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Fault modeling of the foreshocks of the 2011 Tohoku-oki earthquake based on near-field tsunami observation

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We calculated the fault slip distribution of two large (Mw 7.3 on March 9 and Mw 6.5 on March 10) foreshocks of the 2011 Tohoku-Oki mainshock (Mw 9.0 on March 11) by inverting tsunami waveforms recorded by ocean bottom pressure gauges (OBPs) that had been deployed around the source area of the mainshock. These two foreshocks are the two largest foreshocks of the Mw9.0 mainshock. Both tsunami and coseismic vertical displacement of the seafloor were recorded clearly by OBPs. For the Mw 7.3 foreshock, the recorded tsunami amplitude and seafloor vertical displacement were up to 15 and 10 cm, respectively. During the Mw 6.5 foreshock, the vertical movement of 4 cm uplift was recorded at one of the OBP stations, and the tsunami with an amplitude of about 3 cm was recorded at several stations. In the tsunami waveform inversion for the both foreshocks, we use the same fault geometry based on Ito et al. (2005). As a first step of our analyses, we estimated the initial water surface height distribution through the inversion. The result is consistent with the pure reverse-fault type focal mechanism for both foreshocks. The results indicate that the main slip area of the Mw 7.3 foreshock is 40 km in length and 40 km in width and is located to the northwest of its epicenter. The maximum slip and the magnitude are estimated to be 1.0 m and Mw 7.3, respectively. The results indicate that the Mw 6.5 foreshock occurred about 20 km south of the epicenter of the Mw 7.3 foreshock and that the main slip area is 20 km in length and 40 km in width and is situated to the west of its epicenter. The maximum slip and magnitude are estimated to be 0.2 m and Mw 6.6. The calculated main slip area of the Mw 6.5 foreshock is located immediately south of the Mw 7.3 foreshock and is sandwiched between the epicenters of the Mw 7.3 foreshock and the mainshock. This indicates that the aseismic rupture propagated southwards sequentially. The postseismic slip of the Mw 7.3 foreshock likely caused aftershocks, which led to the second largest Mw6.5 foreshock. There were more aftershocks following the Mw 6.5 foreshock than Mw 7.3 foreshock. It is likely that this swarm of aftershocks triggered the initial rupture of the mainshock. The comparison between the tsunami sources of an M 7.0 earthquake off Miyagi in 1981 and the Mw 7.3 foreshock indicates that the Mw7.3 foreshock ruptured the same area of the 1981 event or that the area partially contained the rupture area of the 1981 earthquake.

Keywords: The 2011 off the Pacific coast of Tohoku earthquake, Foreshocks, Tsunami