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On predicting the size of an earthquake from the first 2-seconds of P or S wave data

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Ideally, an earthquake early warning (EEW) system should be able to determine the location and magnitude of an earthquake as rapidly as possible in order to broadcast an alarm to regions that will undergo severe ground shaking. Therefore, it would be especially beneficial if the magnitude of larger earthquakes could be predicted from just several seconds of the initial P-wave data. Zollo, Lancieri, and Nielsen"s (2006, GRL) recent study seemed to suggest that this was possible and their research quickly caught the attention of a top magazine (Science, 2006). Their method of analysis was to determine the peak in the ground displacement (PGD) from just a couple of seconds of P- and S-waveform data, which reportedly scaled with earthquake size. Here we report on performing a similar analysis on waveform data from the Japanese K-net and KiK-net data.

We analyzed K-net and KiK-net waveform data from 1130 earthquakes with magnitudes larger than 3.5 as determined by the Japanese Meteorological Agency (Tsuboi, 1954). Our method of analysis is comparable to that of ZLN except with some differences that are specific to the seismotectonics of Japan and the KiK-net array. Instead of limiting the maximum hypocentral distance to 50 km, we instead used a distance cutoff that depended on the size of the earthquake; we used a limit of 50 km for events smaller than M5 and linearly increased this limit with magnitude to 75 km for the largest events. We found that the low-background noise of the KiK-net stations allowed for a very accurate determination of the P-arrival at distances greater than 50 km for the larger events; indeed, we only used those events for which the P-arrival was clearly identified by our automated P-picker [Horiuchi, et al., 1992]. As done by ZLN, we then used 2 seconds of the vertical component of calibrated P-wave data after the initial arrival and determined the PGD in this relatively short time window. The PGD were then normalized to a reference distance of 20 km. However, unlike ZLN where PGD was determined for both the P- and S waves data, the results reported here are only concerned with P-waves since we believe that an effective EEW would be best served with earthquake magnitude estimated from the rapid analysis of the P-wave seismic energy, i.e. before the arrival of the destructive S-waves.

Below M˜5.5, we did find a strong correlation (R=0.99) between the JMA magnitude and PGD determined from the first 2-seconds of P wave data (Figure 1). A couple of seconds of P-wave data would contain nearly the entire history of fault rupture and a scaling relation, as observed, is consistent with conventional seismic source theory. The data for events larger than this magnitude has, however, a correlation coefficient of only R=0.22 with a good chance (prob=0.39) of being obtained from a random distribution of data. Therefore, we believe that fitting a straight line to all the data in Figure 1 is not justified. The data is better modeled by a linear relation between the logarithm of PGD and magnitude up to a level M˜5.5 and then a significantly flatter line above this magnitude.

In conclusion, our analysis of the K-net and KiK-net data indicates no significant correlation between PGD and magnitude for events larger than about magnitude 5.5; we therefore cannot support the claim that earthquake magnitude can be predicted from just 2 seconds of the initial P-wave data. The result of our analysis indicates that the eventual size of large earthquakes cannot be estimated from this short amount of data, i.e., more time is need. We also note that the large scatter at all magnitudes would raise necessary concerns regarding the usefulness of this prediction method, if possible, in a real-time EEW system.

Figure 1. Plot of the lograrithm of PGD versus M_{JMA}. A straight line model can be rejected with 95% confidence according to the chi-square test (broken line).