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A Method for Real-Time Magnitude Estimation from Inversion of Displacement Spectra

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The Spectrum Matching (SM) method is an evolutionary Bayesian approach to magnitude estimation with potential application in earthquake early warning (EEW). Given an EEW location estimate, continuously updated estimates of magnitude and its associated uncertainty are calculated by matching the observed displacement spectra of available waveforms with theoretical source spectra. The method consists of three main steps: 1) comparison between observed displacement spectra and a theoretical model relating displacement spectra to seismic moment, 2) introduction of a prior distribution, and 3) estimation of magnitude and its uncertainty. We use a Brune omega-squared spectral model to relate displacement spectra to seismic moment, and the Hanks Kanamori relationship to relate seismic moment to moment magnitude. Calibrating the SM approach to a given region requires specifying a regional average stress drop and a 1D velocity model.

The SM approach assumes that EEW location estimates are available from other algorithms. Given a location estimate, the SM method can provide an initial magnitude and magnitude uncertainty estimate with 1 second of waveform data after the P-wave arrival at a single station. These estimates are updated at each second, as the ground motions propagate to further stations, and longer waveform time series are available at closer stations. We use the distance between the theoretical and observed spectra to define a probability density function (pdf) of estimated magnitude. The total magnitude pdf at any second is a combination of station-specific pdfs. This total magnitude pdf becomes narrower with time, as the uncertainty on the magnitude estimates decrease, due to the availability of longer time series at the various stations providing better constrains on the low frequency spectral plateau.

We use the Gutenberg-Richter magnitude-frequency relationship as prior information for the initial magnitude estimate. Subsequent estimates use the previous estimate as prior information. This guarantees that outlier observations do not heavily influence the final estimates.

This method has been tested on waveform datasets from M>3.0 events in Southern California and Taiwan. On average, the SM method can give stable and reliable magnitude estimates within 20 seconds of the earthquake origin time, although the final size of the earthquake and the source-station geometry can result in event-specific variations.