PHOTOMETRIC METHOD OF TOPOGRAPHY RECONSTRUCTION: MARS RELIEF FROM A SINGLE IMAGE.

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Introduction. Photometric method for relief reconstruction proposed in [1] allows calculation of the most probable surface height variations based on available images. This method is the most mathematically rigorous. It can be classified as a photoclinometric (rather than photogrammetric) method because it uses the fact that the observed surface brightness depends on the surface tilt.

Correct relief reconstruction requires at least two images of surface obtained at different illumination directions [2, 3]. But the majority of known planetary surface observations are single images. Single images are often used by traditional photoclinometry (for example, [4]), although attempts of processing often face irresolvable difficulties [3].

In the present work we analyzed possible errors in elevations due to the lack of information caused by the use of a single image. We also show examples of reconstruction of Martian surface relief by the photometric method using HRSC images.

Photometric method for the planet relief determination. The photometric method used here is based on the statistical approach to a problem of surface relief determination from a set of images taken under different viewing conditions and with different levels of noise and/or blur. This approach allows determination of the height distribution that is the most probable for the given set of images [1].

In the spatial frequency domain (frequency coordinates are denoted as k_x, k_y), the most probable relief $H_M(k_x,k_y)$ can be derived from images (j – image number in the set) with an equation:

$$\tilde{H}_M(k_x,k_y) = \frac{i\sum_j D_j \tilde{g}_j^*(k_x,k_y)\beta_j(k_x,k_y)\tilde{J}_j(k_x,k_y)}{\alpha(k_x,k_y)+\sum_j (D_j)^2 W_j}, \quad (1)$$

where $\tilde{J}_j(k_x,k_y)$ and $\tilde{g}_j(k_x,k_y)$ are Fourier transforms, respectively, of observed image brightness and the point spread function due to recording system transfer function, phase distortions of the radiation during the propagation through a medium, and so on. “ * ” means complex conjugation, $\alpha(k_x,k_y)$ and $\beta_j(k_x,k_y)$ are reciprocal of expected height and noise spectral density, respectively. $W_j = \tilde{g}_j^*(k_x,k_y)\tilde{g}_j(k_x,k_y)\beta_j(k_x,k_y)$, and $D_j = k_x c_{xj} + k_y c_{yj}$. The pair ($c_{xj}$, c_{yj}) is the first derivative of the photometric function.

Eq. (1) specifies an optimal filter for derivation of the most probable relief from a set of images. This filter depends strongly on a-priori known factors that distort received signals.

Possible errors of elevation derived with the photometric method. We studied errors of elevation estimations with the photometric method from single image using a synthetic test lunar-like cratered surface. We generated the test surface (**Fig. 1a**) with slopes varying between 0 and 28°, like for real planetary surfaces. Brighter shades in Fig. 1a denote higher elevations. To simulate images of the test surface, we used the Lambert law as a photometric function and different signal to noise ratios SN (image in **Fig. 1b** has SN = 10). Illumination direction was chosen along the image rows (shown by arrow in Fig. 1b) and the incidence angle was 35.5°.

Surface topography reconstructed using only one image with the optimal filter (1) was very similar to test relief for every simulated SN values. Correlation coefficients between reconstructed and test relief for the whole surface vary from 0.903 (SN = 50) to 0.901 (SN = 1). It points to a high relative similarity of calculated and test elevation variations. The standard deviation of the reconstructed relief was equal to 99% (SN = 50) - 101% (SN = 1) of that of the test relief.

Spatial distribution of height errors does not exhibit any similarity to the test relief itself or to the simulated images (see an example of the error filed for SN = 1 in **Fig. 1c**). Local errors of elevation estimates can be rather high: from ~38% of test relief standard deviation (SN = 1) down to ~13% (SN = 50).

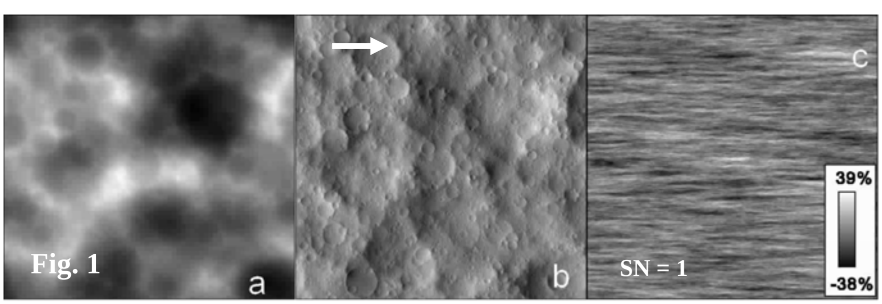

Fig. 1

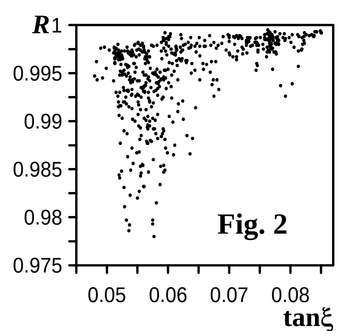

Fig. 2

Slope variability strongly influences an accuracy of relative heights reconstruction by photometric method. In **Fig. 2** correlation coefficients (*R*) between reconstructed and test relief calculated for every line of illumination (for every row in Fig. 1b) are plotted against the RMS slope (tanξ) calculated over the same line. The plot shows that noisy images of very flat areas with no topographic details give the most inaccurate relative elevation values.

Relief reconstructed from a single image has no topography components in orthogonal direction to the illumination.

Martian surface relief reconstruction by the photometric method. To illustrate the method, we used small areas (512×512 pixels) from Mars Express HRSC image h0561-0000-s1 of Martian surface. Resolution of this image is about 110 m per pixel. Examples of the initial image portions used for relief reconstruction are shown in **Fig.3a** and **Fig. 5a.** They are in the original spacecraft projection (level 2 data). We adopted Lambert law as an a priori known photometric function of the surface. SN ratio for the optimal filter was considered to be constant over the spatial frequencies and equal to 8.

Results of relief reconstruction by the photometric method are presented in **Fig. 3b** and **Fig. 5b.** For comparison, **Fig. 3c** and **Fig. 5c** show portions of global Mars topography map derived from MOLA laser altimeter data for the same areas (in simple cylindrical projection). Brighter shades in Fig. 3, 5 (b,c) denote higher elevations.

There is a global similarity of topography derived by photometric method and obtained by laser altimeter. Craters and channels in Fig. 3b and 5b look like depression as in reality.

Bright areas (false mounds) seen at the crater rims (like marked with thin arrows in Fig. 3b) are systematic errors due to the linear approximation used in the photometric method.

Relief data shown in Fig. 3b give topographic information, which is not available from MOLA measurements (notice the gap between orbits in Fig. 3c).

Since the photometric method cannot give absolute elevations, only elevation difference matters. Differences in elevations Δ*H* between two profiles AA′ and BB′ (Fig. 3b) are presented in **Fig. 4**. Segments AA′ and BB′ (Fig. 3b) are segments of two MOLA tracks; the direction from A to B and from A' to B' coincides with the illumination direction (thick arrow in Fig. 3a). We chose segments in this way because the use of a single image allows topography reconstruction in the illumination direction only. Curve 1 (Fig. 4) shows elevation difference calculated from portions of MOLA profiles and curve 2 is corresponded to data obtained with the photometric method (Fig. 3b). There is a general similarity of two curves but data in Fig. 3b are influenced by the lack of information in the direction orthogonal to illumination.

Conclusion. The use of one image for relief reconstruction allows only reconstruction of relative heights deviations along the lines of illumination. Even in such cases relief reconstruction by photometric method is preferable in comparison to other existing photoclinometry techniques because it gives the most probable surface relief based on the image used. Relief reconstructed from a single image has no topography components in the direction orthogonal to the illumination. To estimate the whole height deviations over the surface some additional information has to be involved (for example, in Mars case, MOLA data as low-resolution base).

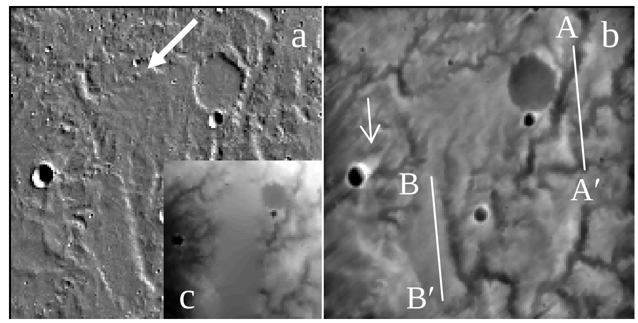

Fig. 3.

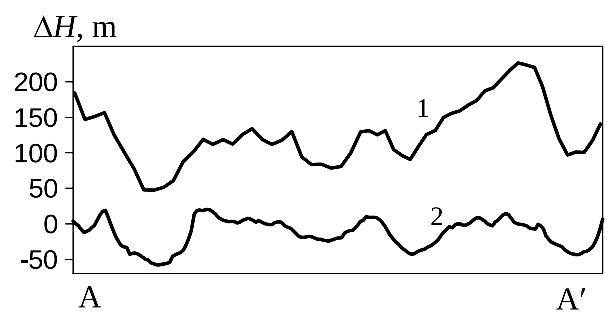

Fig. 4.

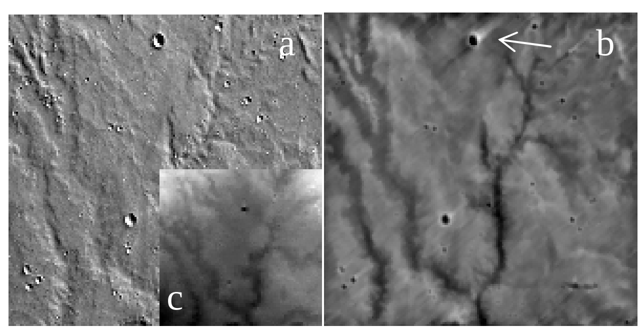

Fig. 5.

References: [1] Kornienko Yu.A., Dulova I.A., Nguyen Xuan Anh. (1994) *Kinematics and Physics of Stellar Bodies* **10**, 69. [2] Skuratovsky S.I. et al. (2005) *42 Vernadsky – Brown Microsymposium* Abstract #m42_61. [3] Lohse V. et al. (2006) *Planet. Space Sci.* **54**, 611. [4] Davis, P.A. Soderblom, L.A. (1984) *J. Geophys. Res.* **89**, E10, 23,689.