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Use of STNRW and DFA methods to discriminate between explosions and natural earthquakes

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1 Introduction

Seismic waves are waves of energy arising from human activities, such as a large human-made explosion that gives out low-frequency acoustic energy, or from natural phenomena such as large landslides, magma movement or volcanic eruptions. The presence of the human-made explosion in a seismic catalog may result in errors of statistical analysis of seismicity. One of the major seismological recent challenges is to monitor human-made explosion arising from mining, road excavating, and other constructional applications. Therefore, the development of methodologies that ensure a correct identification of the type of source generating a recorded seismic signal is, from many perspectives, a very significant and critical issue $[1, 4, 7]$.

In this work we propose an additional classification tool to discriminate between natural tectonic earthquakes and human-made explosions. It is based on the *Detrended Fluctuation Analysis* and on the *Seismic Trace Noise Reduction by Wavelets and Double Threshold Estimation* method. We analyze all seismic trace signals from astsa R package, in order to identify differences between seismic trace signals of explosions and seismic signal of natural earthquakes.

2 Methodology

The *Detrended Fluctuation Analysis* (DFA) method is a well established method for detecting long-range dependence in non-stationary time series [6]. The object of this technique is to evaluate the statistical fluctuation $F(l)$ in order to obtain a set of measures, where l represents the window length. By varying the length l, the fluctuation can be characterized by the scaling exponent, that is the slope of the line obtained by regressing $\ln(F(l))$ on $\ln(l)$. It has successfully been applied to different fields of interest $[2, 4, 6]$.

Wavelets are becoming increasingly popular in different areas of applied and theoretical sciences $[3, 5, 7]$. Two functions are very important in wavelet analysis: the mother and

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father wavelets. These wavelets generate a family of functions that can reconstruct a signal. A *mother wavelet* $\psi(\cdot)$ and a *father wavelet* (*or scale function*) $\phi(\cdot)$ are real functions $\psi, \phi : R \to R$ such that

$$\int_R \psi(t)dt = 0, \qquad \int_R \phi(t)dt = 1$$

and satisfy the integrability condition, that is, $\psi, \phi \in L^2(R) \bigcap L^1(R)$. Given the wavelets $\psi(\cdot)$ and $\phi(\cdot)$, we construct wavelet sequences through translations and dilatations of mother and father wavelets, respectively, given by $\psi_{j,k}(t) = 2^{-j/2}\psi(2^{-j}t - k)$, $\phi_{j,k}(t) = 2^{-j/2}\phi(2^{-j}t - k)$. The functions $\{\psi_{j,k}(\cdot), j, k \in Z\}$ and $\{\phi_{j,k}(\cdot), j, k \in Z\}$ form bases that are not necessarily orthogonal. The advantage of working with orthogonal bases is that they allow the perfect reconstruction of a signal from the coefficients of the transform. In general, the most used orthogonal wavelets are: Haar, Daublets, Symmlets and Coiflets. In statistics, wavelets have been used primarily to deal with problems of a nonparametric character [3, 5]. Some particular problem of interest is de-noising using the Seismic Trace Noise Reduction by Wavelets and Double Threshold Estimation (STNRW) method [7]. The basic aim of the STNRW method is to separate the detailed wavelet coefficients into three groups. The first group contains detailed wavelet coefficients that are considered to be signal information, the second group contains detailed wavelet coefficients that are considered to be noisy information, and the third group contains detailed wavelet coefficients that belong to an indecision region, where the decision-making process is done through a classification function.

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