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Tectonic deformations related to the 2011 Tohoku earthquake at different stages of the seismic cycle

Irina Vladimirova (1,2), Yurii Gabsatarov (1,2), Leopold Lobkovsky (1,3)

(1) Moscow Institute of Physics and Technology (State University), Moscow, Russian Federation (ir.s.vladimirova@yandex.ru), (2) Geophysical Survey of the Russian Academy of Sciences, Obninsk, Russian Federation, (3) P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences, Moscow, Russian Federation

The region of Japanese island arc is one of the most seismically active regions of the world due to very high plate convergence rate. On March 11, 2011, the great Mw=9.0 Tohoku earthquake occurred in the central segment of the Japan subduction zone, the region where the previous megathrust earthquake was in 869. The duration of seismic cycle in this part of Japan subduction zone is estimated at about 800-1100 years. To identify the spatiotemporal variations of surface deformations following the 2011 earthquake we analyzed more than 12 years of continuous GPS observations from over 1400 stations of GEONET network that covers the entire territory of Japanese islands. Analysis of GPS data prior to Tohoku earthquake revealed a notable anomaly – a subsidence of coastal region directly opposite the future source zone of 2011 earthquake. This can be an evidence for the termination of elastic stresses accumulation and the transition of corresponding part of the seismogenic zone to the preseismic stage of the seismic cycle. Coseismic displacements captured by GPS stations allowed us to model the slip distribution in the earthquake source and to reveal significant effect of Fossa Magna Graben on the coseismic deformations pattern. Source zone of the Tohoku earthquake affected all possible seismogenic blocks, limited by geological bounds, such as Fossa Magna, which resulted in reestablishing of seismic cycle for the whole northeastern part of Japan subduction zone. The observed surface displacements before, during and after the Tohoku earthquake exhibited good agreement with the expected motions implied by the keyboard model of subduction zones [Lobkovsky et al., 1991] at the appropriate stages of the seismic cycle. At the same time, analysis of the displacement rate variations estimated over 1-year intervals after the Tohoku earthquake showed an intense ongoing postseismic motion of complex mechanism. We tested a hypothesis of significant afterslip in the earthquake source using 1-month cumulative displacements for the first half of the year after the earthquake. Our analysis of the afterslip process showed that its maximal contribution rapidly decreases in the first six months after the earthquake from 1-3 meters to 10-20 centimeters per month and cannot predict the observed long-term displacements. We also assessed the effect of coseismically-induced viscoelastic relaxation in the underlying asthenospheric wedge on observed surface deformations. Such a long-term postseismic process, which can last after megathrust earthquakes up to several decades can significantly affect the seismic cycle in the northeastern part of the Japan subduction zone, providing a probable explanation for seismic cycle prolongation.