Spatio-temporal characteristics of seismicity in the source region of the 2011 Tohoku earthquake

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A major earthquake will be followed by many smaller earthquakes and tremors, which are called aftershocks, around its hypocenter in the source area. Omori (1894) discovered that the number of aftershocks generally decreased inversely proportional to the elapsed time from the origin time of the largest earthquake. Later, Utsu (1961) found a simple equation that describes the number of aftershocks n(t) as a function of the elapsed time t: n(t)=K(t+c)^(-p) where p indicates the decay rate of aftershocks and K represents the aftershock activity immediately after a major earthquake. The parameter c controls the retarded time of aftershock activity (Nanjo et al., 2007) and is usually a finite short time. Omi et al. (2015) reported that the parameter p is generally from 0.9 to 1.5 around Japan.

In this study, we focused on aftershock activity of The 2011 off the Pacific coast of Tohoku Earthquake (hereinafter, referred to as the 2011 Tohoku earthquake) and analyzed its p and K values. We then investigated their relationships in space and time with respect to the slip distribution of the 2011 Tohoku earthquake and the regular seismicity before the earthquake.

We analyzed the number of earthquakes on the subducting Pacific plate that occurred from 34.0N to 42.0N in latitude and from 141.0E to 145.0E in longitude during the 16 years from 2003 to 2018. Since it is important that all the earthquakes are detected, earthquakes with a magnitude (M) of 3.0 or larger were used for the analysis. As a result, 24,942 earthquakes were included in the analysis.

The number of daily earthquakes in each area of 0.5 degrees in latitude and longitude was counted and averaged over each month for the period from April 2011 to December 2018. We then deduced values of p and K in the equation of Utsu (1961) that explain the aftershock activity for individual areas, assuming that the parameter c is equal to zero. We obtained values of p and K in the range of 0.07-1.06 and 0.06-400, respectively. Estimated p values were smaller than those derived by Omi et al. (2015), suggesting that the aftershock activity of the 2011 Tohoku Earthquake has been decaying slower than those of other large earthquakes around Japan. We also found that values of p and K had positive correlation. Although these two parameters may not be always independent as suggested by the equation of Utsu (1961), the correlation was significant in taking the estimation error into account.

Focusing on their spatial pattern, values of p and K in the area around the source region of the 2005 Miyagi-oki earthquake were smaller than those in other areas. In addition, these parameters had also smaller values in areas with a large coseismic displacement during the 2011 Tohoku earthquake and in the northern border of its source region. It should be noted, however, that numbers of earthquakes in these areas were relatively small and they might be apparent.

In order to investigate the relationship between the seismicity before and after the 2011 Tohoku earthquake, we finally investigated the spatial pattern of the number of earthquakes N that occurred in 2003 through 2010 and its correlation to the values of p and K of the aftershock activity. We found that values of N and K had a positive correlation. It would be natural to assume that aftershocks take place as a result of the disturbance of shear stress and strength due to a large earthquake and some previous studies

reported a spatial correlation of aftershocks and the coseismic displacement and the change of shear stress associated with a large earthquake. Our results, however, suggests that the spatial pattern of the coseismic slip during the 2011 Tohoku earthquake and of the stress perturbation due to the earthquake may not control the aftershock activity in the study area.

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