x less that of nominally illuminated terrain) result in an increase in the percentage of out-of-field scattered light from nearby illuminated terrain, resulting in diminished contrast with PSR images. This scattered light is often seen as a brightness offset between NAC images in mosaicked products.

Most often the 12 bit (0-4095) NAC values have enough dynamic range to capture illuminated terrain and shadowed terrain with detail. However, there are instances where the contrast of the terrain is too high. Increasing the exposure time to capture the low number of photons coming from the PSRs occasionally over exposes nearby illuminated terrain. The saturated pixels "bleed" the signal in the crosstrack direction, leading to an increase in the background DN values of the shadowed areas bordering illuminated terrain.

Data Processing: As NAC PSR observations are acquired and delivered to the LROC Science Operations Center (SOC), automated processing generates Planetary Data System (PDS) Experiment Data Record (EDR) products for release and archive. The NAC observations tagged as part of the PSR campaigns are further processed from Level 0 to Level 3 data products [5], utilizing routines from the Integrated Software for Imagers and Spectrometers (ISIS) software suite [5,7]. Post-processing evaluation is performed using QGIS [8], which allows loading of individual observations on top of LOLA topography [9] and LOLA PSR boundary shapefiles to determine suitability for inclusion into the final PSR mosaic or atlas products.

Controlled Mosaics: High resolution controlled mosaics are generated for select areas as a demonstration of the capabilities of the dataset (e.g., Fig. 1). These controlled mosaics will be released at full resolution as a PDS Reduced Data Record (RDR) product in the larger LROC RDR Volume [10].

Controlled mosaics are processed using ISIS routines. Multiple NAC images are registered in a control network and tie points are reviewed to insure correct alignment. New spacecraft ephemeris is computed with jigsaw using the control network and correct light-time information. Cam2map is used to create orthorectified images, which are then mosaicked together. A manual linear stretch is performed on individual NAC observations before the final product is generated.

Polar PSR Mosaic: NAC PSR observations are acquired at a variety of pixel scales, and the final uncontrolled PSR mosaics are assembled from images resampled at 20 meters per pixel. The ordering of images is based on image quality and areal coverage of individual PSRs. NAC PSR observations will be compiled into a north pole and south pole mosaic, which will then be delivered and archived in the LROC PDS RDR archive volume.

PSR Atlas: The NAC PSR Atlas includes 310 PSRs >10 km^2. Each PSR atlas page is composed of a section of meta-data (area, perimeter, features of interest,), a context image (166 km width) for each specific PSR on a color-shaded LOLA topography basemap, one or more day-of-year images, which are planimetrically corrected, mosaicked, and displayed, as well as a composite best coverage mosaic. If a controlled mosaic has been generated, it is also included for that PSR.

Atlas images were generated using scripting capabilities within the QGIS Python console [11]. For all

images, the LOLA PSR boundary shapefile, clipped NAC observations, LOLA topography basemaps, a north arrow, and a scale bar are included (e.g., Fig. 2).

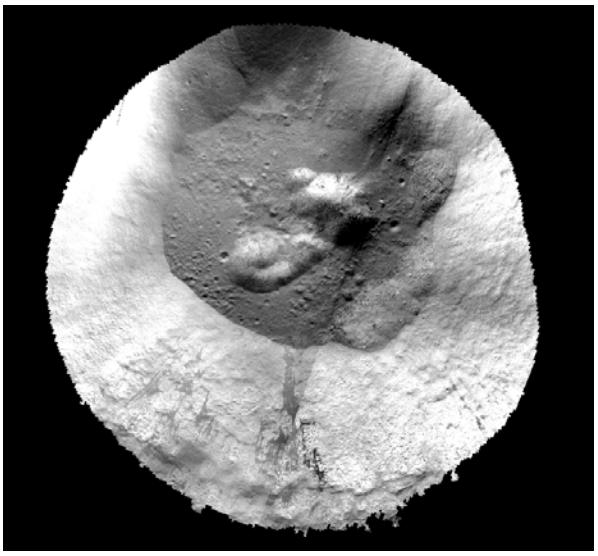

Figure 1. *LROC NAC controlled mosaic of Sylvester N (20 km diameter; 82.34° S, 291.34° E). Note the dark albedo streaks on the crater wall (center bottom).*

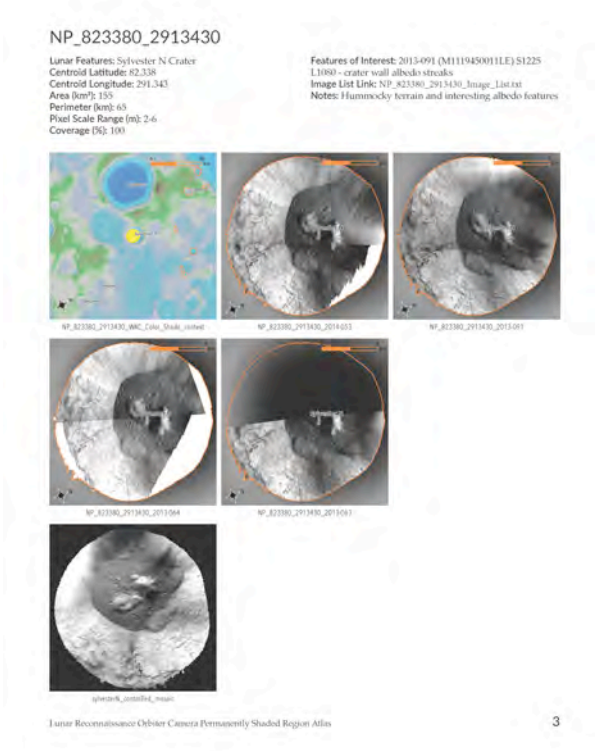

Figure 2. *Example page from LROC PSR Atlas for Sylvester N crater.*

Analysis efforts have focused on craters ranging from 82° N to 90° N and 90° S to 82° S. Areas of high scientific interest include Shackleton, Cabeus, Amundson, DeForest, Faustini, Haworth, Shoemaker, Lovelace, and Sylvester N craters.

Continuing Work: Tasks include releasing the PDS RDR products of the north and south pole mosaics, improving coverage and quality of PSR images by replacing observations with those that have higher SNR and spatial resolutions if and when they are acquired, and quarterly updates to the PSR Atlas PDF file.

Conclusions: Compilation of the Lunar PSR Atlas provides a much needed and useful tool for the planetary science community to further facilitate study of the lunar polar regions. Coupled with the other LRO instrument data sets, a more complete understanding of the lunar poles can be pursued. Delivery of atlas and PDS products will be part of the March 15, 2017 LRO PDS release, which can be accessed via the LROC Data Node (https://lroc.sese.asu.edu/ under Archive).

References: [1] Tooley, C.R. et al. (2010) *Space Sci. Revs.*, 150:23-62. [2] Robinson, M.S. et al. (2010) *Space Sci. Revs*, 150:81-124. [3] Koeber, S.D., and Robinson, M.S. (2013) *LPSC XLIV*, abstr. 2588. [4] Koeber, S.D, et al. (2014) LPSC XLV, abstr. 2811. [5] NASA Planetary Data System (2009) Planetary Data System Standards Reference, JPL D-7669, Part 2, version 3.8. [6] Becker, K.J. et. al. (2013) *LPSC XLIV*, abstr. 2829. [7] Anderson, J.A. et. al (2004) *LPSC XXXV*, abstr 2039. [8] QGIS Development Team (2015) QGIS Geographic Information System, http://qgis.osgeo.org [9] Neumann, G. A. (2011), LOLA RDR SIS 2.42. http://imbrium.mit.edu/DOCUMENT/RDRSIS.PDF. [10] Bowman-Cisneros, E. and Eliason, E.M. (2011) LROC RDR SIS v1.4, http://lroc.sese.asu.edu/data/LRO-L-LROC-5-RDR-V1.0/LROLRC_2001/DOCUMENT/RDRSIS.PDF. [11] QGIS Development Team (2016). https://docs.qgis.org/2.8/en/docs/pyqgis_developer_cookbook/