A202

Non-tectonic Long Duration Signal Recorded at Ocean Bottom Inferred by Beamforming on a Seismometer Array

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Hyuga Nada, a region offshore of Miyazaki Prefecture nowadays attract wide attention of seismologists as its potential of megathrust earthquake accompanying tsunami, and slow earthquake activity near the trench. From March 2018 to September 2018, we performed dense Ocean Bottom Seismometer (OBS) array observation in a region where active tectonic tremor activities [Yamashita et al., 2015; 2021] and Very Low Frequency Earthquake activities [Tonegawa et al., 2019] have been observed. The OBS array consists of 10 OBSs, forming double concentric circles of radius 1 km and 2 km. The primary objective of the observation was to investigate seismic structure of slow-earthquake-genic field. Receiver Function images constructed based on the array record reveals possible fluid reservoir on the Kyushu-Palau ridge [Akuhara et al., 2022]. Besides the seismic structure, we aimed to detect slow earthquake activity through array analysis.

Array analysis, specifically array beamforming is a type of method to extract information such as arrival direction and/or apparent velocity of wave observed by a dense array. It has been widely used in a field of telecommunication, but also adopted in seismology as well. One of the advantages of incorporating beamforming analysis on seismology is its high capability in detection of weak but coherent signals. Ghosh et al (2012; 2016) detected and located tectonic tremor through array beamforming, including low amplitude events which were not detected by a conventional method to detect tectonic tremors. Since the OBS array was deployed in the field of active slow earthquake activity, we also attempted to detect tectonic tremors by the array beamforming.

To detect signal source which stable in space and time, we perform a slant-stack beamforming [e.g. Rost and Thomas, 2002] to the OBS array data. First, continuous waveforms of vertical component are band-pass filtered in 2 Hz and 4 Hz. The analyzed frequency band is selected based on ambient noise characteristics of observed data. Then, the waveforms are beamformed every 60 seconds with half-overlap moving time window. In the array beamforming, the waveforms of multiple stations are time-shifted in frequency domain based on assumed pairs of apparent velocity (1.4 km/s – 40 km/s) and direction (0° - 360°), and stacked to enhance coherently observed signals.

As a result of analysis, unfortunately we were able to detect only limited number of tectonic tremors. However, we detected several non-tectonic signals with substantially long duration. One is a seismic wave associated with passage of seasonal typhoon near the Kyushu, and the other is the signal possibly generated by eruption of Nishinoshima, a volcanic island in the Izu-Bonin-Mariana Arc.

Seismometer records signal originated from various sources. Typhoon is one of such sources, and it is known to increase ambient noise level of seismometer records when it passes nearby. Although typhoon-originated noise is not rare phenomenally, its generation mechanism is still a matter of debate. It is often explained as oceanic wave hits a coastal line or shallow continental shelves and produce seismic noise [e.g. Bromirski et al., 1999; Kedar and Webb, 2005]. The other proposed mechanism explains ambient noise is converted from large oceanic gravity wave generated by typhoon [e.g. Stehly et al., 2006; Gerstoft et al., 2008; Yang et al., 2022].

On September 4th, 2018, the Typhoon No.21 (JEBI) hits Kinki district and caused severe economic loss. Before it hit the Kinki district, it moved toward north on Philippine Sea, Off Kyushu. As the typhoon approached the array, we observed increase in noise level at two frequency bands. One is a frequency range correspond to a double-frequency (DF) microseism (0.1 Hz – 0.5 Hz). The other frequency band is a 2 Hz – 6 Hz, which is anomalously high frequency compares to DF microseism. Increase of DF microseism associated with approaching typhoon have been observed frequently [e.g. Chi et al., 2010; Lin et al., 2022], but a report of noise level increase above 1 Hz is rarely documented [Ko et al., 2021]. This high frequency noise was observed over 6 hours, and arrival direction estimated by the array beamforming indicates the signal continuously emitted from place surrounding a lowest pressure point of the typhoon. Although we observe temporal change in the arrival direction of signal source, apparent velocity of the signal did not change over time. It is estimated as 2 km/s, which is faster than propagation speed of hydroacoustic wave within seawater. Estimated arrival direction and apparent velocity suggest that the high frequency signal generated near the lowest pressure point of the typhoon, converted to body wave at oceanbottom, and propagate toward the seismometer array. This is the first research to estimate the source of high frequency signal associated with typhoon.

Besides the typhoon, we also observed high frequency (> 2 Hz) signal which duration is substantially long. On July 12th and 13th, the array beamforming reveals arrival of signal below noise level from direction of 105˚ for 32 hours. On July 12th, Nishinoshima, the active volcanic island in the Izu-Bonin-Mariana Arc started the eruption [Marine Volcano Database, Japan Coast Guard]. Although the island is apart from the array site for nearly 950 km, temporal and directional coincidence suggest that the observed signal is possibly produced by the eruption in the Nishinoshima. Since the island has large distance from the array, it is less likely that this high frequency signal arrived from the Nishinoshima directly. Rather, we interpret that the hydroacoustic wave generated during the eruption propagate through the ocean, and converted to the body wave on its path.

The results of array beamforming suggest signals of not only known volcanic activity, but also reveals possible hidden submarine volcano eruption. The eruptive activity at the Nishinoshima was not confirmed by aerial observation after July 30th [Marine Volcano Database, Japan Coast Guard]. However, the array beamforming indicates high frequency signal arrived from direction of 128˚ and 90˚ for 12 hours on August 10th, similar to the event of July 12th to 13th. The signal arrived from 128˚ has apparent velocity of 1.5 km/s, and the signal from 90˚ has apparent velocity of 2.4 km/s. The apparent velocity of those waves possibly indicate that we observed both of hydroacoustic wave travelled through seawater, and body wave converted from the hydroacoustic wave. The hydroacoustic wave from 128˚ may suggest a submarine eruption on part of the volcanic chain near the Nishinoshima. However, such eruption is not reported so far; hence the source of these long duration signals remains unknown.