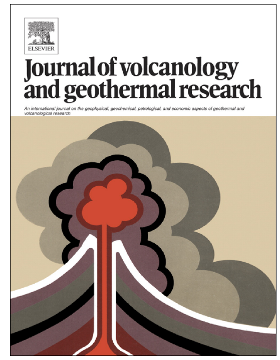

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Spectro-temporal features applied to the automatic classification of volcanic seismic events

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Abstract

Feature extraction and selection are very relevant processes in the design of automatic classifiers. In the context of volcanic seismic signal classification, most of the features presented in the literature have been extracted separately from a single domain, such as time or frequency. However, spectrograms, which combine time and frequency information, are widely used by experts during the classification of manual seismic events. This paper proposes to evaluate the performance of classifiers trained with features extracted from the spectro-temporal domain, individually or combined with other conventional features. The parameters were extracted from the spectrogram, based on a curve which combines the high energy components and the frequency bandwidth information through the duration of the event. The tests were performed at the Llaima volcano and seismic events were classified into four classes: long-period, tremor, volcano-tectonic and tectonic, using a database of signals recorded between the years 2009 and 2017. The main achievements of this study were the reduction of more than 70% of the error and false positive rates and also a reduction of approximately 30% of the number of features, compared with a baseline established in previous studies. Thus, the inclusion of spectro-temporal information was considered relevant to complement the conventional features and to support classification.

Keywords: Volcano monitoring, Signal processing, Pattern recognition, Spectrogram, Spectro-temporal curves

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1. Introduction

There are approximately 1,500 active volcanoes in the world producing, on average, 30 eruptions per year. Many of these massifs are close to populated areas, resulting in a permanent risk situation to the populations in their vicinity (Brown, 2017). Moreover, the strategic position of threatened cities, coupled with other consequences of eruptions, such as climatic change or water pollution, directly affect the economy of the region (Chester et al., 2000). Hence, monitoring volcanic activity, including ground deformation, volcanic gases, temperature variations, and seismic signals, are crucial in hazard assessment and in the development of contingency plans (Sparks et al., 2012).

Volcano monitoring is based also on the assumption that the quantity and/or behavior of seismic volcano events change before an eruption. The growing need to monitor a high number of volcanoes has driven the development of automatic identification systems (AISs), either by volcanic events detectors or classifiers (Orozco-Alzate et al., 2012). In particular, the analysis of seismic signals based on pattern recognition (PR) techniques has been the principal method used to develop AISs. Designing a seismic events classifier is not a trivial task due to the large amount of volcanic earthquakes with similar features, hindering signal discrimination. Thus, to ensure a good performance of an AIS, two PR stages are required: feature extraction and classification.

To the best of our knowledge, the most frequently used AIS classification techniques are hidden Markov model (HMM), support vector machine (SVM) and self organizing map (SOM). HMM has been widely used in volcanic seismic event identification, achieving a true positive accuracy of over 90% and an average accuracy of over 85% in classifying events, as shown in Bhatti et al. (2016) and Bicego et al. (2013), respectively. SVM has been less explored than HMM in seismic event identification. However, SVM has classification results similar to HMM, as in Masotti et al. (2006), which applied SVM to classify volcanic tremor data recorded during different states of activity at Etna volcano (Italy) achieving an accuracy over 90%. In