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Multifractal fluctuations in seismic interspike series

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Abstract

Multifractal fluctuations in the time dynamics of seismicity data have been analyzed. We investigated the interspike intervals (times between successive earthquakes) of one of the most seismically active areas of central Italy by using the Multifractal Detrended Fluctuation Analysis (MF-DFA). Analyzing the time evolution of the multifractality degree of the series, a loss of multifractality during the aftershocks is revealed. This study aims to suggest another approach to investigate the complex dynamics of earthquakes.

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1. Introduction

Earthquakes belong to the class of spatio-temporal point processes, marked by the magnitude. Power-law statistics characterize their parameters. The Gutenberg-Richter law states that the probability distribution of the released energy is a power-law [1]. The epicentres occur on a fractal-like distribution of faults [2]. The Omori's

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law states that the number of aftershocks, which follow a main event, decays as a power-law with exponent close to minus one [3]. The fractal behavior revealed in these statistics could be considered as the end-product of a self-organized critical state of the Earth's crust, analogous to the state of a sandpile, which evolves naturally to a critical repose angle in response to the steady supply of new grains at the summit [4].

In recent studies, it has evidenced that characterizing the temporal distribution of a seismic sequence is an important challenge. The interspike intervals (time between two successive seismic events) follow a Poissonian distribution for completely random seismic sequences, while they are generally power-law distributed for time-clusterized sequences [5]. Time-clusterized seismic sequences are featured by time-correlation properties among the events, contrarily to Poissonian sequences, which are memoryless processes. But the probability density function (pdf) of the interspike intervals is only one window into a point process, because it yields only first-order information and it reveals none about the correlation properties [6]. Therefore, time-fractal second-order methods are necessary to investigate the temporal fluctuations of seismic sequences more deeply. The use of statistics like the Allan Factor [7], the Fano Factor [8], the Detrended Fluctuation Analysis (DFA) [9], has allowed getting more insight into the time dynamics of seismicity [10]. All these measures are consistent with each other, so that we can define one scaling exponent that is sufficient to capture the time dynamics of a seismic process.

But one scaling exponent is sufficient to completely describe a seismic process under the hypothesis that this is monofractal. Monofractals are homogeneous objects, in the sense that they have the same scaling properties, characterized by a single singularity exponent [11]. The need for more than one scaling exponent can derive from the existence of a crossover timescale, which separates regimes with different scaling behaviors [12], suggesting e.g. different types of correlations at small and large timescales [13]. Different values of the same scaling exponent could be required for different segments of the same sequence, indicating a time variation of the scaling behavior, relying to a time variation of the underlying dynamics [14]. Furthermore, different scaling exponents can be revealed for many interwoven fractal subsets of the sequence [15]; in this case the process is not a monofractal but multifractal. A multifractal object requires many indices to characterize its scaling properties. Multifractals can be decomposed into many-possibly infinitely many-sub-sets characterized by different scaling exponents. Thus multifractals are intrinsically more complex and inhomogeneous than monofractals [16] and characterize systems featured by a spiky dynamics, with sudden and intense bursts of high-frequency fluctuations [17].

A seismic process can be considered as characterized by a fluctuating behavior, with temporal phases of low activity interspersed between those where the density of the events is relatively large. This "sparseness" can be well described by means of the concept of multifractal.

The simplest type of multifractal analysis is given by the standard partition function multifractal formalism, developed to characterize multifractality in stationary measures [18]. This method does not correctly estimate the multifractal