

# Moment-rate functions of repeating earthquakes of varying magnitude and surrounding earthquake distributio

\*Keisuke Yoshida<sup>1</sup>

1. Tohoku University

Some repeating earthquakes showed significant changes in magnitude after the Tohoku earthquake. Off Kamaishi, an M5.7 earthquake occurred immediately after the Tohoku earthquake at the location that previously caused M4.9 repeating earthquakes regularly (Uchida et al., 2015). In this earthquake sequence, not only did the amount of slip increase, but the rupture area also significantly increased. Previous studies suggested that the increase in seismic area under high loading rate and the occurrence of compound ruptures at multiple patches are key factors (Uchida et al., 2015; Hatakeyama et al., 2017).

We here investigate the characteristics of many repeating earthquakes in the offshore area from Miyagi to Iwate based on precisely-determined hypocenter distribution and moment-rate functions (MRFs). For the deep area off Miyagi (40-60 km), Yoshida et al. (2022) and Yoshida (2023) relocated the centroids of small earthquakes using waveform correlation data and identified M2-7 repeating earthquakes based on source overlapping. In this study, we first use the same method to newly determine the centroids of earthquakes with  $M_{JMA} > 2$  at 30-60 km off the Iwate plate boundary and to identify repeating earthquake groups.

We obtained 279 repeating earthquake group including 2124 earthquakes in the offshore Iwate area, 27 of which contained more than 20 repeating earthquakes. Seven of the 27 sequences show a marked increase in the magnitudes after the Tohoku earthquake and a subsequent decrease after that. The largest magnitude change is about 2. An examination of the characteristics of the hypocenter distribution of repeating earthquake sequences with temporarily increased magnitude shows a presence of different repeating earthquake sequences in the vicinity. It may suggest that compound ruptures of adjacent slip patches is a key to changes in the magnitude of these activities. However, there are some sequences that do not show changes in magnitude, even though different repeating earthquake sequences appear to occur very close.

We then focus on areas of repeating earthquake concentration. The sequences to the west of the 2015 Mw6.8 earthquake area in Kesenuma is one example. In this region, about five repeating earthquake sequences (M2-4) are distributed next to each other in the WNW-ESE direction parallel to the subduction direction (Yoshida, 2023). The typical magnitude is about 3, but larger earthquakes (Mw 4.0-4.9) occurred mainly immediately after the Tohoku earthquake. We obtained the moment-rate function (MRF) for M2.0-4.9 earthquakes by the seismic waveforms of a small earthquake (M1-2) as an empirical Green's function, using one station only. Seismic moment was estimated for each earthquake. Mw tended to be systematically larger than  $M_{JMA}$  for  $M_{JMA} < 3$ . Among the repeating earthquake series,  $M_0$  and  $T^3$  tended to be correlated. This suggests that in these repeating earthquakes that change Mw with time, the fault length also changes with the change in Mw.

We estimated the directional distribution of AMRFs for earthquakes using the same method as Yoshida & Kanamori (2023, GJI). The results show that many earthquakes with  $M_w > 3.5$  exhibit AMRFs with multiple peaks. These results suggest that the repeating earthquakes with increased magnitude tend to have ruptured multiple slip patches in tandem. Since changes in fault size alone are not sufficient to explain the

change in  $M_w$ , an increase in slip, and possibly stress drop, likely accompanied. However, there are also earthquake sequences that appear to have simply ruptured a much larger area rather than multiple patches, as seen off Kamaishi (Uchida et al., 2015). This may be explained by the occurrence of seismic slip in the surrounding area where seismic slip occurs only under high loading rate. Additionally, the hierarchy of asperities may have an effect on the large changes in magnitude.

Keywords: Tohoku earthquake, repeaters, moment rate functions