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Morphometric signatures of landslides

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Abstract: Morphometric parameters are widely used in landslides mapping and modeling. Here we present a framework/procedure to analyze the morphological fingerprints of landslides in a territory. For this purpose we identify a set of morphometric variables and a procedure to distinguish different morphological landslide signatures. Our intent is to create a library of the landslide morphological signatures as much as possible complete. Results will be helpful to improve the ability to detect landslide on the surface, the modeling capabilities, and the knowledge of landslide processes.

Keywords: Landslide, Geomorphometry, signature, GIS

1 Introduction

Pike et al. (2008) defined Geomorphometry as the science of quantitative land-surface analysis. The term Geomorphometry has got a great impulse and a renewed interest starting from the book edited by Hengl & Reuter in 2008, which probably represents a sort of milestone for this interdisciplinary field. The primary objective of geomorphometry is the characterization of discrete surface features (landforms) through the analysis of land-surface parameters (e.g. slope, curvatures, etc.). Recently Jasiewicz & Stepinski (2013) introduced the concept of "geomorphons", a new approach (criterion) to identify/characterize surface landforms.

Morphometric analysis is widely used in landslide mapping and modeling. Geomorphologists implicitly (i.e. exploiting their own experience/capacity to analyze the shape of the slopes looking, as an example, for an upper concavity and lower convexity on a slope, that typically indicates the presence of a landslide -

Guzzetti et al. 2012) use morphometric information to map landslides in the field or through aerial photo-interpretation. Indeed spatial variation in slopes, aspect, roughness and curvature help photo-interpreters to detect and map landslides, particularly when slope movements are not recent and their surfaces not straightforward discernible by their photographic signature (i.e. by the variation in tones, textures and patterns in the image).

Landslide models can explicitly consider this information. For instance, the slope parameter is fundamental in physically-based landslide models, such as those based on the infinite slope criteria (e.g. Baum at al. 2008, etc.), or based on a more complex three-dimensional landslide schema (e.g. Mergili et al. 2013).

However, the widest use of morphometric parameters in the framework of landslide hazard assessment, is to estimate their importance as an explanatory variable in landslide susceptibility studies (e.g. Rossi et al. 2010, etc.). For this purpose mainly multivariate statistical classification models are used. Those statistical approaches evaluate the likelihood of a landslide occurring in a given area, given a set of local geo-environmental conditions which mostly include geomorphic parameters. Researchers have also attempted at quantifying morphological changes produced by landslides locally or in small areas. As an example, land-surface parameters have been used to identify active landslides (Berti et al. 2013) and, coupled with remote sensing data and techniques, to create reliable landslide event inventories (Mondini et al. 2013).

The lack of a set of common tools to identify and quantify these changes is an important limitation when trying to generalize (or extend) results obtained locally. In fact at present, no common criteria, or set of variables or analysis tools exist to globally compare such morphological changes.

2 The framework

2.1 Description

We have implemented a procedure, through an open source framework, to analyze the morphometry of landslides and non-landslides areas in a territory, and hence to identify the combination of morphometric conditions that characterize the areas where landslides have been mapped (Rossi et al. 2013). Our aim is to build a standard procedure to compare globally the landslide morphometric characteristics.

The procedure will be helpful to improve: (a) the ability to detect landslides from the analysis of Digital Elevation Models (DEMs), (b) the capabilities to model landslides in different environmental context, and (c) the knowledge of landslide processes.

The proposed framework makes use entirely of open source software and it consists of three steps (Figure 1).

In the first step a Digital Elevation Model and a landslide inventory map are selected as inputs. Then a software tool extract a set of morphometric variables from the Digital Elevation Model both for different type of landslides in the inventory map, and for landslide free areas. The tool exploits GRASS GIS (GRASS GIS Development team, 2013) to calculate, for the different landslide types (classes) and for different kernel sizes, the main land-surface morphometric parameters: slope, cross curvatures, longitudinal curvature, etc. This part of the procedure exploits the GRASS GIS morphometric algorithms r.param.scale (Wood 1996) and r.slope.aspect (Horn 1981) but we are planning to introduce other algorithms, e.g. the aforementioned r.geomorphon. In the second step the Empirical Distribution Functions (EDFs) of the values of each parameter are analyzed using R (R Core Team, 2014) for each combination of class and kernel. The results of this analysis are stored in the system as R data files which represent the obtained Geomorphological Signature Function. Red connecting lines in Figure 1 identify the sequence and the tools used in the first two steps.

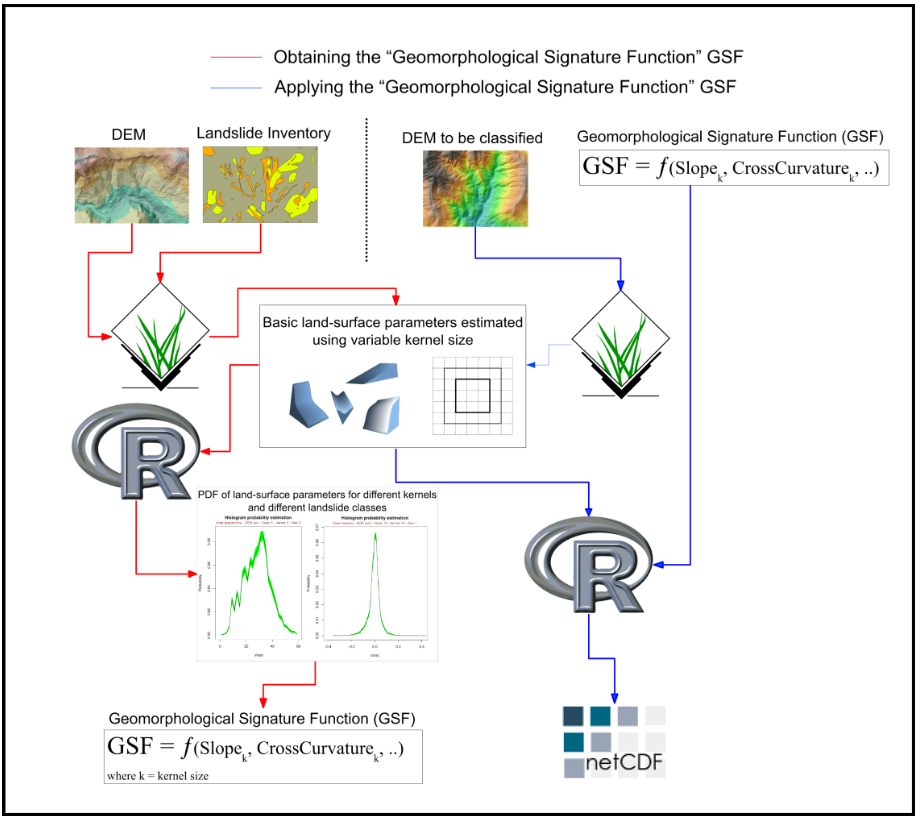

Figure 1: The procedure steps

The third step (blue connecting lines in Figure 1) deals with the application of the previously obtained EDFs and can be applied to another adjacent/similar zone where comparable slope processes and digital elevation model exist. Over this zone the basic land-surface parameter layers, the same type (slope, curvature, etc.) as used in the first two steps, must be re-calculated through GRASS GIS. Then, using R again, the stored EDF functions are exploited to estimate the probability that each single pixel of the zone belongs to a specific class among those defined in the step 1, i.e the landslide types and the no-landslide areas. This is done for each land-surface parameter layer and for each kernel size considered in the first step.

The output of the third step is a set of raster layers, stored into a netCDF file, where each raster corresponds to a combination of land-surface parameter, kernel size and landslide class. The values of the raster cells range from 0 to 1 and represent the probability of each cell for being in each landslide class given the particular combination of land-surface parameter and kernel size. The NetCDF was chosen since it is a well documented format, capable to maintain a huge amount of raster layers, appendable (in case previous results must be enhanced with more recent ones), portable, scalable and since there are a lot of R libraries able to efficiently read and write this format.

2.2 A preliminary application

The method was preliminarily applied on a small test area of the territory of the Messina Province, Sicily (Italy), where a high-resolution DEM (1m) was available. The area was subdivided in two adjacent basins.

In the first basin we have applied the proposed procedure using landslides and no-landslide areas information to identify EDF functions. For this basin a DEM and a landslide inventory map were available. Landslide inventory include different types of slope movements: rock falls, flows, slides, and complex movements. Here we present an example of the analysis performed considering small (3m), medium (33m) and large (63m) kernels sizes and few land-surface parameters: slope, longitudinal curvature, i.e. measured in direction of gradient, and cross curvature, i.e. measured in direction perpendicular to gradient).

In the second basin we used the derived EDF functions to calculate the probability of each cell for being in each landslide class. Figure 2 B,C,D,E,F show the probability raster layers for each combination of land-surface parameter and kernel size. In the figure red color represents high probabilities while blue color corresponds to low probabilities.

In figure 2A we show the probabilities associated to the five landslide classes (No-landslide, Slide, Rock fall, Flow, Complex landslide) derived for a single pixel (red square in the inset) in the test area in the Messina Province. For simplicity we drawn the probabilities corresponding to a single pixel, but similarly the probabilities associated to each other pixel can be derived. The morphometric probability spectrum shown in Figure 2A shows that the considered pixel can belong to a rock fall landslide body.

3 Conclusions

The results of the procedure really depend on (i) the date of the mapped landslides respect to that of the DEM, (ii) the resolution of the DEM, (iii) the method used to produce the DEM, (vi) the post-processing procedures possibly applied to correct DEM artifacts, (v) the quality of the landslide inventories.

The proposed framework can be used to determine the geomorphological signature of the instability phenomena in a territory starting from the analysis of a specific set of geomorphic parameters. This information can provide a quantitative estimation of the relation existing among landslides and geomorphic parameters, and can be valuable (i) for the detection of landslides in a territory and (ii) for the landslide hazard assessment.

The strong interoperability between the used Open Source software, proved really powerful for both geomorphological and statistical analysis. Moreover it allows to exploit, in parallel, all the available CPUs of a very powerful computer, reducing the computational time. Open Source software was fundamental in our work of creating a standardized analysis framework that simplifies the collection of comparable geomorphometric results in other study areas.

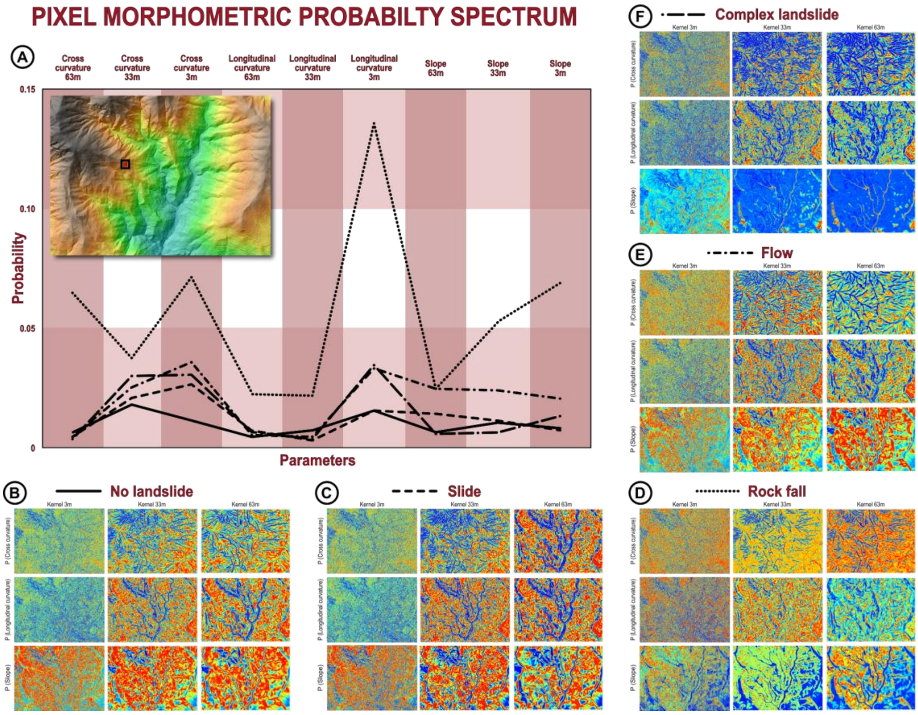

Figure 2: Example of the EDF functions and of the morphometric probability

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