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Use of wavelets techniques to discriminate between explosions and natural earthquakes

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HIGHLIGHTS

- Improve the analysis and understanding of parameters associated to critical events.
- Discriminate between explosions and natural earthquakes.
- Model and describe some of the key distributional features of typical geophysical time series.

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ABSTRACT

Wavelets analysis is used to discriminate between explosions and natural earthquakes. We applied wavelets techniques to analyze the seismograms of a set of mining explosions, reported in catalogs as earthquakes, and compared them with natural earthquakes that occurred in the same region (within a radius of 10 km).

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1. Introduction

The development of methodologies that yield a correct identification of the type of source generating a recorded seismic signal is very important from many perspectives. For example, sources of small-amplitude seismic signals include: chemical explosions, nuclear explosions, underground collapses, rock bursts, mining explosions and landslides. A correct discrimination between these sources based on the seismic signals generated might help to mitigate some of the effects of these events.

Different modeling techniques have been developed to depict various aspects of the mathematical modeling of seismic occurrence patterns. For instance, Lévy models have been used to estimate parameters related to some major events [1]. In this work, by looking at the preceding data collected before a major earthquake, the model estimated the parameters leading to these critical events. The modeling approach used was similar to Ref. [2], where they described the behavior of the financial market before a crash.

In the present study, we investigate the use of wavelets technique as a tool for discriminating between different seismic sources, in particular, between mining explosions and earthquakes. Mining explosions are very commonly performed, and

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their seismic waves tend to be misinterpreted as natural small earthquakes. Small earthquakes are important in releasing accumulated tectonic stress. In Ref. [3], the authors used stochastic models to describe a unique type of dependence in earthquakes. Thus, a correct characterization of small-magnitude seismic signals has important implications in assessing seismic hazard.

Different discriminants have been used to separate mining explosions from natural earthquakes with varying degrees of success [4]. In general, phase amplitude discriminants, such as the use of the ratio of the Pg and Lg seismic phases, have been found to be successful in discriminating between nuclear explosion and earthquakes, however, these techniques perform poorly in distinguishing between mining explosions from earthquakes. In many cases, this is because there exists a large variability in Pg and Lg amplitudes for similar events types at high frequencies, partially resulting from ray path effects. For example, [4] used different combinations of filtering frequencies for events in Russia and Western US and they found no amplitude ratio discriminants that could efficiently separate mining events from earthquakes.

Other discrimination methodology use the Fourier Transform of the seismograms and measure variations of spectral characteristics of direct wave phase (Pn, Pg, Lg, Rg) or on spectral ratios at different frequencies (see Refs. [5,6]). Nevertheless, these direct phases are strongly affected by the source–receiver path, thus determining if the observed differences in frequency are due to source or propagation path effects many times result in a very difficult task, especially when the location of the explosions and the earthquakes are not close. Refs. [4,7] also utilized time-varying spectral analysis. They observed a time-independent spectral modulation in the explosions not evident in the spectrum of the earthquakes. This methodology implies performing multiple combinations of training parameters in order to effectively separate mining explosions from earthquakes. Their results showed that in one of the study regions the time–frequency discriminant was effective at distinguishing large mining explosions from earthquakes, but not at distinguishing small mining explosions.

Fourier analysis modeling techniques have been applied to the problem of distinguishing between waveforms generated by earthquake and those generated by explosions. However, the technique of Fourier analysis is only localized in frequency [8]. Therefore, in an attempt to make the method more general and to overcome the restriction of stationarity, we propose the wavelets technique method. Wavelets have been proved to be more efficient in representing signals in a amplitude–frequency–time domain than spectrograms obtained using for example, short window Fourier transforms.

In this study we investigate the use of wavelets technique as a potential tool to discriminate between natural tectonic earthquakes and human made explosions. We will investigate and compare the characteristics of the seismic waves generated by a cluster of earthquakes and a set of mining explosions.

In Section 2, we present a brief background of the wavelets modeling technique and the suitability of the method. Section 3 gives a brief description of our data and an application of the wavelets technique to the seismograms containing the seismic waves generated by the earthquakes and the explosions. Section 4 contains the conclusions and discusses the suitability of our method to discriminating between a cluster of earthquakes and a set of mining explosions.

2. Wavelets analysis

Regularity of a series can best be expressed in terms of periodic variations of the underlying phenomenon that produced the series and it is expressed as Fourier frequencies being driven by sines and cosines. From a regression point of view, we may imagine a system responding to various driving frequencies by producing linear combinations of sine and cosine functions. If a time series X_t is stationary, its second-order behavior (mean, variance and covariances are constant throughout time) remains the same regardless of the time t, then we can match a stationary time series with sines and cosines because they behave the same forever.

A stationary series can be represented as the superposition of sines and cosines that oscillate at various frequencies. But non-stationary time series require a deeper analysis. The concept of wavelet analysis is to imitate dynamic Fourier analysis, but with functions that may be better suited to capture the local behavior of nonstationary time series. Wavelets analysis is a more general method which are localized in both time and frequency whereas the standard Fourier analysis is only localized in frequency [8].

2.1. Definition

The wavelet transform of a function $f(t)$ with finite energy is defined as the integral transform with a family of functions $\eta_{\lambda,t}(u) \equiv \frac{1}{\sqrt{\lambda}}\eta(\frac{u-t}{\lambda})$ and is given as

$$Wf(\lambda,t) = \int_{-\infty}^{\infty} f(u)\eta_{\lambda,t}(u)\mathrm{d}u \quad \lambda > 0. \tag{2.1}$$

Here λ is a scale parameter, t a location parameter and the functions $\eta_{\lambda,t}(u)$ are called wavelets. In the case where $\eta_{\lambda,t}(u)$ is complex, we use complex conjugate $\overline{\eta}_{\lambda,t}(u)$ in (2.1). The normalizing constant $\frac{1}{\sqrt{\lambda}}$ is chosen so that

$$\|\eta_{\lambda,t}(u)\|^2 \equiv \int |\eta_{\lambda,t}(t)|^2\mathrm{d}u = \int |\eta(t)|^2\mathrm{d}t = 1$$

for all the scales λ. The choice of the wavelet $\eta(t)$ is neither unique nor arbitrary. The function $\eta(t)$ is a function with unit energy (i.e. $\|\eta(t)\|^2_{L^2} = 1$) chosen so that it has the following properties: