An extreme value analysis of seismograms designed for early forecast of aftershocks

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Conventional aftershock forecasting has been operated through applying the Gutenberg-Richter and Omori-Utsu laws to an earthquake catalog. However, catalog’s quality is influenced by detectability of earthquake signals (P or S waves), which causes degradation of the catalog in the early stage after a large earthquake and at regions which are sparsely covered by seismograph network. This eventually causes the catalog’s nonuniformity and limitation of the forecasting performance.

In this study, we propose a new approach designed for high-performance early aftershock forecasting without using earthquake catalog. Instead, we use a continuous seismogram recorded at each station. First, we pick the maximum amplitude of the seismogram obtained in every assigned time interval (e.g., 1 minute). This picking process can be completely automated and is rarely affected by overlap of multiple seismic signals occurring in approximately the same time. We empirically derive a probability distribution (PD) that accounts for the frequency of the maximum amplitudes. This PD is essentially a non-stationary extreme value distribution derived from the generalized Pareto distribution (GPD) and the Omori-Utsu type temporal decay. We optimize three parameters that control the PD shape (K_a: parameter that controls whole aftershock activity, p_a: parameter that controls temporal decay of the aftershock frequency, m: parameter that controls power-law decay of the maximum amplitude) by applying the maximum likelihood estimation to the observed maximum amplitudes. By extrapolating the optimized PD, we estimate the number of maximum amplitudes that will exceed a threshold value within arbitral time interval in the future. The proposed approach provides forecast of peak ground motion at each station rather than magnitude, which is directly desired for public use. Moreover, the forecasted peak ground motion may automatically incorporate many factors that cannot be described by a simple ground motion attenuation model (e.g., site amplification, radiation pattern, rupture directivity, and so on).

We apply the proposed method to 25 Hi-net seismograms recorded the 2016 Kumamoto earthquakes in Japan. We set the learning periods every one hour after the mainshock (Mj7.3), and set the forecasting period within 24 hours after the end of each learning period. We find that parameters K_a and m become temporally stable within a few hours after the mainshock at many stations. On the other hand, the parameter p_a temporally varies more probably because the induced seismicity at northeast area (Aso and Oita regions) strongly affects the apparent temporal decay rate of the amplitudes. Within 3 hours after the mainshock, the forecasted number of the maximum amplitudes exceeding 10^{-4} m/s is within 0.5 to 2.0 times the actual observation for about 80 % of the used stations. For the threshold amplitude of 10^{-3} m/s, on the other hand, the forecasted number tends to overestimate, probably due to saturation of seismograms by both artificial and physical reasons.

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