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Analyzing Scaling Behavioral Trends in Self-potential Earthquake-related Data Measured in Mexico

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Abstract: The scaling behaviour of self-potential data (in the frequency range between 0 and 0.125Hz) observed in 1995 at Acapulco station in Mexico were investigated using the detrended fluctuation analysis (DFA), which is a powerful method to detect scaling in nonstationary time series. Approximately two scaling regions with two different scaling exponents - α_1 (on low timescales) and α_2 (on high timescales)- can be detected in the data, with a time-varing crossover. The analysis of the time variation of the scaling exponents in the two scaling regions shows, particularly, a significant increase of α_1 before the occurrence of the strongest earthquake of magnitude M=7.4, that struck the area on September 14, 1995. These first results could be useful in the framework of earthquake prediction studies.

Keywords: Self-Potential; Detrended Fluctuation Analysis; Power-law

1 Introduction

During few last decades many complex systems have been studied through data sets expressed as time series [1-4]. In particular, the dynamical behavior of earth crust has been analyzed by means of the properties of several kinds of time series. Earthquakes represent one of the most challenging and debated topics in the scientific community, especially concerning their prediction. Despite the complexity of this field at both theoretical and experimental levels, research programs on this issue were developed around the world [5-10]. One of the techniques used in the study of possible precursory phenomena of earthquakes consists in monitoring the self-potential field in seismic regions, generating a voltage time series $\Delta V = \Delta V(t)$. Some authors have proposed a correlation between patterns of self-potential fluctuations and the mechanism of preparation of earthquakes [5, 9, 11, 12]. Since more than ten years ago, self-potential field has been measured at several sites in Mexico [13] (Fig. 1). Some stations were located along the Guerrero state coast, near the Middle American trench, which is the border between the Cocos and the American tectonic plates, where strong earthquakes generally ocurr (some of them with $M \geq 8$). In particular, on September 14, 1995 a Ms = 7.4 occurred at (16.31N, 98.88W) was located approximately 110Km far away from Acapulco station (16.85N, 99.9W), which was working during that period. The self-potential signals associated to this main shock have been studied by means of several techniques particularly in [6, 7] the spectral exponent and the correlation time exhibit changes during the different phases of the seismic processes. In terms of the correlation function [14] showing that some statistical features were seemingly correlated with the preparation mechanisms of this earthquake, on the other hand, fractal and correlation dimension were computed in [15] although their interpretation is not easy. We found that DFA analysis is better in comparision with spectral

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analysis, correlation function and Higuchi fractal dimension because the DFA exponents describe a better behavior of the correlation prior the mainshock. On the other hand DFA was also applied to characterize the level of seismicity in three regions of Mexico in terms of the scaling exponents α_1 and α_2 [17]. In this paper, we perform a fractal analysis of self-potential data observed at station Acapulco (Mexico) during 1995, in order to identify some anomalous precursory patterns associated with earthquakes.

2 The method

In order to investigate the scaling behaviour in the self-potential time series, we applied the method of detrended fluctuation analysis (DFA)[16]. The DFA avoids spurious detection of scaling and correlations that could be artifacts of trends and nonstationarity, often presented by experimental data. Such trends have to be well distinguished from the intrinsic fluctuations of the system in order to find the correct scaling behavior of the fluctuations. Very often we do not know the causes and the scales of these underlying trends [18]. The DFA method works as follows. With x_{ave} we indicate the mean value of the series. The signal is first integrated,

$$y(k) = \sum_{i=1}^{k} |x(i) - x_{ave}| \tag{1}$$

Next, the integrated time series is divided into boxes of equal length *n*, with *n* ranging from 4 to N/4, where N is the length of the series. In each box a polynomial is fit to the data, representing the trend in that box. The fitting polynomial is denoted by $y_n(k)$. Next we detrend the integrated time series *y(k)* by subtracting the local polynomial trend $y_n(k)$ in each box. In this way the trends with order up to the order of the polinomial are removed. Thus the root-mean-square fluctuation is calculated according to the following formula

$$F(n) = \sqrt{\frac{1}{N} \sum_{k=1}^{N} |y(k) - y_n(k)|^2} \tag{2}$$

where N is the length of the series. Repeating this calculation over all box sizes, we obtain a relationship between *F(n)*, that represents the average fluctuation as a function of box size, and the box size *n*. If *F(n)* behaves as a power-law function of *n*, it will obey the relationship:

$$F(n) \propto n^{\alpha} \tag{3}$$

Under these conditions the fluctuations can be described by the scaling exponent α, representing the slope of the line fitting *log F(n)* to *log n*. For a white noise process, $\alpha = 0.5$. If there are only short-range correlations, the initial slope may be different from 0.5 but will approach 0.5 for large window sizes. An $\alpha > 0.5$ indicates the presence of persistent long-range correlations, meaning that a large (compared to the average) value is more likely to be followed by large value and vice versa. An $\alpha < 0.5$ indicates the presence of antipersistent long-range correlations, meaning that a large (compared to the average) value is more likely to be followed by small value and vice versa. An $\alpha = 1$ is typical of flicker-noise or 1/f-noise process; $\alpha = 1.5$ characterizes Brownian processes [16].

3 Data

The experimental setup was based in the VAN methodology [5, 11] which consider that the electric field is determined by measuring the potential difference between two electrodes and, with two channels perpendicularly oriented allow the determination of the total electric field at the site of the station. Our time series represent the electric self-potential fluctuations ΔV (sampled with a period of $\Delta t = 2s$) between two electrodes buried 2m into the ground and separated 50m long way apart [13]. Fig.1 shows the location of the station Acapulco and the epicenter (16.31N, 98.88W) of the strong Guerrero-Oaxaca earthquake occurred on September 14, 1995, and Fig.2 exhibits the time series analyzed.

4 Results and discussion

We analysed the self-potential data observed at Acapulco station in Mexico during three years of measurement from 1994 to 1996. During the observation period a strong earthquake occurred with magnitude M_S=7.4 in the region of Guerrero-Oaxaca. To examine transient phenomena, the time series was analysed in overlapping windows of fixed length N_W. Therefore the DFA method was performed in a sliding window of N_W=1 day, in order to have a sufficient amount of data. The shift between two successive windows was set to 1/3 days, in order to have a good smoothing among the calculated values. In each window, we applied the DFA, removing the polynomial trends up to the 4-th order.

In each sliding window, we identified two scaling regions and calculated the crossover timescale, the scaling exponent in the first scaling region (α_1), corresponding to the low timescales, and the scaling exponent in the second scaling region (α_2), corresponding to the high timescales.

Fig.3 shows the results. The time variation of both the scaling exponents at low and high timescales shows a clear increase of the value before the occurrence of the strong Guerrero-Oaxaca earthquake. In particular, the time variation of α_1 (Fig.3a) reveals a white-noise behaviour ($\alpha_1 \approx$ 0.5) during most of the year 1994; then the scaling exponent increases significantly at the end of the 1994 and for all 1995, reaching the value of approximately 1.5, returning to the value of about 0.5 after the earthquake, maintaining it for most of the year 1996. The time variation of α_2 (Fig.3b)shows a noisier behaviour, and an increase can also be detected before the occurrence of the Guerrero-Oaxaca earthquake; however, it should be noted that other increases of the scaling exponent are shown even if not connected with the occurrence of a strong earthquake.

5 Conclusions

The detrended fluctuation analysis of self-potential data measured in Acapulco station, Mexico during 1994-1996, reveals scaling behavior in the temporal fluctations of the signal. Furthermore, analyzing the time variation of the scaling behaviour, a significant increase of the scaling exponent at low timescales is revealed before the occurrence of the strongest Guerrero-Oaxaca earthquake. These results can represent a contribution to the debated question of earthquake prediction.

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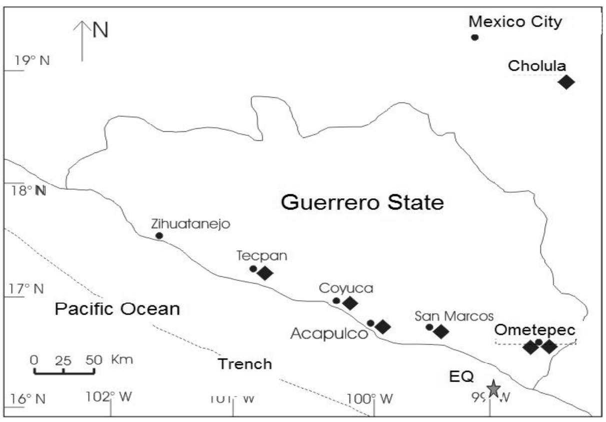

Figure 1: Localization of the station Acapulco and the epicenter (star)

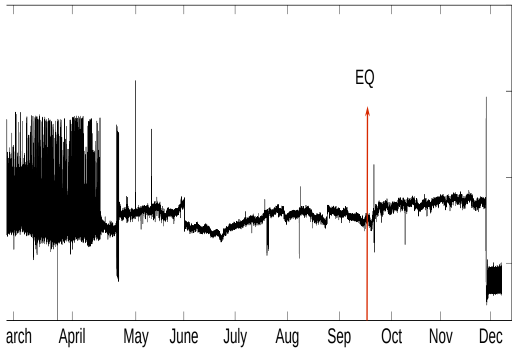

Figure 2: Time variation of α_1 (a) and α_2 (b)

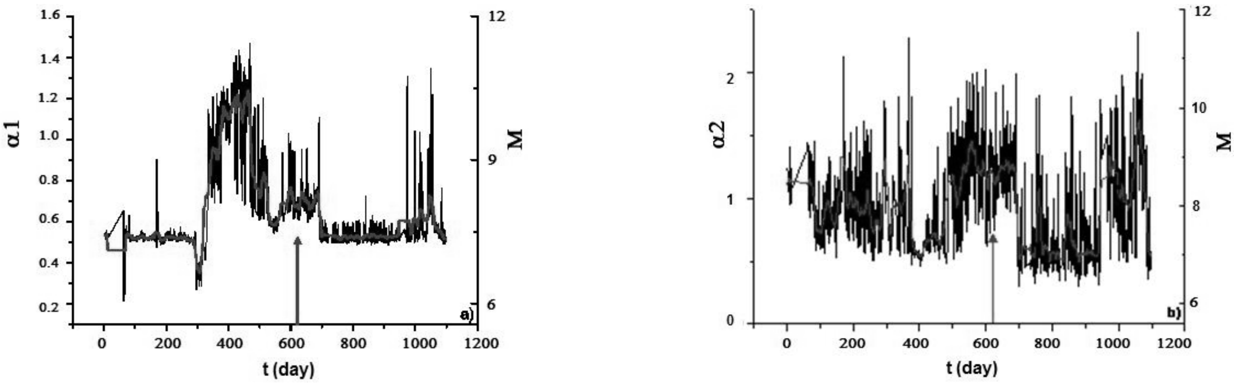

Figure 3: Time variation of α_1 (a) and α_2 (b)

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