A Comparison of Methods to Incorporate Scale in Geomorphometry

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1. Introduction

Although debated, it seems to be unsettled if scales in digital representations of the land surface are explicitly detectable, or if scale is a ‘window of perception’ (Marceau 1999).

In geomorphometry, scale is predominantly considered as a function of DEM resolution (Hengl and Evans 2009; MacMillan and Shary 2009). Increasing availability of high resolution DEMs is leading to a shift of paradigm regarding scale issues in geomorphometry. While in the past researchers were looking for finer resolution DEMs as a premise for improving analysis, now when they are available there is growing evidence that higher levels of detail represent just noise for some applications. This raises interest for considering scale issues in geomorphometry.

The scale dependency of land-surface parameters and objects derived from DEMs has been demonstrated in a number of studies (Wood 1996, 2009; Florinsky and Kuryakova 2000; Evans 2003; Fisher et al. 2004; Schmidt and Andrew 2005; Hengl 2006; Arrell et al. 2007; Drăguţ et al. 2009) and methods to account for scale through DEM generalization have been proposed. However, a comprehensive assessment of scaling methods- particularly from the perspective of their suitability of enabling scale detection- is still missing. This motivates our work.

Several methods to generate scale levels were selected to comparatively evaluate their performances under controlled conditions.

2. Modelling and Data

Scale levels at constant increments were produced for slope gradient with the following methods:

a. Resampling. The input DEMs were resampled using bilinear interpolation;
b. Smoothing the DEM with focal mean statistics. The input DEM was filtered using focal mean statistics within constantly increased windows, then slope was calculated for each derived dataset;
c. Smoothing slopes with focal mean statistics. Slopes were calculated in a 3X3 window, then filtered using the previous method;
d. Multiscale surface characterization (Wood 1996). Slopes were calculated globally within increasing neighbourhood using LandSerf (Wood 1996);
e. Object-based image analysis (OBIA). Multiple scale levels were produced by increasing the scale parameter within a multi-resolution segmentation process using Definiens Developer® (see Drăguţ and Blaschke 2006 for details on segmentation method).

Scale sensitivity of up-scaling methods was evaluated both against field measurements and using the method of local variance (Woodcock and Strahler 1987). In the former case, relationships between measured and calculated values of slope gradient were assessed through Spearman’s rank of correlation coefficient and Root Mean Squared Error (RMSE). Both estimator values were plotted against scale levels. The latter evaluation method is based on local variance (LV), defined as the average of standard deviation (SD) within a small neighbourhood (3X3 rowing window passing over the entire area). For details on the reason behind this method see Woodcock and Strahler (1987). To assess the LV dynamics from a scale level to another, we used a measure called rate of change (ROC) of LV (Drăguț et al. in review). Values of LV and its ROC were plotted against scale levels as well.

The research is carried out in two test areas, each of them of 3X3 km in size, located in the Federal State of Salzburg, Austria (Fig. 1). Test areas cover two types of land surface in terms of roughness: relatively flat (Eugendorf) and mountain (Schlossalm) (Fig. 1). For each test area, LiDAR DEMs at 1 m spatial resolution are available. 50 points per test area were randomly generated (Fig. 1), then slope values were measured at each point, with a digital inclinometer (HEDÜ, display accuracy: 0,1°).

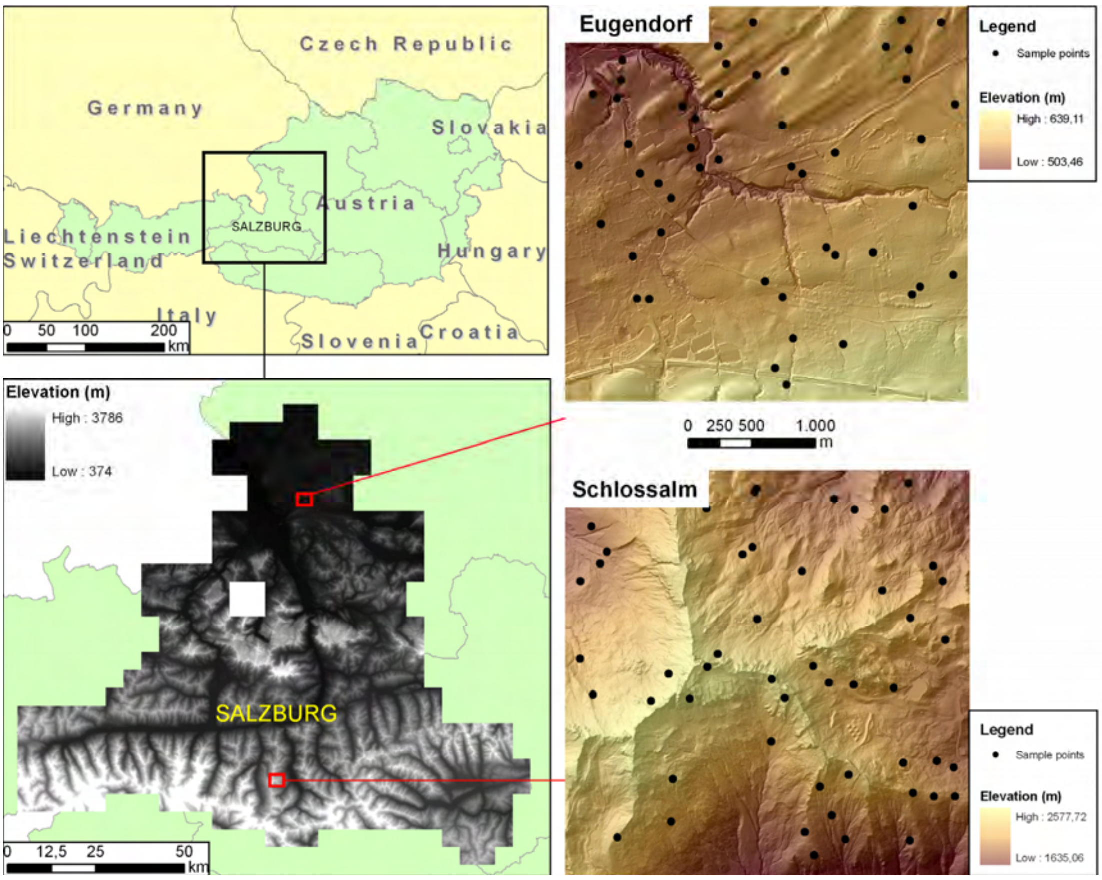

Figure 1. Locations of test areas. Black dots represent locations of field measurements.

3. Results and Discussion

In this experimental research we aim to test whether the graphs obtained as described above could help in detecting characteristic scales in geomorphometric analysis.

Similar to concepts in landscape ecology and remote sensing, breaks in constant evolutions of land-surface parameters across scales might reveal levels of organization in the structure of data as a consequence of the occurrence of similar sized spatial objects. Here ‘objects’ are not defined as classical geomorphologic objects (e.g. landforms), but rather as ‘morphometric primitives’ (Gessler et al. 2009) or pattern elements, carriers of information on slope gradient. This term is seen as bridge between ‘real’ objects and their representation. Morphometric primitives can be further classified in landform elements and integrated in nested hierarchies (Minar and Evans 2008; Evans et al. 2009), but this falls beyond the scope of this paper.

For each scaling method, specific scale signatures (sense Wood 2009, but applied globally) have been obtained (Fig. 2) in scale ranges up to 21 for cell-based methods, and up to 100 for OBIA respectively. Thresholds in trends of curves have been comparatively analysed.

In contrast to OBIA and resampling, all other methods produce decreasing curves of LV (Fig. 2). This is because these methods do not emulate real world ‘objects’, as resampling does (e.g. through different cell sizes, which may or may not approximate characteristic dimensions of homogeneous slopes at given scale). Therefore, LV does not increase as a consequence of contrasting neighbour cells, but reduces with raising spatial autocorrelation. Further, thresholds in R and RMSE curves only occasionally indicate similar scale levels.

For resampling and OBIA, LV graphs are provided in two versions to reveal thresholds at higher scale (otherwise obscured due to huge values of ROC at lowest levels).

For OBIA, four thresholds in LV and ROC curves (corresponding to scale parameters of 10, 25, 40 and 85) have been identified for Eugendorf, and three (20, 50 and 90) for Schlossalm. Thresholds at these values or close to them are visible in R and RMSE curves as well. For Schlossalm, thresholds in curves of R, RMSE, and LV show a notable fit, despite aforementioned indicators were calculated on different basis.

For resampling methods, two thresholds have been identified for each of the two test areas, at the same scales: 5 and 19. Except for the threshold at 5 in Schlossalm, all others appear on R and RMSE curves, too. For Eugendorf, a misfit between R and RMSE curves duplicate the threshold at 19, suggesting an interval from 15 to 19 rather than a single value.

Results were visually evaluated for OBIA, and through profiles for resampling. Figure 3 displays slope profiles at scales as in Figure 2 (resampling). Variations in profiles correspond to levels of generalization of land-surface. While profiles at scales 5 and 19 show distinct representations of slopes (which suggests good performance of LV method in detecting meaningful scale levels), scale levels are the same for both study areas, regardless of differences in topography.

In Figure 4, areas of similar homogeneity are delineated with OBIA for Schlossalm, with the scale parameters presented above. Good agreements between slope values and their aggregation in objects at these scale levels are depicted. In OBIA, anisotropy is readily incorporated in analysis, contrary to cell-based methods (see Schmidt and Andrew 2005, pp. 347, for details). Thus, various features in terms of size and shape (from extremely elongated to circular) occur in the same scale level, according to land-surface patterns (Fig. 4). Well individualized features may persist across scales without changing shape (e.g. elongated features inside the polygon at scale 90 persist at finer scales).

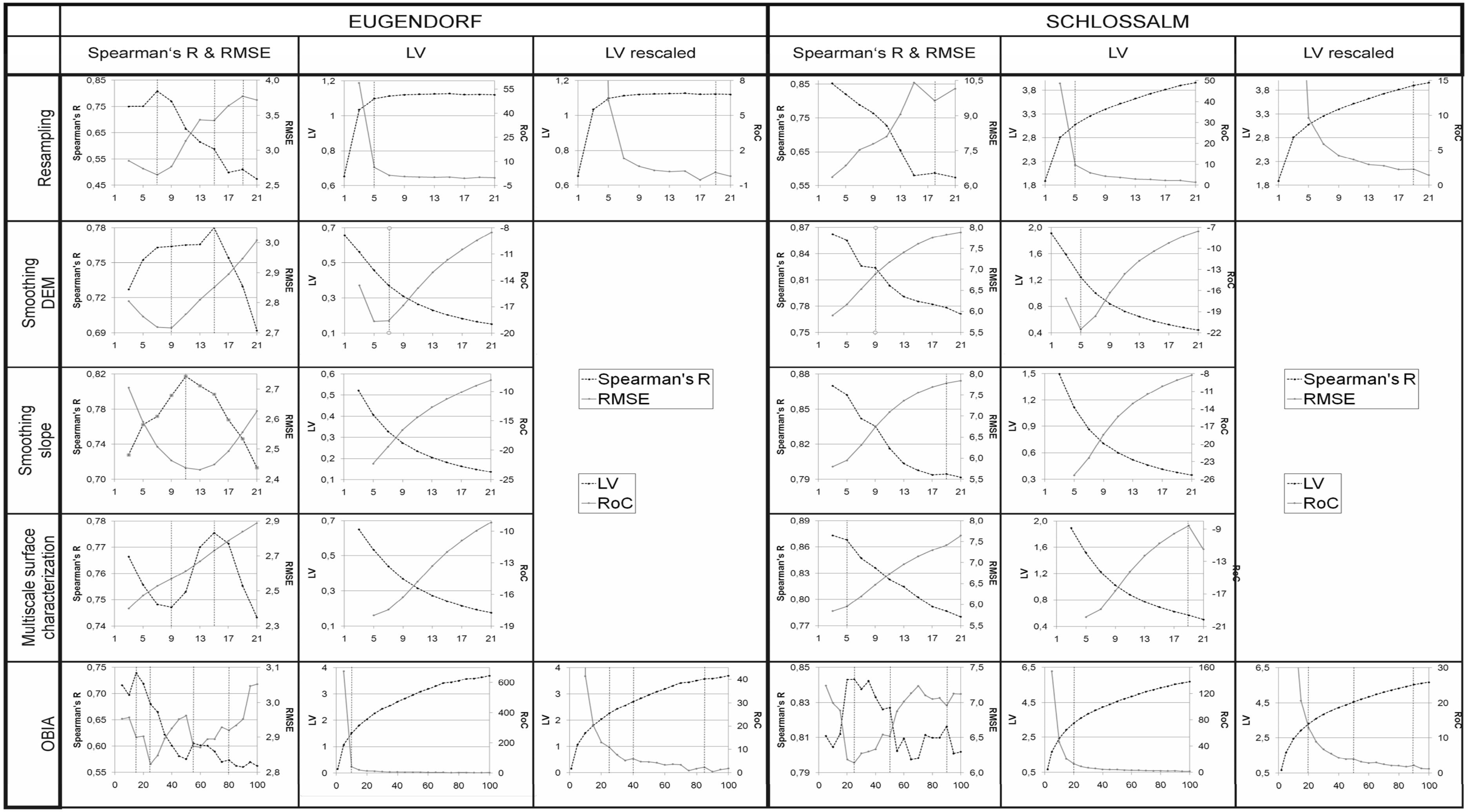

Figure 2. Comparative view of scale signatures. Where applicable, vertical lines in graphs represent scale thresholds.

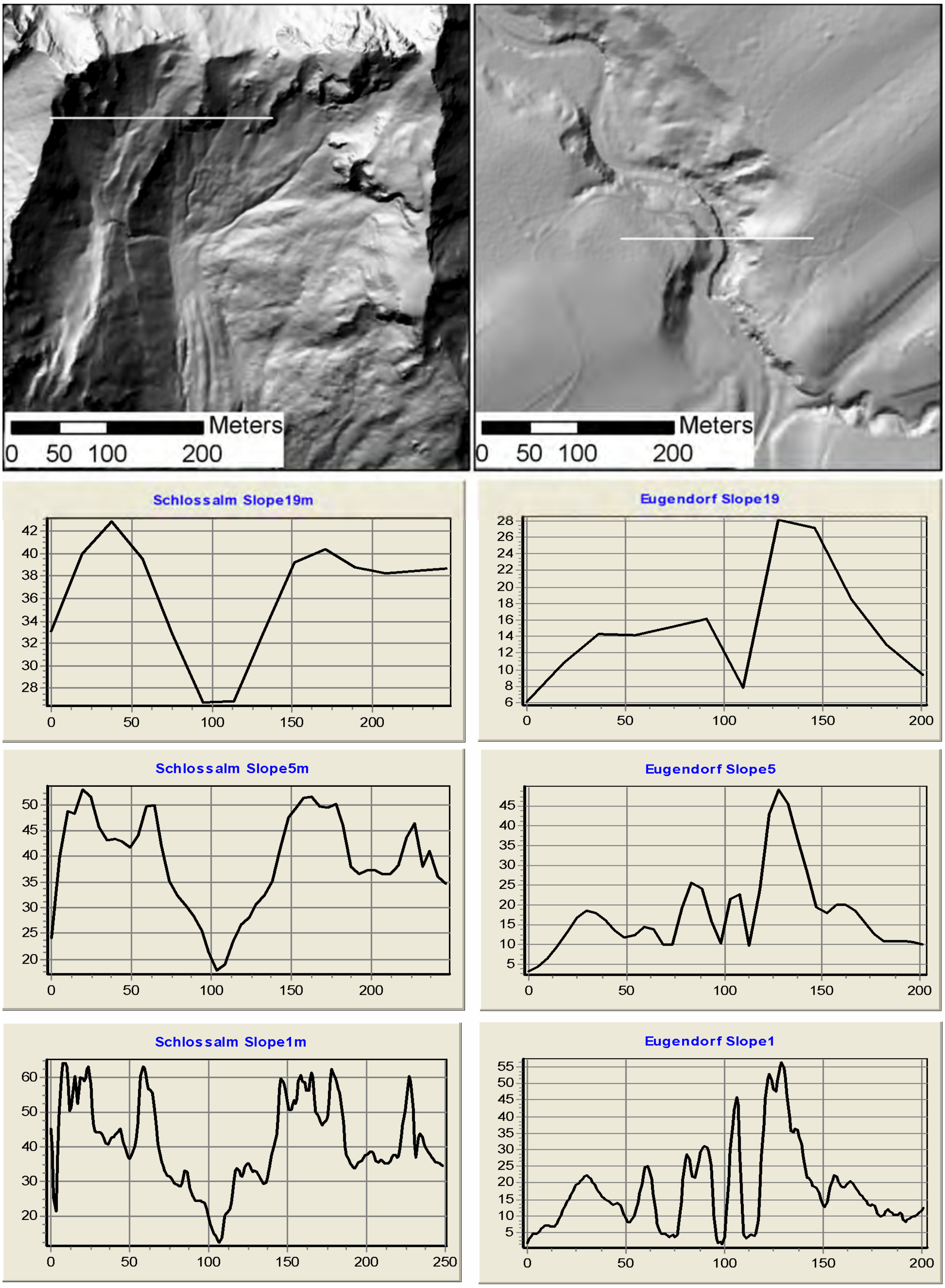

Figure 3. Slope profiles at original and detected scales for Schlossalm (left) and Eugendorf (right). White lines on shaded maps show profile locations.

Li (2008) suggested the LV method should be applicable to DEM data (pp. 79). In this study, we compared scale sensitivity of five up-scaling methods using both LV and field-based methods. We found that filtering and multi-scale surface characterization do not enable scale detection in slope maps with the methods presented here. More research is needed (particularly on other parameters and larger scale ranges) to evaluate the suitability of resampling for scale detection. OBIA produced visually appealing representations of homogeneous slopes at scales detected by all methods. Although land-surface 'objects' are characterized by smoother transitions in comparison with land cover objects, the application of LV method on segments looks promising for multi-scale analysis in geomorphometry too.

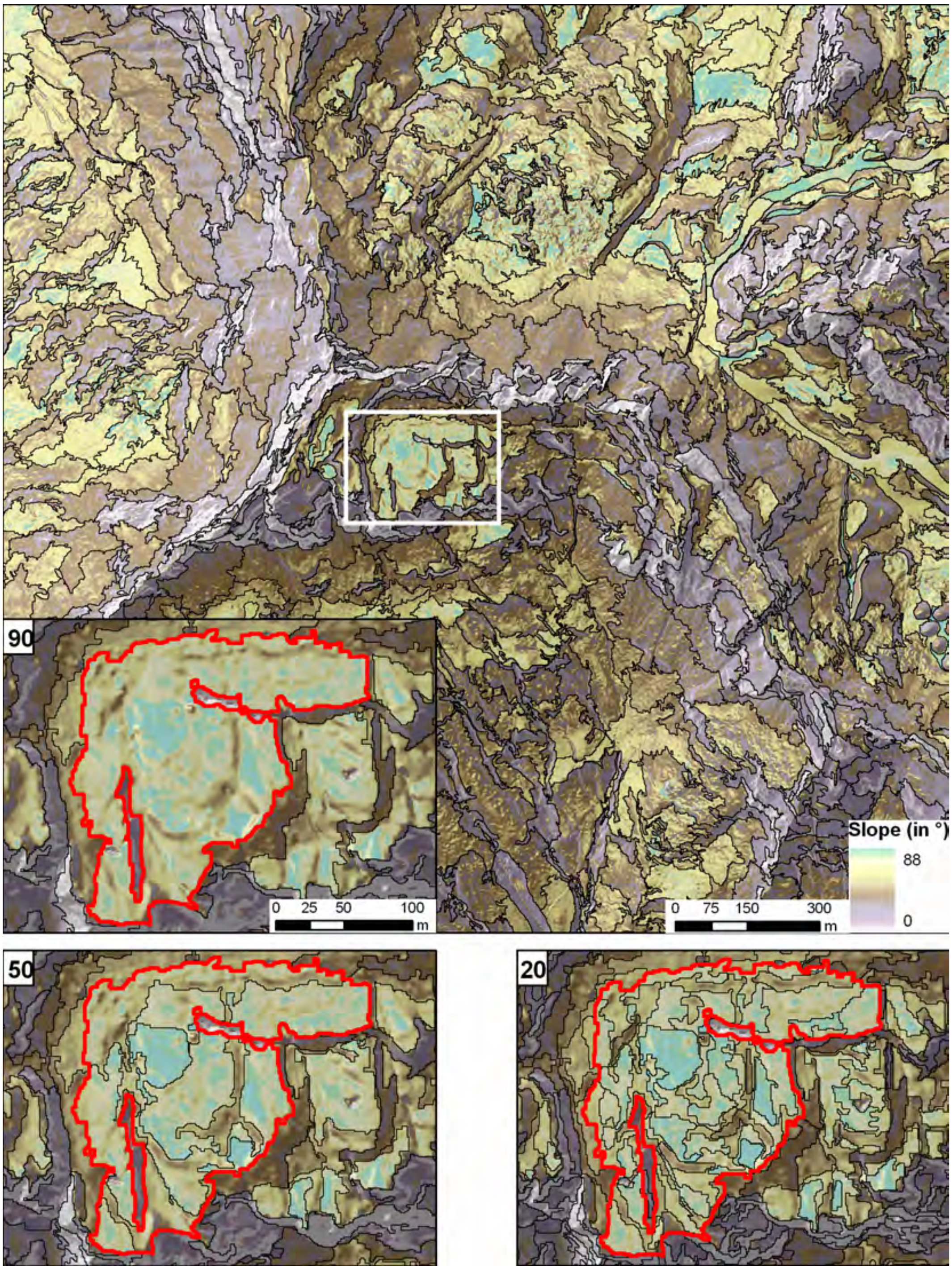

Figure 4. Multi-scale object representation in OBIA environment. Results of segmentations with detected scale parameters (SP) are visible. The whole Schlossalm test area (top) with slope segments delineated at a SP of 90. For the object marked in white rectangle, detailed views are provided at SPs of 90, 50 and 20.

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