LROC NAC PHOTOMETRY: A GLOBAL PHOTOMETRIC FUNCTION. A. K. Boyd and M. S. Robinson, School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA (aboyd@ser.asu.edu)

Introduction: Due to the slow rotation of the Moon, lighting conditions beneath the Lunar Reconnaissance Orbiter (LRO) systematically vary from month-to-month. As a result, the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) has acquired a robust set of multi-temporal photometric observations sampling the whole Moon.

Each NAC has a 2.85° field-of-view [1], thus 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], vary dominantly from topography in a single image. To allow quantitative comparisons of reflectance values from spatially dispersed NAC images, we derived an empirical photometric solution from 3.8 million LROC NAC image tiles (1 km x 1 km) similar to the method described in Boyd et al. [3], but with more LROC NAC images at higher resolution than the previous work [3]. We call this solution the Mean Moon Photometric Function for the Highlands (MMPF-H), signifying the highlands were used as the primary dataset.

Method: Farside LROC NAC images were selected based on latitude (40°S to 40°N), longitude (90°E to 270°E), incidence angle (<60°), and slew angle (<60°). Only images with data quality IDs < 16 and exposure times < 1 ms were included in the study.

Data Preparation: Radiometrically calibrated I/F [4,5] NAC images were binned to 1 km x 1 km pixel scales enabling accurate photometric angle calculations from the GLD100 [6], while maintaining a manageable dataset size. Photometric angles (phase, local emission, and local incidence angles), latitude, and longitude were calculated for each tile.

The data were transformed, enabling a linear least squares fit for the MMPF-H. The response variable log(IOF) and dependent variables $g$, $\cos(e)$, and $\cos(i)$ were calculated and stored for use in curve fitting.

Curve Fitting: The resulting dataset was binned by photometric angles and only the average for each bin was used for fitting the MMPF-H. This removes bias in the MMPF-H of higher point density regions (nadir and larger incidence angles).

The preliminary and final fitting was performed using phase angles >10° and emission and incidence angles <80°. After the preliminary fitting, the normalized IOF was computed for all original data points, and outliers were identified as points greater than three standard deviations from the mean normalized IOF. With outliers

Figure 1: The MMPF-H is valid for phase angles between 10° and 90°, all emission angles, and incidence angles < 80°. In this range, the normalized IOF ($IOF/modelIOF$) shows little trending against illumination angles. Outside of the valid geometry range, the MMPF is smooth, but increases in error magnitude as the distance from the valid range increases.
excluded, the mean for each bin was recomputed, and the MMPF-H was fitted using the bins.

\[
\log \left( \frac{I}{F} \right) = -2.47 - 0.013g - 0.25\cos (e) + 1.08\cos (i)
\]

**Mean Moon Photometric Function for the Highlands (MMPF-H), IOF depends linearly on phase (g), emission (e), and incidence (i) angles.**

**Results and Discussion:** The MMPF-H is designed as a general purpose correction for highlands terrain. The function is well fit for phase angles between 10° and 90°, all emission angles, and incidence angles <80°; roughly 85% of all NAC images within 60° latitude of the equator. The solution presented here is improved upon that of Boyd et al. [3] in terms of spatial scale (5 km vs. 1 km) and fit accuracy due to significantly more observations.

**Residuals:** At phase angles <10° the normalized IOF curves upwards toward 0° (Fig. 1A) showing that the MMPF-H is not adequately describing the opposition surge [2]. Creating a smooth function took precedence over modeling these small phase angle non-linear effects. Normalized IOF departs from the horizontal fit as emission angle approaches 35° (Fig 1B) for many tiles. For nadir images, the departure is due to steep slopes (>25°), which are composed of immature material with higher reflectance. Emission angles >40° generally do not show elevated IOF because they are slewed observations in regions with little topography (Fig. 1B). Normalized IOF vs. incidence angle is horizontal out to 80° (Fig. 1C), beyond which the presence of shadows due to km scale topographic facets begins to dominate the observed radiance.

**Application:** NAC mosaics over regions larger than a NAC pair often require observations with significantly different geometries; often over 50° change in phase angle across a single mosaic. These photometric differences cause significant reflectance offsets within a mosaic. However, with MMPF-H photometric normalization (applied over valid phase angles) mosaics are relatively seamless [Fig. 2]. The underestimated model IOF at low phase angles (<10°) is due to the nonlinear increase in reflectance approaching 0° phase angle [2], and a correction will be added in future work.

Terrain types with varying composition or physical parameters may have different photometric properties (mare vs. highlands, mature vs. immature), thus requiring a separate solution for each terrain. For the MMPF-H, the mean lunar highlands will have the highest accuracy. Caution should be exercised when applying to other terrains, such as, immature, blocky, glassy, ilmenite rich, and high Fe content materials.