Radiated energy and source complexity of small earthquakes estimated from a large source time function data base in Japan

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Although the corner frequency is widely used in earthquake source studies, its relation to physical source parameters is often ambiguous. Specifically, the source corner frequency or source duration does not explicitly include information about the complexity of the source process. The radiated energy is a more direct physical quantity for studying the dynamic characteristics of earthquake rupture. In Japan, high-quality seismic waveform records are available from the dense national seismic networks, which allow the determination of detailed source time functions even for small earthquakes (Mw > 3.3) (Yoshida, 2019). We systematically examined the radiated energy of small earthquakes in Japan using the abundant source time function data.

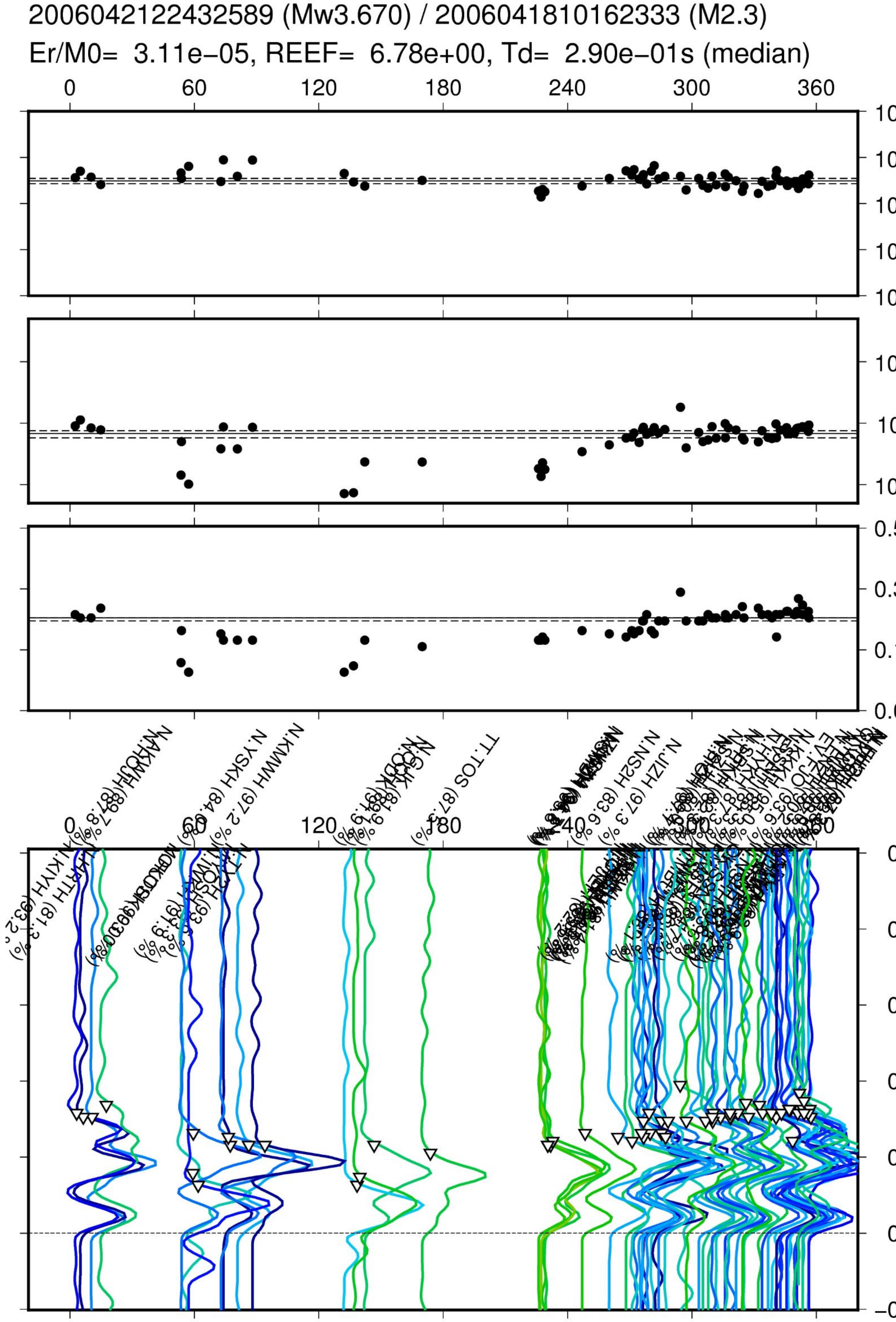
We estimated the radiated energy of earthquakes for which the moment tensor is listed in the F-net moment tensor catalog from 2004 to 2019 (Mw3.3-5.5). The waveform data were derived from the stations of national universities, JMA, NIED Hi-net, F-net, and V-net. We applied the deconvolution algorithm developed by Ligorria and Ammon (1999) that employs the method of Kikuchi and Kanamori (1982) to SH waves and estimated the apparent source time functions (ASTFs). We used the waveforms of smaller earthquakes that occurred close to the target earthquake (< 3 km) with magnitude differences from 1 to 2 as the empirical Green's functions (eGFs). We first applied a low-pass filter to the raw velocity waveforms, with a cut-off frequency increasing with $M_0^{-1/3}$ of the target earthquake.

For approximately 1300 earthquakes (Mw3.3-5.5), we derived ASTFs at more than ten stations. Many earthquakes show a coherent azimuthal dependence of AMRFs. Some earthquakes are characterized by distinct multiple pulses (Fig. 1), indicating complex ruptures of multiple patches. Then, we estimated the radiated energy E_R from each AMRF using the method of Vassiliou & Kanamori (1982). We also measured the source duration T and computed the radiated energy enhancement factor (REEF; Ye et al., 2018). As representative values of E_R, source duration T, and REEF for each earthquake, we used the median of the results estimated from the different AMRFs.

The estimated values of E_R are generally proportional to M_0, with a typical ratio E_R/M_0 of about 3.6×10^{-5}. The duration cubed, T^3, tends to be proportional to M_0, with a typical value of M_0/T^3 about 3.9×10^{16} (in SI unit). This corresponds to a stress parameter of 2.0 MPa in Brune's (1970) model. REEF is typically ~3 but tends to be larger for multiple shocks. We do not see significant spatial variations of E_R/M_0, M_0/T^3 and REEF, or any clear dependence of these parameters on depth, focal mechanism, and seismicity type.

The scaled energy E_R M_0 =3.6×10^{-5} obtained in this study for small earthquakes (Mw<5.5) is comparable to the estimates for larger earthquakes (e.g., Kanamori et al., 2020) in Japan. E_R/M_0 in our dataset does not significantly vary with the earthquake size, as suggested by Ide et al. (2001). The typical values of $T/M_0^{1/3}$ and REEF in our data set tend to be smaller than those of larger global earthquakes (Duputel et al., 2013; Ye et al., 2018). At face value, this suggests that small earthquakes have simpler source processes than large ones. However, this trend may be affected to some extent by our low-pass filter with a relatively low cut-off frequency.

Although the median values of E_R/M_0 and M_0/T^3 are fairly constant with M_0 (or Mw), the individual values do vary over an approximately 1.5 order of magnitude. E_R/M_0 in our dataset generally increases with M_0/T^3 with an approximate slope of 0.5 on the log-log plot. This suggests that M_0/T^3 or stress parameter can be used to approximately estimate the scaled energy. However, the proportionality relationship does not hold for complicated ruptures (high REEF events). The variation of REEF ranging from 1 to 40 obtained in this study suggests that considerable rupture complexity is involved in small earthquakes too.



20060421224332589 (Mw3.670) / 20060418101623333 (M2.3)
Er/M0= 3.11e−05, REEF= 6.78e+00, Td= 2.90e−01s (median)
Er/M0
REEF
Duration (s)

