TOWARDS GEOMORPHOMETRIC MODELLING OF THE TOPOGRAPHY OF THE ARCTIC OCEAN FLOOR

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Abstract

We develop a system for geomorphometric modelling of the topography of the Arctic Ocean floor. The system will provide: (a) Storage of a big digital elevation model (DEM) of the ocean floor; (b) Derivation of models of morphometric variables from this DEM; (c) Interactive three-dimensional (3D) multiscale visualization of the obtained models; and (d) Free access to this information via Internet. The system development includes the following main stages: (1) Adaptation of previously developed computational methods of geomorphometry and algorithms of interactive 3D visualization to handle and process big DEMs; (2) Development of software implementing these methods and algorithms; (3) Selection of the most accurate DEM describing the topography of the Arctic Ocean floor; (4) Filtering of the selected DEM; (5) Derivation of models of morphometric variables from the filtered DEM for several scales; (6) Creation of interactive multiscale 3D morphometric models; (7) Development of a geoportal.

INTRODUCTION

Topography is a one of the key factors determining the course and direction of processes occurring at the boundary of the lithosphere and the atmosphere, as well as the lithosphere and hydrosphere. Submarine topography influences ocean currents, circulation of ocean waters, spatial distribution of perennial ice, and movement of sediments along the slopes. Submarine valleys, being extensions of river valleys, take part in the gravitational transport of substances from land to ocean. Topography, being the result of interaction of endogenous and exogenous processes of different scale level, can act as an indicator of the geological structure of the ocean floor.

In this connection, digital terrain modelling and geomorphometry are widely used for solving various problems of geomorphology, geology, glaciology, oceanology, climatology and other geosciences [Florinsky, 2016; Lecours et al., 2016]. Of special interest are digital models of local, nonlocal, and combined morphometric variables derived from digital elevation models (DEMs), such as horizontal curvature, vertical curvature, mean curvature, maximum curvature, minimum curvature, catchment area, stream power index, etc.

In this paper, we describe briefly an ongoing project on the development of a system for geomorphometric modelling of the topography of the Arctic Ocean floor.

METHODS AND MATERIALS

We develop a system for geomorphometric modelling of the topography of the Arctic Ocean floor. The system will provide:

- Storage of a big DEM of the ocean floor.
- Derivation of models of morphometric variables from this DEM.

- Interactive three-dimensional (3D) multiscale visualization of the obtained models.
- Free access to this information via Internet.

The system development includes the following main stages:

1. Adaptation of several previously developed methods for mathematical terrain modelling [Florinsky, 2016] to handle and process big DEMs.

The list of such methods includes: (1) two computational methods based on finite-difference approximations of the partial derivatives of elevation, which allow one to derive digital models of local morphometric variables from DEMs on square grids and spheroidal equal angular grids [Florinsky, 1998, 2009]; (2) a method for derivation of nonlocal and combined morphometric variables based on the Martz-de Jong flow-routing algorithm adapted to spheroidal equal angular grids [Florinsky, 2016, pp. 137–139]; (3) a universal spectral analytical method for terrain modelling based on high-order orthogonal expansions using the Chebyshev polynomials with the subsequent Fejér summation [Florinsky, Pankratov, 2016]. This method is intended for the processing of regularly spaced DEMs within a single framework including DEM global approximation, denoising, generalization, and calculating the partial derivatives of elevation.

2. Development of software implementing these methods and algorithms.

As a prototype we will use the program LandLord 4.0 created earlier [Florinsky, 2016, pp. 413–414].

3. Selection of the most accurate DEM describing the topography of the Arctic Ocean floor for subsequent calculations and modelling.

There are several DEMs including a description of the topography of the Arctic Ocean floor. The most modern DEMs are:

- International Bathymetric Chart of the Arctic Ocean (IBCAO), version 3.0 [Jakobsson et al., 2012; IBCAO, 2012]
- General Bathymetric Chart of Oceans (GEBCO) 2014 Grid [Weatherall et al., 2015; BODC, 2015]
- Global DEM SRTM30_PLUS V11 [Sandwell et al., 2008; Becker et al., 2009]
- Global DEM SRTM15_PLUS V1 [Olson et al. 2014; Sandwell et al., 2014]

For a resolution of 500 m (a square grid) or 30 arc-seconds (a spheroidal equal angular grid), a DEM of the Arctic Ocean floor and adjacent land areas consists of about 135 million points.

Figure 1 displays a bathymetric map for the Arctic Ocean floor based on a DEM extracted from the IBCAO 3.0 (IBCAO_V3_500m_RR). The DEM with a resolution of 5 km includes 1,347,921 points (the 1161×1161 matrix) encompasses the territory measuring about 5,792,000 km by 5,792,000 km. The map is presented in the polar stereographic projection. For the land surface, elevations are not shown.

At this stage, we will use several methods for estimating quality and accuracy of bathymetric models including a method for estimation of DEM accuracy based on comparison of DEM depth values with independent high-precision data from a multi-beam echosounder, as well as a method for quantitative estimation of bathymetric artefacts in DEMs [Abramova, 2012].

4. Filtering (noise suppression and artefact removal) of the selected DEM.

5. Derivation of models of morphometric variables from the filtered DEM for several scales with different generalization levels.

At this stage, we plan to derive models of the following morphometric variables: (1) Local variables: slope gradient, slope aspect, horizontal curvature, vertical curvature, mean curvature, Gaussian curvature, minimal curvature, maximal curvature, unsphericity curvature, difference curvature, vertical excess curvature, horizontal excess curvature, ring curvature, accumulation curvature, the generating function, rotor; (2) Nonlocal variables: catchment area and dispersive area; and (3) Combined variables: topographic index and stream power index.

Figures 2–4 represent examples of some morphometric maps for the Arctic Ocean floor. Digital models of horizontal, vertical, and maximum curvatures were derived from the DEM (Fig. 1), which was thrice smoothed to suppress high-frequency noise. These three models consist of 1,338,649 points (1157×1157 matrices).



Figure 1. The Arctic Ocean floor: elevations (based on IBCAO 3.0 data).

Data processing and visualization were carried out by software LandLord [Florinsky, 2016, pp. 413–414]. All maps are presented in the polar stereographic projection. For the land surface, curvature values are not shown.

6. Creation of interactive multiscale 3D morphometric models for the floor topography.

At this stage, we will apply principles and algorithms for constructing interactive, numerically modelled systems in the open-source, multi-platform software environment Blender [Hess, 2010; Blain, 2014; Blender Foundation, 2003–2018] together with the Blend4Web extension package, based on the original methods and algorithms for representing 3D data [Filippov and Sobolev, 2002; Florinsky and Filippov, 2017]. Integration of the source data into the Blender environment will be carried out using specially written Python scripts. In the final system, we plan to implement a dynamic adaptation of geometry and map resolution, as well as methods for synchronous presentation of the diverse scientific data provided by a new architecture of the digital representation of complex 3D objects.

A brief description of a methodology of the Blender-based 3D terrain modelling (including examples from the topography of the Arctic Ocean floor) can be found elsewhere [Florinsky and Filippov, 2018].



Figure 2. The Arctic Ocean floor: horizontal curvature (based on IBCAO 3.0 data).

7. Development of a geoportal for storage of the obtained models, their interactive multiscale 3D visualization, and free use by online requests.

To provide free Internet access to big bathymetric DEMs, digital models of morphometric variables, and 3D terrain models as well as to work with these data interactively online, we will apply technologies of interactive browser-based applications based on the WebGL API and HTML 5 standards.

CONCLUSIONS

As a result of the project, we will develop an information and computing system for morphometric modelling of the topography of the Arctic Ocean floor. The system will provide storage of a big DEM for the ocean floor; derivation of morphometric models from the DEM; interactive 3D multiscale visualization of the obtained models; and free access to this information via the Internet, with the possibility of 3D real-time visualization online.

A new interactive online information tool will be created to support hydrographic, marine geomorphological, geological, geophysical, and oceanological studies of the Arctic Region, in particular, to determine the outer limit of the Russian continental shelf in the Arctic [Fridman, 2008; Firsov, 2016; Piskarev et al., 2017].



Figure 3. The Arctic Ocean floor: vertical curvature (based on IBCAO 3.0 data).

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Figure 5. The Arctic Ocean floor: maximum curvature (based on IBCAO 3.0 data).

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