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Emergence, moment change and disappearance of small repeating earthquakes following the 2011 Tohoku earthquake

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Small repeating earthquakes, which occur repeatedly at almost the same location, are thought to represent repeated ruptures of a small seismic patch on a fault plane. There are many unknown features about repeaters such as detailed structures of the patch and causes of irregularity in the magnitude and the recurrence interval.

Some small repeating earthquake sequences show systematically increased seismic moments after the 2004 M6.0 Parkfield earthquake (Chen et al., 2010) and the 2011 M9.0 Tohoku earthquake (Tohoku EQ; Uchida et al., 2015) in the areas where large afterslip occurred. These phenomena can be explained by increases in rupture areas due to aseismic-to-seismic transitions at high loading rate in conditionally stable regions around the repeaters. Understanding slip behavior changes in conditionally stable regions due to stress perturbation is important for revealing the generation mechanisms of recurrent interplate earthquakes.

In this study, we performed hypocenter relocations in a small area off Miyako-city, Iwate-prefecture, Japan, to examine temporal changes in seismic activities before and after the Tohoku EQ. We selected a small area including a cluster of earthquakes with repeaters at a depth of ~40km, corresponding to the depth to the plate boundary. A large afterslip of the Tohoku EQ was estimated to have occurred in this area (e.g., Ozawa et al., 2012).

We used the double-difference method (Waldhauser and Ellsworth, 2000) for the hypocenter relocation. Firstly, we relocated events around the cluster by using pick-data of the Japan Meteorological Agency to select earthquakes in the cluster for further analysis. Secondly, we precisely relocated events in the cluster by using travel-time differences estimated from waveform cross-spectra.

The results show that before the Tohoku EQ, M2.5-2.9 events (Group A) repeatedly occurred at almost the same location with quasi-periodic recurrence intervals (9-12 months). There were no events whose magnitudes were larger than 2.0 within 5km from the repeaters.

After the Tohoku EQ, three significant changes were observed in the seismic activities in the cluster.

(1) At the location where the Group-A events had occurred before the Tohoku EQ, earthquakes larger than M3.0 started to occur repeatedly. The recurrence intervals were much shorter than before (eleven events from March to December 2011).

(2) In some areas where there had been no events before the Tohoku EQ, two repeating earthquake sequences appeared: M3.2-3.9 events (Group B) to the northwest of Group A and M2.2-4.4 events (Group C) to the northeast of the Group A. The centroids of the events in the Groups A-C were estimated to be located within 1 km.

(3) Magnitudes of the events in each group tended to become smaller as time passed. The Group-C events disappeared after the M2.2 event in January 1, 2012.

The phenomena similar to (1) were previously reported by Chen et al. (2010) and Uchida et al. (2015). These suggest that conditionally stable regions around the Group-A patch slipped seismically with the patch due to fast loading rate caused by afterslip of the Tohoku EQ. The phenomena in (2) can be interpreted as slip behavior changes in conditionally stable regions from aseismic to seismic due to the fast loading rate. The phenomena in (3) can be interpreted as that the rupture areas in the conditionally stable regions gradually shrunk over time as the loading rate decreased.

These results suggest that slip behavior changes that were probably dependent on the loading rate could cause not only changes in magnitudes but also emergence and disappearance of repeating earthquakes in some cases. These observations will be useful in the modeling of the plate boundary off Tohoku.

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Keywords: repeating earthquake, 2011 Tohoku earthquake, hypocenter relocation, conditionally stable region, afterslip