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Semiautomatic construction of isobase surfaces: A case study from the central Western Carpathians

Karel Jedlička [a,*], Ján Sládek [b], Jakub Šilhavý [a]

[a] *Section of Geomatics, Department of Mathematics, Faculty of Applied Sciences, University of West Bohemia in Pilsen, Univerzitní 22, Pilsen 306 14, Czech Republic*
[b] *Department of Physical Geography, Geomorphology and Natural Hazards, Institute of Geography, Slovak Academy of Sciences, Štefánikova 49, Bratislava 814 73, Slovak Republic*

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ABSTRACT

This article describes a method for semiautomated construction of isobase surfaces in the environment of a Geomorphological Information System (GmIS). The motivation to automate the process is that the manual construction of isobase surfaces involves several decision procedures, and also a lot of manual vectorization which can be time-consuming if the area of interest is large.

A (semi-)automated process of isobase surface construction could accelerate the process of morphostructural analysis. Therefore, the contribution focuses on design, development and testing of such a method. The developed tools were compared to an expert driven construction of isobase surfaces. The automatically constructed data layers were compared to the layers that were constructed manually in the southwest part of the study area (Turčianska kotlina basin (Western Carpathians) and surrounding area in Slovakia). Three different statistical methods were used (correlation, linear regression and DTM volume difference checking). All three methods proved very high similarity of automatically created isobase surfaces to expert driven isobase surfaces creation. The results show that the method of semiautomated creation can be used in morphostructure analysis and save the time needed for manual isobase surface creation.

The method's technological background is based on the ESRI platform. The original desktop solution has been developed for use on a client/server architecture that is able to present the capabilities of GmIS to a wider geomorphological audience.

1. Introduction

The construction of isobase surfaces is one of the main tools employed for morphostructure analysis. According to Filosofov (1960) and Spiridonov (1975), constructed isobase surfaces simplify recent georelief and uncover wider and larger morphostructures. Isobase surface analyses provide increased knowledge of morphostructure evolution, boundaries and inner segmentation. This type of analysis is useful for large areas containing a well-developed river or valley network, for example mountain ranges. Although the concept of isobase surface construction is not new, such analyses are rarely carried out. This is partly due to the time required for their manual construction. Therefore, we decided to focus our study on the semi-automated construction of isobase surfaces in the area of the central Western Carpathians.

The following text briefly reviews the terminology related to isobase surface or isobase line in literature. According to Grohmann et al. (2011), the base level was defined by Powell (1875) as the level “below which the dry lands cannot be eroded”. Base-level maps were first applied by Dury (1952) and extensively employed by Filosofov (1960) and Pannekoek (1967) for the study of young orogeny development (Raczkowski et al., 1984). According to Lacika (1997), a map of isobase lines in the Western Carpathians was first developed by Zuchiewicz (1981). As mentioned above, a single set of terminology has not yet been agreed upon for isobase analysis. Different authors freely substitute alternatives for certain words. For example, *base level map* (Raczkowski et al., 1984; Grohmann et al., 2011), *base level surfaces* (Zuchiewicz and Oszczypko 2008), *isobase surface* (Filosofov, 1960; Grohmann et al., 2007), *base surface* (Ufimtsev et al., 2009), *subenvelope map* (Stearns, 1967; Raczkowski et al., 1984) and *isobase map* (Lacika, 1997) are all generally used to analyze similar problems. Furthermore, the term *base surface* is also extensively employed in a non-geomorphological sense – in mathematics, informatics, computer graphics, etc. (e.g., Dong et al., 2005). The present study uses the

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* Corresponding author.
E-mail addresses: smrcek@kma.zcu.cz (K. Jedlička), sladek.jan@savba.sk (J. Sládek), jsilhavy@kma.zcu.cz (J. Šilhavý).

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term *isobase surface* or the term *isobase line* when isolines are used as an interpretation of an isobase surface. In that meaning, isobase lines connect points of equal height (altitude) between adjacent thalwegs of the same hierarchic order.

The interpretation of isobase surfaces is particularly relevant in areas containing a well-developed valley network, with investigation potentially uncovering older and wider morphostructures (Spiridonov, 1975). The interpretation of isobase lines is analogous to contours. Isobase line cumulation pointing to positive or negative morphostructures, or long-time tectonic differentiation. Missing isobase lines can indicate relatively flat areas (e.g., lowlands, basins, or relatively long-term tectonic decreases), while sharp changes in isobase maps indicate the possible locations of faults and/or lithological contrasts (Shahzad and Gloaguen, 2011).

The construction of isobase surfaces involves several steps. As a result of this, the analysis of large areas is typically time-consuming. Automation of these steps in a Geomorphological Information System (GmIS) could thus simplify and accelerate the whole process.

An automation process for isobase surface construction has been defined by several authors for use in different software products. The most relevant of these studies are by Grohmann (2004), and Shahzad and Gloaguen (2011). They developed automatic construction of isobase surfaces or isobase lines using the GRASS GIS and MATLAB software programs, respectively. Based on our experience with morphostructure analyses in the ESRI ArcGIS environment, we designed a semiautomatic construction of isobase surfaces also for ArcGIS users. The first attempt of the semiautomatic isobase construction in ArcGIS was outlined in Jedlička and Sládek (2009). The main aim of this article was to present such a semiautomatic construction of isobase surface in the ESRI ArcGIS environment, which quality is comparable to expert driven construction, just in a fraction of the time. Furthermore, a web application for isobase surface construction is also presented. This application is independent of any desktop GIS application on the client side.

The following text of the paper firstly describes the area of interest. Then, methods used for both expert driven and automatic construction of isobase surfaces from recent terrain model are described. Section 4 describes the way of comparing automated construction to manually constructed surfaces using three different comparison methods. The following section describes the implementation of the server based solution. Finally, Section 6 deals with limitations of the developed and presented software solution and Section 7 summarizes the main benefits of the solution. The overview of both manual and automated methods of isobase surface construction is depicted in Fig. 1. The figure shows which data are derived from which source data. Data are portrayed in eclipses, processes are shown just as arrows, as they are described in detail in Section 3.

2. The area of interest – the central Western Carpathians

The automated construction of isobase surfaces was carried out as part of the morphostructural analysis of the central Western Carpathian Mts. (Fig. 1). The area of interest (AOI) is a system consisting of a half-graben basin with sedimentary infill (Kováč et al., 2011) and horsts. This system was selected as it enables the testing of a wide range of different landforms (flat surfaces, narrow ridges and canyons, high altitude differentiation etc.) for the calibration of automated isobase surface construction. The altitude in the AOI varies from 300 m a.s.l. on the south-west border to 1700 m a.s.l. on the north ridge of the Malá Fatra Mts. The analyzed AOI contains a well-developed valley network (approx. 1.53 km/km^2) with a maximum of 7th order (Strahler) valleys. In addition, young morphotectonic movements and features have been identified (Hók et al., 1998; Kováč et al., 2011; Minár and Sládek, 2009; Minár et al., 2011). The geological setting of the AOI is a typical example of a core mountain range in the Western Carpathians. The Paleozoic granites create main rock formations in this core, largely located in the central part of the Malá Fatra, Veľká Fatra, and Žiar Mts. On one side, there are relatively smoothly modeled landform types, and on the other side (in a region characterized by tectonic faults) there are relatively narrow valleys and steep slopes. Contrast landform types are formed by Mesozoic rock formations (various types of limestones and dolomites), which occur as mosaics of ridges and canyons. The landforms of the Turčianska kotlina basin were recently created by fluvial processes. Quaternary – gravels and sands, Paleogene – claystones (north-east border) and Neogene – isolated remains of clays, sandstones, gravels and conglomerates create sedimentary infill of the basin. However, the bottom of the basin is tectonically fragmented by young tectonic lines (neotectonics), as well as relatively wide and smooth landform types with no sharp steps. For testing and calibrating the automation algorithm, we used the south-west region of the AOI due to the availability of expert-constructed isobase surfaces for this area. Those were produced in earlier studies (e.g. Bizubová et al., 2005; Sládek, 2008, 2012).

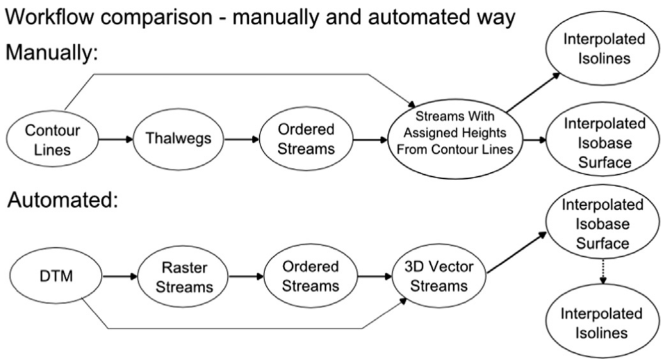

Fig. 1. Overview of both manual and automated methods of isobase surface construction.

3. Methods

3.1. *Outline of the expert construction of isobase surfaces*

A series of isobase level surfaces were constructed after Filosofov (1960) and Spiridonov (1975). The first stage in the expert (manual) construction of isobase surfaces is a digital terrain model (DTM) or contour construction. This is followed by the construction of the valley network (thalwegs), including valley ordering. The Strahler (1952) valley (stream) ordering was used for construction of series of isobase surfaces. Following this step, contours and thalweg intersections were found. Isobase lines were created by joining intersections with the same altitude at the same level of the ordered thalwegs. For example, when we would like to create an isobase surface of 2nd and higher order, contours and thalwegs intersections lying on thalwegs of 2nd, 3rd, …, *n*th order must be used. Analogically, for isobase surface of 3rd and higher order we select intersections lying on thalwegs 3rd, 4th, …, *n*th order. The “*Kriging*” interpolation (Surfer 8 software) of intersected points were then employed for 3D visualization of isobase surfaces. Although the described steps appear to be simple, they are time-consuming when applied to large areas.