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On the transferability of rule sets for mapping cirques using Object-based feature extraction

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Abstract: Cirques are complex landforms resulting from glacial erosion and occur in the mountains of western Austria at various topographic levels. After deglaciation they may potentially hold climate proxies, are showcases of vegetation regrowth and play an important role in the regulation of mountain hydrology. Our objective is to develop a workflow to test an object-based rule-set that decomposes LiDAR DEMs into the main cirque components: divide, cirque headwall, cirque floor and into the sub-component cirque lake by using stratified segmentation and classification. One cirque cluster was used to train the classification settings, which were tested in a second cirque cluster. Classification results and accuracy of both clusters were compared. We conclude that the transferability of rule sets for the extraction of cirque components is promising, but that younger depositional and erosional landforms may influence correct cirque component extraction. Fine-tuning of rule sets and integration of additional data is necessary to discriminate cirques moraines and cirque thresholds, as these sub-components highly depend on variations in local cirque development.

1. Introduction and background

Cirques are complex landforms resulting from glacial erosion. Ivy-Ochs et al. (2008), regard a cirque as ‘a landform eroded by a glacier positioned in isolated niches in mountains’. Three main cirque components are commonly recognized (see Fig. 1): 1) an upper semi-circular ‘cirque divide’, bounded by 2) steep surrounding slopes or ‘cirque headwall’ and 3) a relatively flat lower surface or ‘cirque floor’ bordering the headwall. In many cirques, three sub-components related to (de)glaciation are found on the cirque floor: a ‘cirque threshold’ developed in bedrock, (a) cirque moraine(s), representing recessional phases of the former cirque glacier and a ‘cirque lake’, often located in the lowest part of the valley floor in between cirque moraines and cirque threshold. In western Austria (Fig. 1-left), cirque glaciers were active during the waxing and waning stages of former glaciations (De Graaff et al. 2007), their existence linked to former Equilibrium Line Altitudes (ELAs) and topographical levels. Transformation of conceptual semantic models for cirques into rule sets was emphasized by Eisank (2013) as a necessity to develop transparent workflows when applying Object-Based Image Analysis (OBIA), in order to improve objectivity and transferability of rule sets. This way, it is possible to further automate the creation of maps containing different landscape features (Dra\u0169u\u015f and Blaschke, 2006). Eisank et al. (2010) and Ardelean et al. (2011) both used mean curvature for segmentation of cirques, focusing on the upper divides. Altitudinal thresholds were used in combination with specific context rules as input for segmentation and classification. Anders (2013) has shown that topographic openness can
successfully be used to classify (glacial) landforms in mountainous terrain. Within cirques post-glacial depositional and erosive landforms, may disguise the boundaries of the main components of a cirque (Fig. 1-right). Our objective is to develop and test an object-based rule-set that decomposes LiDAR DEMs into the three main cirque components: divide, cirque headwall and cirque floor, and into cirque lake.

![Figure 1. Outline of Vorarlberg and study areas (left, highlighted in red). The coordinates refer to the MGI M28 projection. The top-right inset shows a bird’s eye view of the false color infrared (FCIR) orthophoto and a cross section that illustrates the potential complexity of cirque morphology due to younger processes.](image)

2. **Study area**

Two clusters of cirques have been selected in the State of Vorarlberg, western Austrian Alps, i.e. the mountains near Gargellen-West (left in Fig. 1-left) and Hochmäderer (right in Fig. 1-left). In Vorarlberg, the glacier network developed in relation to the relative altitude of feeding areas during glaciations: higher areas became glaciated first, while lower areas became glaciated in later phases (De Graaff et al., 2007). During late-glacial phases the opposite occurred: in an early phase, relatively low-lying cirques became already ice-free while higher located areas remained glaciated, as a response to the rise in ELA after climatic warming. For low-lying cirques this means that they have been glacially eroded for a shorter period. This may indicate that the resulting cirques including their (sub)components are potentially less well-developed and have more suffered from denudation and accumulation processes, such as fluvial erosion and fall type mass movements.

3. **Methods**

A LiDAR data set from 2011 was used from which the raw point data were acquired, filtered and interpolated using linear squares interpolation into 1 m resolution LiDAR raster DTM's by TopScan (http://www.TopScan.de/). ArcGIS 10.1 and python/GDAL were used to calculate the LSPs Slope, Elevation Percentile (EPC), and Openness. The main steps of our analysis are based on the approaches of Anders et al. (2011) and Eisank (2013). The sequence of segmentation and classification of the cirque components in the Object-Based Digital Terrain Analysis comprised image segmentation using the region merging multi-resolution segmentation algorithm (Baatz and Schäpe 2000), and classification rule development and
feature extraction of the cirque components. Segmentation parameters and classification rules were manually developed in the Gargellen-West cluster and tested in the Hochmäderer cluster. Divide was segmented and classified with EPC because it registers relative elevation accurately. Headwall was segmented and classified primarily using Slope angle (steep slopes) within a close proximity of the divide. Lakes were segmented and classified based on the low reflectance values in the FCIR images, combined with Slope angle (gentle slopes). Cirque floor was primarily segmented and classified using EPC (relatively low values because the floor is surrounded by mountains) and Slope angle (gentle slopes). The output maps were compared by means of a confusion matrix and a manually classified reference dataset. Rule set development for segmentation and classification was done in eCognition Developer 8.8.

Figure 2. Classification results of both areas. Object boundaries are transparent to increase readability. The FCIR orthophoto from 2001 is used as backdrop image.

4. Preliminary results
The classification results of both clusters are presented in Fig. 2. The user’s and producer’s accuracies are presented in Tab. 1. In the Gargellen-West area the cirque headwall and cirque floor are extracted most accurately. The divide and lake have lower accuracies due to fuzzy boundaries. The Hochmäderer area shows significantly lower accuracies. Here the divide is characterized by lower Elevation Percentile values which reflect subtle differences in morphology and as such classification rules fail. Cirque headwall and floor are more often confused and the few lakes were not recognized, possibly due to different reflectance.

<table>
<thead>
<tr>
<th>Area</th>
<th>Gargellen-West</th>
<th>Hochmäderer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cirque component</td>
<td>User’s</td>
<td>Producer’s</td>
</tr>
<tr>
<td>Divide</td>
<td>63</td>
<td>57</td>
</tr>
<tr>
<td>Cirque Headwall</td>
<td>92</td>
<td>86</td>
</tr>
<tr>
<td>Cirque Floor</td>
<td>72</td>
<td>86</td>
</tr>
<tr>
<td>Cirque Lake</td>
<td>61</td>
<td>74</td>
</tr>
<tr>
<td>Overall accuracy</td>
<td>84</td>
<td>74</td>
</tr>
</tbody>
</table>

5. Discussion and conclusions
Cirques are complex landforms. The divide, cirque headwall and cirque floor components can be extracted from high resolution LiDAR data using OBIA rule sets. Difficulty is that the
lower boundaries of cirques often merge into glacial valleys, larger landforms that exhibit similar characteristics as cirques, but are of higher order in a glacial network. Cirque lakes, cirque thresholds and cirque moraines require landform-specific rule sets and do not need to completely fit within a hierarchical framework that is typical for OBIA workflows. Rule sets for cirque detection need further fine-tuning to optimize transferability. Future work should include 1) automated parameterization to further enhance objectivity of the OBIA process chain and 2) classification rules for sub-components of a cirque and landforms resulting from younger processes. This may require the use of different cell sizes for the segmentation and classification of sub-components. If successful, new applications arise from cirque detection, for example the support of estimates to determine the (relative) age since deglaciation, and to unravel regional deglaciation and climate history.

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