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Evaluating the Real-time and Offline Performance of the Virtual Seismologist Earthquake Early Warning Algorithm

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The Virtual Seismologist (VS) algorithm is a Bayesian approach to regional, network-based earthquake early warning (EEW). Bayes' theorem as applied in the VS algorithm states that the most probable source estimates at any given time is a combination of contributions from relatively static prior information that does not change over the timescale of earthquake rupture and a likelihood function that evolves with time to take into account incoming pick and amplitude observations from the on-going earthquake. Potentially useful types of prior information include network topology or station health status, regional hazard maps, earthquake forecasts, and the Gutenberg-Richter magnitude-frequency relationship. The VS codes provide magnitude and location estimates once picks are available at 4 stations; these source estimates are subsequently updated each second. The algorithm predicts the geographical distribution of peak ground acceleration and velocity using the estimated magnitude and location and appropriate ground motion prediction equations; the peak ground motion estimates are also updated each second.

Implementation of the VS algorithm in California and Switzerland is funded by the Seismic Early Warning for Europe (SAFER) project. The VS method is one of three EEW algorithms whose real-time performance is being evaluated and tested by the California Integrated Seismic Network (CISN) EEW project. A crucial component of operational EEW algorithms is the ability to distinguish between noise and earthquake-related signals in real-time. We discuss various empirical approaches that allow the VS algorithm to operate in the presence of noise. Real-time operation of the VS codes at the Southern California Seismic Network (SCSN) began in July 2008. On average, the VS algorithm provides initial magnitude, location, origin time, and ground motion distribution estimates within 17 seconds of the earthquake origin time. These initial estimate times are dominated by the time for 4 acceptable picks to be available, and thus are heavily influenced by the station density in a given region; these initial estimate times also include the effects of telemetry delay, which ranges between 6 and 15 seconds at the SCSN, and processing time ($\sim$1 second). Other relevant performance statistics include: 95% of initial real-time location estimates are within 20 km of the actual epicenter, 97% of initial real-time magnitude estimates are within one magnitude unit of the network magnitude. Extension of real-time VS operations to networks in Northern California is an on-going effort. In Switzerland, the VS codes have been run on offline waveform data from over 125 earthquakes recorded by the Swiss Digital Seismic Network (SDSN) and the Swiss Strong Motion Network (SSMS). We discuss the performance of the VS algorithm on these datasets in terms of magnitude, location, and ground motion estimation.