A detection method for P and S waves of deep low-frequency earthquakes using a 3D array in the Tokai area and its application to hypocenter determination

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We have developed a novel method that uses a 3D array to detect the P and S waves of deep low-frequency earthquakes (LFEs) that occur along the subduction zone of the Philippine Sea plate in southwest Japan. Obtaining accurate hypocenters of LFEs is very difficult because their seismic waves are characterized by low amplitude and the absence of sharp pulses. In particular, identifying P phase arrivals is not readily possible using conventional methods and seismic networks. To determine their hypocenters accurately-not only their epicenters but also their depths-we tried to find their P and S wave pairs and obtain S-P times. We constructed a 3D array (6 km x 4 km area, see Fig.1) using 14 seismic stations in the Tokai area with three component seismographs, including ones with deep (600 m at the deepest) borehole seismographs. We observed remarkable LFE activity occurring in the Tokai area over November 10-30, 2010. We successfully detected not only S waves but also very weak P waves of LFEs using the 3D array data and the semblance method. Assuming a homogeneous half-space model with P wave velocity=4.5 km/s and S wave velocity=2.2 km/s in the 3D array, we calculated the semblance distributions for more than 20 LFEs to obtain their propagation parameters (back azimuth and the incident angle of seismic waves) and to identify P and S-waves. Using the time of the maximum value of the semblance in each component, we detected the direct P wave in the vertical component and the S wave in the horizontal component, providing S-P time. Fig.2 shows an example of hypocenter determination (red star) using estimated S-P time and propagation parameters, where we found 8.2 km difference in depth between the hypocenter in this study and that (green star) listed in Japan Meteorological Agency (JMA) catalogue. This example suggests that the inclusion of the S-P time strongly reduces the uncertainty on source depth, because the LFEs in the JMA catalogue were generally located using only S-arrival times. Choosing 4 LFEs with reliable results obtained from the semblance analysis, we located their hypocenters and found they distribute in the depth range from 28 km to 35 km approximately along the plate interface inclining in depth from 30 km to 32 km.Because a single array inherently has a limitation in the precise location estimate, especially for epicenter, we also tried to locate hypocenters (for example, a blue star in Fig.2) of LFEs using 3D array data together with arrival times (in many cases, S-arrivals) of surrounding stations that listed in JMA catalogue. For the LFE in Fig.2, we found 4.5 km difference (between a blue star and a red star) in the epicenter by combining the arrival times of surrounding stations, which is not always negligible for better understanding the spatial and temporal distribution of LFEs.

Keywords: deep low-frequency earthquake, 3D array, P- and S-waves, semblance analysis, plate boundary

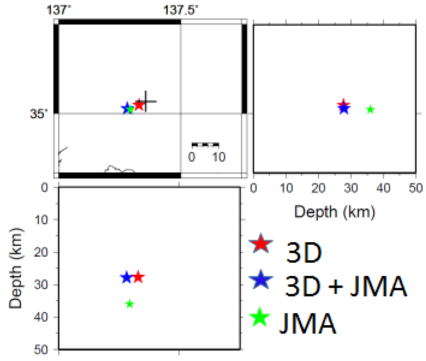

Fig. 2. An example of the difference in depth of hypocenter of LFE (LFE13) between 3D, 3D+JMA, and JMA. The 3D and 3D+JMA hypocenters were located using not only S-arrival times but also P-arrival times, while the JMA hypocenter was located using only S-arrival times.

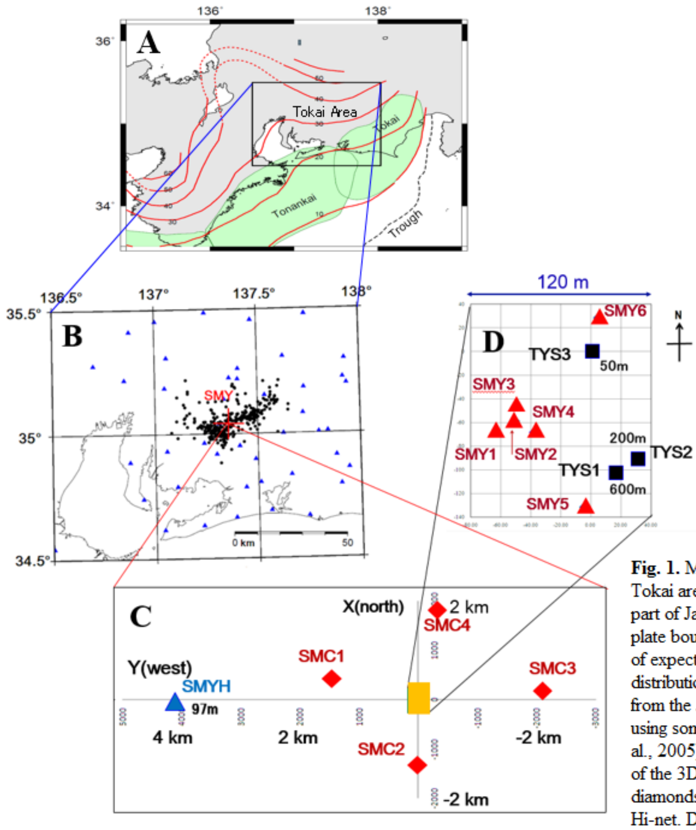

Fig. 1. Map of seismic stations comprising the 3D array of SMY in the Tokai area, located in the central part of Japan. A: Index map of the central part of Japan. Red lines represent the depth contours of the Philippine Sea plate boundary (Hirose et al., 2008). Green areas show the source regions of expected Tokai and Tonanki interplate earthquakes. B: Epicenter distribution (black points) of LFEs occurring in November 2010 derived from the JMA earthquake catalog. The epicenters were located mainly by using some of the seismic stations (blue small triangles) of Hi-net (Obara et al., 2005) operated by NIED. A thin red cross shows the central location of the 3D array of SMY. C: Distribution of four SMC stations (red diamonds) of a medium-sized array and SMYH station (blue triangle) of Hi-net. D: Distribution of six stations (red triangles) of a small-sized array and three borehole stations (black squares). Numbers followed by m show the depths of the boreholes.

