PAIRING SEMANTICS AND OBJECT-BASED IMAGE ANALYSIS FOR NATIONAL TERRAIN MAPPING - A FIRST-CASE SCENARIO OF CIRQUES

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ABSTRACT:

As the new National 3D Elevation Program (3DEP) prepares to provide high-resolution lidar coverage for continental United States, Hawaii, and the territories, it is important to consider that terrain information captured in elevation data are pixel-based instead of feature-based. Referencing 3DEP data for semantic access and inferencing requires the transcription of pixels into accessible features. Indeed, accessing and inferencing terrain features renders them more operational for long-term national mapping. Much progress has been made in transcribing pixels into terrain features using Geographic Object-Based Image Analysis (GEOBIA), as compared to traditional, pixel-based image analysis. However, these studies have focused mainly on European terrain, while their applicability and use for United States transcription has not yet been adequately determined. This research evaluates that applicability relative to the mapping of glacial cirques in the Tahoe Basin using an established GEOBIA workflow, run on eCognition. Results suggest that while some parameters of the workflow may require modification, the general workflow steps may apply to other regions.

1. INTRODUCTION

1.1 Background

As the National 3D Elevation Program (3DEP) is preparing to provide high-resolution lidar coverage for the continental United States, Hawaii, and territories, it is important to consider that terrain information captured in elevation data is pixel-based instead of feature-based. Referencing 3DEP data for semantic access and inference requires the transcription of pixels into accessible features. Indeed accessing and inferencing terrain features renders them more operational for long-term national mapping.

'An object view is essential when people communicate about terrain using natural language and when they use landforms as landmarks for navigation and wayfinding' (Mark and Smith, 2004). Much progress has been made in transcribing pixels into terrain features using Geographic Object-Based Image Analysis (GEOBIA), as compared to traditional, pixel-based image analysis. However, these studies have focused mainly on European terrain, while their applicability and use in regions of the United States has not yet been adequately determined. This research evaluates that applicability relative to the mapping of glacial cirques in the Tahoe Basin using an established GEOBIA workflow, run on eCognition. It is important to note that while it is unlikely that the actual threshold values provided by the established model will produce satisfactory results, it is hoped that the general workflow itself can be applied to other regions.

A landform is "a terrain unit created by natural processes in such a way that it may be recognised and described in terms of typical attributes wherever it may occur" (Lobeck, 1939). As the earth's surface is structured into landforms as a result of processes across the geomorphic, geological, hydrological, and ecological realms, these natural objects function as fundamental spatial entities that partition that surface, and define the boundary conditions for processes within these realms (MacMillan and Shary, 2009).

Cirques as landforms are important to study because they are one of the most characteristic forms of glacial landforms in mountain areas (Tricart and Cailleux 1962), and their elevation is an important indicator of paleo equilibrium line altitude (Trenhaile 1976). Identified as bowl-shaped, amphitheater-like depressions associated with glacial erosion, cirques are fairly easy to delineate where they are clearly defined. Evans and Cox (1995) note that larger cirques tend to have better plan and profile closure, and are more likely to develop cols (a saddle-like narrow depression formed by two headward eroding cirques) and tarns (a small lake that collects in a cirque basin when the cirque foot is closed by rock debris. Cirque sizes studied across several regions vary from about 250 - 1000 m length by approximately the same values in width, or ~ 15 to 25 acres (Evans and Cox, 2015). Hence, cirques smaller than 10 acres were not analyzed in this study.

1.2 Study Area

The study area is a small group of mountains in the east central Sierra Nevada range, just west and southwest of Lake Tahoe (Figure 1), covering about 225 km^2. Elevation ranges from 1798 m a.s.l. to 3043 m a.s.l.

The Sierra Nevada is the longest and highest mountain range in the contiguous United States. The backbone of the range is mostly granitic, formed during the Mesozoic, where a chain of volcanoes intruded into the older Palaeozoic rock. By the Late Cretaceous erosion had exposed the deep granite, which was then either uplifted along a north-south fault east of the range, or the eastern basin subsided (Henry, 2009). Soon after the uplift began, the Pleistocene Epoch was marked by the onset of global cooling, causing the growth of glaciers in the high Sierras.

The study region experienced extensive and recurring alpine glaciations during the Pleistocene, exhibiting numerous cirques, as well as other typical glacial features, as evidence of glacial erosion. Over 100 glaciers still existed in the range as of 2008 (Basagic, 2008).

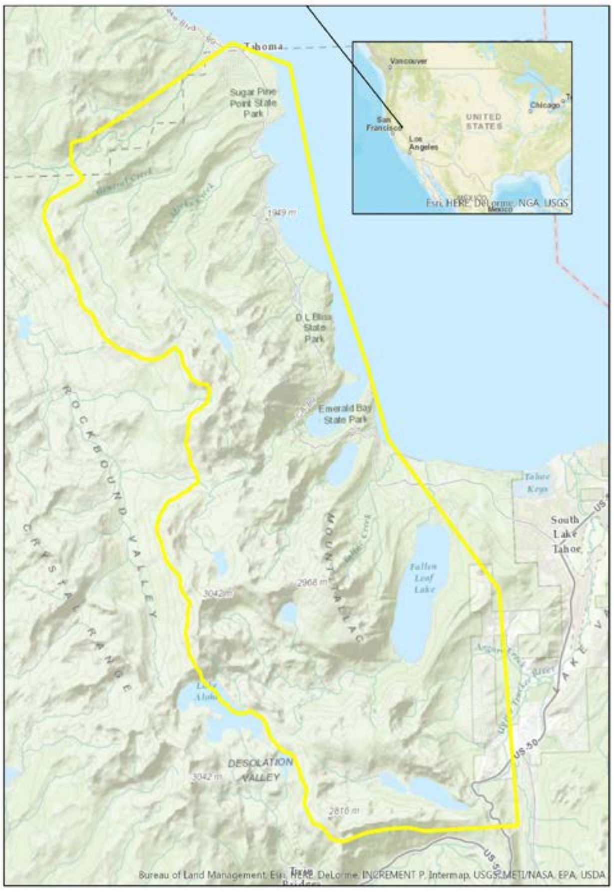

Figure 1.Study area outlined in yellow in the central eastern Sierra Nevadas.

Most of the study area falls within Desolation Wilderness, a federally protected wilderness area in the Eldorado National Forest and Lake Tahoe Basin Management Unit, in El Dorado County, California. Notable topographic features within the region include Mount Tallac, Emerald Bay, Cascade Lake, Fallen Leaf Lake, Echo Lake, Maggies Peaks, Angora Ridge, and Dicks Peak, Jacks Peak, Phipps Peak and Rubicon Peak.

Lidar data were collected for the Tahoe Basin in August of 2010 by Watershed Sciences with an average native pulse density of > 8 pulses per square meter over terrestrial surfaces. Data from this collection were delivered as a point cloud with an average ground point density of 2.26 points per square meter, and as a DEM with a half meter resolution. The delivery was incorporated into The National Map's 1/9, 1/3, and 1 arc-second datasets. The availability of a range of resolutions will allow future comparison of the impact these resolutions have on feature analysis within the same terrain.

2. METHODS

Eisank et al. (2010) developed a semantics-based glacial cirque classification workflow for a test area in Austria, in hopes that it would be useful in other regions. The workflow connects the conceptual domain to the software domain using informal semantics, providing a foundation for future work in landform realms even beyond the glacial (Figure 2). The precise methodology used is discussed below.

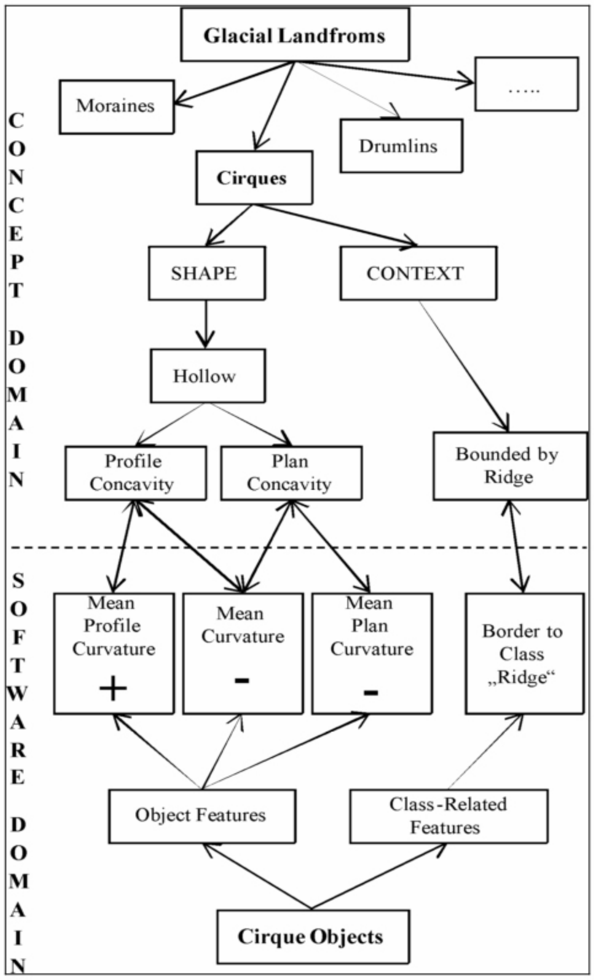

Figure 2. The European semantic model for integrating the cirque concept in OBIA software (from Eisank et al 2010).

2.1 Reproducing previous work

An algorithm reproducing as closely as possible the methodology of Eisank et al (2010) was developed to compare to their results, and as a starting point for the Tahoe Basin cirque extraction model. This baseline methodology will hereafter be referred to as the European model.

Three general steps were duplicated from the European model. These steps included classification of ridge-like objects from the mean curvature surface derived from the DEM, masking out ridges from the mean curvature raster to remove them from cirque classification, and classifying cirque objects.

To identify ridge-like objects, mean curvature was calculated from the DEM using ArcGIS 10.2.2, which was smoothed by a 10 x 10 mean filter. Pre-processing steps were completed on a larger region to avoid edge-effects. The resulting surface was segmented using the multi-resolution segmentation algorithm in eCognition using the scale parameter of 95 chosen using the Estimation of Surface Parameter tool (ESP) in the European model to best represent ridges in their study area. The ESP tool evaluates scale parameters (SPs) by running stepwise through multi-resolution segmentations of the image, creating image-objects at iteratively increasing scale (Drăguţ et al., 2010). Upon plotting the local variance (Strahler et al., 1986) against the rate of change (ROC) in image objects at each SP, characteristic scale levels for future segmentation can be assessed.

In the segmentation algorithm, the composition of the homogeneity criterion was based entirely on color, excluding shape (0), and compactness was set at 0.5. Resulting objects with a mean curvature greater than 85 radians/100 m were classified as ridges. Ridge objects were exported as vectors for use in the masking process.

Masking was performed using ArcGIS by first erasing the ridge polygons from the study area polygon. The resulting vectors were used to clip the raster, using the polygon outlines.

The masked mean curvature surface was subjected to a multi-resolution segmentation at scale parameters 43, 11 and 220, values selected in the European model using the ESP tool. Resulting objects with a negative mean curvature that bordered ridge objects were classified as cirques.

2.2 Improving on previous work

Based on output from reproducing the European model, adjustments were generated that fell into three basic categories: streamlining of ridge production, improvements to cirque segmentation and enhancements to the cirque classification. Of the three, changes to the ridge extraction model were the least complex.

2.2.1 Ridge extraction: Ridge extraction followed the setup and segmentation steps of the European model exactly, including the use of 95 as the scale parameter for segmentation, as this value produced satisfactory ridge-like objects. However, the classification was altered by greatly decreasing the lower threshold of the curvature values from 85 to 25 but restricting the objects assigned to the class to those objects with a length to width ratio of 1.75 or higher. Then ridge objects were merged and those with a length shorter than 100 m were removed from the ridge class. The resultant ridge objects were then exported to a polygon vector file for use in the cirque extraction. They were then subtracted from the original mean curvature raster for use in cirque extraction.

2.2.2 Cirque extraction: In order to maximize segmentation for cirque delineation, both the unmasked and masked mean curvature rasters were evaluated for characteristic scale parameters using ESP. The five most characteristic SPs were calculated as those with the highest change in ROC from the previous level, for each image (Table 1). The spikes in the rate of change in the unmasked image were much greater and SPs were easier to detect. ROC fell to almost 0 by SP = 43 in the masked image, and changed little for the rest of the algorithm run (Figure 3). Because of the difficulty in detecting characteristic SPs for the masked image, the unmasked image was used for subsequent modeling.

Image layer	Detected scale parameters
Filtered mean curvature	36, 66, 83, 88, 211
Filtered mean curvature with excluded ridge areas	18, 28, 41, 68, 81

Table 1. Suitable scale parameters for segmentation of mean curvature surfaces

Objects were first segmented using an SP of 1 as a baseline segmentation that provided input into segmentation at the first identified SP (36). The output objects were then classified as ridges where they matched those output from the ridge extraction. Unclassified objects were classified as cirques where they have a negative mean curvature (concave), but also bordered a ridge object with at least 2% of its border. Cirque objects were then merged and those smaller than 10 acres (~40,000 m^2) were removed from the cirque class.

The output from the first characteristic SP segmentation provided input to the next (66) and so on, until cirques were classified on the five object levels. Cirque objects were exported as a separate shapefile for each level.

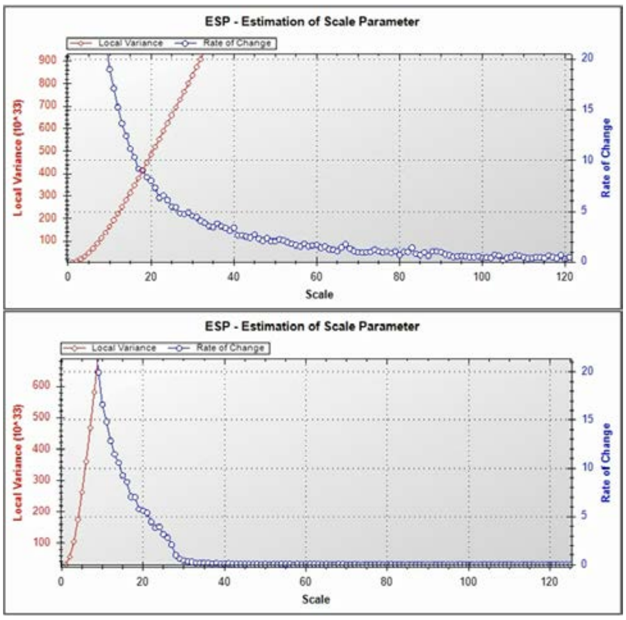

Figure 3. Output from the ESP tool run on the unmasked (top) and masked (bottom) mean curvature, used to estimate characteristic scale parameters for segmentation. Local Variance (10^33) is displayed on the left-hand y-axis and Rate of Change is displayed on the right-hand y-axis. The x-axis displays scale parameter.

3. RESULTS

3.1 Reproduction

Replication of the European model's segmentation parameters resulted in objects that were quite satisfactory for classifying ridges within the study area. Ridge-like objects are clearly outlined. However, classification of objects into the Ridge class fell short; missing ridgelines are clearly identifiable (Figure 5).

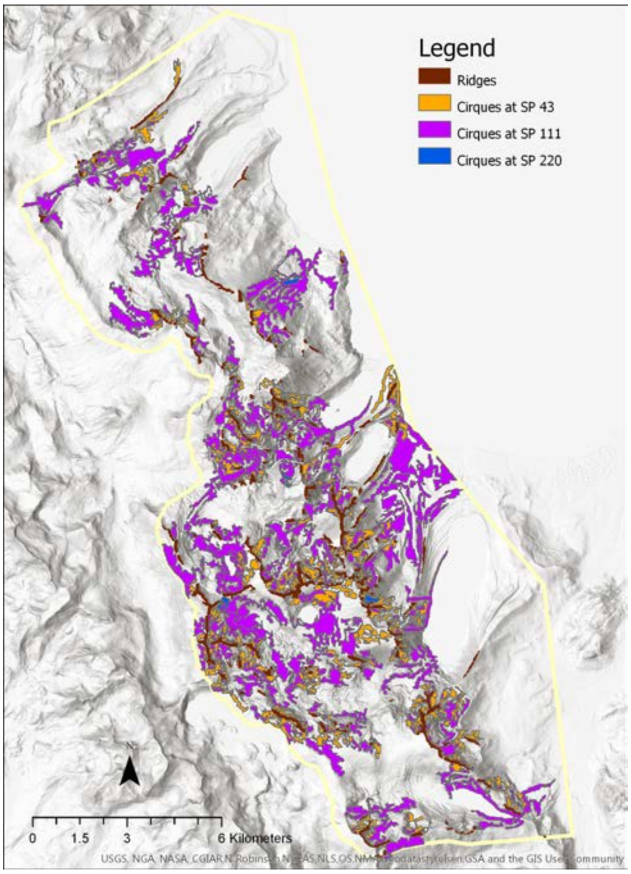

Figure 5. European classification of image objects into the ridge class and three levels of cirque objects based on increasing scale parameters.

3.2 Improvements

With improvements to the workflow and threshold values, ridges and cirques were more suitably delineated (Figure 6). Ridges clearly follow visual ridges more closely, and gaps in coverage by the European model have been closed in many places. Cirques are more contained and closer to their signature arm-chair shape.

While the three image segmentations seem to offer adequate objects to represent cirques, the classification still proves inadequate. For example, on Mt Tallac in the southern part of the study area, several older, larger cirques have been re-eroded by smaller glaciers, resulting in the overlay of smaller cirques (Figure 7). The classification was successful at capturing the smaller cirques but not their older, larger parent cirques.

The use of derived profile and plan curvature was not incorporated into the European model, although it was considered in the conceptual-to-software domain semantics. The inclusion of these layers in the cirque segmentation and classification, following the European workflow (Figure 2), may improve their representation.

4. DISCUSSION

The expectation that actual threshold values would require alteration for the entire model was proven incorrect by the original ridge segmentation. This is a promising result. These results also validate the concept that the general cirque workflow can apply beyond the region for which it was originally developed, contradicting the widely-held concern that GEOBIA produces methods that are rarely transferable (Arvor et al., 2013). With just minor changes in the algorithm parameters, the workflow was adequately successful. The results support the use of natural language semantics in producing the object extraction workflow.

A next step in the research is to understand how plan and profile curvature can improve such a workflow. Slope calculations may also positively impact the model. Future work will also compare the extraction at the different available DEM scales, as well as from the lidar point cloud.

Ideally, results should be quantitatively compared to reference datasets. However, cirque mapping is a tedious process (which is one of the justifications for automated extraction). A future plan to compare these results, and improve the delineation, includes expert digitization of the study area cirques by glacial geomorphologists.

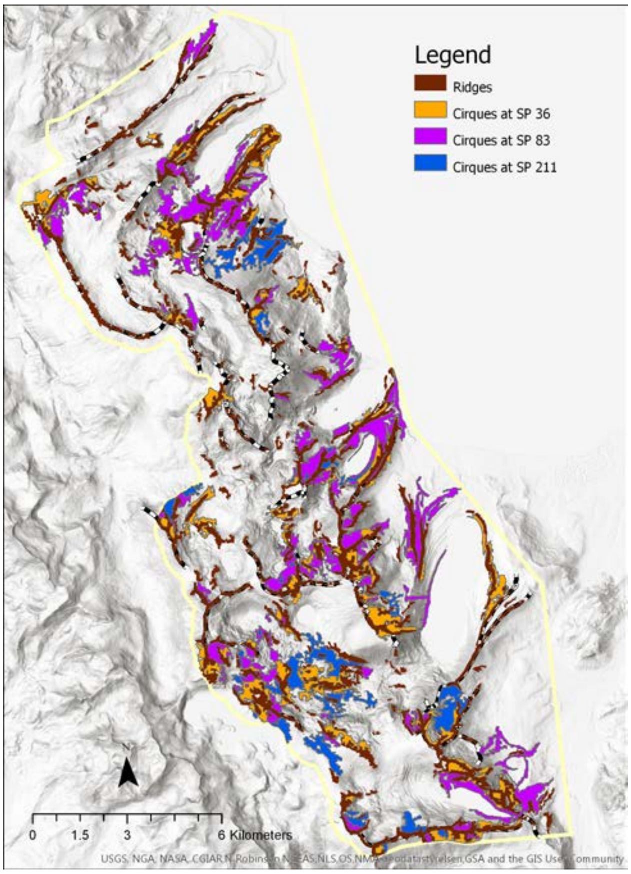

Figure 6. Improved classification of image objects into the ridge class and three levels of cirque objects based on increasing scale parameters.

5. CONCLUSION

An existing, semantically-driven GEOBIA workflow for extracting glacial cirques was tested for its transferability to another geographical region. While some changes were made to the workflow, the general steps were successful in delineating cirques in the southwestern Tahoe Basin of California. Future work includes quantitative comparison to expert-driven cirque mapping, and inclusion of slope, plan and profile curvatures in the segmentation and classification model.

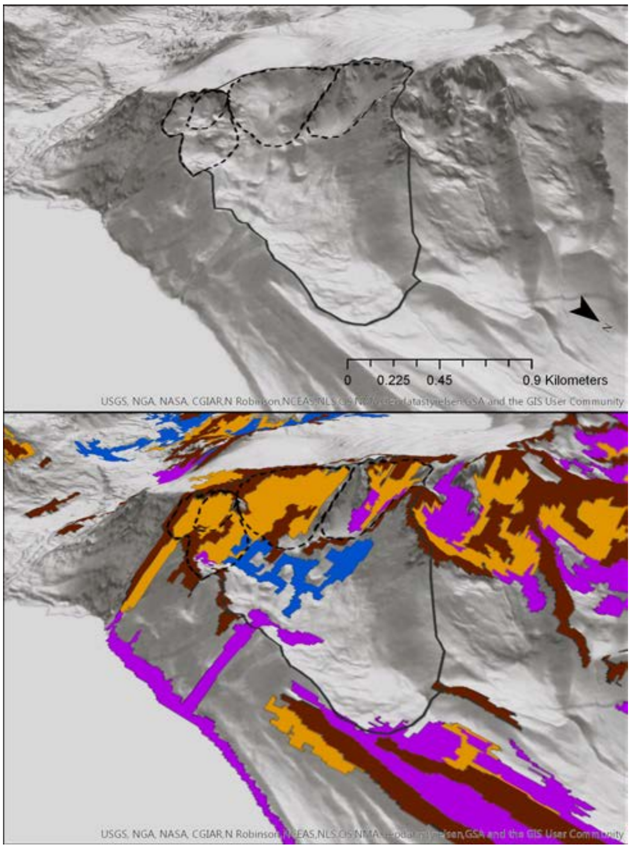

Figure 7. Example of nested cirques delineated by hand in Mt Tallac (top), along with cirque objects created by the improved model.

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