1. CISN EEW TESTING CENTER DEVELOPMENT

As part of the CISN EEW algorithm development, the CISN and the Southern California Earthquake Center (SCEC) have established an independent an EEW algorithm performance testing system. The CISN EEW testing center addresses several important aspects involved in evaluating the seismological and speed of operation performance for the CISN EEW algorithms. Development of a common testing environment has helped the CISN EEW algorithm developers standardize on specific testing issue such as the region for which CISN EEW should be tested, and the types of performance summaries that should be produced on a nightly basis. The CISN EEW testing activity has helped to define common algorithm performance information such as standardized timestamps, and standardize algorithm parameters (e.g. origin time, estimated magnitude). The CISN EEW testing center activity has also developed standardized data reporting formats.

The CISN EEW testing center is designed to perform prospective testing in order to eliminate the possibility of bias towards a known correct answer which is possible in retrospective testing. In the case of EEW, prospective testing requires that the CISN EEW algorithms report (or log to a file) predicted parameters such as final magnitude while the event is in progress. Currently both the CIT TauC-PD and the Virtual Seismologist algorithms report prospective predicted parameters to the testing center. The UCB ElarmS currently reports retrospective information to the testing center, although prospective information may be available to the UCB development groups.

2. CISN EEW TESTING CENTER OPERATIONS:

The CISN EEW testing center has now been in operation for over one year. On a nightly basis, the CISN EEW Testing Center software retrieves current ANSS catalog information for California, and compares CISN EEW triggers against events in the ANSS catalog. These comparisons are used to produce CISN EEW performance summaries which are then automatically posted on the CISN EEW Testing Center web site. (http://www.scec.org/eew) (Username: guest) (pwd: cisneew). The performance summaries on the CISN EEW web site are updated on a daily basis at about midnight PST.

In the CISN EEW performance summaries, the ANSS catalog is used as the reference data set. CISN EEW trigger information, including origin time, location, and magnitude, are compared against the ANSS catalog information. The CISN EEW testing center software framework that runs on a nightly basis is derived from an open-source software framework created at SCEC for the Collaboratory for the Study of Earthquake Predictability (CSEP) (http://www.scec.org/csep). Use of the CSEP software has helped reduce the required software development needed to support the CISN EEW testing center.

3. CISN EEW PERFORMANCE SUMMARY RESULTS:

The CISN EEW testing center provides a variety of performance summaries as specified in a CISN EEW Testing specification document [Bose et al 2008]. These performance summaries are based on two input data sets. One, performance reports are created by the real-time or near real-time, algorithms and transferred to the CISN EEW testing center. Second, the CISN EEW testing center retrieves earthquake catalog data from the ANSS catalog. This ANSS data is consider the reference data. EEW forecasts are compared against the ANSS to determine their accuracy.

These CISN EEW performance summaries are produced automatically on a daily basis. An example performance summary that is available on the SCEC web site is a trigger summary. An example trigger performance summary for events > Ml4.0 is shown below. Information that can be gleaned from this summary includes the following.

Yellow rows indicate ANSS events. Green rows following an ANSS event indicate EEW triggers for that event that contained accurate information (such as event origin time and magnitude). This example table shows several ANSS events with EEW triggers. It also shows that for several ANSS event, in both NC and SC, there were ANSS Ml3.0+ events with no EEW triggers.

For the first ANSS event (Ml3.9), this table shows that ElarmS triggered on the event. ElarmS produces a timeseries of information during the event. The multiple green rows show that the ElarmS information about the event evolved with time. ElarmS reports only Algorithm time to the testing center. With this time, ElarmS reported good (within 1 Magnitude unit and -10 to +30 seconds) origin time and magnitude information with 11 seconds of network data.

After these reports, we see a series of events with no associated triggers. In NC, offshore events may produce no EEW triggers. In SC, events in Mexico often produce no EEW triggers.

Next, we see a SC event (Ml3.53) that has associated TauC-PD (aka OnSite) and VS triggers. Three TauC-PD stations triggered for this event and reported reasonable magnitudes. The TauC-PD algorithm reports alert time which represents how long after origin time an EEW alert can be produced with the current network, telemetry, and processing systems. In this case, a single station alert could have been produced at 16 seconds. The VS system also triggered on this event and could have produced an alert with a reasonable magnitude within 21 seconds.

1	ANSS Event	*Times*	Obs	2008-11-15 17:50:41	[-10 to +30]			*Mags*	Obs	3.90	[-1.0 to +1.0]			Alert	Algo	NC	51211277
1	**Correct Trigger**	*Times*	Obs	2008-11-15 17:50:41	Fcst	2008-11-15 17:50:43	**2**	*Mags*	Obs	3.90	Fcst	3.04	**-0.86**	--	11	UCB-Elarms-NI	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 17:50:41	Fcst	2008-11-15 17:50:45	**4**	*Mags*	Obs	3.90	Fcst	3.16	**-0.74**	--	15	UCB-Elarms-NI	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 17:50:41	Fcst	2008-11-15 17:50:45	**4**	*Mags*	Obs	3.90	Fcst	3.16	**-0.74**	--	20	UCB-Elarms-NI	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 17:50:41	Fcst	2008-11-15 17:50:44	**3**	*Mags*	Obs	3.90	Fcst	3.16	**-0.74**	--	25	UCB-Elarms-NI	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 17:50:41	Fcst	2008-11-15 17:50:44	**3**	*Mags*	Obs	3.90	Fcst	3.16	**-0.74**	--	30	UCB-Elarms-NI	
1	ANSS Event	*Times*	Obs	2008-11-15 17:12:55	[-10 to +30]			*Mags*	Obs	2.21	[-1.0 to +1.0]			Alert	Algo	NC	51211273
1	ANSS Event	*Times*	Obs	2008-11-15 16:44:57	[-10 to +30]			*Mags*	Obs	2.35	[-1.0 to +1.0]			Alert	Algo	NC	51211270
1	ANSS Event	*Times*	Obs	2008-11-15 13:20:52	[-10 to +30]			*Mags*	Obs	2.42	[-1.0 to +1.0]			Alert	Algo	CI	14403424
1	ANSS Event	*Times*	Obs	2008-11-15 12:36:28	[-10 to +30]			*Mags*	Obs	2.86	[-1.0 to +1.0]			Alert	Algo	NC	51211265
1	ANSS Event	*Times*	Obs	2008-11-15 09:52:51	[-10 to +30]			*Mags*	Obs	3.53	[-1.0 to +1.0]			Alert	Algo	CI	14403392
1	**Correct Trigger**	*Times*	Obs	2008-11-15 09:52:51	Fcst	2008-11-15 09:52:59	**8**	*Mags*	Obs	3.53	Fcst	4.19	**0.66**	16	8	CIT-OnSite	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 09:52:51	Fcst	2008-11-15 09:53:00	**9**	*Mags*	Obs	3.53	Fcst	3.49	**-0.04**	18	9	CIT-OnSite	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 09:52:51	Fcst	2008-11-15 09:53:10	**19**	*Mags*	Obs	3.53	Fcst	3.23	**-0.30**	26	19	CIT-OnSite	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 09:52:51	Fcst	2008-11-15 09:52:52	**1**	*Mags*	Obs	3.53	Fcst	3.58	**0.05**	21	--	ETH-VS-RT	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 09:52:51	Fcst	2008-11-15 09:52:51	**0**	*Mags*	Obs	3.53	Fcst	3.62	**0.09**	23	--	ETH-VS-RT	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 09:52:51	Fcst	2008-11-15 09:52:51	**0**	*Mags*	Obs	3.53	Fcst	3.63	**0.10**	26	--	ETH-VS-RT	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 09:52:51	Fcst	2008-11-15 09:52:51	**0**	*Mags*	Obs	3.53	Fcst	3.64	**0.11**	30	--	ETH-VS-RT	
1	**Correct Trigger**	*Times*	Obs	2008-11-15 09:52:51	Fcst	2008-11-15 09:52:52	**1**	*Mags*	Obs	3.53	Fcst	3.63	**0.10**	35	--	ETH-VS-RT	

Figure 1: CISN EEW Algorithm Performance Summary showing results from three different CISN EEW algorithms.

4. LESSONS LEARNED IMPLEMENTING THE CISN EEW TESTING CENTER:

Development of the CISN EEW testing center identified several important insights into testing of EEW algorithms and systems. In this section, we discuss some of the lessons learned during as we implemented the current CISN EEW Testing Center.

Software Development to Support Testing:

We noted early that each CISN EEW algorithm development group uses their own testing tools and techniques. The challenge for the testing center is to establish comparable results. In order to do this, there needs to be agreement amount algorithm developers on metrics to be used. Also, each development group needs to implement support for the agreed metrics. The critical issue here is that introduction of testing impacts the EEW algorithm development. Software must be written and implemented by the EEW algorithm developers in order to support the EEW testing. In some cases, software changes needed to fully support the EEW testing goals were not available on the project. Because of this, some desired performance reports were not available.

An example of the software development required to support testing is the time reporting by EEW algorithms. The group identified alternative timestamps that the EEW algorithms use including (a) algorithm time, and (b) alert time. Details describing these different timestamps are described below. The point is that as a project, the three algorithms were never able to standardize on their time reporting. ElarmS reported algorithm time, OnSite reported alert time, and VS reported both. The reason these time stamps were not standardized seems to be the level of software development effort needed by the EEW algorithm developers to update their codes to report new timestamps. So, as testing efforts continue, there needs to be general understanding that testing will increase the software development required.

Tracking of EEW System Versions:

As we reviewed the EEW performance summaries, we recognized that the testing system needs to keep track of the version of the system (or software) under test. If the EEW performance summaries are to be interpreted correctly, users need to know when the system under test is changed. Changes that affect the performance may include hardware changes, configuration changes, algorithm changes, or significant software changes. Unless the EEW algorithms under test report when they are changed, performance results are difficult to interpret. If we cite EEW algorithm performance, we should specify what version of the system and software produced those results.

EEW algorithm changes were not rigorously tracked during this project. This should be changed in future testing efforts. During this project, several significant EEW algorithm changes were implemented but the performance measures do not indicate when those changes were made.

In our current testing results, we address this by limiting the length of time for which we examine performance. While not completely rigorous, we suggest that the algorithms under test were reasonably stable during the last year of the project (10/1/2009 – 9/30/2009). The system contains some performance measures prior to this time; however, the results from earlier time periods will probably not be representative of the algorithms performance near the end of the project.

Need to Track Active Channels:

As we evaluated the EEW performance metrics, we recognized that performance of the algorithms depends on which stations are being used by the EEW algorithms. For some metrics, such as "missed events", the metrics isn't meaningful unless the "active channels" are known. Ideally, to compare the "missed event" performance for two algorithms, both algorithms would use the same active channels. If they do not use the same list of channels, the performance may not be comparable.

In the current implementation of the testing center, we used a manual procedure in which EEW algorithms sent a list of active channels to the testing center. Our experience is that this is not a reliable and efficient approach. The active channel lists were often out of date. A new, improved, automatic reporting of active channels in use by each EEW algorithm would improve the testing center.

A related issue to this we encountered is the reporting of site specific information. ElarmS forecast site specific intensity at sites where CISN operated seismic stations. The list of sites for which information was reported was manually coordinated between UCB and SCEC. Again, automating this type of configuration information is important in the future. We found that the lists of reports were out of sync with actual CISN network so that we often received site-specific information for stations that were no longer operational, or that we did not receive site-specific reports for new stations.

Universal Metrics versus Catalog-specific Metrics:

During this development, we recognized that some EEW metrics are "event specific" and some are not. For example, a metrics of clear interest is "how long the system takes to produce a warning" (i.e. we call this the Warning Delay). It turns out that we cannot provide a universal answer to this. We can measure how an EEW system performs for a series of earthquakes and we can estimate how it would perform for scenario earthquake. But this type of metric must always be related to specific earthquakes.

We have learned that as we define metrics, we should consider whether these metrics are "Universal" or whether they must be measured only for a specific set of earthquakes.

Defining a Testing Region and a Service Region:

We determined that some EEW metrics of interest require agreement on a testing region. In order to define, for example, the rate of missed events, the scientific group must agree on a testing region. For the CISN, the state of California might serve. However, it is possible that a subset of this region would be selected. For the performance reports given in this summary, we used a Testing Region definition that included all of California and a small additional buffer region around the state which matches the California Testing region used in RELM and CSEP testing.

In a similar way, once an EEW system is distributing warnings, the region for which warnings are to be distributed must be defined. The CISN groups should consider the goals of the EEW development and then define both a CISN EEW Testing Region and a CISN EEW Service Region for future testing.

Event Metrics versus Ground Motion Metrics:

During our testing center developments, we recognized the importance of distinguishing between Event Metrics and Ground Motion Metrics. For example, for a trigger, and EEW algorithm may forecast the final magnitude (an event metric). An algorithm many also forecast site-specific information such as peak intensity.

Event metrics are easier to track. Site-specific metrics are problematic particularly due to the infinite number of sites for which information might be reported. If site-specific metrics are measured in the future, a list of sites of interest needs to be coordinated. Reporting of site-specific information at seismic station locations is probably a useful approach. In this case, we could use the seismic recordings to confirm the site-specific forecasts.

Defining False Alarms and Missed Events:

We anticipate that EEW system users will want to know how reliable the CISN EEW system is using metrics such as false alarms and missed events. We have learned that these metrics require significant scientific qualification in their definitions.

To begin, we need to decide whether we are going to use event-specific information, or site-specific information. An "event-specific" definition for a false alarm might state that the EEW system will not declare any triggers unless there is an event in the testing region. A "site-specific" definition for false alarms might state that the EEW system will not declare a ground motion alert for a specific site unless strong ground motion occurs at the site. Event specific definitions are simpler; however, site-specific information may be more valuable to system users. Similarly, missed events can be defined in terms of earthquakes, or site-specific ground motions.

There are further complications in these definitions. For example, if a false alarm metric is used, an algorithm must be used to match ANSS events with CISN EEW triggers. A trigger without an event is a false alarm. However, this matching process is non-trivial. For example, we may get a trigger in San Diego at the same time there is an earthquake in San Francisco. Even though the time is right, the San Diego Trigger may be a false alarm. What tolerance in time and location should we give as we try to classify a trigger as "real" or a "false alarm." As we continue EEW testing, we should clarify our definition of these measures.

Further CISN scientific agreement on appropriate definitions for these measures should be developed. We report on both false alarms and missed events in the current testing center. However, the definitions for these metrics are not clearly and widely known.

False alarm definitions seem like they will require time, location, magnitude tolerances. For false alarm rates to be comparable, these tolerances must be known. Also, false alarm metrics need to include an active channel list. False alarm rates will not be comparable unless the active channels in use are also known.

We also note that false alarm metrics trade-off with metrics about the accuracy of seismological parameters. If an algorithm triggers on something seismic, over-estimates the magnitude, and produces an alert, we must decide how to classify this. Is this a false alarm? Or is this a valid trigger, and an inaccurate magnitude estimate? In the future, we recommend that false alarm definition moves towards a more seismological meaningful definition. We suggest that if seismic ground motions cause a trigger, it is a correct trigger, and is not considered a false alarm. Implementing this definition may be challenges as we'd need to review waveforms, but such a metric would probably be more meaningful than current approach.

Need to Access Waveforms:

The current testing center uses ANSS event catalog as "reference" data and compares CISN EEW triggers against this data. In future testing, the CISN EEW algorithms will forecast site-specific information such as peak intensity. To evaluate this information, the testing center will need access to site-specific parametric data. This information is currently not available through the ANSS data center. The Testing Center will need to interface to either SCEC Data Center or Northern California Data Center. The complexity of the testing center processing increases significantly if retrieval of waveforms and processing of waveforms into parameters is required.

5. PRESERVATION OF COLLECTED DATA:

The automated performance summaries provide some limited analysis of the CISN EEW testing results. Further analysis of the CISN EEW testing data collected during the project may provide some additional value. To support analysis efforts, we have produced data archives at SCEC containing both the original EEW algorithm performance reports and the contents of the testing center database for the final year of the project (10/1/2009 through 9/30/2009). This full data set can be provided to any group interested in further analysis of the system.

6. PRELIMINARY OBSERVATIONS ON CISN EEW PERFORMANCE:

The data in the CISN Testing Center can be analyzed to evaluate the performance of the CISN EEW algorithms. We find it is often helpful to distinguish between seismological performance measures and speed of operation measures. We summarize seismological and speed of operation results from the CISN EEW testing center in the next few tables. The information in these tables is from the CISN EEW testing center and is available through the CISN EEW testing center although it may not be in the form we present.

A metric we propose for future testing is EEW system "uptime." Basically, we'd like to know whether the EEW system is operational at all times. The following reports try to get at this by comparing triggers to ANSS events on a daily basis. In these plots, we show days on which ANSS triggers occurred during the final testing year (10/1/2008 – 9/30/2009) and we should which days each algorithm triggered. Missing triggers may be caused by a number of reasons including network coverage issues, EEW algorithm down, the testing center down, or other possible causes. However, these plots may give some idea of consistency of reporting by the various algorithms.

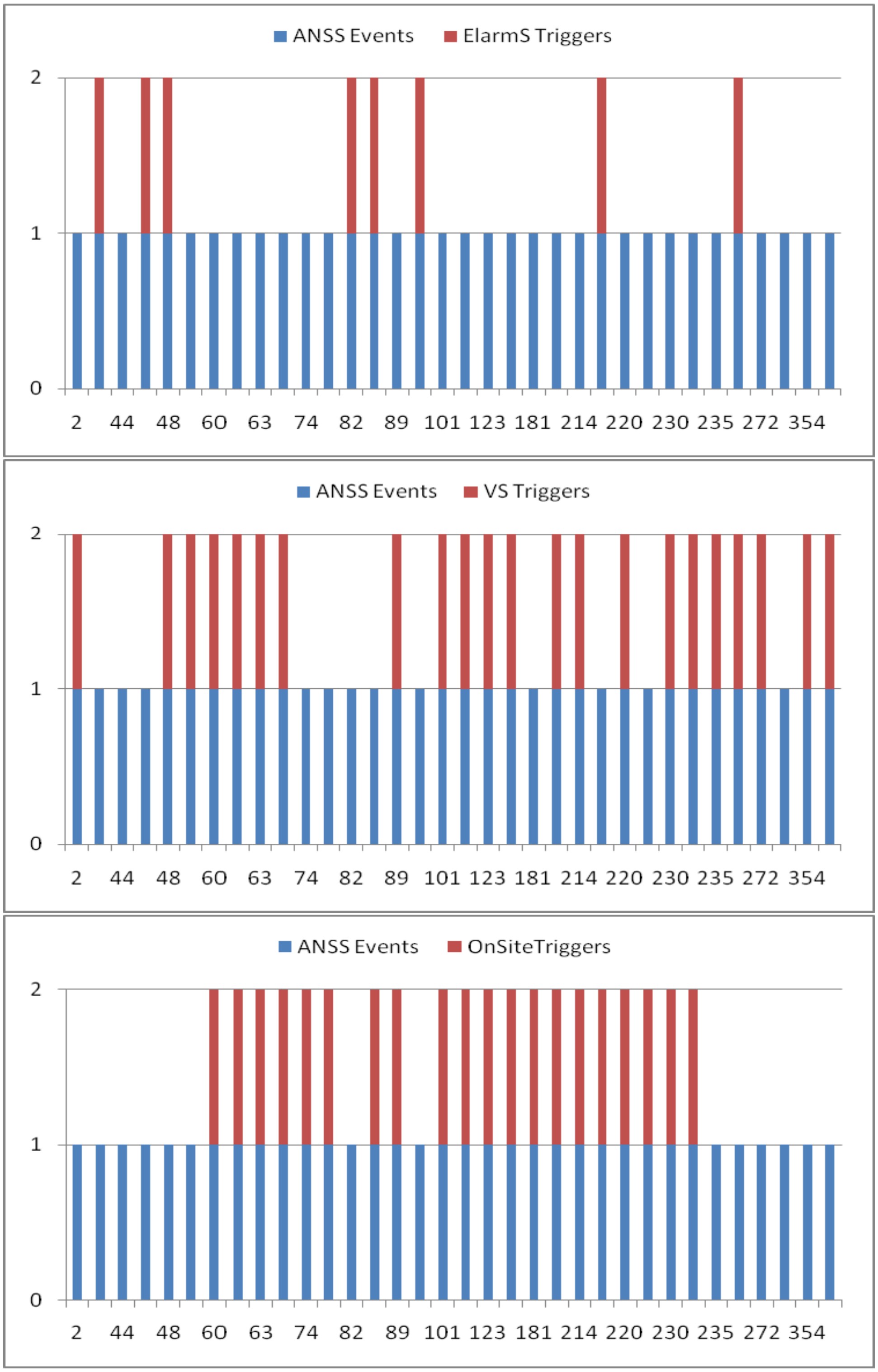


Figure 1: During the CISN EEW project year 3, these show the days of the year for which there is at least one M4.0 event in the ANSS catalog in the California Testing Region. The red marks indicate the days on which EEW Algorithms produced triggers forecasting M4.0 events. Missing triggers may be due to a number of reasons including testing center problems. However, the plots may give some indication of the uptime for the algorithms.

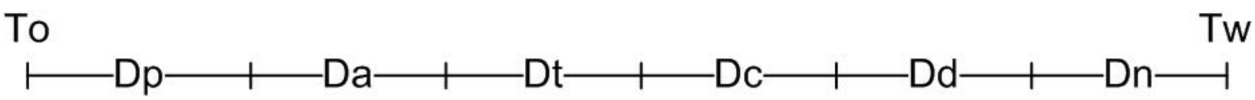
7. CISN EEW TIME MEASUREMENT MODEL

During the CISN EEW testing center development, we recognized that CISN EEW performance metrics need to include both speed of operation as well as accuracy of seismological parameters. Both categories of performance metrics are of interest to both scientists and potential users.

With regards to speed of operation, the group spent significant effort defining specific time measurements. The testing document discussed two main types of timestamps which we called algorithm time, and alert time and these are defined in the testing document. While these measures represented reasonable starting place, further work has led to an improved definition of time measurements. Our improved time measurement model replaces these other terms. These other terms can now be identified as variations in our current time measurement model.

The current time measurement model is based on tracking where delays occur during EEW processing as the system works to produce an alert. Sources of delay may include wave propagation time, transmission delay, and others.

Fast operation helps reduce the blind zone for an EEW system. To help us understand the speed of operation of the current CISN EEW algorithm, we first define the goal of an EEW as delivering ground motion warning to users at a specific site. Then we note that speed of operation changes event-by-event based on location of earthquake, station density, telemetry and processing delays. We identify where delays may occur delivering a waning to a user in the following timeline and define Speed of Operation in the following terms:



The terms in this formula are (expressed in its single channel form):

To – Origin time of earthquake
Dp – Duration of P-wave propagation time to sensors
Da – Duration of data after P-wave arrival needed by algorithm
Dt – Duration of transmission (packaging and telemetry) delay
Dc – Duration of computation time on EEW processing system
Dd – Duration to deliver data to users warning device
Dn – Duration of time to produce user notification
Tw – Time point warning notification is available to user

Then the warning time (a point in time after the event origin) is:

$$Tw = To + Dp + Da + Dt + Dc + Dd + Dn \qquad \text{(Equation 1)}$$

The duration to produce a warning (which we want to minimize) can be expressed as:

$$Dw \text{ (i.e. Duration to Produce Warning)} = Tw - To \qquad \text{(Equation 2)}$$

We want to use this Dw value to evaluate the speed of operation of the current CISN EEW algorithms. We must make a few assumptions. First, CISN EEW system does not currently deliver the warnings to users so the terms Dd and Dn are not known. We will set these to zero for now.

We can now identify the algorithm and alert times using this definition as shown below as EEW delay measurements without some of the terms in the full equation.

Origin Time	Ptt to sensor	Algorithm	Transmission	Computation	Delivery	Notification
To	Dp	Da	Dt	Dc	Dd	Dn
To	Alert Duration				0	0
To	Algorithm Duration		0	0	0	0

Figure 2: This shows how the time measures in the CISN EEW testing document can be defined using a more complete Warning Delay definition.

8. SUMMARY OF CISN EEW SEISMOLOGICAL PERFORMANCE:

In order to evaluate the seismological performance of the CISN EEW algorithms, we try to address three basic questions: (1) Are the algorithms triggering for all M4.0 and larger events in California? (2) Are the predicted magnitudes within 1.0 init of the final ANSS magnitude? (3) Are the algorithms triggering on non-events (false triggers)? The following tables try to address these basic questions.

The following tables contain a few assumptions and qualification criteria. We only examine results from a 6 month period of time for a number of reasons (11/01/08 to 05/20/09). All three algorithms were operating and reporting to the testing center during that time. Prior to that time, the algorithms were changing rapidly and the performance was changing significantly. We only consider magnitude M4.0 and larger events based on the belief that system performance changes for larger magnitude events. Also, only events within the California testing region are considered. These performance summaries could be repeated with a more complete data set if needed. We present the following as a representative sample of results.

The following performance reports have several qualifications. First, the CISN EEW algorithms run on only part of the CISN stations. Typically UCB ElarmS-NI runs on Northern California stations, and TauC-PD and VS-RT run on Southern California stations. Efforts are underway to run the algorithms state-wide. Also, the CISN EEW algorithm developer may have versions of their codes running which do not report to the CISN EEW testing center. If the CISN EEW algorithm performance reports differ from performance reports from the Algorithm groups, it may be due to the fact the algorithm groups are reporting on performance of preliminary code implementations that are not yet reporting to the CISN EEW testing center.

Table 1: Summary of CISN EEW Performance on M4.0 Events (11/01/08 to 05/20/09)

Data Sources	**ANSS Catalog Event**	**CISN Totals**	**ElarmS-NI**	**TauC-PD**	**VS-RT**
Correct Event Info	26	23	4	14	16
Errors/Misses					
No Reports			22	11	10
Mags Too High (> 1.0+)			2	1	2
False Triggers			0	1000+	1

Table 1 show that the ANSS catalog contains 26 M4.0+ in California over the last 6 months. Of those, only three events did not produce valid triggers with accurate predicted magnitude information from the CISN EEW algorithms. Table 2 below shows the list of 26 ANSS events during this time periods and shows which algorithms triggered correctly for each event. In Table 2 below nr = no report, and mth= magnitude too high. The three events which did not produce a trigger are shown in bold italics.

Table 2: CISN EEW Seismological Performance Summary for M4.0+ Events (11/01/08 to 05/20/09)

Event IDs	Event Locations	Mag	ElarmS-NI	TauC-P	VS
10411545	33.93 -118.34	4.04	nr	1	1
10410337	33.94 -118.34	4.70	nr	1	1
10406593	34.44 -119.18	4.17	nr	mth	1
51220943	40.75 -124.16	4.17	1	nr	nr
10403777	34.07 -118.88	4.42	nr	1	1
14443704	32.07 -115.76	4.30	nr	nr	1
14443616	32.33 -115.25	4.22	nr	1	nr
40234037	***37.28 -121.61***	***4.30***	***nr***	***nr***	***nr***
14433456	33.32 -115.73	4.77	nr	1	1
14418600	35.41 -117.79	4.39	nr	1	1
10374021	32.69 -118.23	4.19	nr	1	1
10370141	34.11 -117.30	4.45	nr	nr	1
51214595	***38.78 -122.77***	***4.30***	***nr***	***nr***	***nr***
10368325	32.57 -115.54	4.52	nr	1	1
200812262043	39.96 -120.87	4.50	1	nr	nr
51213534	36.67 -121.30	4.00	1	nr	nr
10366249	32.55 -115.54	4.03	nr	1	nr
10366101	35.97 -117.32	4.01	nr	1	nr
14408052	34.81 -116.42	5.06	nr	1	1
14407020	35.97 -117.32	4.03	nr	1	1
14406304	35.97 -117.32	4.04	nr	1	1
14406196	35.97 -117.33	4.03	nr	1	1
14404512	32.33 -115.33	4.98	nr	nr	1
14403732	33.50 -116.86	4.11	nr	nr	1
51211307	40.31 -124.60	4.60	1	nr	nr
51211113	***40.44 -125.27***	***4.00***	***nr***	***nr***	***nr***
Totals Correct Triggers			**4**	**14**	**16**

The seismological reports in Table 1 above also identify which CISN EEW algorithms are producing false triggers. The UCB ElarmS, because it is reporting retrospective data, should never produce a false trigger. This does not represent its real-time performance. The VS only rarely reported false triggers. The TauC-PD, as a single station algorithm, produces many false triggers. This might be partially addressed by adjusting the algorithm to only trigger on larger events (e.g. M5.0+)

A wide variety of other seismological performance measures are reported by individual research groups. In the future, we propose to select useful seismological performance measures used by individual research groups and implement those within the CISN testing center.

9. SUMMARY OF CISN EEW SPEED OF OPERATION:

Along with seismological performance, the CISN Testing Center also reports metrics on system speed of operation. As noted above, EEW speed of operation measures are typically event specific. The system speed of operation varies on an event-by-event basis.

We focus initially on measurements of the parameter we call Warning Delay (Dw) as defined above. This is intended to be a real-time measurement of how long after origin time that a user receives notification that an event is in progress. Shorter values are better.

In the following table, we list the Dw for the first correct trigger from the algorithm. A correct report contains a predicted magnitude within 1.0 unit of the final ANSS magnitude. In a real-time system, there is no way of knowing which of the incoming reports contains a correct magnitude.

The TauC-PD reports single station triggers. In this table, we report Dw for the first correct TauC-PD trigger. Single station triggers may not be practical due to increased possibility of false triggers.

ElarmS-NI reports only Dp + Da. In this table, Dw values for ElarmS-NI assume that Dt and Dc are zero. These terms vary significantly for the other algorithms, so Dw for a real-time ElarmS implementation is likely to add 5-10 seconds to the reported values.

Given these considerations, the table shows that the CISN EEW algorithms, running on the existing network, with existing telemetry and central processing systems, are capable of predicting accurate magnitudes in less than 20 seconds in many cases. A 20 second Dw corresponds to a blind zone (in California with Vs of 3.6 km/s) of about 72 km.

Table 3: CISN EEW Speed of Operation Summary for M4.0+ Events (11/01/08 to 05/20/09)

Event IDs	Event Locations	Mag	Dw (ElarmS-NI) Seconds	Dw (TauC-P) Seconds	Dw (VS) Seconds
10411545	33.93 -118.34	4.04		14	15
10410337	33.94 -118.34	4.70		15	15
10406593	34.44 -119.18	4.17			19
51220943	40.75 -124.16	4.17	10		
10403777	34.07 -118.88	4.42		16	19
14443704	32.07 -115.76	4.30			32
14443616	32.33 -115.25	4.22		20	
40234037	***37.28 -121.61***	***4.30***			
14433456	33.32 -115.73	4.77		15	18
14418600	35.41 -117.79	4.39		19	20
10374021	32.69 -118.23	4.19		27	28
10370141	34.11 -117.30	4.45			18
51214595	***38.78 -122.77***	***4.30***			
10368325	32.57 -115.54	4.52		19	29
200812262043	39.96 -120.87	4.50	15		
51213534	36.67 -121.30	4.00	5		
10366249	32.55 -115.54	4.03		19	
10366101	35.97 -117.32	4.01		16	
14408052	34.81 -116.42	5.06		15	24
14407020	35.97 -117.32	4.03		16	25
14406304	35.97 -117.32	4.04		28	38
14406196	35.97 -117.33	4.03		29	26
14404512	32.33 -115.33	4.98			29
14403732	33.50 -116.86	4.11			20
51211307	40.31 -124.60	4.60	15		
51211113	***40.44 -125.27***	***4.00***			

We have plotted these results graphically in the figures below. These figures seem to indicate that for the current CISN EEW system, longer Dw values occur for events near the edges of the network as might be expected. We suggest that it would be instructive to map the events, the delays, and the location of the seismic stations used by the EEW system.

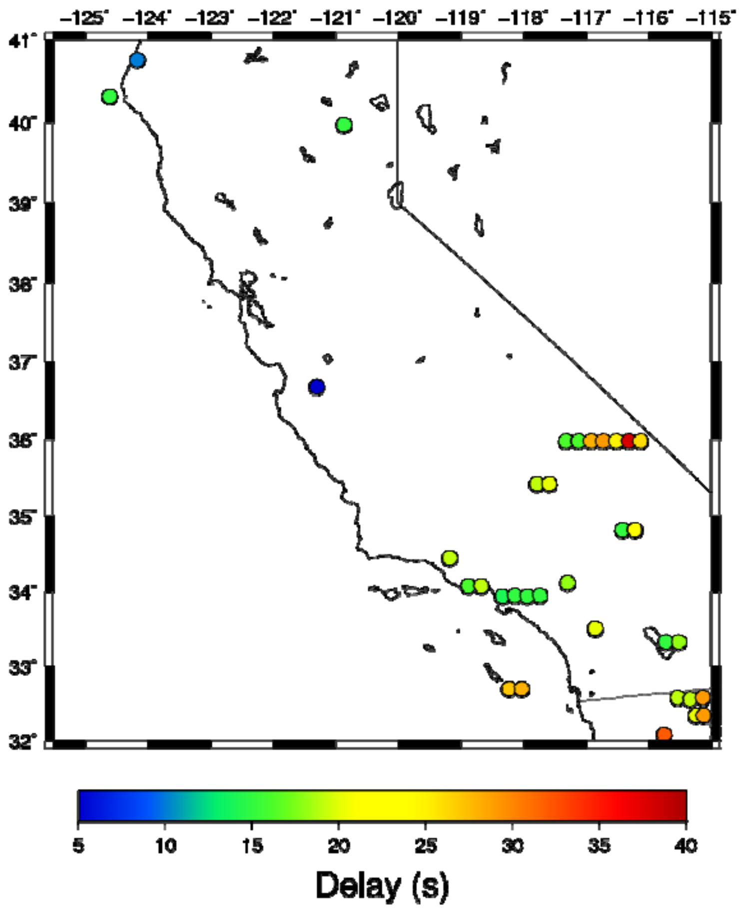


Figure 3: This shows the location of M4.0+ ANSS events for which the CISN EEW algorithms triggered. This shows the performance of all three CISN EEW algorithms. Colors indicate the Warning Delay (in seconds) for each event.

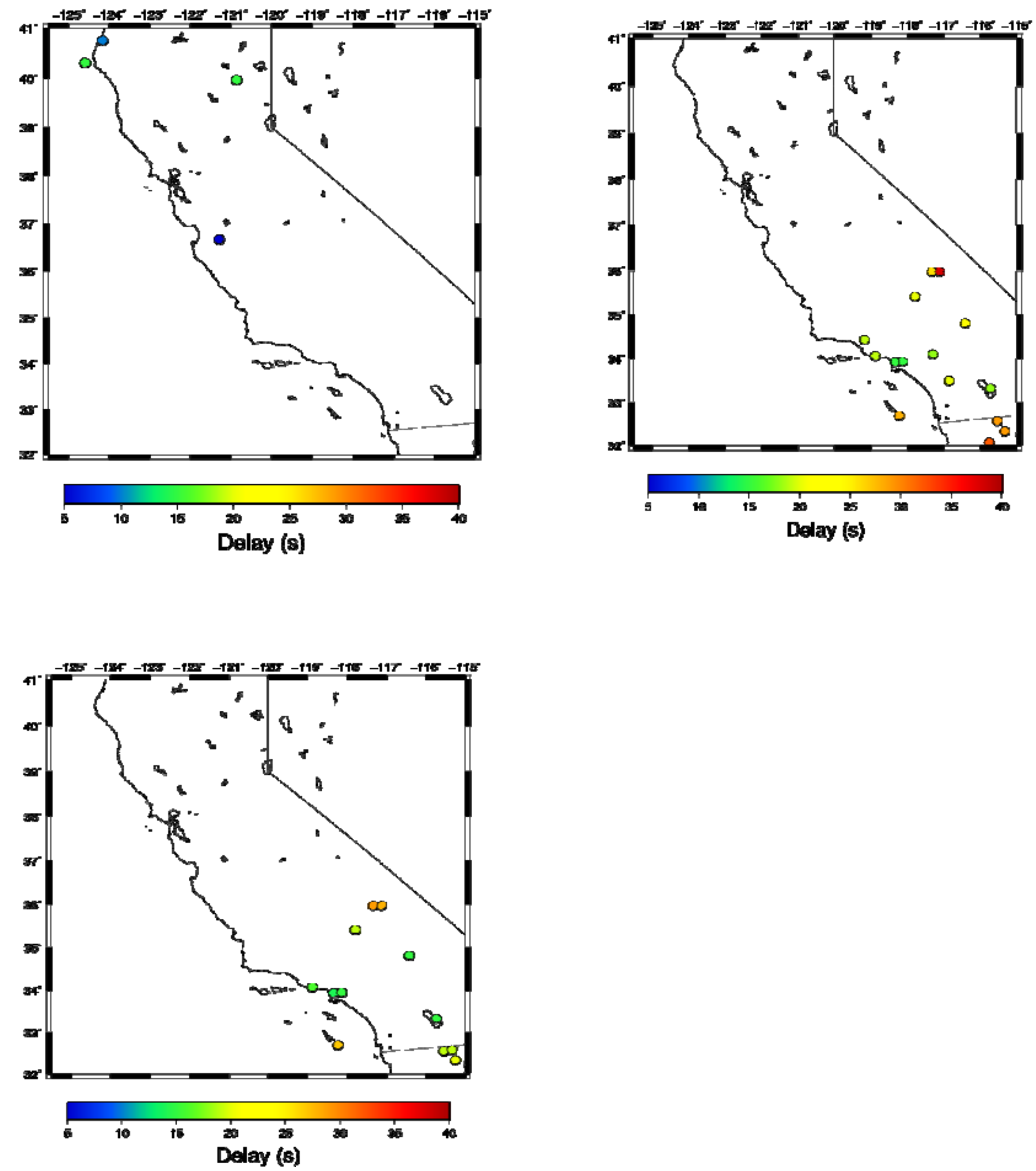


Figure 4: Warning Delay (in seconds) by CISN EEW Algorithm for 6 months of ANSS M4.0+ events in California. UCB- ElarmS (top left) ETH-Virtual Seismologist (top right) CIT-On-Site (bottom left)