Quantifying the early aftershock activity of the 2004 Mid Niigata Prefecture Earthquake (Mw6.6)

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Abstract: *The goal of this work is to determine an accurate image of the aftershock activity immediately following the 2004 Mid Niigata (Chuetsu) earthquake. For this purpose, we examined the JMA earthquake catalog and also the continuous seismograms recorded at six Hi-Net seismic stations located close to the aftershock distribution. By high-pass filtering the seismograms we were able to count aftershocks starting at about 35 sec. after the mainshock. The results show that the c-value, which expresses the saturation of the aftershock rate close to the mainshock, is very small (less than about 3 min.), but has a non-zero value of about 100 sec. that relates to the physics of the aftershock generation process.*

1. Introduction

The occurrence rate of aftershocks is empirically well described by the Modified Omori formula (Utsu, 1961) : $n(t) = k/(t+c)^p$, where $n(t)$ is the frequency of aftershocks per unit time, at time t after the mainshock, and k, c and p are constants. The parameter c, which relates to the rate of aftershock activity in the earliest part of an aftershock sequence, typically ranges from 0.5 to 20 hours in empirical studies (Utsu et al., 1995). Since the behaviour of aftershock sequences during the first minutes and hours after the mainshock is a significant component of theoretical models of seismicity (e.g., Dieterich, 1994; Rubin, 2002), it is essential to determine whether the coefficient c is a physical parameter (Vidale et al., 2003; Shcherbakov et al., 2004) or if it simply indicates a measure of instrument and technique deficiency (Kagan, 2004).

We focus in this study on the decay of the early aftershock activity following the 2004 Niigata earthquake (M6.8) and try to estimate the c parameter by using *a) JMA* (Japanese Meteorological Agency) earthquake catalog data and *b)* continuous *Hi-Net* waveform data.

2. Analysis of the JMA catalog data

2.1 Analysis of the decay of aftershocks number

We first analyse the decay of the aftershocks of the 2004 Niigata earthquake by using the *JMA* catalog data. By constructing the frequency-magnitude distribution of earthquakes after 0.01, 0.05, 0.2 and 0.5 days after the mainshock, for a 100-event window, we could easily estimate the magnitude of completeness (Mc) of the catalog at these times. By fitting these data, we could determine a semi-logarithmic relationship between the level of catalog completeness, expressed by Mc, and the time elapsed since the mainshock, t. The decay of aftershocks, for different threshold magnitudes, is fitted using the Modified Omori formula and the parameters p, c and k are determined in each case using a maximum likelihood algorithm (Ogata, 1983). For example, the c-values obtained by using threshold magnitudes of 3.0 and 4.0 are 0.027 and 0.012, respectively. These values, however, are comparable with the times at which the catalogue becomes complete in events above the corresponding threshold magnitude. This observation demonstrates that it is practically impossible to estimate a “real” *c*-value from earthquake catalog data.

2.2 Analysis of the decay of the moment release rate of aftershocks

We also determine the decay of the seismic moment release rate of aftershocks, using the approach suggested by Kagan and Houston (2004). An advantage of using the moment summation of aftershocks instead of the usual counting of aftershocks number is that the missing small events at the beginning of the catalog are weighted much less because their seismic moment is relatively small. Assuming that the aftershock size distribution follows the Gutenberg-Richter relation, we could also calculate the moment rate which is due to the missing small aftershocks and compensate for an incomplete catalogue record (Kagan and Houston, 2004). As one can notice in Fig. 1, there is little difference between the moment release rate calculated using the catalogue data and the “corrected” rates, which account for the under-reported small aftershocks. The only notable difference is at the very beginning of the aftershock sequence. The decay of the corrected moment release rate is well fitted by a power-law with a slope of 1.2 in the log-log plot of Fig. 1. The graph suggests that there is no significant saturation of the moment release rate of aftershocks close to the mainshock. As the first aftershock recorded in the JMA catalogue occurred after about 3 minutes from the mainshock, it is impossible to get information on the aftershock moments at earlier times. We can only speculate that the c-value is smaller than about 3 minutes (~0.002 days). We also show in the same figure the source time function of the mainshock, determined by Miyazawa et al. (2005). The extrapolation of the fit of the moment decay of aftershocks to the end of the mainshock rupture seem to suggest a smooth transition from the mainshock rupture to the aftershock process.

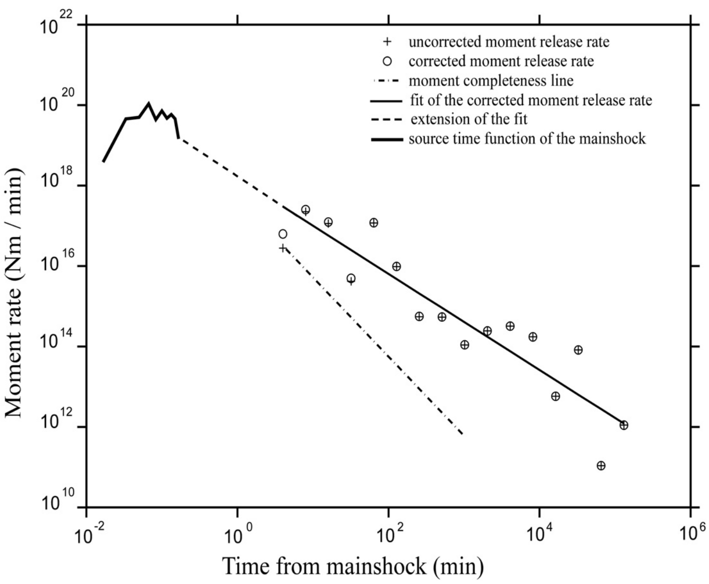

Figure 1

Decay of the uncorrected and corrected moment release rates of aftershocks and a power-law fit to the data (slope of 1.2 in the log-log graph). The source time function of the mainshock is also shown.

3. Analysis of the Hi-Net continuous waveform data.

As a next step in our analysis, we try to identify as many events as possible on the continuous seismograms recorded at six *Hi-Net* stations located closely to the aftershock distribution. The waveforms were high-pass filtered at 7Hz to attenuate the low-frequency coda of the mainshock. Clear early aftershocks can be identified on the filtered waveforms, starting at about 35 sec. after the mainshock (Fig. 2). Most of these early events are not recorded in the *JMA* catalog. We then select two representative stations (*YNTH* and *NGOH*), situated on opposite sides and close to the aftershock distribution, and count the events with amplitudes above some threshold value which can be clearly seen on the continuously recorded waveforms. This threshold value corresponds to about a magnitude 3.3 earthquake. The identified events satisfy well the Modified Omori law, with a *p*-value close to 1.0. The *c*-value is about 100 sec (~0.001 days), i.e. the number of events is smaller than predicted by a simple power-law distribution at very short times after the mainshock.

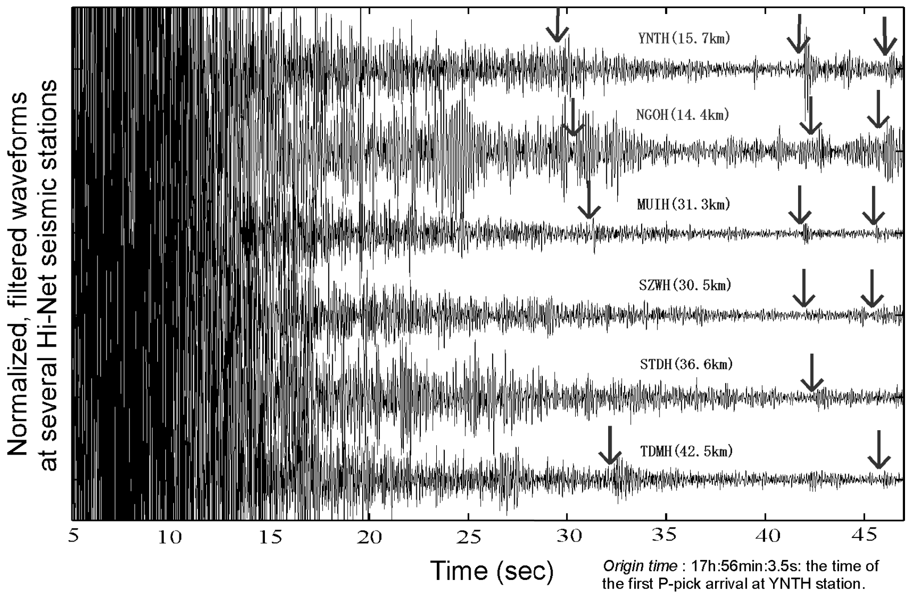

Figure 2

Clear early aftershocks (indicated by arrows) can be identified on these high-pass filtered waveforms, starting at about 35 sec. after the mainshock. The names of the recording Hi-Net stations are also shown.

4. Conclusion

By using three different approaches we tried to estimate the *c*-value of the Modified Omori law for the aftershocks of the 2004 Niigata earthquake. We showed that the estimated value of the parameter by using usual aftershocks counting mainly reflects the under-reporting of small events at the beginning of the aftershock sequence. An alternative approach, using the decay of the moment release rate of aftershocks, indicates that the c-value is smaller than about 3 minutes (~0.002 days). An additional argument for a very small c-value is suggested by the smooth transition between the source-time function of the mainshock and the moment release rate of aftershocks. By analysing the high-pass waveform data recorded at several High-Net stations, we confirmed that the c-value is very small, but has a non-zero value of about 100 sec (~0.001 days). This observation relates to the physics of the aftershock generation process.

5. Acknowledgements

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