NEW SPICE TO IMPROVE THE GEODETIC ACCURACY OF LROC NAC AND WAC IMAGES. E. J. Speyerer[1] (espeyere@asu.edu), R. V. Wagner[1], A. Licht[1], M. S. Robinson[1], K. J. Becker[2], and J. A. Anderson[2], [1]School of Earth and Space Exploration, Arizona State University; [2]Astrogeology Science Center, United States Geologic Survey.

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) consists of two imaging systems that provide synoptic and high resolution imaging of the lunar surface [1]. The Wide Angle Camera (WAC) is a seven color push-frame image, while the Narrow Angle Camera (NAC) consists of two identical cameras capable of acquiring images with a ground sampling distance of 0.5 from an altitude of 50 km. Using a subset of the over 707,000 NAC and 190,000 WAC images of illuminated terrain collected between 30 June 2009 and 15 June 2013, the LROC team improved the interior and exterior orientation parameters for each camera, including the addition of a wavelength dependent radial distortion model for the multispectral WAC. These geometric refinements, along with refined ephemeris, enables seamless projections of NAC image pairs with a geodetic accuracy better than 20 meters, and WAC images to be projected on the surface with sub-pixel precision and accuracy.

LROC Geometry: To produce cartographically accurate image mosaics and stereo image based digital terrain models (DTM), the position of each pixel in a given image to a corresponding region on the lunar surface must be known to a high degree of accuracy and precision. Therefore, characterization of the WAC and NAC extrinsic and intrinsic geometry is essential. The extrinsic geometry describes the rapid changing exterior orientation parameters such as the attitude of the camera systems, while the intrinsic geometry defines the orientation parameters that describe the physics of the optics and sensor geometry [2]. Both orientation parameter sets are archived in a series of binary and text based Spacecraft, Planet, Instrument, C-Matrix and Events (SPICE) kernels. The Navigational and Ancillary Information Facility (NAIF) at the Jet Propulsion Laboratory maintains the SPICE ancillary information system, which numerous planetary missions use for observation planning and data analysis [3]. Integrated Software for Imagers and Spectrometers (ISIS) [4], which is a specialized image processing package developed by the Astrogeology Science Center of the United States Geological Survey (USGS), invokes these orientation parameters using the extensive subroutine library that is part of the SPICE Toolkit and applies them during image orthorectification. This process removes distortions in the image due to the instrument (e.g., temperature), spacecraft motions, and topographic variations in the scene during the creation of orthorectified data products [4-6].

LROC Geometry Refinements: Using both preflight data and observations collected on-orbit, the LROC team successfully characterized the geometry of the entire camera system, including the relative motion of the twin NACs (Fig. 1) and their accuracy using the known location of the three retro-reflectors at the Apollo 11, 14, and 15 landing site as well as the two on board the Lunokhod rovers [7] (Table 1). To implement the pointing correction, we produced a series of C-matrix kernels that modify the exterior orientation parameters, more specifically instrument attitude, based on the thermal environment.

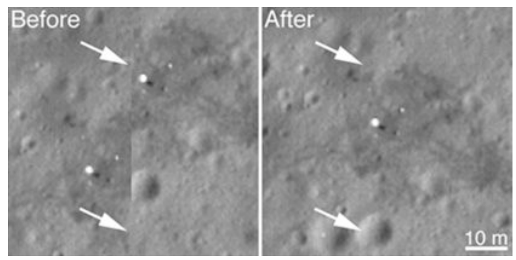

Figure 1. Image-to-image boundary before (Left) and after (Right) applying the relative exterior orientation correction.

In addition, we also characterized the geometric parameters used to describe the WAC. While conducting this analysis, the large in-flight dataset revealed spatial offsets between bands after orthorectification due to chromatic aberrations in the optical system. This lateral chromatic aberration effect, also known as “chromatic difference in magnification” introduces variation to the effective focal length for each WAC band (Fig. 2). To compensate for these variations, the LROC team developed a new wavelength dependent camera model. The new model, along with a small pointing adjustment improves geodetic accuracy to a sub-pixel scale (Table 2).

Distribution of new SPICE: The updated geometric properties will be available through an updated Instrument Kernel (IK), Frames Kernel (FK), an ISIS specific Instrument Addendum Kernel (IAK), and a series of C-Matrix Kernel (CK). The temperature correction C-matrix kernels (prefix: soc31 and lrolc), which the LROC operations team produces on a daily basis, contain a continuous set of Euler angles that define a system of rotations for the three cameras with respect to the spacecraft bus. This kernel works in conjunction with the CKs provided by the LRO Mission Operations Center at Goddard Space Flight Center to define the absolute pointing of the instrument in the J2000 reference frame. In addition, users upgrading to ISIS 3.4.5 will also be able to use the new WAC wavelength dependent camera model and kernels when processing images.

References: [1] Robinson et al. (2010) *Space Sci. Rev*. 81-124. [2] Mugnier et al. (2013) in *Man. Photogramm.*, edited by J.C. McGlone. [3] Acton (1996) *Planet. Space Sci*. 44-1. [4] Anderson et al. (2004) *LPSC, 2039* [4] Anderson et al. (2008) *LPSC,* 2159 [6] Anderson et al. (2013) *LPSC,* 2069. [7] Wagner et al. (2014) LPSC, 2259.

Table 1*: Geodetic accuracy of the LROC NAC (units = meters)*

Ephemeris kernels	Mission Operations Center SPKs	LOLA/GRAIL SPKs	LOLA/GRAIL SPKs
Exterior orientation parameters	pre-flight geometry	pre-flight geometry	on-orbit geometry
Geodetic accuracy from the 50 km orbit, m (Left/Right/Both NACs)	106.9/109.9/109.0	30.7/36.2/36.3	11.0/13.3/12.5
Geodetic accuracy for the entire mission, m (Left/Right/Both NACs)	126.3/132.6/129.2	64.4/67.6/71.5	18.8/18.8/18.8

Table 2*: Geodetic accuracy of the LROC WAC (units = meters)*

Ephemeris kernels	Mission Operations Center provided SPKs	LOLA/GRAIL SPKs	LOLA/GRAIL SPKs
Exterior orientation parameters	pre-flight geometry	pre-flight geometry	on-orbit geometry
415 nm (VIS-1)	294.5	282.1	41.7
566 nm (VIS-2)	208.5	167.2	42.2
604 nm (VIS-3)	195.5	139.8	42.0
643 nm (VIS-4) color	197.2	142.9	42.7
643 nm (VIS-4) mono	187.3	156.9	50.5
689 nm (VIS-5)	219.2	181.7	40.6
321 nm (UV-1)	713.3	679.5	43.0
360 nm (UV-2)	715.8	701.3	57.0

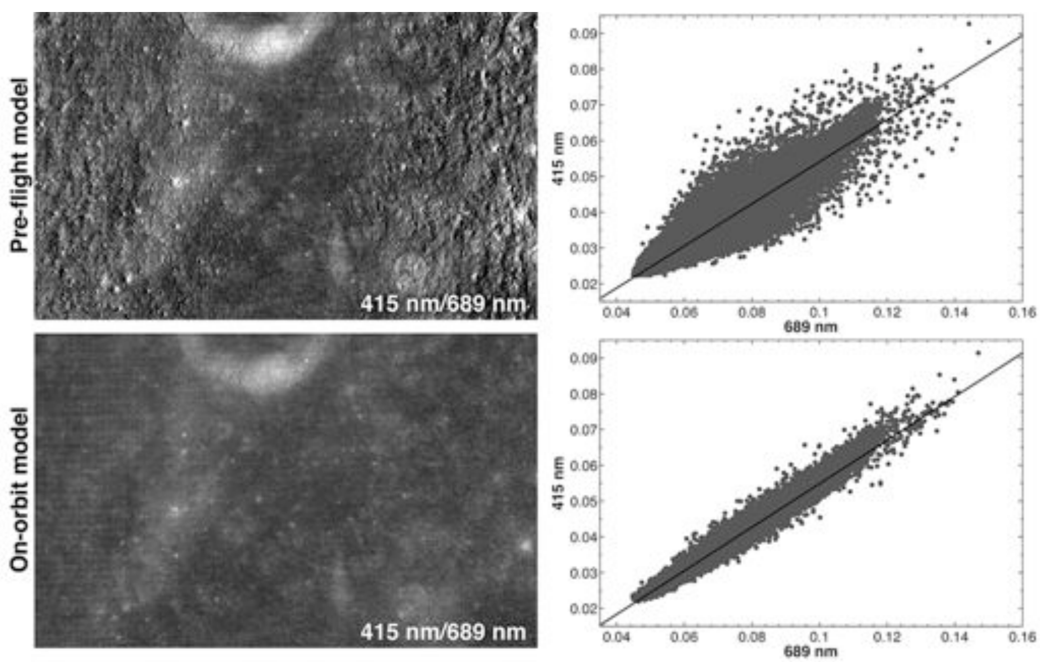

Figure 2. Pre-launch and on-orbit WAC precision: (Upper left) Ratio image of the 415 and 689 nm bands of a spectrally neutral region with high frequency noise near the outer edge of the WAC framelet (left and right side) caused by planimetric offsets due to the inaccuracies in the original WAC distortion model. (Lower left) Ratio image of the same region orthorectified with the on-orbit derived geometry with no visible texture caused by projection errors. The plots on the right show the corresponding joint-distribution for each case. Since this image (M143574778C) covers a spectrally neutral region, the relationship should be linear with limited deviation.