

Simulations of the 2011 Tohoku giant earthquake cycle including the change of plate coupling in Off-Fukushima

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The 2011 Tohoku giant earthquake ruptured the vast area extending from Off-Miyagi to Off-Ibaraki, and the Mw was 9.0. The observed large slip is localized in the shallow Off-Miyagi, amounting to 60m [GSI, 2011]. The tsunami deposit surveys suggest this giant earthquake has a long recurrence time of 400-800 years [Sawai et al., 2010]. In the rupture area (megathrust area), there have been observed Mw7-class earthquakes, at least before the giant earthquake. The deep Off-Miyagi region had Mw7-class earthquakes with a recurrence interval of 30 - 40 years [Yamanaka and Kikuchi, 2004]. In Off-Ibaraki, Mw7-class earthquakes have recurred at intervals of about 28 years. The slip deficit maps show the decrease of the deficit rate in Off-Fukushima, just before the giant earthquake [GSI, 2011]. Some researchers consider this decrease may indicate the preparation just before the giant earthquake.

For this Tohoku earthquake, some cycle models have been proposed. Hierarchical asperity (HA) model [Hori and Miyazaki, 2011] set the whole megathrust area possesses the potential of generating earthquake. Kato and Yoshida [2011] considered the standard asperity (SA) model in 2D fault model. They set a strongly coupling asperity in the shallow area and other Mw7-class asperities surrounded by the stable sliding regions. Both models can reproduce the giant earthquake with a long interval and a large slip. The difference is the frictional state of the megathrust area. In this study, we perform the quasi-dynamic earthquake cycle simulations for HA and SA models, respectively.

For calculation, we use the 3D plate surface [Baba et al., 2006] as the fault. We subdivide it into 200,704 subfaults. We solve the simultaneous equations of motion and friction with adaptive time-step 5th Runge-Kutta [Press et al., 1996]. For the friction, we use the composite rate- and state- friction law [Kato and Tullis, 2001]. At each subfault, we set frictional parameters A, B, and L. For the fast computation, we use the H-matrices approximation method [Ohtani et al., 2011].

In both models, we set the frictionally unstable $A-B < 0$ asperities in the deep Off-Miyagi and the Off-Ibaraki regions. We also set a strongly coupled asperity with $A-B = -0.8$ - -0.95 MPa in the shallow Off-Miyagi region. In HA model, we set the whole megathrust area to be frictionally unstable with $A-B < 0$. In SA model, we set the megathrust area with $A-B > 0$, and an $A-B < 0$ asperity in Off-Fukushima to reproduce the complex slip behavior. In this study, we consider the region only from Off-Miyagi to Off-Ibaraki.

In the results, both models could reproduce the characteristics of the Tohoku earthquake; the long recurrence time, the vast rupture area, and the localized large slip of the giant earthquake and the inside Mw7-class earthquakes with recurrence intervals of several decades. In both models, the localized large slip is due to the strongly coupled asperity. HA model can reproduce the long interval and the vast rupture area, even without the strong asperity. However, the large slip region broadens out in that case. Then, the strongly coupled region is required for slip localization.

After the afterslip of the giant earthquake, HA model shows the plate coupling at the whole megathrust area, while SA model gets to show the steady slip. This difference also makes the difference in the Mw7-class earthquake occurrences after the giant earthquake and in the plate coupling rate change in the interseismic period. Since the noticeable difference is seen after the giant earthquake, the further observation of the plate coupling will distinguish these models.

In our results, repeated slow slips occur in Off-Fukushima. The slow slips may be the cause of observed slip deficit decrease. They occur repeatedly, because the giant earthquake does not occur till the strongly coupled asperity is enough stressed. Thus, in both models, the occurrence of the slow slip does not indicate the preparation just before the giant earthquake.

Keywords: Tohoku earthquake, cycle, Off-Fukushima