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Detection of land surface memory by correlations between thickness of colluvial deposits and morphometric variables

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A B S T R A C T

Some morphometric variables store information about past land surfaces longer than others. This property of morphometric variables is recognised as land surface memory. Slope deposits, soils, and vegetation also have this memory. In this study, a memory effect was quantitatively detected by Spearman correlations between thickness of colluvium and morphometric variables of the modern land surface.

During long-term sedimentation, the sign of horizontal curvature (*kh*) may be inverted from minus to plus, suggesting that locations with positive *kh* values are not accumulation zones. However, the thickness of colluvial deposits at such locations in our study area indicates sediment accumulation. The sign of minimal curvature (*kmin*) tends to be more stable and remains negative. This difference provides the stronger correlation of colluvial layer thickness with *kmin* than with *kh*. The strongest correlation was found for total thickness of the colluvial deposits of the Neolithic and Iron Age with *kmin* (−0.84); the correlation with *kh* was weaker (−0.71).

1. Introduction

The fact that the modern land surface stores information about the past is a basic principle of geomorphology. In geomorphometry it is known that one group of morphometric variables (MVs) can store information about past land surfaces longer than others (Shary, 1991; Shary et al., 2002). Comparisons of these MVs enable quantitative description of the land surface memory. Unfortunately, such investigations are not common in geomorphometry. However, investigations of soil memory are popular in classical soil science (Targulian and Sokolova, 1996; Targulian, 1999; Targulian and Goryachkin, 2008; Lin, 2011) and are used for quantitative palaeoenvironment reconstructions (e.g. Mitusov et al., 2009).

To understand land surface memory from a geomorphometrical point of view, one example of interaction between memory effects in soil and the land surface will be considered (Shary et al., 2002). MVs that depend on the gravity field potentially affect the present surface flow. These MVs are known as “morphometric pre-requisites of surface runoff” (Shary, 1995). The direction, pattern or other properties of flow will be changed where the land surface changes, e.g. due to tilting. At the same time, changes in the morphometric pre-requisites of surface runoff will take place, implying that this group of MVs will reflect new information about the land surface. However, some landforms that were formed in the past can be resistant to land surface transformation. These old forms are described by MVs that are not dependent on the gravity field. These MVs are known as “characteristics of geometrical landforms” (Shary, 1995). In the case of land surface transformation, the characteristics of soils (sediments and vegetation) that formed under the long-term impact of flows will also change at different rates. In this situation, such landscape properties will show stronger correlations with characteristics of geometrical landforms rather than with morphometric pre-requisites of surface runoff: i.e. with field-invariant rather than with gravity-field-specific MVs.

The above example considers relatively fast transformation of a large part of the land surface as a whole body without changes in the local geometry of the surface. Such events are more likely in tectonically active regions. For relatively stable geological regions, land surface transforms are mainly due to erosion–accumulation processes. For example, a pattern of surface flows varies in time due to deposition of sediments in an old channel; hence the location of sediments indicates the past pattern of surface flows. The location of the sediments can be determined by material measurements (sampling) and by the analysis of land surface features.

The general idea of land surface memory detection in conditions of long-term sedimentation in tectonically stable regions is clear. Many features of spatial distribution of colluvial (slope) deposits, however, cannot be described in general terms. Methods of geomorphometry and statistical comparisons have to be used for quantitative description of land surface memory, with a detailed geomorphometrical explanation of the memory. Generation of such an explanation is the goal of the present investigation.

The research is based on consideration of correlations between MVs of the modern land surface and thickness of colluvial deposits

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of different ages, in conditions of a relatively small dry valley located in a tectonically stable area with unindurated surface materials.

2. Study area and methods

2.1. Region

The study area (54° 04′ N; 10° 15′ E) is located in northern Germany approximately 40 km south of Kiel (Fig. 1). The main morphological elements of the surrounding landscapes, as well as the substrate (outwash sands at the study site), result from the Weichselian Glaciation (Piotrowski, 1991). After some alteration of the land surface during the Late Glacial, natural soil formation proceeded until the Neolithic settlers cleared the forests around 4300 cal BC (Hoika, 1993, 1994; Hartz, 2004). The area has been under extensive agricultural land use since the Slavonic Period of Early Medieval Times (Dreibrodt et al., 2009). Today, Cambisols and Luvisols (FAO, 1998) are the dominant soil types in the region (Schleuss, 1991). At many sites these soils are developed in the remnants of capped pristine soils on upper slopes, or in the associated colluvia downslope. The land use and soil erosion history of the region are well investigated (e.g. Garbe-Schönberg et al., 1998; Lütjens and Wiethold, 1999; Dreibrodt and Bork, 2005).

2.2. Study area

The study area is situated in the uppermost part of a small dry valley. Trenches up to 3 m deep and up to 200 m long were excavated in the thalweg area; 23 cores up to 2 m depth were made on slopes (Fig. 1). A digital elevation model (DEM) with a 5 m grid mesh was made based on a differential GPS survey. The thickness of colluvial layers was measured every 20 cm along the trenches. Mean thickness of colluvial layers was calculated for each DEM cell that was crossed by the trenches. For auger cores, however, this procedure was unnecessary. As a result, the data set consisted of the 71 points shown in Fig. 2.

2.3. Colluvial deposits

The sequences of colluvial layers and soil horizons were identified and described using conventional methods (FAO, 1998; Munsell, 2000; Ad-hoc-Arbeitsgruppe Boden, 2005). Colluvial layers were denoted with the abbreviation M for "*migrare*" (lat.) according to Ad-hoc-Arbeitsgruppe Boden (2005). Detailed description of the soils and colluvial deposits was made by Dreibrodt et al. (2009).

Colluvial deposits were considered because their spatial distribution is strongly dependent on erosion–accumulation processes caused by surface flow. An important advantage of the investigation of colluvial deposits is the possibility of determining their age. Sequences of colluvial deposits are mainly used for the assessment of palaeoerosion during the Holocene and palaeorelief reconstruction (e.g. Dotterweich, 2008; Dreibrodt et al., 2010). Quantitative models of spatial distribution of colluvial deposits (e.g. Ries, 2002; Follain et al., 2006; Reiss et al., 2008; Mitusova, 2010) are based on geomorphometric analysis of the modern land surface and on methods of predictive soil mapping (e.g. Moore et al., 1993; McBratney et al., 2000, 2003; Scull et al., 2003).

2.4. Morphometric variables

During recent decades many MVs calculated from DEMs have been introduced to geomorphometry (e.g. Shary, 1995; Zhou et al., 2008; Hengl and Reuter, 2009). In our investigation the land surface was described by 17 MVs of general geomorphometry (Table 1). These MVs were combined by the physical–mathematical theory of Shary (1995) into one system, with clear internal relationships (e.g. Evans, 1980; Shary, 1995; Evans and Cox, 1999; Shary et al., 2002; Sharaya and Shary, 2003; Shary et al., 2005), which is important for the correct interpretation of correlations between thickness of colluvial deposits and the MVs.

The MVs were divided into three groups: i) morphometric pre-requisites of surface runoff; ii) characteristics of land surface dissection; and iii) characteristics of geometrical landforms. Depending on the situation, one group of MVs or another can show the best correlations with landscape properties (e.g. Mitusov, 2001; Mitusov and Mitusova, 2005; Shary, 2005). Maps of the basic MVs are depicted in Fig. 2. For the calculation of the MVs, Analytical GIS Eco was used.

According to the statistical hypothesis of Shary (1995), the frequency of occurrence of signs of any curvatures can be predicted in a statistical sense for large data sets. Based on this hypothesis, positive and negative signs of kh (horizontal curvature), kv (vertical curvature) and H (mean curvature) occur in equal proportions, $kmin$ (minimal curvature) < 0 or $kmax$ (maximal curvature) > 0 occurs in the two-thirds of observations, and $kmin > 0$ or $kmax < 0$ in the one-third. The statistical hypothesis can also predict combinations of the signs of different curvatures. Hence, in the one-third of observations the sign of H does not coincide with

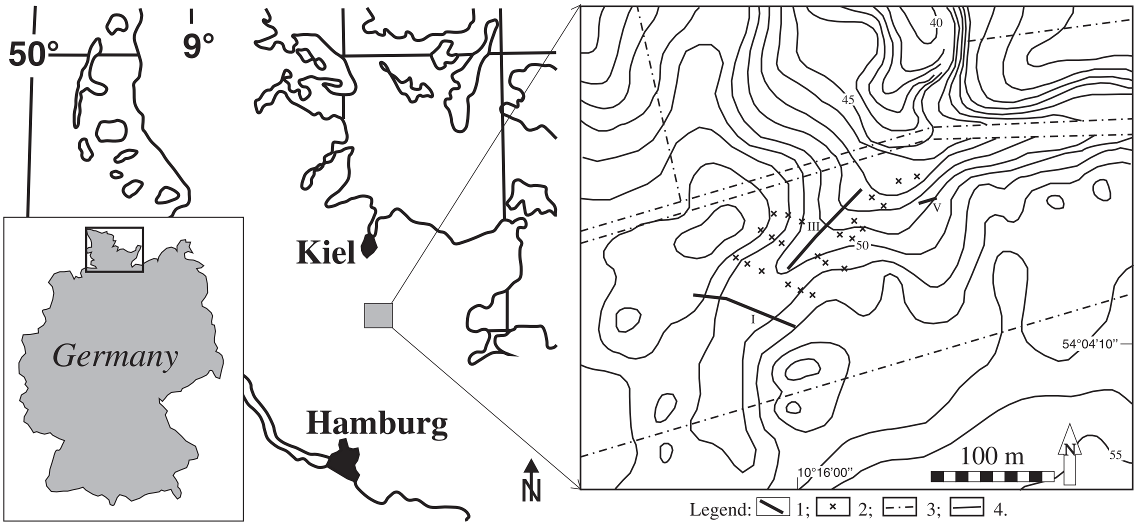

Fig. 1. Study area. Legend: 1 — trenches (I, III and V), 2 — auger sites; 3 — hedgerows; 4 — contour lines (contour lines have 1 m vertical interval).