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# A web system of virtual morphometric globes for Mars and the Moon

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ABSTRACT

We developed a web system of virtual morphometric globes for Mars and the Moon. As the initial data, we used 15-arc-minutes gridded global digital elevation models (DEMs) extracted from the Mars Orbiter Laser Altimeter (MOLA) and the Lunar Orbiter Laser Altimeter (LOLA) gridded archives. We derived global digital models of sixteen morphometric variables including horizontal, vertical, minimal, and maximal curvatures, as well as catchment area and topographic index. The morphometric models were integrated into the web system developed as a distributed application consisting of a client front-end and a server back-end. The following main functions are implemented in the system: (1) selection of a morphometric variable; (2) two-dimensional visualization of a calculated global morphometric model; (3) 3D visualization of a calculated global morphometric model on the sphere surface; (4) change of a globe scale; and (5) globe rotation by an arbitrary angle. Free, real-time web access to the system is provided. The web system of virtual morphometric globes can be used for geological and geomorphological studies of Mars and the Moon at the global, continental, and regional scales.

## 1. Introduction

Topography is one of the key characteristics of a celestial body. Data on global morphometry can be useful in planetary exploration, for example, for studying internal structure of planets and moons, revealing of topographically expressed endo- and exogenic structures (such as, lineaments, destroyed craters, palaeo-channels, and palaeo-deltas), modeling of terrain evolution, terrain visualization, and so on (Solomon et al., 1991; Smith et al., 1999; Wieczorek, 2007; Florinsky, 2008, 2018; Karachevtseva et al., 2014; Wählisch et al., 2014).

Virtual globes — programs implementing interactive three-dimensional (3D) models of a planet — enable to carry out 3D multi-scale visualization of complex spatially distributed multi-layer data with capabilities to move around the globe and to change the user viewing angle and position (Cozzi and Ring, 2011; Blaschke et al., 2012). Virtual globes are increasingly used to solve various tasks in geosciences (Chen and Bailey, 2011; Paraskevas, 2011; Whitmeyer et al., 2012; Yu and Gong, 2012; Scheffers et al., 2015).

We earlier developed a *desktop* system of virtual morphometric globes for Mars and the Moon (Florinsky and Filippov, 2017). In this article, we briefly describe the development of a *web* system of virtual morphometric globes for these celestial bodies.

## 2. Geomorphometric modeling

To create the first versions of the web system of virtual morphometric globes, we worked with low-resolution models. As the initial data, we used the following global, 15-arc-minutes-gridded digital elevation models (DEMs): 1) A DEM of Mars extracted from the Mars Orbiter Laser Altimeter (MOLA) gridded data record archive (Smith et al., 1999, 2003); 2) A DEM of the Moon extracted from the Lunar Orbiter Laser Altimeter (LOLA) gridded data record archive (Neumann, 2008; Smith et al., 2010). To suppress high-frequency noise in the extracted DEMs, they were twice and thrice smoothed, correspondingly, by a weighted average filter.

For Mars and the Moon, we derived global digital models of sixteen local, nonlocal, and combined morphometric variables (Table 1) from the smoothed DEMs. To calculate local morphometric variables, we applied a finite-difference method intended for spheroidal equal angular grids (Florinsky, 1998, 2017b). Equations of local morphometric variables can be found elsewhere (Florinsky, 2016, 2017a). Digital models of nonlocal morphometric variables were derived from the smoothed DEMs by a method of Martz and de Jong adapted to spheroidal equal angular grids (Florinsky, 2017b). The DEMs and each global morphometric model included 1,036,800 points (the matrix 1440 × 720).

The DEMs were processed by software LandLord (Florinsky, 2016).

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**Table 1**

Definitions and interpretations of some morphometric variables (Shary et al., 2002; Florinsky, 2016, 2017a).

| Variable, notation, and unit | Definition and interpretation |
|---|---|
| *Local morphometric variables* | |
| Horizontal curvature, $k_h$, $\mathrm{m}^{-1}$ | A curvature of a normal section tangential to a contour line at a given point of the topographic surface. A measure of flow convergence and divergence. Gravity-driven overland and intrasoil lateral flows converge where $k_h < 0$, and they diverge where $k_h > 0$. |
| Vertical curvature, $k_v$, $\mathrm{m}^{-1}$ | A curvature of a normal section having a common tangent line with a slope line at a given point of the topographic surface. A measure of relative deceleration and acceleration of gravity-driven flows. Overland and intrasoil lateral flows are decelerated where $k_v < 0$, and they are accelerated where $k_v > 0$. |
| Minimal curvature, $k_{\min}$, $\mathrm{m}^{-1}$ | A curvature of a principal section with the lowest value of curvature at a given point of the topographic surface. $k_{\min} > 0$ corresponds to hills, while $k_{\min} < 0$ relates to valleys. |
| Maximal curvature, $k_{\max}$, $\mathrm{m}^{-1}$ | A curvature of a principal section with the highest value of curvature at a given point of the topographic surface. $k_{\max} > 0$ corresponds to ridges, while $k_{\max} < 0$ relates to closed depressions. |
| Mean curvature, $H$, $\mathrm{m}^{-1}$ | A half-sum of curvatures of any two orthogonal normal sections at a given point of the topographic surface. $H$ represents two accumulation mechanisms of gravity-driven substances — convergence and relative deceleration of flows — with equal weights. |
| Gaussian curvature, $K$, $\mathrm{m}^{-2}$ | A product of maximal and minimal curvatures. According to *Teorema egregium*, $K$ retains values in each point of the topographic surface after its bending without breaking, stretching, and compressing. |
| Unsphericity curvature, $M$, $\mathrm{m}^{-1}$ | A half-difference of maximal and minimal curvatures. $M = 0$ on a sphere; $M$ values show the extent to which the shape of the topographic surface is non-spherical at a given point. |
| Difference curvature, $E$, $\mathrm{m}^{-1}$ | A half-difference of vertical and horizontal curvatures. Comparing two accumulation mechanisms of gravity-driven substances, $E$ shows to what extent the relative deceleration of flows is higher than flow convergence at a given point of the topographic surface. |
| Horizontal excess curvature, $k_{he}$, $\mathrm{m}^{-1}$ | A difference of horizontal and minimal curvatures. $k_{he}$ shows to what extent the bending of a normal section tangential to a contour line is larger than the minimal bending at a given point of the topographic surface. |
| Vertical excess curvature, $k_{ve}$, $\mathrm{m}^{-1}$ | A difference of vertical and minimal curvatures. $k_{ve}$ shows to what extent the bending of a normal section having a common tangent line with a slope line is larger than the minimal bending at a given point of the topographic surface. |
| Accumulation curvature, $K_a$, $\mathrm{m}^{-2}$ | A product of vertical and horizontal curvatures. A measure of the extent of flow accumulation at a given point of the topographic surface. |
| Ring curvature, $K_r$, $\mathrm{m}^{-2}$ | A product of horizontal excess and vertical excess curvatures. Describes flow line twisting |
| *Nonlocal morphometric variables* | |
| Catchment area, $CA$, $\mathrm{m}^2$ | An area of a closed figure formed by a contour segment at a given point of the topographic surface and two flow lines coming from upslope to the contour segment ends. A measure of the contributing area |
| Dispersive area, $DA$, $\mathrm{m}^2$ | An area of a closed figure formed by a contour segment at a given point of the topographic surface and two flow lines going down slope from the contour segment ends. A measure of a downslope area potentially exposed by flows passing through a given point |
| *Combined morphometric variables* | |
| Topographic index, $TI$ | The logarithm of a ratio of $CA$ to $\tan G$ at a given point of the topographic surface. A measure of the extent of flow accumulation |
| Stream power index, $SI$ | The logarithm of a product of $CA$ and $\tan G$ at a given point of the topographic surface. A measure of the potential flow erosion |

## 3. Web system

The web system of virtual morphometric globes is designed as a separate unit of a 3D web GIS for storage and access to planetary data (Garov et al., 2016), which is currently developed as an extension of an existing 2D web GIS (MexLab, 2012–2016). To implement the web system of morphometric globes, a distributed application was developed. The application consists of (1) a client front-end, running in a browser and providing a user with an interface and visualization of a globe and morphometric parameters; and (2) a server back-end, which supports a client and feeds it with all required data. Although the application underwent several cycles of implementation and is still in the development, the major design goals and decisions stayed the same. The general development vector is directed toward the increase in client interactivity while keeping server resources usage at a possible minimum. Thus, a final application can be classified as a "rich" or "thick" web client.

### 3.1. Back-end

The application back-end represents a layered structure consisting of data storage, web service, and http server layers.

The data storage layer was implemented as a structured query language (SQL) database (we used SQL Server). The character of data, which are split for many small-keyed chunks/tiles, makes the use of data tables a viable and fit solution. Although a raw file system could also be used for storage, we chose a relational database management system (RDBMS) to ensure fast-key search and effective thread utilization and re-use.

For the web service layer, we used an application server previously developed in-house (Garov et al., 2016), which provides an application programming interface (API) similar to the OpenGIS Web Map Tile Service (WMTS) standard (OGC, 2010). The application server extracts data tiles from the database and sends them to a client as responses for client's Hypertext Transfer Protocol (HTTP) *POST* or *GET* requests.

The http server is used for the static site hosting. No site templating or dynamic server-side site rendering is used (this does not relate to morphometric data, which can be pre-rendered; see below). Session state is not used at the server; we opt for a fully stateless approach.

The described back-end has been already successfully approbated in the planetary portal devoted to Phobos and the Moon (MexLab, 2012–2016; Karachevtseva et al., 2014).

### 3.2. Front-end

For the front-end implementation, we used an approach utilizing a modern graphic API, in which graphics processing unit (GPU) helps to builds 3D scenes (in our case, a globe surface for visualization) taking into account an observer position, dynamically transforming via OpenGL Shading Language (GLSL) (Khronos Group, 2008–2016) shaders and mutually adjusting a set of standard quad geometries into sphere segments. This set is then re-used (for example, when changing the observer position).

Models of morphometric variables are presented in the form of data layers with the possibility of separate as well as joint visualization. When displayed, the layer data are aligned with a correspondent sphere segment and loaded into the GPU memory. We implement scaling with automatic adjustment of level of detail.

We decided not to use existing JavaScript virtual globe engines, such as Cesium (AGI, 2012–2015) or World Wind (NASA, 2003–2011), because of our plans to integrate a model generation code directly into a visualization chain (see below).

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