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Automatic classification of sources of volcanic tremors at the Klyuchevskoy volcanic group (Kamchatka) based on the seismic network covariance matrix analysis

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Volcanic tremors may be caused by magma moving through narrow fractures, by fragmentation and pulsation of pressurized fluids within the volcano, or by escape of pressurized steam and gases from fumaroles. They present an important attribute of the volcanic unrest and their detection and characterization is used in volcano monitoring systems. The tremors might be generated within different parts of volcanoes and might characterize different types of volcanic activity. The main goal of the present study is to develop a method of automatic classification of different types (sources) of tremors based on analysis of continuous records of a network of seismographs.

The proposed method is based on the analysis of eigenvalues and eigenvectors of the seismic array covariance matrix. First, we followed an approach developed by Seydoux et al. (2016) and analyzed the width of the covariance matrix eigenvalues distribution to detect time periods with strong volcanic tremors. In a next step, we analyzed the frequency-dependent eigenvectors of the covariance matrix. The eigenvectors corresponding to strongest eigenvalues can be used as fingerprints of dominating seismic sources during the period over which the covariance matrix was calculated.

We applied the method to the data recorded by the permanent seismic monitoring network composed of 19 stations operated in the vicinity of the Klyuchevskoy group of volcanoes (KVG) located in Kamchatka, Russia. The KVG is composed of 13 stratovolcanoes with 3 of them (Klyuchevskoy, Bezymianny, and Tolbachik) being very active during last decades. In addition, two other active volcanoes, Shiveluch and Kizimen, are located immediately north and south of KVG. This exceptional concentration of active volcanoes provides us with a multiplicity of seismic tremor sources required to validate the method.

We used 4.5 years of vertical component records by 19 stations and computed network covariance matrices from day-long windows. We then analyzed the ensemble of eigenvectors corresponding to strongest eigenvalues. We developed a clustering method that is based on the similarity (correlation coefficient) between the eigenvectors. This automatic procedure identified 6 clusters of seismo-volcanic activity. The comparison of these cluster with the catalogued volcanic unrest showed that three of them correspond to three different stages of the activity of the Klyuchevskoy volcano and three additional clusters correspond to tremors emitted by Tolbachik, Shiveluch, and Kizimen.

The last step of the analysis was to identify within every cluster the most characteristic eigenvector. The 6 characteristic eigenvectors were then used as fingerprints for the matching detection and classification of tremors via comparison with the covariance matrix eigenvectors computed in the moving windows from the continuous records. The developed detection and classification procedure does not require a-priori knowledge of the tremor sources and is fully automatic and adaptive.