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Multifractal detrended fluctuation analysis of earthquake magnitude series of Mexican South Pacific Region

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ABSTRACT

The multifractality of the earthquake magnitude series of seismicity occurred on the Mexican South Pacific Coast was investigated. The area is composed by five seismic regions that are characterized by different tectonic subduction features, due to the interactions between the La Rivera and Cocos plates with the North America plate. Among the five seismic regions, Jalisco is tectonically characterized by the existence of active spreading center (the East Pacific Rise). The multifractal analysis shows that all the five seismic regions are characterized by very close multifractal properties; however, Jalisco is featured by a higher persistence of the magnitude series.

1. Introduction

It is well known that critical complex systems are characterized by spatial and temporal long-range correlations, and the dynamical behavior depends of both the short and long-range interactions between the non-equilibrium states of the system. According to Varotsos et al. [34], earthquakes can be considered, in natural time domain, as a phase transition characterized by an order parameter. Furthermore, many studies have been focused on the fractal properties of the occurrences of EQs in several seismic regions around the world [2,6,24,25].

Those studies have been mainly dealt with the characterization of fractality of spatial and temporal distributions revealing scaling, monofractal and multifractal features (see, for instance, the Iranian seismicity analysis by Zamani and Agh-Atabai [40], the Japanese microseismicity analysis by Hirata and Imoto [11], the Italian inter-event time distribution study by Telesca et al. [27], Telesca and Lapenna [28], and the Mexican seismicity study by Flores-Marquez and Valverde-Esparza et al. [9]).

However, besides the space and time, another important parameter describing a sequence of earthquakes is the magnitude; such parameter is statistically characterized by the magnitude distribution well known as Gutenberg–Richter (GR) law [10], whose power-law form suggests a scale-free statistics of the fractal tectonic plates. Several studies [19–21,33,35] suggest that the crust evolves as a critical complex system, implying that the seismic phenomenon could be characterized like a self-organized critical process (SOC) [4,5], where the magnitude of the earthquakes is one of the measurable dynamic variables and is associated with the released energy.

Although the most of the studies of fractal/multifractal characteristics of earthquake sequences have been extensively focused on the space and time domain [7,26,30], very few works have investigated the fractal/multifractal features of the earthquake

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Fig. 1. Subduction zones located along the Mexican South Pacific Coast and the five sub regions studied.

magnitude series. Lennartz et al. [14] studied the long-range correlations of the magnitude sequences in Northern and Southern California by using the detrended fluctuation analysis (DFA) and showed that the temporal fluctuations of magnitudes are characterized by long-term memory. Varotsos et al. [32] applying the DFA to the magnitude sequence of California seismicity between 1973 and 2003, found that, while in the regimes of stationary seismic activity long-range temporal correlations exist between earthquake magnitudes with a DFA exponent ∼0.6, these correlations break down and the value of the exponent becomes even lower than 0.5, thus showing anti-correlated behavior, before the occurrence of the largest earthquakes. They also found, more or less similar results by applying DFA to the magnitude time series of the Japanese region by considering the seismicity during 1967–2003 [36] as well as by focusing on the periods just before the occurrence of major earthquakes from 1 January 1984 until the Tohoku EQ occurrence on 11 March 2011 [37]. Notably, the application of DFA to the time series of preseismic electric signals also reveals long range temporal correlations [38,39]. Very recently, Aggarwal et al. [1] characterized the multifractal properties of the earthquake magnitude sequences of Kachchh (India) seismicity considering both the whole and the aftershock-depleted catalogues.

In this paper we studied the fluctuations of magnitudes of earthquakes occurred in the Mexican Subduction Zone (MSZ) on Pacific coast by using the multifractal detrended fluctuation analysis. In MSZ three tectonic plates are interacting: the Rivera and Cocos plates interact between them and both move above the North America plate. The MSZ is divided in five different seismotectonic regions on the basis of the *b*-value of the GR law [15,41]. They are Jalisco, Michoacan, Guerrero, Oaxaca and Chiapas (Fig. 1). Some recent studies analyzed the temporal and spatial fluctuations of the seismic sequences occurred in the MSZ by using statistical tools that were developed in the theory of complex dynamical systems. For instance, the non-extensivity approach based on the Tsallis entropy was applied to the seismicity occurred from 1988 to 2010 [31], indicating a possible correlation between the non-extensive parameters and the seismicity pattern associated with the inclination angle of subduction; in particular, the highest non-extensivity parameter q value was obtained in Jalisco, while Oaxaca was characterized by the lowest q value. Very recently the application of the method of the visibility graph to the earthquake magnitude time series of the five seismic regions of the MSZ has revealed a strong relationship between the topological and the seismological parameters of the seismicity of the five Mexican subduction regions [29].

In this paper, we apply the multifractal detrended fluctuation analysis to investigate the multifractal properties of the earthquake magnitude sequences of the five subduction regions of the MSZ. This investigation has been never performed so far.

2. Data

The analyzed data correspond to the seismicity catalogue of the Mexican Subduction Zone for earthquakes occurred from 2005 to 2010. The Rivera, Cocos and North America plates' boundary is characterized by an oblique motion, as in between transform faults. We assume a segmentation of this boundary proposed by Zuñiga and other authors [23,13,16,22,41], in five zones on the basis of their studies that takes into account the geometry of the subducted Rivera and Cocos plates beneath the North American lithosphere. Their regionalization is based on the differences in the estimation of local *a*- and *b*-values in the Gutenberg–Richter approximation and also the estimations from the same parameters of the local recurrence time. Then, the southern Mexico may be segmented in the next five regions: the Jalisco–Colima region to the west, where the Rivera plate subducts at a steep angle that resembles the geometry of the Cocos plate beneath the Caribbean plate in Central America; the Michoacán region, where the dip angle of the Cocos plate decreases gradually toward the southeast; the Guerrero region bounded approximately by the onshore projection of the Orozco and O'Gorman fracture zones, where the subducted slab is almost sub horizontal and under plates the upper continental plate for about 250 km, the Oaxaca and Chiapas region in southeastern Mexico, where the dip of the subduction gradually increases to a steeper subduction in Central America. In Fig. 2a–e the earthquake magnitude time series of the five sub-regions is displayed.

2.1. The multifractal detrended fluctuation analysis

Multifractal time series are characterized by variability on a wide range of temporal or spatial scales that can be associated to intermittent fluctuations and long-range correlations. When a time series is characterized by only one scaling exponent, this