



## Spatio-temporal characteristics and focal mechanisms of deep low-frequency earthquakes beneath Zao volcano, Japan

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Deep Low-Frequency earthquakes (DLFs) beneath volcanoes are possible evidence for deep-seated magmatic activities in the crust and uppermost mantle. After the 2011 Tohoku Earthquake (Mw 9.0), the number of DLFs beneath Zao volcano in the northeast Japan started increasing. The hypocenters of these DLFs form two clusters at shallow (20~28 km) and deep (28~38 km) depths. The shallow and deep clusters are located central and lower part of a high Vp/Vs zone, respectively (e.g., Okada et al., 2015), and the fact suggests different fluid involvement and source processes of DLFs at two clusters. In addition, after the activation of DLFs in 2012, increase in shallow (< 2 km depth) seismicity has been observed since 2013, which implies the interaction of shallow and deep volcanic fluids. However, the small magnitude of DLFs makes it rather difficult to discuss detailed spatio-temporal characteristics of DLFs and focal mechanism of individual DLF. Therefore, in this study, we first detected DLFs using waveform correlation and determine their hypocenter, and then classified DLFs using waveform correlation to reveal the spatio-temporal characteristics and focal mechanism of each event type.

To detect DLFs, we applied the matched filter method to the continuous three-components waveform data recorded at stations operated by Tohoku Univ., NIED, and JMA. 146 DLFs listed in the JMA unified earthquake catalog between Jan. 2012 and Sept. 2016 were selected as templates. For each newly detected DLF, we estimated the differential arrival times using cross-correlation between the detected DLF and the template having maximum correlation, and determined the relative hypocenter using the master event method. As a result, we determined hypocenters of 1202 DLFs between Jan. 2012 to May 2018, which is about 4 times the number of DLFs listed in the JMA catalog.

We then classified newly detected DLFs using the hierarchical clustering method based on the waveform correlation, and classified 939 events into seven types (Type A: 241 events, B: 222, C: 295, D: 79, E: 42, F: 37, G: 23). The characteristics of individual waveform types are summarized as follows: Type C shows high frequency components (4-8 Hz) superimposed on the P wave, while the other types only have low frequency components (1-4 Hz); S-wave/P-wave spectral ratio of type C observed at each station shows larger azimuthal variation than that of the other types, and shows maximum peaks in northeast and southwest direction; Type C occurs mainly in the deep cluster while the other types occur in the shallow cluster; The activity of type C started in 2012 and showed rapid increase in 2015, while the other types show similar temporal changes in 2013 and

2016.

These results of this study suggest fluid transportation in the crust and different dynamic processes at each depth beneath the volcano.