INVESTIGATION OF FORESHOCKS FOR M_j3.0 TO M_j7.4 MAINSHOCKS IN JAPAN FROM 2001 TO 2021

2001年から2021年までの日本におけるM_j3.0からM_j7.4の本震に対する前震の研究

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Foreshocks are usually regarded as one of the most prevalent phenomena of the earthquakes. With the development of extensive seismic observation networks, seismologists now can monitor both the large and small earthquakes. Although there had been many studies about the foreshocks for moderate and large earthquakes, little is known about the foreshocks for a large number of relatively smaller earthquakes. One of the most important questions for studying the foreshocks is that can the foreshocks be used to determine the time, location and magnitude of the following mainshocks? This question is related to the physical mechanism of foreshock-mainshock sequences, for which two models had been proposed. The 'cascade model' or rupture-controlled model interprets foreshocks as a series of triggered earthquakes that result in the mainshocks. The nucleation-controlled model interprets foreshocks as the byproducts of slow aseismic slip across the regions.

Here, I had used the Japan Meteorological Agency (JMA) earthquake catalogue and earthquake waveforms from high-sensitivity seismograph network (Hi-net) to investigate the spatiotemporal characteristics of foreshocks for shallow onshore and offshore mainshocks in Japan during the past 20 years (2001 – 2021). I found that the most possible spatiotemporal window of foreshocks for shallow onshore and offshore mainshocks were 10 days and 3 km, 10 days and 7 km, respectively. Under this definition, around 38% of the shallow onshore mainshocks and 24% of the offshore mainshocks showed the foreshocks. Then I had used the epidemic-type aftershock sequences model (ETAS model) to validate the spatiotemporal window of foreshocks for shallow onshore mainshocks, the results were similar. Finally, I had developed a new method for determining the relative location of foreshock-mainshock sequences based on their waveforms.

The conclusions in this thesis were the following:

1. There was a downtrend of foreshock occurrence rates with mainshock depth, and normal faulting earthquakes had higher foreshock occurrence rates than strike-slip and thrust faulting earthquakes (Chapter 2 and 4). A possible explanation for the trends in mainshocks depth and focal mechanism is that higher normal stress may inhibit the foreshock occurrence.

2. No dependence of the mainshock magnitude on the foreshock magnitude (Chapter 2, 3 and 4). When I calculated the foreshock occurrence rates by counting the number of times that a foreshock of a given size was followed by a mainshock, there was no clear trend as a function of the foreshock and/or mainshock magnitude. This suggested that the foreshock magnitude was not related to the subsequent mainshock magnitude.

3. According to the relocations for foreshock-mainshock sequences, no obvious trend between the foreshock-mainshock distance and the foreshock or mainshock magnitude (Chapter 5). I had introduced another possible explanation for this which was related to the 'self-organized criticality' (SOC) model. This model assumed a region of high critical stress where any small change can trigger a large earthquake. For example, if there is a wide region of critical stress before a large earthquake, no matter where the foreshocks occurred (at a farther distance or a closer distance), it can trigger the mainshock. The foreshock can tell us that it might trigger an impending mainshock, but nothing about the size of mainshock.

4. There was a decrease in the foreshock-mainshock time difference with the increased foreshock magnitude (Chapter 6). This can be explained if we consider that a larger foreshock can produce a larger surrounding region of stress change. The larger stress change would trigger the subsequent earthquake more rapidly. For example, in the rock mechanics experiments, a sample of rock under high stress can slip within a short time, but it took a longer time to slip for the same sample under low stress. Similarly, when considering the Poisson process, a larger foreshock can cause more earthquakes after its occurrence which should induce a faster occurrence time of the impending mainshock statistically. Thus, the mainshock occurrence following a larger foreshock should be more rapid.

There had been two end-member models proposed to explain the mechanism of earthquake occurrence. The 'preslip' model or 'nucleation-controlled' model implied that there can be a continuous occurrence of foreshocks which were the byproducts of a pre-seismic slip or some other type of slow aseismic slip across the regions. In this case, the mainshock might be predicted by the observation of foreshocks. The 'cascade model' or rupture-controlled model considered that one or more foreshocks will occur and trigger the next foreshock or mainshock. There was no aseismic slip or predetermined pattern of the triggering, and it was difficult to predict the mainshock magnitude.

The characteristics of the foreshock-mainshock sequences seemed to be more consistent with the triggering mechanism rather than the nucleation-controlled process. Thus, the 'cascade model' or rupture-controlled model should be more reasonable for explaining the physical mechanism of earthquakes in Japan.

Seismologists have long been trying to construct some earthquake hazard assessment systems for short-term earthquake forecasting. Due to the complexities of earthquakes, it is still very hard to find some reliable methods or clear empirical results. Predicting mainshocks from foreshocks requires at least three pieces of information, time, distance, and magnitude. My analyses showed that predicting the distance and magnitude of an impending mainshock was very difficult, but predicting the time of an impending mainshock from the foreshock magnitude might be possible. However, the observed scatters of foreshock-mainshock sequences were very large, and the overall estimating rates for the mainshock occurrence were too small, usually less than 5%, this information was probably not adequate for practical evaluations of short-term earthquake hazard assessments at present.