Validation of Grid-Based Surface Reconstruction Techniques Applied to Digital Elevation Models Including the Shuttle Radar Topographic Mission

Thomas Selige
Technical University Munich, Department of Plant Sciences,
Am Hochanger 2, 85350 Freising, Germany,
Tel.: +49 8161 71 4528 Fax.: +49 8161 71 4500
Email: selige@weihenstephan.de

Andre Ringeler, Juergen Boehner, Olaf Conrad
University of Goettingen, Institute for Geography
Goldschmidstrasse 5, 37077 Goettingen, Germany

Ruediger Koethe
Scilands GmbH, Goetheallee 11, 37073 Göttingen, Germany
URL: http://www.scilands.de/

Abstract- For the suitability towards the reconstruction of geomorphological sound surfaces using digital elevation models different methods as a weighted neigborhood member procedure, a ordinary kriging procedure, a gradient spline technique and a new modification of heat flow equation were tested. Round-off effects and effects of local noise-signal ratio were investigated.

I. INTRODUCTION

Digital elevation models (DEM) are mainly used in geosciences, hydrology, agriculture and other applied sciences, to identify process dynamics and to delineate process units within the landscape. This requires the modelling of landforms and the calculation of lateral movements (e.g. water, soil, snow) from the DEM. Examples of applications with an economical and ecological importance are the monitoring of watersheds and groundwater, landslide forecast, mapping flood areas, avalanche risk mapping, erosion risk assessment, soil regionalisation and regional planning. On technical grounds DEMs often show artefacts, that result in miscalculations and misleading information. The two major causes for this situation are the round-off effect and the local noise-signal ratio. The argumentation to apply round-off is not to suggest to the user a better accuracy of altitude, to reduce the necessary storage space or to improve the local noise-signal ratio. But the round-off procedure affects the representation of the real terrain shape. The round-off creates terraces and produces a thin plate surface. The implications of these artefacts can be momentous for DEM applications. How important the round-off effect will be, depends on the grid cell size and the round-off error of the DEM as well as the local relief energy of the landscape. The correction of the round-off artefacts should fulfil some requirements: realistic display of landforms, geomorphological sound reconstruction of slope profiles, to preserve the original grid cell size, the faithfulness of contour lines, realistic identification of channel lines and crest lines.

Most of the available interpolation and approximation algorithms are not producing surfaces being quantitatively and qualitatively accurate. While there are numerous interpolation and approximation methods, the computation of accurate and geomorphological sound reconstruction of surfaces is still an unresolved problem. In this work we compared different grid-based reconstruction techniques and validated the suitability of the algorithms for different DEM. A new implementation of a modified heat flow equation has been developed.

II. MATERIALS AND METHODS

The testsites are located in a hilly landscape of Bavaria and in the lowland of Lower-Saxonia in Germany.

The terrain of the bavarian testsite is characterized by long extended, gently inclined hilltops. The valleys are of anisotrophic shape with steep slopes in northwest exposition and gently inclined to the southeast exposition. The terrain of the Lower-Saxonian testsite has flat valley cuts, broad valleys, large plains and slightly undulated slopes of gently inclinations.

Different common and state of the art terrain models are available from these areas and are used for this study. A laser-scanning digital terrain model with 25 m resolution was processed based on a point density of better than 3 m in average and a height accuracy of better than ±0.15m.

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The X-band and C-band SRTM digital elevation models will be available after final delivery.

At the present development stage of this study four different grid-based surface reconstruction methods are in use: (1) a weighted neigborhood member procedure, (2) a kriging procedure, (3) a gradient spline technique and (4) a new modification of heat flow equation.

A wide range of terrain analytical parameters were calculated to compare the different reconstruction methods. Exemplary, the altitude itself, the slope, the slope curvature, the divergence index, the catchment area of a given grid cell and the erosion accumulation index were investigated in this study.

III. RESULTS

The threshold value for the local occurrence of terracing artefacts depends on grid cell size and the round-off error. Local differences ≤ 2.3 degrees (or 4%) of inclination between two grid cells of 25 m cell size will lead to terracing artefacts if there is a round-off error of ± 0.5 m. Local differences ≤ 0.7 degrees (or 1.1%) of inclination between two grid cells of 90 m cell size will lead to terracing artefacts if there is a round-off error of ± 0.5 m. This result emphasize the importance to correct the round-off effect in DEMs. Most valleys, agricultural land, settlement areas also large areas of lowlands and hilly landscapes will be affected by terracing artefacts.

In both testsites and for most of the analysed terrain parameters the weighted neigborhood member procedure produced the biggest deviations from the original DEM and was rated for the time not being useful to be applied. But it indicates a potential to become improved with a new implementation especially for lowland areas with less terrain information.

The kriging procedure produced deviations from the original altitude with less than ± 1.4 m at 70 % (Fig. 1), deviations from the original divergence index with less than ± 12 at 80 % (Fig. 4) and deviations from the original erosion accumulation index with less than ± 0.24 at 80 % (Fig. 7).

The heat flow equation procedure produced deviations from the original altitude with less than ± 1.2 m at 80 % (Fig. 2), deviations from the original divergence index with less than ± 9 at 80 % (Fig. 5) and deviations from the original erosion accumulation index with less than ± 0.24 at 80 % (Fig. 8).

The spline procedure produced deviations from the original altitude with less than ± 1.4 m at 70 % (Fig. 3), deviations from the original divergence index with less than ± 15 at 80 % (Fig. 6) and deviations from the original erosion accumulation index with less than ± 0.35 at 80 % (Fig. 9).

IV. DISCUSSION

The kriging procedure tend to over- and under-estimates of altitude. But this procedure was quite reasonable to reconstruct curvature related terrain parameters as the divergence index. The miscalculations of altitude caused in bigger deviations from the original erosion accumulation index than done with the heat flow equation and the spline procedure.

Best results of grid based surface reconstruction are actually given by the modified heat flow equation. This procedure was so far the only method to enable the recovery of the original DEM and the faithful display of contour. It enables the most realistic display of landforms and geomorphological sound reconstruction of slope profiles. Using another modification, the heat flow equation enabled also the identification of channel lines and crest lines. The method was most robust against over-estimates with splines.

The gradient spline technique produces significant noise to the resulting DEM and required a smooting procedure for extreme cases. The display of landforms was significant less realistic than using the modified heat flow equation. But it enabled the production of realistic channel networks and it indicates a great potential to become improved.

V. CONCLUSION

All of the tested grid-based reconstruction methods have advantages and disadvantages. Especially in lowland areas with less terrain information they produce momentous artefacts for calculations of lateral processes. The realistic identification of the channel network is the most important challenge for surface reconstruction on lowlands. The reconstruction of curvatures is the major challenge for surface reconstruction on hilly landscapes.

First tests with previously delivered SRTM DEM showed that the problem of round-off effects, as described here, is comparable with the noise-signal ratio in principle. Better surface reconstruction and local noise smoothing methods are strongly required to use these DEMs for the above mentioned applications.

After delivery of the final SRTM data, the effect of local noise-signal ratio of the SRTM DEM has to be validated. Depend on the noise-signal ratio also smooting spline interpolation techniques will have to be considered for grid based surface reconstruction in future.

VI. ACKNOWLEDGMENT

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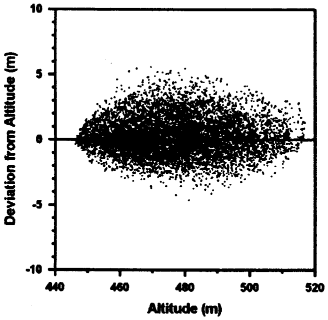

Fig. 1. The deviation from altitude caused by the kriging procedure (y) compared to the original altitude (x)

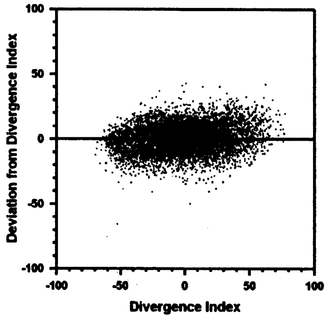

Fig. 4. The deviation from divergence index caused by the kriging procedure (y) compared to the original divergence index (x)

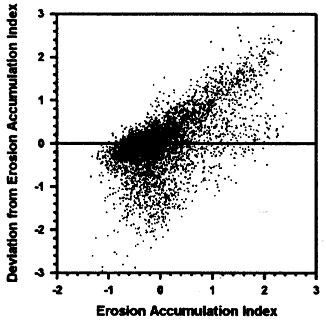

Fig. 7. The deviation from erosion accumulation index caused by the kriging procedure (y) compared to the original erosion accumulation index (x)

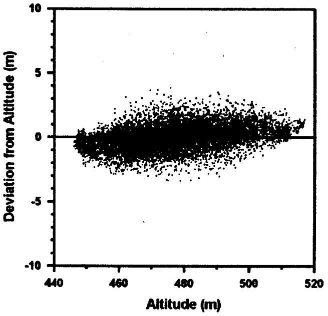

Fig. 2. The deviation from altitude caused by the heat flow equation procedure (y) compared to the original altitude (x)

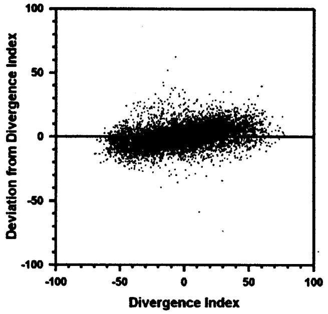

Fig. 5. The deviation from divergence index caused by heat flow equation procedure (y) compared to the original divergence index (x)

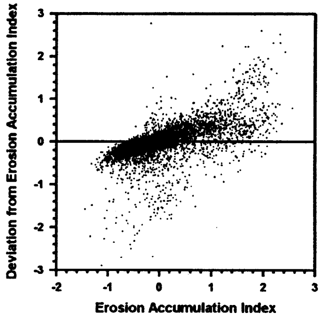

Fig. 8. The deviation from erosion accumulation index caused by the heat flow equation procedure (y) compared to the original erosion accumulation index (x)

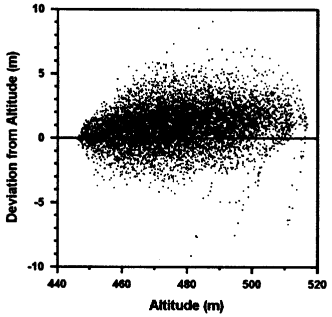

Fig. 3. The deviation from altitude caused by the spline procedure (y) compared to the original altitude (x)

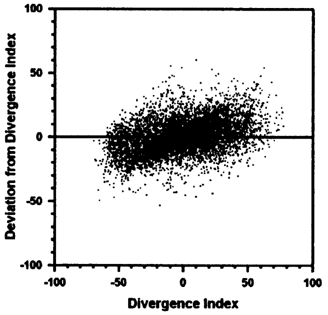

Fig. 6. The deviation from divergence index caused by the spline procedure (y) compared to the original divergence index (x)

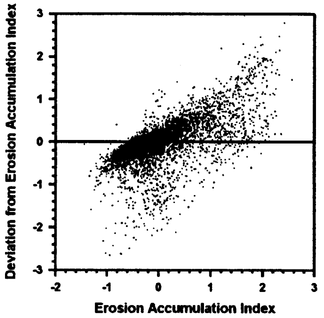

Fig. 9. The deviation from erosion accumulation index caused by the spline procedure (y) compared to the original erosion accumulation index (x)