Stress change in the northern Ibaraki prefecture and the Fukushima Hamadori areas from geodetic and seismicity data

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The 2011 Tohoku-oki earthquake significantly influenced the seismicity in many areas especially in northeast Japan. In the northern Ibaraki prefecture (IBR) and Fukushima Hamadori (FKS) areas, although the seismicity rate (depth < 15 km) had been very low before the Tohoku-oki earthquake, so many normal faulting earthquakes have occurred since then. In FKS, the 2011 Iwaki earthquake (M_j 7.0) occurred one month after the Tohoku-oki earthquake. In IBR, the moderate earthquakes around M_j 6 occurred just 8 minutes after the Tohoku-oki earthquake and also on March 19, 2011. In addition, the 2016 northern Ibaraki prefecture earthquake (M_j 6.3) occurred in IBR on December 28, 2016, almost 6 years after the Tohoku-oki earthquake. Uchide et al. (SSJ, 2017) reported that the slip areas of two moderate earthquakes in 2011 and that in 2016 overlapped each other, suggesting the partial re-rupture of the fault. In order to specify the cause of these seismic activities, we investigated the stress change at seismogenic depths in IBR and FKS by the ground surface strain and the seismicity rate change.

Surface Strain inferred from the GNSS Data

We estimated the surface displacement at the epicenters of the 2016 northern Ibaraki prefecture earthquake and the 2011 Iwaki earthquake and their vicinity by the method of Sandwell & Wessel (2016) using the Daily Coordinate (F3 solution) inferred from the GNSS network (GEONET) by Geospatial Information Authority (GSI). Then we calculated the strain (ε) at the ground surface.

The surface strain suddenly changed at the time of the Tohoku-oki earthquake. Particularly, ε_{xx} (the x axis is easting) increased for years both in IBR and FKS as $\Delta\varepsilon_{xx} \propto \log t$, where t is the time lapse since the Tohoku-oki earthquake, and Δ denotes the difference from the value just before the Tohoku-oki earthquake. In IBR, the strain increased up to the end of 2016, although, in FKS, ε_{xx} turned into a decline from the middle of 2012.

Seismicity Analysis using ETAS Model

We studied the seismicity in IBR and FKS using the ETAS model (Ogata, 1988), which has the background seismicity rate (μ) parameter and four more parameters for the modified Omori's law. Since the analysis is more unstable than usual cases due to the rapid stress change as discussed later, we fixed the values of all the parameters except μ based on the physical property and preliminary analyses. We took time windows to include 100 events and shift by 50 events.

In both IBR and FKS areas, the μ values dropped rapidly and $\mu \propto t^{-1}$ up to t ~ 1000 days. Afterward, the μ value in FKS decreased even faster, although that in IBR were stagnant.

Implications

$\Delta\varepsilon_{xx} \propto \log t$ implies $\Delta\sigma_{xx} \propto \log t$ at depth, where σ is the stress. If $\mu \propto d\sigma/dt$, $\mu \propto t^{-1}$ is consistent with the

geodetic observation. This stress change is probably due to the postseismic process of the Tohoku-oki earthquake. On the other hand, the cause of the seismicity rate change since ~ 1000 days after the Tohoku-oki earthquake is still unclear.

We have found that the geodetic and seismicity data commonly suggested the log *t* stress change at the seismogenic depths. This result supports the simple hypotheses that the surface strain is a good indicator of the stress at seismogenic depths and the seismicity rate is roughly proportional to the stress rate.

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We used the Daily Coordinate by GSI and the JMA Unified Earthquake Catalog. We also used Generic Mapping Tools (GMT) (Wessel & Smith, 1991), gpsgridder code (Sandwell & Wessel, 2016) and etas_solve code (Kasahara et al., 2016).

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