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Historical seismicity explains the dynamic rupture process of the 2011 Tohoku-Oki earthquake

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Many small repeating earthquakes identified in the Tohoku subduction zone imply some kind of irregular structures are maintained for long time, at least longer than the history of the instrumental seismology. However, these structures are not always the source of characteristic earthquakes, nor so-called asperities without rigid definition, which is proved by the 2011 Tohoku-Oki earthquake. Nevertheless, these structures probably constrained the dynamic process of the earthquake. Here we simulate the process using the circular patch model of Ide and Aochi (2005), in which heterogeneous distribution of fracture energy is given by the patch radius.

The distribution of patches is deduced from the historical seismicity in the catalog of Japan Meteorological Agency since 1923. We assume every historical earthquake of M7.8-8.3, M7.2-7.7, and M6.7-7.1 occurred on a patch centered at the hypocenter with the radius of 50, 25, and 12.5 km, respectively. These patches and the source area of the 1896 Sanriku earthquake demarcate the large slip area of the Tohoku-Oki earthquake, which we represent by an ellipse of 260 x 150 km. If we introduce an artificial patch, the patch distribution is sufficient to explain various features of the Tohoku-Oki earthquake.

Following Ide and Aochi (2005) we carried out numerical simulations of dynamic rupture on the patch distribution with a slip weakening friction law using a boundary integral equation method. The result shows (1) downward rupture propagation up to about 30 s, (2) the rupture of the largest patch nucleated by the previous stage and the break of the trench at about 60 s, and (3) successive ruptures of surrounding patches in the deep part of the plate interface, all of which are observed features in many slip models. The rupture stop before breaking patches representing aftershocks. Although the model does not have free surface and the total seismic moment is underestimated, the overall characteristics of moment rate function is reproduced. The calculation also shows that the foreshock on March 9 and its stress disturbance are essential to rupture the largest patch. Without the foreshock, the rupture stops after the stage (1), which corresponds to M7.5-8 earthquake similar to the 1978 Miyagi-Oki earthquake.

Keywords: The 2011 Tohoku-Oki earthquake, dynamic rupture process, fractal patch, seismicity