Gradient based filtering of digital elevation models

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Abstract

We present a filtering method for digital terrain models (DTMs). The method is based on mathematical morphological filtering within gradient (slope) defined domains.

The intention with the filtering procedure is to improve the *cartographic* quality of height contours generated from a DTM based on draping and optimum interpolation methods.

The contours from the unfiltered DTM has shown to become ragged and hard-to-interpret—especially in areas of minor slope.

The contours from the filtered DTM are significantly more smooth. They are however not smoothed to an extent where local breaks in the landscape are washed out and misrepresented.

KEY WORDS: Digital terrain model, mathematical morphology, optimum interpolation, contour lines, LOCO filter

1 Introduction

Until recently, the height contours on topographic maps of Denmark have been based on a comprehensive set of more than 100 year old manual field measurements. Prior to their original publication, these measurements were generalized by experienced cartographers to strike a proper balance between the conflicting goals of high accuracy and ease of visual interpretation (Michaelsen, 2004a). In the 1980s, the generalized data were digitized and used in the preparation of later grid based height models; due to their hand crafted heritage, height contours based on these models retained the ease-of-interpretation feature (Michaelsen, 2004b).

In the 1990s a new countrywide, fully 3D GIS database based on photogrammetric stereo mensuration was established by the National Survey and Cadastre—Denmark (Kort- & Matrikelstyrelsen, KMS). This meant that a large number of high precision point measurements of ground features became available. In principle these measurements are of much higher quality than the old field measurements. Being scattered point observations they are, however, not in any way as good as the old measurements when it comes to representing the shape of the landscape.

To combine the precision of the new photogrammetric data set with the descriptiveness of the old field measurements, a new digital terrain model (DTM) was recently generated. This DTM was based on a set of draping and optimum interpolation techniques originally developed by Ekholm (1996), and represents a major improvement in terms of precision. In terms of cartographical expressiveness the new DTM is however a setback: due to the inherent characteristics of the optimum interpolation procedure, the height contours become much more detailed, compromising the ease-of-interpretation. This cannot be reduced simply by low-pass filtering of the entire DTM; closer inspection shows that the problem must be handled by combining domain specific approaches in at least three different domains:

1. high slope areas, where the generated contours are quite acceptable
2. low slope areas, where the contours need generalization
3. in the vicinity of regional extrema, which should be reproduced as faithfully as possible.

Item 3 above relates especially to river valleys, which should be preserved to keep the map appropriate for hydrological applications.

Below, we present a solution based on a combination of morphological operations and traditional filtering. It is, however, important to note that we are only concerned with the *graphical* representation of the DTM: we want to achieve a set of easy-to-interpret contours, i.e. a cartographically more suggestive representation. We do not work towards anything that should be used for filtering of the gridded DTM when used for analytical work: the unfiltered, gridded DTM represents the currently best available estimate of the actual heights.

2 Method

Figure 1 shows some basic properties of the morphological opening and closing operators which figuratively speaking, cut off lint and fill in cracks, respectively (cf. e.g. Haralick et al., 1987, for a comprehensive review of mathematical morphology). Staying with the figurative and descriptive terms, we note that the combination of opening and closing results in an *ironing out* of minor irregularities on an edge, while preserving the position

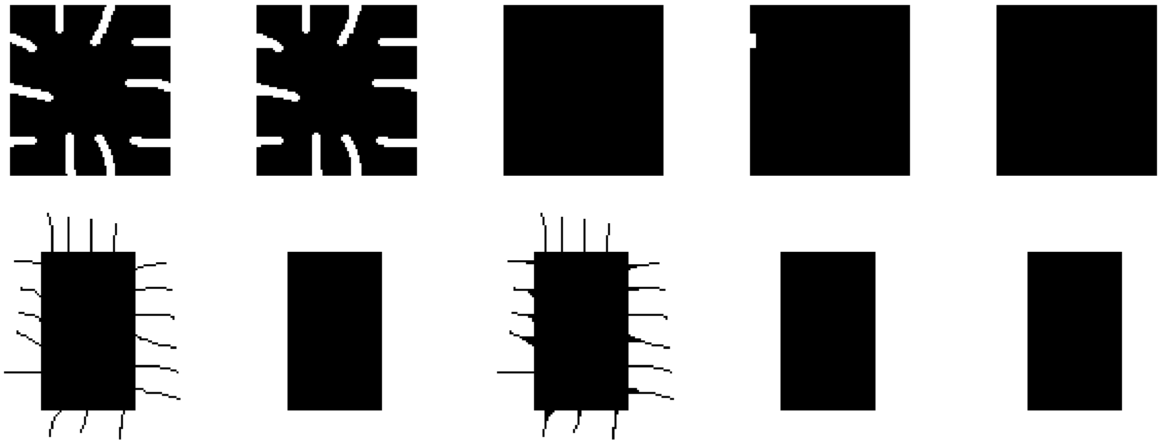

Figure 1: Morphological operations on a binary (i.e. black-and-white) image. Left to right: 1: Original image, 2: Opening of the original image removes lint, 3: Closing of the original image fills in cracks, 4: Opening followed by closing, 5: Closing followed by opening.

of the edge and its corners. This is actually a very good description of what we need in order to improve the visual impression of the height contours.

The combination of opening and closing operators were studied by Schulze and Pearce (1993), who introduced the *LOCO filter*, defined as the mean of two operators: the first being the closing of an opening (CO) and the second being the opening of a closing. In other words, for an image I and a structuring element s, the LOCO operator is defined as

$$\mathrm{LOCO}(I,s) = \frac{\mathrm{open}(\mathrm{close}(I,s),s) + \mathrm{close}(\mathrm{open}(I,s),s)}{2}$$

Schulze and Pearce (1993) note that in the greyscale case, the LOCO operator is an unbiased and very efficient suppressor of gaussian as well as impulse noise; impulse noise is halved, as the CO term eliminates positive peaks and passes negative peaks, while the OC term has the opposite characteristics. Assuming that the disturbances from the optimum interpolation procedure can be (coarsely) approximated as impulse noise in the vicinity of photogrammetric observations, and gaussian noise at some distance away from these observations, the LOCO filter seems to be an ideal fit to the problem at hand.

In order to keep the long wave part of the DTM intact, we start by splitting the dataset in two: a lowpass filtered L and a highpass filtered H (i.e. the original DTM minus the lowpass filtered). From there, the algorithm goes as follows:

1. Compute S, the slope of the lowpass filtered dataset (figure 2, upper right)

2. Compute C, the LOCO filtering of the highpass dataset (figure 2, centre right)

3. Compute M, a river valley mask based on the morphological bottom-hat operator (figure 2, lower left)

4. Compute weight factor, W, for each DTM point:

   (a) $S > 3^\circ$: $W = 1$

   (b) $S < 3^\circ$: $W = (S/3)^2$

   (c) under the mask M: $W = 1$

5. Compute the final filtered product as $F = L + W \times H + (1 - W) \times C$

This procedure reconstructs the original dataset where the slope is above 3° and near the bottom of valleys. For areas of slope below 3°, an empirical quadratic weight function is employed, such that the morphologically filtered component is assigned gradually higher weight as the slope approaches 0.

Table 1: relative shortening of lengths of filtered contours

level	raw length	lowpass	our filter
11	321	27.72%	13.71%
12	514	27.04%	22.76%
13	722	33.38%	17.73%
14	1106	36.44%	19.80%
15	1901	35.09%	15.31%
16	2404	29.62%	16.31%
17	2494	37.05%	17.76%
18	2279	36.33%	16.50%

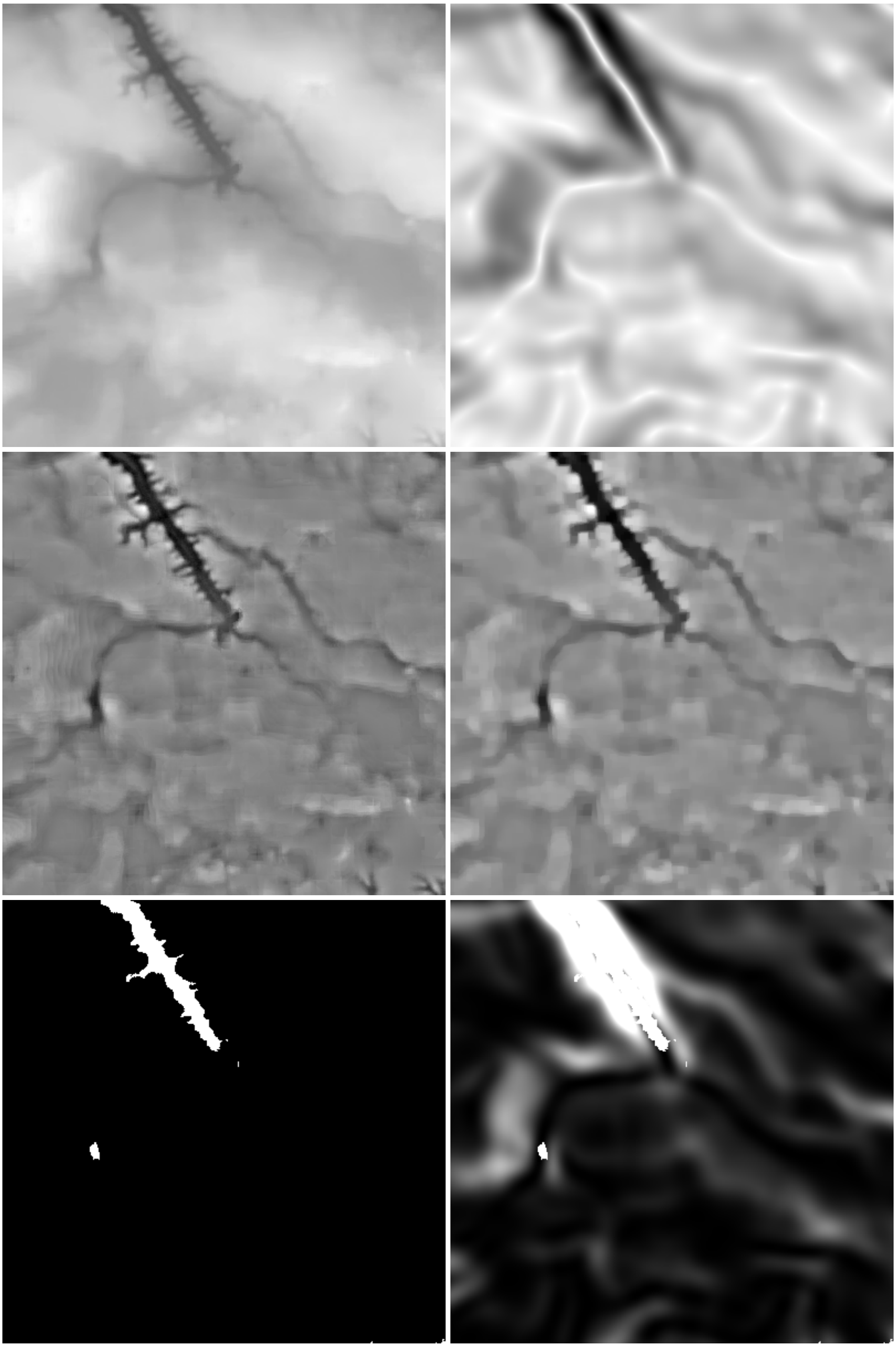

Figure 2: Left column: top: original DTM; centre: highpass filtered DTM; bottom: river valley detected by bottom hat filter. Right column: top: slope of lowpass filtered DTM; centre: morphological filtering of the highpass component; bottom: weights used for original DTM versus morphologically filtered DTM

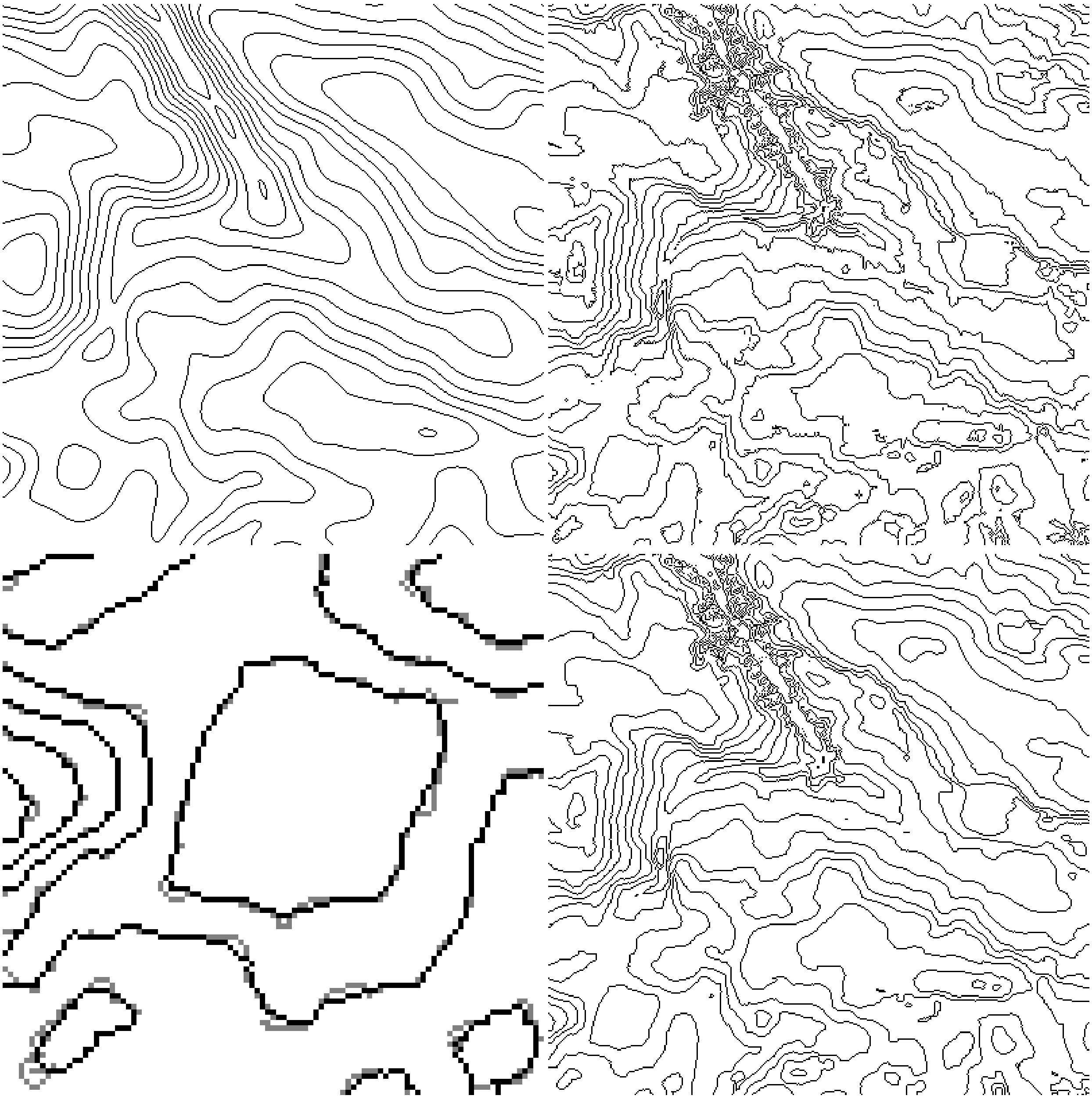

Figure 3: Contours from three different levels of DTM filtering. Top left: lowpass filtered; top right: raw; bottom left: detail—raw in gray, our method in black; bottom right: our method. See also figure 4

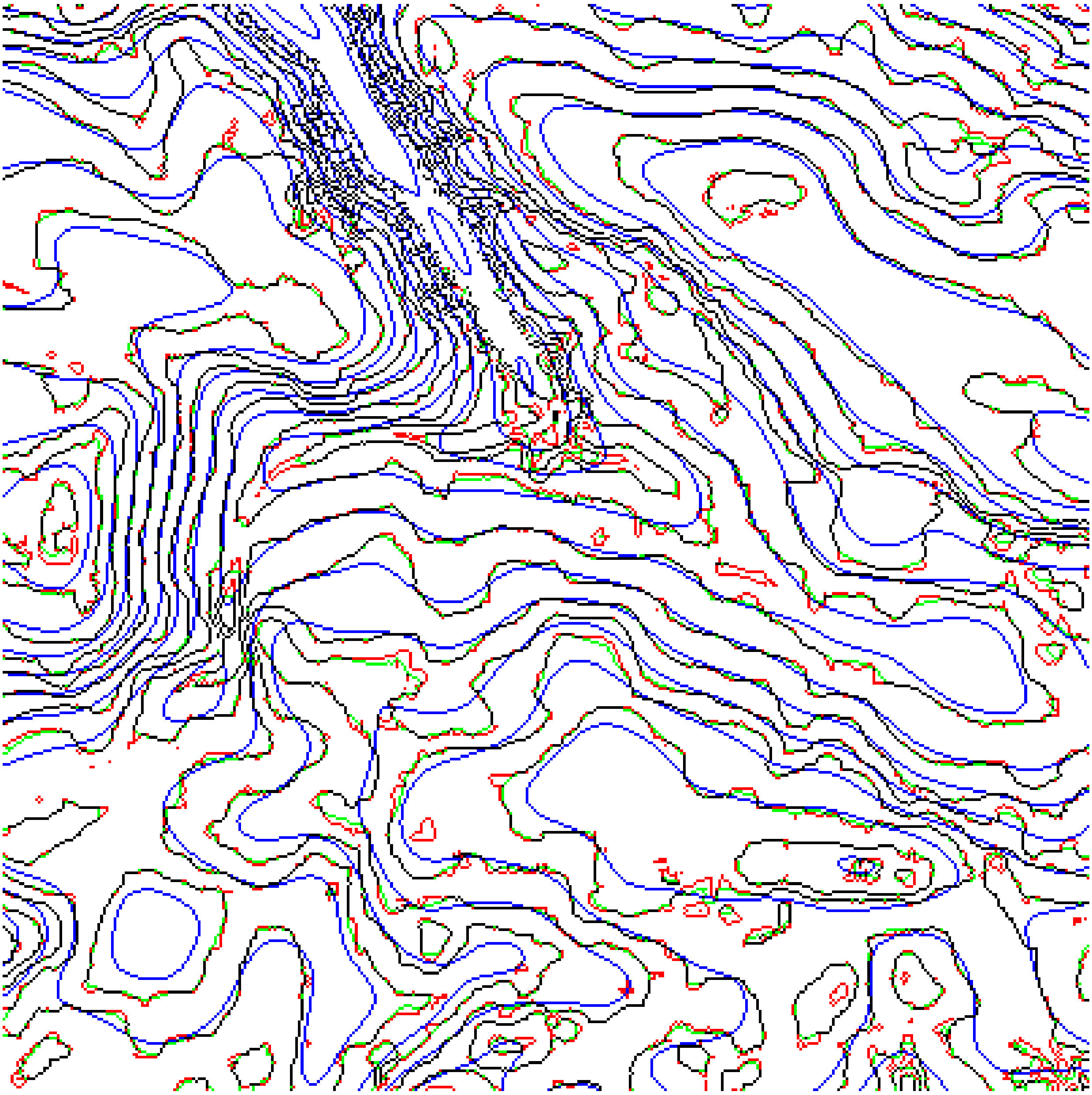

Figure 4: Combined contours red: raw, blue: lowpass, green: our method

3 Results and discussion

The results presented below are based on a 10 m resolution gridded DTM. The subset shown in the figures is 401 by 401 points, i.e. 4 km by 4 km in the field. The initial lowpass filtering was done using a standard 2D gaussian filter with a standard deviation of 10 grid units, which amounts to a full width at half maximum of approximately 230 m. The structuring element for the bottom-hat based valley detector was a radius 15 disk shape. The structuring element for the LOCO filtering was a radius 3 disk shape.

Selected steps of the algorithm is shown in figure 2. The valley detector is seen to be quite efficient (although it must be tuned to the valley widths of interest). The plain high pass part and the morphologically filtered part needs close attention to reveal any differences. The small differences do, however, result in a quite dramatic effect when generating contours, as shown in figure 3. This is especially clear in the enlarged detail and in the combined contour set in figure 4. Note, however, that the contours shown here were generated using a rather simplistic approach. For final mapping a more detailed algorithm is used, including a generalization step based on the algorithm by Douglas and Peucker (1973). One of the advantages of the filter presented here, is that it allows us to use a less aggressive amount of generalization, while still preserving a compact and easier-to-interpret representation.

In order to quantify the effects of the filtering, the relative lengths of some selected contours are shown in table 1. It is seen that in this metric, our method is significantly less intrusive than the plain lowpass filtering.

4 Conclusion

We have derived a filtering procedure for DTM based height contours. The initial results, presented here, are quite promising. At its current level, however, the procedure is in no way a replacement for traditional cartographic craftmanship.

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