Practical method to determine relative orientation of horizontal components of ocean bottom seismometer in an array

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Japan Trench is one of typical subduction margins with fast and slow seismic activities, such as M9 Tohoku-Oki megathrust event, slow slip events [Kato et al., 2012], low frequency tremors [Ito et al., 2015] and very low frequency earthquakes [Matsuzawa et al., 2015]. To observe such offshore seismicity with high precision and resolution, we installed three arrays of ocean bottom seismometers (OBS) on offshore Fukushima prefecture near the trench axis. Each array consists of one broad band OBS, and six 1Hz short period OBSs. Those seven OBSs form triangular array with diameter of 1km, and 500m of interstation distance. Continuous observation was performed between September 2016 and October 2017.
We have processed data with beamforming, which is a method allows us to reveal azimuth and apparent velocity of incoming wave observed by an array. It has been used to detect tremors in Cascadia subduction zone [Ghosh et al., 2009; 2012] and San Jacinto Fault [Hutchison and Ghosh, 2017]. Beamforming was applied to OBS array dataset in previous study [Ohta et al., 2017, EGU]. However, only waveforms of vertical components had been used, because of unknown orientation of horizontal components due to free-fall deployment of the OBSs. Definite orientation of horizontal components can be obtained using particle motion of regional or teleseismic earthquakes [e.g., Scholz et al., 2016]. However, associated uncertainty is too large to satisfy required condition of beamforming, which is horizontal components of all seismometers in an array must oriented in a same direction. Here, we align the orientation of horizontal components of all OBSs within each array by cross correlating observed waveforms. On each array, we pick one OBS as a reference. Horizontal components of the other OBSs in an array are rotated every 1 degree, and cross correlated with the horizontal components of the reference OBS using first several seconds of P-wave radiated from regional and local earthquakes. As a result, we obtained relative orientation where waveforms of horizontal components of the other OBSs correlate for the best with the reference OBS. We verified these orientation angles are accurate enough for beamforming through beamform of local, regional and teleseismic earthquakes.
Our method can determine relative orientation of horizontal components of OBSs in the array accurately, which is a crucial condition for any array analysis technique. Analysis of waveforms of horizontal components would be a huge advantage for study of low frequency tremors, since S-wave dominates its waveform [Obara, 2002; La Rocca et al., 2005] and thus expected to be more energetic in horizontal components rather than vertical.
Acknowledgement: This study is supported by JSPS KAKENHI (26000002).

Keywords: Ocean Bottom Seismometer, array, orientation of ocean bottom seismometer, beamform, offshore observation, slow earthquake

