Preprocessing of Digital Elevation Models – derived from Laser Scanning and Radar Interferometry – for Terrain Analysis in Geosciences

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1. Introduction

The application and availability of digital elevation models (DEM) and digital terrain models (DTM) is increasing since many years. Whereas in former years DTM were often derived from contour lines of topographic maps and stereoscopic measurements form aerial images nowadays small scale DEM are often derived form radar interferometry such as the well known DEM from the Shuttle Radar Topography Mission (SRTM) (http://www.jpl.nasa.gov/srtm/) which covers 80% of the earth's landmass (Guth 2006). Large scale DTM are based increasingly on laser scanning which allows the interpolation of high resolution DTM with cell sizes < 1m.

However you can observe that the terms DEM and DTM are often used inaccurately. Another aspect is that for terrain analysis in geosciences often the DEM of other surfaces than the terrain (earth's surface) is used. For example: using SRTM DEM in flat regions for calculating drainage basins will produce watersheds on forest canopies because SRTM DEM is (approximately) a DEM of the vegetation surface.

This article aims – beside clarifying terms as DEM and DTM - on presenting approaches of preprocessing DEM/DTM to enable advanced terrain analysis in geoscience. The emphasis is on reducing elevation of forest canopies in radar based DEM (SRTM) and identifying and eliminating man-made terrain features in laser based DTM.

2. Definition of DEM, DTM and Earth's Surface

Going back to the suggestions of Hofmann (1986) and corresponding to the compendium Maune (2007) gave in his “DEM Manual” the following definitions may help to clarify the terms DEM/DTM:

Definition of digital elevation model (DEM): Digitally stored xyz triples of a surface. It is necessary to always mention *which surface* is represented by the DEM (for example DEM of the vegetation surface, DEM of the ground water surface).

Definition of digital terrain model (DTM): Digitally stored xyz triples of the *earth's surface.* Thus a DTM is simply one special case of the common term DEM: a DTM is a DEM of the earth's surface.

Therefore it is obvious that terrain analysis which calculates geomophometry or classifies terrain features should use a *DTM* as data base.

Nowadays most of the DEM/DTM are provided as raster (square grid) data. As the original measurements (xyz triples) in most cases are irregularly spaced, various interpolation techniques (which impact the quality) are used to create the grid data.

Definition of earth's surface: The earth's surface is commonly defined as the boundary layer between the solid crust and the atmosphere or water bodies.

You have to distinguish between different types of the earth's surface: *natural surface and man-made surface*. (A third type the *quasi natural surface,* relief formed by natural processes caused by human activity such as soil erosion, is not considered in this paper.)

3. Consequences of the Definitions for Terrain Analysis

From the above definitions a number of problems arise for terrain analysis:

a) It is not suitable to use DEM which represent the vegetation surface when morphometric parameters of the earth's surface should be calculated. In chapter 6 is presented an approach to convert SRTM DEM into a DTM.

b) Depending on the objective of the terrain analysis you have furthermore to distinguish between the natural surface and the man-made surface. Whereas contour lines in topographic maps show the natural surface (man-made terrain forms are omitted) especially laser based DTM always represent the man-made surface in all details. For modelling the surface runoff (e.g. for soil erosion or phosphate washout) the man-made terrain features are very important. For supporting digital soil mapping however man-made features cause problems. An example: the crossing of river flood plains by embankment dams has consequences for calculating soil relevant complex terrain parameters based on overland flow and stream lines, such as wetness indexes, relative elevation above stream lines or erosion/accumulation indexes.

c) Another problem is the identification and the handling of water bodies in DTM. Whereas SRTM provides water bodies as very useful information, DTM from laser scanning normally do not have this information. Without this information modelling hydrological parameters, such as flow accumulation or stream lines, is problematic. Solutions for these problems are still under development and therefore not presented in this paper.

4. Noise Reduction

A first step of preprocessing DEM/DTM is noise reduction. Both, laser and radar based DEM/DTM imply a certain noise. This noise (variation of elevation in local neighbourhood) does not contain any information for terrain analysis. In the case of radar based DEM the noise is immanent and termed 'thermal noise'. The noise of DTM derived from laser scanning depends on the roughness of the different measured surfaces (forest floors, fields, meadows, etc.).

To reduce or eliminate the noise advanced filter techniques are required which identify and eliminate the noise while saving the terrain information hidden under the noise. We used a modified and extended version of a multi directional noise filter (Lee 1980) to achieve this objective. In a first step the implemented filter creates bands of cells in all directions (e.g. with a length of 9 and a width of 3 cells) around every grid cell. Then the standard deviation (of elevation) is calculated for every band (direction). The new value (elevation without noise) for the grid cell is calculated from the mean elevation of the band with the lowest standard deviation and the original elevation of the cell. The weighting between mean and original value is controlled by the noise level and a user given noise reduction parameter (the more noise the more the weighting tends to the mean - and vise versa). To avoid bulges on slopes (parallel to contour lines) optionally the above calculations can be executed on slope gradient instead of elevation.

The results of the noise reduction are presented in fig. 1B, 2b and 3b.

5. Identifying and Eliminating Man-made Terrain Features in DTM Derived from Laser Scanning

DTM based on laser scanning (Liu 2008) are highly accurate models of the earth's surface. Buildings as well as trees are normally already filtered and provided as additional DEM of buildings and vegetation surface. However laser based DTM also show all man-made modifications of the earth's surface. As already mentioned (3.) for modelling relief controlled processes under natural conditions, it is necessary to identify the man-made terrain features and to "reconstruct" the natural surface. (Surely this attempt will find its limits within urban areas.)

As no high resolution spatial information about these terrain features is available, the developed filter to identify man-made features works without any additional data (e.g. about traffic buildings). Certainly manual control and correction of the result is definitely necessary. The functionality of the filter shall be briefly explained on the example of embankment - the most wide-spread man-made terrain feature outside of settlements:

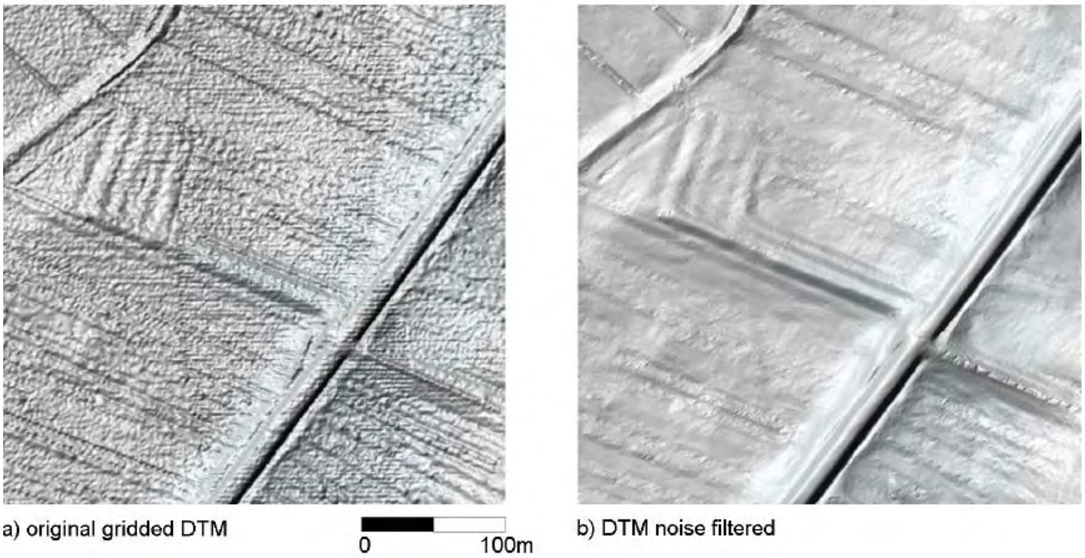
The filter is based on a resampling module to generalise grid data. The developed algorithm calculates the values for the generalised grid cells under consideration of local maxima and minima within a given radius. For the maxima and minima the "trend" is calculated:. e.g. if the surface is flat within the radius but a pit exists there is a high trend for a local minimum. If pits and bumps are canceling each other the trend tends to "0". Thus the resampling module is able to conserve maxima and minima - or used in an inverse function to eliminate both which creates a very smooth surface.

The embankments normally show a much sharper shape than natural terrain features. Furthermore the dam crests mark local maxima of the elevation. These facts are utilised by the filter using the resampling approach described above. The difference of the original DTM and the version where maxima and minima are eliminated, contains nearly all man-made features (fig. 2a,c). Additional algorithms such as skeletonising crest lines and modified relief intensity are used to enhance the result. After manual controling the identified terrain features are eliminated and interpolated (fig. 2b) using standard gap filling module of free GIS SAGA (http://www.saga-gis.org/).

6. Estimating Elevation of Forest Canopies in DEM Derived from Radar Interferometry

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement number 211578. The processed data for EU countries will be distributed on a ftp server of the European Commission's Joint Research Centre. The mentioned grant agreement number stands for the e-SOTER project, the regional pilot platform as EU contribution to a Global Soil Observing System.

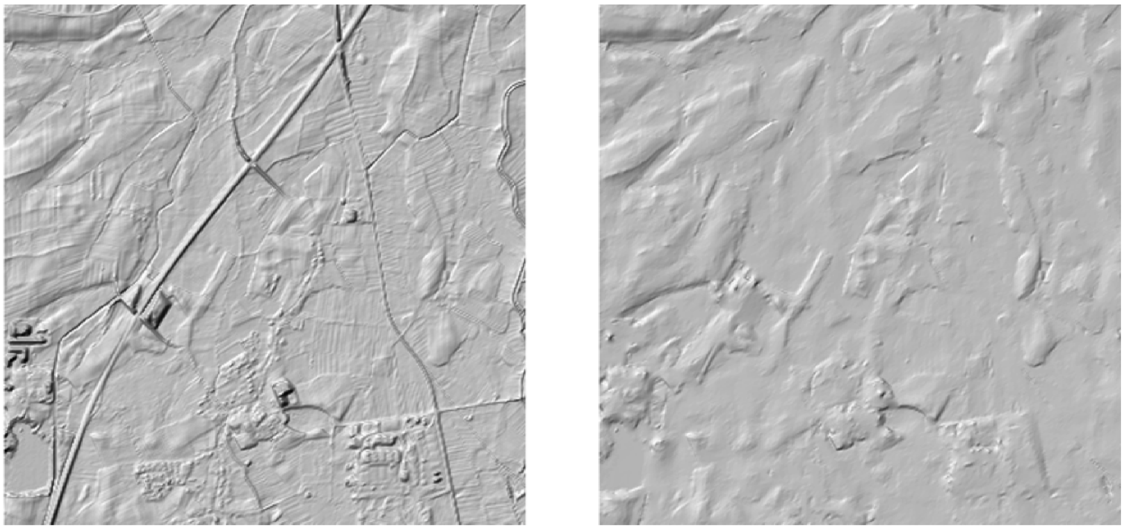
The spatial resolution of elevation measurements by radar signals and optical remote sensors is normally much lesser than that recorded by laser scanners. DEM derived from radar interferometry (e.g. SRTM) as well as from satellite images (e.g. ASTER) represent the earth's surface only in areas with low or sparse vegetation and low building densities. Particularly forest canopies cause problems for terrain analysis.



a) original gridded DTM

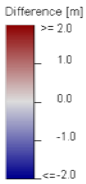
b) DTM noise filtered

Figure 1. Noise Filtering for a DTM from Laser Scanning (1m grid cell size)



a) DTM including man-made Terrain Features

b) DTM man-made Terrain Features filtered



0 2km

Rem.:
DTM with 10m cell size (derived from laser scanning)
DTM preprocessed for terrain analysis to support soil mapping

DTM b) additionally noise filtered

DTM data kindly provided by LGRB Baden-Württemberg

c) man-made Terrain Features (Difference a - b)

Figure 2. Identifying and Eliminating man-made Terrain Features

The objective of the presented approach is the conversion of a DEM of the vegetation surface into a DTM. Calculating the elevation of forest canopies from a DEM representing the vegetation surface without having any information about tree/forest heights certainly is a "mission impossible". But the estimation of forest elevation - to a certain degree - is possible.

In contrast to the identification of man-made terrain features (see 5.) the estimation of forest elevation needs information about the *location* (not height) of forests. In Europe this information is available for large areas. For the processing of SRTM DEM we used the Pan-European Forest/Non-Forest Map (FMAP) 2000 version 1.4 (Pekkarinen 2009) for forest locations (Rem.: CORINE landcover data turned out as too coarse for SRTM DEM with a cell size of 3 arc sec. (approx. 75 to 90m).

The estimation of forest elevation is only possible at the forest borders. The flatter the terrain the better is the estimation. At first the forest borders - including a fringe of 3 grid cells inside and outside the forests - are located. The fringe is necessary because the 90m cell size of the DEM imply generalisation of the forest borders. For the cells of the "inside forest fringe" the positive relief intensity (a) is calculated. The "positive relief intensity" is defined as the altitude of a given cell minus the lowest of the lower neighbour cells within a given radius (here: 3 cells). In our case only cells of the "outside fringe" are considered as lower neighbour cells. Next the "negative relief intensity" (similar to "positive" but only higher cells are considered) is calculated for cells located only in the inside fringe. This second value (b) is subtracted from the positive relief intensity (a). The result is the estimated forest elevation. The subtraction a - b may result in "0" which means that the relief intensity inside the forest fringe is greater than the potential forest height. In this case it is impossible to estimate forest elevation.

The next step is to interpolate the forest elevation from the forest borders into the woods. This is achieved by an approach which creates fringes of 1 cell width from the borders into the centers of the forest bodies. With the increasing fringe number the radius for calculating mean values (of forest elevation) also increases (including a inverse distance weighting).

The last step is to subtract the estimated forest elevation from the DEM to get the DTM.

This is only a brief description of the approach which implies some more details than described. Moreover there are still some problems to solve (e.g. with small clearings and big forest bodies).

Figure 3 presents the result of the attempt to convert SRTM DEM into a DTM. The improvement of the data is also demonstrated by the change of the summary statistics of the deviation of a reference DTM from the two SRTM versions: Subtracting the reference DTM from the SRTM DEM (fig 3d) only for forest cells indicated by FMAP2000 results in an artithmetic mean of 7.98 meters with a standard deviation of 6.54 meters. After the procedure to create a DTM (fig 3e) the subtractions arithmetic mean is reduced to 1.91 meters with a remaining standard deviation of 4.44 meters.

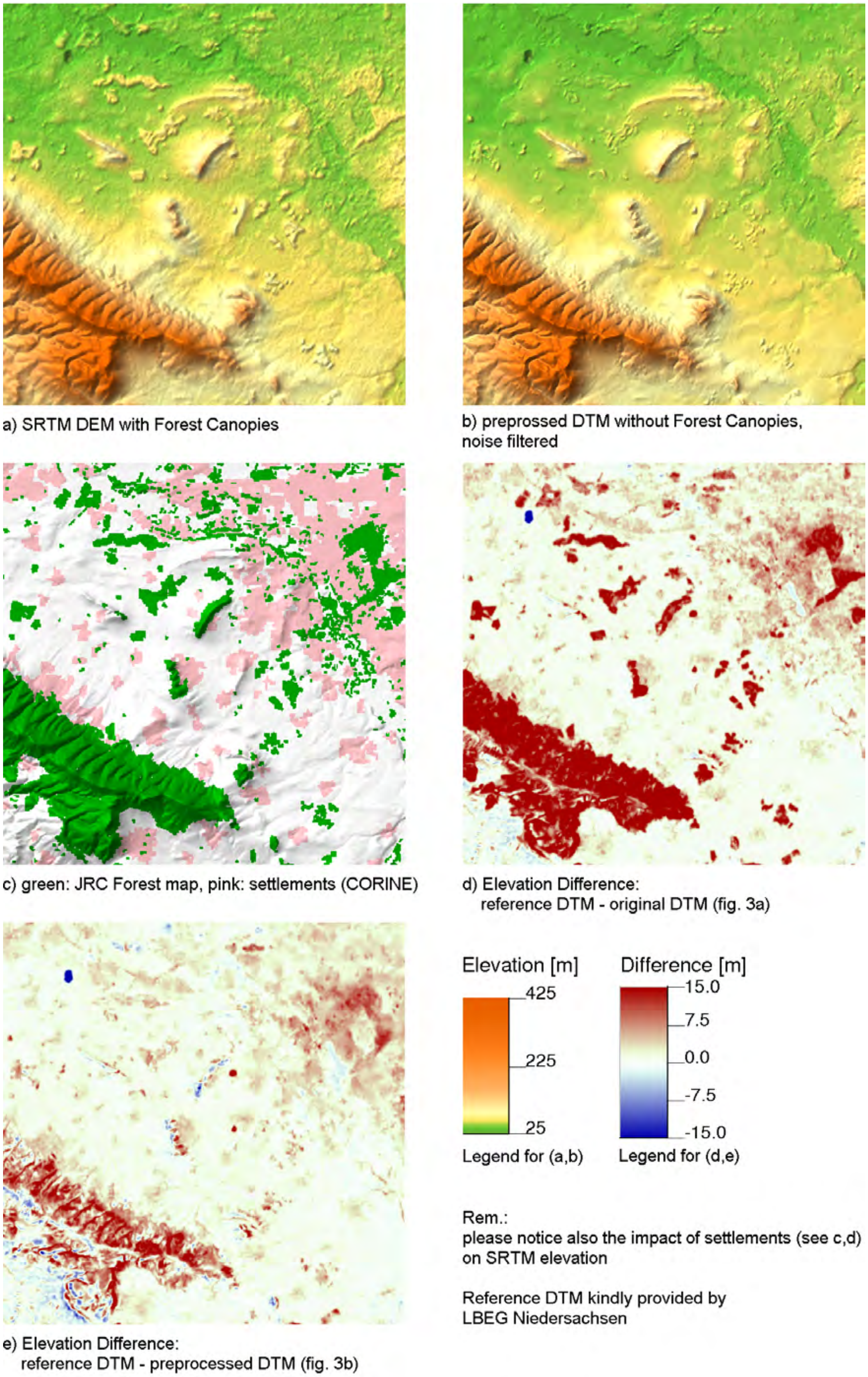


Figure 3. Converting SRTM DEM into a DTM

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