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Photometric normalization of LROC WAC global color mosaic

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Abstract

Monthly global Lunar Reconnaissance Orbiter (LRO) Wide Angle Camera (WAC) observations of the Moon, with varying emission and incidence angles, enable the precise derivation of spatially resolved Hapke photometric parameters. Global mosaics are stacked in a time series to enable phase curve fitting using a tile-by-tile method, with a wide range of phase angle in each tile. Tile-by-tile calculations provide the best global color mosaic without any recognizable tile boundary offsets, and photometric parameter maps (w, xi, Bco, and hc) that allow new resolved measurements to characterize the surface properties of the Moon.

1. Introduction

The WAC acquires near global coverage on a monthly basis. The WAC is a push-frame sensor with a 90° field of view (FOV) in BW mode and 60° FOV in 7-color mode (320 nm to 689 nm)[1]. WAC images are acquired during each orbit in normally 10-12° latitude segments with cross track coverage of ~50 km. Before mosaicking, WAC images are radiometrically calibrated to remove instrumental artifacts and convert to radiance factor (known as *I/F*).

Next, the images are photometrically normalized to common viewing and illumination angles (see Eq.1), a challenge due to the wide-angle nature of the WAC where large differences in phase angle (±30°) are observed in a single image line. The light scattering properties of the lunar surface depend on incidence (*i*), emission (*e*), and phase (*p*) angles as well as soil properties such as single-scattering albedo and roughness that vary with terrain type and state of maturity [2]. In order to find the best photometric normalization scheme, we tested a new "tile-by-tile method".

2. Methodology

The surface illumination dependence on *i*, *e*, *p* is empirically obtained by curve fitting. As a fitting function, we used a simplified Hapke function [3], composed of four free parameters (*w*, *xi*, *Bco*, and *hc*). In preparation for fitting, *I/F*, *i*, *e* and *p* are pre-calculated for each image pixel. The three photometric angles (*i*, *e*, and *p*) were calculated using GLD100 DTM derived from WAC stereo matching [4], to take the topographic variations into account. Thus the brightness due to slopes can be accurately normalized, resulting in pure albedo images.

In order to overcome the complicated regional variations for photometric properties and albedos, we developed the "tile-by-tile method". We divided the planet into small tiles and derived photometric parameters within each tile. Currently, 1°x1° tiles for latitudes between ±70° using 20 months of data (up to about 60,000 images) were processed. Each pixel within a tile is then normalized to $p = i = 60°$. These angles were chosen because high latitudes never receive low phase and incidence angles.

Normalized I/F (*nIOF*) is obtained by

$$nIOF = \frac{IOF}{f\left(p,e,i\right)} f\left(60,0,60\right) \qquad (1)$$

where *f* is the simplified Hapke function including four fitted parameters at each tile.

USGS ISIS (version 3) was utilized for image calibrations, map projections, and mosaicking. Curve fitting for parameter calculations are achieved by Levenberg-Marquardt least-squares minimization, based on MINPACK-1, translated into IDL [5] and Python [6]. The final image normalization was performed using IDL.

3. Results and Discussions

A global mosaic normalized by the tile-by-tile method exhibits no recognizable tile seams for much of the Moon, suggesting good photometric corrections within each tile. A noticeable difficulty in terms of Hapke parameter calculation is Bco (the parameter controlling the backscatter opposition surge) at high latitudes where LRO does not observe the surface at low phase angles. We interpolated the *Bco* parameter by using the correlation between *Bco* at ±15° latitude and surface albedo (*w*), thus reducing one free parameter allowing accurate derivation of the other parameters.

Large albedo contrasts within one tile can result in poor fitting results, such as in dark Oceanus Procellarum with contrasting bright crater ejecta (Fig. 1). In order to reduce such failed areas, we will continue to reduce the tile size eventually to one-tenth of a degree (~3-km) as more months of global observations are obtained.

All of the parameters in the simplified Hapke function have physical interpretations [7]. Since the tile-by-tile method derives the parameter set at each tile, each parameter can provide a map displaying the local variations that may be linked with local geology. Single scattering albedo (*w*) appears highly consistent with apparent albedo, as expected. The cosine asymmetry factor (*xi*) in the Henyey-Greenstein phase function exhibits a weaker correlation to albedo. The amplitude of the coherent backscatter opposition surge effect (*Bco*) is not well defined, due to the lack of low phase data at high latitudes. A parameter related to transport mean free path in the medium (*hc)* could be related to surface grain size or microscopic roughness, but no interesting regional patterns are seen at the present resolution.

4. Conclusion

The best photometric normalization of the LROC WAC global color mosaic is obtained with the simplified Hapke function and our tile-by-tile method. Strong albedo variations cause large scatters within the data resulting in fitting difficulties, inducing failed areas. Shrinking the tile size will capture the surface variations and reduce failed tiles. Derived Hapke parameter maps provided by the tile-by-tile method will allow unique characterization of the surface properties of the Moon. More importantly, the well-normalized global color dataset will enable a range of Lunar studies (e.g. [Denevi et al.], [Robinson et al.], and other abstracts submitted to EPSC).

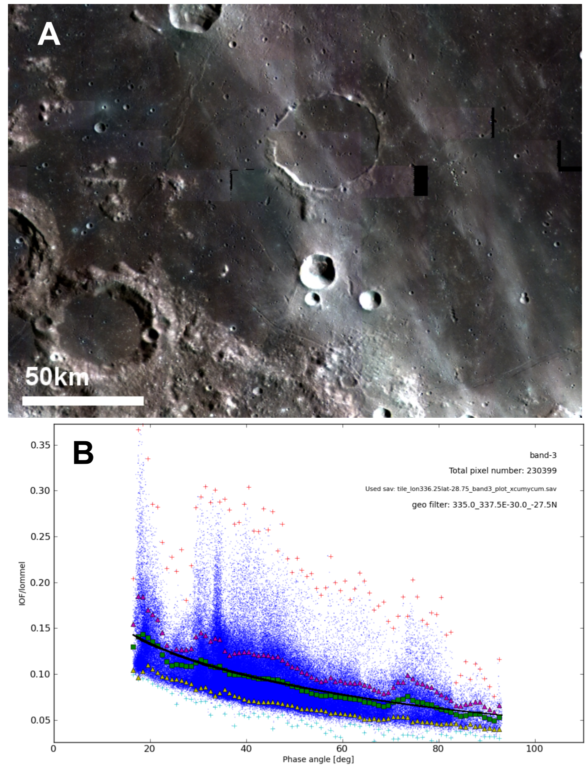

Figure 1: WAC color mosaic (R:689, G:415, B:320 [nm]) in southern Oceanus Procellarum (A), and example of fitting to the data scatter for the 415 nm band (B).

References

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