SPHERICAL HARMONIC AND STATISTICAL ANALYSIS OF THE SURFACE TOPOGRAPHY OF THE MOON AND THE CONNECTION OF THE RELIEF WITH GRAVITATIONAL FIELD

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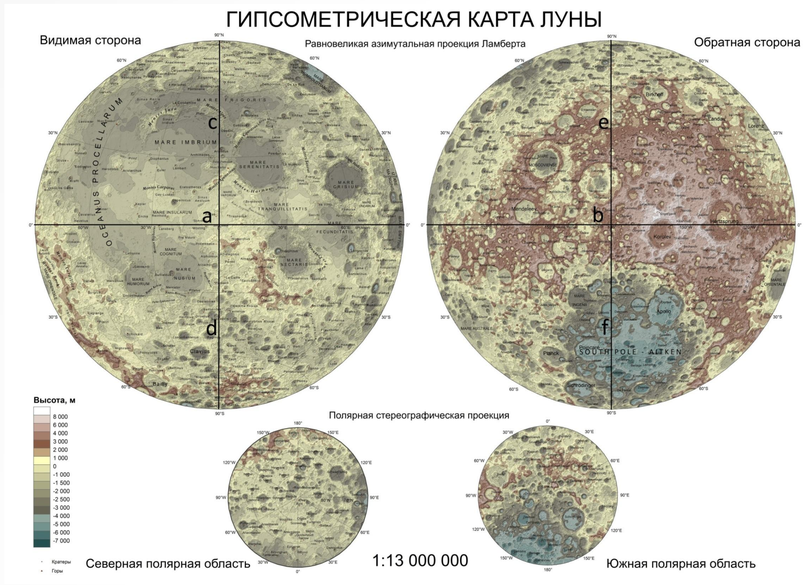
Summary

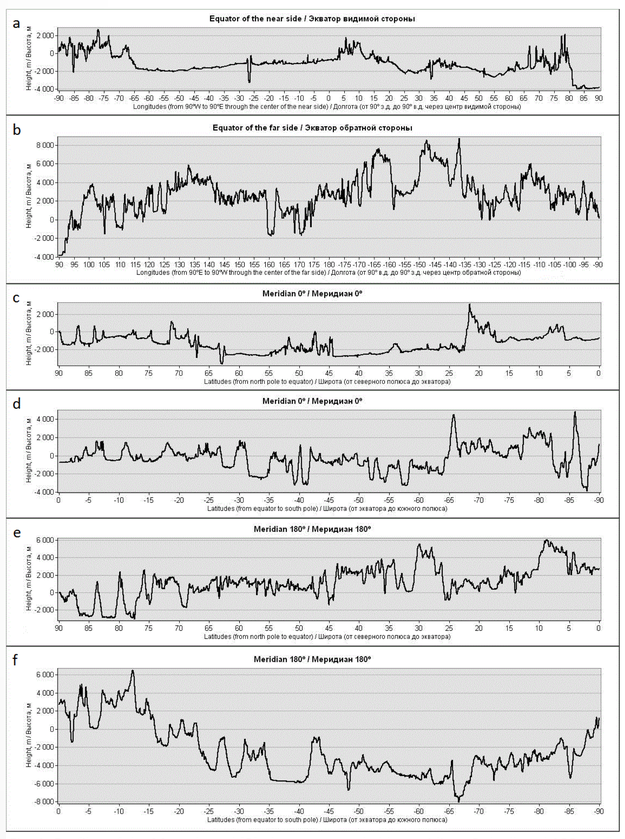
We performed harmonic and statistical analysis of the Moon' surface topography basing on the hypsometric map. It was found that there is a negative correlation between the relief and gravity field harmonics at degrees 10-11 corresponding to mascons

To study the global structure of the deep interior of the Moon based on the developed by us method of solving the inverse problem of gravimetry [1,2], it is necessary to remove from the gravity field influence of surface layers. The initial data for this task was the array of the relief height, averaged on 5x5o grid. The averaging was made on the basis of hypsometric map of the Moon, compiled by Sternberg astronomical Institute and Geographical faculty of Moscow State University in 2014 [3].

The topography of the lunar surface in details is displayed on the Hypsometric map [3] using contour lines, color layers, elevation and a hillshade. We used digital elevation model based on the data of laser altimeter (LOLA) spacecraft Lunar Reconnaissance Orbiter (LRO) with an accuracy of 64 pixels per degree (0.5 km per pixel) [4]. Cartographer - Grishakina E. A., editors, Lazarev E. N. and Rodionova Zh. F., scientific supervisor - Shevchenko V. V.

Hypsometric map of the MOON





Heights are measured from the sphere the average radius of which is 1737,4 km. This level is taken as zero. Altitude scale comprises 17 stages: seven stages of elevation are located above the zero mark 0, 1, 2, 3, 4, 6, 8 and more than 8 km , and for portions of the surface are located below zero level were used for more detailed scale 0, -1; -1,5; -2; -2,5; -3; -4; -5; -6, -7 and below -7 km away. Thus, on the seas, occupying a large area, the relief surface is transferred in more details. Contours on the map are given in accordance with the scale heights. Fig. 1a shows the profiles of lunar surface along equator, meridians λ=0 and λ=180 based on [3].

Fig. 1. Profiles of the Moon based [3] along equator (a,b), meridians 0° (c,d) and 180° (e,f)

Fig. 1b shows a height map of the original topography, averaged over 5-degree areas. The average of relief heights on 5x5 grid allows to receive the expansion of the heights hi in terms of a spherical function system up to the degree N_k =180/5=36.

Fig.1b. Map of the Moon relief relative to a radius of 1737.4 km (averaged over 5x5 grid)
min= -6099,88 m (lat.=-62.5, long.=-162.5),
max= 7092.388 m(lat.=2.5, long.=-162.5)
the interval - 500m,

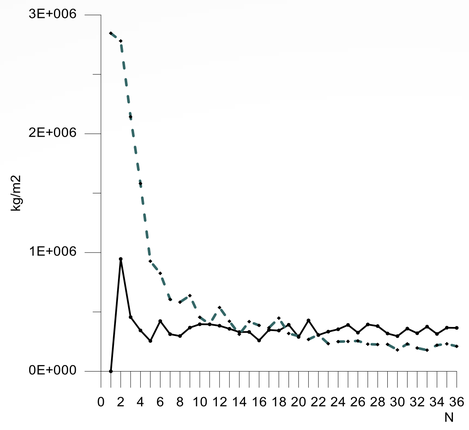
We developed a methodology and created a theory [5], that allows to receive for each degree N=1 Nk the most well-conditioned solution, which does not give, with a large degree of N, accumulation of computational errors. Since the system of spherical functions is orthogonal on the sphere, the coefficients of each successive degree of N is determined independently by successively solving Nk systems of conditional equations of the form

$$\sqrt{cos\varphi_i}\sum_{m=0}^{N} S_{nm}^{i} = \sqrt{cos\varphi_i}\,(h_i - \sum_{n=0}^{N-1}\sum_{m=0}^{n} S_{nm}^{i})$$

where $cos\varphi_i$ - weights of 5° cells

- $S_{nm}^{i} = (\overline{A_{nm}}\cos m\lambda_i + \overline{B_{nm}}\sin m\lambda_i) * \overline{P_{nm}}(\sin\varphi_i)$

$\overline{P_{nm}}$ – norma lized adjoined Legendre polynomials.



The coefficients of the expansion allowed to determine :
- the average radius of the relief surface (1737648,54 m);
- the displacement of the center of the figure relative to the center of mass 1 933,24 m (*Δz=238.09 m, Δx= -1773.95 m, Δy = -730.65 m*) in the direction φ=7° λ =202° ,
- the polar compression (0.00128),
- power dispersion and correlation between topography and gravitational field.

Fig.2 shows a plot of the correlation between the coefficients of topography and gravity field for different degrees of expansion. The initial data for the coefficients of the gravitational field was used the modern model GL0420A is derived according to the system of sputnik-sputnik (GRAIL mission [6]). The negative correlation of harmonics of degree n=10-11, which corresponds to the horizontal size of mascons Δ=18 16°. Comparative analysis of the heights of selenoid and the relief allows to allocate space for negative correlation, i.e., a possible distribution of mascon. Our subsequent analysis of the internal structure will allow to find connection of mascons with anomalies of the internal structure of the Moon.

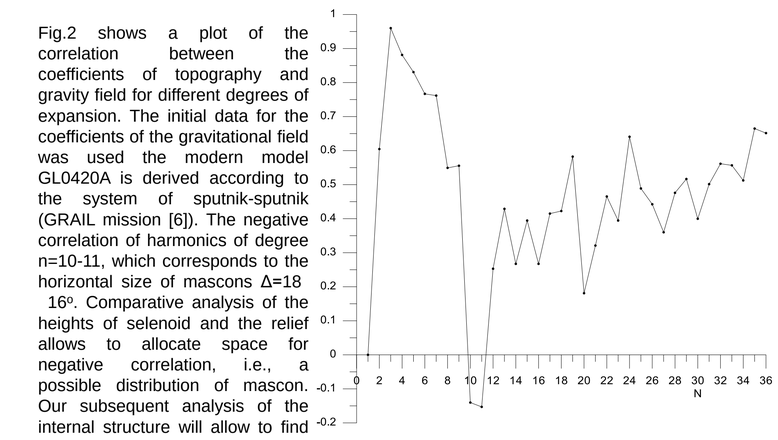


Fig.2. Correlation coefficients of harmonic of relief and gravity field for degree N=1-36

Fig.3a shows the distribution of density of a simple layer for the gravitational field corresponding to the negative correlation of the field and the topography. If one compares this map with the map of a simple layer for relief for the expansion to 36 degree (Fig 3b), we see that positive values of the field correspond to the lunar seas (i.e. positive maskons), and a negative may indicate the possible presence of water and other volatile elements (oil, gas, helium-3) under the high elevations of the Moon.

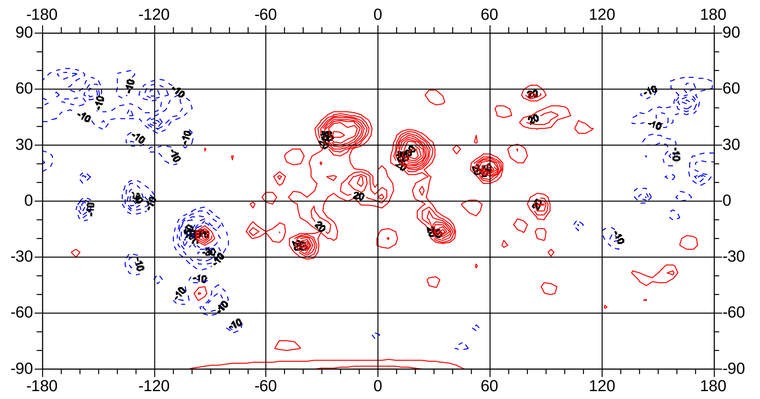


Fig.3a. Map of Moon' mascons distribution (layer field/layer relief < 0) N=36
red – positive values of density, blue - negative values
numbers on contours are given in units 10^5 kg/m^2
min= -74.6993 (lat.= -17.5, long.= -102.5),
max= 109.9362 (lat.= 17.5, long.= 57.5)
contours step – $10*10^5$ kg/m^2

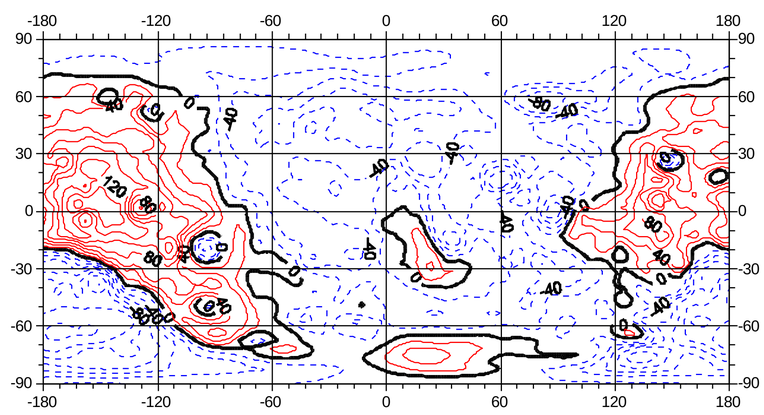
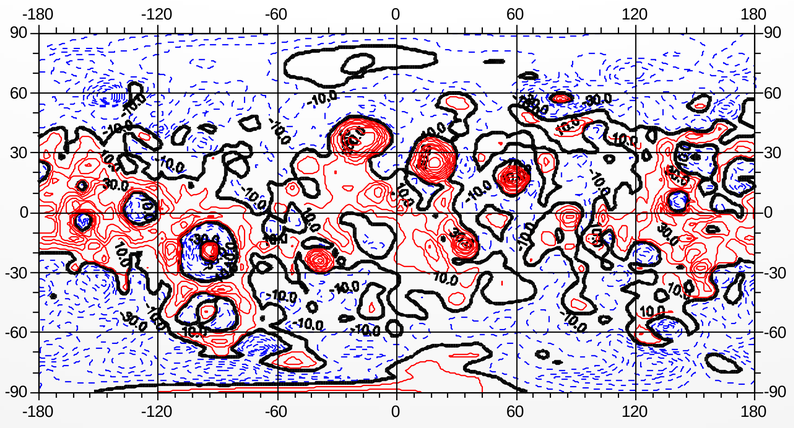


Fig.3b. Density of simple layer for relief
min= -149.1997 (lat.= -62.5, long.= -172.5),
max= 178.3672 (lat.= 2.5, long.= -162.5)
numbers on contours are given in units 10^5 kg/m^2
contours step– $10*10^5$ kg/m^2,



Density of simple layer for field
min= -92.9167 (lat.= 57.5, long.= -147.5),
max= 109.9362 (lat.= 17.5, long.= 57.5)
numbers on contours are given in units 10^5 kg/m^2
contours step – $10*10^5$ kg/m^2

In Fig. 4 shows possible locations of water supplies and volatile elements in the lowlands of the Moon. They correspond to the positive correlation field and the topography. The absolute value of the negative density of a simple layer for a field exceeds the absolute value of the negative density for the topography.

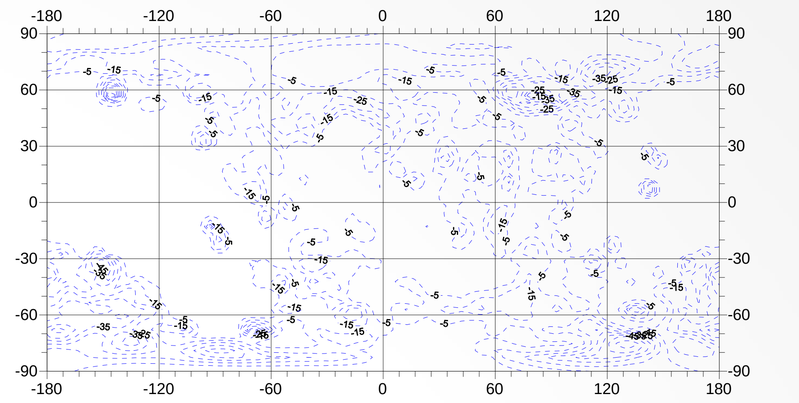


Fig.4. (layer field/layer relief >1) N=36
min= -92.9167 (lat.= -57.5, long.= -147.5), max= -0.0120 (lat.=47.5, long.= -77.5)
numbers on contours are given in units 10^5 kg/m^2
the scale – $10*10^5$ kg/m^2

For comparison, we show the same characteristics for Earth and Mars : 5a and 6 – graphs of exponential correlation for Earth and Mars, 5b,c – distribution of positive and negative mascons for the Earth.
Fig 5a shows that negative correlation for the Earth (unlike the Moon) is, for low harmonics of degree N=2,3,5, which leads to the conclusion that there are large deposits in places negative values for the density of a simple layer for the field (Fig. 5b). Basically, this corresponds to the presence of oil and gas reserves in Siberia, the Americas, the Persian gulf countries and Antarctica.

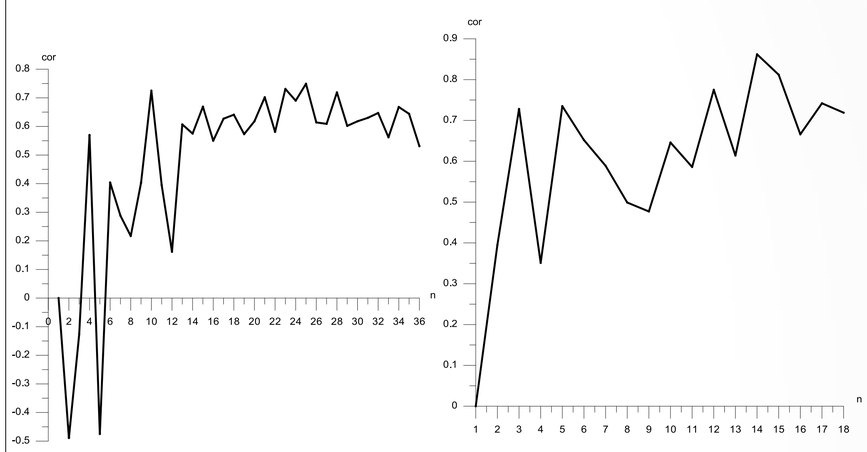


Fig.5a Correlation coefficients for harmonic relief and gravity field for the Earth

Fig.6 Correlation coefficients for harmonic relief and gravity field for the Mars

The location of the positive and negative mascons for the Earth (Fig. 5b,c), possibly reflecting the traces of collision of the growing Earth (5 billion years ago) with a few large bodies (microimpact), and not one Theia (megaimpact). The fragments of these collisions could participate in the formation of the moon [7,8]. For Mars such effects are not observed clearly (fig.6) – negative correlation is nonexistent.

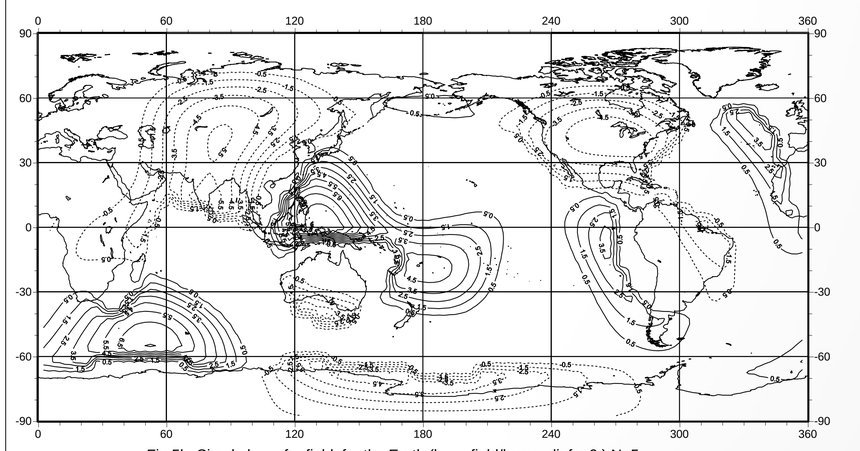


Fig 5b Simple layer for field for the Earth (layer field/layer relief < 0) N=5
the dotted lines – negative mascons ; min= - 6.17 (lat.=7.5, long.=82.5),
solid lines – positive mascons ; max=9.29 (lat.=2.5, long.=132.5)
numbers on contours are given in units 10^5 kg/m^2

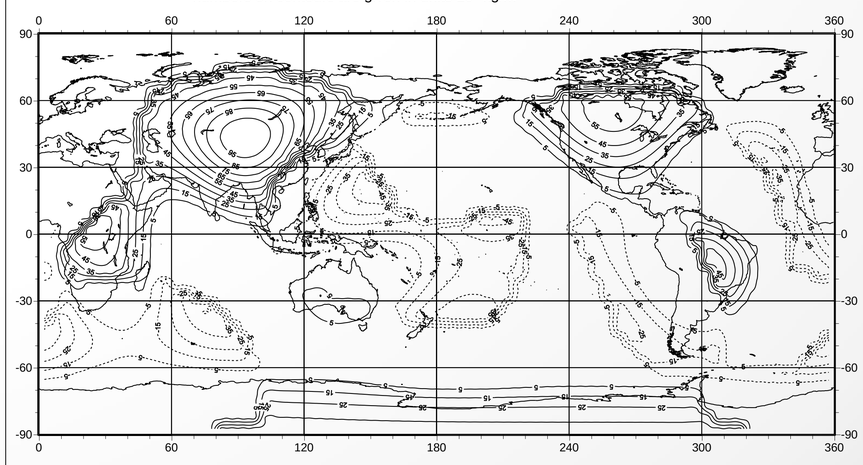


Fig 5c Simple layer for relief for the Earth
min= - 52.31 (lat.=22.5, long.=152.5),
max=103.51 (lat.=42.5, long.=92.5)
numbers on contours are given in units 10^5 kg/m^2

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