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Rapid earthquake magnitude from real-time GPS precise point positioning for earthquake early warning and emergency response

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For earthquake early warning (EEW) and emergency response, earthquake magnitude is the crucial parameter to be determined rapidly and correctly. However, a reliable and rapid measurement of the magnitude of an earthquake is a challenging problem, especially for large earthquakes (M>8). Here, the magnitude is determined based on the GPS displacement waveform derived from real-time precise point positioning (PPP). The real-time PPP results are evaluated with an accuracy of 1 cm in the horizontal components and 2-3 cm in the vertical components, indicating that the real-time PPP is capable of detecting seismic waves with amplitude of 1cm horizontally and 2-3cm vertically with a confidence level of 95%. In order to estimate the magnitude, the unique information provided by the GPS displacement waveform is the horizontal peak displacement amplitude. We show that the empirical relation of Gutenberg (1945) between peak displacement and magnitude holds up to nearly magnitude 9.0 when displacements are measured with GPS. We tested the proposed method for three large earthquakes. For the 2010 Mw 7.2 El Mayor-Cucapah earthquake, our method provides a magnitude of M7.18$\pm$0.18. For the 2011 Mw 9.0 Tohoku-oki earthquake the estimated magnitude is M8.74$\pm$0.06, and for the 2010 Mw 8.8 Maule earthquake the value is M8.7$\pm$0.1 after excluding some near-field stations. We therefore conclude that depending on the availability of high-rate GPS observations, a robust value of magnitude up to 9.0 for a point source earthquake can be estimated within 10s of seconds or a few minutes after an event using a few GPS stations close to the epicenter. The rapid magnitude could be as a pre-requisite for tsunami early warning, fast source inversion, and emergency response is feasible.