Deep low-frequency earthquakes corresponding to the 2011 and 2018 eruptions in Kirishima volcano

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Deep low-frequency earthquakes (LFEs), or sometimes called as deep long-period earthquakes (DLPs), are earthquakes whose dominant frequencies are lower than those of regular earthquakes of the same magnitudes. Deep LFEs occur beneath Kirishima volcano in southwest Japan at the depths of about 10-15 km and 20-25 km according to the catalog of Japan meteorology agency (JMA), while deep LFEs at most volcanoes in Japan occur at the depth of about 30 km.The LFEs near volcanoes can be a key to reveal physical processes of volcanic activities including eruptions because deep LFE activities are supposed to correlate with eruptions. For example, White (1996) showed that the deep long-period earthquakes (DLPs), so-called LFEs, occurred before the 1991 eruption of Pinatubo volcano, Philippine. Shapiro et al. (2017) showed the relationship between DLPs and long period earthquake near the surface beneath the Klyuchevskoy volcano group at Kamchatka, Russia. However, the relationships are still unknown in many volcanoes in Japan. Takahashi and Miyamura (2009) analyzed deep LFEs all over Japan using the catalog of JMA and concluded that they could not find deep LFEs corresponding with the surface volcanic activity such as eruptions. In fact, LFEs were constantly observed in Kirishima volcano in the JMA catalog. In this study, in order to reveal the relationships between activities of volcano such as eruptions and activities of deep LFEs, we first investigated spatial distribution of LFEs by relocation of the hypocenters of LFEs occurred from April 2004 to December 2015 in the JMA catalog using Network correlation coefficient method (Ohta and Ide, 2011). We then obtained time-series change of LFEs by comprehensive detection of deep LFEs based on matched filter technique (Gibbons and Ringdal, 2006; Shelly et al., 2007) from April 2004 to March 2018.

In results of relocation, hypocenters of the deep LFEs are concentrated in small clusters at the depth of 13 km and 22 km, especially many LFEs are located at the depth of about 22 km. On the other hand, result of the matched filter technique shows that deep LFEs at the depth of 23-25 km are activated for about two years including 2011 subplinian eruptions of Shinmoe-dake in Kirishima volcano group. The period of activation corresponds to the period of crustal deformation due to the volume change of the magma reservoir located beneath Ebino plateau at the depth of about 8 km (Nakao et al., 2013). From both results, we find that deep LFEs activated in the two years are located at the depth of 23-25 km, deeper than the locations of deep LFEs which constantly occurred from 2004 to 2018. Waveforms of deep LFEs activated around the 2011 eruptions have different characteristics such as lower frequencies and weak P wave onsets. The locations of activated deep LFEs migrated from shallow part to deep part of the small cluster at the depth of about 23-25 km during the two years of activation. In addition, there are some characteristic deep LFEs which were intensively observed in the periods of phreatic eruptions from March 2010 to July 2010 and phreatomagmatic eruptions from June 2011 to September 2011.Activation of deep LFEs was also observed in the period of eruptions in 2018, however, the depth and waveforms of the deep LFEs are same as those of deep LFEs which constantly occur at the depth of 20-23 km.
These results suggest that the deep LFEs occurring at the depths of 20-25 km are triggered by fluid flow. The difference of deep LFEs in 2011 and 2018 suggest that the fluid paths of the 2011 eruptions and 2018 eruptions are different. Activation of deep LFEs was not observed at the depth of 13 km in the periods of both eruptions, therefore, this deep LFEs may correspond to Ohachi volcano which did not erupt in the periods.

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