Multi-Scale and Object-Oriented Image Analysis of High-Res LiDAR Data for Geomorphological Mapping in Alpine Mountains

N. S. Anders, A. C. Seijmonsbergen, W. Bouten

Institute for Biodiversity and Ecosystem Dynamics, Computational Geo-Ecology, Universiteit van Amsterdam,
Nieuwe Achtergracht 166, 1018 WV Amsterdam, The Netherlands
Telephone: +31 (0) 20 525 7436
Fax: +31 (0) 20 525 7431
Email: n.s.anders@uva.nl

1. Introduction

Geomorphological maps are useful to a wide variety of applications, such as hazard risk analysis (Seijmonsbergen 1992), forest ecological research (Van Noord 1996) and geoconservation evaluation studies (Seijmonsbergen et al. in press). Traditional field-based geomorphological mapping strategies are often time consuming and the accuracy of these methods is questionable in steep and difficult-to-access terrain.

Topographic analysis of remotely sensed digital elevation data is a potential tool to speed up and increase accuracy of the mapping procedure. Recent studies argue that image segmentation and object-oriented classification strategies are intuitive to (semi-) automatically produce a classified hillslope or geomorphological map (Drăguţ and Blaschke 2006; Van Asselen and Seijmonsbergen 2006) based on Digital Elevation Models (DEMs) and their derivatives. However, an accurate identification and classification of individual landforms and their genesis remains a challenge, partly due to the multi-scale nature of geomorphological processes.

This research-in-progress is part of a PhD project for developing a method to classify image objects on their geomorphological nature in a multi-scale framework, based on geomorphometric parameters derived from high-resolution LiDAR (Light Detection And Ranging) data. In future research, we will integrate this detailed LiDAR-derived geomorphological information in a dynamic simulation model to facilitate landscape evolution research in complex and difficult-to-access terrain at greater detail than before.

2. Materials and Methods

Our approach is being developed and tested at several locations in the Alpine mountains of Vorarlberg (W-Austria). In this paper, we study the Gamp valley catchment (approximately 10km^2), which is characterised by a large variety of geomorphological processes and related landforms (e.g. gypsum karst, basin fill of glacially shaped valleys and steep fluvial incision of bedrock rivers). Available data of this area include a LiDAR Digital Terrain Model with 1 m spatial resolution and digital geomorphological maps in a GIS, which are digitised and hierarchically categorised from 1:10,000 field-based geomorphological maps (Seijmonsbergen 1992) and are used as ground truth reference data.

Our method is focused on extracting geomorphological information from remotely sensed LiDAR data, or more specifically, (semi-) automatically mapping geomorphological features based on their genesis. Seijmonsbergen et al. (in press) have developed a hierarchical classification scheme to apply to polygon-based geomorphological maps in a GIS. In this scheme, landforms are first distinguished on their forming process, such as fluvial or glacial processes, karst, mass movement, etc. In a second step, these classes are further separated based on erosion or accumulation processes before the final (genesis of the) landform (such as alluvial fans, karst collapse holes, fluvial incision, etc.) is determined.

In this research a comparable method will be used. Firstly, image objects are created at multiple scales, using multi-resolution image segmentation (Baatz and Schäpe 2000) of high-resolution LiDAR data, which is based on getting maximum internal homogeneity of parameter values within image objects at a user-defined scale. Secondly, image objects are classified using a rule-based hierarchical classification approach to categorise image objects on their geomorphological nature. Input arguments on which classification rules are based use DEM derivatives, such as slope gradient and curvature. In addition, topographic openness is a relatively unknown, yet promising parameter for further implementation in multi-scale image classification schemes. Openness can be defined as the degree of enclosure of a location in the landscape and is an angular measure of surface relief and horizontal distance (Yokoyama et al. 2002; Prima et al. 2006). The distance over which openness is measured is variable (Fig. 1): measurements over longer distances clearly show patterns for recognising individual landforms and processes, such as gypsum-karst collapse holes (small black spots), alluvial fan development (bright triangular shapes) and fluvial incision (dark, long and narrow shapes) at a broad scale (A), while openness measured over short distances show detailed variation at a fine scale (B and C), representing local differences of curvature (C). The multi-scale nature of topographic openness encourages a multi-scale expert rule setup for image segmentation and classification, where both broad-scale and fine-scale openness values could be incorporated. For the full theoretical and mathematical background Yokoyama et al. (2002) are referred. Fig. 2 illustrates the workflow of our approach.

2.1 Multi-Scale Image Segmentation Using Geomorphometrical Parameters

In this study, we automatically segment the image into objects of multiple scales using Definiens Developer software, based on multi-resolution segmentation using DEM-extracted slope and openness parameters. The software allows to create scale-specific image objects using a user-specified scale parameter. Broad scale image objects are derived using a set of slope, curvature and openness (measured over wide areas) parameters in combination with a large scale parameter for classifying broad-scale geomorphological features. More detail on the classification strategy is discussed in section 2.2. The broad-scale image objects will be further segmented into smaller objects using smaller scale parameters, in order to identify fine-scale geomorphological features. Such a hierarchical segmentation and classification structure facilitates the analysis of image object’s context, since small-scale objects uses classification results of broad-scale features, which in turn promotes a multi-scale analysis of image objects and geomorphological features.

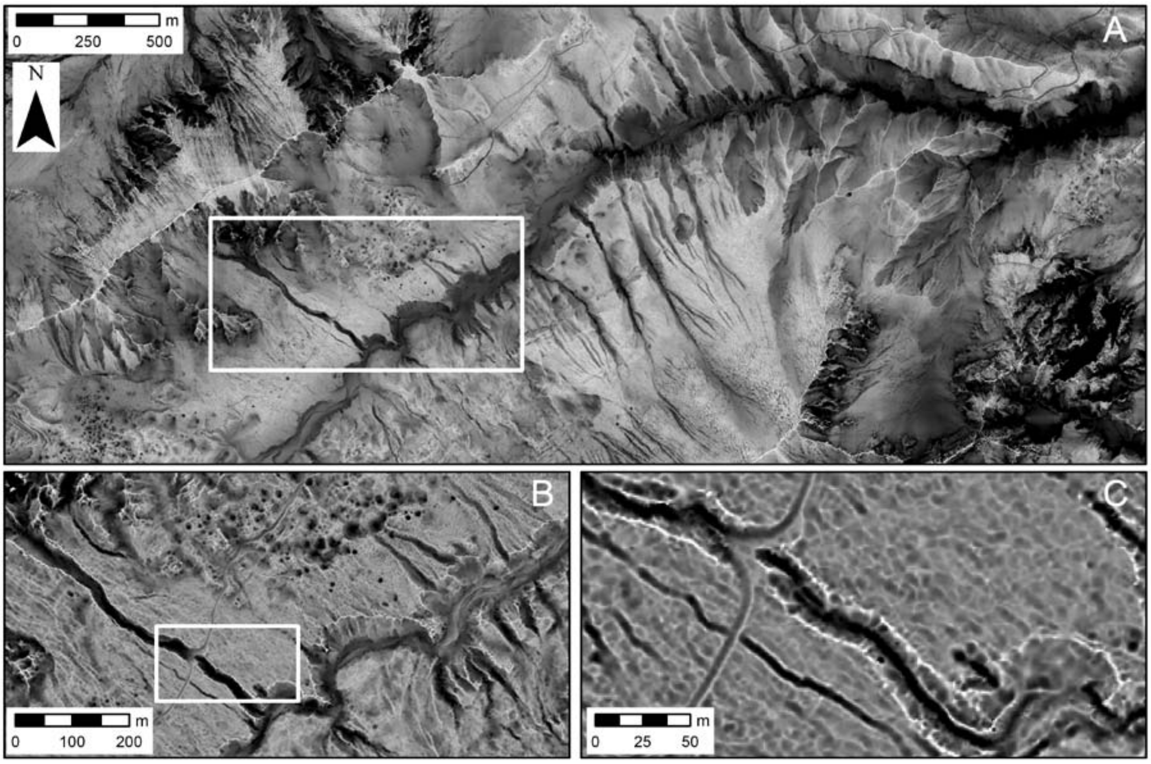

Figure 1: Topographic openness values of a subset of the Gamp valley. Bright hues represent open and wide areas, while dark hues represent enclosed, narrow areas. The values are calculated as a mean angle in eight directions, (a) measured over a diameter of 400 m; (b) measured over a diameter of 40 m; and (c) measured over a diameter of 10 m. The white boxes in (a) and (b) illustrate the locations of (b) and (c), respectively.

2.2 Rule-Based and Expert-Driven Object Classification

Each set of image objects are classified using slope, curvature and topographic openness (measured over various distances) parameters. Additional parameters are used to classify specific geomorphological features, such as flow accumulation values for identifying landforms related to fluvial processes. Internal statistics of surface parameters, relations with objects at higher scale levels and spatial properties of objects related to neighbouring objects are hierarchically used for developing a final classification of landscape features. Expert-knowledge is essential in developing the fuzzy classification rule sets.

2.3 Accuracy Assessment

The reference dataset include 1 : 10 000 symbol-based geomorphological field maps that have been translated into GIS-based polygon maps. Classification results are exported to polygon maps and are compared with the reference dataset for estimating the classification accuracy. A field campaign is set up this summer to link automatically derived objects with field geomorphology.

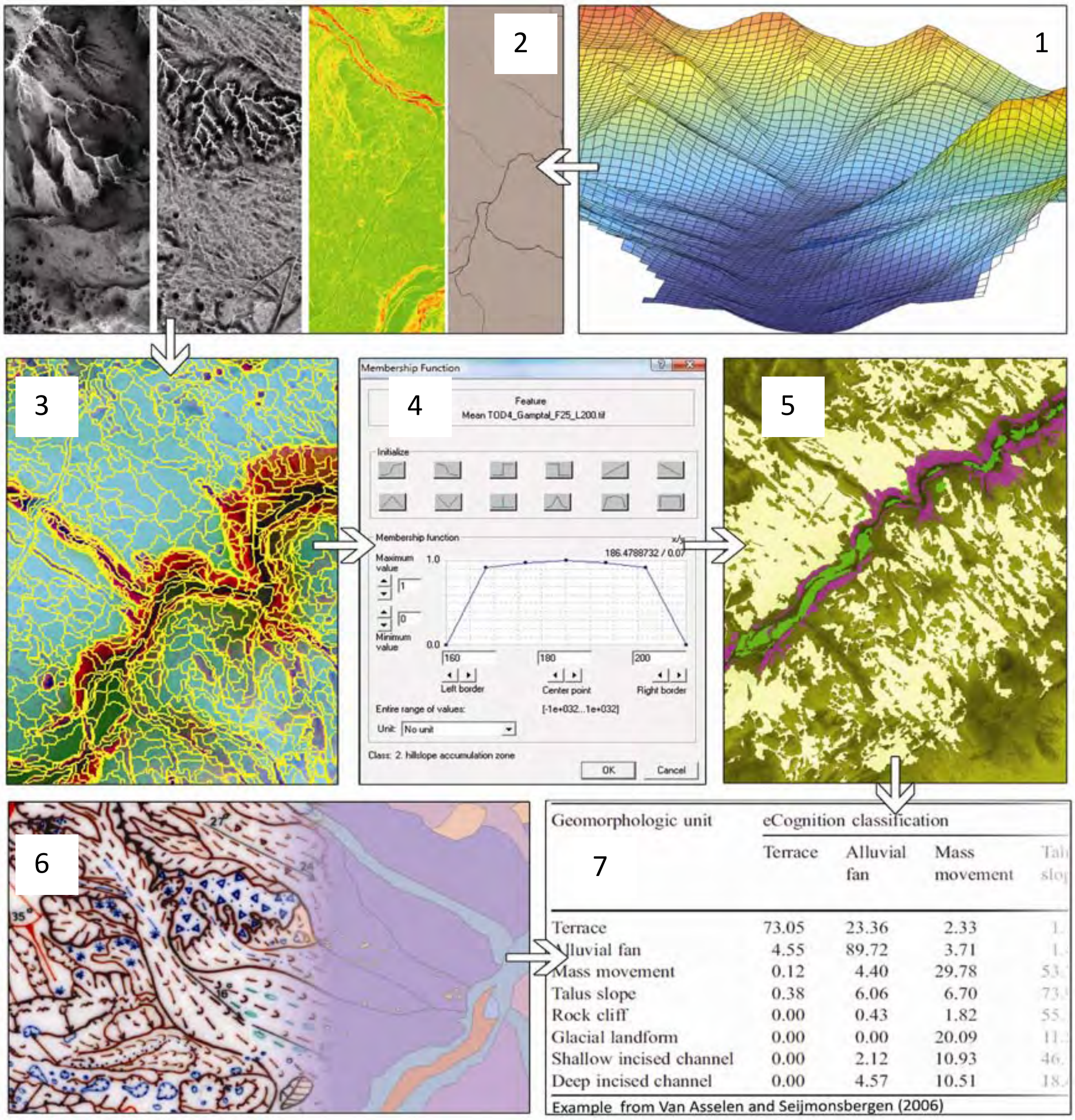

Figure 2: Schematic overview of the methods. High-res LiDAR data (1) is used to derive various sets of geomorphometrical parameters (2) to create image objects at multiple scales (3). Internal statistics, higher level object information, spatial properties regarding neighbouring objects and expert knowledge are used create fuzzy rules (4) for mapping geomorphological features. Final classification results (5) are compared with field-based geomorphological maps (6) for estimating classification accuracy (7).

3. Results

At the time of writing this extended abstract, the research is still in progress. It is expected that a multi-scale framework of both the image segmentation and classification process will significantly increase classification results or mapping accuracy, especially if the topographic openness parameter is incorporated. First experiments of extracting gypsum karst collapse holes and fluvial landforms are promising. Image object boundaries can follow openness patterns that are measured over long distances (400 m), while internal textures of fine-scale (10 m) openness values within image objects can be incorporated—in combination with other relevant DEM-derivatives and object-oriented properties—for classifying image objects in subsequent rules following a hierarchical classification structure.

4. Future Research

Future research will integrate the automatically extracted geomorphological features with a dynamic simulation model (Anders et al. in press) to calculate alpine landscape evolution, in which channel incision is incorporated in high spatial detail. A vector-based channel incision model (CIM) calculates the longitudinal profile development of bedrock rivers at a fine spatial scale (1 m), based on a modified stream power formula, while taking into account the upstream area, channel gradient, channel disequilibrium and the geological strength against fluvial erosion. The CIM is combined with a raster-based reaction-diffusion erosion model (Minasny and McBratney, 2001) to incorporate hillslope development as a response to the fluvially incising network of river channels at a broad scale (50 m). The model is time efficient and realistically adapts to variable geological substrates, resulting in temporally and spatially variable incision values, knick-point regression and variable hillslope development. Automatically classified and detailed geomorphological information is necessary to serve as input data in the erosion model to improve results of simulated hillslope dynamics in complex terrain. Results from the landscape evolution model will be a step forward in using high-resolution data in dynamic geomorphological simulation models, to pave the way for more efficient landscape evolution research of difficult-to-access terrain and can contribute to increasing the understanding of the functioning of geo-ecological systems.

Acknowledgements

This research is supported by the Research Foundation for Alpine and Subalpine Environments (RFASE) and is carried out in the context of the Virtual Laboratory for e-Science project, which is supported by a BSIK grant from the Dutch Ministry of Education, Culture and Science (OC&W) and is part of the ICT innovation programme of the Ministry of Economic Affairs (EZ). The ‘Land Vorarlberg’ (http://www.vorarlberg.at/) has kindly allowed us to use the 1 m LiDAR DTM.

References

Anders NS, Seijmonsbergen AC and Bouten W, in press, Modelling channel incision and alpine hillslope development using laser altimetry data. *Geomorphology*.

Baatz M and Schäpe A, 2000, Multiresolution Segmentation–an optimization approach for high quality multi-scale image segmentation, In: Strobl J and Blaschke T (eds), *Angewandte Geographische Informationsverarbeitung*, Wichmann, Heidelberg.

Drăguţ L and Blaschke T, 2006, Automated classification of landform elements using object-based image analysis. *Geomorphology*, 81(3-4): 330-344.

Prima ODA, Echigo A, Yokoyama R and Yoshida T, 2006, Supervised landform classification of Northeast Honshu from DEM-derived thematic maps. *Geomorphology*, 78(3-4): 373-386.

Seijmonsbergen AC, 1992, Geomorphological evolution of an Alpine area and its application to geotechnical and natural hazard appraisal, PhD thesis, University of Amsterdam, 109 pp.

Seijmonsbergen AC, De Jong MGG and De Graaf LWS, in press, A method for the identification and assessment of significance of geomorphosites in Vorarlberg (Austria), supported by Geographical Information Systems. *Geografia Fisica e Dinamica Quaternaria*.

Van Asselen S and Seijmonsbergen AC, 2006, Expert-driven semi-automated geomorphological mapping for a mountainous area using a laser DTM. *Geomorphology*, 78(3-4): 309-320.

Van Noord H, 1996, The role of geomorphological information in ecological forest site typology in mountainous areas, a methodological study in the E-Rätikon and NW-Montafon mountains (Vorarlberg, Austria), PhD thesis, University of Amsterdam, Amsterdam: 185 pp.

Yokoyama R, Shirasawa M and Pike RJ, 2002, Visualizing topography by Openness: A new application of image processing to digital elevation models. *Photogrammetric Engineering and Remote Sensing*, 68(3): 257-265.