Terrain Sculptor:
Generalizing Terrain Models for Relief Shading
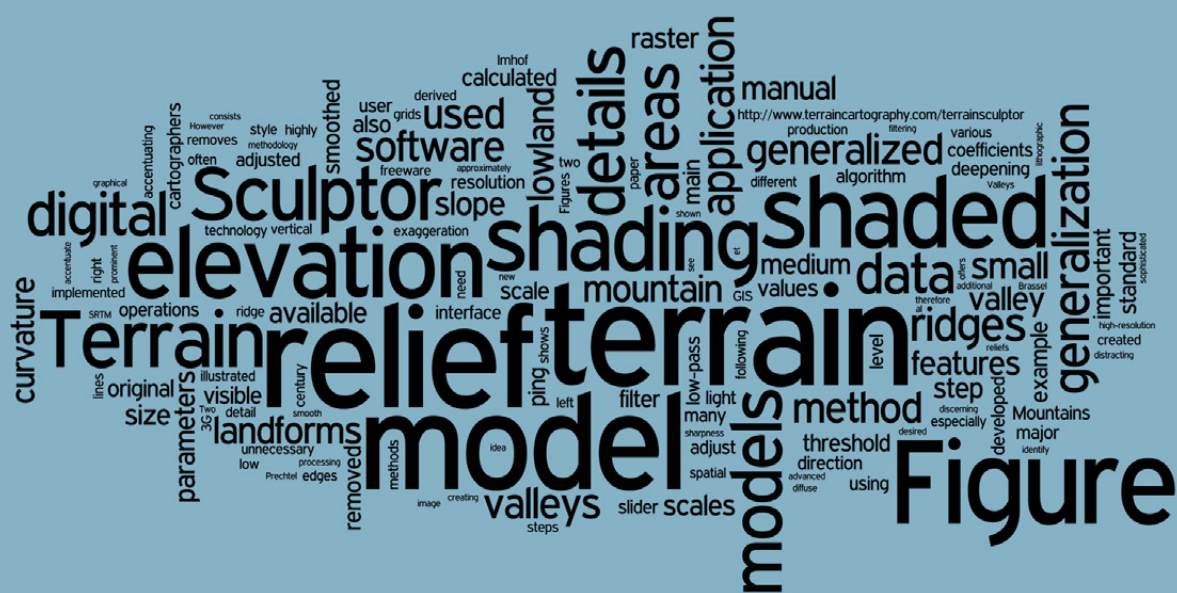
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ABSTRACT

Shaded relief derived from high-resolution terrain models often contains distracting terrain details that need to be removed for medium- and small-scale mapping. When standard raster filter operations are applied to digital terrain data, important ridge tops and valley edges are blurred, altering the characteristic shape of these features in the resulting shaded relief. This paper introduces Terrain Sculptor, a software application that prepares generalized terrain models for relief shading. The application uses a generalization methodology based on a succession of raster operations. Curvature coefficients detect and accentuate important relief features. Terrain Sculptor offers a graphical user interface to adjust the algorithm to various scales and terrain resolutions. The freeware application is available at http://www. terraincartography.com/terrainsculptor/.

INTRODUCTION

Shaded relief can be calculated from digital elevation data with most GIS applications and with many raster mapping software packages. With high-resolution digital elevation data now available for almost the entire Earth, relief shading has become a de facto standard for visualizing terrain. However, relief shading is not a recent addition to mapping, as it was

developed long before digital computer technology. Manuscript maps have employed shaded relief for hundreds of years, for example, the maps painted of the Zurich area by Hans Conrad Gyger in the seventeenth century (Imhof 1982). At the end of the nineteenth century, the lithographic printing process was the first technology to allow for mass production of maps with smooth tonal variations (Ristow 1975). With the advent of lithographic printing, the high-contrast hachures representing terrain were replaced with varying, continuous tones. Of note were the experiments by Swiss cartographers with this new technology during the first half of the twentieth century to create highly sophisticated shaded relief maps (Jenny and Hurni 2006). Today, few cartographers possess the extensive training and understanding of relief interpretation needed to create manual shaded relief in this same manner.

Digital relief shading—also called analytical shading—has major advantages compared to manual shading: it does not depend on the individual style of a cartographer, and it is faster and cheaper to produce (provided a digital terrain model is available). However, digital relief shading is not without problems, especially at medium and small map scales where excess detail is commonplace. A small-scale shaded relief with many intricate terrain details can inhibit the perception of the main landforms (for example, main ridges and valleys). As Patterson (2001a) notes, the dense details obscure macro topography—it is impossible to see the forest for the trees. Nowadays, when highly detailed elevation data are abundant and freely available, conducting research to automate the removal of unwanted details from terrain is highly relevant. The software available to production cartographers does not adequately address this issue. Although simple methods exist to remove local irregularities from terrain (for example, low-pass filtering), they also apply smoothing to important ridges and valley edges, solving one problem but creating another. More sophisticated methods, specifically developed for simplifying terrain models for relief shading, are not implemented in commercial software, and therefore rarely used (Weibel 1992, Böhm 2000, Prechtel 2000, Patterson 2001b, c, Leonowicz et al. 2010).
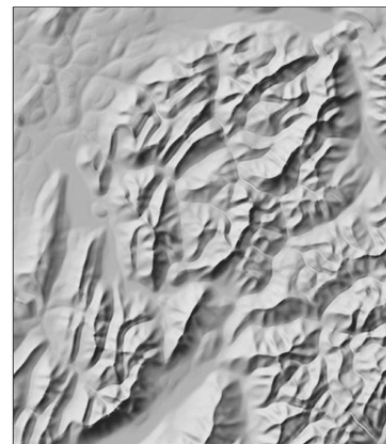
DIGITAL RELIEF SHADING IS NOT WITHOUT PROBLEMS, ESPECIALLY AT MEDIUM AND SMALL MAP SCALES WHERE EXCESS DETAIL IS COMMONPLACE. A SMALL-SCALE SHADED RELIEF WITH MANY INTRICATE TERRAIN DETAILS CAN INHIBIT THE PERCEPTION OF THE MAIN LANDFORMS
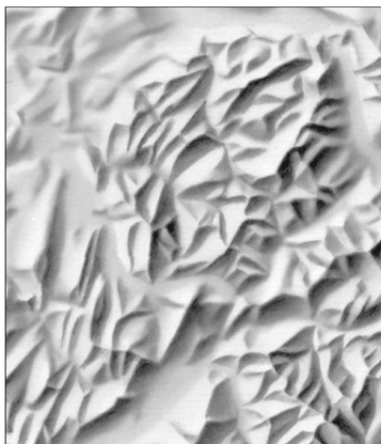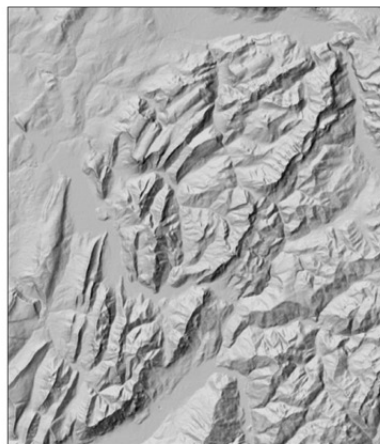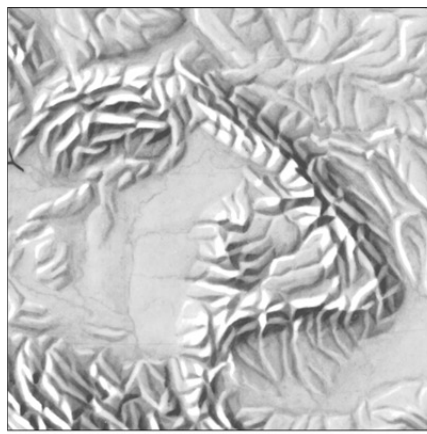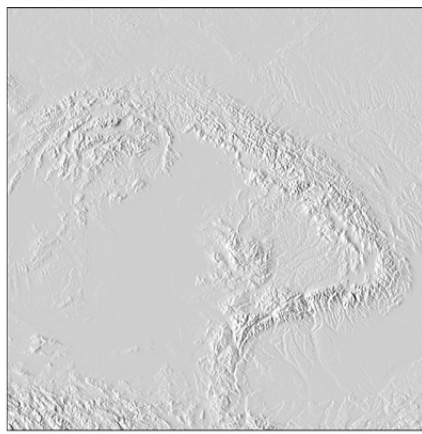

Manual **Digital** **Digital Terrain filtered with Terrain Sculptor**
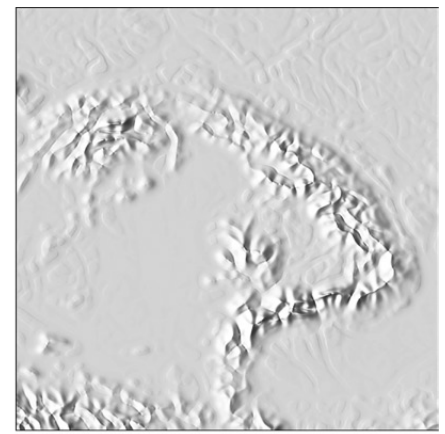
Figure 1: Shaded relief at 1:1,000,000. Left: Federal Office of Topography swisstopo (DV033492.2). Middle: from raw SRTM data. Right: from SRTM data generalized with Terrain Sculptor.

Figure 2: Shaded relief at 1:15,000,000. Left: Swiss World Atlas 2008. Middle: from raw GTOPO30 data. Right: from GTOPO30 data generalized with Terrain Sculptor.

TERRAIN SCULPTOR DOES NOT OFFER A NEW SHADING METHOD, BUT INSTEAD GENERALIZES TERRAIN MODELS VIA A FILTERING METHODOLOGY.

Figures 1 and 2 compare manual and automated shaded relief of the same geographic areas. Digitally shaded relief is often not successful at portraying the main structures of a terrain at medium and small scales. For example, looking at the unfiltered shaded relief (Figures 1 and 2, middle), the many details and the static light direction result in an unstructured portrayal of the terrain. It appears as a disjointed collection of minor features, and major landforms are difficult to detect. By contrast, the major landforms are immediately visible in the manual shading because unnecessary details are removed and the light direction is locally adjusted to optimally illuminate landforms within the terrain trending in different directions.

This paper presents a method for the generalization of digital elevation models, specifically designed for calculating shaded relief. The method not only removes terrain details from digital elevation models, but also accentuates important relief features. The method was implemented in the freeware software application Terrain Sculptor. Terrain Sculptor does not offer a new shading method, but instead generalizes terrain models via a filtering methodology. All shaded relief images presented in this paper are computed with a standard shading algorithm simulating diffuse reflection. More advanced methods developed for manual (Imhof 1982) and digital shading are not included in the current version of this application. For example, the light direction is not locally adjusted (Yoeli 1967, Brassel 1974, Zhou and Dorrer 1995, Prechtel 2000) and areal perspective is not simulated (Brassel 1974, Jenny 2001). These techniques also aim at a more clear representation of the terrain by graphically accentuating important landforms, but do not alter the underlying terrain model.

Terrain Sculptor implements a generalization method developed and described by Leonowicz et al. (2010). The method consists of a succession of raster operations performed on digital elevation data. The general idea is to classify the terrain as mountainous and lowland areas and to separately generalize these morphologically different areas—in different ways—and afterwards re-combine them into one elevation model. This idea follows a principle formulated for manual relief shading by Imhof (1982), who recommends accentuating ridge lines in high mountain areas and river valleys on flat plains. The digital method uses the following operations, which are illustrated in Figure 3:

1. Digital elevation data (Figure 3A) are filtered with a low-pass mean filter to produce a smoothed elevation model (Figure 3B). This model serves as a base surface onto which relevant details are added, using the following processing steps.
2. Terrain features (ridges and valleys) are detected by curvature coefficients: maximum and plan curvature are used to identify ridge lines, and minimum curvature is used to identify valleys (see Wilson and Gallant 2000 for details on curvature computation). For detecting large terrain features and removing small details, elevation data are smoothed, using a mean filter, before calculating the coefficients.
3. Two additional elevation models are created by vertically exaggerating and deepening the smoothed elevation model (models not represented in Figure 3).
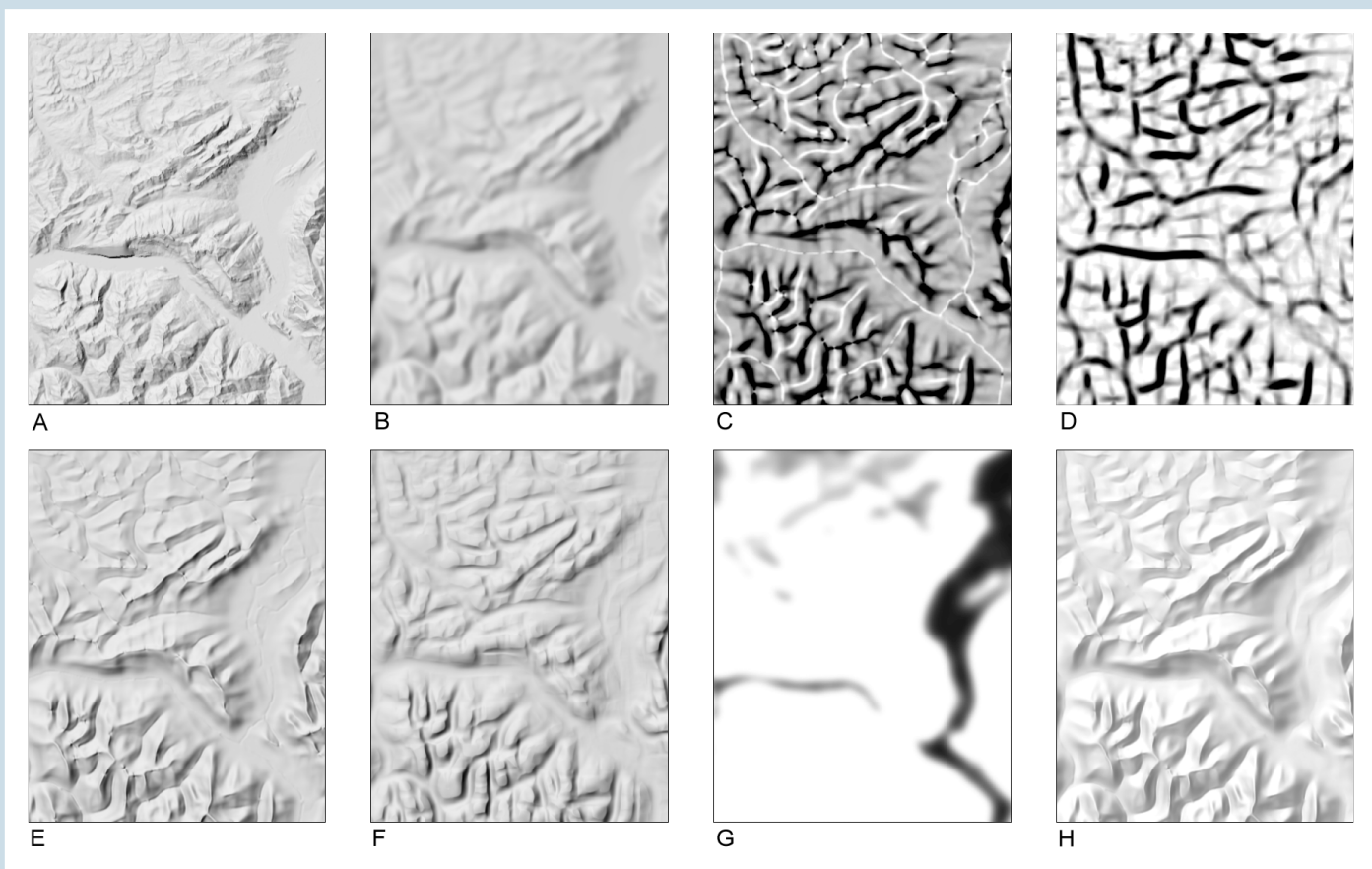

Figure 3: Intermediate steps of the generalization method. A. ungeneralized terrain model; B. smoothed terrain model; C. weights for exaggerating ridges; D. weights for deepening valleys; E. mountain model with exaggerated ridges; F. lowland model with deepened valleys; G. weights for combing models E and F; H. final shaded terrain model.

4. Two grids with weighting factors are created from curvature coefficients (Figure 3C and D) and used to combine the exaggerated model and the deepened model of step 3 with the smoothed model generated in step 1. In areas with extreme curvature values, either the exaggerated model or the deepened model of step 3 is used, whereas the smoothed model of step 1 is used in areas with low curvature values. As a result of these combinations, two elevation models are created: a mountain model (Figure 3E) and a lowland model (Figure 3F).

5. Smoothed slope values (Figure 3G) are used to re-combine the mountain model with the lowland model. The mountain grid is used in the areas with high slope values (white in Figure 3G) and the lowland grid in areas with low slope values (black in Figure 3G).

6. A shaded relief image is calculated from the model generated in step 5 (Figure 3H).

IMPLEMENTATION: TERRAIN SCULPTOR

Terrain Sculptor is a cross-platform Java application implementing the generalization procedure described above. The application is intended as a production tool for creating generalized shaded reliefs at small and medium scales. It is freely available at http://www.terraincartography.com/ terrainsculptor/. Terrain Sculptor reads digital elevation models as grids in ESRI ASCII format and saves generalized models to the same format. The generalized models can then be visualized with any shading algorithm in other GIS or mapping software. Terrain Sculptor can also calculate shaded relief using a standard diffuse shading algorithm and export it as a raster image file.

Terrain Sculptor processes elevation data according to the steps outlined in the previous section. Intermediate models produced after each processing step can optionally be visualized within the software (i.e., the lowland model, the mountain model, the slope mask used for the combination, as well as the original and the final generalized model). The user can interactively adjust several parameters to achieve the desired level of generalization, depending on the map scale and the spatial resolution of the original elevation model.

The user of Terrain Sculptor is not required to understand the details and the various steps of the generalization method. The graphical interface instead aggregates various detail parameters and displays them as slider controls that are straightforward to understand. The application offers two interface modes: the basic mode consists of only two sliders to adjust the level of detail and the scale-dependent shading style. The interface elements of the advanced mode are shown on the left side of Figure 4 marked with numbers 1–5. They adjust the following parameters (numbers as in Figure 4):

1. the size of the low-pass filter to smooth the original elevation model;
2. the size of ridges that are removed from the elevation model;
3. the vertical exaggeration of ridges;
4. the sharpness of ridges; and
5. the slope threshold discerning between lowland areas and mountain areas.
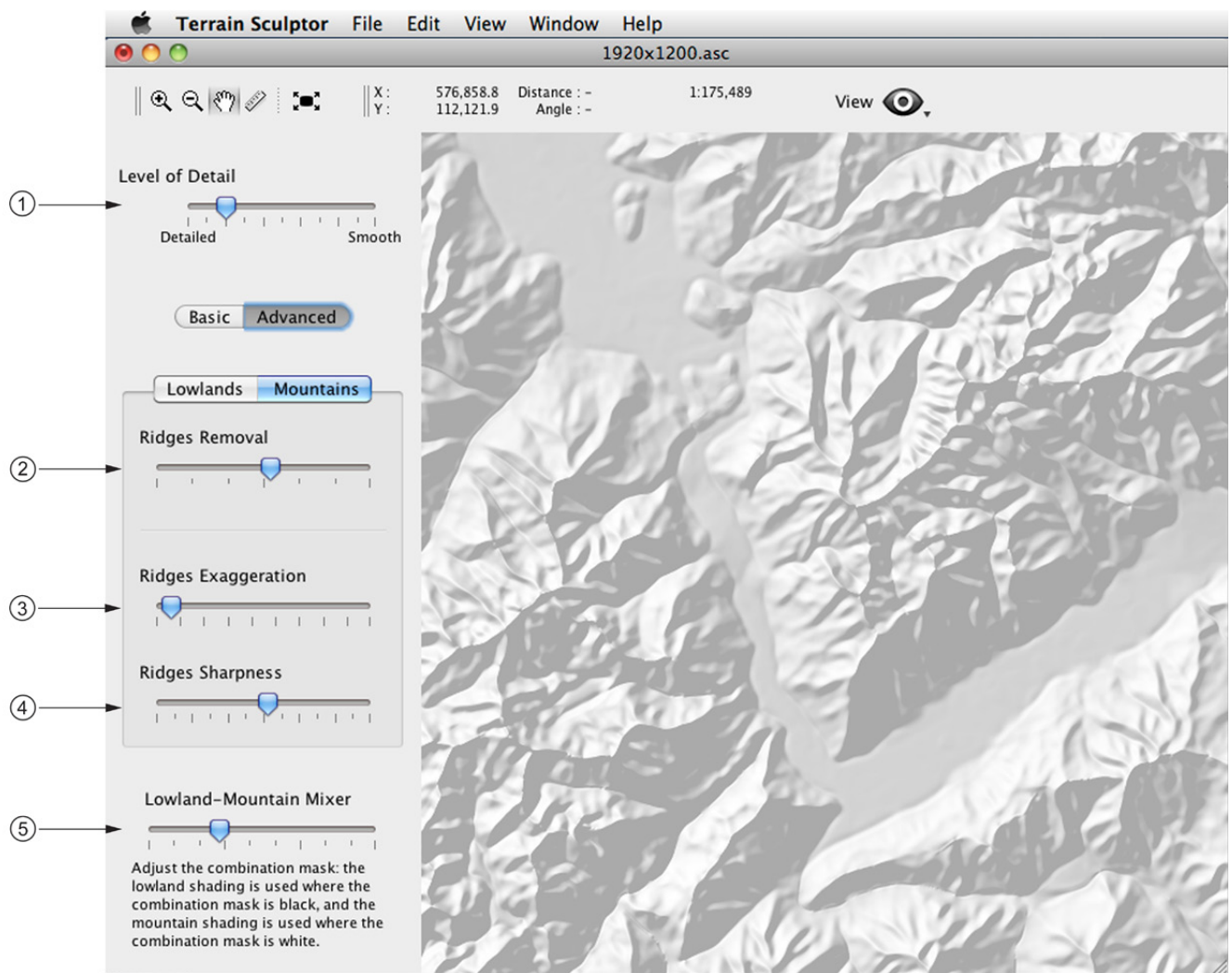
THE USER CAN INTERACTIVELY ADJUST SEVERAL PARAMETERS TO ACHIEVE THE DESIRED LEVEL OF GENERALIZATION, DEPENDING ON THE MAP SCALE AND THE SPATIAL RESOLUTION OF THE ORIGINAL ELEVATION MODEL.

Figure 4: Graphical user interface of Terrain Sculptor in "Advanced" mode for adjusting generalization parameters.

Three additional parameters can be adjusted in the lowlands panel (not visible on Figure 4):

- the size of valleys that are removed from the elevation model;
- the amount of valley deepening; and
- the width of valley bottoms.

RESULTS

Figures 5 to 8 show how parameters influence the resulting shaded relief. Figure 5 compares three levels of generalization achieved by moving the "Ridges Removal" slider, which increases the size of ridges removed from the elevation model. Valleys are generalized in the same way using the "Valleys Removal" slider (in the Lowlands panel, not visible in Figure 4). Ridge lines can be made more prominent by increasing their vertical exaggeration. This is illustrated in Figure 6 showing the Carpathian Mountains calculated from GTOPO30 data. To accentuate valley edges, the user increases the amount of valley deepening. This operation is illustrated in Figure 7, which depicts a section of the Jura Mountains in
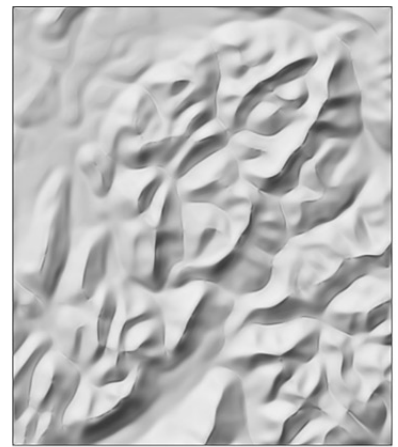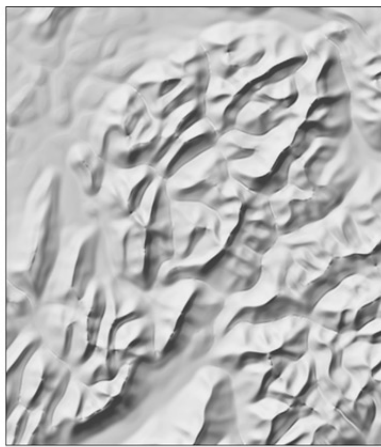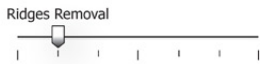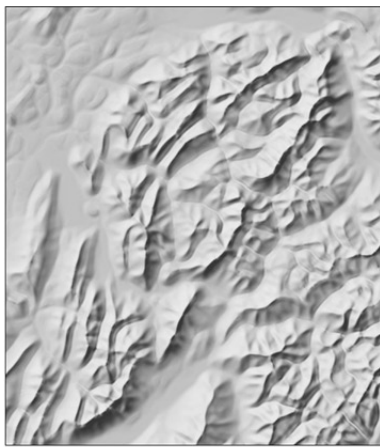
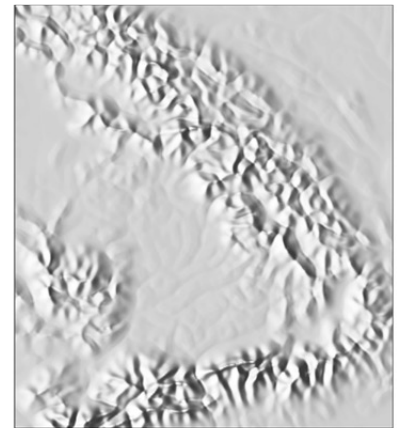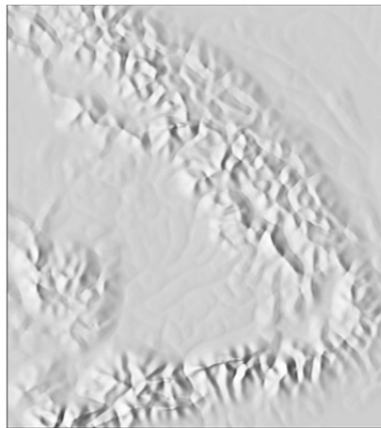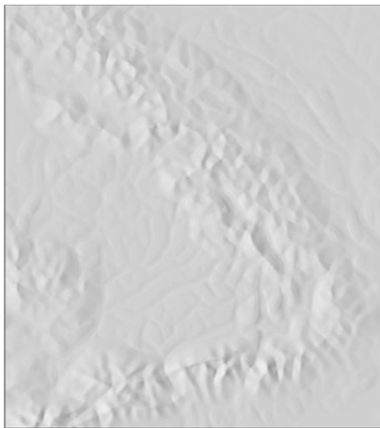*Figure 5: Increasing the size of ridges removed from the elevation model (1:1,000,000).*

Figure 6: Increasing vertical exaggeration of ridge lines (1:7,500,000).

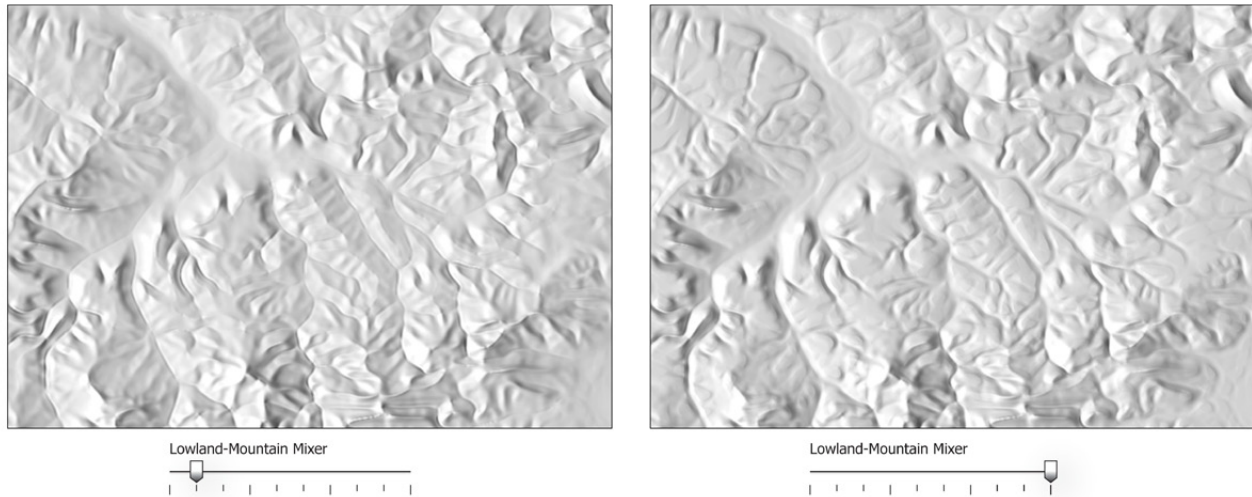*Figure 7: Increasing the depth of valleys (1:200,000).*

Figure 8: Increasing the slope threshold discerning between lowland and mountain areas (1:200,000).

northern Switzerland, calculated from a model at 25 meters resolution (DHM25 by Swisstopo) and generalized to the scale of 1:200,000. The character of the shaded landforms can be accentuated by adjusting the slope threshold that differentiates between lowland and mountain areas (slider "Lowland-Mountain mixer"). A lower threshold creates a shaded relief with a more mountainous aspect (Figure 8, left), while a higher threshold produces a gently undulated surface carved with valleys (Figure 8, right).

Figure 1 shows medium scale terrain shadings at 1:1,000,000. SRTM data with a spatial resolution of 3 arc seconds (approximately 100 meters) were generalized with Terrain Sculptor (Figure 1, right). A comparison with the shading derived from the original SRTM data (in the center of Figure 1) shows that Terrain Sculptor removes many of the unnecessary small terrain details, while the sharp structures of the main landforms are preserved. Ridges and valleys are clearly visible and unmarred by small terrain irregularities. The level of details achieved with Terrain Sculptor is similar to that of the manually-produced shaded relief at the same scale (Figure 1, left). Differences are mainly due to local adjustments of the light direction and the individual cartographer's manual shading style. Identical results can, therefore, not be expected.

Figure 2 shows shaded reliefs at 1:15,000,000 of the Carpathian Mountains. They were calculated from GTOPO30 data with a spatial resolution of 30 arc seconds (approximately 1 km). The shaded relief derived from the terrain model generalized with Terrain Sculptor is shown on the right. Compared to the ungeneralized shaded relief, major landforms are more clearly visible, especially in low relief areas. Mountains are much more prominent and have a unified structure.

In summary, to increase the level of generalization, the minimum size of ridges and valleys as well as the size of the low-pass filter for smoothing the original elevation model need to be increased. Low-resolution grids at small scales generally need stronger vertical exaggeration of ridges and stronger valley deepening. In addition, the width of valleys and the sharpness of ridges should be increased, and the slope threshold for discerning between lowland and mountain areas can be lowered.

TERRAIN SCULPTOR REMOVES MANY OF THE UNNECESSARY SMALL TERRAIN DETAILS, WHILE THE SHARP STRUCTURES OF THE MAIN LANDFORMS ARE PRESERVED.

CONCLUSION

Terrain Sculptor is a freeware software application that can be downloaded from **http://www.terraincartography.com/terrainsculptor/**. The implemented generalization method removes unnecessary and distracting terrain details from digital terrain models, while accentuating main landscape features. Several generalization and feature-enhancing parameters can be interactively adjusted according to the desired visualization scale. The application can preprocess terrain models before standard shading is applied in GIS and raster mapping software, which often does not provide appropriate terrain generalization algorithms. Terrain Sculptor will hopefully help geographers and cartographers generate improved shaded terrain visualizations, especially at small and medium scales.

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