Geomorphology 288 (2017) 66–82

Contents lists available at ScienceDirect

Geomorphology

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

Object-based classification of global undersea topography and geomorphological features from the SRTM30_PLUS data

Maria Dekavalla *, Demetre Argialas

Remote Sensing Laboratory, National Technical University of Athens, Iroon Polytechneiou 9, Zografou, 15780 Athens, Greece

ARTICLE INFO

Article history:
Received 30 March 2016
Received in revised form 20 March 2017
Accepted 21 March 2017
Available online 29 March 2017

Keywords:
Geomorphometry
Multi-scale classification
OBIA

ABSTRACT

The analysis of undersea topography and geomorphological features provides necessary information to related disciplines and many applications. The development of an automated knowledge-based classification approach of undersea topography and geomorphological features is challenging due to their multi-scale nature. The aim of the study is to develop and evaluate an automated knowledge-based OBIA approach to: i) decompose the global undersea topography to multi-scale regions of distinct morphometric properties, and ii) assign the derived regions to characteristic geomorphological features. First, the global undersea topography was decomposed through the SRTM30_PLUS bathymetry data to the so-called morphometric objects of discrete morphometric properties and spatial scales defined by data-driven methods (local variance graphs and nested means) and multi-scale analysis. The derived morphometric objects were combined with additional relative topographic position information computed with a self-adaptive pattern recognition method (geomorphons), and auxiliary data and were assigned to characteristic undersea geomorphological feature classes through a knowledge base, developed from standard definitions. The decomposition of the SRTM30_PLUS data to morphometric objects was considered successful for the requirements of maximizing intra-object and inter-object heterogeneity, based on the near zero values of the Moran's *I* and the low values of the weighted variance index. The knowledge-based classification approach was tested for its transferability in six case studies of various tectonic settings and achieved the efficient extraction of 11 undersea geomorphological feature classes. The classification results for the six case studies were compared with the digital global seafloor geomorphic features map (GSFM). The 11 undersea feature classes and their producer's accuracies in respect to the GSFM relevant areas were Basin (95%), Continental Shelf (94.9%), Trough (88.4%), Plateau (78.9%), Continental Slope (76.4%), Trench (71.2%), Abyssal Hill (62.9%), Abyssal Plain (62.4%), Ridge (49.8%), Seamount (48.8%) and Continental Rise (25.4%). The knowledge-based OBIA classification approach was considered transferable since the percentages of spatial and thematic agreement between the most of the classified undersea feature classes and the GSFM exhibited low deviations across the six case studies.

1. Introduction

The analysis of undersea topography and geomorphological features provides necessary information to related disciplines and many applications. It can help to the understanding of undersea geomorphology (Harris et al., 2014; Sandwell et al., 2014) and the determination of the effects of bathymetry to climate, ocean circulation (Munk and Wunsch, 1998; Kunze and Smith, 2004) and benthic habitats (Harris and Whiteway, 2009; Brown et al., 2011). Bathymetry data can also be analyzed for offshore mineral and hydrocarbonate exploration, environmental assessment (Wenzhi et al., 2014) and tsunami disaster mitigation planning (Koiwa et al., 2014).

Knowledge of the undersea topography was made possible by the development of bathymetric methods. Heezen et al. (1959) produced the first map of the ocean floor topography through manual interpretation of hand drawn contours and profiles, derived from echo sounder data. The map of Heezen et al. (1959) improved the knowledge of the actual form of the ocean floor and the understanding of the ocean geology and global tectonics. Over the last couple of decades, the resolution of bathymetric datasets from echo sounders and shipborne technologies has been improved significantly, but only 10% of the ocean floor has been mapped with these technologies (Becker et al., 2009). On a global scale, satellite bathymetry is used to complement other available bathymetry data and contribute to datasets of global extent (Abramova, 2014).

The interpretation of undersea topography and delineation of undersea geomorphological features, regardless of scale, is often made manually from contours, shaded relief maps and morphometric and

* Corresponding author.
E-mail address: argialas@survey.ntua.gr (D. Argialas).

http://dx.doi.org/10.1016/j.geomorph.2017.03.026
0169-555X/

relative topographic position parameters (e.g. slope gradient and the topographic position index) derived from raster bathymetric data (Harris et al., 2014). Manual derivation of geomorphological feature maps is time-consuming (Drăguţ and Blaschke, 2006). Mapping quality may be influenced by interpreter's experience and subjective decisions, which constitute the results non-reproducible and transparent (Smith and Clark, 2005; Minár and Evans, 2008; Smith, 2011; Bishop et al., 2012; Otto and Smith, 2013; Hillier et al., 2014). These problems encourage scientists to resort to automated, robust and reproducible classification methods (Seijmonsbergen et al., 2011). However, most existing automated methods for undersea topography classification and geomorphological feature extraction are tailored to high resolution data and specific areas of limited extent (Lundblad et al., 2006; Lucieer and Pederson, 2008; Lucieer and Lamarche, 2011; Siakavara and Argialas, 2013) and not to global extent bathymetric data of coarse resolution.

The increasing availability of free access globally distributed bathymetric data (Abramova, 2014) can offer potential towards investigation of automated and robust approaches for global scale classification of the undersea topography and geomorphological features. Few attempts have been made so far. Examples include pixel-based methods proposed by Kitchingman and Lai (2004) and Yesson et al. (2011) for the identification of seamounts from 2 arc-minutes resolution ETOPO2 (NGDC, 2001) and 30 arc-seconds resolution SRTM30_PLUS bathymetry data (Becker et al., 2009), respectively. Their method was based on identifying local peaks and then classifying them as seamounts by examining the heights of the peaks relative to fixed distances of 90 km (Kitchingman and Lai, 2004) or 20 km (Yesson et al., 2011). Gorini (2009) developed a multi-scale pixel-based approach to classify global undersea topography. Statistical measures were computed for various parameters (e.g. mean slope gradient and standard deviation of depth and aspect) over a range of scales (i.e. different window sizes) (Wood, 1996) from the ETOPO2 bathymetry data (NGDC, 2001). The derived statistical values of the parameters were clustered to abstract morphometric classes by the unsupervised ISODATA algorithm and the resulted morphometric classes were further assigned to specific physiographic classes by author's experience.

In terrestrial geomorphometry, only a few automated approaches for global scale morphometric classification of the continuous topography were developed. First, Pike (1988) introduced the *geometric signature* term, which is a combination of parameters used to describe topographic form and distinguish different geomorphically disparate landscapes. The majority of global morphometric classification approaches (Dikau et al., 1991; Brabyn, 1998; Gallant et al., 2005; Iwahashi and Pike, 2007) ignore the complex structure of land surface and employ scale dependent parameters (Drăguţ and Eisank, 2012). They focus on the decomposition of the topography in terms of thematic similarity alone, ignoring spatial contiguity. Therefore, these approaches can produce classes, which exhibit minimum intra-class heterogeneity and maximum inter-class heterogeneity, are scattered across the map and do not correspond directly with specific geomorphological features (Minár and Evans, 2008). The employment of a segmentation technique, which is a fundamental step of Object-Based Image Analysis (OBIA), can help towards the extraction of locally distinct objects (Drăguţ and Blaschke, 2006; Minár and Evans, 2008). Drăguţ and Eisank (2012) developed an object-based approach to decompose SRTM30 elevation data into increasingly homogeneous spatial domains on three scale levels, detected with the help of local variance graphs (Woodcock and Strahler, 1987) and the nested means method (Iwahashi and Pike, 2007). The final derived domains were homogenous entities represented in terms of roughness and altitudinal position and having boundaries matching natural discontinuities (Drăguţ and Eisank, 2012). The authors claimed that the derived homogenous entities could be further interpreted by incorporating expert knowledge and supplementary data in order to extract geomorphological features.

In order to design automated knowledge-based approaches for geomorphological feature mapping, there is a need of using semantically rich descriptions, which go beyond simple geometric and topographic position considerations (Argialas, 1995; Dehn et al., 2001; Drăguţ and Blaschke, 2006; Eisank et al., 2011). Pixel-based classification is based on the digital values of individual pixels and ignores contextual information, which is especially important to semantic description of geomorphological features. OBIA plays an important role in the reduction of the semantic gap between digital representations and the corresponding real world features and gives meaning to the low-level digital information of raster data. Most OBIA approaches use segmentation algorithms, which partition the data into primitive objects. The partitioning into objects is akin to the way human brain functions in order to comprehend the landscape (Hay and Castilla, 2008). OBIA can integrate local geometry of the surface, morphological properties (e.g. shape and extent), spatial context and hierarchical relationships between geomorphological features and thus assist the representation of expert knowledge through classification rules (Blaschke et al., 2014). While the number of OBIA applications in analysis of DEMs has increased in the last 10 years (Drăguţ and Blaschke, 2006; Anders et al., 2011; d'Oleire-Oltmanns et al., 2014), an object-based methodology applicable to undersea topography and geomorphological feature classification from global bathymetry data is still missing.

In view of the complex structure and multi-scale nature of the undersea topography and geomorphological features, the transferability of a knowledge-based OBIA approach is considered difficult. One of the major transferability issues is the difficulty of an automated knowledge-based approach to classify a wide variety of geomorphological features of various shapes and sizes. Even entities belonging to the same geomorphological feature type can differ morphometrically under different geomorphological settings, and thus the automated classification results in low accuracies across different geomorphological settings (Anders et al., 2015). The transferability issues of OBIA knowledge-based classification of geomorphological features has been discussed in the literature (Eisank et al., 2011; Anders et al., 2015). The knowledge integration is considered problematic, since most knowledge-based classification approaches rely on individual expert knowledge, and they are too much tailored to specific areas and/or scales of the data employed (Eisank et al., 2011). Transferring these classification approaches to a different area would involve time-consuming revision of the parameterization and segmentation of the data and the knowledge base. Although the problem of defining the scale for the parameterization and the segmentation of elevation or bathymetry data is a well-known problem in the field of geomorphometry, only a few authors discussed and addressed the problem in studies related with the parameterization and segmentation of the elevation data in general (Wood, 1996; Minár and Evans, 2008; Drăguţ and Eisank, 2012; Jasiewicz and Stepinski, 2013). There is lack of studies addressing this problem from the perspective of classifying individual geomorphological features. The parameterization and regionalization of the undersea topography through the employment of data-driven techniques can provide the necessary information (i.e. object boundaries and their descriptive features), with which to capture the geomorphological features of various spatial scales (i.e. shape and size), represented in a DEM of a given resolution. This information in combination with supplementary data and a knowledge base developed from standard and scientifically accepted definitions can lead towards transferable automated geomorphological feature mapping approaches.

The evaluation of the transferability of an automated method for the classification of undersea geomorphological features across various areas is not possible through ground truth (Micallef et al., 2007), but only through the comparison with a reference dataset produced by the interpretation of digital bathymetry models, like the digital global seafloor features map (GSFM) from Harris et al. (2014). The GSFM contains thematic layers of 29 undersea geomorphological feature classes. The features were mapped through SRTM30_PLUS bathymetry data