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The inter-, co- and post-seismic crustal deformation in the Tohoku region by the kinematic earthquake cycle model

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The Northeast Japan arc is a typical arc formed by the subduction of the Pacific plate beneath the North American plate. The interplate earthquake has been considered to be of M7 at the maximum. However, after Mw 9.0, the 2011 off the Pacific coast of Tohoku earthquake, tectonics of the Tohoku region of the northeast Japan should be reexamined under the environment of great earthquake cycles.

From geological observations, the Northeast Japan arc is considered to be under east-west compression. The late Quaternary vertical deformation is estimated to be uplift in the whole Tohoku region, revealed from the distribution of marine and river terraces. On the contrary, geodetic observation of the recent 100 years shows subsidence up to 5˜10 mm/yr particularly on the Pacific coast. In terms of long-term balance, great uplift is expected at the great earthquake. In fact, GPS observation shows further subsidence at the 2011 off the Pacific coast of Tohoku earthquake. Therefore, it is necessary to reveal the stage of the earthquake cycle where the deformation turns to uplift, and its mechanism. On the other hand, seismicity of inland area of Tohoku is mostly reverse fault of east-west compression before the great earthquake. However, this type of earthquakes is notably decreased.

As is stated, the crustal deformation and the pattern of inland earthquake reflecting the regional stress fields are variable at each stage of the earthquake cycle. Because each of them is caused by the plate subduction and associated earthquake cycles, we should construct the model to explain these features in the big picture. One of the models is the plate subduction model with the elastic dislocation theory. In this study, we examine the temporal variation of subsidence in the later stage of the earthquake cycle, subsidence at the time of the earthquake, and long-term uplift.

In this study, we take the two-dimensional geometry of the plate interface from the vertical section of the CAMP model near the epicenter of the Tohoku earthquake. The slip on the plate interface is decomposed into 3 components: steady slip on the whole plate interface (steady subduciton), increase of slip deficit in the locked region (interseismic locking) and periodic seismic slip. We give plate relative velocity (10 mm/yr) as steady slip and assume that fracture occur each 1000 years on the locked region of the horizontal 500-km width extending to 40-km depth. In the long-term deformation model, it is necessary to consider viscoelasticity in the asthenosphere. Here, we assume elastic surface layer over viscoelastic half-space as lithosphere-asthenosphere system.

First, long-term deformation is affected only by the effect of steady subduciton, regardless of the coseismic slip. The deformation shows subsidence at the trench and uplift in the arc region, which agrees with the long-term uplift in Tohoku. The coseismic deformation shows uplift at the upper edge of the slip region and subsidence at the lower edge and inland area.

The interseismic deformation clearly depends on the extent of fracture in the elastic lithosphere. In the case of the earthquake dividing the lithosphere entirely (lithospheric thickness H = 40 km), the arc region uplifts due to the effect of the interseimic locking. In the case of the introduction of steady slip region below the coseismic slip (H = 50 km), the inland region uplifts in the 200 years after the earthquake. On the other hand, 400 years before the earthquake, inland region turns to subsidence. This result is consistent with the subsidence in Tohoku in the later stage of the earthquake cycle.

In the earlier stage, the effect of viscoelastic response to the coseismic slip is dominant and in the later stage, the intersesmic locking. The results also show the importance of the observation of the long-term deformation in the ocean area of the Pacific coast, because the vertical deformation pattern strongly depends on the distance from the trench axis.

Keywords: 2011 off the Pacific coast of Tohoku earthquake, Crustal deformation, Earthquake cycle, Viscoelasticity, Steady subduction, Tectonics