Tremor and slow slip associated with afterslip of the 2011 Tohoku earthquake

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Characterizing shallow interplate slip is essential for modeling the potential generation of megathrust earthquakes and tsunamis. Large postseismic crustal deformation caused by the 2011 Tohoku-Oki earthquake suggests the occurrence of shallow afterslip, but it is unclear what kind of slip is dominant at the shallow plate interface. Here we report episodic tremor activity south of the primary rupture area based on ocean bottom seismometer observations.

We deployed 24 OBSs at 6 sites close to the trench axis in the Fukushima-Oki region. Three of these sites were small arrays, each consisting of 1 broad-band OBS and 6 short-period (1 Hz) OBSs. The 3 other sites each had 1 short-period OBS. Continuous observations were made from October 2016 to September 2017. For OBS records, we applied the envelope correlation method to detect and locate tremor activity. We also estimate the focal mechanisms of the detected tremor events using S-wave polarization particle motion.

We identified ~ 2000 tremor events in five burst episodes. The duration of each burst ranges from 6 to 18 days, with recurrence intervals of ~60 days. The tremor region largely coincides with the region of very low frequency earthquakes and lies between geodetically observed coseismic and afterslip region of the Tohoku earthquake. Tremor shows clear migration behavior with the speed of ~ 5 km/day and shear mechanisms consistent with plate subduction direction.

The characteristics of the tremor –episodicity, migration and shear mechanisms –strongly suggest that it is accompanied by slow slip events (SSEs). We further approximated the slip amount of SSEs based on the ground displacement of the tremor seismograms. The estimated slip of 1.5 cm/year corresponding to a seismic moment of ~7.4×10^{17} Nm is slightly smaller than but comparable to that of typical short-term SSEs, however, much smaller than that of afterslip. Thus, both SSEs and afterslip exist in the shallow part of the Japan trench. We propose that the tremor and SSE region illuminate the boundary between coseismic slip and stable aseismic slip that could limit the rupture extent of future megathrust earthquakes. Besides, the observed tremor and slow slip activities may also suggest that the interplate stress state has been recovered to the level of that before the Tohoku earthquake.

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