Modern Methodology for Planetary Mapping

Karachevtseva I.P.[1], Kokhanov A.A.[1], Rodionova Zh.F.[1,2], Zharkova A.Yu[1]., Zubarev A.E.[1], Garov A.S.[1], Matveev E.V.[1,3] and J.Oberst[1,4,5]

[1] Moscow State University Of Geodesy And Cartography (MIIGAIK), MIIGAIK Extraterrestrial Laboratory (MExLab), Russia
[2] Sternberg State Astronomical Institute Lomonosov Moscow University, Russia
[3] Yandex Company, Russia
[4] German Aerospace Center (DLR)
[5] Technical University of Berlin, Germany

Abstract. In the paper we describe methods and stages of planetary mapping using modern advances in the geoscience, Internet and web technologies. The mapping workflow and new maps of celestial bodies have been presented. Our approach based on developing spatial information web-system which integrated various functions and possibilities for storage, image processing, spatial analysis, and visualization of results of planetary cartography using remote sensing data of moons and planets of the Solar system

Keywords. planetary cartography, GIS, geodatabase, data model, spatial analysis, Geoportal, web-mapping.

1. Introduction

Nowadays the rapid development of GIS and web-technologies as well as terabytes of data obtained from different planetary missions provides big opportunities for mapping and study of extraterrestrial territories by cartographical methods. Here we present the modern workflow for mapping of the terrestrial planets and their satellites based on results of photogrammetry image processing and spatial analysis of newest remote sensing data received by scientific spacecrafts (Fig.1).

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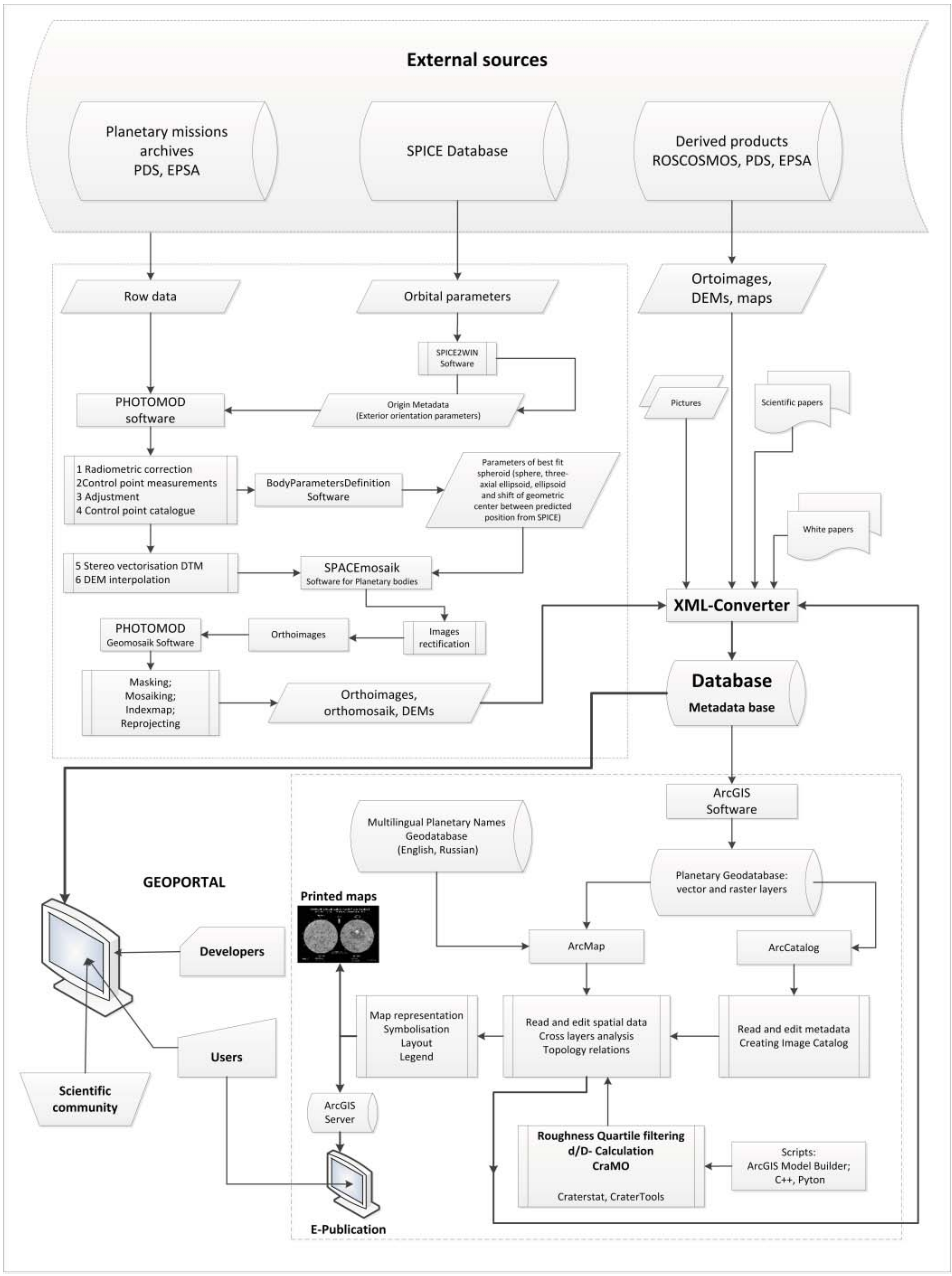


Figure 1. The flowchart of the mapping of celestial bodies based on photogrammetric (PHOTOMOD software), GIS (ArcGIS software) and web-techniques (Geoportal and ArcGIS online).

2. Data processing

2.1. Data sources

The most of planetary remote sensing data are structured according to the Planetary Data System standard (PDS) and provided by special nodes (www.pds-geosciences.wustl.edu) or national archives (NASA, ESA, JAXA). The most new planetary data were received recently from various missions, mainly lunar and martian: Lunar Reconnaissance Orbiter (NASA), SELENE/Kaguya (JAXA), Mars Express (ESA), Mars Global Surveyor (NASA) and from recently finished mission to Mercury – Messenger (NASA). All these missions provide wide range remote sensing data of the planetary surface: high resolution images for region of interest (ROI), e.g., for lunar landing sites up to 30 cm/px; global mosaics (up to 100 m/px); laser altimetry data; Digital Elevation Models (DEM) from 1-10 to 100 m/px. These datasets usually need to be processed for further using in GIS.

2.2. Photogrammetry image processing

In addition to data from planetary archives, we produced our own data based on photogrammetry image processing of raw non-calibrated data. For creation of new spatial products such as DEM or orthomosaics we use PHOTOMOD™ software (www.racurs.ru/?lng=eng&page=634) which was specially updated for celestial bodies (Zubarev et al., 2012). The results of processing are the basic data for planetary mapping such as control point networks, which provide coordinates for surface objects. We produce the control points networks for different celestial bodies (Fig. 2) based on bundle block adjustment of coordinate measurements by least squares analysis techniques using large numbers of overlapping stereo images. Typically, during the adjustment, also position and pointing data is improved for the images involved. This is crucial for the production of geometrically accurate maps.

The results of data processing are orthomosaics and DEMs for the celestial bodies (global extent) or for ROI (local extent) like landing sites, rovers traverse, unique geological objects, etc.

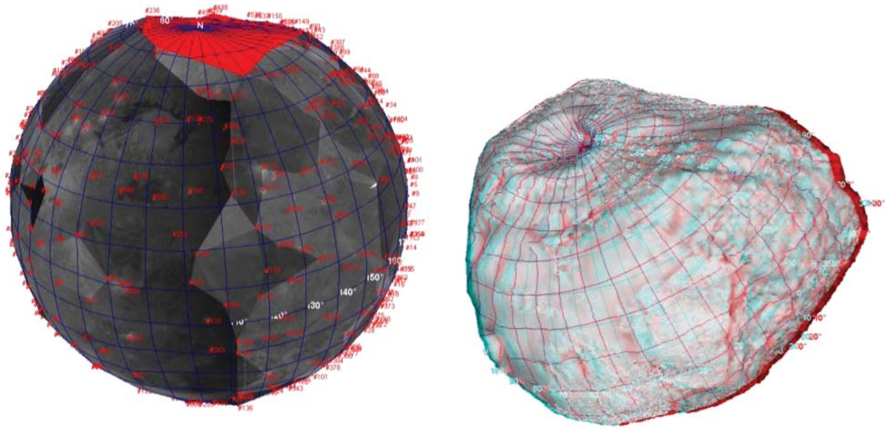


Figure 2. 3D planetary control points networks: for Ganymede (left) and for Phobos (right).

2.3. Data transformation

Using unification of metadata based on various standards like PDS4 (Crichton et al., 2012) and FGDC (http://www.fgdc.gov/index.html) we transform data into standard format and projection, which carried out with special developed software Converter, based on XML-schemes (Karachevtseva et al., 2014). It provides the spatial and information description of the data at SQL-geodatabase.

After the processing we can also use data in ArcGIS software (http://www.arcgis.com/) for spatial analysis, cataloging of planetary surface objects and for further thematic mapping based on spatial referenced data.

3. Mapping

3.1. GIS catalogues of surface objects

The catalogues of spatial objects are the keys to geomorphological study of the surface of planetary bodies. Such catalogues not only highlights location and spatial distribution of objects, but includes their morphometric parameters (Basilevsky et al., 2014) or results of cluster analysis (Kreslavsky et al., 2014a), surface dating or calibration of automatic object detection. Maps, derived from the catalogues, show various spatial parameters of study area, for example, craters density (Fig. 3).

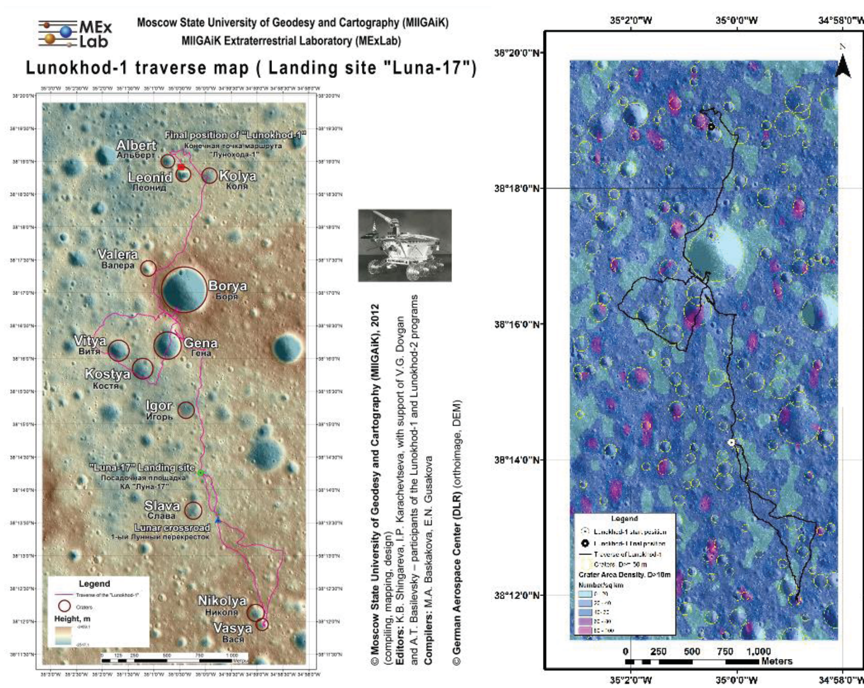


Figure 3. Maps of the landing site of first planetary rover Lunokhod-1 controlled distantly from Earth: Base map (left); Map of craters density (right).

3.2. Maps of relief characteristics

Maps of relief characteristics are a useful instrument for morphological study of surface (Kreslavsky et al., 2015), for example, for estimation of safety for landing of spacecrafts (Karachevtseva et al., 2015a). Mapping of statistical characteristics could reveal inconspicuous on the physical maps structures of surface (Kokhanov et al., 2013). As result of morphometric study of Lunar and Mercurian relief we have prepared maps of topographic roughness of these planets (Fig. 4). Also the first hypsometric Mercury globe (Fig. 5) has been created based on new DEM, which completely covers the planet's surface with resolution 22 000 m/pixel. Global Mercury's DEM was produced in German Aerospace Center (DLR) based on limb measurements (Elgner et al., 2014) of MESSENGER wide-angle camera (MDIS WAC). For mapping DEM has been processed in MIIGAiK using ArcGIS 10.3 software: Mercury's relief is shown by contours (in 500 m) and with color hypsometric scale in 16 intervals (Zharkova et al., 2015). The elevations are referenced to the sphere with radius 2 439 700 m recommended by International Astronomical Union.

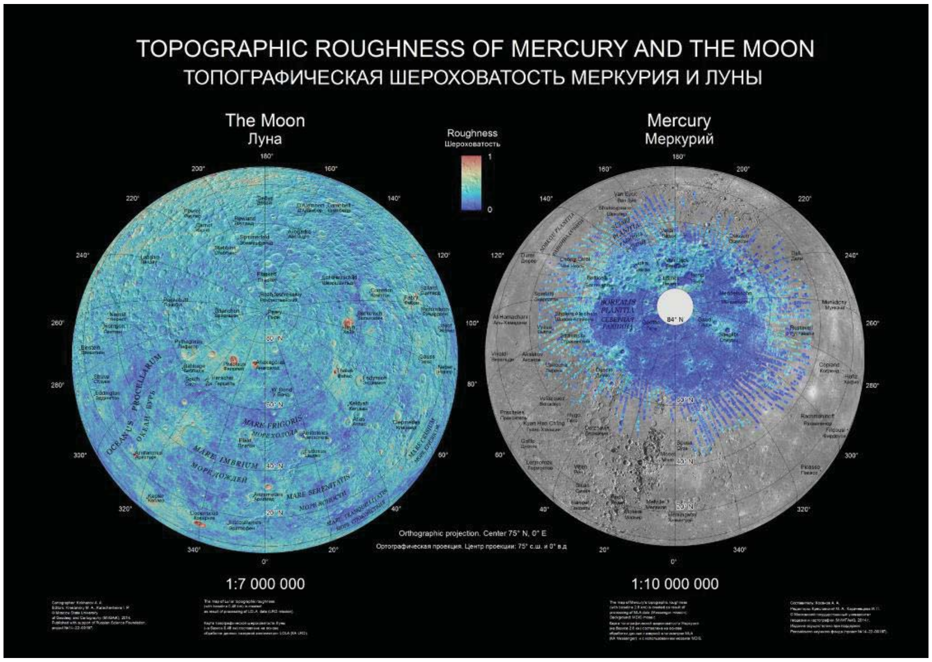


Figure 4. Wall maps of topographic roughness at the one layout: The Moon (left) and Mercury (right) (Kokhanov et al., 2014).

Figure 5. Mapping of Mercury relief: the first hypsometric globe (left) with diameter 15 cm and scale 1:32 500 000; Pamphlet to accompany with global topographic maps (1: 60 000 000) of the northern and southern hemispheres in azimuthal equidistant projection (right).

3.3. New tools and software

Additionally to the existing planetary tools such as CraterTools (Kneissl et al, 2011) or Craterstat (Michael et al., 2012), new different methods and algorithms of calculation of morphometric parameters have been developed for realization in ArcGIS software. Using Python we have developed the tool for roughness estimation based on various approach (Kokhanov et al., 2013), e.g. the roughness can be calculated as the interquartile range of the second derivative of the relief. As there are no universal methods of roughness calculation, this type of estimation provides symmetrical scale-defined stable results. For automatization of calculation of the morphometric parameters the special model has been developed based on ArcGIS Model Builder. The developed algorithms (Roughness Quartile filtering, d/D-Calculation, CraMO, see Fig. 1) provide the measurement of surface roughness, morphometric characteristics of relief features such as profiles, depth and form of objects, which can be used for morphological analysis of craters degradation and properties of surface.

4. Map publishing

4.1. Printed maps

The examples of successful realization of described workflow are the results of mapping of celestial bodies: map of the parameters of Lunar relief (Kreslavsky et al., 2014b), hypsometric Mercury Globe and maps (Fig.5), hypsometric map of Phobos (Fig.6), hypsometric map of the Moon (Fig.7), and new maps in Phobos Atlas (Fig.8) as well as online maps and Geoportal (Fig.9-10).

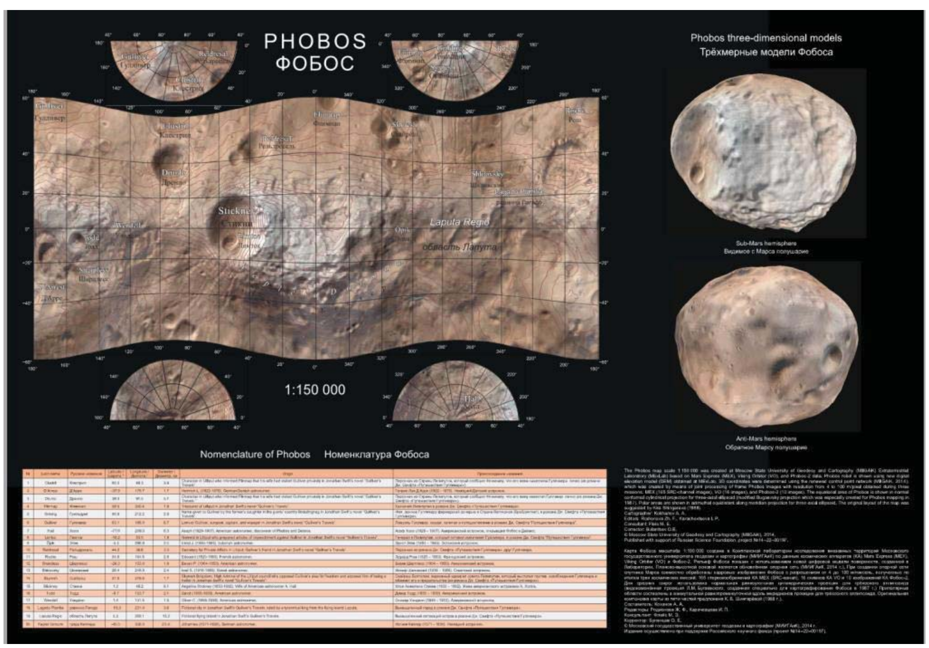


Figure 6. Hypsometric wall map of Phobos.

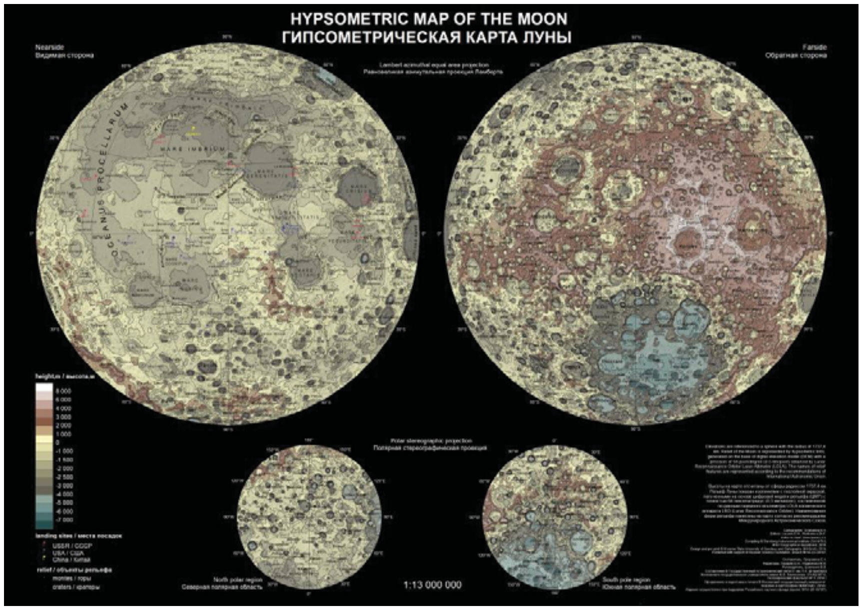
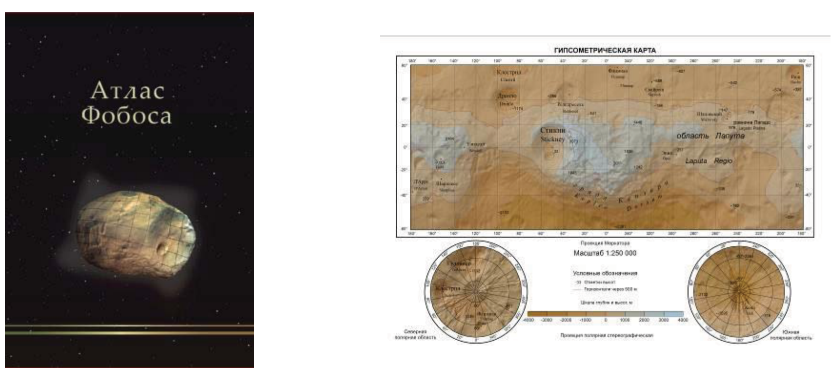


Figure 7. Hypsometric wall map of the Moon.

Based on the physical and thematic maps of Phobos the new planetary Atlas has been developed (Karachevtseva et al., 2015b). Phobos Atlas contains over 40 maps with size 32×22 cm, which represent miscellaneous characteristics of surface and physical properties of one of Martian satellite, as well as description of study and results of Phobos research. (Fig. 8). Despite the fact that the atlas is prepared in Russian, feature names on the maps are presented in bilingual form (Russian and English), so Phobos Atlas can be used by international community.



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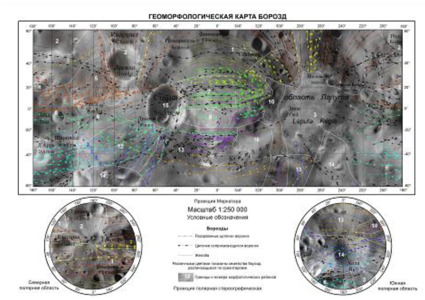

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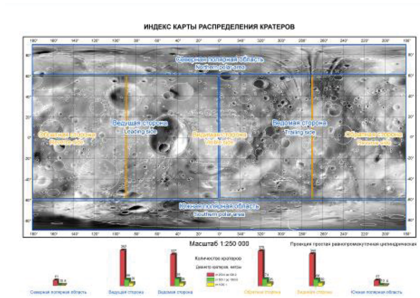

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Figure 8. The Phobos Atlas: a) the Atlas cover, based on DEM and results of 3D-modeling; b) the layout of Hypsometric map; c) the layout of Geomorphological map of Grooves; d) the layout of Map of Craters distribution.

4.2. Web-mapping

Some new original planetary maps are published using ArcGIS online services with presentation of the design it gives the ability to scale and get more details than from paper map. For example, web-based techniques were implemented for online mapping of Phobos (http://bit.ly/Phobos_topography) and lunar landing site (http://bit.ly/Lunohod_1).

4.3. Geoportal

For sharing and visualization of results of image processing and data analysis the Geoportal as Geodesy and Cartography Node (Fig. 9) has been developed (Karachevtseva et al., 2014). The Geoportal (http://cartsrv.mexlab.ru/geoportal/) provides access to the spatial data of studied celestial bodies (the Moon, Phobos, Mercury and Ganymede) and contains raster and vector layers of various extents (from global to local) as products of different processing levels equipped with spatial metadata.

For further development, we propose to organize access to the data using a new architecture based on info-communication solution and cross platform (desktop, web and mobile application) for representation of spatial planetary data in 3D web GIS.

Our approach provides possibilities to represent planetary data in 3D-form for scientific use: for geological study and morphometric measurements, planning of future missions. A new developed architecture provides possibilities to organize “online laboratory” based on interactive tools widely used for planetary studies and realistic representation of result of scientific research as well as collaborative research and joint online meeting within common spatial context to share and discuss observations (Fig.10).

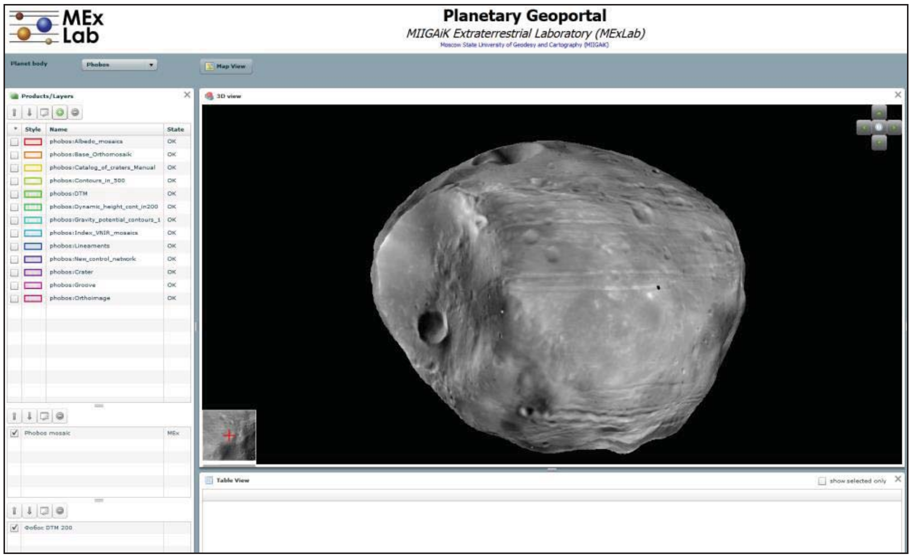

Figure 9. MIIGAiK Planetary Geoportal: three-dimensional view of Phobos surface.

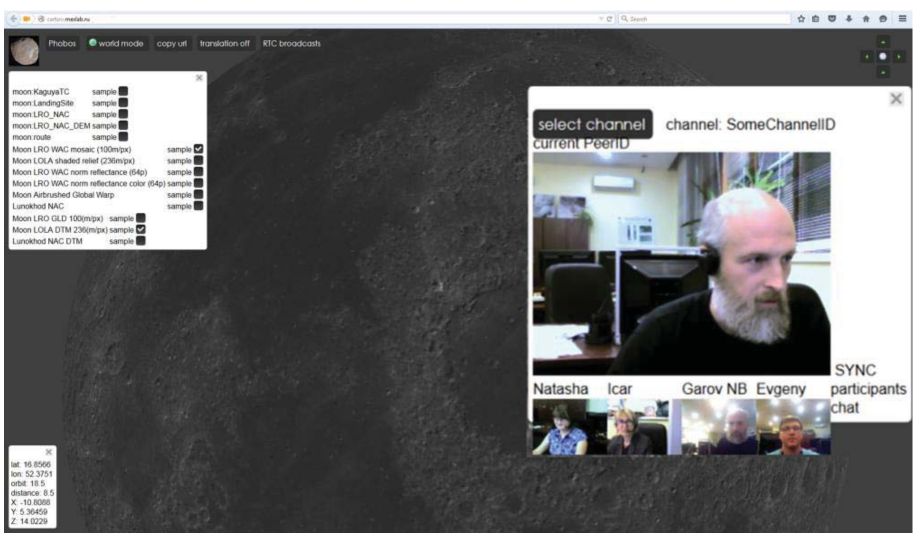

Figure 10. MIIGAiK Planetary Geoportal: new prototype of 3D web-GIS based on three-dimensional view of the Moon surface in teleconference regime including video/audio broadcasting.

5. Conclusion

We have developed the methodology of mapping of celestial bodies using modern approach based on GIS and innovative web-techniques which includes various stages: from raw image processing to online maps. The proposed methodology has been implemented for planetary mapping of various planets and satellites; the results can be used for Solar system research, for planning of future missions, etc.

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