New Megathrust Locking Model for the Southern Kurile Subduction Zone Incorporating Viscoelastic Relaxation and Non-uniform Compliance of Upper Plate

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In the southern Kurile subduction zone, many megathrust earthquakes have occurred, including a M 9 tsunamigenic event in the 17th century. Current locking state of the megathrust has been inferred from land GNSS data before the 2003 M_w 8.0 Tokachi-oki earthquake in many previous studies using either elastic or viscoelastic models. The previous locking models exhibit physically unreasonable features such as slip deficit rates exceeding the plate convergence rate and/or high a degree of locking at large depths where stick-slip behavior is not expected. We think the cause of the problems is the assumption of a mechanically uniform upper plate. In order to improve the locking model, we have constructed a subduction zone model that includes variations in the elastic compliance of the upper plate in the margin-normal direction, consistent with the thermal regime of the subduction zone.
We construct a 3D viscoelastic model using the Finite Element Method. In our model, the rigidity values in the backarc, volcanic arc, and forearc regions are 48 GPa, 16 GPa, and 48 GPa, respectively. The elastic thicknesses of the three areas are 10 km, 7.5 km and 25 km, respectively, except for a portion of the forearc that has a greater thickness to account for the presence of a “cold nose” of the mantle wedge. For comparison, we also construct a model in which the upper plate rigidity and elastic thickness are uniformly 48 GPa and 25 km, respectively. We generate interseismic viscoelastic Green’s functions using these structures and derive megathrust locking distributions by inverting GNSS velocities prior to the 2003 earthquake.
In the model of non-uniform upper plate, full locking of the megathrust is limited to depths shallower than the downdip rupture limits of the 2003 mainshock and the 1973 M_w 7.8 Nemuro-oki earthquake in the northeastern neighbor region. Similar results in which parts of past megathrust rupture areas are not fully locked during the interseismic period have been reported for the Tohoku-oki and Kamchatka regions. It is consistent with the shrinking of megathrust locked zone during the interseismic period and/or the invasion of dynamic rupture into low-locking areas predicted by numerical simulations with a rate-and-state friction laws. However, sensitivity tests using forward modeling show that full locking covering the 2003 rupture area can also reasonably fit the horizontal GNSS data. To constrain spatiotemporal changes in megathrust locking during the interseismic period in future studies, we will need a much longer observational time window which requires additional conventional geodetic data prior to the GNSS era. In our preferred model, the near-trench part of the megathrust is fully locked. A model in which the near-trench part is forced to creep can fit the land GNSS velocities equally well. Therefore, even after incorporating the non-uniform compliance and interseismic viscoelastic relaxation, the locking state of the megathrust near the trench cannot be resolved by the land data only. Nevertheless, we infer locking near the trench axis of the Nemuro-oki region because no tremor is detected with the seafloor observation network S-net.

Keywords: Megathrust Locking, Viscoelastic Relaxation, Earthquake Cycle, The Southern Kurile Subduction Zone

