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Research Paper

Detrended fluctuation analysis for spatial characterisation of landscapes

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The interactions among abiotic, biotic, and anthropic factors and their influence at different scales create a complex dynamic in landscape evolution. Scaling and multifractal analysis have the potential to characterise landscapes in terms of the statistical signature of the selected measure, in this case, altitude. This work evaluates the multifractality of altitude data points along transects that are obtained in several directions using Detrended Fluctuation Analysis (DFA) in a protected area adjacent to Madrid. The study data set consist of a matrix 2048 × 2048 pixels obtained at a 5 m resolution and extracted from a digital terrain model (DTM) using a Geographic Information System (GIS). We found that the distribution of altitude fluctuations at small scales revealed a non-Gaussian character in the statistical moments, indicating that Fractional Brownian modelling is not appropriate. Generalised Hurst dimensions (H(q)) were calculated on several transects crossing the area under study, all of which exhibited multifractality within a certain scale range. The results show a persistent behaviour in all directions because all of the H(q) values exceeded 0.5 and because there were differences in the intensities of the multifractality.

The analysis of the directionality by means of a generalised Hurst rose plot showed differences in the scaling characteristics both along and across rivers and reservoirs. This indicates a clear anisotropy that is mainly due to the directions of the two river basins located in the area and the basement movement as a consequence of gradual tectonic displacement, which must be considered in two-dimensional DFAs.

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1. Introduction

Landscape is created and modified by human and natural processes. The type of rock and soil, shape of the land, amount of rainfall, type of vegetation, river shape, size and flow, slope influence and drainage pattern are factors that may act individually or together to produce gradual changes in the dynamics of landscape morphology. Therefore, landscape

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topography is the result of the overall complex interactions among them (Veneziano & Niemann, 2000). The study of these dynamics is very complex. Various scientific disciplines have contributed to its understanding (Gupta, Castro, & Over, 1996).

Digital elevation models (DEMs) provide the information basis in many geographic applications, for example, topographic and geomorphologic studies and landscape analyses employing geographic information systems (GIS). The information obtained from those models has been combined with powerful mathematical methods such as fractal geometry to study landscape dynamics (Aguado, del Monte, Moratiel, & Tarquis, 2014; Cheng, Russell, Sharpe, Kenny, & Qin, 2001; Lovejoy & Schertzer, 2007; Lovejoy, Lavallee, Schertzer, & Ladoy, 1995). Topography has often been cited as an example of scaling processes in nature; when the topographic surface over a small region is properly magnified, it becomes indistinguishable from the topographic surface over a larger region (Mandelbrot, 1983; Mark & Aronson, 1984; Voss, 1985). Fractional Brownian motion (fBm), which has stationary first-order increments, has been used to model realistic topographic profiles (Mandelbrot & Van Ness, 1968). The interest in fBm is due to its ability to represent a wide class of non-stationary and statistically self-similar signals based on a few parameters, many of which are applied in image processing when modelling natural landscapes and textures (Jennane & Harba, 1994; Pentland, 1984; Zachevsky & Zeevi, 2014).

Based on Mandelbrot's work (Evertsz & Mandelbrot, 1992), the development of multifractal (MF) theory, which was introduced in the context of turbulence, has been applied in many areas, including earthquake distribution analysis (Hirata & Imoto, 1991), soil pore characterisation (Kravchenko, Boast, & Bullock, 1999; Tarquis, Gimenez, Saa, Dıaz, & Gasco, 2003), local-level environmental applications (Roering, Kichner, & Dietrich, 1999), image analysis (Sanchez, Serna, Catalina, & Afonso, 1992) and remote sensing (Cheng & Agterberg, 1996; Turiel, Isern-Fontanet, Garcia-Ladona, & Font, 2005). MFs are scaling fields; fields at different scales are related only by a transformation that involves the scale ratio, and locally different scaling laws have been found (Pachepsky & Ritchie, 1998). Based on several parameters extracted from this MF analysis, multifractal transects or multifractal surfaces (two-dimensional) can be generated (Mandelbrot, 1974; Meneveau & Sreenivasan, 1987, 1991; Novikov, 1990).

There are several MF methods that can be used to characterise scaling properties, and several relations among them can be found in the literature (Morató, Castellanos, Bird, & Tarquis, 2016). In the context of soils, the most popular method applied to soil transect data, including altitude, is the moment method developed by Halsey, Jensen, Kadanoff, Procaccia, and Shraiman (1986). This type of MF analysis can be directly applied on original data if the variable under study does not present any significant trend with distance. However, many authors do not check that condition, which can lead to inaccuracies (Tarquis et al., 2017). Detrended Fluctuation Analysis (DFA) is a MF method that includes the elimination of trends to properly analyse the scaling properties of local fluctuations.

DFA is commonly used to study long-term correlations in time/space series. This method is simply based on fluctuation analysis (FA), which consists of the calculation of fluctuation functions F(s) for different scales s. For long-term-correlated data, F(s) behaves like a power law. In a typical fluctuation analysis, the differences between the ends of the profiles of the segments are calculated. The squares of those differences represent the squares of the fluctuations in the segments. The FA does not eliminate trends, which is also true of conventional spectral analysis (Govindan et al., 2002). DFA has been applied in several fields, including studies on DNA sequences (Yu, Anh, & Lau, 2004), meteorological data (Lin & Fu, 2008; Tarquis, Morató, Castellanos, & Perdigones, 2008) and topographic data (Cao et al., 2017). In the last study, the authors applied MF-DFA on topographic data series extracted from shoulder lines in three areas on the Loess Plateau of China. Recently, the DFA algorithm has been extended to two dimensions (2D), assuming isotropy, for studying multifractality on 2D synthetic surfaces (Wang, Zou, 2014; Wang, Fan, & Stanley, 2016) and for classifying leaf textures (Wang, Liao, Li, & Liao, 2015).

Based on the studies described above, the present study uses Multifractal DFA (MF-DFA) to evaluate the multifractality of altitude data points along transects and for comparison with other works. The transects present several directions for studying the isotropic characteristics of the scaling properties to determine whether the DFA algorithm can be extended to 2D.

First, a statistical analysis of selected altitude transects and their increments was undertaken using several lags to study their stationarity. The MF-DFA technique was used to assess the scaling characteristics of the altitudinal transects for different directions using generalised Hurst dimensions and a Hurst Rose.

2. Materials and methods

2.1. Site description

The study area is known as “Monte de El Pardo”, which encloses 10537 ha. It is located a short distance from Madrid city at an altitude ranging from 908.2 to 595.3 m and with UTM zone 30N coordinates (Northern Hemisphere), X: 424303.456 to 434563.431 and Y: 4494559.721 to 4484299.529 (Fig. 1).

The location has its genesis as a continental detrital formation derived from the erosion of the granites of the Central System. This is clearly seen in the northwest of the area, where there is contact between the area of detritus and granite. According to the drainage network and slope map, two units that are clearly defined by the Manzanares river and correspond to each of its margins are distinguished in this zone (Monte del, 1982, p. 464). The area studied in this work corresponds to the right or western margins of the river. In this zone, two geomorphological units corresponding to two “watersheds” are distinguished. The small basin, which belongs to Trofa creek (a tributary of the Manzanares river) is located on the left side of the area (Fig. 1), and the larger basin is the Manzanares river. The watershed between the basins can be observed. The area of the Manzanares river basin has a long drainage network. The basin has a uniform SE–NW slope and a topography in which soft forms predominate without

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