LROC NAC PHOTOMETRIC ANALYSIS: A GLOBAL SOLUTION AND LOCAL APPLICATIONS.

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Introduction: The Lunar Reconnaissance Orbiter (LRO) entered lunar orbit in June 2009 and since then each month the Moon revolves underneath the LRO orbital plane. As a result repeat imaging with different illumination geometries is possible for any place on the Moon. These multitemporal observation opportunities enable the creation of a robust, ever-increasing, dataset for photometric analysis.

Each Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) has a 2.86° field of view [1], thus photometric angles vary little throughout a single image. However, lighting conditions typically vary considerably from month-to-month (dependent on location) creating radiometric discontinuities when making NAC mosaics. Therefore, in order to improve NAC mosaics as well as to allow quantitative comparisons of reflectance values from spatially-dispersed NAC images, we derived an empirical global photometric solution from ~740,000 LROC NAC image tiles.

Method: NAC images were divided into 1250 m x 1250 m (2500 x 2500 native NAC pixels) tiles. For each tile the following values were computed: mean I/F, mode I/F, footprint (four corner latitude and longitude values), and the photometric angles of incidence (angle of sub-solar vector relative to the surface normal), emission (angle of camera boresight vector relative to the surface normal), and phase (angle between emission and incidence vectors) [2]. These values were calculated for 36,000,000 tiles similar to [3].

Global data fitting. To increase the accuracy of the model for special observations, such as geometric stereo and Featured Mosaics [4], the data were constrained as follows: tiles must have an I/F mode greater than 0.005 (screen out heavily shadowed images) and tiles must have an emission angle greater than 3.0° to preserve the emission portion of the phase function. After filtering there were 740,000 tiles remaining. If the data were unfiltered, the nadir observations (98% of all NACs) would dominate the fitting, and the photometric function with respect to emission angle would be essentially unconstrained.

Next a Principal Component Analysis (PCA) was performed on the phase angle, cos(emission angle), and cos(incidence angle) to determine an orthonormal basis for fitting the I/F values.

The log of the mode I/F was used as the response variable for robustness of the least squares fit. The fitting equation (eq. 1) is simple, and the variance of the residuals is 8.9×10^{-5}.

$$\log\left(\frac{I}{F}\right) = a_0 + a_1\, g + a_2 \cos(e) + a_3 \cos(i)$$

eq. 1 The equation used to describe I/F as a function of phase angle (g), emission angle (e) and incidence angle (i); a_0 through a_3 are constants.

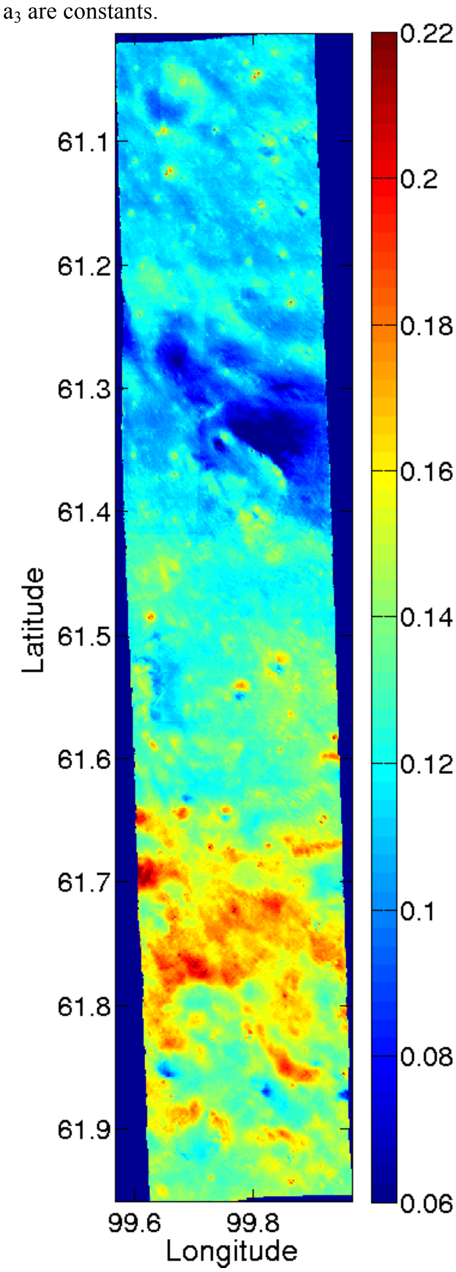

Fig. 1 The mean photometrically normalized I/F of 54 LROC NAC observations of CBVC.

Mare and non-mare areas were treated separately with the aid of mare shape file (archived at the LROC PDS website) [5] and fit independently. The ratio of the mare vs. highland models was examined to investigate the robustness of the two solutions.

High resolution NAC normalization and analysis. In addition to the global dataset comparison, NACs with overlapping footprints were normalized with the global photometric solution and evaluated.

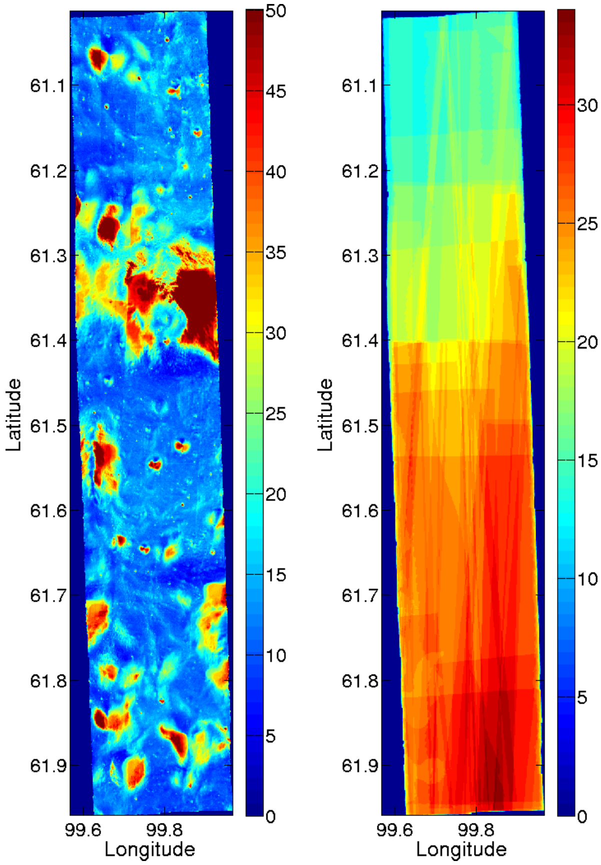

Fig 2. *Left.* The percent standard deviation of 54 photometrically normalized NAC images overlapping the CBVC DTM. *Right.* The number of overlapping observation at each location.

The NAC Digital Terrain Model (DTM) Planetary Data System product of the Compton Belkovich Volcanic Complex (CBVC) NAC_DTM_COMPTONBELK_E610N1000.IMG (2 meters/pixel) was smoothed using a 5x5 averaging window and used to calculate local photometric angles. There were 54 NAC images that overlap the CBVC DTM and have incidence angles <80°; these images were photometrically normalized (phase=30°, emission=0°, incidence=30°) at the pixel scale using the new global fitting equation and the NAC DTM. The normalized NAC images were then map projected and stacked for analysis. The mean (**Fig. 1**), standard deviation (**Fig. 2;left**), and count of valid pixels (**Fig. 2;right**) were calculated for each map location.

Results and Discussion: At the global scale, differences between photometric fits to the mare and highlands return similarly shaped curves, with the ratio of the highlands to the mare model fit trending from 1.85 at an incidence angle of 0° to 1.6 at an incidence angle of 90°.

The fit to the mare likely provides a more robust global solution; the data in the mare are a more uniform unit than non-mare terrains, which include mature and immature highland material and crater ejecta material. Using data from one uniform unit minimizes the added factors of composition and space weathering on the reflectance values.

However, one potential weakness of applying the mare photometric curve to the global dataset, is that a compositional unit with a significantly different photometric response function from the mare will have larger variances in normalized values.

High Resolution Application. When comparing the photometrically normalized NAC images (computed using high resolution topography) at the CBVC, the percent standard deviation is low (10%-15%) for regions that do not have high frequency topography and are generally free of shadows. Shadows are the largest contributor to noise in the photometrically normalized NACs at CBVC.

The mean normalized I/F values at the CBVC range from 0.12 to 0.2 with the highest reflectance location in the center of the complex where many irregular depressions exist [6]. The higher reflectance zone is consistent with the area of single scattering albedo increase in [7].

Summary: The NAC global photometric solution is robust and effective for a large range of the photometric angles. The residuals from the linear least squares fit are small, with a mean of 0.0 and variance of 8.9×10^{-5}, and the normalized tiles mosaic well. Thus, a global photometric solution provides an accurate normalization technique for LROC NAC images.

References: [1] Robinson et al. (2010) Space Science Rev. 150: 81-124. [2] Hapke B. (2012) Cambridge University Press, pp. xxx. [3] Boyd et al. (2012) Lunar Science Forum #587. [4] Klem et al. (this conference) LPSC 45. [5] Koeber et al. (this conference) LPSC 45 [6] Jolliff et al. (2012) LPSC 43 #2097. [7] Clegg et al. (this conference) LPSC 45.