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Tidal triggering of earthquakes preceding the 2011 off the Pacific coast of Tohoku earthquake

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We observed tidal triggering of earthquakes preceding the 2011 off the Pacific coast of Tohoku earthquake (Mw 9.1). We measured the statistical correlation between the Earth tide and earthquake occurrence in and around the rupture area of the Tohoku earthquake. The data we used are the centroid moment tensor (CMT) solutions of 2330 earthquakes with Mw 4.0 or larger from June 2003 to October 2011, which is reported by Asano et al. (2011). For each earthquake, we theoretically calculated tidal stresses on the fault plane (Tanaka et al., 2002); this calculation includes the direct solid Earth tide and the indirect term due to the ocean tide loading. Assigning the tidal phase angle at the occurrence time of each earthquake, we tested whether they concentrate near some particular angle or not by using the Schuster's test. In this test, the result is evaluated by p-value, which represents the significance level to reject the null hypothesis that the earthquakes occur randomly irrespective of the tidal phase angle.

Considering the shear stresses in the slip direction, we examined the spatial distribution of p-value before the Tohoku earthquake. As a result of analysis, we found no significant correlation. Changing the threshold magnitude of the data set, however, we observed small p-values in the nortern part of the mainshock source region. The smallest p-value of 0.19% is obtained in the 200 km square region (hereafter this region is referred to as region A), which includes the epicenter of the Tohoku mainshock, for the threshold magnitude of 4.8. The phase distribution in this case shows a peak near the angle 0, where the tidal shear stress is at its maximum to accelerate the fault slip. The temporal variation of p-value in region A shows that the p-value had been smaller than 5% over about a decade before the Tohoku earthquake. It gradually decreased with time, which lasted to the mainshock occurrence. After the Tohoku earthquake, the p-value was large (50%), indicating absence of significant correlation in this period.

We also observed similar space-time patterns of p-value when restricting our analysis to interplate earthquakes, which were identified following the method of Asano et al. (2011). However, the resultant p-value in the pre-mainshock period tends to be smaller than that observed for the data including all earthquakes. The p-value in region A is 0.08% for the threshold magnitude of 4.8.

Focusing on interplate earthquakes, we also try to evaluate the effects of fault-normal and Coulomb failure stresses. The data used for this analysis are the events with Mw 4.8 or larger that occurred in region A before the Tohoku earthquake. For these events, we assumed the west-dipping nodal planes as the fault planes. The p-value for normal stresses is 1.1%, which is larger than that for shear stresses, and a clear increase in the rate of events is found during times of compressional stresses inhibiting fault slip. We also examined Coulomb failure stresses giving different values of friction coefficient. A smaller p-value is obtained for a smaller friction coefficient, and the best correlation is for friction coefficient of 0 (shear stress only). This implies that shear stresses could play a dominant role on earthquake triggering in this region.

Keywords: the 2011 off the Pacific coast of Tohoku earthquake, earth tide, earthquake triggering, precursor