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Development of the ElarmS methodology for earthquake early warning: Realtime application in California and offline testing in Japan

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ABSTRACT

In July 2009, the California Integrated Seismic Network concluded a three-year study of earthquake early warning systems in California. Three algorithms were expanded and examined during the study. Here we discuss the history, methodology, and performance of one of the algorithms, ElarmS. Earthquake Alarm Systems, or ElarmS, uses peak displacement and maximum predominant frequency of the P-wave to detect earthquakes and quantify their hazard in the seconds after rupture begins. ElarmS was developed for Northern and Southern California, and now processes waveforms in realtime from 603 seismic sensors across the state. We outline the methodology as currently implemented, present several example events from different regions of California, and summarize the performance in terms of false and missed alarms. ElarmS was also tested offline with a dataset of 84 large magnitude earthquakes from Japan. The results from the Japan dataset were used to create a statistical error model for the algorithm. The model can be used to provide realtime uncertainty estimates at any stage in processing. In August 2009 the CISN embarked on a second three-year study of earthquake early warning. As part of this ongoing research, we identify the technological and methodological challenges facing ElarmS. Telemetry latencies and false alarm rates are two key opportunities for improvement.

1. Introduction

Earthquake early warning (EEW) systems are algorithms that detect the initial P-waves from an earthquake, rapidly estimate the location and magnitude of the event, and then predict subsequent ground shaking in the surrounding region. EEW systems offer the potential for a few seconds to a few tens of seconds warning prior to hazardous ground shaking: enough time for individuals to get to a safe location, perhaps under a sturdy table, for shutdown of utilities, slowing of trains, and other automated steps to reduce hazards from ground shaking.

In July 2009, the California Integrated Seismic Network (CISN) completed a three-year investigation into the viability of an EEW system in California. Three algorithms were expanded, tested, and compared during the study: Onsite, a single-station method that uses τ_c and P_d [8], Virtual Seismologist, a network-based method that uses peak amplitudes and Bayesian statistics [10], and ElarmS, a network-based method that uses τ_p^{max} and $P_{d/v}$ [5].

The goal of the three-year project was to determine whether EEW is feasible in California. Results from each algorithm were continuously reported to a central database run by the Southern California Earthquake Center (SCEC) for analysis. By the end of the three years, all three algorithms had successfully predicted ground shaking before it was felt for many earthquakes in the state. At the end of the study the CISN determined that EEW is feasible, potentially desirable, and within reach for California. In August 2009 a second three-year study was initiated, to integrate the three test algorithms into a single prototype EEW system and provide realtime warning to a small group of test users by the end of the study in summer 2012.

Here we delineate the methodology, progress, and results of the ElarmS algorithm, which is now an integral part of the forthcoming prototype CISN EEW system. The ElarmS algorithms for magnitude and location estimation were developed offline with two datasets of events from Northern and Southern California. Those algorithms are now used in realtime, continuously processing waveforms from throughout the state of California and producing predictions of ground shaking within seconds of event detection. A separate dataset of events from Japan was processed offline to test ElarmS' performance for large events. From the Japan results we developed an error model which can be used in realtime to estimate the uncertainty in any ElarmS prediction.

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