Simultaneous estimation of stress drops and rupture directivities of small and moderate-sized earthquakes in the offshore Tohoku region based on S-net data

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Rupture process of an earthquake reflects the state of fault such as the spatial distribution of stress and frictional parameters and material properties. Systematic examination of earthquake ruptures may provide information about the states of fault zone. Rupture processes are usually only estimated for large earthquakes (M>6), but recent development of seismic networks allows to estimate the rupture process to some extent even for smaller earthquakes. The present study aims to systematically examine the rupture process of small and moderate-sized earthquakes in the offshore Tohoku region by using S-net data.

We analyzed earthquakes which are listed in the F-net moment tensor catalogue and occurred in Tohoku-Oki for the period from Sep. 2016 to Oct. 2018. We first classified earthquakes into three groups following Asano et al. (2011): the interplate earthquake group, the intraslab earthquake group and the overriding plate earthquake group. We then estimated apparent source time functions of interplate earthquakes based on the waveform deconvolution using waveforms of nearby small earthquakes (eGF events) at various seismic stations. The criteria for selecting an eGF event was that the distance between the target and eGF event is less than 3 km and the magnitude of the eGF event is 1-2 less than that of the target event. We analyzed 234 of 421 interplate earthquakes, which have at least one eGF event.

Obtained apparent source time functions are similar among different stations for some earthquakes, but are largely different for other earthquakes (Fig. 1). The diversity of directional dependencies of apparent source time functions reflects the diversity of rupture propagation. We adopted the rupture model used by Yoshida (2019), which is a generalized version of the source model of Sato & Hirasawa (1973), to account for the rupture directivity. We simultaneously estimated rupture propagation directions and stress drops of 121 earthquakes of which apparent source time functions were obtained at more than 15 different stations by fitting the corner frequency. We evaluated the significance of asymmetrical rupture by using the difference of AIC (Akaike, 1974) between the general rupture model and the ordinary symmetrical rupture model.

The general rupture model yields a significantly better fit for 88 of 121 earthquakes, indicating that the effects of rupture directivity should be incorporated for the source modeling of many of analyzed earthquakes. The median value of stress drops simultaneously estimated with rupture propagation directions is 24.1 MPa, which is larger than that of the crustal earthquakes (16.8 MPa) determined by Yoshida (2019) using exactly the same method. Fault length increases with the power of 1/3 of seismic moment, which is consistent with the scaling relationship of earthquakes (Aki, 1967). Stress drops largely change over short distance; we could not recognize significant spatial characteristics.

Ruptures tend to propagate to the shallower part or along the strike-direction, which is similar to the result of previous global scale studies (Henry & Das, 2001; Chounet et al., 2018). The rupture propagation direction seems to have some regional characteristics. Rupture tends to propagate to the shallower part in Miyagi-Oki and Iwate-Oki, while they tend to propagate along the strike direction in Kanto-Oki. These

characteristics may reflect the state of the interplate boundary such as stress, friction, and material properties.

Keywords: Rupture directivity, stress drop, Tohoku-Oki, S-net