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Application of object based image analysis for glacial cirques detection. Case study: the Ţarcu Mountains (Southern Carpathians)

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Abstract

Geomorphologic mapping is an important fact in many research studies and the traditional methods are time consuming and expensive. This paper aims to develop a semi-automated rule-based method for the detection of glacial cirques for a test area located in the Ţarcu Mountains (Southern Carpathians) in an object-oriented approach. In this study we have established the morphometric characteristics of the glacial cirques developed in a particularly geomorphologic context at the edge of planation surfaces, using a 10 m horizontal resolution DEM (Digital Elevation Model). The parameters extracted from DEM (i.e. curvature) were further used in segmentation and classification process. Also, other factors were introduced in the rule set, as the context regarding neighboring objects like planation surfaces to the target class. The most important factor in segmentation was the curvature and to choose an appropriate scale factor we have used the available ESP (Estimation of Scale Parameter) tool. The results achieved were very close to the field reality, except for some areas where there are large negative landforms such as gullies and torrents, which were identified as objects belonging to glacial cirques class and also some roches moutonnées with high positive curvature values, objects that could be filtered manually by the user based on previous field knowledge and ancillary data such as orthophotoplans and the geomorphologic map of glacial relief in the Ţarcu Mountains. For further research, we intend to identify the characteristic thresholds for morphometric parameters that can be integrated in a set of rules in order to detect and classify other type of landforms in the alpine domain of the Ţarcu Mountains.

Keywords: *landforms classification, OBIA (object based image analysis), segmentation, geomorphometry, glacial cirques, the Ţarcu Mountains, Southern Carpathians.*

Rezumat. Analiza şi clasificarea orientată-obiect a circurilor glaciare din Munţii Ţarcu (Carpaţii Meridionali)

Cartarea geomorfologică oferă rezultate cu importanţă mare pentru foarte multe studii, iar metodele tradiţionale de cartare necesită foarte mult timp și sunt costisitoare. Acest studiu prezintă un set de reguli pentru identificarea semi-automată a circurilor glaciare pentru arealul test din Munţii Ţarcu (Carpaţii Meridionali) utilizând metode de analiză orientate-obiect. În lucrarea de faţă au fost stabiliţi parametrii morfometrici caracteristici ai circurilor glaciare aparţinând reliefului glaciar de tip Godeanu, cu circuri glaciare dezvoltate la marginea suprafeţelor de nivelare, pe baza unui model digital de elevaţie cu o rezoluţie spaţială de 10 m. Parametrii morfometrici ai reliefului generaţi din acest model au fost folosiţi în procesul de segmentare şi apoi de clasificare a circurilor. Astfel, în setul de reguli de clasificare au fost introduşi atât factori morfometrici, precum curbura terenului, dar şi de context, cum ar fi vecinătatea faţă de suprafeţele de nivelare. Factorul cel mai important utilizat în procesul de segmentare este curbura medie, iar pentru stabilirea unui factor de scară cât mai obiectiv, s-a folosit un instrument implementat în Definiens, numit – ESP. Rezultatele obţinute sunt apropiate de realitatea din teren (exceptând unele areale cu forme de relief negative, precum organismele torenţiale sau pozitive, cum sunt rocile mutonate din cadrul circurilor, elemente ce pot fi filtrate manual de către utilizator) demonstrează că metoda utilizată este una de interes, aceste rezultate fiind verificare cu date din teren şi cu ortofotoplanuri, hărţi existente ale reliefului din domeniul alpin ai Munţii Ţarcului. În studiile viitoare intenţionăm să îmbunătăţim metoda prezentată şi să determinăm parametrii morfometrici şi valorile-prag caracteristice, care să fie incluse în reguli de identificare semi-automată, pentru localizarea și clasificarea altor forme de relief din etajul alpin al Munților Ţarcu.

Cuvinte-cheie: *clasificarea semi-automată a formelor de relief, analiza imaginilor orientată-obiect, segmentare, geomorfometrie, circuri glaciare, Munţii Ţarcu, Carpaţii Meridionali.*

INTRODUCTION

Object based terrain analysis and semi-automated classifications in geomorphology create new possibilities for landforms and landform elements delineation and analysis, and represent a new alternative that increase the accuracy of mapping, which is time and cost efficient compared to other methods, i.e. total station survey, LIDAR data etc. The process of image segmentation in objects at different levels of detail is used as a mandatory step in the development of the rule set for classification in OBIA environment. The way of representing the world in objects rather than in cells is closer to human perception of reality, this being one of the big advantages of this method. Some mountain regions represent difficult terrain regarding classical methods of mapping and require a lot of time to generate geomorphologic maps. This method provides a new perspective in the study of landforms and landforms mapping and integrates GIS and remote sensing in a more appropriate way of representing the world in human perception about the landscape than the cell-based approach (Drăguţ and Blaschke, 2006; Drăguţ et al., 2010).

Sensor development in the last decade increased spatial and spectral resolution and one negative aspect of data processing is that it leads to high heterogeneity inside classes of interest (Schneevoigt, 2008), problem that could be better solved if we use image segmentation and classification based not only on pixel values, but also including the context and the shape of the objects.

The use of DTMs (Digital Terrain Models) and other remotely sensed data in landforms detection and analysis is a common approach in earth sciences and geomorphometry (Pike et. al, 2009). In the field of geomorphometry there were several studies that developed methods for automated landforms classification based on Hammond system (Dikau, 1989, 1990, Dikau et al., 1995), delineation of slope types (MacMillan et al., 2000), automated classification of topography using derived features from DEMs (Iwahashi and Pike, 2007), automated extraction of landform elements (Drăguţ and Blaschke, 2006), automated delineation of valleys (Straumann and Purves, 2008) etc.

In Romania the study of automated detection of planation surfaces in the Godeanu and Mehedinţi Mountains is to be mentioned (Török-Oance et al., 2009).

In high mountain areas regarding glacial relief and related processes there are few studies that deal with object oriented approach in delineation of specific landforms: Schneevoigt et al., 2008, for alpine landforms multi-scale classification, and Eisank et al., 2010, for automated extraction of glacial cirques.

Glacial cirques are the most representative landforms of the glacial relief in high mountains and sustain the existence of past Pleistocene glaciation. Clear cirque forms are accepted as one of the best proof of glaciation in mountains. The form of cirques consists essentially of a "steep headwall slope arcing around a gentler floor" (Evans and Cox, 1974). The floor of cirques in the mountains is the morphologic result of glacial erosion (scouring, quarrying, plucking, abrasion, breaching etc.). Glacial cirques have generally concave shape both in plan and profile curvatures (Eisank et al., 2010) and variable extend up to few kilometers (Benn and Evans, 1998). The cirques are connected with valleys by means of rocky thresholds (Hambrey and Alean, 1992) and as in all landforms delineation, the borders between those two landforms interfere due to high heterogeneity and transitional nature of natural limits. In this context, the object-based approach in cirques delineation best fitted the purpose of this study.

STUDY AREA

Ţarcu Mountains are located in the north-western flank of the Southern Carpathians being part of the Retezat-Godeanu range. This mountaineous area, with altitudes over 2000 meters, is characterized by considerable development of planation surfaces especially at altitudes above 1800 m, where Borăscu sculptural complex occupy large areas. The highest peaks from Ţarcu Mts. have altitudes between 1800 and 2192 m, high enough to support small glaciers during the glacial periods of the Pleistocene. Although the amplitude of the glacial periods is not as remarkable here as in Retezat Mts., an expressive glacial relief was left behind after melting the glaciers at the end of Pleistocene. Niculescu (1990) mapped 37 glacial cirques in this area developed especially at the edge of the planation surfaces at over 2000 meters. The glaciers from these cirques were short, their tongues having less than 3 kilometers, being considered by Niculescu pyrenean glaciers. Most of the cirques are simple cirques, but we found also compound cirques and even cirque complexes (Olteana glacial complex).

The presence of the glacial features in the Ţarcu Mts. was first noticed by Schafarzik (1899) so that in 1907, Emmanuel de Martonne described some glacial cirques and Kräutner (1929) carried out a first draft of the glacial landscape of this area. In 1990 Niculescu described the glacial landscape from the Ţarcu Mts. presenting the first

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comprehensive map of the glacial cirques distribution from the Ţarcu, Bloju and Baicu Massifs. Further, Urdea (2004) recalculated the length of main Pleistocene glaciers from Ţarcu and got over 4 km length for the Hideg, Şuculeţ and Netiş glaciers. He also found two plateau glaciers in this area: Pietrele Albe and Ţarcu-Căleanu. In 2006 Mândrescu brought new information on the number of glacial cirques (he counted 60 cirques) and their morphometric characteristics (Mîndrescu, 2006).

The morphology of glacial cirques from the Ţarcu Mountains is strongly influenced by the complex lithology (granitoide, schists, conglomerates, gneisses and amphibolites) and by a dense network of faults as a result of the geographical position between two main geotectonic domains (Danubian Domain and Getic Nappe).

The test area from the Ţarcu Massif (Fig. 1), was chosen because of the representative glacial cirques developed at the edge of planation surfaces. The area of the site is 87 km², with elevation ranging between 1034 and 2190 m a.s.l. The highest peaks from this test area exceed 2100 m: Ţarcu (2190 m), Căleanu (2190 m), Bodea (2160 m), Nedeia (2150 m) and Brusturu (2116), but their appearance is more like a rounded plateau rather than reshaped in a periglacial manner. The glacial cirques are distributed in the upper part of the Olteana, Şuculeţu, Râu Rece and Râu Alb watersheds. Besides glacial cirques other expressive glacial landforms were mapped in the field, like: moraines, glacial thresholds, roches moutonnées.

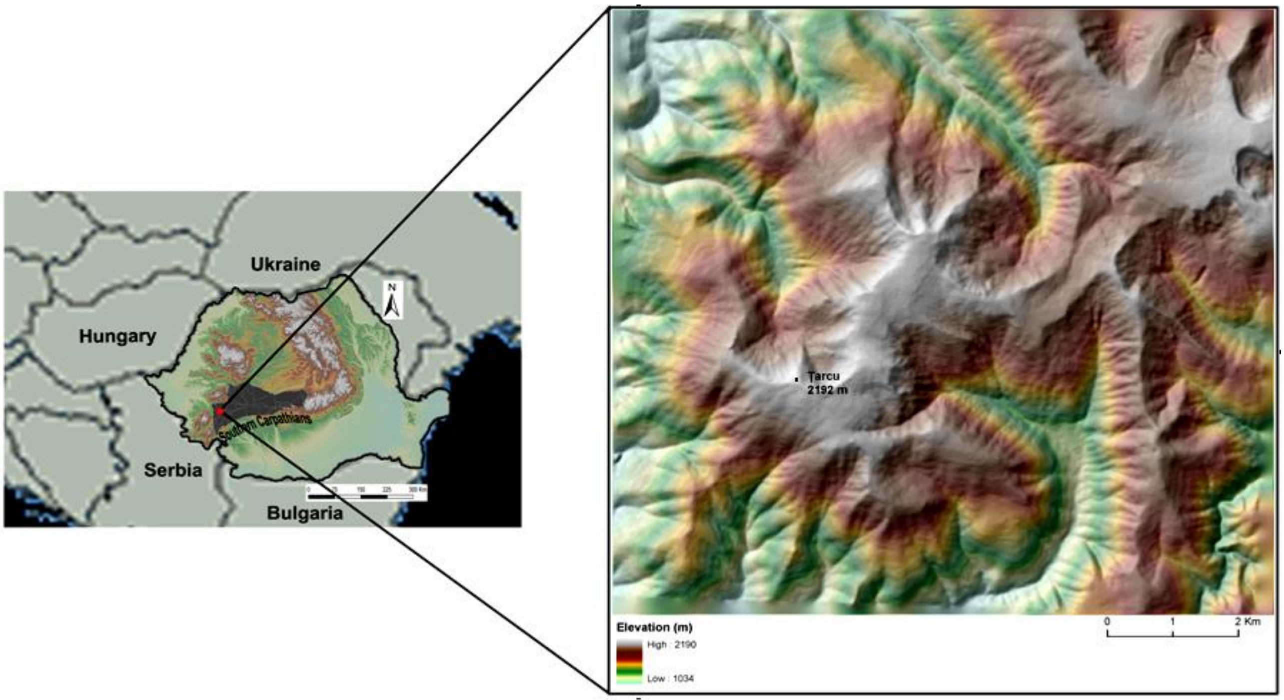

Fig. 1. The location of the Ţarcu Mountains and of the test site

DATA AND METHODS

"To be a landform, a part of the Earth's surface must have some coherence of form (shape) or process or both" (Smith and Mark, 2003, cited by Mark, 2009, p. 13). The landforms are defined in a specific geomorphometric fashion as discrete surface features (Evans, 1972), thus to obtain proper semi-automated delineation we need to define which morphometric parameters best describe the landform (glacial cirques) and how to apply that knowledge into a rule set based algorithm for classification. This approach of using preexisting knowledge and defined concepts and integrate them into software to achieve results as close as possible for an objective representation of the reality, was realized through semantic modelling (Dehn et. al, 2001) developed for the glacial cirques in Alps, with study area located in Carinthia, Austria (Eisank et al., 2010).

In this paper we have used a 10 meters horizontal resolution DTM generated from contour lines based on topographic map scale 1:25000 for the central part of the Ţarcu Mountains. The model was obtained in ArcGIS using TopotoRaster function and ancillary vector data as rivers, ridges, altitude points and was filtered in a 5x5 moving window to reduce noise.

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From this DTM we derived the models representing morphometric parameters such as slope, mean curvature, profile curvature, plan curvature. These derived models best describe the concavity of glacial cirques through positive or negative values in all curvatures and they were–further used in the segmentation and classification process.

The methodology presented in this paper consists of few steps: the identification of the glacial cirques in the field and based on old geomorphologic maps (i.e. glacial relief map of the Ţarcu Mountains made by Niculescu in 1990), image segmentation using ESP (Drăguţ et al., 2010), glacial cirques visual identification (i.e. based on hillshade DTM), morphometric parameters of glacial cirques analysis, glacial cirques classification and validation of the method applied.

Given the already known limitations of pixel based relief analysis on DEMs, the most important being the context information and the shape of the objects (Blaschke & Strobl, 2002), the method of object based analysis can be used as a new solution in glacial cirques detection.

The upscaling from pixel level to object or spatial primitives level was realized in Definiens Developer v.7 and this is a step that require specification of scale, which regards the homogeneity of the objects. This task required a lot of time before and was realized in a subjective manner depending on the user knowledge.

To avoid the subjective selection of the segmentation scale, this being a key factor of analysis, we used the ESP tool available for Definiens Developer v.7. This tool allows a more objective segmentation of the layers based on the local variance, a value that indicates the local variability within an image, so in a graph representation of the local variance, the breaks will indicate the optimal scale for segmentation, actually defining the objects that are very similar in the image and probably belonging to the same class in reality (Drăguţ et al., 2010).

The morphometric parameter that we used as base layer in segmentation is the mean curvature (Eisank et al., 2010), because this parameter is the one that best describe the glacial cirques morphology. Applying the ESP tool we obtained several characteristic scales, the most representative being 60 for cirque delineation and 24 for glacial cirques components, but in the end 24 was chosen for future analysis, because the value of 60 identified too large areas well beyond the limit of the cirques.

In the Ţarcu Mountains the glacial cirques being developed at the edge of planation surfaces, we identified two connected classes in the field (glacial cirques and planation surfaces). For the glacial cirques identification we have used threshold values defined for other land surface models like altitude (above 1800 m), mean general curvature, mean plan curvature and mean profile curvature (negative values).

Also we have used the context rules - neighbour to class for the classification of cirques in order to identify those objects which are always located at the edge of the planation surfaces (cirques class border to planation surfaces class).

We have identified also the planation surfaces (Fig. 2), based on the rules developed in a previous study, as being objects with mean slope values less than 14 degrees and minimum slope value less than 2 degrees, runoff less that 80, positive mean curvatures close to 0 (Török-Oance et al., 2009).

RESULTS AND DISSCUSIONS

In the case of the Ţarcu Mountains, the cirques are located at the edge of planation surfaces, well developed above 1800 m altitude. Using the knowledge about planation surfaces and some conditions developed for the planation surfaces in a previous article mentioned above and also the existing maps and longitudinal profiles over the cirques and glacial valley, we have delineate the shape of cirques (vectorized polygons) for the central part of the Ţarcu Mountains for comparison reasons. The objects identified as cirques were overlaid on a hillshade model (Fig. 3) and compared with the geomorphologic map (Niculescu, 1990) and with the results of objects detection using Defininiens.

In a specific geomorphometric analysis, there are some stages to follow, among those in the beginning being important the conceptualization and complete delimitation from the neighbour landforms (Evans, 1987).

The results achieved were compared to the map of glacial relief in the Ţarcu Mountains made by Niculescu in 1990. In this context, we must take into account that many maps about glacial landforms made for the Romanian Carpathians only identify the upper part of cirques as bounded by ridge or planation surfaces, but there is no delineation on the contact with glacial valleys.

The objects identified as cirques by applying the rule set delineate more the walls of this landform and less the contact with the glacial valley or the floor of the cirques due to low values of mean curvature and some high positive values in profile curvature and the existence of areas that are similar with the planation surfaces.

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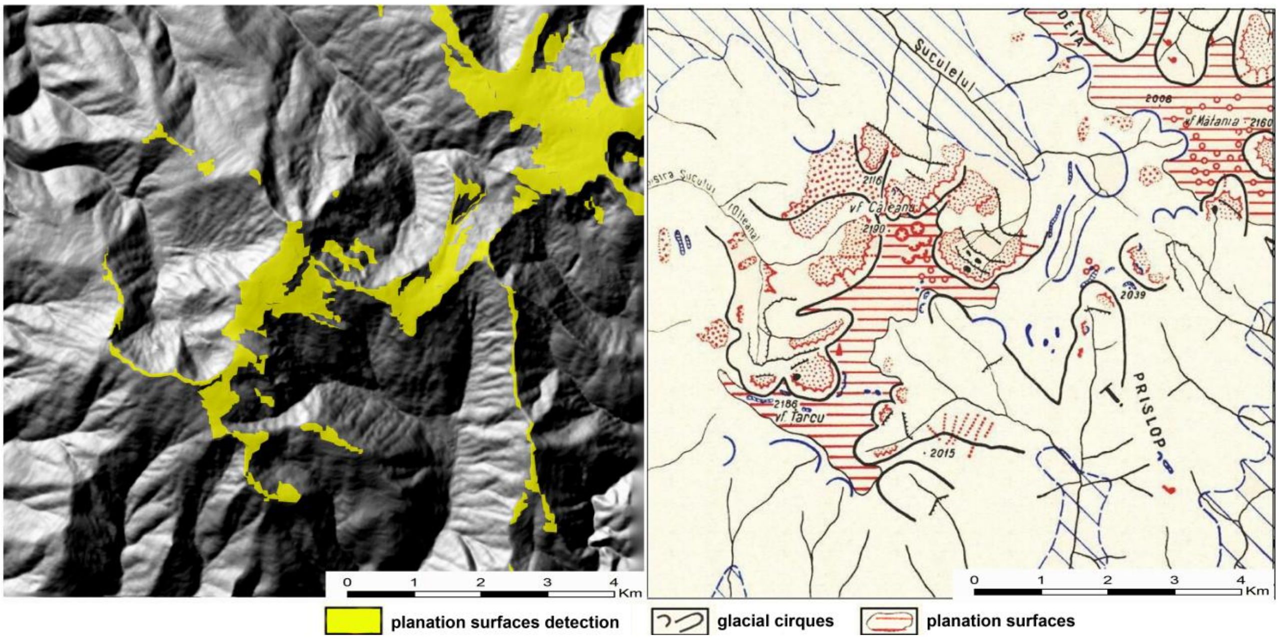

Fig._2. The planation surfaces detection compared to the geomorphologic map (Niculescu, 1990)

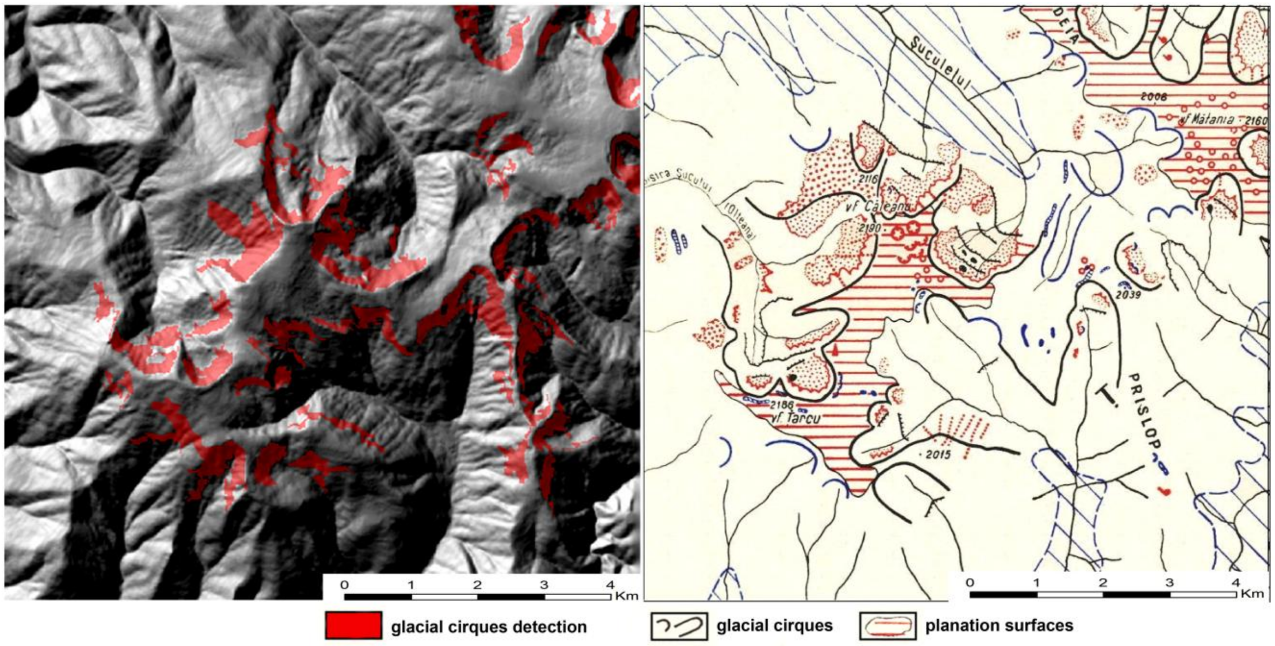

Fig._3. The cirque detection overlaid on DEM - comparison with the glacial relief map by Niculescu, 1990.

Some negative landforms with the same morphometric characteristics (negative mean curvatures) were identified as cirques and these objects were manually filtered based on previous knowledge about the test area.

Because of the similar extent of individual cirques in the test area we used only a single scale of analysis for glacial cirques detection, but it is desirable to use multiscale analysis for more complex topographic conditions and cirques extent (Eisank et al., 2010).

CONCLUSIONS

This study is a preliminary research and presents only the first results of the application of a semi-automated method for glacial landforms delineation based on DTMs in the alpine domain of the Țarcu Mountains. In this case the location of glacial cirques was well identified, but the

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estimation of their extension could be improved if we use in further research a hierarchical system for cirques detection and more characteristic scales of analysis and different spatial resolution of the data. Also the method could be improved by identifying and integrating the glacial slope breaks as the limit line between glacial cirques and glacial valley. This research will be improved in further studies and extended in a more complex analysis for a complete delineation of glacial cirques and also for the classification of other landforms from the alpine domain of the Ţarcu Mountains (moraines, rock glaciers).

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