Computers & Geosciences 49 (2012) 308–314

Contents lists available at SciVerse ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

A modified basal outlining algorithm for identifying topographic highs from gridded elevation data, Part 1: Motivation and methods

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ARTICLE INFO

Article history:
Received 17 February 2012
Received in revised form
20 April 2012
Accepted 23 April 2012
Available online 3 May 2012

Keywords:
Volcano identification
Terrain analysis
Digital elevation models
Remote sensing

ABSTRACT

A new approach is developed to improve the automated identification and characterization of topographic highs having quasi-elliptical basal shapes. It is designed for the study of volcanic edifices in subaerial and submarine environments, but may be applied to identify any enclosed topography feature within a digital elevation model. The procedure utilizes the results of a standard closed-contouring approach, but then adjusts the elevation of the volcanic base by evaluating the shape of the edifice along a series of topographic profiles. The algorithm overcomes the principal limitations of a stand-alone closed-contouring approach and provides improved estimates of edifice size that are less sensitive to topographic gradients and the choice of contour search interval.

1. Introduction and motivation

The closed-contouring method is a technique for identifying topographic highs in gridded elevation models or contour maps. It has been applied chiefly to detect volcanic mounds within the mid-ocean ridge and abyssal settings (e.g., Behn et al., 2004; Bohnenstiehl et al., 2008; Cochran, 2008; Jaroslow et al., 2000; Smith and Cann, 1992; White et al., 2006). Conceptually, the algorithm works by selecting the lowest elevation contour with a quasi-elliptical shape that completely encloses a topographic high. Limits may be imposed to constrain the area or height of the enclosed feature, the eccentricity of the closed-contour outlining the base or its goodness-of-fit relative to an elliptical shape in map view.

The closed-contouring approach is intuitive and easy to automate. It operates directly on the digital elevation data and does not rely on derived products, such as slope, curvature and flood maps (e.g., Ghosh et al., 2010), which can be more sensitive to artifacts in the gridded elevation model (e.g., Garbrecht and Starks, 1995; Guth, 1999). It also has the advantage of being scale independent, meaning the technique does not rely on filtering to separate a specific wavelength of topography, nor does it require the use of spatial transforms and pattern-matching to isolate features at a given scale (cf., Hillier, 2008; Lazarewicz and Schwank, 1982; Stepinski et al., 2009). The method therefore can be applied without modification to analyze variable resolution datasets in both submarine and subaerial environments.

The principal limitation of the closed-contouring method is that the base of the selected topographic feature is constrained to lie at a constant elevation—with its boundary defined by a single contour. The resulting dimensions of the topographic high therefore are sensitive to the choice of contour interval. Fig. 1 illustrates this limitation using a simple cone shaped edifice, superimposed on flat-lying regional topography.

Graphed in Fig. 1c and d are the maximum errors associated with estimating the area and volume of a cone using a closed-contouring algorithm with a given contour search interval. When expressed as a percentage of the true cone size, these errors are independent of the slope of the cone, but increase with decreasing cone height. With a 20 m contour search interval, for example, the area and volume of a 100 m-tall cone may be underestimated by up to 36% and 49%, respectively. For a 1000 m-tall cone, however, the maximum unreported area and volume are only 4% and 6%, respectively, when a 20 m contour search interval is used.

For volcanic mounds constructed on sloped topography, the constraint that the base lie at a constant elevation leads to additional errors in estimation of the height, area and volume of the volcanic edifice. This under-representation of edifice size occurs even as the contour search interval approaches zero. For simple tilted-cone geometries (Fig. 2), the percentage errors associated with the closed-contouring approach are independent of the cone height, but depend on the slope of the cone's flanks

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http://dx.doi.org/10.1016/j.cageo.2012.04.023

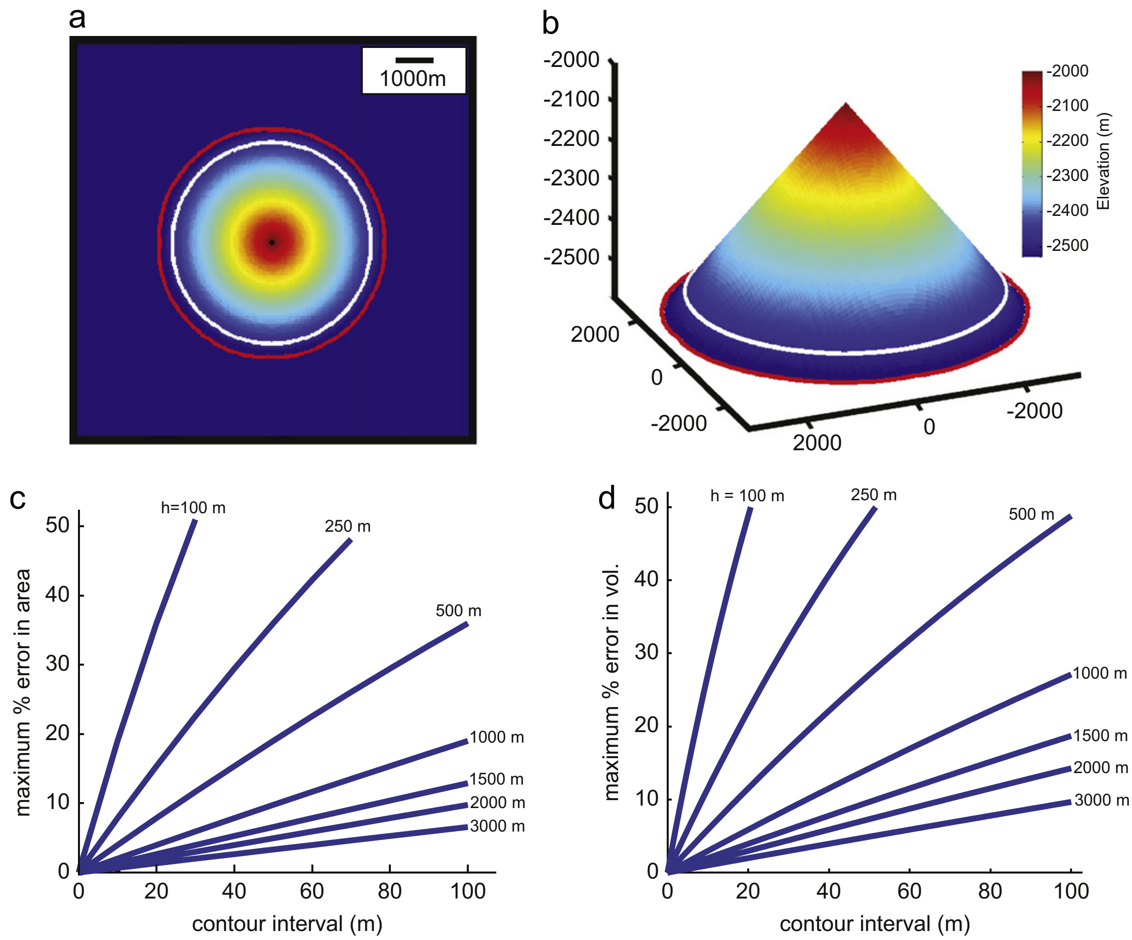

Fig. 1. The upper panels show (a) map and (b) three-dimensional views of a synthetic seamount edifice constructed from a 528 m-tall cone with 10° sloping flanks superimposed on flat lying bathymetry. The white line at −2480 m elevation marks the outline of the edifice determined using a closed-contour algorithm with a 50 m contour search interval. Using this approach, the area and volume are under-estimated by 17% and 25%, respectively. The red line at approximately −2528 m elevation delineates the base of the cone determined from the application of the *A*/*O* criteria discussed in Section 2.2. Its position more closely follows the break in slope and the area and volume of the cone are recovered to within a few percent of their true values. The lower panels show the maximum errors in cone (c) area and (d) volume that might be introduced for a given choice of contour search interval. These errors are expressed as a percentage of the cone height (*h*). For any given cone, the actual errors may be less, depending on where the contours fall relative to the base elevation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and the gradient of the topography surrounding the edifice. As demonstrated in Fig. 2, even modest regional slopes of ∼2% may result in errors on the order of ∼5%–30% in estimating cone area and volume.

Consequently, although the closed-contouring method may provide a reasonable accounting of the number of topographic highs, the statistics derived will under estimate the dimensions of the features identified. This result reflects both the error associated with the use of a finite contour interval and the inherent inability of the procedure to adequately represent sloping bases.

This paper outlines a new procedure for advancing the closed-contour determined boundary of an edifice down-slope to capture the full spatial extent of the topographic high better. The focus is on demonstrating the potential improvements made by this algorithm relative to a stand-alone closed-contouring algorithm. A Matlab-based implementation of this procedure has been developed and is openly available (Section 3). These codes are collectively referred to as the Modified Basal Outlining Algorithm (MBOA).

In a companion research article, (Howell et al., in this issue) apply this algorithm to a high-resolution digital-elevation model of the Springerville Volcanic Field in Arizona. The Springerville Volcanic Field was chosen due to the availability of digital cone-boundary data derived from detailed field observations by Condit (2010). This provides a unique opportunity to assess our ability to accurately quantify the area and volume of volcanism using topographic analysis.

2. Algorithm and methods

To mitigate the limitations outlined in Section 1, a procedure is developed to migrate the boundary of a closed-contour defined base radially outward and down slope—provided certain geometric conditions are met. This adjustment is aimed at providing a better representation of edifice size, relative to that returned by a stand-alone closed-contouring algorithm. The approach draws on the methodology used by Hillier (2008) to isolate seamounts in track line bathymetric data; however, it is extended to work on gridded datasets using the closed-contour defined boundaries as starting points.

2.1. Selection of closed-contour bases

Given gridded elevation data, the procedure initially selects all closed-contours. Within the MBOA (Section 3), contouring may be accomplished using the *contourm* function available as part of Matlab's Mapping Toolbox, or using the much faster *grdcontour* algorithm included within the popular Generic Mapping Tools (GMT) package (Wessel and Smith, 1991). The contour interval