CISN Earthquake Early Warning: ElarmS

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The CISN EEW Project

In summer 2009 the California Integrated Seismic Network (CISN) began a three-year project to develop a functional statewide Earthquake Early Warning (EEW) system for California. EEW systems detect earthquakes from P-waves, rapidly estimate their location, magnitude, and hazard potential, and then issue alerts of impending ground shaking, ideally before the damaging S- and surface-waves reach nearby population centers.

The CISN EEW project began with three individual test systems, run at UC Berkeley, Caltech, and ETH. The three systems are being upgraded for faster processing and combined to provide a single output of data and earthquake alert messages. The new unified EEW system, called ShakeAlert, will provide warnings to a small group of test users by summer 2012.

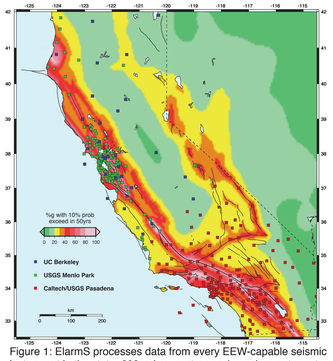
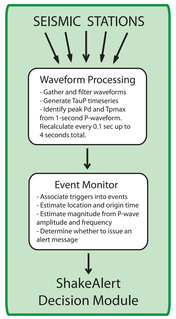


Figure 1: ElarmS processes data from every EEW-capable seismic instrument in the state: 603 seismometers and accelerometers at 383 stations. These stations, run by UC Berkeley, the USGS, and Caltech, are concentrated in the regions most susceptible to damaging earthquakes.

ElarmS Processing Flow



ElarmS Development History

The EEW algorithm at UC Berkeley is called Earthquake Alarm Systems, or ElarmS. ElarmS was originally developed offline using datasets from Southern and Northern California. A correlation was found between the amplitude (*Pd*) and frequency (*Tpmax*) content of the P-wave and the final event magnitude.

In 2007 ElarmS was converted to run in realtime, continuously processing seismic data from seismometers and accelerometers in Northern California. The first successful test of ElarmS on a large earthquake was less than a month after realtime processing began: the M5.4 Alum Rock earthquake. ElarmS detected the P-wave, estimated an event magnitude of 5.7, and accurately predicted the shaking in San Francisco before the arrival of the S-wave and peak shaking there. See box below for more details.

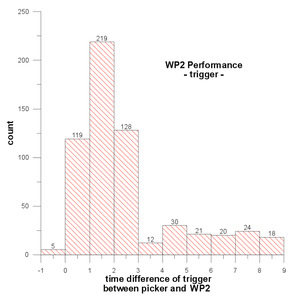
In 2009 ElarmS was expanded to cover the entire state, and now processes data from every EEW-capable seismic station in California (above). The current work on ElarmS is focused on improving the speed of the system (see Waveform Processing and Event Monitoring boxes at right) and connecting it to the new CISN ShakeAlert system.

Waveform Processing Version 2

As part of the current CISN EEW project, the EEW partners are developing an updated Waveform Processing (WP) algorithm. The Waveform Processing module transfers data from all early warning capable seismic stations in the state to central event monitoring computers, identifies P-wave triggers, and filters the data for processing by the Event Monitors.

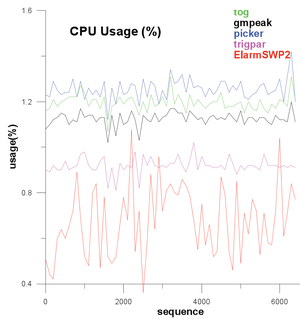
The EEW partners at Caltech designed new WP libraries for use by all members of the project. At Berkeley, our new WP algorithm is running in realtime, utilizing the Caltech libraries. The new Berkeley WP is not yet connected to the ElarmS event monitor, but we can already compare the arrival times of triggers from the new WP to the arrival times of triggers from the old WP, to see improvements in speed and memory usage.

Improvements in trigger process times: new WP - old WP (seconds)

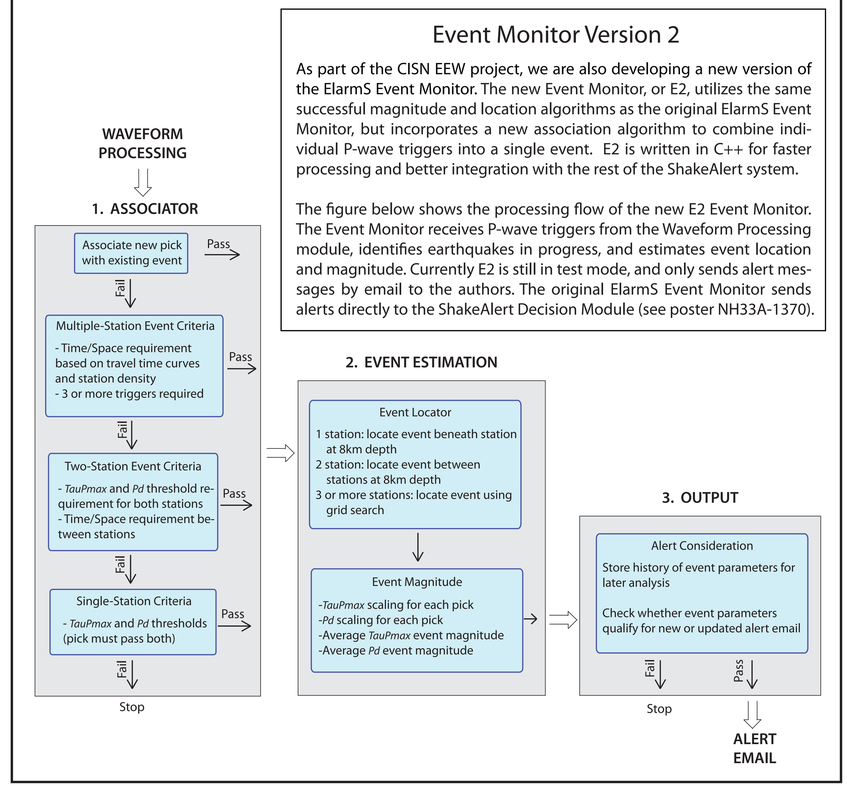


Triggers from the new WP module were processed faster 99% of the time. The mean improvement was about 2 seconds, but individual triggers can be up to 10 seconds faster.

Improvements in CPU usage:



The old WP module used four different functions, called tog, gmpeak, picker, and trigpar. The new WP module uses a single function, WP2, which uses only a quarter of the CPU on average compared to the old module.



Event Monitor Version 2

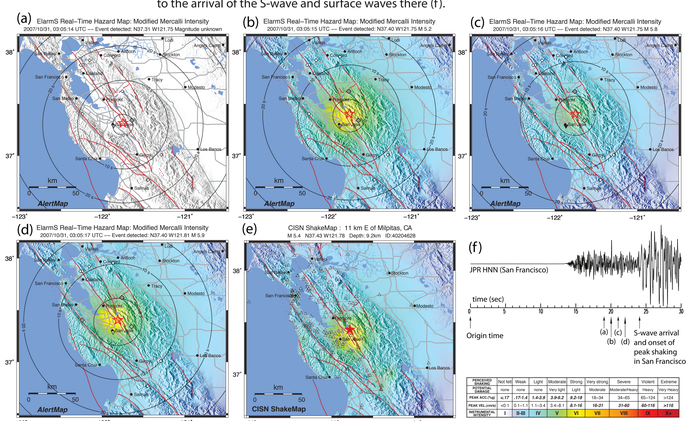
As part of the CISN EEW project, we are also developing a new version of the ElarmS Event Monitor. The new Event Monitor, or E2, utilizes the same successful magnitude and location algorithms as the original ElarmS Event Monitor, but incorporates a new association algorithm to combine individual P-wave triggers into a single event. E2 is written in C++ for faster processing and better integration with the rest of the ShakeAlert system.

The figure below shows the processing flow of the new E2 Event Monitor. The Event Monitor receives P-wave triggers from the Waveform Processing module, identifies earthquakes in progress, and estimates event location and magnitude. Currently E2 is still in test mode, and only sends alert messages by email to the authors. The original ElarmS Event Monitor sends alerts directly to the ShakeAlert Decision Module (see poster NH33A-1370).

Sample Event:

Alum Rock, CA
31 Oct 2007, Ml 5.1

The Alum Rock earthquake was the first realtime test of ElarmS. Figures a-d (below) show second-by-second progression of ElarmS magnitude and ground shaking estimates. ElarmS' predictive AlertMap (d) is nearly identical to the CISN ShakeMap produced several minutes after the event ended (e). Using the stations from the BK network in the dense SFBA region, ElarmS was able to predict ground motions in San Francisco prior to the arrival of the S-wave and surface waves there (f).



Sample Event:

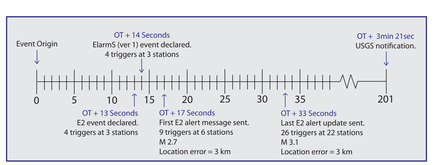
Aromas, CA
24 Nov 2010, 03:22:57 UTC
Ml 3.3

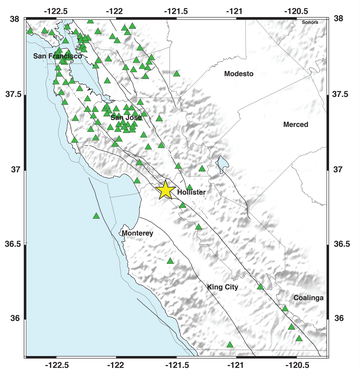
The Aromas earthquake is a recent northern California event processed by the new E2 Event Monitor. E2 made an initial magnitude estimate of 3.0, using 4 triggers at 3 seismic stations (one of the stations had a co-located accelerometer and seismometer, each of which provided P-wave information). Below is a timeline showing the processing times for this event. At right is the final alert message sent by E2 to the authors for this event.

Subject: E2 ALERT: M 3.1, nT 23, 36.9, -122, 2010/11/24, 03:22:59
Date: Tue, November 23, 2010 7:23 pm

E2 Event # 30045
UTC Time 2010/11/24, 03:22:59
Epoch Time 1290569003
Triggers 23
Stations 19
Event Magnitude 3.1
Tp Magnitude 2.8
Pd Magnitude 3.3
Location 36.866, -121.591
http://maps.google.com?q=@36.866,-121.591

Above: Final E2 alert message sent to the authors for the Aromas event. The original ElarmS Event Monitor sends messages directly to the ShakeAlert Decision Module for wider distribution, but E2 is still in the testing phase and sends alert messages only to the authors.





Above: Map showing the location of the Aromas event.

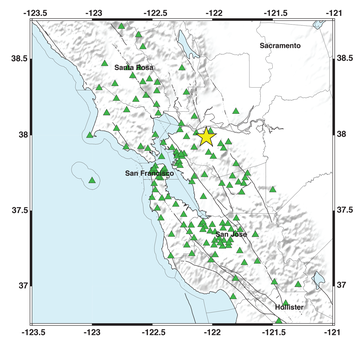
At left: Timeline of E2 processing. The new E2 Event Monitor was one second faster than the version 1 Event Monitor, and approximately 3 minutes faster than the automatic USGS notification.

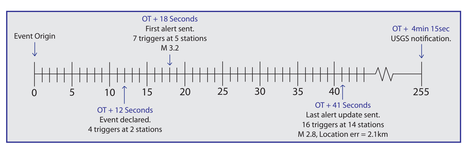
Sample Event:

Concord, CA
01 Sept 2010, 01:26:55 UTC
Ml 3.2

The Concord earthquake was one of the first events processed by the new E2 Event Monitor. E2 made an initial magnitude estimate of 3.2, using 7 triggers at 5 seismic stations. Throughout the event processing, the estimated magnitude ranged from 2.5 to 3.2, with mean of 2.8.

At right: Map showing the location of the Concord event.
Below: Timeline of E2 processing.





Acknowledgements:

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