Mechanics-based scenarios for great thrust earthquakes in subduction zones using GNSS data analysis: Released strain energy and dissipated energy

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Owing to developments of geodetic observation using satellite systems such as GNSS, we can now estimate slip-deficit rate distribution at plate interfaces. There are roughly two types of attempts to predict possible scenarios for future megathrust earthquakes based on the estimated slip deficit rates. One is kinematic modeling, in which coseismic slip distribution is modeled by multiplying the estimated slip deficit rates by the recurrence time (e.g., Baranes et al. 2018 GRL; Watanabe et al, 2018 JGR). The rupture area and seismic moment can be easily modeled, but the model is not always consistent with the mechanics of fault rupture. The other is dynamic modeling, in which source models are obtained via dynamic rupture simulations using shear stress calculated from the slip deficit rates and assuming frictional parameters (e.g., Hok et al., 2011 JGR; Lozos et al., 2015 GRL; Yang et al., 2019 JGR). The method reasonably predicts the rupture processes based on the mechanics of fault rupture, but generally needs a lot of computing resources for parametric studies of the frictional parameters because of the difficulty to estimate them. In this study, we propose a mechanics-based method to bridge the gap between the kinematic and dynamic modeling. The method predicts possible static slip models with a small computational load, and then examines whether each model actually happens from the viewpoint of the mechanics of fault rupture.

First, we calculated shear stress change rates at the plate interface from the slip-deficit rate distribution estimated from GNSS data (Noda et al., 2018 JGR). In each scenario, we assumed a rupture region and obtained stress drop distribution by multiplying the shear stress change rates in the region by accumulation period. The coseismic slip distribution of each scenario was estimated from the assumed stress drop distribution by using an inversion method. We created scenarios for various rupture regions and various accumulation periods. Next, we investigated the possibility that the scenario happens based on the conservation law of energy. Fault rupture releases shear strain energy accumulated in the lithosphere and the released strain energy is consumed as the radiated energy and the dissipated energy. We assumed some plausible frictional constitutive relations for the plate interface to evaluate the dissipated energy for each case. We calculated the strain energy released by shear faulting in each scenario and compared it with the dissipated energy considering that the released strain energy is necessarily larger than the dissipated energy in earthquake occurrence. If the released strain energy is smaller than the
dissipated energy, we find that the scenario will not happen in terms of earthquake mechanics.

We applied this method to the subduction zone along the Nankai trough, southwest Japan, where great thrust earthquakes have repeatedly occurred with a recurrence time of about 100 years. Based on possible scenarios predicted in this region, we discussed the necessary condition of fault strength and accumulation period for earthquake generation.