A classification of geomorphometric variables

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Abstract—**A hierarchical taxonomy of fundamental geomorphometric variables is proposed (Table 1) covering both those related to fields and those characterizing objects. The former include field-specific and field-invariant as well as local and regional variables. Local variables may be point-based or area-based. Variables for objects differ between areal, linear and point features.**

I. Introduction

Geomorphometry from DEMs is a young field that has inherited some concepts from earlier cartometric measurements (Maling, 1981; Zavoianu, 1985), and some from more qualitative approaches to terrain analysis based on air photos and satellite remote sensing (Townsend, 1981). The structure of the field is still forming, with many concepts, methods and applications recognized by Hengl and Reuter (Eds., 2009). The types of variable that are relevant are an important aspect of this structure, and here we attempt to increase the degree of organization and illuminate relations between different variables. We focus on the more fundamental variables, rather than combined indices (for which, see Table 4 of Schmidt and Dikau, 1999). Classification clarifies relationships, and may highlight neglected or formerly unused variables. We hope that readers may discover useful new variables, or new relationships between variables, from our Table 1.

Evans (1972) attempted to provide some structure to general geomorphometry: he complained about the proliferation of indices and the reinvention of old variables under new names. His 'derivatives and moments' scheme, however, covered only local variables - a small part of the field. It was considerably extended by Shary et al. (2005): focusing on general rather than specific geomorphometry, they classified variables as local, regional or global, any of which can be field-specific or field-invariant. Here we propose a more comprehensive classification, and provide a hierarchical structure.

Moore et al. (1991) and Wilson and Gallant (Eds., 2000, pp.7-9) listed numerous variables used in geomorphometry. Many further variables are specific to particular landforms or elementary forms, as discussed in Hengl and Reuter (Eds., 2009) and Goudie et al. (Eds., 1990). In Table 1 we give a classification of the more fundamental variables in both general and specific geomorphometry.

A number of dichotomies are applicable. The most widely accepted division of geomorphometry is into general and specific: the related variables are field-based and object-based, and we take this as the primary division. Field-based variables can be defined at or around any point on the land surface. Geomorphologists have emphasized variables related to the gravity field, but the relation of the land surface to other fields such as wind or solar radiation is important, not only in climatology but also for surface processes. There are as yet only a limited number of variables in the 'specific to other fields' category, so it is not further subdivided here.

II. Field variables: local and regional

The systems proposed by Evans (1972) and Krcho (1973) for field variables are local-based, relating to a vanishingly small area around each point, and in theory involving planes or surfaces tangential to the actual surface at a point. In practice, when measured from a DEM, estimation uses a local neighbourhood: at least one neighbouring point but preferably a 3×3 or 5×5 window. Both systems are based on changes of altitude (1st, 2nd, or 3rd partial derivatives), both in the direction of flow lines, controlled by the gravitational field, and in the orthogonal contour line direction.

As computer power developed, these local variables were supplemented by regional variables based on lines of surface flow, especially important in hydrology-related applications (emphasized in Wilson and Gallant, 2000). These require searching upslope and downslope, if necessary over long distances until a ridge line or channel / thalweg is reached; they therefore have a problem with the boundaries of non-global DEMs. Regional variables include area drained, either to a point on a channel (total catchment area), or per unit contour width on a slope (specific catchment area), and distances to topographically significant lines or points. Catchment area controls quantity of water, but distance affects travel times. Having traced a flow line from ridge to channel, we can also define any point's position in the vertical / horizontal as a proportion of the drop / distance from ridge to channel, as well as the absolute drop / distance in both directions.

A complication arises because variables such as local relief (highest minus lowest altitude) describe a fixed, finite area (usually square or near-circular). We classify this, and other statistics within fixed radii, as 'area-based local field variables', as opposed to conceptually 'point-based'.

Most consideration of curvatures has used plan, profile or transverse curvature, which are local point-based variables defined in the gravity field (Schmidt et al., 2003). This is a geomorphologist's approach, whereas starting from a mathematical, geometric viewpoint and following Gauss, a rich set of field-invariant curvatures can be defined (Shary, 1995; Shary et al., 2005), for example, the maximum, minimum and total curvatures of the surface. These can be defined at any point and thus form a third type of field variable, distinct from those related to the gravity or other fields. As they are independent of any coordinate system, they are stable under tectonic tilting, with implications for geomorphological history.

III. Characterizing objects

In classifying object-related variables, the above considerations are not relevant except that any field variable can be averaged within the defined extent of a geomorphometric (geomorphological) object. A topological classification seems more appropriate and to date most variables used relate to linear or to areal objects. We are dealing with a single-valued surface, albeit in 3-D, so volumetric objects are considered geological or pedological rather than geomorphological. Point objects such as summits, passes or pit-centres have attributes limited to local point-based variables, unless areas or lines are considered. Actually, all linear and areal geomorphometric objects are 3-D when studied in detail, but it is convenient to conceptualize them as 1-D or 2-D.

Objects are meaningful parts of the land surface such as elementary forms (defined for homogeneity in point-based local variables: Minár and Evans, 2008), land elements (taking into account position also) or landforms (where genesis is considered: Evans, 2011): they are not arbitrary squares, map sheets, circles or transects. Landforms include the important special case of drainage basins (catchments) (Zavoianu, 1985). The shape and pattern of objects, whether areas, lines or points, is a new consideration, absent among field variables. Some approaches subdivide the whole land surface, with or without recognition of contiguity (regionalization versus classification, and various hybrids) (Dragut and Blaschke, 2006). Other approaches, such as the recognition of dunes, drumlins or cirques, select patches which may be contiguous or not, and exclude the rest of the surface (Evans, 2011). Variables based on contiguities of objects, and quality of edges, require much fuller investigation.

Objects on the land surface have long been defined subjectively, with increasing attempts to improve consistency, followed by attempts (of varying success) to define them automatically from DEMs. Once areal and linear objects have been delimited and measured, frequency distributions of their size and shape may be summarized by descriptive statistics such as moment- or quantile-based measures. Objects may have multiple (alternate) boundaries, or fuzzy boundaries with fields of varying degrees of object or class membership. Normally these will be 'defuzzified' before geomorphometric characterization (Arrell et al., 2007), but it is conceivable to characterize them by a frequency distribution of a geomorphometric variable rather than by a single value (Evans, 2011). Fuzziness may also apply to linear objects such as river channels and networks, especially at different stages of discharge.

IV. Finale

Shary et al. (2005) also distinguished geomorphometric variables that preserve relatively stable statistical characteristics with change of the input DEM density (scale-free variables) from others that change without limit as the DEM density increases (scale-dependent variables). This dichotomy cuts across other classes, and hence is not covered in Table 1. Altitude is scale-free, but its derivatives (slope gradient and curvature) are scale-dependent (Evans, 1972; Wood, 1996), and reduce in magnitude as grid mesh increases. Regional variables such as catchment area and depression area are scale-free, but the majority of area-based local variables are scale-dependent. Most object variables are scale-free, except for perimeter and those that include stream length. All variables are affected by random error that increases with the coarseness of sampling (e.g. the spacing between data points in a DEM).

Why do we use the term 'variables' in preference to 'parameters' as used by Schmidt and Dikau (1999) and Hengl and Reuter (Eds., 2009)? A parameter is defined as a constant in a fitted model, a variable specifying the mathematical form of a distribution, or a variable held constant while others are being investigated. Thus the term should be used more sparingly, not for variables that are continuous over space and/or time. Variable (and attribute) are more general terms.

It is worth considering what type of variable is relevant to a particular problem, and the alternative ways in which it may be defined. Some analyses may require variables of a single class: others may work best if a balance between variables from different classes is achieved. Table 1 is not comprehensive, but does cover the main variables or types of variable in geomorphometry – other than combined indices, for which there are very many possibilities.

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TABLE I. CLASSIFICATION OF THE FUNDAMENTAL GEOMORPHOMETRIC VARIABLES OR CHARACTERISTICS.

1. FIELD VARIABLES

1.1 VARIABLES SPECIFIC TO GRAVITY FIELD

1.1a LOCAL: POINT-BASED
Zero order (Primary): Altitude;
First order: Slope gradient and Slope aspect;
Second order: Plan, Profile and Rotor curvatures;
Third order: Change of plan, profile or rotor curvatures.

1.1b LOCAL: AREA-BASED
Descriptive statistics of any of the above, within given radius;
Percentile of height, within given radius;
Relief, within given radius;
Drainage density within given radius.

1.1c REGIONAL (POSITIONAL)
Height/Depth above/below any regional level (hill/depression boundary, thalweg, ridge-line);
Distance to stream; Distance to ridge (Flow path);
Total or Specific Catchment Area; Total or Specific Dispersal Area.

1.2 VARIABLES SPECIFIC TO OTHER FIELDS

Angle of incidence of solar radiation;
Angle of incidence of wind flow;
Amount of solar radiation, integrated over a given time period;
Degree of exposure to / shelter from a wind regime.

1.3 FIELD-INVARIANT VARIABLES

1.3a LOCAL: POINT-BASED
Principal curvatures: Maximal, Minimal and Total (Gaussian) curvature;
Unsphericity and Mean curvature.

1.3b LOCAL: AREA-BASED
Descriptive statistics of any point-basedvariable, within given radius.

2. OBJECT VARIABLES

2.1 AREAL
Area; Length; Width; Perimeter; Drainage density; Shape; Spatial pattern;
Edge characteristics; Neighbours;
Mean (and other descriptive statistics) of any field variables, for any specific landform or element.

2.2 LINEAR
Stream order; Stream link length; Stream direction; Flowline length;
Relative height (between stream and ridge);
Morpholineament orientation;
Mean (and other descriptive statistics) of any of the above variables for any specific line (thalweg, flow line, ridge, morpholineament).

2.3 POINT
Point-based local variables.