Modeling space-time heterogeneities of hypocenter catalog

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A spatio-temporal model of earthquake detection rate was devised and implemented to enable unbiased prediction of seismic activity and probability from long-term heterogeneous data, even if the earthquake magnitude threshold is reduced.

As seismographs and seismic observation networks develop over time, the number of detected earthquakes will increase significantly over time. In addition, the detection rate of small and medium earthquakes is decreasing with respect to distant offshore from the Japanese archipelago. Thus, the catalog of earthquakes over a long period of time is not homogeneous. In addition, there are many aftershocks immediately after major earthquakes, but many of them cannot be detected and located because their waveforms overlap each other on the seismograph records, making it difficult to determine their hypocentre coordinates. For example, the spatiotemporal changes in detection rates before and after the M9 Tohoku earthquake are extreme and large-scale.

In order to fit a seismic activity model with an analysis that avoids bias, conventional methods limit the time interval and analysis area, and use data restricted to use only earthquakes of magnitude or greater that are fully detectable, but this results in the loss of a large amount of data. This is not only fatal for research and analysis related to long memory and self-similarity, which are common in geophysical sciences, but also seriously hampers research and prediction of seismic activity to be applied to seismic activity directly beneath inland areas, active offshore areas, and the world at large.

On the other hand, we can consider a seismic model that uses non-homogeneous earthquake data by assuming the Gutenberg-Richter law for magnitude frequency and modeling the detection rate of earthquakes of magnitude. For this, we use the cumulative function of the Normal distribution. That is, the parameter of the mean of the Normal distribution (mu value) represents the magnitude at which half of the earthquakes are detected, and the parameter of the standard deviation value (sigma value) relates to the range of magnitudes over which the earthquakes are partially detected. In fact, these parameters are generally assumed to be expressed as a function of time and location, rather than as constants, to investigate spatio-temporal heterogeneity. The best Bayesian inverse solution for this purpose is to use all detected earthquakes to analyze changes in b-values and seismic activity.

In this presentation, we present the results of the analysis in 2D space plus 1D axis for the epicenter and time of occurrence, ignoring the depths of the earthquakes in the JMA catalog. Therefore, the Delaunay tetrahedral partition by using the earthquake coordinates is effectively constructed. Namely, it is effectively designed to control the computational complexity caused by the huge increase of data after the unification of the sources, and to quantify the sharp incompleteness during a period immediately after large earthquakes. The spatio-temporal b-, mu- and sigma-values are represented by spline functions defined by piecewise linear functions on Delaunay tetrahedra, and the respective weights of the spatial and temporal constraints of smoothing are properly devised and determined by the Akaike Bayesian Information Criterion (ABIC).

The calculated results of the spatio-temporal detection rates and b-value changes for the inland and offshore periphery of Japan obtained in this way are visualized in a movie.

Keywords: earthquake magnitude, Detection rates of earthquakes, Gutenberg-Richter law, Space-time partition by Delaunay tetrahedra, Bayesian inversion solution, Akaike Bayesian Information Criterion