CO-443

GENERALIZING DIGITAL ELEVATION MODELS FOR SMALL SCALE HYPSOMETRIC TINTING

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Abstract: This paper describes an automatic procedure for deriving worldwide small-scale hypsometric layers from digital elevation models. A custom generalisation procedure was developed to remove unnecessary details from the elevation model: (1) the elevation data are filtered with lower and upper quartile filters, (2) a drainage network is extracted from the elevation data, (3) the drainage network is simplified with a custom algorithm that removes the shortest streams, (4) a series of buffers are applied to the generalised drainage network, and (5) the buffered drainage network is used to combine the grids filtered with upper and lower quartile filters. After these five steps, the hypsometric layers are derived with a contouring algorithm. The proposed procedure follows the main guidelines for cartographic relief generalisation and the graphical quality of the resulting hypsometric layers is comparable to manually generalized layers.

BACKGROUND AND OBJECTIVES

Hypsometric tinting is a popular method for representing relief on maps, commonly used at small map scales. In combination with relief shading, it can efficiently portray a three-dimensional terrain surface and therefore is considered as a most appropriate relief representation at strongly reduced scales (Imhof 1982). Many software applications can nowadays easily compute elevation levels or continuous colour gradients from digital elevation models (Brewer, 2005; Heuberger and Kritz, 2006; Patterson, 1997; Schmalz and Kowanda, 2007). However such visualisation derived from high-resolution digital elevation data, if reduced to the small map scale, contains many intricate terrain details that inhibit perception of the main landforms. Traditionally, when hypsometric layers were produced manually, generalisation was applied to the contour lines delimiting hypsometric tints and followed well defined guidelines formulated by e.g. Horn (1945), Pannekoek (1962), and Imhof (1982). Nowadays the software available to production cartographers does not adequately address this topic. 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. More sophisticated methods seldom meet specific cartographic requirements. Therefore nowadays, when highly detailed elevation data are easily available for almost the entire Earth, conducting research to automate the removal of unwanted details from terrain is highly relevant.

This paper describes an automatic procedure for generalizing terrain models and deriving hypsometric layers at a worldwide scale. The goal of our generalization attempt was to produce hypsometric layers automatically at scale 1:15 000 000, which is a map scale commonly used for overview maps of continents and regions in geographical atlases. An important aim was to appropriately generalise the elevation data: the automatic procedure should appropriately reduce the level of details and has to follow the guidelines for terrain generalisation developed for traditional manual cartography.

Traditional generalization of hypsometric layers

Hypsometric tints have been used by mapmakers for over two hundred years (Wallis and Robinson, 1987). The guidelines for traditional terrain generalisation were formulated by Horn (1945), Pannekoek (1962), and Imhof (1982). These guidelines address generalisation of contour lines which were also applied to the generalisation of hypsometric tinting. The most important points can be listed as follows:

- Main landforms should be accentuated, while secondary features should be eliminated.
- Characteristic shapes of the terrain should be retained; relief forms should not be rounded.
- Each landform should be treated as a whole. For example, a valley should be either retained or completely removed, but not shortened.
- Positive forms (i.e. mountain ridges) have priority over negatives forms (i.e. valleys); all positive forms should be retained; the smaller ones can be aggregated if they belong to the same bigger form,
- Small negative forms (i.e. side valleys) should be removed.
- Main valleys can often only be depicted if they are broadened at the expense of neighbouring smaller forms.

DEM generalization

Various methods generalizing digital elevation models have been proposed in the literature, they were reviewed by e.g. by Gesch (1999), McMaster and Monmonier (1989) and Weibel (1992). The simplest procedure downsamples the DEM by increasing the raster cell size using the nearest neighbour or other interpolation techniques. Global filtering is also a simple method widely available in GIS and image processing software. It computes a statistic measure for each output raster cell, such as the mean, median, minimum, or maximum value of neighbouring data values. These methods are however not appropriate for generalizing hypsometric layers. Terrain surface tend to be over smoothed: mountains are lowered down and small mountain peaks disappear, instead of being retained and aggregated; valleys, which should be either completely removed or retained as a whole, are shortened or split into small depression areas.

Surprisingly few studies exist about DEM generalisation for producing cartographic relief representations at small-scales, e.g. Patterson (2001a,b), Böhm (2000), Prechtel (2000), Leonowicz et al. (2010). Such advanced methods are indeed necessary to successfully generalise digital elevation models according to cartographic requirements. Generalisation aspect within the automatic generation of hypsometric tinting was only recently addressed by Leonowicz et al. (2009).

APPROACH AND METHODS

The generalization method applied in this study uses the following operations performed on a digital elevation model, which are illustrated on Figure 1:

1. Digital elevation data (Fig. 1A) are filtered with an upper quartile filter. The upper quartile filter assigns to each raster cell the 75 percentile of its neighbouring values, i.e. the n neighbouring cells are ordered by increasing elevation and the elevation at position ¾ × n is assigned to the cell. The upper quartile filter preserves elevated areas (ridgelines) and aggregates isolated small hills and mountain peaks, which is consistent with the guidelines for manual generalisation (Fig. 1B).

2. Digital elevation data are filtered with a lower quartile filter. This filter assigns the 25 percentile of the neighbouring values to each raster cell. It preserves elevation in valley bottoms, preserves them from being dissected in unconnected depressions and retains mountain passes (Fig. 1C).

3. A raster drainage network is extracted from the elevation model by computing the hydrological accumulation flow using the D8 algorithm (O'Callaghan and Mark 1984). The algorithm computes a drainage network by simulating the flow of water on the DEM. First a flow direction is defined for each cell, which is the direction of the steepest path flowing into one of the eight nearest neighbours. The value of accumulation flow is then calculated for each cell as the number of cells draining into this cell (Wilson and Gallant, 2000). Cells are qualified to be part of the drainage network by applying a threshold to the accumulation flow (Fig 1D).

4. The drainage network is simplified according to the desired level of generalisation with a custom algorithm (Leonowicz et al. 2009). The algorithm takes a raster grid with the accumulation flow as input. Starting at each raster cell, the algorithm creates an upstream path by following cells that have smaller accumulation values than the current cell. The algorithm follows the path with the smallest absolute difference to identify the longest stream passing through the current cell. If the path is longer then a predefined threshold, it is stored in the output raster.

5. A series of thin buffers are applied to the generalised drainage network (Fig 1E). These buffers are used in the next processing step as a weight to combine elevation models filtered with upper and lower quartile filters. When a series of narrow buffers with gradually decreasing value is applied, a smooth transition can be generated for areas where the lower and the upper quartile filter meet. Hence, the resulting valleys are widened and a gradient transition between valley bottoms and the surrounding areas is created.

6. The buffered drainage network is used as weight to combine the two grids filtered with upper and lower quartile filters. Hypsometric layers calculated from the combined model are shown on Fig 1F.

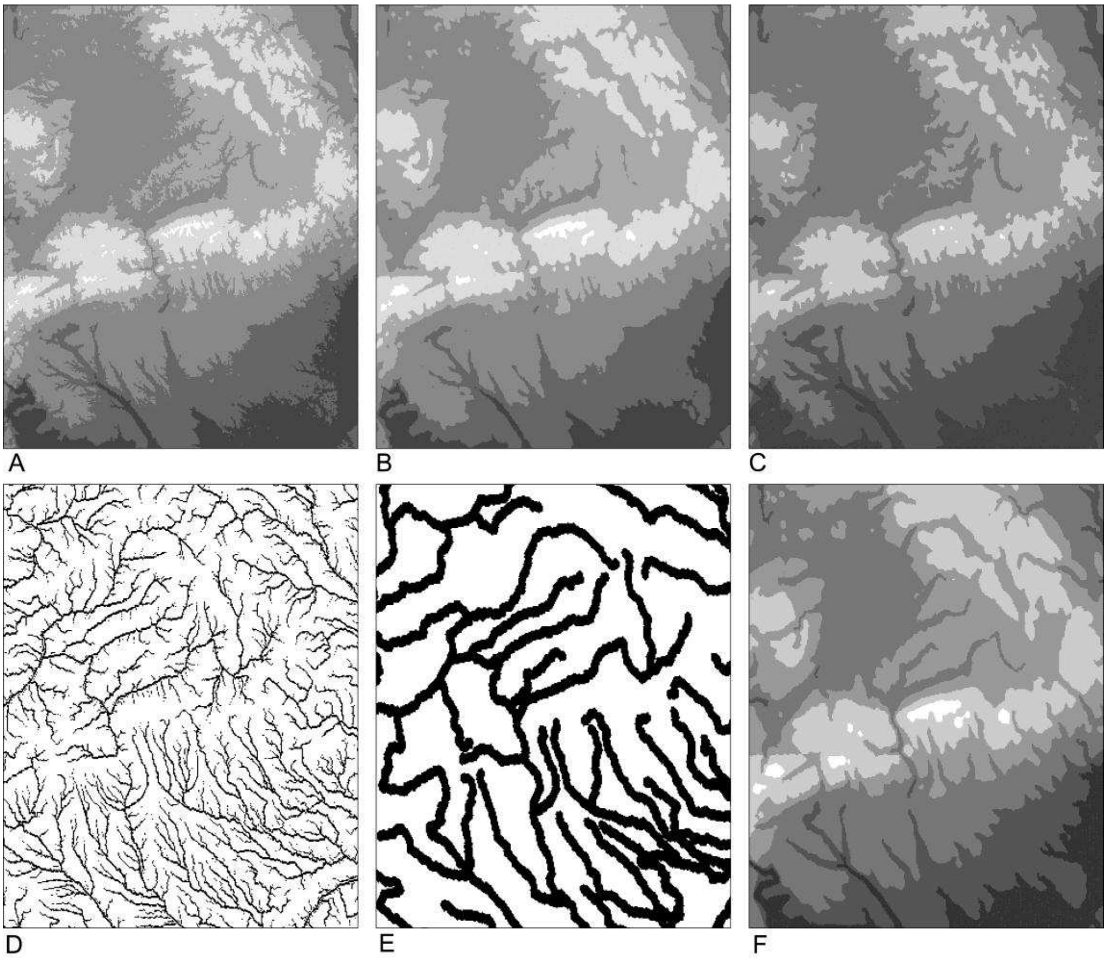


Figure 1. Generalization method. A: ungeneralized GTOPO30, B: upper quartile filter, C: lower quartile filter, D: drainage network, E: generalized and buffered drainage network, F: combination of lower and upper quartile filter.

The SRTM (Shuttle Radar Topography Mission) elevation model was used as source data. SRTM covers almost 80% of the earth's surface and provides elevation data at a resolution of 3 arc seconds (approximately 90 meters at the equator). For computational efficiency, we used SRTM30 , a simplified version at 30 arc seconds. This resolution of approximately 1 kilometre along the equator was considered sufficient for hypsometric tinting at a scale of 1:15 million. Elevation values for areas of high northern latitudes (above 60 degree), which are not covered by the SRTM model, were inserted from GTOPO30 (Global 30 Arc Second Elevation Data Set) .

Instead of calculating accumulation flow from original SRTM data (step 3 in the procedure described in the previous section), we used a freely available data set HydroSHEDS (Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales) developed by the Conservation Science Program of World Wildlife Fund . This data set provides global accumulation flow data calculated from hydrologically conditioned SRTM data, which assure that accumulation flow is not being affected by spurious pits and depressions often present in digital elevation models (Lehner et al., 2006). Only for areas of high northern latitudes which are not covered by SRTM data, accumulation flow was extracted from GTOPO30 data. Most of the processing steps were carried out with standard GIS software. The quartile filters and the custom algorithm for generalising a drainage network were implemented in a Java application. A diagram on Figure 2 summarises the whole procedure.

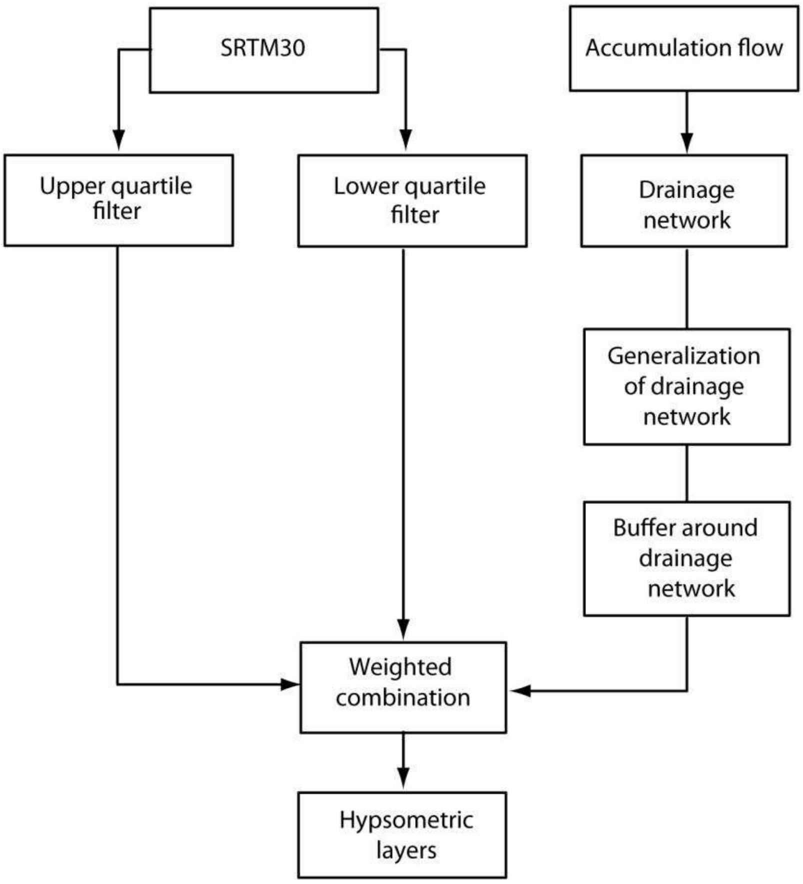
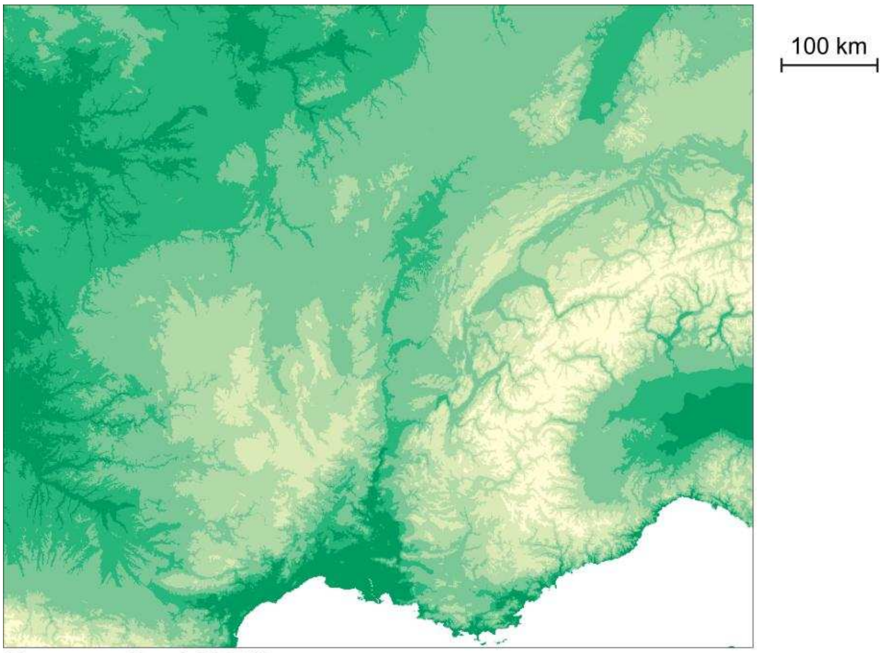


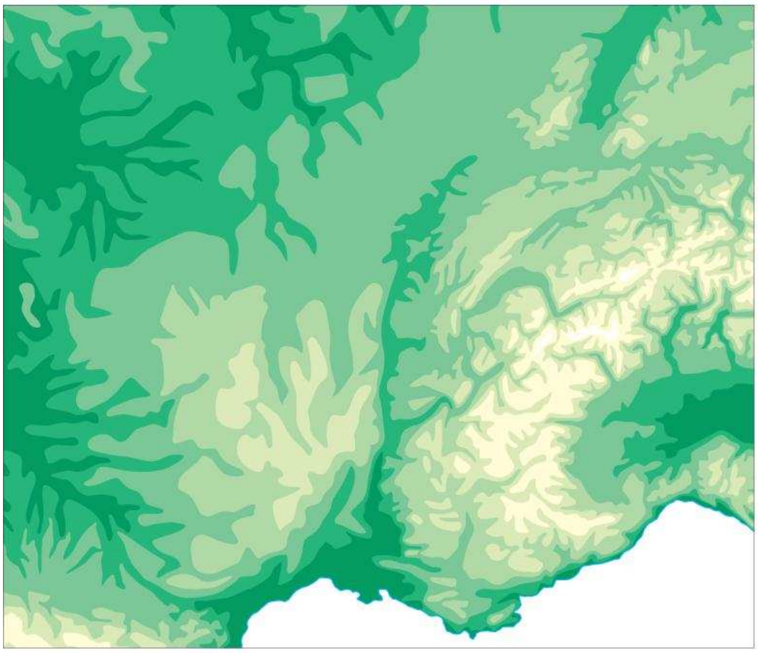
Figure 2. Processing steps leading to generalized hypsometric layers.

RESULTS

The procedure developed in our project allowed for automatically deriving worldwide hypsometric layers at a scale of 1:15 million. As a reference to evaluate and optimize the method we used manually developed hypsometric layers originating from the Swiss World Atlas (Spiess, 2008). Figure 3 showing an excerpt of West European relief, compares the ungeneralized hypsometric layers, the manual reference data and the result of our generalization procedure.



Ungeneralized SRTM



Manual generalization

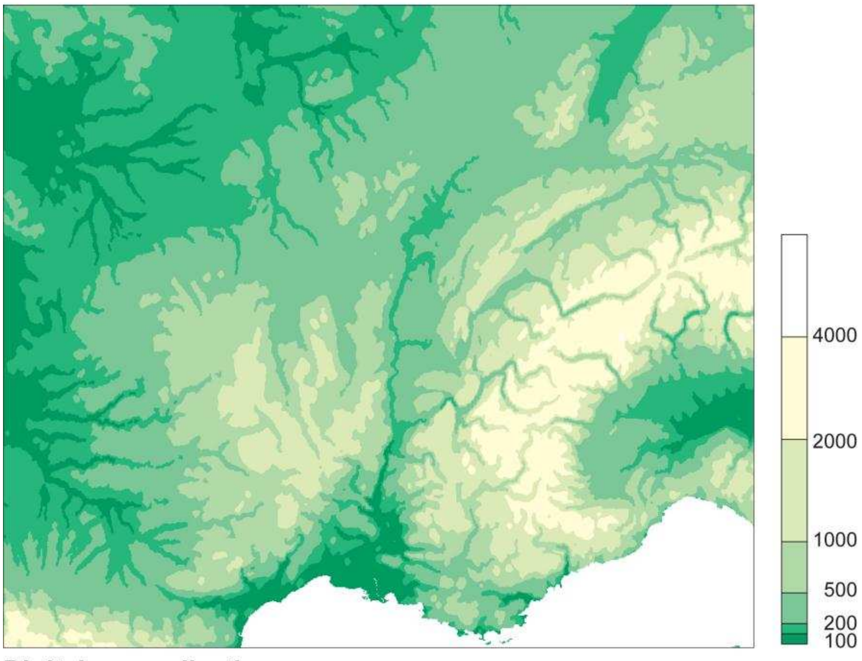


Figure 3. Hypsometric layers derived from SRTM data compared to the manually developed layers (elevation in meters above see level).

Comparison of these examples shows that our generalisation method removes many unnecessary details present in the raw elevation data and allows achieving the desired level of generalisation. The graphical quality is comparable to hypsometric layers produced in the traditional way. The proposed method follows the main guidelines for cartographic relief generalisation: mountain ridges are aggregated and most of them are not removed during filtering; small valleys are removed while the bigger ones are retained, but not shortened. Moreover the hypsometric layers derived with the automatic procedure are based on a uniform data source, which is up to date and geometrically accurate.

However after deriving the hypsometric layers, limited manual postprocessing is required to correct a few artefacts:

- at the upper end of narrow valleys, the unconnected contours become detached polygons forming narrow depressions;
- large valleys are locally too narrow and therefore not as visually salient as required by their hydrological importance;
- isolines in narrow valleys sometimes touch each other;
- in some areas, very small mountain peaks disappear.

CONCLUSIONS

Various types of relief visualisations can be easily derived from global elevation data, which are widely available nowadays. Elevation models are especially useful for mapping at small scales as they provide uniform data for the entire globe. Automatic visualisations, however, not always meet the quality standards of traditional cartography. In particular small-scale relief mapping is a challenging task. Specialized methods are necessary to produce satisfactory results.

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