DEM FROM VARIOUS DATA SOURCES AND GEOMORPHIC DETAILS ENHANCEMENT

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Abstract: *We are demonstrating well-known high importance of the high quality digital elevation model (DEM) for detailed and more effective mapping. The first attempt was to develop a technique for integrating and improving existent DEMs to new one, and the second to visualise the Earth's surface with enhancements of some geomorphic attributes of surface. We are introducing a special fusion and iterative technique that produces a high quality DEM from various datasets that simultaneously removes possible gross errors. The method bases on the weighted sum of data sources with geomorphic enhancement. The most techniques for the Earth's surface presentation from DEMs hide some details that are product of worse chosen interpolation method or of some possible gross errors. Unfortunately, those methods necessarily hide some geomorphic details, too. We are demonstrating some untypical cartographical techniques for enhancement of geomorphic details like bipolar differentiation and enhancing of the edges that can be integrate into "classical" techniques (analytical hill shading, contouring and hypsometrical visualisations) are. The proposed methods are also result of our efforts finding different visualisations for better understanding of the geomorphic characteristics of landform and to get impact into quality of DEMs regarding using different interpolation and production methods. Combination of proposed methods with classical ones can improve multi-scale effects for easier reading of the maps.*

BACKGROUND

Visualisation of the Earth's surface shape is a basis for production of the topographical and most of properties of the thematic maps. The maps are actually diminished models in appropriate scales, used for different purposes. The Earth's surface or landform presentation is mainly employed for the maps' backgrounds. Geomorphic adequate digital elevation models (DEMs) as description of Earth's surface are certainly important sources for high detailed and effective cartographical purposes. High quality DEM enables reflections about the techniques that can uncover every detail of DEM.

DEM is therefore a model that approximates the nature (Earth's surface) and its nominal ground. The models might be different concerning their purpose of use, quality of data sources or interpolation algorithms, experiences of operator, etc. DEM should be carefully produced or chosen regarding purpose of required applications. A very important aim of the final product is to find a balance between the users' demands and the capability of the developed realisation process. A high quality DEM production using well known methods could be very expensive, however users demand higher quality. It is fortunate that the quality and quantity of digital spatial data is on the increase, but those data are mostly not especially designed for DEM production. The solution proposed in here was confirmed through applied experimentation that enabled cost-effective and high quality production. We developed an innovative integrating and iterative technique that produces a high quality DEM from various datasets. The method bases on the weighted sum of data sources with geomorphic enhancement. The advantage of this technique is that the best properties of the each dataset are considered.

As in the past, DEM's quality, especially geomorphic aspect was neglected. The first reason is that the quality of DEMs was very low in general. The second is that the methods for evaluation of the quality were difficult for realize regarding processing capabilities. For cartography purposes, hypsometrical and hill shading methods were mostly employed until recently. Both of the methods are namely very robust regarding exposing of the potential gross errors, for that the most of them isn't perceivable on the maps. Nevertheless, understanding the landform geomorphology is poor by using such visualisation of DEM. Until we do not produce higher quality DEM (for example with data fusion-based methodology, described in this paper), many more attributes of landform can not be presented. In the paper, we are demonstrating our research on some DEM visualisation possibilities. We are describing some untypical cartographical techniques for enhancement of geomorphic details that can be integrate into "classical" techniques like analytical hill shading, contouring and hypsometrical visualisations are. We are also introducing integration of the different techniques of visualisation for multi-scale visualisation. The developed methods adapted especially for the mountain or hilly areas, where are many geomorphic details usually hidden.

DEM MODELLING WITH VARIOUS DATA SOURCES FUSION

DEM interpolation techniques base on spatial autocorrelation, which assumes that objects close together are more similar than objects far apart (Câmara et al., 2004; Mitas et al., 1999). There are no bad DEM interpolation algorithms (Beex, 2003). Some of them provide better results in certain circumstances than the others. The algorithms are actually the most flexible part of the whole modelling process because usually nobody has the opportunity to use the ideal data and can only choose the algorithm that is the most suitable for the selected application.

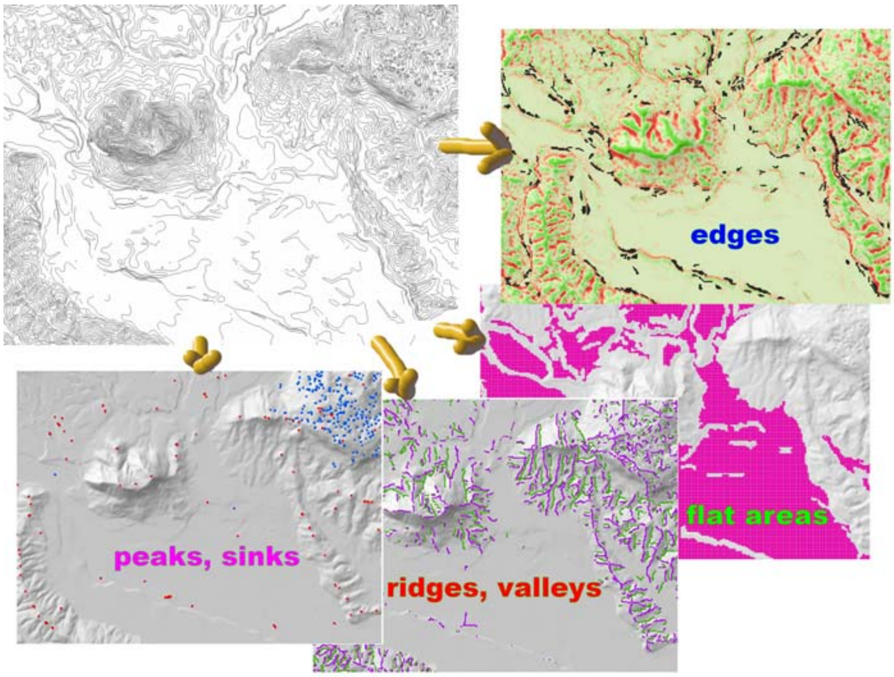

Figure 1: Enhancing of the interpolation: Identifying and producing additional characteristic surfaces used for the final interpolation

The main idea here is to produce as good as possible DEM that would be useful for most of applications, also in cartography. The data sources are contour lines, enhanced with fusion of some other data sources, like local ones, lower quality DEMs (Figure 1), geodetic network points and others. One could even use datasets without a height attribute such as lines of the hydrological network, roads, railways, standing water polygons, etc. The most important in the data fusion is known quality of particular data sources for fusion (Figure 2). The result is that the most suitable is combination of more methods of interpolation and producing additional characteristical areas, lines and points. Our hypothesis here was that with appropriate approach is possible to expose the best properties of existing data sources and integrate them into model that is overall better than particular data sources. With such approach, low in combination with high quality data produces high quality model!

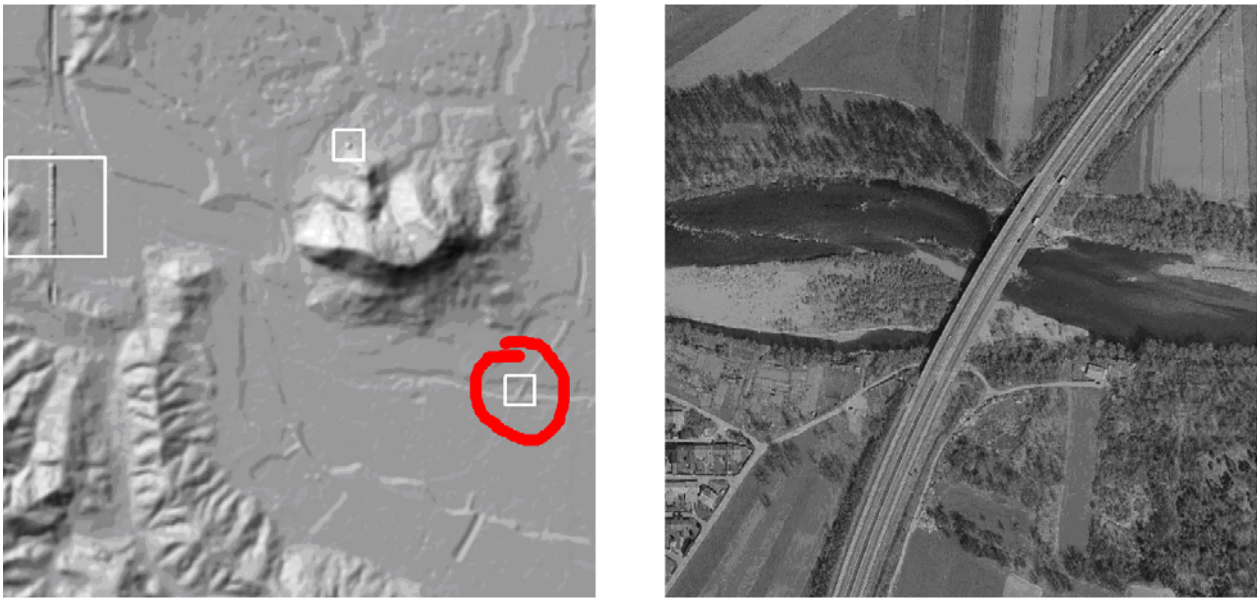

Figure 2: Potential gross errors of DEM 25: Bridge is an object on DEM, so it should not be perceivable on DEM (left DEM 25 and right orthophoto)

For the data fusion, a method of weighted sum of data with geomorphic enhancement was developed (Podobnikar 2005). With this method, DEM is modelled through averaging and fusion of individual datasets considering their quality. Grid based datasets are thus overlaid as regards the weights of particular grid cells. After overlaying, geomorphic enhancement is applied. At the beginning a unique grid size for all data sources is determined – the same as for the final DEM.

Furthermore, each particular data source had been precisely evaluated by a reference points regarding the standard test areas delineated by standard regionalised layers. The result is a predicted quality for each grid cell denoted with a random error (σ). For the sake of simplicity, we are continuing our discussion only with two data sources. Height of DEM (H_{i+j}) regarding weights w_i and w_j and variances σ_i^2 and σ_j^2 are then

$$H_{i+j} = \frac{w_i H_i + w_j H_j}{w_i + w_j} = \frac{\sigma_j^2}{\sigma_i^2 + \sigma_j^2} H_i + \frac{\sigma_i^2}{\sigma_i^2 + \sigma_j^2} H_j$$

Weighted sums of pairs of surfaces (i+j)k are calculated iteratively by adding independent datasets to previous ones (Figure 3). The random error of the computed DEM (σ_{i+j}) incrementally decreases with every iteration. For two datasets it is calculated with the differentiation of heights as (Heuvelink 1998, Burrough and McDonnell 1998)

$$\sigma_{i+j} = \sqrt{\left(\frac{\sigma_j^2}{\sigma_i^2 + \sigma_j^2}\right)^2 \sigma_i^2 + \left(\frac{\sigma_i^2}{\sigma_i^2 + \sigma_j^2}\right)^2 \sigma_j^2} = \frac{\sigma_i \sigma_j}{\sqrt{\sigma_i^2 + \sigma_j^2}} = \frac{1}{\sqrt{w_i + w_j}} \leq \min\left(\sigma_i, \ \sigma_j\right)$$

The best practical solution is to start DEM modelling with data sources of the lowest quality (lowest weights) and to finish with the best datasets.

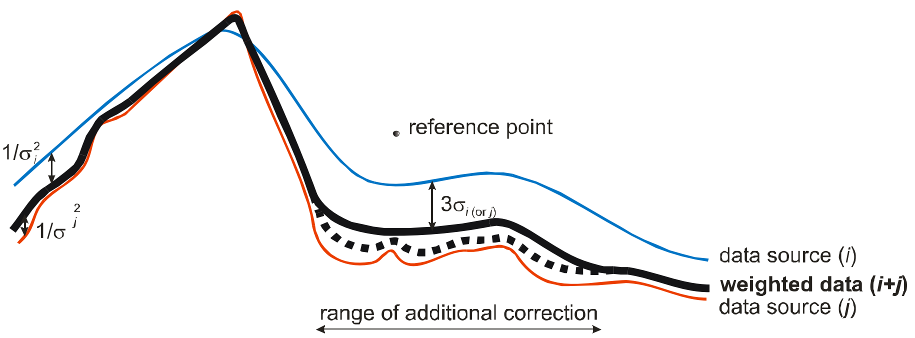

Figure 3: DEM, interpolated as weighted sum of data sources

DEM, derived iteratively with weighted sums of data is smoother than the geomorphic highest quality data source (Figure 4). This is usually a consequence of the nature of the weighted sum. Geomorphic enhancements of such a derived DEM are therefore required. Our solution was to apply the enhancements only when the DEM is already derived from all weighted data sources.

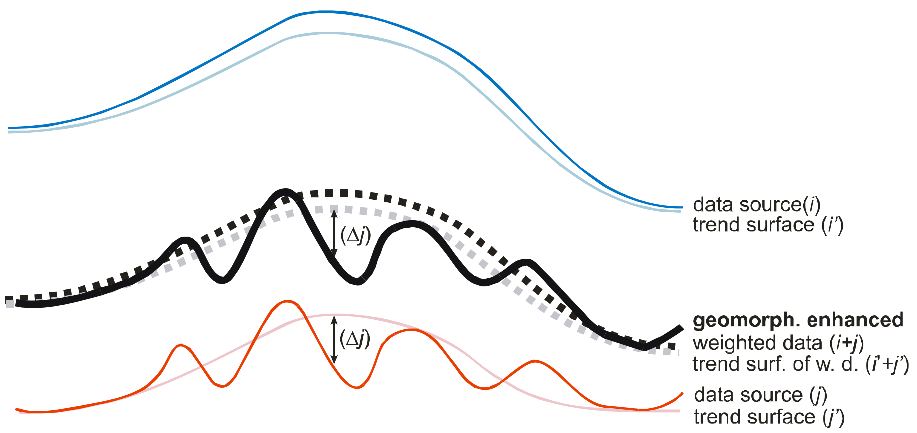

Figure 4: DEM, geomorphic enhanced from weighted sum of data sources

The main step of geomorphic enhancement is the generation of trend surfaces as low frequency functions – with generalising DEMs. Trends are produced with the same conditions for datasets of the statistically best DEM derived by weighting ($i+j$), and the DEM with appropriate geomorphology (j) (Figure 2). Relative elevations (Δj) as a high frequency part are computed from j and then added to the trend surface $i'+j'$ of the dataset $i+j$. In this way the final geomorphic enhanced DEM is produced. Statistically it is slightly worse than the weighted one ($i+j$), but geomorphic it is much better. The main problem of the described enhancement lies in finding a suitable filter to calculate the appropriate trend surfaces. The optimal solution is a compromise between geomorphic improvements and retaining statistic quality. The modelled DEM looks visually geomorphic high quality with clear and reasonable details (Figure 5). As it had been tested on many ways, the method serves also DEM with high precision and accuracy.

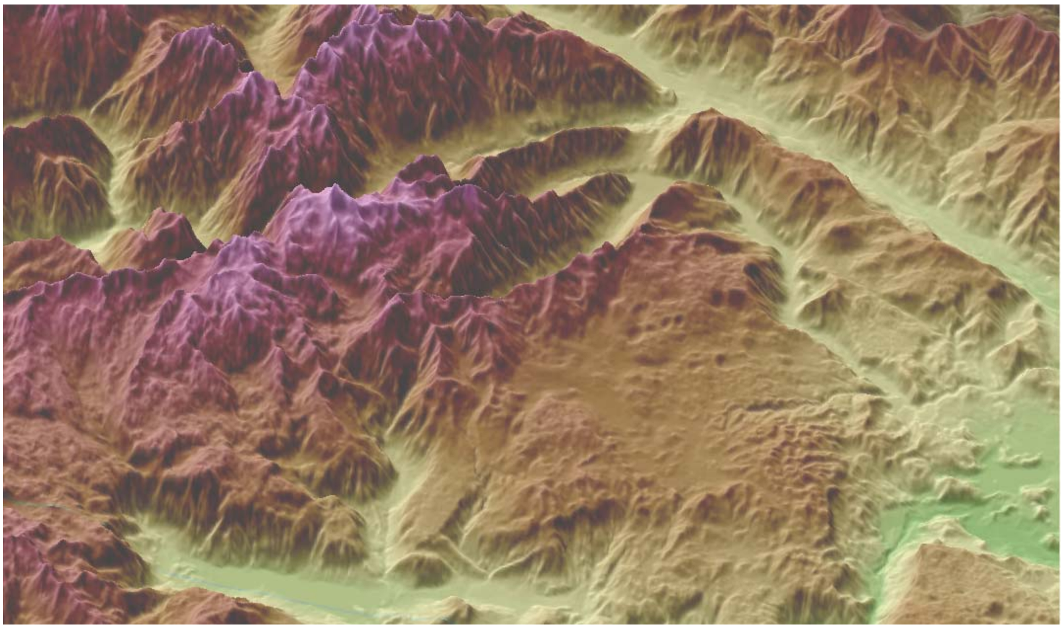

Figure 5: Perspective presentation of DEM, generated with modelling using weighted sum of data with geomorphic enhancement (area of Julian Alps)

The effective and suitable DEM modelling from variable datasets is complex, rather iterative process that cannot be achieved intuitively or via a single step. In this sense, experience is connected to the execution of stacks of tests and analyses, as well as a better understanding of the nature (parameters) of data. The quality of the DEM is evaluated for every data element (Figure 6) and the portion of every data source element used for DEM modelling is known. With purposed approach, we can have full control of the production and effectively inform the final user about the characteristics of the DEM.

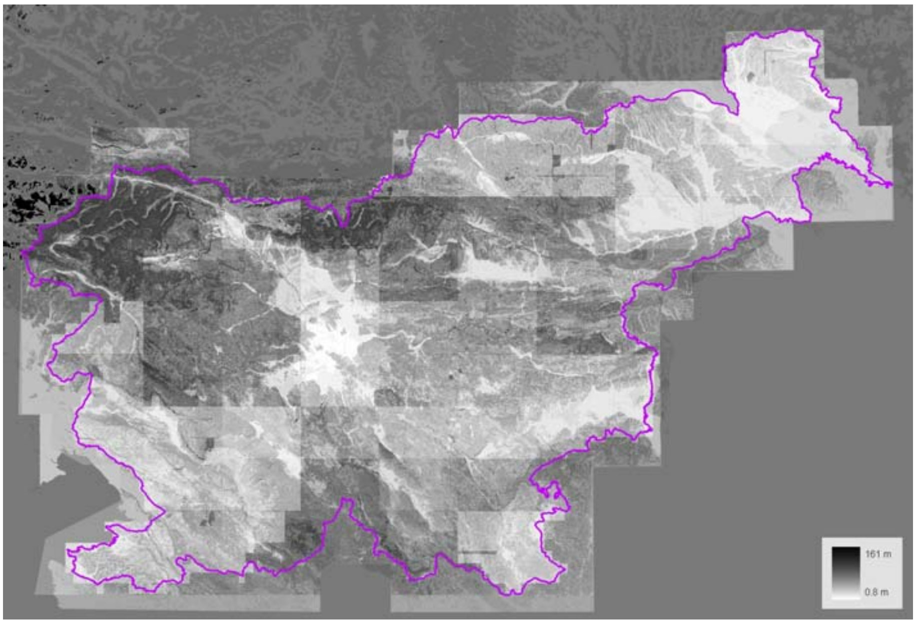

Figure 6: Potential random error for DEM of Slovenia in grid 12.5 x 12.5 m regarding different data sources used

The quality of different DEMs can be very illustrative presented with simulation of optimal path regarding using of different DEMs. This method is very sensible on resolution, and especially on geomorphic quality of DEMs on hilly areas. Such simulation is one of possible additional analytical methods that are used for better understanding the characteristics of DEMs that can be used for visualisations (Figure 7).

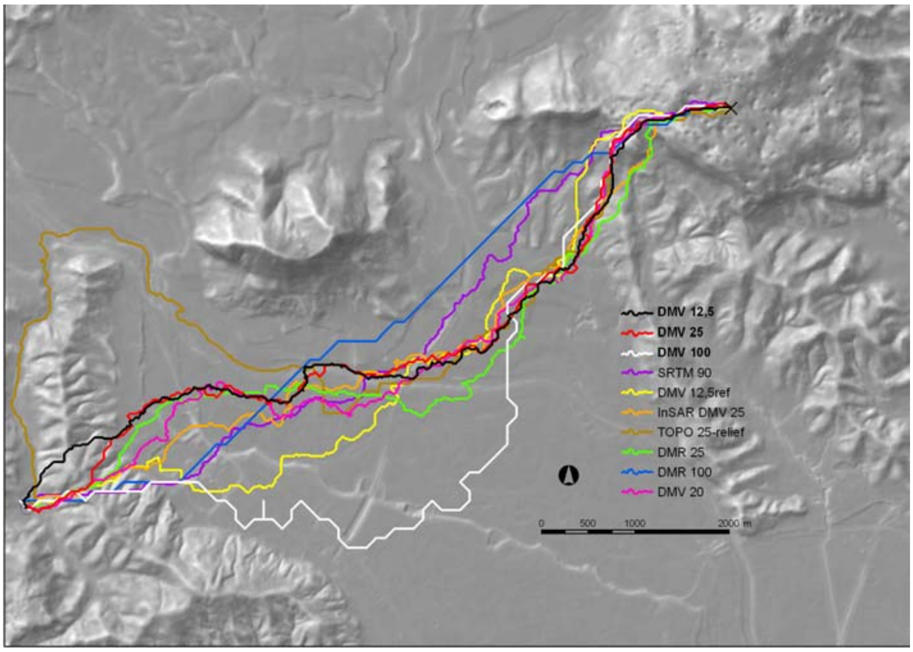

Figure 7: Optimal path of selected circumstances, simulated on different DEMs.

VISUALISATION OF DEM

As we have produced a high quality DEM regarding geomorphic and statistical aspect, and nowadays computers allow realization of many more ideas than whenever before, we are demonstrating some cartographical presentations of the Earth's surface or the landform.

Producing hill shading as plastic-orientated method, bases on visually effective presentation of the landform. Hill shading does not require high quality of data. In general, many average gross, random and systematic errors can not be perceived. On the opposite way, the geometrical-orientated methods like morphometric and terrain unit presentation (Robinson et al. 1995) are better for higher accuracy presentation of the landform. The most common geometrical mapping method is presentation of the contour lines. In the earlier stages of classical cartography, plastic methods were predominating over geometrical ones. That time production of maps didn't base much on surveying (geodetic) methods that bases on measurements. In general, plastic methods are appropriate for small-scale landform presentations, meanwhile geometrical ones for the large scales. Combination of both techniques can improve efficacy in reading of the maps.

Here in the paper are presenting possibilities of presentation of the combination of plastic and geometrical methods. Example is a bipolar differentiation with dichromatic coloured casts in combination with different contrasts in grey scale regarding curvature of landform as ridges, peaks, and sinks are. In combination of both approaches, details of the landform in the maps can be preserved in small and even in large scale at the same time. We are going to use the following methods for the landform presentation:

- *contours*: accurately portray particular elevations of landform (Robinson et al. 1995) by thin lines in (commonly) constant interval
- *hypsometrical* presentation of heights with different contrasts or colours regarding the elevations of landform
- *bipolar differentiation*: similar to contours, but with different casts: light and dark or differently coloured intervals; portray also small details in between contour intervals; the method is also similar to presentation of many supplementary contours; it is kind of hypsometrical presentation, but the interval is not from lowest to highest elevation, but relative, with repeating intervals (using relative relief)
- *enhancing of the edges* (ridges, peaks): increasing the lighting (contrast) regarding natural aspect of

landform curvatures; similar to worn out edges

- *hill shading*: aspect the shape of landform by light and dark casts regarding illumination that is similar to natural sun lighting

In combination of more kinds of methods, we can combine realism, accurate/precise measurements and association-based techniques for better understanding the landform. Regarding particular scales is possible applying different methods of landform presentation regarding their suitability for abstraction of small or rough details. For that, suitable generalisation methods of DEM are required.

In the further part of this chapter, using and various combinations of different visualisation methods of DEM is presented. All of the further comments are bellow the Figures (8 to 14). Many approaches are usable for multi-scale visualisations that would be useful for more effective mapping. Our case study is area around Bohinj lake with dimensions of around 26 x 15 km.

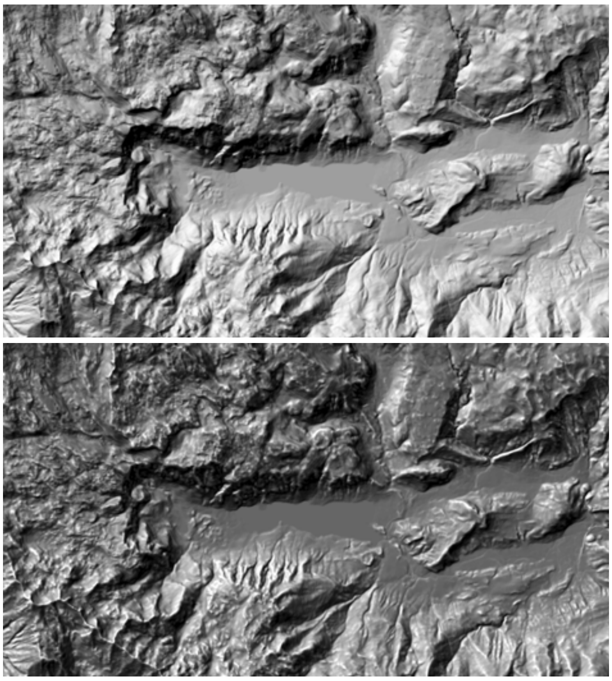

Figure 8: Combination of hill shadings in two different scales and two different horizontal angles (left) is common technique for producing topographical maps. More effective is combination of hill shading and enhanced ridges and peaks with increasing of their lighting (right). On the right visualisation, we can recognise more details than on the left one, but we can still recognize rough landforms.

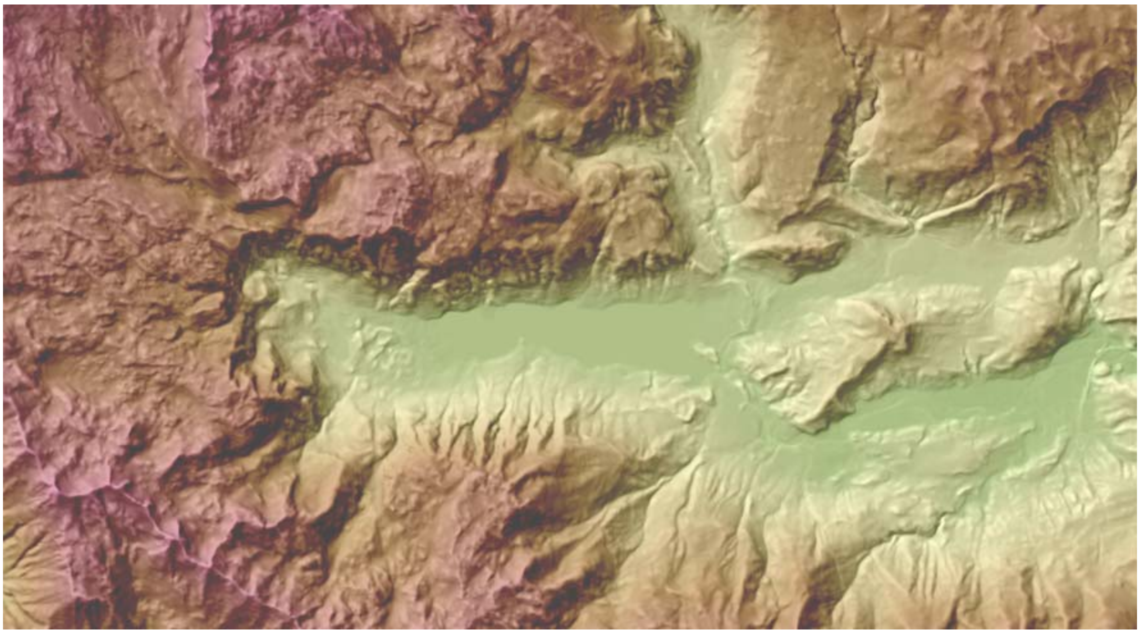

Figure 9: More effective combination of hill shading and enhancement of the ridges with peaks (both in light and dark casts) with hypsometrical presentation of different colours. This presentation could be useful for convenient topographical maps production.

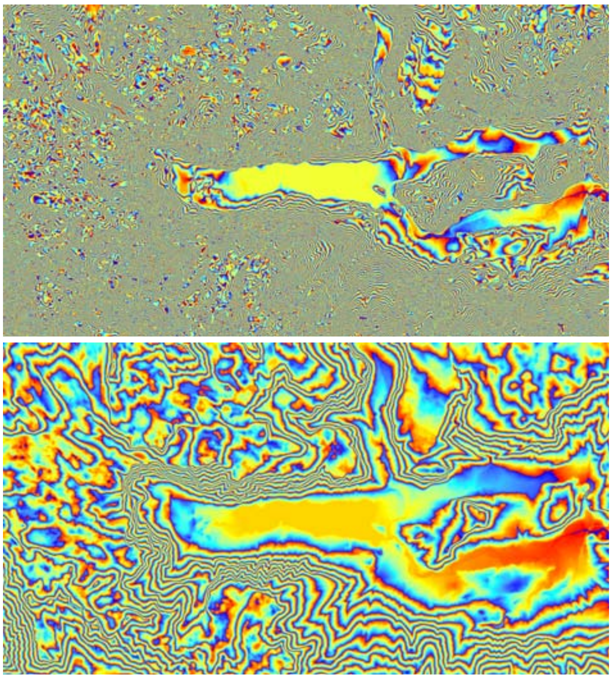

Figure 10: Bipolar differentiation presented with dichromatic colour cast (Wood 1996). Linear or non-linear casts can be applied. On the left, contour interval is 20 m (better for the moderate hilly areas) and on the right 100 m (better for the mountain areas).

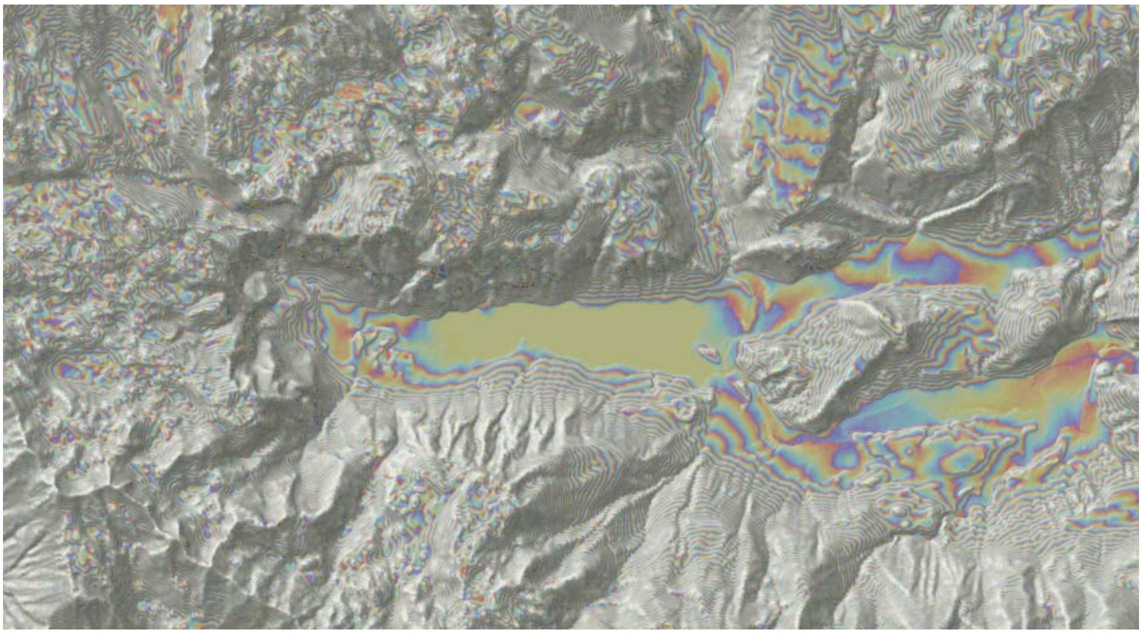

Figure 11: Combination of hill shading and enhancement of the ridges with peaks (both in light and dark casts) with added bipolar differentiation of 20 m interval in differently coloured intervals. First two techniques are very illustrative for hilly areas but the third one for the mainly flat areas.

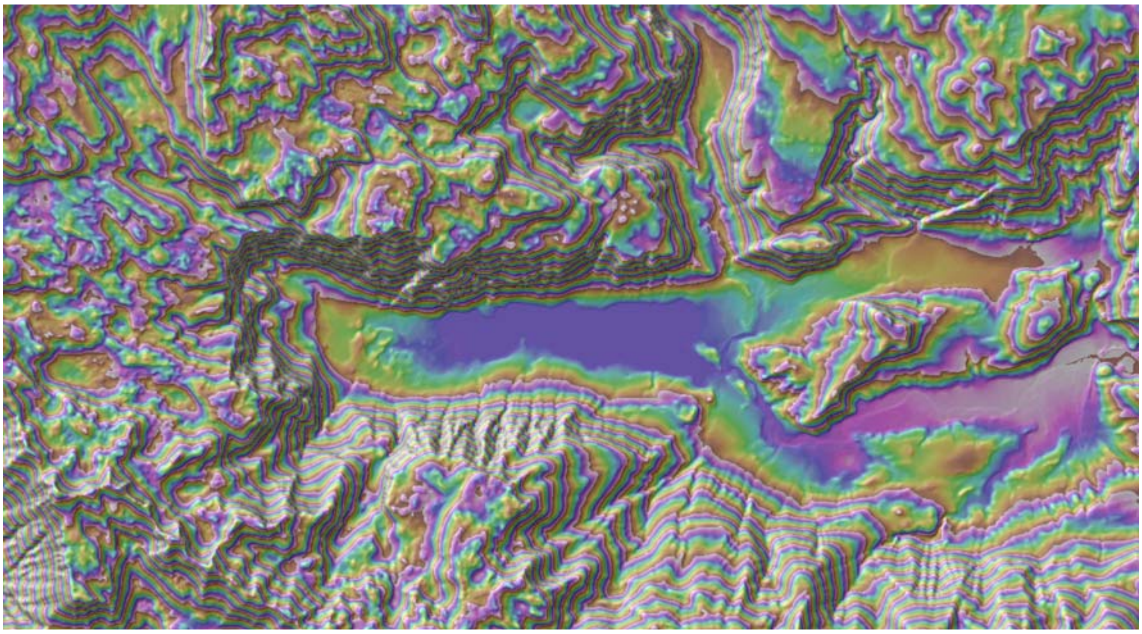

Figure 12: Combination of hill shading and enhancement of the ridges with peaks (both in light and dark casts) with added bipolar differentiation of 100 m interval in differently coloured intervals. This is especially good compromise for understanding of the most of landform features among all of presented techniques, but just with detailed examination.

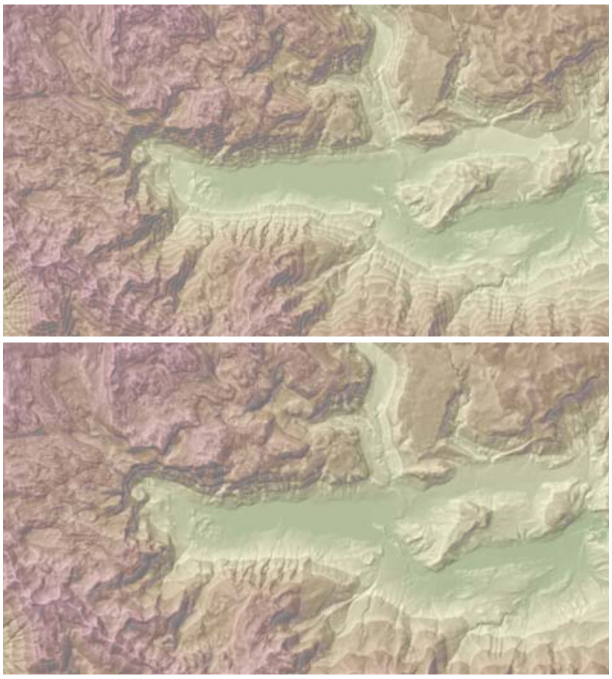

Figure 13: Combination of hill shading and enhancement of the ridges with peaks using bipolar differentiation (all three in light and dark casts) with interval of bipolar differentiation light contrasts of 100 m (left) and 250 m (right).The fourth method used here is hypsometry using different colours.

Figure 14: Combination of hill shading and enhancement of the ridges with peaks using bipolar differentiation (all three in light and dark casts) with interval of bipolar differentiation light contrasts of 100 m. We can imagine this bipolar differentiation like “continuous” contours. The fourth method used here is hypsometry using different colours. Bipolar differentiation is very light. This presentation could be useful for convenient topographical maps production.

CONCLUSIONS

We were demonstrated methodology for enhanced DEM production without of extra data acquisition. The methodology can be used for producing higher quality of DEM and for complex quality control that can remove different errors, especially gross ones. Many gross errors disable possibilities for effective surface presentations.

Using some techniques of DEM presentation, even relatively small gross errors can demolish correctness of visualisation. High quality data are therefore basis of almost all analyses or visualisations. To reach high quality presentation, good geomorphic and statistical quality DEM is required.

Enhanced visualisation of the Earth's surface or landform is important and powerful tool to evaluate or to present results of our work or supporting the other activities. Combination of different techniques can increase understanding of shape of the landform. Another aspect is multi-scale presentation. Hypsometrical and rough hill shading, produced by generalised DEM can introduce the surface in small scale. It gets insight into a large area of landscape and in the same time to a rough overview of it. Fine hill shading in combination with characteristic surface structures as enhanced edges are, together with bipolar differentiation, can introduce details of the landform. All of three techniques supplement each other. Visualisation of landform could be therefore observed from very near, to watch particular details, or from a distance from where is possible to see all map at once and rough characteristics of landform. Proposed combination of the methods can be also used for more effective presentation within topographical maps.

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