Modeling alpine geomorphology using laser altimetry data

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Citation for published version (APA):
Anders, N. S. (2013). *Modeling alpine geomorphology using laser altimetry data*.

Epilogue

Remote Sensing plays a major role in many disciplines in the Earth sciences. Inspired by the bat's ability to measure distances of objects in space through the reflection of their echo (now known as Sound Navigation and Ranging—SONAR), scientists developed a similar technology to emit, and receive reflected, radio waves. Radio Detection and Ranging (RADAR) was one the earliest active remote sensors.

RADAR technology is an important source for creating Digital Elevation Models (DEMs) of the Earth's surface. However, due to the long wavelengths of radio waves, RADAR may not be able to acquire surface elevation at the high detail that is relevant for geomorphological research. Stereophotogrammetry, where digital elevation models are produced by means of aerial stereophotos may produce the required detail, but only of the vegetated surface. The 'terrain', in which the geomorphologist is most interested, remains hidden below the vegetation. Using short wavelengths (e.g. infrared and visible green light) with 'Light Detection and Ranging' (LiDAR), objects can be measured with much higher resolution. Similar to RADAR, LiDAR also has the ability to (partly) penetrate through different layers of vegetation and provides information on the ground surface. Especially after the deployment of the Global Positioning System (GPS) LiDAR systems have increasingly been used for airborne surveying and creating Digital Terrain Models (DTMs).

LiDAR technology initiated a revolution in geomorphological research. Where traditional methods failed, LiDAR technology paved the way for creating very high-resolution DTMs to measure and visualize geomorphological features at detailed scales. Geomorphologists were offered the ability to deeply analyze a study area and were no longer required to carry out extensive preparatory field work campaigns. The high detail of LiDAR data also came with inevitable computational challenges. A typical modern airborne LiDAR campaign stores more than 20 data points m^{-2}: imagine the size of data sets of entire states, countries or mountain ranges which can include billions of data points. Post-processing of raw data and interpolation into terrain models requires high-end computing. But not only data acquisition and processing, also data analysis techniques require new methodologies to take advantage of the detail and scale at which data is presented. For example, single DTM grid cells first represented a mixture of many landforms, while modern LiDAR terrain models are based on grid cells which make up only small parts of landforms. The difference of scale requires different analysis strategies.

As technological advances continue, the amount of data will dramatically increase in the coming years. This is for one because more countries are following the examples of Switzerland, Austria and the Netherlands by creating national LiDAR coverages. But also because repeated LiDAR campaigns for the acquisition of multi-temporal data sets and upcoming full waveform or hyperspectral LiDAR systems (e.g. Hakala et al., 2012) will produce even more data. The amount of data will get, or is already, beyond the ability to manually process. To prevent the 'drowning' in massive amounts of data, supercomputing, data reduction and automation is required in every processing step.

Object-Based Image Analysis (OBIA) is one of aforementioned modern data analysis techniques which includes data reduction and automation by clustering grid cells into 'objects'. Yet, these objects represent more than just groups of grid cells. Internal properties and spatial context of objects are used to classify the shapes. According to their corresponding classification rules these objects enclose valuable information that is relevant for recognizing the morphogenesis of landscape elements and the identification of geomorphological features. OBIA therefore partly automates the geomorphological interpretation of geospatial objects and improves the efficiency of (digital) landscape analysis.

DTM derivatives, known as terrain attributes and Land Surface Parameters (LSPs), form the basis of such digital landscape analysis. Many types of LSPs exist that contain different types of geospatial information over different scales. A careful selection of LSPs is crucial and therefore fully automating of the geomorphological interpretation using digital elevation data is not yet possible. Expert knowledge is essential at this stage in order to select appropriate LSPs and translate geomorphological descriptions of landforms to mathematical formulations as classification rules. As Chapter 3 also indicates, automated methods can speed up landscape analysis and mapping, but the results should be carefully evaluated in every step by an expert who is able to understand the geomorphological interpretation during individual processing steps.

While the details in this thesis were focused merely on the semi-automated parameterization and extraction of geomorphological features in high-alpine area, the approach can be adapted for application in different areas and for different purposes. In order to upscale such analyses for possible future global LiDAR coverages there is a need for initiating a global library to summarize landform characteristics for different regions in the world. High-level global landform classifications could form the basis of extracting large topographic entities, for which specific classification rules can be formulated to extract detailed geomorphological features in these areas. Such a global library should contain 1) a large collection and descriptions of DTM-derived and multi-scale Land Surface Parameters and their algorithms, 2) differentiation of major regions in the world and the occurrence of landforms in these areas (in a nested, multi-scale, hierarchy), and 3) classification rule sets describing the characteristics of the landforms that are required for the identification and extraction of individual landforms. Supplementary material such as (global) soil and geological maps, climate data or (satellite) imagery can be added to increase the number of data sources which may be relevant for differentiating landforms or other relevant landscape objects. This encourages discussions on classification criteria and standardizing methodologies for repeating processing chains. Such a library could potentially generate a global database of landscape objects which can be made publicly available and serve as input for a wide variety of Earth scientific studies.

When such global data sets will form the basis of landform extraction procedures the functioning of landscape features in a dynamic environment and changing global climate can be monitored. Effects of global processes to landform evolution can be analyzed with large simulation models. In addition, geomorphological maps reflect the superficial evolution of a landscape that can be used as source for information on the subsurface, e.g. to create or improve existing soil maps and geological maps. These are only examples of the further continuation of automation in digital landscape analyses.

While automated methods are increasingly useful, field work and process knowledge remain crucial for method development and for quality control that is required to assess (semi-) automatically generated results. Interpretation of model results is to be done by an expert to evaluate model behavior. A close interaction between the continuously improving computational infrastructure and Earth scientific knowledge is of utmost importance to keep increasing our insights on the functioning of geo-ecological systems and the protection of our unique, yet, fragile environment.