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Rapid Earthquake Magnitude Estimation for Early Warning Applications

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Earthquake magnitude is a concise metric that provides invaluable information about the destructive potential of a seismic event. Rapid estimation of magnitude for earthquake and tsunami early warning purposes requires reliance on near-field instrumentation. For large magnitude events, ground motions can exceed the dynamic range of near-field broadband seismic instrumentation (clipping). Strong motion accelerometers are designed with low gains to better capture strong shaking. Estimating earthquake magnitude rapidly from near-source strong-motion data requires integration of acceleration waveforms to displacement. However, integration amplifies small errors, creating unphysical drift that must be eliminated with a high pass filter. The loss of the long period information due to filtering is an impediment to magnitude estimation in real-time; the relation between ground motion measured with strong-motion instrumentation and magnitude saturates, leading to underestimation of earthquake magnitude. Using station displacements from Global Navigation Satellite System (GNSS) observations, we can supplement the high frequency information recorded by traditional seismic systems with long-period observations to better inform rapid response. Unlike seismic-only instrumentation, ground motions measured with GNSS scale with magnitude without saturation [Crowell et al., 2013; Melgar et al., 2015]. We refine the current magnitude scaling relations using peak ground displacement (PGD) by adding a large GNSS dataset of earthquakes in Japan. Because it does not suffer from saturation, GNSS alone has significant advantages over seismic-only instrumentation for rapid magnitude estimation of large events. The earthquake's magnitude can be estimated within 2-3 minutes of earthquake onset time [Melgar et al., 2013]. We demonstrate that seismogeodesy, the optimal combination of GNSS and seismic data at collocated stations, provides the added benefit of improving the sensitivity of displacement time series compared to GNSS alone. This not only means that ground motion can be detected at farther stations, but also that smaller seismic arrivals (i.e. P-waves) become visible in the displacement time series. P-wave amplitude (Pd) has been examined as an early indicator of earthquake magnitude. Relations between Pd and magnitude using seismic-only instrumentation appear to suffer from saturation, while the combination of GNSS and seismic data has been demonstrated to eliminate saturation [Meier et al., 2016, Crowell et al., 2013]. We create seismogeodetic displacements by combining the GNSS dataset with Japanese KiK-net and K-net accelerometer data to explore the potential of seismogeodesy for magnitude scaling with several seconds of data using P-wave amplitude.