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Modeling generation processes of off the Pacific coast of Tohoku earthquake by considering fault lubrication

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We investigate the generation process of the 2011 off the Pacific coast of Tohoku earthquake (M9) on the basis of recent experimental results for fault frictional behavior at low to high slip rates. According to the result of tsunami waveform inversion (Fujii and Satake, 2011), large slips have occurred near the trench off Miyagi and off Fukushima. The maximum slip was estimated to be over 30 m. This result indicates that significant stress drop occurred in this region. Recent experimental studies on friction indicate that fault lubrication occurs at high slip rates and results in a significant decrease in the frictional coefficient (e.g., Di Toro et al., 2011). Therefore, it is considered that fault lubrication occurred in the area with the largest slip in the case of the 2011 off the Pacific coast of Tohoku earthquake.

In this study, we propose a rate- and state-dependent friction law with two-state variables that shows velocity weakening or velocity strengthening with a small critical displacement at low to intermediate slip rates, but strong velocity weakening with a large critical displacement at high slip rates. We use this friction law for quasi-dynamic 2D modeling of earthquake cycles. We consider two asperities where velocity weakening occurs at low to intermediate slip rates, in the region close to land and close to the trench considering the off-Miyagi region. Ruptures of asperities occur at intervals of several ten to one hundred years. On the other hand, large events occur at intervals of several hundred to thousand years. In the case of such an event, ruptures occur in the regions where velocity strengthening occurs at low to intermediate rates since the slip rate becomes enough high that velocity weakening occurs.

Next, we perform 3D quasi-dynamic modeling of earthquake cycles. We consider asperities off Miyagi, off Fukushima, and off Ibaraki and a large asperity close to the trench off Miyagi and off Fukushima. A relatively small rupture occurs repeatedly at the asperities off Miyagi, off Fukushima, and off-Ibaraki. When a rupture occurs at a large asperity close the trench, it grows a very large earthquake by rupturing the surrounding stable regions and some asperities. Very large earthquakes close to M9 occur at intervals of 400-800 years. Based on our numerical results, we propose the following scenario for the 2011 off the Pacific coast of Tohoku earthquake: (1) large slips occurred at the large asperity close to the trench off Miyagi and off Fukushima, (2) the rupture propagated to the region of the velocity strengthening at low to intermediate slip rates but velocity weakening at high slip rates, and (3) then several ruptures of asperities occurred off Fukushima and off Ibaraki.

Keywords: the 2011 off the Pacific coast of Tohoku earthquake, Earthquake cycles, quasi-dynamic modeling, fault lubrication, rate- and state-dependent friction