REMOVAL OF TOPOGRAPHIC EFFECTS FROM ALBEDO AND PHASE-RATIO IMAGES USING LROC NAC DATA.

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Introduction: The phase-ratio method is a powerful tool to investigate the lunar surface, especially when applied to LROC NAC data with resolution on the order of 1 m [1-5]. This method requires coregistration of two images obtained at different phase angles; therefore, the phase-ratio image is usually distorted by the influence of topography. The topographic effects can be weakened using pairs of images having similar illuminations [1-5], which may significantly limit the applications of the phase-ratio method. In order to avoid this difficulty, we have proposed to use photometric corrections of LROC NAC data based on stereophotogrammetry and Akimov's photometric function [2]. This allows the effective compensation for both parallactic and photometric effects of topography on phase-ratio images [6,7]. However, the resolution of the resulting Digital Elevation Model (DEM) is an order of magnitude worse than that of the source images. This does not allow one to compensate for the influence of topography on scales less than 10 m. We here propose a new approach to photometric correction based on the photoclinometry technique.

The new approach: We suggest a modification of the method described in [6,7]. The algorithm applying to LROC NAC images includes the following processing steps: (1) Transformation of initial LROC NAC images [8] to the cylindrical equirectangular projection with the use of the Library of Planet Cartography [9]; (2) Calculation of local parallax shifts from stereo-pair images; (3) Calculation of the DEM from local parallax shifts and orthorectification of the images; (4) Compensation for the influence of local slopes on photometric data using the Akimov photometric function [2]; and (5) Calculation of phase ratio, using photometrically corrected albedo images. We modify step 4 that allows us to compensate for the influence of topography on photometric data.

We use the equigonal albedo $A_{eq}(\alpha)$ [2] instead of the apparent albedo $A(\alpha,\beta,\gamma)$ (radiance factor), considering that $A_{eq}(\alpha)=A(\alpha,\beta,\gamma)/D(\alpha,\beta,\gamma)$, where α is the phase angle; β and γ are the photometric latitude and longitude, respectively; and we exploit the Akimov disk function $D(\alpha,\beta,\gamma)$ [2]. Due to the specificity of illumination of the Moon by the Sun, the principal influence of topography on $A(\alpha,\beta,\gamma)$ is caused by the longitudinal component of slope, changing the photometric longitude γ in $D(\alpha,\beta,\gamma)$.

As has been mentioned earlier [6,7], we calculated slopes for the correction using DEM, although the resulting images have insufficient resolution for photometric correction of small details. Photoclinometry is a technique allowing one to obtain information about the longitudinal component of slopes with the resolution of the source images. We use a pair of NAC images (corrected geometrically on the topography influence using DEM [6,7]) obtained at opposite directions of illumination at approximately equal phase angles α_1 and α_2. In this case, $A_{eq}(\alpha_1)/A_{eq}(\alpha_2) \approx \exp(-\mu(\alpha_1-\alpha_2))$ [2] is close to 1. Therefore we neglect variations of μ over the lunar surface and fit it as a single constant. Using the assumption that $\Delta\gamma \ll 1$, the disk function [2] can be expressed as a Taylor series:

$$D(\alpha,\beta,\gamma+\Delta\gamma) \approx D(\alpha,\beta,\gamma) + D'_\gamma(\alpha,\beta,\gamma)\Delta\gamma,$$

where $\Delta\gamma$ is the correction of photometric longitude caused by topographic slopes. Due to the opposite illumination of the two images, we assume photometric longitudes for them as $\gamma_1+\Delta\gamma$ and $\gamma_2-\Delta\gamma$, respectively, where γ_1, γ_2 are calculated using DEM. So, the ratio of observed apparent albedos is

$$\frac{A\left(\alpha_1,\beta_1,\gamma_1+\Delta\gamma\right)}{A\left(\alpha_2,\beta_2,\gamma_2-\Delta\gamma\right)} \approx e^{-\mu(\alpha_1-\alpha_2)}\frac{D\left(\alpha_1,\beta_1,\gamma_1\right)+D'_\gamma\left(\alpha_1,\beta_1,\gamma_1\right)\Delta\gamma}{D\left(\alpha_2,\beta_2,\gamma_2\right)-D'_\gamma\left(\alpha_2,\beta_2,\gamma_2\right)\Delta\gamma}$$

from whence $\Delta\gamma$ can be found, where angles β and γ are calculated using the DEM. Parameter μ is fitted in the range 0.5-0.9.

Results: We demonstrate the application of the new technique to a phase-ratio analysis of a young 700 m crater (0.778°N, 132.95°W) (Fig. 1a) located on the outer flank of the wall of the crater Hertzsprung S. Figure 2a shows the phase ratio $A(\alpha_1,\beta,\gamma)/A(\alpha_2,\beta,\gamma)$, where $\alpha_1 = 56^o$ and $\alpha_2 = 39^o$. Figures 1b and 2b show results of the topography photometric correction of albedo and phase-ratio images of $A_{eq}(\alpha_1)/A_{eq}(\alpha_2)$ for the area (5.0 × 6.6 km) with rather complicated relief and global slope (elevations difference from left to right is 500 m). Both the images reveal perfect suppression of the topography effects, especially for albedo (Fig. 1b). After such a correction, many features that were invisible in the source images (Fig. 1a, 2a), became apparent for analysis, e.g., the fine structure of the halo, dark ejecta material from small craters and tracks of rolling stones on the albedo image (Fig. 1b).

One may see also dark rays of the large crater and its ejecta on the phase-ratio image (Fig. 2b).

Figure 3 shows the correlation diagram *Phase ratio – Albedo* (see insets) and an example of zoning the surface according to the diagram. We can see a direct correlation between the albedo and the phase ratio $R = A_{eq}(56°)/A_{eq}(39°)$. This behavior is typical for the lunar surface [e.g., 2,3]. The equation for the central regression of this correlation is $R = aA+b$, where $a = 0.24$ and $b = 0.80$ and a correlation coefficient equal to 0.76 We broke the correlation diagram in sections (strips) parallel to the regression line. Points located in the strips have been displayed in the map. We may see clearly the asymmetry of the central crater ejecta. This suggests that the crater was formed from an impactor striking at oblique incidence [10]. It appears that the ejecta materials situated to the left of the crater have a somewhat smoother surface than the ejecta located in the immediate vicinity of the crater and to the right of it.

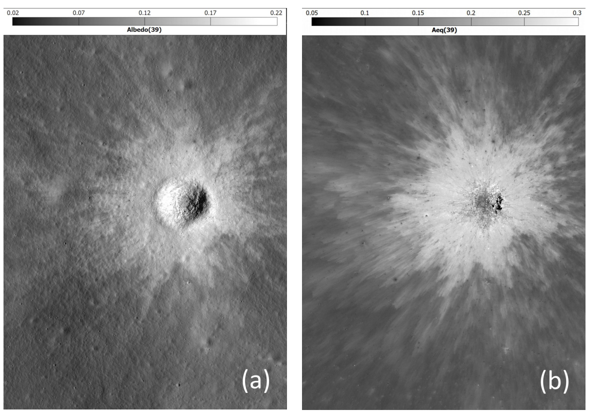

Figure 1. A crater on the outer flank of the wall of crater Hertzsprung S: (a) source apparent albedo $A(39°)$; (b) equigonal albedo $A_{eq}(39°)$ with compensated topography effect.

Conclusion: We propose an enhanced method of removal of the topography influence on albedo and phase-ratio images using photoclinometry. This may allow one to carry out high-quality qualitative and quantitative analysis of LROC NAC data as well as data from other missions.

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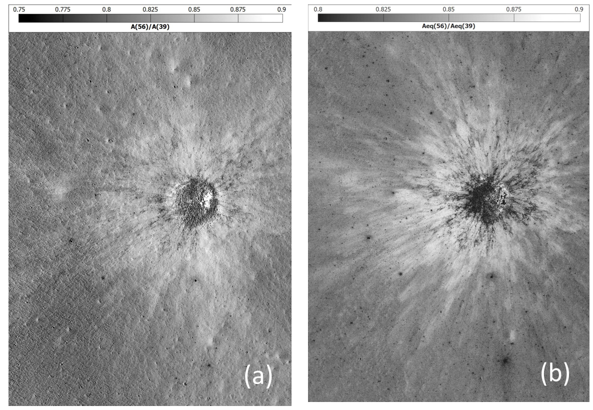

Figure 2. The same area as in Fig. 1: (a) source phase ratio $A(56°)/A(39°)$; (b) phase ratio of equigonal albedo $A_{eq}(56°)/A_{eq}(39°)$ after compensation for the topography effect.

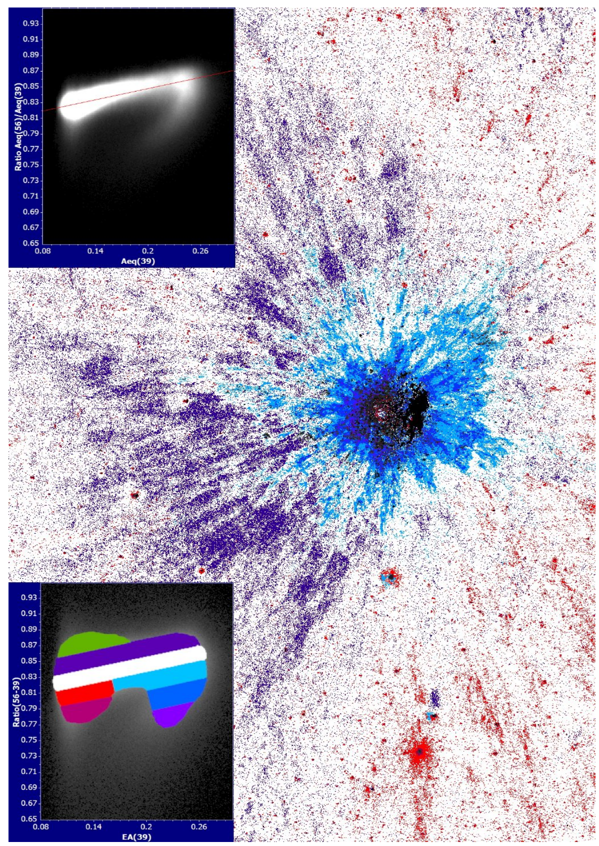

Figure 3. The same scene as in Figs. 1 and 2. Zoning the surface according to the diagram $A_{eq}(56°)/A_{eq}(39°)$ vs. $A_{eq}(39°)$.