Continuous seismic monitoring of Nishinoshima volcano, Izu-Ogasawara, by using long-term ocean bottom seismometers

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Additional note 1: Characteristic events and location

LT-OBSs frequently recorded events with particular characteristics (the characteristic events) during the eruption period. The events have a high frequency onset, and high amplitude tail with a lower frequency. The characteristic event continues for approximately one minute, and has three phases. The first arrivals with high frequency have an apparent velocity of approximately 4 km/s. The apparent velocity is estimated by time difference between NI11 and NI22. The second arrival dominates high frequency (higher than a few Hz) with large amplitude. Apparent velocity of the second arrival seems to be about 2.0 km/s or less. The third arrivals have the largest amplitude and dominant period is around a few seconds. The apparent velocity of the third arrivals is very slow (a few hundred m/s). The apparent velocities of the first and second arrivals are confirmed by the distance-time profile of an event (Figure A1). We interpret the first arrival as a diving P-wave through igneous crust. There is a possibility that the second and third arrivals propagated along the sea floor as a P-wave, T-phase or surface wave.

For the hypocenter location, we mainly used the first arrivals. To pick up the first arrivals as accurately as possible, we used a waveform with a bandpass filter of 4-8 Hz. Although it is difficult to pick up the first arrival times accurately, we estimated that reading errors are less than 0.25 s due to the lowest frequency of the waveform. Because it is also difficult to pick up S-wave arrivals, the depths of the event are not well-constrained. However, the location program reported that the events have shallow depths. Takagi et al. (2016) argued a possibility that the events have shallow depths (less than 1.5 km) using the envelope correlation method.

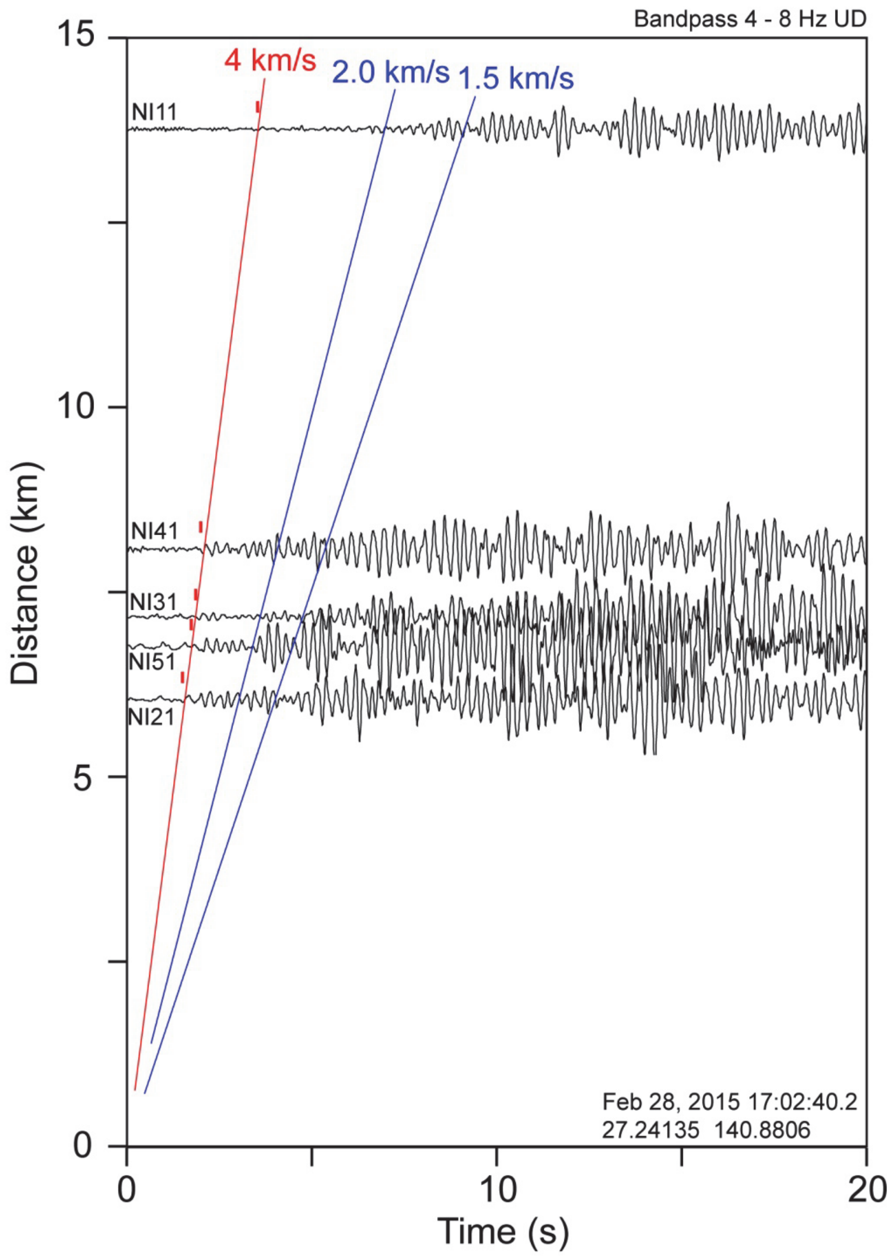

Figure A1

Distance - time record section of a characteristic event for the vertical component of the LT-OBS deployed in the first observation term. Bandpass filtering is 4-8 Hz. Distance and time originate the epicenter and origin time of the event located using first arrivals of each station. The event occurred at 17:02, February 28, 2015 JST, and the epicenter was located close to the island. Red vertical bars show first arrivals. A red oblique line indicates an apparent velocity of 4 km/s. Blue lines denote slower apparent velocities. Later arrivals with large amplitude have slow apparent velocity.

Additional note 2: Detection of characteristic events using the STA/LTA method.

We detected the events with particular features (the characteristic events) using the STA/LTA trigger method. We estimated the power spectra of the event and ambient noises. For estimation of power spectra, we use vertical component data and a data window length of 40.96 s. We calculated the signal-to-noise (S/N) ratio for each frequency from the power spectra of the event and noise data (Figure A2). As a result, the frequency range of 4-8 Hz has the highest S/N ratio. Therefore, we applied the STA/LTA method to waveform data for the vertical component with a bandpass filter of 4-8 Hz to estimate the number of the events. Because using data with higher frequency was expected to give better results, we adopted data with this frequency range for the STA/LTA method.

Among parameters of the STA/LTA method, "STA window", "LTA window", "duration of trigger" and "time for re-trigger" can be determined using typical values, which represent characteristics of the events, for example, the typical duration or typical time interval of events. In contrast, a value of the "STA/LTA ratio" is sensitive to detection of events. Higher values of the "STA/LTA ratio" correspond to detection of event with large amplitude. Therefore, the value of "STA/LTA ratio" for the first term was determined with visual inspection of the results by process of trial and error. After the first term, we chose a "STA/LTA ratio" to maintain continuity from the previous term. We consider that the detection threshold can be maintained almost constant through the whole observation period using this procedure. The numbers of detected events in the first day of an observation period and in the last day of the previous period are almost same. In other words, differences in the "STA/LTA ratio" among observations originate from different configuration of the OBS networks.

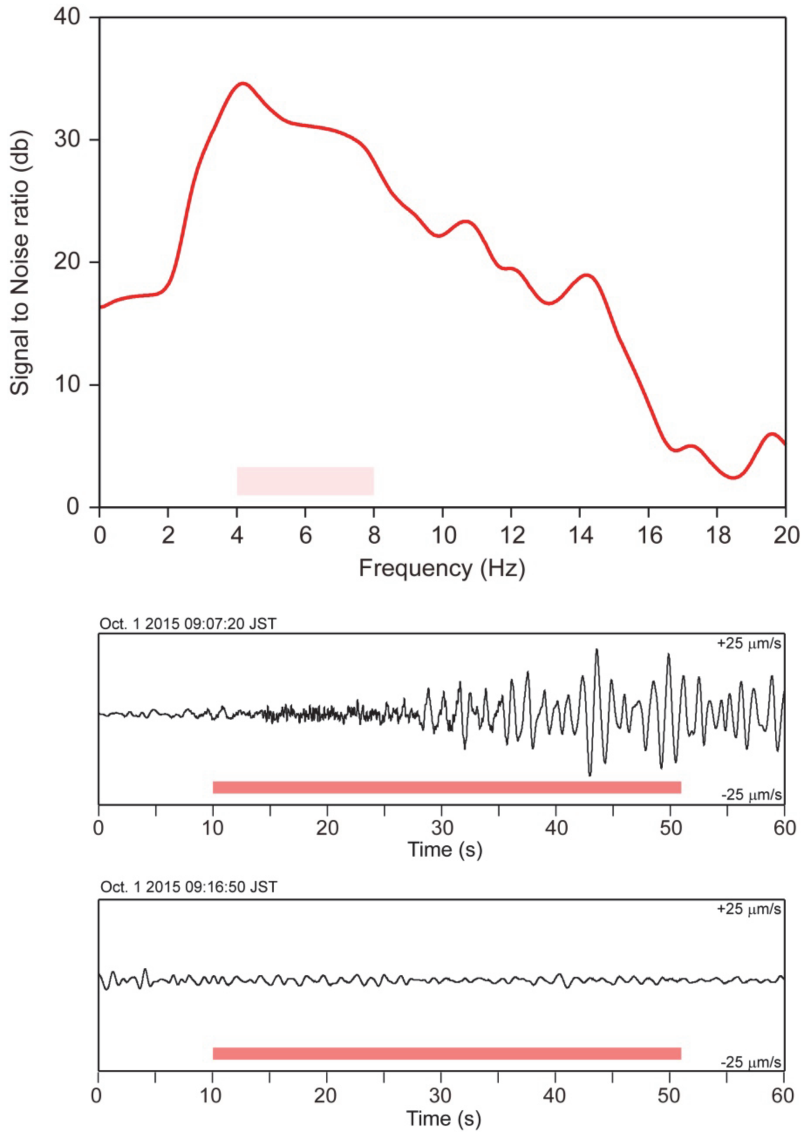

Figure A2

The signal to noise (S/N) ratio of the characteristic event recorded by NI21(upper). First, power spectra were calculated using data of the characteristic event (middle) and data without the event (lower). The window length for the power spectra is 40.96 s and red lines on bottom of middle and lower figure indicate the used data. The sampling frequency of the data is 200 Hz. No filter was applied to the data. After estimating each power spectrum, the S/N ratio is estimated by dividing the power spectrum of the event by that of the noise at the same frequency. As a result, the frequency range of 4-8 Hz has the highest S/N ratio. The red line at the bottom of the upper figure shows the frequency range of 4-8 Hz.

Additional note 3: Comparison with aerial observations.

Active volcanic islands around Japan in the ocean are routinely monitored using aircraft. After the eruption of the Nishinoshima volcano began, the Japan Coast Guard and Japan Maritime Self-Defense Force made visual observations at an interval of approximately one month. They usually stay above Nishinoshima for one hour to observe the volcano visually. Their observations are summarized on the Japan Coast Guard web page (Japan Coast Guard, 2016, 2017). We can compare our results with aerial observations and our results are consistent. The cumulative number of events was decreasing in August and September 2015. Corresponding to the decrease in number of the detected events, aerial observations in the same period reported that interval of the eruption lengthened. The eruption was not confirmed on October 29, 2015 by visual observation, and eruptions were again observed on November 12 and 17, 2015. These observations show good agreement with a temporary increase in the number of detected events in November 2015. From November 25, 2015, the aerial observation confirmed no eruption and a little emission of gases. On July 19, 2016, a halt of gas emission of gases in addition to no eruption was reported by aircraft observation. The detection of the event using the LT-OBS data seems to have no relationship to emission of gases from November 2015 to June 2016. We infer that the emission of volcanic gases did not generate large seismic waves due to their energy size. On April 20, 2017, it was confirmed that the Nishinoshima volcano erupted again. The eruption in April 2017 was coincident with a rapid increase in detected events by the OBS network.

Reference:

Japan Coast Guard (2016) Nishinoshima. http://www1.kaiho.mlit.go.jp/GIJUTSUKOKUSAI/kaiikiDB/kaiyo18-e1.htm. Accessed 20 Oct 2017

Japan Coast Guard (2017) Nishinoshima. http://www1.kaiho.mlit.go.jp/GIJUTSUKOKUSAI/kaiikiDB/kaiyo18-2.htm (in Japanese) . Accessed 20 Oct 2017