Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P46 Room:Convention Hall Time:May 26 14:15-16:15

Source Process of the 2011 Tohoku Earthquake Inferred from Waveform Inversion with Long-Period Strong-Motion Records

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We have investigated the rupture process of the 2011 Tohoku earthquake by the multi-time-window linear waveform inversion method using the long-period strong-ground motion data.

We used the strong-motion data obtained from 30 stations of F-net and KiK-net, and 1 station (MYR) of Hokkaido University. These stations are located on relatively hard rock. It is expected that the broadband seismometers, used for F-net and MYR, accurately recorded very long-period strong motion excited by this M9 earthquake.

We assumed a single planar fault model of 475 km in strike and 225 km in dip. We assume N193E and 14 degrees for the strike and dip angles, respectively, referring to the USGS W-Phase moment solution. The rupture starting point is located at the hypocenter determined by USGS: 38.322.N, 142.369.E, 24.4 km.

Theoretical Green's functions are calculated using the discrete wavenumber method (Bouchon, 1981) and the Reflection/Transmission coefficient matrix method (Kennett and Kerry, 1979) using a stratified medium. We use the same structure model for all stations, because the stations used in the inversion are located on hard rock, so it is expected that the observed seismograms are not affected by local site effects in the long-period range.

We use multi-time-window linear waveform inversion procedure (e.g., Hartzell and Heaton, 1983) in which the moment-release distribution is discretized in both space and time. For discretization in space, we divide the fault plane into 38 columns in the strike direction and into 18 rows in the down-dip direction (making a total of 684 subfaults with area of 12.5 km x 12.5 km). We use 8 smoothed ramp functions with duration of 16 seconds separated by 8 seconds interval to represent the slip history of each subfault. In order to limit the rake-angle variation, non-negative constrains (Lawson and Hanson, 1974) are also adopted. The rake angles are allowed to vary within 45 degree centered at 90 degree. We use the first time window triggering velocity (FTWTV) as 2.2 km/s.

Total moment release of the inverted source model is 3.07×10^{22} Nm (Mw8.9). Overall matching between the synthetics and observed ones is very good. The inverted slip distribution shows a large slip area with a maximum slip of 29 m which is located on the shallower part of the fault plane. Large moment there was released at 60-80 s from the rupture started. The rupture velocity was inferred to be slower than 2.2 km/s (FTWTV) at early stage of the rupture process. The peak moment rate distribution indicates two high peak moment rate areas. One is the identical area with the large slip area. Another one is located on the southern part of the fault plain.

The synthetics calculated from the northern part of the fault model explain the largest amplitude of waves observed at the northern and near-epicentral stations. However, largest ones at the southern stations is explained by the synthetics calculated from the southern part of the fault model. In the southern part of the fault plane, the final slip is not large, but the relative high peak moment rate area is recognized. This relative high peak moment rate suggests making the peak of the waveform observed at the southern stations.

Keywords: 2011 Tohoku earthquake, Long-period ground motion, Strong motion, Source process