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Empirical forecast of mainshocks based on foreshock activities - Application to the north-central Nagano prefecture -

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1. Introduction

An earthquake with magnitude (M) 6.7 occurred on November 22nd, 2014 in the northern Nagano prefecture and it caused many injuries and housing damages. According to JMA, about four days before the mainshock, a pronounced foreshock activity that includes more than 40 small earthquakes with M less than 3.0, had been observed at the very near location of the mainshock. However, it is quite difficult to distinguish foreshocks from background seismicity before a mainshock occurs because we have not yet elucidated the physical process that associates foreshocks with a mainshock. Even though the situation is not easy, empirical approach is one of the realistic ways to use foreshock activity as a precursor of a mainshock. We have been investigating probabilistic features of empirically defined foreshocks and searching for the best parameters to define foreshocks which present relatively high performance to predict large earthquakes. Maeda (1996) and Maeda and Hirose (2012, 2014) proposed a foreshock definition which gives the highest performance to predict large earthquakes along the Japan trench and the Izu region. In this study we basically apply the same method to the seismicity in the north-central Nagano prefecture where foreshock activities are relatively higher than those in other inland regions of Japan. Then we estimate the best parameters to define foreshocks which give good performance of predicting mainshocks in the region.

2. Method

The method to search for parameters for foreshocks that present high prediction performance consists of four steps. 1) To eliminate small aftershocks from the original data. 2) To define foreshock candidates satisfying the condition that the number of Nf earthquakes with magnitude >= Mf occur during the period of Tf days in the segment of the size of D x D degree (latitude x longitude). 3) To set the alarm period of Ta days during which a mainshock is expected to occur after a foreshock candidate is found. 4) To search for the values of D, Mf, Tf, Nf and Ta which give high prediction performance by the grid search method. The prediction performance is measured mainly by dAIC that is defined as the difference of AIC for a stationary Poisson model and a model based on a foreshock activity, and additionally by alarm rate (AR: the fraction of mainshocks alarmed), truth rate (TR: the fraction of foreshock candidates followed by a mainshock), and probability gain (PG: the ratio of mainshock occurrence rate in the predicted space-time to background occurrence rate).

3. Data and Results

By applying the above method to the earthquakes with M >= 1.0 and depth <= 30 km cataloged by JMA during the period from 1998 through 2014 in the north-central Nagano region (35.6N-37.1N, 137.2E-139.0E), we obtained the best parameters for foreshocks as D=0.1 degree, Mf=2.0, Tf=1 day, Nf=5, and Ta=5 days to predict mainshocks with M>=5.0 among 45000 combinations of parameters of D(0.1, 0.2, 0.3), Mf(1, 1.5, 2, 2.5, 3), Tf(1, 2, 3, 5, 10), Nf(1, 2,...,20), and Ta(1, 2,...,30). The prediction performance is expressed as dAIC=66, AR=45% (=5/11), TR=12% (=8/69), and PG=333. If we use these parameters to define foreshocks, the 2014 Nagano earthquake mentioned at the opening sentence comes to be predicted by the foreshocks. Therefore we can say that a seismic activity such that observed about four days before the 2014 Nagano mainshock would be followed by a mainshock of M>=5.0 with about 12 % possibility, and to the contrary a mainshock with M>=5.0 would be preceded by a foreshock activity such that observed before the 2014 Nagano mainshock with about 45 % possibility. The value 12 % of TR is relatively low if compared with that for the specific region in the Japan trench (TR=30%) and for the Izu region (TR=23%) where we know the prediction performance is considerably high. This suggests that the prediction performance based on foreshock activities is largely different among regions.

Keywords: earthquake prediction, performance, foreshocks, Nagano prefecture, statistics, empirical relation