Hypocenter and waveform characteristics of deep low-frequency earthquakes beneath Zao volcano

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The 2011 Tohoku Earthquake (Mw 9.0) caused large crustal deformation in and around the Tohoku region, and strongly affected volcanic fluids in the crust. As an example suggesting such influence, the change in activities of deep low-frequency earthquakes (DLFs) occurring in the lower crust. The analysis of DLFs is thus considered to be one of the important keys to infer the activity of deep magma and to assess the potential risks of mid- to long-term volcanic activity after a huge earthquake. In this presentation, we report the results of our analysis of the DLFs beneath Zao volcano where activation of volcanic activities has been observed after the 2011 Tohoku Earthquake.

Zao volcano is located on the border between Yamagata and Miyagi prefectures. After the 2011 Tohoku Earthquake, the number of DLFs beneath Zao volcano started increasing, and increase in shallow seismicity have been observed since 2013. To investigate such seismic activities, the JMA unified hypocenter catalog (JMA catalog) is often used. However, the completeness of the catalog is not guaranteed in small DLFs. To improve the completeness of event detection, Ikegaya and Yamamoto (2018, JpGU) applied Matched Filter method (MF method) to the continuous waveform data recorded in 2015 and detected DLFs having high correlation to the template DLFs listed in JMA catalog. They successfully increased the number of small DLFs and revealed the spatial distribution of hypocenters showing two clusters above and below 28 km. However, due to the assumption that the hypocenters of the detected events are the same as those of the templates yielding maximum correlation value, it is difficult to discuss the details of the hypocenter clustering. In this study, aiming to understand the detailed spatio-temporal characteristics of DLF activity, we apply MF method to the waveform data for the last seven years, and determine relative hypocenters of the detected events.

In the analysis, we used the continuous three-components waveform data recorded at four permanent stations operated by Tohoku Univ., NIED, and JMA. 146 DLFs listed in JMA catalog between Jan. 2012 and Sept. 2016 were selected as templates for the MF analysis. We used a frequency band of 1-8 Hz and set the detection threshold to 0.2. The time windows exceeding the threshold were visually checked to eliminate false detections. For each detected DLFs, using cross spectrum and correlation functions, we estimated the differential travel times between the detected DLF and the template having maximum correlation, and determined the relative hypocenter using the master event method.

As a result, we detected 1361 DLFs between Jan. 2012 to May 2018, which is about 10 times the number of templates, and determined 1357 hypocenters which spread over wider depth range compared to those estimated with the assumption that the hypocenters of the detected events are the same as those of the templates having maximum correlation. We also checked the individual waveforms of the detected DLFs to understand the spatial clustering of DLFs, and revealed that DLFs can be classified into the following two types in a large sense: the first type (354 events) shows high-frequency (3-4 Hz) component in the initial part (1-2 s) of the waveform, and low-frequency (1-2 Hz) component in the remaining part of the waveform; the second type (1007 events) shows low-frequency (1-2 Hz) component over the entire waveform. The depth distribution of the former type has a peak around 33 km and widely spreads (20-38 km) whereas that of the latter type is confined within a narrow range (20-26 km). These results suggest

that source processes of DLFs differ between two types. On the other hand, there is no clear difference in the Gutenberg-Richter law *b* values of both types.

Our further analysis including estimation of the source mechanisms of the detected DLFs may contribute to the understanding of the distribution and activities of deep volcanic fluid.

Keywords: Zao volcano, deep low-frequency earthquakes, Matched Filter method

