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Case study

# ArcGeomorphometry: A toolbox for geomorphometric characterisation of DEMs in the ArcGIS environment

Juan P. Rigol-Sanchez [a,b,*], Neil Stuart [c], Antonio Pulido-Bosch [a]

[a] Water Resources and Environmental Geology, Department of Biology and Geology, University of Almeria, E-04120 Almeria, Spain
[b] Department of Geology, University of Jaen, E-23071 Jaen, Spain
[c] Institute of Geography, School of GeoSciences, University of Edinburgh, Edinburgh EH8 9XP, Scotland, United Kingdom

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ABSTRACT

A software tool is described for the extraction of geomorphometric land surface variables and features from Digital Elevation Models (DEMs). The ArcGeomorphometry Toolbox consists of a series of Python/Numpy processing functions, presented through an easy-to-use graphical menu for the widely used ArcGIS package. Although many GIS provide some operations for analysing DEMs, the methods are often only partially implemented and can be difficult to find and used effectively. Since the results of automated characterisation of landscapes from DEMs are influenced by the extent being considered, the resolution of the source DEM and the size of the kernel (analysis window) used for processing, we have developed a tool to allow GIS users to flexibly apply several multi-scale analysis methods to parameterise and classify a DEM into discrete land surface units. Users can control the threshold values for land surface classifications. The size of the processing kernel can be used to identify land surface features across a range of landscape scales. The pattern of land surface units from each attempt at classification is displayed immediately and can then be processed in the GIS alongside additional data that can assist with a visual assessment and comparison of a series of results. The functionality of the ArcGeomorphometry toolbox is described using an example DEM.



## 1. Introduction

The analysis and classification of the land surface at various landscape scales is a prerequisite for many studies within the geosciences. In the last two decades geomorphometry – the discipline of quantitative land-surface analysis – has undergone rapid progress due to the flexibility and rapidity with which the required computations can now be performed through the computerised analysis of digital elevation models (DEMs) (Pike, 2000; Pike et al., 2009). DEM analysis is now used to characterise and to extract relevant landscape features in fields as diverse as geomorphology, surface hydrology, visual impact assessment, watershed management, land management, cellular telecommunications, civil engineering, oceanography, ecology, soil science, planetary science, wind energy planning. The almost global coverage of gridded DEMs at resolutions between 30–90 m, from sources such as the ASTER Global Digital Elevation Model (GDEM) and the Shuttle Radar Topographic Mission (SRTM) has renewed interest in semi-automatic methods for the characterisation of contrasting landscapes and for consistently identifying what Lueder (1959) defines as second-order of relief features such as mountain ranges and plains and third-order relief features such as individual hills, mountains and valleys.

Although the basic DEM processing can be conducted almost automatically, there is still a need for user interaction at various stages, for example to review the effects of different analyses and parameterisations, to compare the results of alternative landscape segmentations and classifications and to interpret and to contextualise the results, especially when performed at multiple scales. The ability to visually explore and compare many results along with the availability of faster and friendlier GIS toolboxes have been recognised as important new developments in geomorphometry software (Wood, 2009a; Gessler et al., 2009). Gessler et al. (2009) have identified a number of topics needing research in the field of geomorphometry. They include, among others, algorithm development for true multi-scale characterisation, maintaining operational ease of use despite increasing complexity of morphometric procedures, and tools for static and dynamic visualisation of measures and surface objects. Consequently,

* Corresponding author at: Water Resources and Environmental Geology, Department of Biology and Geology, University of Almeria, E-04120 Almeria, Spain.
*E-mail addresses:* jprigol@ual.es (J.P. Rigol-Sanchez), N.Stuart@ed.ac.uk (N. Stuart), apulido@ual.es (A. Pulido-Bosch).

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there is a need for multi-scale land surface analysis and visualisation tools that facilitate common tasks such as performing multi-scale analyses and exploring the results of using different analysis window sizes and classification parameters and hence finding appropriate settings for identifying landscape characteristics and specific geomorphometric features.

Previously, the analysis of DEMs was usually conducted using specialist, stand-alone software programs. However, the widespread adoption of GIS in academic, professional and commercial arenas, the increased processing power of these systems for handling and visualising DEMs and the large volumes of spatial information now available in GIS formats are practical drivers for greater land surface analysis functionality to be included within GIS. As one means of achieving this, we present here the ArcGeomorphometry tools for geomorphometric characterisation of DEMs in the ArcGIS environment. The tools are implemented in Python/Numpy and enable a wide range of analyses to be conducted efficiently on DEMs. To understand the range of methods presently supported, the more common digital methods for land surface analysis are briefly reviewed. The functionality of the ArcGeomorphometry toolbox is then presented and compared to other existing software to locate it between the more comprehensive, specialist tools and the more limited functionality found in commercial GIS. The key features and operations of ArcGeomorphometry are described and illustrated using an example DEM. Conclusions are then drawn about the utility of the ArcGeomorphometry tools and scope for its further enhancement indicated.

## 2. The analysis of the land surface using digital methods

Geomorphometry is the science of quantitative land-surface analysis (Pike, 1995). Information produced by geomorphometry supports the study of many earth surface processes where landforms act as a controlling or boundary condition (Dehn et al., 2001). Applicable at different scales, geomorphometric analysis can range from the identification of localised landforms through to the characterisation of extensive regional or continental landscapes (Pike, 2000). This leads to the important distinction between specific and general geomorphometry (Evans, 1972). While specific geomorphometry analyses the geometric and topological characteristics of 'landforms' (i.e. bounded segments of a land surface that are discrete and may be discontinuous), general geomorphometry analyses 'land surface form' (i.e. a continuous field that covers the whole globe) (Evans, 2012). Thus, the related variables are object-based and field-based (see Evans and Minar (2011), for a comprehensive classification of the fundamental variables).

A variety of equations have been proposed to calculate the fundamental geomorphometric variables. Well known examples include Evans (1972, 1979, 1980), Band (1986), Jenson and Domingue (1988), Pennock et al. (1987), Zevenbergen and Thorne (1987), Dikau (1989), Moore et al. (1993), Shary (1995), Wood (1996), Florinsky (1998), Wilson and Gallant (2000), Shary et al. (2002) and Schmidt et al. (2003). The present study is focused on the algorithms for the calculation of field local variables, therefore methods for calculating object and regional variables (e.g stream order, distance to stream, catchment area) are not discussed here. In this regard Evans' approach is the most widely used method in relation to field local variables.

Evans' method is based on fitting a second-order polynomial function to elevation in a central point and its neighbours and then deriving local gradient and curvatures (mutually orthogonal – profile and plan curvatures, and minimum and maximum curvatures) from the function:

$$z = ax^2 + by^2 + cxy + dx + ey + f \quad (1)$$

where $a$–$f$ are quadratic coefficients, $x$ and $y$ are local spatial coordinates, and $z$ is elevation. Gradient and curvatures ($[L^{-1}]$) can be derived as (Evans, 1972, 1979, 1980; Schmidt et al., 2003):

$$G = (d^2 + e^{2^{1/2}}) \quad (2)$$

$$C_p = -\frac{ad^2 + 2cde + be^2}{(d^2 + e^2)(1 + d^2 + e^2)^{3/2}} \quad (3)$$

$$C_c = -\frac{ae^2 - 2cde + bd^2}{(d^2 + e^2)^{3/2}} \quad (4)$$

$$C_{p-\min} = -a - b - ((a - b)^2 + c^2)^{1/2} \quad (5)$$

$$C_{p-\max} = -a - b + ((a - b)^2 + c^2)^{1/2} \quad (6)$$

where $G$ is gradient, $C_p$ is profile curvature, $C_c$ is contour curvature, $C_{p-\min}$ is minimum profile curvature, and $C_{p-\max}$ is maximum profile curvature.

Several extensions to Evans' method have been proposed (Zevenbergen and Thorne, 1987; Shary, 1995; Wood, 1996; Shary et al., 2002). Zevenbergen and Thorne (1987) extended Evans' method for estimating land surface slope gradient and curvature by fitting a (partial) fourth-order polynomial surface to elevation values within a processing $3 \times 3$ window centred on a particular cell of a DEM. Shary (1995) extended Evans's method and proposed several new curvature measures, distinguishing those that depend on gravity (i.e. slope) (e.g. rotor, difference curvature) from those that are independent of slope and are derived using only surface geometry (e.g. unsphericity,). Shary (1995) used a quadratic polynomial function and a linear equation system as Evans (1980) but forced the locally interpolated surface to match the elevation of the central point of the $3 \times 3$ window centred at a particular cell (Schmidt et al., 2003). These measures can be derived from Eq. (1) as (see Shary (1995), Shary et al. (2002), and Schmidt et al. (2003), for a complete set of formulae):

$$C_f = \frac{c(d^2 - e^2) - de(a - b)}{(d^2 + e^2)^{3/2}} \quad (7)$$

$$C_m = -\frac{a(1 + e^2) - 2cde + b(1 + d^2)}{2(1 + d^2 + e^2)^{3/2}} \quad (8)$$

$$C_g = -\frac{ab - c^2}{(1 + d^2 + e^2)^2} \quad (9)$$

$$C_{tr} = \frac{c(d^2 - e^2) - de(a - b)^2}{(d^2 + e^2)^2(1 + d^2 + e^2)^2} \quad (10)$$

$$C_{tot} = a^2 + 2c^2 + b^2 \quad (11)$$