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Rupture propagation during the 2011 Tohoku Earthquake deduced from an array of the Fukushima Daiichi Nuclear Power Plant

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1. Introduction

The source region of the 2011 off the Pacific coast of Tohoku Earthquake (Tohoku Eq.) was about 450km by 200km [Yoshida et al., 2011]. The high-frequency energy radiation sources (HFSs) of this great earthquake were estimated using the empirical Green's function method [Kurahashi and Irikura, 2011] and the back-projection methods by teleseismic P waves [Wang and Mori, 2011] and by regional strong motion records [Aoki et al., 2011]. In these studies, the following common features about the HFSs were pointed out: In the first stage of the rupture (0-100 s), the HFSs are located in the area between the epicenter and the coastline of northern part of the source region (off Miyagi). In the next stage (100-140 s), the HFSs move from off Fukushima to off Ibaraki along the coastline.

Nakahara et al. (2011) performed semblance analysis [Neidell and Tarner, 1971] using a small array at the Oshika peninsula in order to estimate the back-azimuths of incident wave packets from the rupture area of the Tohoku Eq. The temporal changes in the azimuthal angles at the Oshika array are almost comparable to those expected for the S wave packets radiated from the HFSs estimated by Aoki et al. (2011).

In this study, we apply the semblance analysis to accelerograms of a dense array installed at the Fukushima Daiichi Nuclear Power Plant for imaging the rupture propagation of the Tohoku Eq.

2. Data and method

The epicenter determined by JMA is located 178 km away in the direction of N64E from the array. The array comprises 20 three-components accelerometers (two of them were broken due to the tsunami), which were located on the surface with a spacing of 100 - 500m in the area of 2 km (NS) by 1 km (EW). Strong ground motions were recorded with a sampling rate of 100Hz, with a resolution of 24 bits, and with a full scale range of 2000 Gal. Because the peak ground accelerations were about 1000 Gal at the array, no recorder was clipped during the Tohoku Eq.

In consideration of the array geometry, a frequency band of 0.5 - 2Hz is selected. For the calculation of temporal changes in semblance, time windows of 5.12 s are used sliding by 0.5 s interval for each component. In this study, we discuss the result calculated using seven stations with high coherence for one another, which are located in northern area of the power plant. However, when the peaks of semblance appeared, the differences between the back-azimuths estimated from seven stations and those from all stations were inconsiderable.

3. Results

After the P arrival, the semblance became high in each component. Especially in the UD component, the semblance reached about 0.98 around the P onset, and remained high until the S arrival. The back-azimuth was estimated to be about N60E, and the direction almost corresponded to that of the epicenter. After the S arrival, some repeating peaks appeared in the time series of semblance calculated by the horizontal components. Also, there were clear temporal changes in the estimated back-azimuth. Since the S onset, the back-azimuth had been estimated to be about N60E for 60 s. After that, the back-azimuth gradually began to rotate clockwise, and reached about N180E at times of about 110 s from the S onset. After 110 s, the semblance value dropped.

These changes in back-azimuth are comparable to those expected for the rupture propagation estimated in the previous studies. Aoki et al. (2011) found five HFSs during the Tohoku Eq. First three HFSs were located in off Miyagi (#1:38 s from initial rupture, #2:57 s, #3: 74 s), and the rest were located in off Fukushima (#4: 105 s) and off Ibaraki (#5: 131 s). The arrival times of S wave radiated from these HFSs almost corresponded to the local peaks in the time series of semblance. Moreover the back-azimuths of these HFSs were within 30 degrees of the estimated back-azimuths at time of the local peaks.

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Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, Rupture propagation, High-frequency energy radiation sources, Semblance analysis, Near-real-time processing