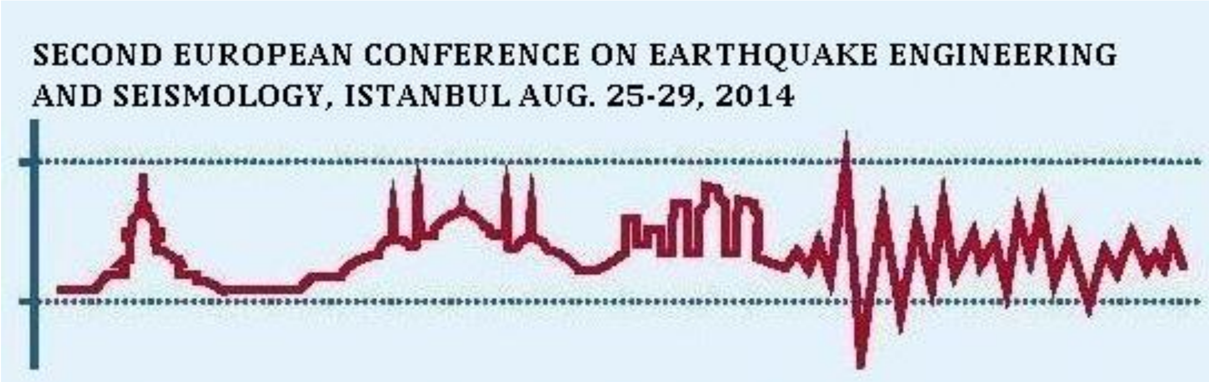

PERFORMANCE OF A NEW MULTISTATION ALARM SYSTEM FOR VOLCANIC ACTIVITY BASED ON NEURAL NETWORK TECHNIQUES

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Numerous eruptive episodes with Strombolian activity, lava fountains, and lava flows occurred at Mt. Etna volcano between 2006 and 2013. In particular, there were seven paroxysmal lava fountains at the South East Crater in 2007-2008 and 46 at the New South East Crater between 2011 and 2013, while months-long lava emissions affected the upper eastern flank of the volcano in 2006 and 2008-2009. The monitoring of such volcanic phenomena is particularly relevant for their potential socio-economic impact in this densely populated volcanic region. For example, explosive activity has often formed thick ash clouds with widespread tephra fall able to disrupt the air traffic, as well as to cause severe problems at infrastructures, such as highways and roads.

Early information about changes in the state of the volcano and/or at the onset of potentially dangerous eruptive phenomena requires efficacious surveillance methods. Several studies on seismic data recorded at Mt. Etna highlight that the analysis of the continuous background seismic signal, the so-called volcanic tremor, is of paramount importance to follow the evolution of volcanic activity (e.g., Alparone et al., 2003; Falsaperla et al., 2005; Langer et al., 2009). Indeed, changes in the state of the volcano as well as in its eruptive style are usually concurrent with variations of the spectral characteristics (amplitude and frequency) of tremor. This signal is recorded at Etna by means of the INGV seismic network equipped with broadband sensors. The huge amount of digital data continuously acquired by INGV’s stations every day makes a manual analysis difficult. To overcome this problem, techniques of automatic classification of the tremor signal were applied to explore the robustness of different methods for the identification of regimes in volcanic activity (Langer et al., 2009). In particular, Langer et al. (2011) applied unsupervised classification techniques to the tremor data recorded at one station during seven paroxysmal episodes in 2007-2008. Their results revealed significant changes in the pattern classification well before the onset of the eruptive episodes. In the wake of this evidence, Messina and Langer (2011) developed KKAnalysis, a software that combines an unsupervised classification method (Kohonen Maps) with fuzzy cluster analysis. This tool was set up at the operative centre of the INGV-Osservatorio Etneo in 2010, and it is hitherto one of the main automatic alerting tools to identify impending eruptive events at Etna. The software carries out the on-

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line processing of the new data stream coming from two seismic stations, merged with reference datasets of past eruptive episodes.

Here we apply KKAnalysis using eleven stations at different elevations (1200-3050 m) and distances (1-8 km) from the summit craters. Critical alert parameters were empirically defined to obtain an optimal tuning of the alert system for each station. To verify the robustness of this new, multistation alert system, a dataset encompassing about eight years of continuous seismic records (since 2006) was processed with KKAnalysis off-line. Then, we analyzed the performance of the classifier in terms of timing and spatial distribution of the stations. As an example, Figure 1a depicts the location of the seismic stations that were operative during an episode of eruptive activity evolving in paroxysm in 2011. Different colors allow us to follow the temporal order of triggers (Figure 1c).

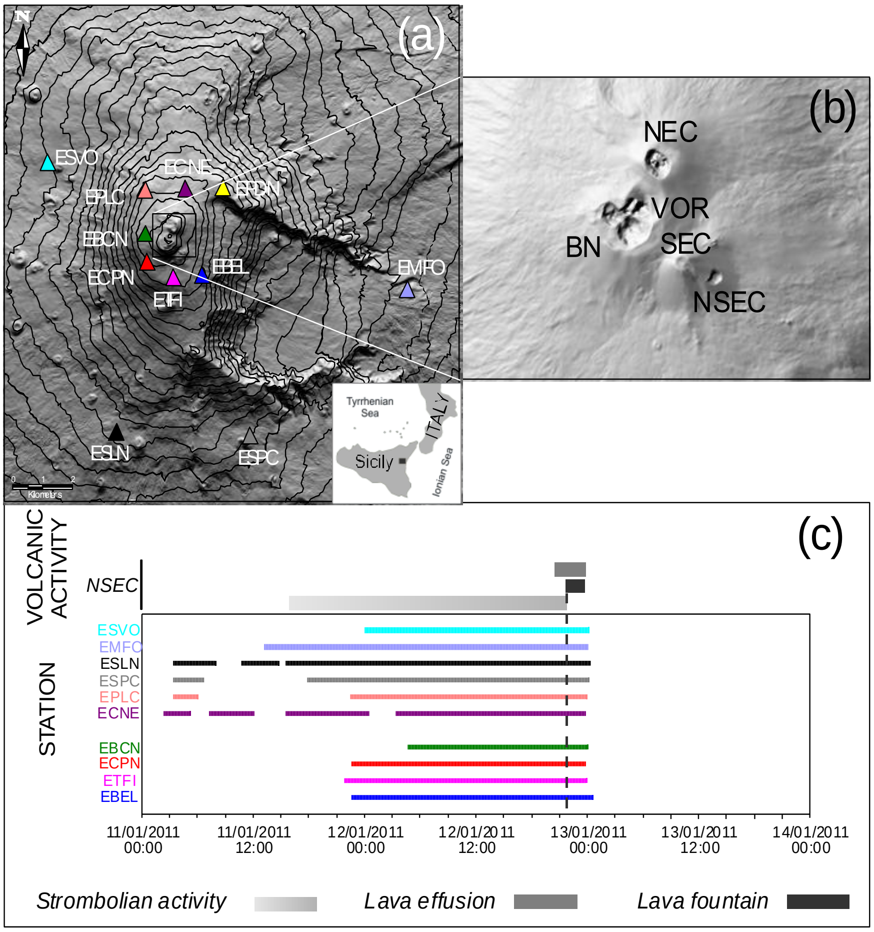

Figure 1. a) Map of Etna and location in southern Italy (inlet in the right corner). Colour triangles mark the seismic stations operative during a paroxysmal episode on 13 January 2011. b) Active craters: NEC=North-East Crater; BN=Bocca Nuova; VOR=Voragine; SEC=South-East Crater; NSEC=New South-East Crater. c) Alarm timing at each seismic station for the same paroxysmal episode. Colour bars correspond to the number of patterns for which the alarm condition was true; each colour identifies a seismic station. Gray rectangles on top of the cartoon mark different styles of volcanic activity at NSEC (Behncke, 2011; INGV, 2011a-b). The dashed, vertical line marks the onset of the paroxysm corresponding to the start of the lava fountain.

We also investigated the performance of the new alert system based on KKAnalysis in case of activation of whatever eruptive centre. Intriguing results were obtained in 2010 throughout periods characterized by the renewal of volcanic activity at Bocca Nuova-Voragine and North East Crater, and in the absence of paroxysmal phenomena at South East Crater and New South East Crater. Despite the low-energy phenomena reported by volcanologists (i.e., degassing, low-to moderate explosions), the triggered alarms demonstrate the robustness of the classifier and its potential: i) to identify even subtle changes within the volcanic system using tremor, and ii) to highlight the activation of a single eruptive centre, even though different from the one for which the classifier was initially tested. It is worth noting that in case of activation of weak sources, the successful performance of the classifier depends upon the general level of signals originating from other sources in that specific time span.

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