ARRAY DETECTION OF HYDROTHERMAL TREMOR IN CAMPI FLEGREI VOLCANIC AREA

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Introduction. Campi Flegrei caldera is an active volcanic area located in southern Italy, west of Naples. Two caldera collapses (Campanian Ignimbrite, 39 ka; Neapolitan Yellow Tuff (NYT), 15 ka) defined its present structural setting (Selva et al., 2011). In the past 15 ka, volcanic activity has been concentrated within NYT caldera and the last eruption occurred in 1538 (Mt. Nuovo eruption) after a long period of quiescence. Campi Flegrei caldera is one of the highest risk volcanic area in the world. A large ground inflation in 1982–1984 was followed by a subsidence period lasting about 20 years, until a new uplift phase started in 2006. Geochemical data collected during the last two decades indicate that a change in the hydrothermal system is ongoing (Chiodini et al., 2012). Low magnitude volcano tectonic seismic events mostly characterized the seismicity of the last fifteen years (Galluzzo et al., 2016), while Low Frequency events (hereafter LF) were detected only during the year 2006 (Saccorotti et al., 2007). Since the current status of the volcano is considered as “unrest”, the local seismic network was improved in order to detect seismic signals associated with volcanic activity reawakening (La Rocca and Galluzzo, 2016). LF events and volcanic tremor are observed at hundreds of active volcanoes worldwide (McNutt, 2005) but, due to the high background noise (Del Pezzo et al., 2013), the detection of signals characterized by emergent onset and low amplitude like volcanic tremor is a very difficult task in the investigated area. To further improve the detection of coherent signals a dense short period array named ARF was installed in 2010 in an underground environment (La Rocca and Galluzzo, 2012). Nowadays, the seismic network is composed by more than 30 digital seismic stations equipped with broad band, short period and accelerometric sensors and
the seismic array ARF (Fig. 1). Array ARF is composed by a 18 channels acquisition system with short period seismic sensors. The use of array techniques applied to continuous recorded data has allowed to detect some LF events and an episode of tremor at the beginning of 2015.

**Data analysis and results.** ARF array was installed in the middle of CF caldera (Fig. 1) and is working since 2010 with a great continuity. The detection of volcanic events is performed mainly by array analysis in frequency domain. By evaluating the coherence and propagation properties (slowness and backazimuth) of the seismic wavefield, we can identify transient signals different from seismic noise and potentially interesting for monitoring purposes (La Rocca and Galluzzo, 2012). Signals characterized by coherence higher than a chosen threshold are then observed at the nearby network stations to establish their origin (first of all if they are natural or artificial events) and main features. Those events possibly related with the volcanic activity, that are any signals compatible with volcanic tremor and LF earthquakes, are further analyzed.
by considering all available data. During the past years many events have been classified as LF events. They are characterized by low amplitude, emergent onset, frequency content between 1 Hz and 5 Hz, and shallow source location. An example of LF event recorded at the array ARF is shown in Fig. 2. Signals with the same features but much longer duration, classified as tremor, were first detected in January 2015. The results of array analysis of data recorded on January 30, 2015, show the presence of many coherent bursts of energy for some hours during the day, particularly from 12:00 to 15:00. These coherent signals identify wavefronts with the same backazimuth from SE (between 140 and 150 degrees) and similar apparent velocity of about 0.7 km/s. The results of array analysis for one hour of such signals are shown in Fig. 3. The vertical component of the seismic signals recorded at one of the array sensors, bandpass filtered around 1.75 Hz, is shown at the top of Fig. 3. The coherence of the seismic wavefield among the array stations, backazimuth and slowness estimated by the array analysis are also shown in Fig. 3. Many signal bursts are characterized by coherence higher than 0.6, while their backazimuth is stable between 135° and 150° (clockwise starting from north). The average slowness of coherent signals is about 0.7 s/km, corresponding to about 1.4 km/s, which indicates a shallow source. By taking into account the raw arrival time at network stations with the best signal-to-noise ratio, we estimate a localization of the tremor source in an area located southwest of Solfatara crater (La Rocca and Galluzzo, 2015). The spectral content of tremor signals shows the most of energy in the frequency range 1.0 – 5 Hz, with the main peak at 2 Hz, the same observed for many small seismic events classified as LF earthquakes. In Campi Flegrei area LF earthquakes recorded during the last 15 years are located at shallow depth and their source is believed to be tightly related with the hydrothermal system. After a full comparison of tremor signals with many LF earthquakes, taking into account their frequency contents, waveform, amplitude, and propagation features observed at the array ARF, we conclude that the tremor
recorded on January 30, 2015, is a sequence of LF events. Therefore the source of such tremor must be the hydrothermal system.

**Conclusions.** Since the level of background noise in the frequency range 0.5 – 5 Hz limits the detection of low amplitude and emergent signals like volcanic tremor and LF earthquakes, the use of array methods is necessary to detect coherent signals. Taking advantage of the array ARF, we could identify many coherent signals occurred in the area since 2010. Many of them revealed to be small LF earthquakes, while some others remained unclassified due to the very small amplitude, poor signal to noise ratio, and poor station coverage in some cases. However, the most interesting event is the tremor of hydrothermal origin occurred in January 2015 because it is the first observation of such kind of event in Campi Flegrei caldera. In the past years LF events of hydrothermal origin were located inside and at the east border of Solfatara crater (Saccorotti et al., 2007), while the tremor described here is located more than 1 km to the SW. Therefore we conclude that the sources of such signals have similar mechanisms but different location. Further analysis about the source mechanism which generates LF earthquakes and tremor are in progress. The detection, analysis and classification of low amplitude tremor like the episode described here indicate a good performance of the current monitoring system. However, considering the very high risk of the area, further efforts are needed to detect seismic signals of volcanic origin as small as possible, and a multidisciplinary approach to their analysis and interpretation.

**References**


