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# Multi-Scale Landscape Analysis (MSLA) — A method to identify correlation of relief with ecological point data

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ABSTRACT

A common problem in ecology is identifying the relationship between relief and site properties obtainable only by point measurements. The method of Multi-Scale Landscape Analysis (MSLA) identifies such correlations. MSLA combines frequency filtering of the digital elevation model (DEM) with an estimation of the optimum filter coefficients using an optimization procedure. Tested using point data of soil decarbonation from a German young moraine landscape, MSLA provided significant results. Implemented within open source software SAMT, MSLA is comfortable and flexible to use, offering applications for numerous other spatial analysis problems.



## 1. Introduction

In addition to climatic, pedologic and petrographic conditions, the ecological potential of landscapes is related to surface relief. Thus, numerous ecological parameters and processes correlate with relief to some extent. For example, relief correlates with soil moisture distribution (Penna et al., 2009), matter dislocation (Van Oost et al., 2006), toxin distributions (Müller et al., 2011), trace gas emissions (Sommer et al., 2004), and radiation input (Huang et al., 2008). Additionally, relief is also an important source of information for geological conditions and geomorphologenesis. It can be used to stratify landscapes, e.g. for the multidata fusion of various non-invasive methods (Sommer et al., 2003). From a general perspective, both relief and other ecological parameters bear patterns of various scale. However, only a certain scale (or scales) bears information that is relevant to a certain question (Levin, 1992).

Numerous relevant ecological site properties can only be obtained by point measurements (e.g. soil profile data), whereas digital elevation data (DEM) are spatially comprehensive. Against this backdrop, the relationship of relief to soil properties is often investigated in order to

- learn about processes (soil genesis) and
- derive soil properties for the entire area under investigation (spatially comprehensively).

The second purpose requires combining heterogeneous data types (gridded relief data (DEM) and soil parameter values from point samples).

For this purpose, the contiguous surface relief is usually separated into isolated features, e.g. landforms or land form elements (such as slopes, ridges, channels and valley bottoms). These landform elements can be derived according to approaches by Peuker and Douglas (1975), Wilson and Gallant (2000), Macmillan et al. (2000), Reuter et al. (2006), Minar and Evans (2008), Hengl and Reuter (2009) and Deumlich et al. (2006). They are standard features in recent software designed to extract morphometric features, such as Saga[1] and IDRISI.[2] Albeit these implementations, the landform extraction is often based on expert knowledge and therefore remains arbitrary to different extent.

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[1] http://www.saga-gis.uni-goettingen.de.
[2] http://www.idrisi.com/.

Attempts to automatically extract landforms on specific scales have also been made with respect to particular purposes, such as landform genesis (Brown et al., 1998), soil properties (Florinsky et al., 2002), soil genesis (Sommer et al., 2008) and soil transport processes (Möller et al., 2008). Automatic extraction approaches, on the other hand, are highly complex and also rarely scale invariant.

In contrast to these approaches, the scale-related filtering of relief data (e.g. by Fourier analysis) has not been applied. It was, however, employed successfully for similar purposes, based on aerial photographs. Mugglestone and Renshaw (1998) calculated objective estimates of orientation and scale to characterize surface patterns (glacial landforms such as drumlins and flutes) via Fourier analysis. Couteron (2002) successfully detected changes in patterns referring to the dominant wavelength and main orientation. Couteron et al. (2006), on the other hand, identified prominent scales of landscapes pattern (coarseness by radial power spectrum). Delenne et al. (2008) applied local Fourier transforms to classify plots from the aerial photograph power spectrum. Another interesting approach is discussed in Barbier et al. (2010), where cross-spectral analysis was used to conduct independent correlation analysis at different scales of two variables.

Wieland and Dalchow (2009) isolated tops and hollows of a deliberately chosen scale from complex relief data by Fourier transformation and singular value decomposition (SVD). They did not, however, relate them to any other site parameters.

The aim of this paper is to introduce “Multi-Scale Landscape Analysis” (MSLA) within SAMT (Wieland et al., 2006). MSLA links the spectral analysis of relief data (DEM) to point-measured soil properties, using various filtering algorithms (windowed sinc, wavelet, singular value decomposition) for the relief data, while identifying the relevant high and low frequencies by the optimization procedure HOPSPACK. The correlation between the point data and the filtered DEM is performed in the time (space) domain, rather than in the frequency (wavelength) domain.

We demonstrate MSLA testing the following hypothesis: “There is a specific scale (wavelength window), at which relief correlates to certain soil properties most strongly”. The hypothesis is tested as an example by investigating the correlation of relief with the thickness of a decarbonated surface soil layer (“depth of carbonate”). The data used are a DEM and soil measurements from a young Pleistocene lowland in northeastern Germany.

This data was considered to be appropriate, according to investigations by Lobb et al. (1994), Florinsky et al. (2002) and De Alba et al. (2004). These authors investigated tillage erosion in comparable moraine landscapes (southwestern Ontario, Canadian prairies and west central Minnesota), and found that the thickness of decarbonated surface horizons (resulting from soil leaching, partly stripped off by tillage erosion) is correlated with relief position.

Beyond this specific application, the further potential of the approach presented will be discussed.

## 2. Data and method

### 2.1. Investigation area and data set

The landscape section chosen to test and illustrate the application of MSLA is a predominantly agriculturally used area of about 5 × 5 km, situated in the young Pleistocene lowland of northeastern Germany, approximately 100 km N of Berlin in the Federal State of Brandenburg (Fig. 1). At elevations ranging between 40 and 60 m a.s.l., the area has parent subsoil material of calcareous glacial sediments (mostly till) and a rolling topography with slope angles up to 9°. There is a transient Atlantic to continental climate with approximately 490 mm of average annual precipitation. Resulting from Holocene soil development, the uppermost horizons are decarbonated, unless they have been disturbed or dislocated by erosion. In the southwestern section of the investigation area, soil profiles were investigated at 81 randomly distributed positions in the course of a field campaign in 2007 (section a, see Fig. 1). One of the parameters measured was the thickness of decarbonated soil horizons covering the calcareous parent material (“depth of carbonate”).

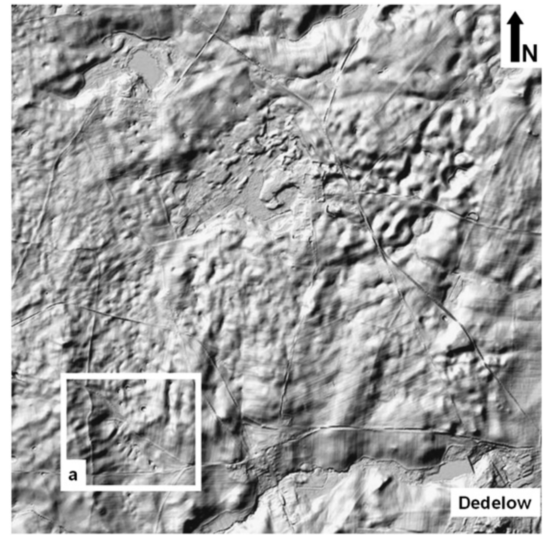


**Fig. 1.** Investigation area for MSLA (5.12 × 5.12 km), located in northeastern Germany, 100 km N of Berlin in the Federal State of Brandenburg, NW of the village of Dedelow. Shaded relief derived from laser scan DEM data with 5 m resolution. a) Section of data set “depth of carbonate” from 81 drill holes.

This parameter was chosen for the MSLA approach because it could be measured precisely and it is assumed to relate to relief position within landforms (see ch. 1, Introduction). The gridded elevation map (1024*1024 grid cells) of the investigation area has a grid size of 5 m, originating from the laser scan digital relief data set DEM 5 from the Land Survey (LGB) of the Federal State of Brandenburg, Germany.

### 2.2. Multi-Scale Landscape Analysis (MSLA)

The basic idea behind MSLA is to achieve a signal separation of the spectral information from digital elevation models (DEM), also known as “band pass filtering”. Band pass filtering removes some of the unwanted low wavelength and high wavelength (noise) from the gridded data. The wavelengths related to soil properties can be separated using an appropriate filter parameter.

The relationship between the DEM and the “depth of carbonate” can be expressed as the correlation between the filtered part of the DEM ($X$) and the depth of carbonate ($Y$). The estimated correlation coefficient $r$ of the random variable $X$ and $Y$ can be calculated using Eq. (1):

$$\frac{\sum_i (x_i-\bar{x})*(y_i-\bar{y})}{\sqrt{\sum_i (x_i-\bar{x})^2*\sum_i (y_i-\bar{y})^2}} \quad (1)$$

where $\bar{x}=\Sigma_i x_i/n$.

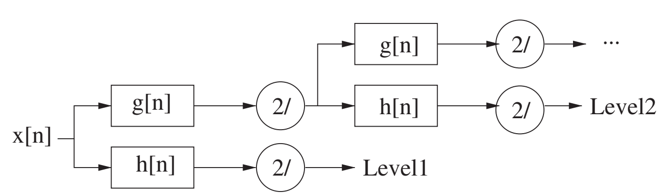


**Fig. 2.** The wavelet transformation applies the high pass filter h [n] and the low pass filter g [n] successively to the filtered signal and produces a collection of filtered signals. Half of the samples can be discarded according to Nyquist's rule, which is the aim of sub sampling operator 2/.