Final Report: August 2012 - July 2013
Earthquake Hazards Program Assistance Awards

USGS Award Number:	G12AC20348 (UCB) G12AC20343 (Caltech) **G12AC20339 (USC/SCEC)** G12AC20342 (ETH Zürich)	
Title of award:	Prototype Implementation and Development of the New CISN ShakeAlert: Collaborative Research with the California Institute of Technology, University of California Berkeley, University of Southern California and Swiss Federal Institute of Technology	
Author(s) and Affiliation(s) with Address and zip code. Author's telephone numbers, fax numbers and E-mail address.	Richard Allen & Margaret Hellweg UC Berkeley Berkeley Seismological Lab 215 McCone Hall #4760 Berkeley, CA 94720-4760 510-643-9449 f: 510-643-5811 rallen@berkeley.edu peggy@seismo.berkeley.edu	John Clinton Swiss Seismological Service Institute of Geophysics ETH Zurich, NO F63 Sonneggstr. 5 CH-8092 Zurich, Switzerland ++41-44-632-9338 f: ++41-44-633-1065 jclinton@sed.ethz.ch
	Thomas Jordan SCEC, University of Southern California MC 0740 Los Angeles, CA 90089 tjordan@usc.edu	Thomas Heaton Caltech M/C 252-21 Pasadena, CA 91125 626-395-4323 heaton@caltech.edu,
Term covered by the report:	1 August 2012 - 31 July 2013	
Funding expended for the term covered by the report:	Each organization will submit separately	

Introduction and Background:

In 2006 the USGS began funding the California Integrated Seismic Network's (CISN) Earthquake Early Warning (EEW) group to take a series of EEW algorithms that had been developed and tested offline and begin the process of implementing them on the CISN's realtime system. At that time the seismological community in the US was skeptical that EEW was possible in California. We are now at the end of the first year of Phase III. By the beginning of the current phase of the project in August 2012, the CISN EEW group had implemented and was operating an integrated end-to-end demonstration EEW system. This system routinely detects earthquakes and issues alerts. The alerts are sent to a group of test users who are beginning to develop and implement applications. Not only has the seismological community accepted that EEW is possible, many see the implementation of a public system as an inevitable next step in earthquake mitigation.

The focus of Phase III is the transition from the *demonstration* system software from Phase II to a *production* system that is integrated into the CISN AQMS environment. On-going evaluation of the system and the engagement of users are also targets of our efforts. Continued research into improved algorithms is largely supported by other sources of funding, but the results of these efforts will be

integrated into the operational systems as appropriate. We participate in the development of the EEW implementation plan with the USGS.

Specific goals for the Phase III component of USGS funded support of CISN EEW implementation are:

Goal 1: Transfer algorithms to AQMS operational environment to create and operate a prototype *production* system;

Goal 2: Continue to support and enhance the existing *demonstration* system;

Goal 3: Evaluate system performance on a region-by-region basis, identifying causes of strong/weak performance and providing feedback to algorithm developers;

Goal 4: Continue to interact with users in collaboration with the USGS; and

Goal 5: Develop an implementation plan with the USGS.

Progress toward these goals is accomplished through discussions among project members at the cooperative institutions to define standards and assign tasks. Project members are organized into thematic groups to cover the goals, that is a Production System group, a Demonstration System group, a Performance Evaluation group and a User Interactions group. General oversight, direction and integration are provided by the Scientific Coordination group. The development of the implemenation plan (Goal 5) is spearheaded by Doug Given of the USGS. Each organization has contributed a summary of its activities.

UC Berkeley: August 2012 - July 2013

In the following we describe and discuss project activities, investigations undertaken, accomplishments and problems encountered as we move toward completing each of the goals, with specific emphasis on the tasks and activities of project members at the Berkeley Seismological Laboratory (BSL).

Goal 1: *Transfer algorithms to AQMS operational environment to create and operate a prototype production system.*

The elements of the demonstration EEW system created as part of Phase II of this project operate in a "research" environment. Primarily that means that robustness was not the primary consideration in supporting the computers running the softare, the connections between those computers and in the communications links needed to forward alert information to users. Neither was robust operation a main consideration in making sure that all EEW software continued to operate all of the time.

The main elements of the EEW system, regardless of algorithm are waveform processing (WP), the “algorithms” (current Elarms (E2), Virtual Seismologist (VS) and Onsite (OS)), the Decision Module (DM) and user interfaces, primarily the User Display (UD). Waveforms arrive in each of the AQMS operations centers for CISN, Berkeley, Menlo Park and Pasadena, where they are processed to determine parameters for the EEW system. The EEW parameters are forwarded to the algorithms, which detect and characterize earthquakes in progress. The algorithms in turn forward the event information to the decision module. The decision module passes alert information to the user display. In the demonstration system all this processing occurred in the research environment. The most robust part of the system was the waveform collection, which takes place in the regular AQMS environment. One additional element of the EEW system is the messaging system, Active MQ (AMQ), which is used to pass alert information between the algorithms and the decision module, through a message broker system.

The production group had many conference calls to consider various models for improving the robustness of the EEW system and integrating it more closely with the AQMS system. Figure 1 shows the proposed architecture developed by Doug Neuhauser and Ivan Henson (BSL) in consultation with the production group. It provides redundant processing at all levels and redundant messaging at all levels of the system.

BSL project members are responsible for the operation of E2 and the DM. At UCB and in Menlo Park (MP), we transitioned waveform processing for E2 into the AQMS environment. E2WP services are now running on the real-time operations computers also used for data collection and "network services" (continuous waveform processing for AQMS to determine picks and other waveform parameters) at both data centers. Processing occurs redundantly on two computers for all waveforms at both sites, and

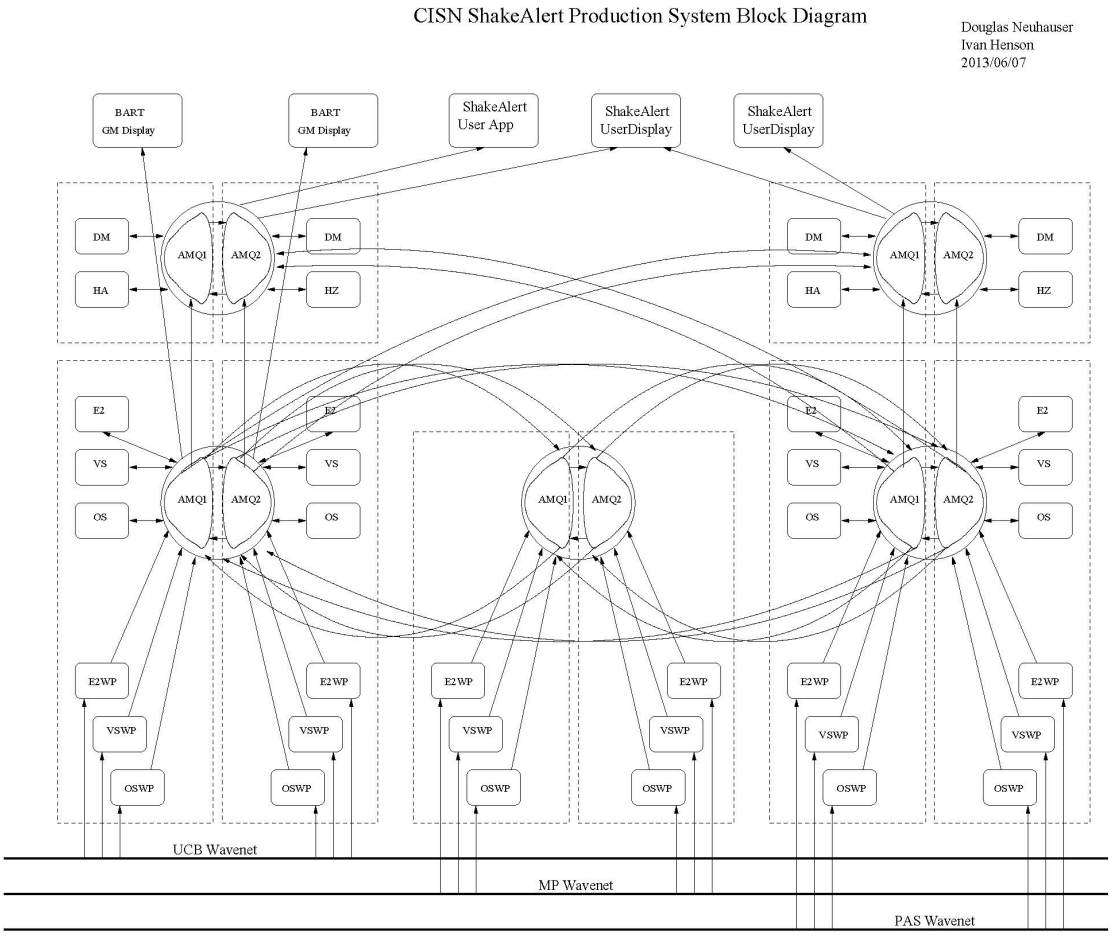

Figure 1. Proposal for a robust ShakeAlert production system with built-in redundance. Horizontal lines across the bottom represent incoming waveforms at each of the CISN data centers, UC Berkeley (UCB), Menlo Park (MP) and Pasadena (PAS). The vertically oriented boxes represent computer systems at UCB (left), Menlo Park (center) and Pasadena (right). Processing centers can provide end-to-end EEW services (UCB, PAS) or only waveform processing (MP). Each element of the system is duplicated at each processing center (i.e. two waveform processing packages for each algorithm at UCB, at MP and at PAS). All "interprocess communication" takes place through the Active MQ (AMQ) message brokering system. All AMQ nodes communicate with each other passing all information among all nodes. All processing elements at a given site communicate with all AMQ nodes at that site. This system allows maximum redundancy should any element fail or its operation be interrupted. An important open question, being discussed in the Production group, is how the User Display and other EEW user modules can take advantage of this system.

redundant EEW parameters are passed through AMQ brokers to E2 running on a development system at UCB. We have been testing the system to explore possible limitations on messaging and on individual processing elements, such as the algorithms or the decision module, receiving duplicate information. So far, we have not encountered any major stumbling blocks.

We have also been preparing and documenting codes in preparation for passing an "operational version" to the production group.

Goal 2: *Continue to support and enhance the existing demonstration system.*

During the past year, we have continued to operate and enhance the E2 and DM modules of the demonstration system. Evaluation, enhancements and improvements to E2 will be discussed under Goal 3, System Performance. Here we will report on improvements to the Decision Module (DM). At the end of Phase II, the DM received event information from up to three algorithms for each event, E2, VS and

OS. Each algorithm provided fixed uncertainties in the event parameters and probabilities based on estimates from the algorithm operators. The BSL led an evaluation of the parameter uncertainties and event likelihoods for all three algorithms based on the events that they had submitted to the DM between May 2012 and January 2013. Likelihoods are based on the ratio of "false alerts", those not associated with an earthquake in the ANSS catalog, to released alerts. Uncertainties are based on a statistical evaluation comparing alert parameters (origin time, location, magnitude) and those for the corresponding event in the ANSS catalog. For a given alert from each algorithm, uncertainties and likelihood may change over time as more stations contribute data to the analysis. Each algorithm now submits time-dependent likelihood and uncertainty information to the DM. The algorithms also include the number of stations contributing to an event at each time step.

In the initial implementation, the DM simply averaged event parameters (magnitude, origin time, location) from different algorithms and published them as alerts. Now that improved uncertainty and likelihood estimates are available from the algorithms, the alerts produced by the DM are based on weighted averages of the event parameters. These parameters may change over time, as an algorithm provides updated event information and uncertainties.

Goal 3: *Evaluate system performance on a region-by-region basis. Identify causes of strong/weak performance and feedback to algorithm developers.*

For E2, we have continued our regular evaluations of performance, and tested and implemented improvements over time. In particular, we have targeted elimination of false and missed events, and reducing timeliness of reporting and uncertainties of origin time, location and magnitude. Two particular problems have been caused by trigger reporting of grouped stations (stations within a few miles of each other) and teleseisms. We appear to have eliminated most problems from grouped stations and are close to a solution for eliminating false triggers from teleseisms. We have also been investigating improvements to magnitude estimation for both small and large quakes for E2.

For our reviews, we are developing and improving an interactive tool which displays event related information in both map and table from, from both E2 and the ANSS catalog. It allows easy review of parameters and timing, and is a great support in our effort to improve E2's performance. We are currently expanding the tool to allow comparative performance of the DM and the three algorithms, E2, VS and OnSite. It will then be available for use by other algorithm developers.

We also target improved timeliness of alerts. Currently average alert time is on the order of 10 s, with alerts for events in the Greater LA and BA regions available within ~8 s. In recent months, E2 has regularly been the fastest algorithm.

Goal 4: *Continue to interact with users in collaboration with the USGS.*

We continue to participate in group interactions with users, such as the now regularly scheduled tests of major "scenario" alerts to beta-users. We also continue to recruit new prospective users, providing information and training as they come on-board. The BSL leads the Communications Group— the project's outreach and public information team—which include public affairs personnel from USGS, UC Berkeley, Caltech, U Washington, and the Moore Foundation. The group's focus is to steer and coordinate EEW outreach and communications among the project partners. This includes communications with users, stakeholders, and elected officials, to build support for the system, to maintain user relations and to support and shepherd the public education campaign.

Goal 5: *Develop an implementation plan with the USGS.*

We participated in the conference calls and workshops to support the USGS development of an EEW implementation plan, and provided feedback on the draft plan. In particular, we also contributed to the development of a budget for the path toward a fully operational EEW system for the US West Coast.

Caltech: August 2012 - July 2013

Goal 1: Transfer algorithms to AQMS operational environment to create a prototype production system and operate the system.

- Participated in discussions on an overall strategy for implementing EEW algorithms into the AQMS operational environment to create the production system.
- Provided initial set-up of linux machines for production system.
- Checked latest versions of Onsite, EEWserver, and UserDisplay codes into CISN svn; started to provide code documentation and installation guidelines on trac wiki.
- Supported initial installation of VS codes on production machines (not completed); purchased linux machines for compiling and testing Onsite, FinDer (ffd) and GPSlip codes on linux.

Goal 2: Continued support and enhancement of the existing demonstration system.

- Led and participated in discussions of the Demonstration and Scientific Coordination Groups.
- Maintained and enhanced Onsite and UserDisplay (UD) codes as necessary in response to performance and feedback from users: modified association algorithm and alert filters; added new uncertainty and likelihood estimates; improved logging capabilities; performed hardware maintenance & various bug fixes; developed framework for Onsite testing using archived picks and triggers; added ability to use station meta-data from flat file if database inaccessible; cleaned-up make and start-up scripts; made UD more user-friendly and robust; fixed NTP reconnect bug (that could fill up disk); improved health status so it includes NTP status; added finite-fault capabilities to UD; added improved intensity estimates for large earthquakes; started to investigate how to display alert information for users with multiple locations; released UD v.2.4; provided feedback and support for development of Android User app at Caltech.
- Developed (prototype) codes for finite-fault algorithms FinDer (ffd), and GPSlip in Matlab (waveform processing in C++); offline and real-time tested codes without reporting to ShakeAlert system; attended various meetings with GPS group to discuss usage and formats of real-time GPS data.
- Developed and implemented extended xml-ShakeAlert message format (including finite-fault and slip information from FinDer and GPSlip) in collaboration with Scientific Coordination and Demonstration Groups.
- Started to develop framework for end-to-end offline testing of ShakeAlert system for archived and simulated waveform data using Earthworm tankplayer; performed initial test runs for Onsite and FinDer (ffd); encountered various problems with sampling rates, gain corrections, and frequency bands of simulated waveforms which are being addressed.

Goal 3: Evaluation of system performance on a region-by-region basis.

- Participated in performance evaluation of the three algorithms and ShakeAlert system; determined and implemented preliminary uncertainty and likelihood estimates for Onsite.

Goal 4: Continued interaction with users in collaboration with the USGS

- Participated in discussions of the User Group and USGS.
- Continued interaction with new and previous Beta Test Users from 27 organizations (6 additional in transition); compiled and maintained email lists of all Beta Test Users; documented User feedback; updated UserDisplay Operations Guide; distributed UserDisplay software updates to Users; provided training and technical support; run regular monthly tests of the UserDisplay software for demonstration and feedback; continued to identify EEW advocates essential in providing critical support and development of public/private partnerships (Beta Users were instrumental in providing critical support for State Senate Bill 134); planned and hold Caltech Earthquake Research Affiliates' (ERA) meeting about EEW; responded to requests for information regarding EEW to potential user groups and media.

- Contributed to the outreach section of the USGS EEW Implementation Plan

Goal 5: Development of an implementation plan with the USGS

- Participated in workshops/working groups/writing groups etc. as requested by the USGS to help develop the implementation plan.
- Responded to requests for information on performance and expected performance of EEW algorithms to help formulate an implementation plan.

Research:

- Continued EEW research: detection and processing of finite-fault ruptures (FinDer); usage of GPS-data for slip and magnitude estimation (GPSlip); improved ground-motion prediction for large earthquakes with consideration of finite-fault, directivity, and basin response effects (using SCEC CyberShake waveform simulations); assessment of threshold magnitudes and available warning times for various scenario earthquakes along active faults in Southern California; developed method to predict shaking in high-rise buildings; developed method to analyze complex earthquake sequences; developed concept of a simple gut check algorithm for DM; developed framework for automated decision-making.
- Presented and discussed results at various meetings, workshops, and conferences.
- Documented research results in scientific papers, on webpage etc.

ETH: August 2012 - July 2013

Goal 1: Transfer algorithms to AQMS operational environment to create a prototype *production* system and operate the system.

- Contributed to the discussion on developing a strategy for an operational EEW system within AQMS
- Handed over the latest version of the VS source code by checking it in to the CISN/ShakeAlert version control system
- Provided support in the installation and setup of VS on one of the new production machines. This installation is currently running in testing mode.

Goal 2: Continue to support and enhance the existing *demonstration* system.

- Monitored VS installations at Berkeley, Caltech and Menlo Park
- Started the statewide implementation of VS in the demonstration system. Expected completion date is end of September.
- Included newly defined uncertainty and likelihood estimates (see Goal 3)
- Included changes to the XML messaging format

Goal 3: Evaluate system performance on a region-by-region basis. Identify causes of strong/weak performance and feedback to algorithm developers

- Contributed to the evaluation of the ShakeAlert system performance and the definition of revised uncertainty and likelihood values.

Goal 4: Continue to interact with users in collaboration with the USGS.
No expected contributions from ETH.
Goal 5: Develop an implementation plan with the USGS.

- Participated in conference calls, workshops, and discussions on developing an implementation plan

Gave feedback on VS performance and implementation specifics

University of Southern California: August 2012 - July 2013

Goal 3: Evaluate system performance on a region-by-region basis. Identify causes of strong/weak performance and feedback to algorithm developers.

- Operated the existing ShakeAlert performance-monitoring system and monitored the performance of the ShakeAlert demonstration system with the CISN Testing Center at USC with testing results posted at: http://scec.usc.edu/scecpedia/CTC_Results
- Implement new, prototype, "False Alarm" performance summaries in the CTC and began analysis of the ShakeAlerts identified in these summaries that do not correspond with ANSS events.
- Updated the CISN Testing Center to extract performance information from updated ShakeAlert log formats as implemented on the ShakeAlert demonstration system.
- Prepared and presented ShakeAlert performance summaries for significant California Earthquakes and for selected performance periods to CISN technical and management groups during project coordination calls.

Research:

- Implemented two new prototype cumulative summaries that provide new information about ShakeAlert system False Alarm performance. Currently, the CTC performance summaries only described ShakeAlert performance during significant California events found in the ANSS Catalog. We have now introduced two new performance summaries that show the total number of ShakeAlerts issued by the Decision Module (and individual Algorithms) and the number of these ShakeAlerts that can be easily associated with ANSS events. Any ShakeAlerts not associated with ANSS Events are considered False Alarms (or False Alerts). Below are examples of these two new performance summaries, the False Alerts Table (Figure 2), and False Alerts Magnitude Distribution (Figure 3). These two figures show ShakeAlert system performance from 1 Jan 2013 through 31 July 2013 (212 days). We will review these performance summaries with the ShakeAlert development team and, after group review, we will install final implementations of these performance summaries in the operational CTC ShakeAlert Testing Center, so they are produced routinely along with existing CTC ShakeAlert performance summaries.

CISN Testing During Project Years 2 and 3:

- The USC/SCEC CISN Testing activity is funded for only project year 1. This will affect our ability to add new capabilities to the ShakeAlert testing. Based on the fairly low level of effort to operate the existing CISN Testing Center, we plan to continue to run the existing system during Project Year 2 and 3, and produce the current event and cumulative summaries. During this time, we will fix any computational problems or errors that are identified in the current testing center performance summaries, but we will not plan to implement new performance summaries during that time period unless this testing activity is re-funded.

Overall Performance for [2013-01-01; 2013-07-31]
Using reference ANSS events: M>=0.0; [] codes; 60 seconds since origin

	All ShakeAlerts During Catalog Period [#]	ShakeAlerts Associated with an ANSS Event (All Magnitudes) [#(%)]	ShakeAlerts With No Associated ANSS Events (No Cancellation) [#(%)]	ShakeAlerts with No Associated ANSS Events (With Cancellation) [#(%)]
ShakeAlert	637	574 (90)	54 (8)	1 (0)
VS	493	449 (91)	44 (9)	0 (0)
Onsite	58	48 (83)	4 (7)	1 (2)
ElarmS	783	736 (94)	39 (5)	0 (0)

Figure 2: False Alert performance summary for ShakeAlert system 1Jan2013 - 31Jul2013 (212 days) showing total number of alerts issued by Decision Module and the fraction of these alerts that are not clearly associated with earthquakes of any magnitude in the ANSS catalog for the California region.

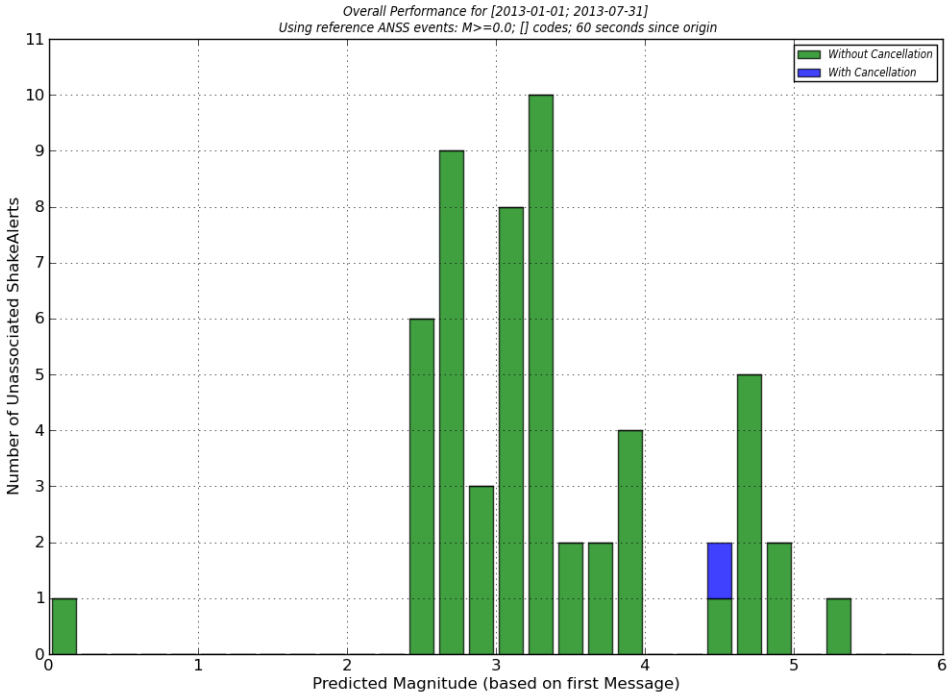

Figure 3: False Alert Magnitude Distribution shows the magnitude distribution of the Unassociated ShakeAlerts and shows what fraction of these False Alerts were cancelled by the system.

Publications and presentations to date

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