Detection and location methods of volcanic tremors using seismic cross-correlation: application to Sakurajima volcano

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Volcanic tremors are associated with the movement of volcanic fluids such as magma and gas in the conduit of a volcano. Determination and monitoring of their source locations are important to understand the mechanism that controls the eruptive behavior. However, seismic records of volcanic tremors are known to have complex waveforms with unclear seismic phases and variations in the amplitude and duration. We develop and evaluate methods to detect volcanic tremor signals from continuous seismic records and determine the source location. We employ cross-correlation analysis to avoid reading the arrival time of seismic phases and assume the propagation of direct S-wave. The calculated cross-correlation functions (CCFs) contain information on signal coherency and relative travel time that are useful for detection and location. The method is applied for every 10-minute of the seismic data of six JMA stations at Sakurajima volcano.

For the detection, we adopt a detection method called the network covariance matrix analysis that measures the signal coherency over the seismic network, referred to as the “spectral width”. However, this method does not specifically detect volcanic tremors, since any signal that is coherent across the seismic network may also be detected. We extend the network covariance matrix method by further computing a classification measure. To specifically target volcanic tremors, a weight function is defined, where the weight is set to be non-zero at the frequencies where the tremor signal is the most coherent. For the location method, we apply the CCF-based source scanning algorithm (CCF-based SSA) that locate the source by finding a location that maximizes the “brightness” function in a grid-search scheme. The location method has been evaluated in the previous study by using volcano-tectonic earthquakes and simulated tremors (Permana et al., 2020). Therefore, application to real seismic data is new.

We analyze continuous seismic data during the period of April-September 2017 in the frequency range of 1-4 Hz. Catalog and reports of activities at Sakurajima volcano by the JMA are used for validation. For each source location, the corresponding spectral width value is used as a measure of location reliability. For further interpretation, we select only reliable source locations by imposing a criterion of the spectral width and correlation coefficient that is computed from CCFs calculated between component pairs of the seismometer. We successfully detect two time periods where volcanic tremors mostly occurred associated with the increase in eruptive activity. In the first time period in May, the tremors are characterized by long-duration signals, the source locations are mostly distributed at depths of 0-6 km beneath the Minamidake and Showa craters, and the eruptions are characterized by continuous ash emission. Changes in source location preceding and following an eruption are also observed. In the second time period is in August-September, the tremors are mostly short-duration and intermittent, but we are able to detect a continuous tremor that accompanies an episode of Strombolian eruption and their sources are determined at shallow depths (<2 km depth). Comparison with magma supply system from various studies shows that the estimated depth distribution of the source location appears to consistent with the movement of magma from the shallow magma chamber at about 5 km depth to beneath Showa crater. Our results show that the detection and location methods based on cross-correlation analysis can be very useful to monitor tremor activity at a volcano and provide insights into the movement of magma and eruptive behavior.