Final Technical Report 2010-2014

Mid-America Integrated Seismic Network -- CERI

USGS Cooperative Agreement G10AC00082

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1. Executive Summary

The CERI seismic network consists of 138 permanent seismic stations (both NM and ET network codes) and 199 stations are imported from other networks for a total of 1179 data channels processed in real-time. Automatic solutions produced by the real-time systems of our ANSS Quake Monitoring System (AQMS) are manually reviewed within about 2-5 minutes prior to posting to the Product Distribution Layer (PDL). Products include online catalogs, archived waveforms, rapid notifications and maps of recent earthquakes. About 300 earthquakes per year are processed in the NM region and 150 in the SE region though induced seismicity swarms may swell those rates to more than 1000/year. Earthquake risk is the potential impact on society of earthquake hazard, and FEMA estimates the Annualized Earthquake Loss for the Central U.S. is $0.38B and for the Southeast U.S. is $0.16B (FEMA 366, 2008).

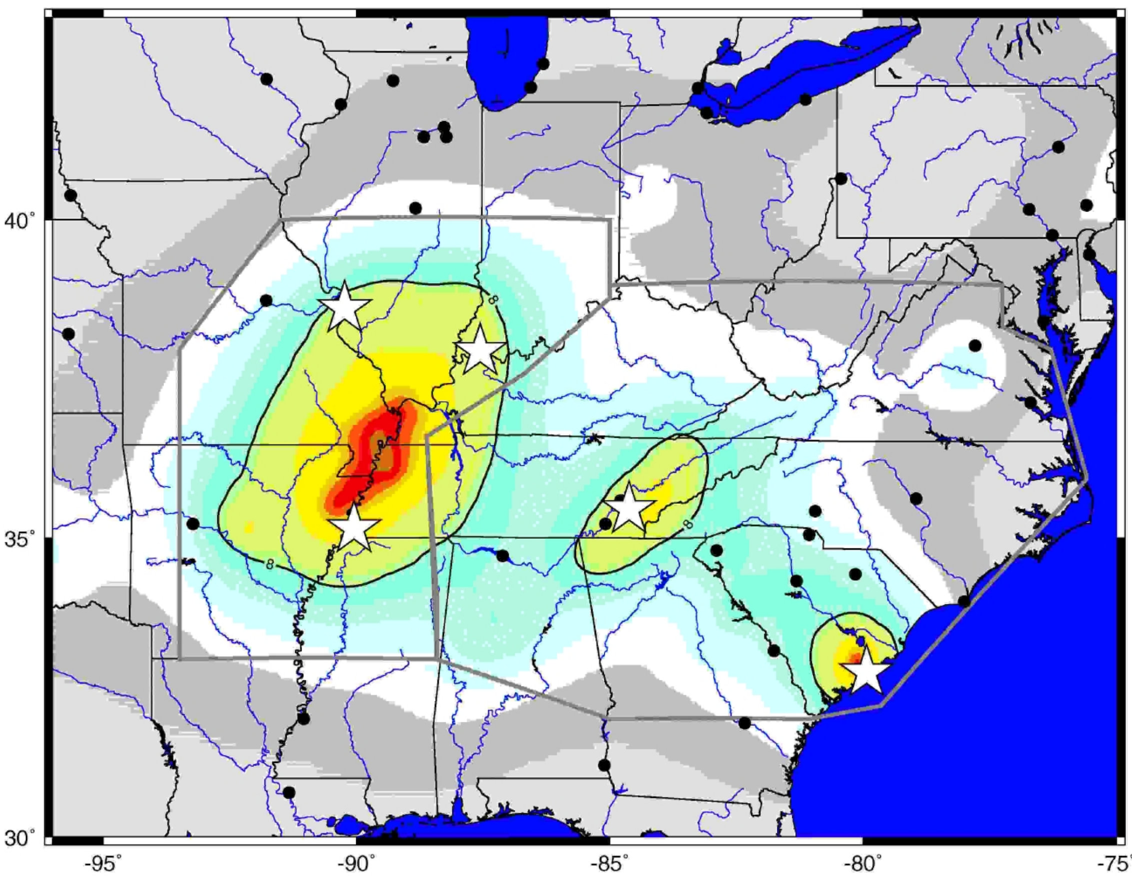

Figure 1. 2014 National Hazard Map. PGA, 10% probability of exceedance in 50 years for the NM and SE authoritative regions (gray polygons). Stars are urban monitoring targets from USGS Circular 1188 and black dots are Nuclear Power plants. The 8%g exceedance level is the line contour.

CERI is the Tier I network for the central and southeast U.S. and works with our ANSS partners, St Louis University, University of South Carolina, and USGS to meet or progress toward all four goals in section 3.3 of USGS Circular 1188.

CERI maintains an advanced infrastructure for seismic monitoring with the NM and SE regions (gray polygons in Figure 1). Data are integrated in real-time from the various networks at the data processing center in Memphis. AQMS systems are used to continuously monitor earthquakes and other seismic disturbances with a special focus on area of elevated hazard (yellow in Figure 1). AQMS systems automatically broadcast alarms for events of interest to a seismologist for rapid review and then, using PDL, disbursement to the public which enables rapid assessment of the impacts of the event. Most digital stations include collocated strong-motion accelerometers to assure on-scale recording of damaging earthquakes. Diverse communications infrastructure and backups provide reliability and redundancy. Strong-motion networks in urban areas near major fault zones (stars in Figure 1 as listed in Circular 1188) provide high-fidelity measurements of strong ground shaking.

The high hazard areas of focus include the New Madrid and Wabash Seismic Zones, the East Tennessee Seismic Zone, and the Charleston Seismic Zone. Urban areas include Memphis, St Louis, Evansville, Knoxville/Chattanooga, and Charleston. There are also 16 nuclear power plants within or near the NM and SE polygons as well as the Oak Ridge National Lab in east Tennessee.

2. Year 1 (2010) Update

ARRA upgrades to 12 broadbands were completed. They are now 6-c Reftek RT130's with trillium 120PA seismometers and RT147 accelerometers.

Station FPAL was upgraded to Reftek RT130/Trillium 120PA/Episensor.

6-station AG network was installed and operating in Arkansas. The Arkansas Geological Survey supports CERI in the O&M of this network which takes advantage of the ANSS data infrastructure.

Initial installation and configuration of AQMS was completed.

Performed maintenance functions at NSMP stations on 3 occasions as requested by NSMP.

Processed significant swarm activity for north central Arkansas in October, 2010.

Completed migration to EIDS.

Completed migration to ew v7.4 and turned off all remaining v6 processes.

Moved active page generating processes off webserver (folkworm) and onto standalone system (e.g. heli_ew, eids, qdm, recenteqs, etc). Migrated static web pages from folkworm to main ceri webserver (www.ceri.memphis.edu/seismic). Folkworm remains a valid url but now acts only as a portal and hosts very few pages.

Completed initial version of Continuity of Operations plan.

Modified automated catalog submissions to include error information and fill all fields available in cube format. Submissions are now done daily rather than weekly.

3. Year 2 (2011) Update

ARRA upgrades to three ET stations and three additional non-ARRA upgrades to ET stations were completed. Upgrades included conversion from analog to digital telemetry and addition of a strongmotion sensor. We now have 6 stations in the ET network that are Reftek RT130 digitizers with 3-c S-13 weak motion sensors and either Episensor or RT147 strongmotion sensors for a total of six channels each.

Met with ISTI in June 2011 for hands on tour of AQMS.

Have initial dataless for all CERI stations. There were several problems highlighted by IRIS and NEIC that we were working on and expected to have addressed by the end of the calendar year (2011).

Configured central and southeastern US velocity models for Hypoinverse and completed initial determination of Hypoinverse defaults. Comparisons with 2011 network catalog were favorable but still needed some tuning.

Continued to process significant swarm activity for north central Arkansas.

Responded to Mw 5.8 central VA earthquake.

Added dsl to all NM nodes for secondary data path (except for New Madrid which is fixed wireless not dsl). Access to each node is now available via both private microwave and dsl. Two separate waveservers at each node allow independent data access via microwave or dsl.

Implemented Google map based recent earthquakes (many thanks to UW Seattle for initial development and installation advice),

http://www.ceri.memphis.edu/seismic/recenteqs/REQ2.html (was since replaced with REQ3).

Began filtering asynchronous data with wftwimefilter and turned off the sqlite portion of waveserver.

Turned off posting of automated locations into EIDS. The significant numbers of large magnitude earthquakes outside the dense portion of the NM network were causing severe mislocations. We began working to be able to run autolocs on the entire authoritative polygon(s) in AQMS.

Updated authoritative polygons for the NM and SE network codes. These were sent to Dave O. on October 13.

4. Year 3 (2012) Update

Recreated dataless using PDCC to address issues discovered by NEIC and IRIS. Developed new resp files from transfer functions for previously undescribed analog hardware. Submitted dataless to IRIS and NEIC and uploaded to AQMS.

Developed new Hypoinverse configurations and tested using dataset that includes all events located by CERI in the central and southeast U.S. with magnitude greater than 2.5 and origin time between Jan 1, 2012 and June 1 2013. Uploaded new configurations to AQMS postproc and both real-time servers.

Developed new picking and association parameters that includes all of the central and southeast U.S. and tested on the same dataset as Hypoinverse tests. Previously automatics were only done in the active part of the New Madrid Seismic Zone. Uploaded new configurations to AQMS postproc and both real-time servers. Adjusted alarms to include duty review personnel.

Assisted NEIC in response to activity in the vicinity of the Bayou Corne Salt Dome in Louisiana.

Acquired hardware funded by the West Tennessee Seismic Safety Commission for a 6-c broadband station in Middle Tennessee. Completed siting and began permitting for location in Cedars of Lebanon State Forest southwest of Nashville. Waiting on permit.

Acquired hardware to upgrade two more 3-c analog stations (tentatively PWLA and BHT) to digital.

Acquired DAS's to upgrade two additional TBD analog stations in the ET network to digital (tentatively RCGA and LRVA).

Installed seven new Granites on the I40 bridge over the Mississippi river to replace obsolete data acquisition systems. Data are now real-time to a "remote" node at Autozone Headquarters in downtown Memphis. Telemetry improvements are needed.

Turned over O&M of 4 South Carolina urban strong motion stations to the University of South Carolina at Columbia (ADSC, C1SC, C2SC, and TRSC). Network codes for these stations was NM and is now CO. For convenience, data still flow through a server in Memphis and are forwarded to SC.

5. Year 4 (2013) Update

Upgraded 3 stations from analog to digital (PWLA, BHT now PMTN, and CMGA)

Installed Trillium 120/Episensor/Reftek RT130 station in central Tennessee. Station code CLTN.

Acquired DSL at all three New Madrid remote nodes as alternate communications path and a means to export the remaining channels to CERI in real-time. Acquired and configured 2 large Ubuntu servers with expanded and redundant waveservers and with IRIS ew2ringserver/ringserver. All channels are now sent to IRIS in real-time continuous via ringserver (seedlink).

Switched incoming EIDS to pull from CISN Quakewatch servers and outgoing messages to PDL EIDSInputWedge.

Completed alarms for AQMS RT systems; now in production. This included new alarms that do not rely on stored procedures (which were unacceptably slow with the large places table needed for this region) to find the closest town and station.

Added capability to process gain-ranged data in AQMS post-processing.

Completed location and metadata configuration in AQMS post-processing.

Added capability to handle both NM and SE network codes in AQMS post-processing.

Began work on AQMS postproc alarms.

Implemented new Google-based recent earthquakes maps (REQ3).

Continued efforts to replace hardware installed in the 1990's with new components.

Continued data handling for Bayou Corne.

Provided technical support to NSF sponsored PASSCAL experiment, Northern Embayment Lithosphere Experiment (NELE).

6. Year 5 (2014) Update

AQMS is our production system, including postprocessing, as of January 1, 2015. We also migrated from CUBE to Quakeml formats when sending hypocenter information to NEIC via PDL.

As part of the migration to AQMS, our online catalog is now updated automatically directly from the AQMS archdb.

Also as part of the migration to AQMS, created various tools including ev2db and sac2db to update Hypoellipse event data and associated sac waveforms to the archdb. Other developed tools include manually creating new triggers and scripts to continue the offline event directory archive. This archive acts, essentially as an alternative backup to the AQMS database.

Integrated the N4 network into routine processing.

Finished scripts to clean out deleted events, including waveforms, from the archdb.

Worked with a STEM undergraduate to develop code to create carltrig subnets based on circles and polygons. This was used to create new groups for the AQMS rt systems.

We lost the data collection node at Mt Gibbs in North Carolina after repeated severe ice storms during the winter of 2014/2015. We identified and permitted an alternative site at High Peak, NC and reconfigured the half dozen stations to transmit to this new node. We expect it to be online in March 2015.

Continued with conversion of analog stations to digital where appropriate and as resources allow. Continued with hardening of aging analog hardware at stations not appropriate for conversion to digital.

7. Network Description and Routine Operations

A. Routine Field and Data Center Operations

The CERI seismic network consists of 138 permanent seismic stations (23 broadband, 20 freefield strong-motion, and 95 short-period 3-component). Telemetry concerns require operation of twelve data concentrators (or nodes) linked to a central processing facility at CERI (Figures 2 and 3). Each node contains about 11 days of continuous revolving buffer and local creation and storage of triggered datasets. All nodes are linked to CERI in continuous near-real-time. The remote nodes are able to operate autonomously in the event of communication failure and thus, in addition to helping solve the last mile communication problem, provide a backup for the regional processing in Memphis.

CERI maintains a microwave communications backbone (red line figure 2) to provide private TCP/IP communications between the central processing at CERI and the remote New Madrid Seismic Zone (NMSZ) nodes. To mitigate against fades during inclement weather (and avoid single points of failure), DSL or other ISP internet is available at each node.

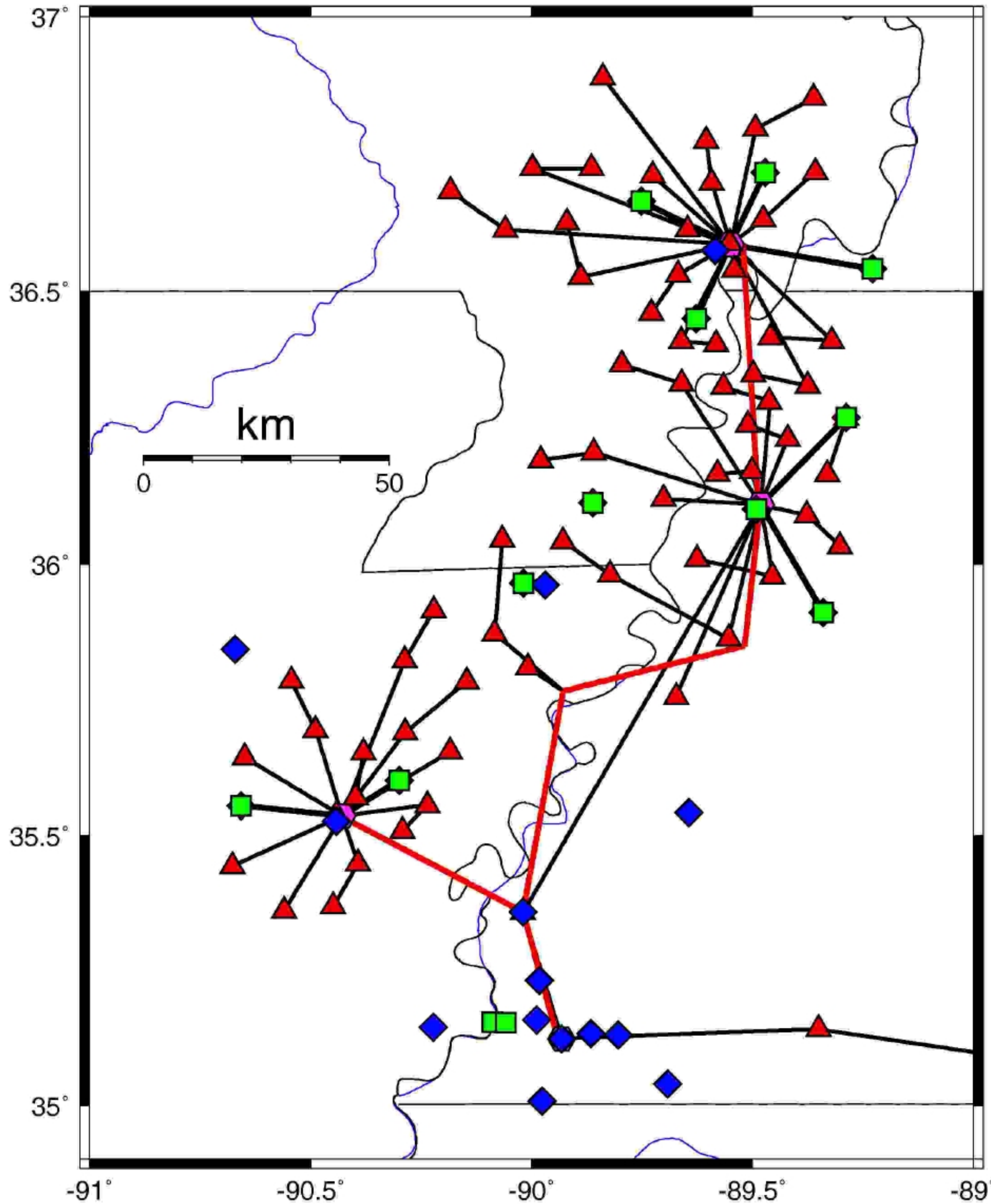

Figure 2. NMSZ stations operated by CERI with telemetry topology. Red triangles are short-period stations, green squares are broadband, and blue diamonds are strong-motion. Black lines are digital or analog radio. Red lines are the 2.4 GHz spread spectrum digital backbone that provides TCP/IP connectivity with the nodes.

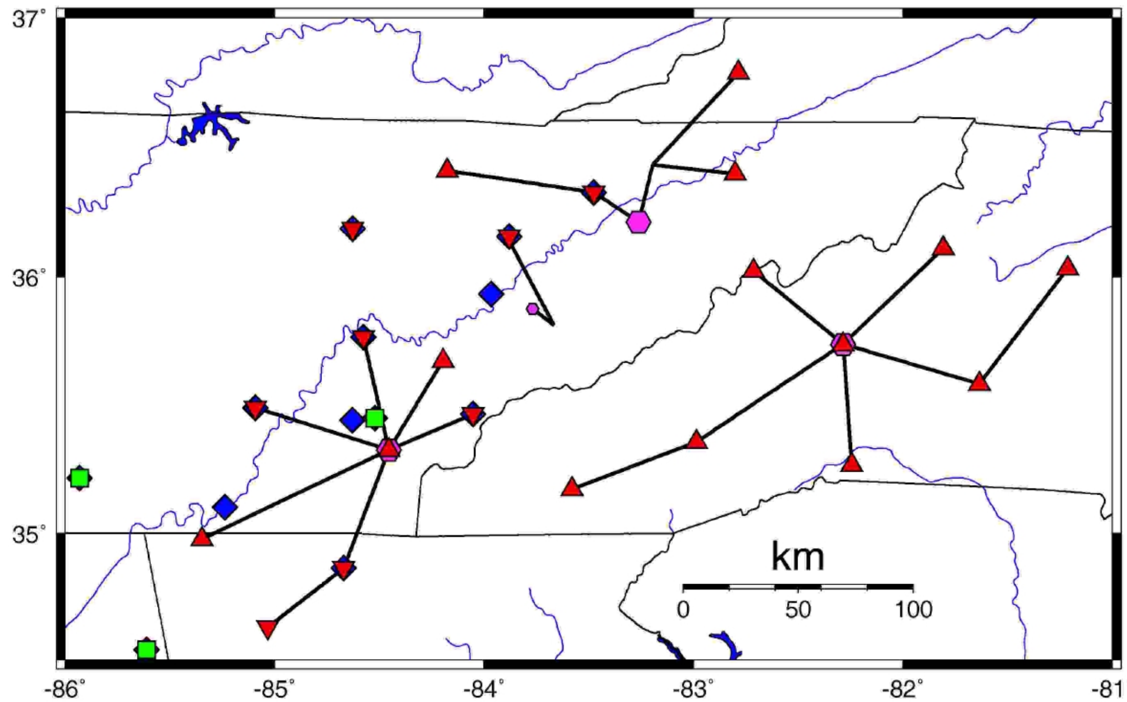

Figure 3. ETSZ stations operated by CERI with telemetry topology. Red triangles are short-period stations, green squares are broadband, and blue diamonds are strong-motion. Black lines are digital or analog radio. Node connectivity is accomplished via public internet or DSL.

Subnetwork triggers are analyzed daily at CERI for both the NMSZ and East Tennessee Seismic Zone (ETSZ). Digital *helicorder* records are monitored for state of health purposes and missed events (paper *helicorders* were deprecated in 2008). From one to several hours of data are archived locally for teleseismic events of interest. Routine event locations are submitted to Comcat via PDL. Reviewed parameters are similarly shared and are emailed to the ENS listserve. By far the most popular tool has been the *recenteqs* and Google based REQ webpages accounting for more than half of the 15 million hits over the past twelve months. Reviewed and automated earthquake summaries are available for events within the past six months. Various catalog searches are also supported. Pseudo-helicorder images provide a quick review of station operation and events for the previous week. All channels are made available for archiving continuously at the IRIS DMC using the IRIS *ringserver* software.

Dual AQMS real-time systems are in production and produce alarms for events above about magnitude 1.8 anywhere in both NM and SE authoritative polygons (gray polygons in Figure 1) using all ANSS stations in the region, including the recently converted EarthScope stations also known as the N4 network (brown squares in Figure 7). Alarms are emailed to analysis staff for all events and sent to their cell phones for events greater than 2. The AQMS Duty Review Page provides the ability to “accept” an event, which triggers alarms that submit the event to Comcat via PDL.

A single AQMS post-processing system is also in production as of January 1, 2015. We began sending quakeml format data to NEIC Comcat in mid-January and back-filled to January 1, 2015. We continue to make improvements to this system as issues are identified.

Seismicity rates in the central and southeast U.S. do not support use of a rotating duty seismologist. Instead the full-time analyst and PI are on call 24/7. A CERI seismologist (usually Steve Horton) is able to fill in if both the analyst and PI are unavailable.

In the following station list, types are broadband (bb), strong-motion (sm), short-period analog (sp), and short-period digital (sd). All stations are three or more components. The Arkansas Geological Survey (AGS) stations are operated and maintained by CERI under a separate contract with AGS.

Station	Net	Lat	Lon	Operator	type	hardware
CCAR	AG	33.917	-91.772	AGS	bb, sm	Reftek/Trillium 120P/RT147
FCAR	AG	35.890	-92.124	AGS	bb, sm	Reftek/Trillium 120P/RT147
HHAR	AG	36.282	-93.940	AGS	bb, sm	Reftek/Trillium 120P/RT147
LCAR	AG	36.070	-91.154	AGS	bb, sm	Reftek/Trillium 120P/RT147
WHAR	AG	35.290	-92.289	AGS	bb, sm	Reftek/Trillium 120P/RT147
WLAR	AG	33.688	-93.112	AGS	bb, sm	Reftek/Trillium 120P/RT147
CPCT	ET	35.450	-84.522	CERI	bb, sm	Reftek/Trillium 120P/RT147
FPAL	ET	34.540	-85.611	CERI	bb, sm	Reftek/Trillium 120P/Episensor
SWET	ET	35.216	-85.932	CERI	bb, sm	Reftek/Trillium 120P/RT147
ASTN	ET	36.327	-83.476	CERI	sd,sm	Reftek/3-c S-13/Episensor
BCRT	ET	35.766	-84.576	CERI	sd,sm	Reftek/3-c S-13/RT147
CCRT	ET	35.466	-84.053	CERI	sd,sm	Reftek/3-c S-13/Episensor
CMGA	ET	34.629	-85.034	CERI	sp	3-c S-13
CPRT	ET	36.157	-83.881	CERI	sd,sm	Reftek/3-c S-13/Episensor
DYTN	ET	35.491	-85.092	CERI	sd,sm	Reftek/3-c S-13/RT147

GMG	ET	34.863	-84.670	CERI	sd,sm	Reftek/3-c S-13/Episensor
PMTN	ET	36.187	-84.628	CERI	sd,sm	Reftek/3-c S-13/Episensor
CCNC	ET	36.023	-82.714	CERI	sp	L4-3D
ETT	ET	35.326	-84.455	CERI	sp	3-c S-13
GFM	ET	36.111	-81.807	CERI	sp	L4-3D
GRBT	ET	35.674	-84.197	CERI	sp	3-c S-13
LRVA	ET	36.788	-82.786	CERI	sp	3-c S-13
MGNC	ET	35.737	-82.286	CERI	sp	L4-3D
RBNC	ET	35.357	-82.986	CERI	sp	L4-3D
RCGA	ET	34.976	-85.348	CERI	sp	3-c S-13
SMNC	ET	35.584	-81.636	CERI	sp	L4-3D
TRYN	ET	35.267	-82.246	CERI	sp	L4-3D
TVNC	ET	36.033	-81.213	CERI	sp	L4-3D
VHTN	ET	36.399	-82.802	CERI	sp	3-c S-13
WMTN	ET	36.410	-84.176	CERI	sp	3-c S-13
WSNC	ET	35.173	-83.581	CERI	sp	L4-3D
CLTN	NM	36.091	-86.332	CERI	bb, sm	Reftek/Trillium 120P/Titan
GLAT	NM	36.269	-89.288	CERI	bb, sm	Reftek/Trillium 120P/RT147
GNAR	NM	35.965	-90.018	CERI	bb, sm	Reftek/Trillium 120P/RT147
HALT	NM	35.911	-89.340	CERI	bb, sm	Reftek/Trillium 120P/RT147
HBAR	NM	35.555	-90.657	CERI	bb, sm	Reftek/Trillium 120P/RT147
HDAR2	NM	35.154	-90.089	CERI	bb, sm	CMG6TD/CMG5TD
HDBT	NM	35.153	-90.058	CERI	bb, sm	CMG6TD/CMG5TD
HENM	NM	36.716	-89.472	CERI	bb, sm	Reftek/Trillium 120P/RT147

HICK	NM	36.541	-89.229	CERI	bb, sm	Reftek/Trillium 120P/RT147
LNXT	NM	36.101	-89.491	CERI	bb, sm	Reftek/Trillium 120P/RT147/Basalt
LPAR	NM	35.602	-90.300	CERI	bb, sm	Reftek/Trillium 120P/RT147
PARM	NM	36.664	-89.752	CERI	bb, sm	Reftek/Trillium 120P/RT147
PEBM	NM	36.113	-89.862	CERI	bb, sm	Reftek/Trillium 120P/RT147
PENM	NM	36.450	-89.628	CERI	bb, sm	Reftek/Trillium 120P/RT147
X502	NM	35.490	-92.387	CERI	bb temporary	CMG6TD
X601	NM	35.401	-92.470	CERI	bb temporary	CMG6TD
X702	NM	35.554	-91.639	CERI	bb temporary	CMG6TD
PWLA	NM	34.980	-88.064	CERI	sd,sm	Reftek/3-c S-13/Episensor
ASAR	NM	35.843	-90.671	CERI	sm	CMG5TD
ATTN	NM	35.443	-84.630	CERI	sm	CMG5TD
CBHS	NM	35.133	-89.865	CERI	sm	CMG5TD
COLT	NM	35.039	-89.692	CERI	sm	CMG5TD
CSTN	NM	35.101	-85.237	CERI	sm	CMG5TD
CUET	NM	35.007	-89.976	CERI	sm	CMG5TD
CVTN	NM	35.542	-89.644	CERI	sm	CMG5TD
CVVA	NM	38.022	-78.532	CERI	sm	CMG5TD
GILT	NM	35.231	-89.983	CERI	sm	CMG5TD
GSAR	NM	35.962	-89.969	CERI	sm	CMG5TD
LPAR	NM	35.602	-90.300	CERI	sm	CMG5TD
MCAR	NM	35.145	-90.223	CERI	sm	CMG5TD
MKAR	NM	35.526	-90.442	CERI	sm	CMG5TD
NAIT	NM	35.130	-89.804	CERI	sm	CMG5TD

NHIN	NM	38.130	-87.936	CERI	sm	CMG5TD
NMEM	NM	36.574	-89.585	CERI	sm	CMG5TD
RDST	NM	35.158	-89.989	CERI	sm	CMG5TD
SEAR	NM	35.255	-91.715	CERI	sm	CMG5TD
SFTN	NM	35.358	-90.019	CERI	sm, sp	CMG5TD, 3-c L28
SHTN	NM	35.933	-83.967	CERI	sm	CMG5TD
TUMT	NM	35.123	-89.932	CERI	sm	CMG5TD
ARPT	NM	35.756	-89.673	CERI	sp	3-c L28
BACM	NM	36.724	-89.865	CERI	sp	3-c L28
BETM	NM	36.612	-90.059	CERI	sp	3-c L28
BFAR	NM	35.873	-90.084	CERI	sp	3-c L28
BLAR	NM	35.369	-90.449	CERI	sp	3-c L28
BOAR	NM	35.823	-90.287	CERI	sp	3-c L28
BRGM	NM	36.205	-89.859	CERI	sp	3-c L28
BRNM	NM	36.724	-89.998	CERI	sp	3-c L28
BROM	NM	36.682	-90.184	CERI	sp	3-c L28
BVAR	NM	35.443	-90.677	CERI	sp	3-c L28
CACT	NM	36.230	-89.420	CERI	sp	3-c L28
CATM	NM	36.613	-89.647	CERI	sp	3-c L28
CHNM	NM	36.042	-89.929	CERI	sp	3-c L28
CHRM	NM	36.852	-89.362	CERI	sp	3-c L28
COKM	NM	36.711	-89.726	CERI	sp	3-c L28
CPAR	NM	35.556	-90.236	CERI	sp	3-c L28
CWPT	NM	36.009	-89.626	CERI	sp	3-c L28

DLAR	NM	35.810	-90.008	CERI	sp	3-c L28
DWDM	NM	36.796	-89.493	CERI	sp	3-c L28
EBZ	NM	35.141	-89.351	CERI	sp	3-c L28
EDIT	NM	35.863	-89.554	CERI	sp	3-c L28
EPRM	NM	36.717	-89.358	CERI	sp	3-c L28
FLPT	NM	36.409	-89.321	CERI	sp	3-c L28
FPST	NM	35.978	-89.455	CERI	sp	3-c L28
GLST	NM	36.269	-89.288	CERI	sp	3-c L28
GOBM	NM	36.191	-89.979	CERI	sp	3-c L28
GUAM	NM	36.889	-89.839	CERI	sp	3-c L28
HCAR	NM	35.654	-90.380	CERI	sp	3-c L28
HOPT	NM	36.327	-89.376	CERI	sp	3-c L28
HOVM	NM	36.045	-90.067	CERI	sp	3-c L28
HTAR	NM	35.655	-90.185	CERI	sp	3-c L28
KEWM	NM	36.698	-89.593	CERI	sp	3-c L28
LFRT	NM	36.165	-89.331	CERI	sp	3-c L28
LRAR	NM	35.571	-90.398	CERI	sp	3-c L28
LVAR	NM	35.915	-90.222	CERI	sp	3-c L28
MADT	NM	36.298	-89.463	CERI	sp	3-c L28
MARM	NM	36.530	-89.669	CERI	sp	3-c L28
MATM	NM	36.774	-89.605	CERI	sp	3-c L28
MCAM	NM	36.120	-89.702	CERI	sp	3-c L28
MFRT	NM	36.090	-89.377	CERI	sp	3-c L28
MIST	NM	36.171	-89.502	CERI	sp	3-c L28

MLDM	NM	36.625	-89.920	CERI	sp	3-c L28
MORT	NM	36.325	-89.566	CERI	sp	3-c L28
MSAR	NM	35.784	-90.147	CERI	sp	3-c L28
MTAR	NM	35.538	-90.442	CERI	sp	3-c L28
NFAR	NM	35.448	-90.393	CERI	sp	3-c L28
NHAR	NM	35.786	-90.544	CERI	sp	3-c L28
NHIN	NM	38.130	-87.936	CERI	sp	3-c L28
NMDM	NM	36.588	-89.552	CERI	sp	3-c L28
NNAR	NM	35.981	-89.823	CERI	sp	3-c L28
NWCT	NM	36.416	-89.459	CERI	sp	3-c L28
PGVM	NM	36.460	-89.729	CERI	sp	3-c L28
POBM	NM	36.409	-89.662	CERI	sp	3-c L28
PPLM	NM	36.403	-89.583	CERI	sp	3-c L28
QUAR	NM	35.644	-90.649	CERI	sp	3-c L28
RDGT	NM	36.256	-89.511	CERI	sp	3-c L28
RELT	NM	36.033	-89.303	CERI	sp	3-c L28
RVAR	NM	35.690	-90.286	CERI	sp	3-c L28
SJBM	NM	36.631	-89.476	CERI	sp	3-c L28
STAM	NM	36.331	-89.661	CERI	sp	3-c L28
TMAR	NM	35.695	-90.489	CERI	sp	3-c L28
TNMT	NM	36.166	-89.579	CERI	sp	3-c L28
TOPM	NM	36.526	-89.889	CERI	sp	3-c L28
TWAR	NM	35.361	-90.560	CERI	sp	3-c L28
TYAR	NM	35.509	-90.292	CERI	sp	3-c L28

WADM	NM	36.366	-89.796	CERI	sp	3-c L28
WALK	NM	36.539	-89.542	CERI	sp	3-c L28
WYBT	NM	36.348	-89.498	CERI	sp	3-c L28

B. Implementation of Policies, Standards, and Procedures

ANSS policies, standards, and procedures are primarily summarized in the five documents approved by the NIC in May 2014 that include Instrumentation Standards, Implementation Standards, and Performance Standards.

1. Instrumentation Standards

All broadband and strong-motion stations in the NM and ET networks conform to ANSS instrumentation standards for regional seismic networks. We also operate a significant number of short-period stations that remain critical to meeting other performance standards.

a. The case for short-period stations

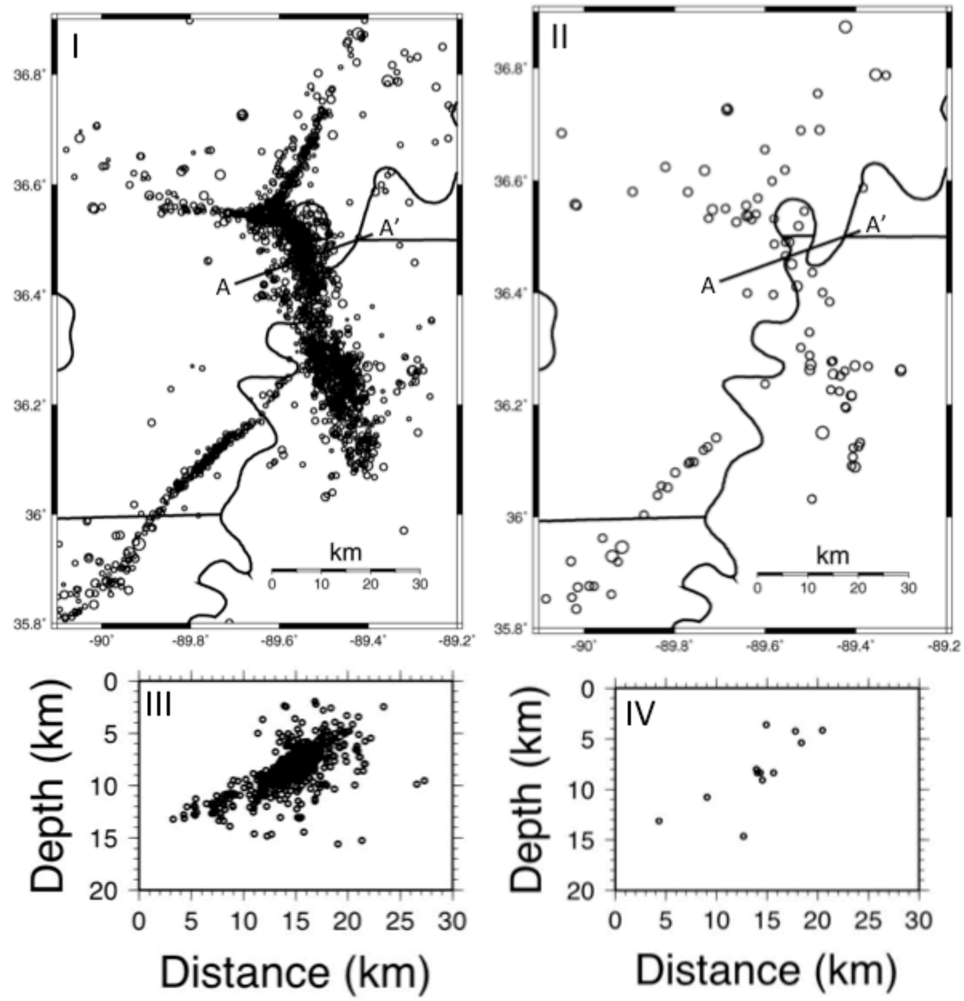

Figure 4. NMSZ Catalog epicenters 1995 to present (I). NMSZ catalog epicenters 1995 to present with magnitude greater than 2.5 (II). Cross section of hypocenters within 4 km of line A-A' (III). Cross section of hypocenters within 4 km of line A-A' with magnitude greater than 2.5 (IV).

The NMSZ network is composed of a sparse (30 km spacing) network of broadband stations and a dense (12 km spacing) network of short-period stations. The blanket of embayment sediments reduces recorded signal and increases cultural noise. Consequently a much higher density of monitoring sites is required to achieve performance similar to a network situated on hard rock. Further, the rate of seismicity requires a lower detection threshold than interplate seismic zones to better understand the sources contributing to the hazard. The latter is true for all seismic zones in the CEUS: the NMSZ, ETSZ, Wabash Valley Seismic Zone (WVSZ), and the Charleston Seismic Zone (CSZ). The density of the short-period NMSZ network is currently sufficient to provide a detection threshold low enough to image faults within a reasonable time frame. A threshold of about magnitude 2.5 could probably be met with the existing broadband network but, as shown in figure 4, this threshold is insufficient to image faults within a reasonable monitoring period. Further, location errors increase by about a factor of 5 horizontally

(Figure 5 left) and a factor of 10 or more vertically in the absence of short-period instruments (Figure 5 right). Thus, we're able to cost effectively meet performance standards for completeness and accuracy by relaxing instrumentation standards for a subset of stations.

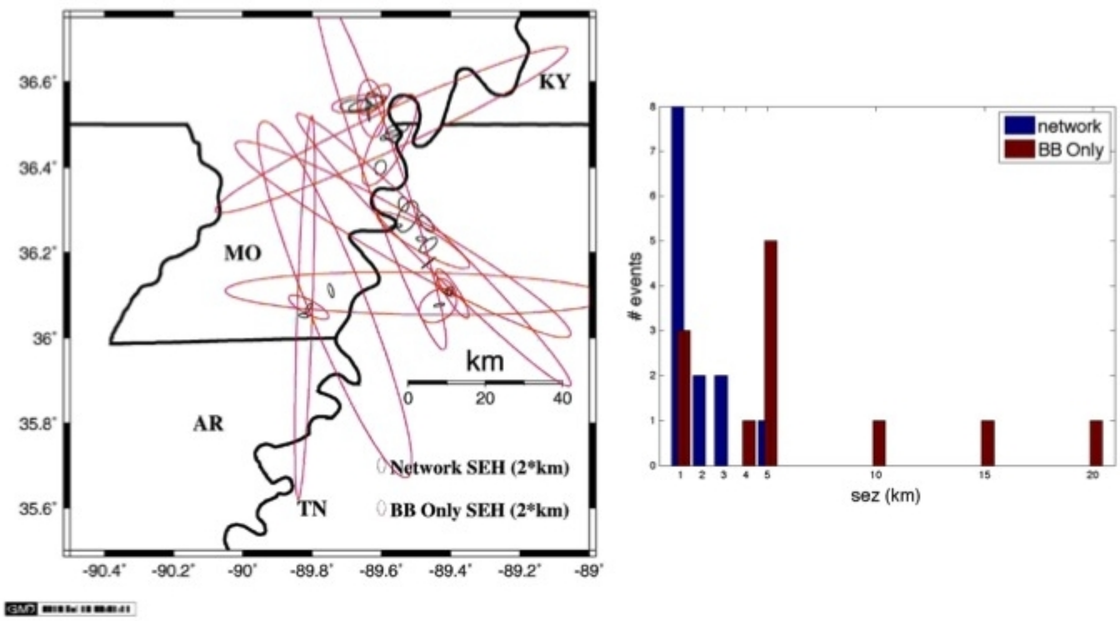

Figure 5. Epicentral error ellipses from June 2014 (left) earthquakes using the entire network (black) and only the broadband network (red). The bar graph on the right shows depth error (SEZ) for the same earthquakes using the entire network (blue) and only the broadband network (red).

b. ET digital short-period and telemetry issues

The ET network also has a significant number of short-period stations. Six of the ET short-period stations are digital (Reftek RT130) with 3-c S-13 sensors and co-located strong-motion sensors. While not broadband, these stations are able to record most local and regional earthquakes with high fidelity. They are prime candidates for upgrade to ANSS instrumentation standards (e.g. broadband) if the resources become available. Example seismograms and spectra from an M6.8 earthquake in Northern California are shown in Figure 6 to compare data recorded at broadband station CPCT (Trillium 120P/Reftek RT130) and short-period station DYTN (3-c S-13/Reftek RT130) along with their spectrum.

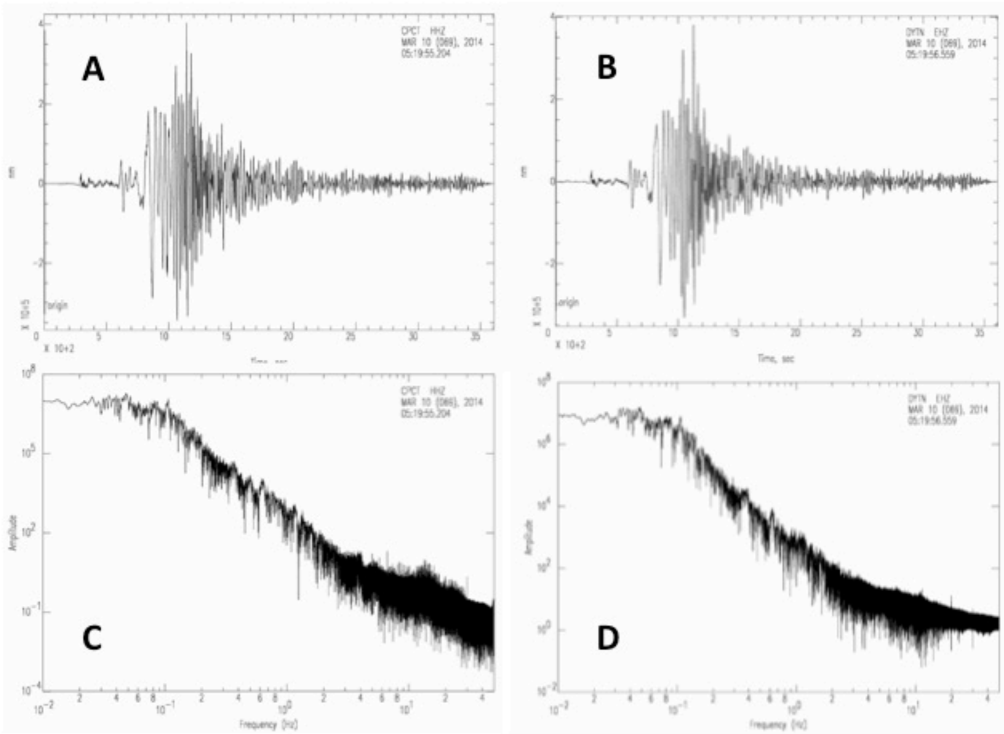

Figure 6. Seismograms and spectra for an M6.8 earthquake near Ferndale, CA on March 10, 2014 recorded at broadband station CPCT (A) and short-period digital station DYTN (B). Spectra for the CPCT data (C) and DYTN (D).

There are fifteen short-period analog stations in the ET network. We have hardware in hand to upgrade one of them to digital. Six of them have no simple upgrade path because of communications limitations due to dense foliage, terrain, and lack of IT and cell access. We will assess the ability to upgrade the remaining stations as resources permit.

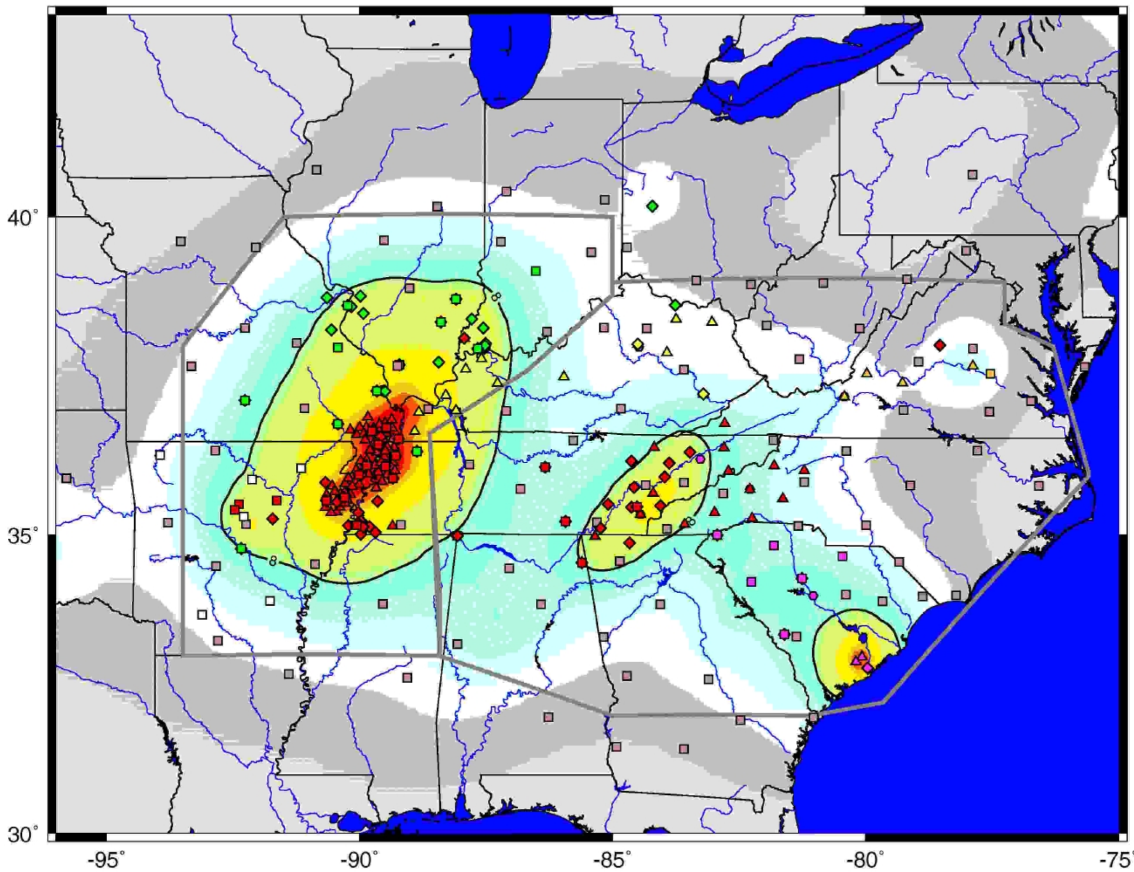

Figure 7. Station Map. Strong-motion are diamonds, short-period are triangles, and broadband are squares. Red is CERI, green is SLU, yellow is UKY, orange is VPI, purple is USC, brown is USNSN, and light brown is other contributor (e.g. EarthScope). The underlay is the 2014 PGA 10% probability of exceedance with the 8%g level contoured using the black line.

2. Implementation Standards

a. Station Inventory and Metadata

We currently keep hardware inventories of University of Memphis owned equipment in the University of Memphis property management system. GFE inventories are maintained with excel spreadsheets and we look forward to better tools. In anticipation of ANSS adoption of SIS, we assigned a staff member (J. Davis) as the SIS primary point of contact responsible for learning the system, creating the necessary templates, initial data population, and continued updates.

Metadata is maintained in dataless seed format using the IRIS Portable Data Collection Center (PDCC). These files are updated within 3 days of changes to the response (usually the same day). They are made available to IRIS and NEIC via anonymous ftp. They are more conveniently available to the public and research community through the IRIS Metadata Aggregator. We intend to migrate from dataless seed to StationXML after adoption of SIS.

b. Distribution of Earthquake Products

We currently use PDL to submit earthquake parametric data in Quakeml format to the ANSS Comcat. Automated solutions are not sufficiently reliable to submit to PDL without review. Rapid review is performed using the AQMS Duty Review Page (DRP). If the event location and magnitude are reasonable, the "accept" button on the DRP is linked directly to PDL so reviewed automatic solutions are submitted within 2 to 5 minutes of the event origin time. The reprocessed solution is then updated in PDL within about 20 minutes. Automated solutions with magnitude greater than 2.0 are sent to staff cell phones for rapid review. Automated solutions with magnitude less than 2.0 are only sent to email so may not be reviewed and processed until the following morning.

We also store event data locally (waveforms and parametric data) that are available on request. CERI maintains an online searchable catalog that is updated every 6 hours.

c. ShakeMap

CERI installed and configured ShakeMap in 2005 (Brackman, 2006) but subsequently decided to outsource this function. In order to reliably and robustly operate a complex and highly visible program like ShakeMap, it is essential that an organization frequently test and exercise the system. The rate of earthquakes in the NM and SE regions that produce reasonable opportunities to produce a ShakeMap are insufficient to instill confidence that the system will perform adequately after a damaging earthquake. For this reason, we have agreed with NEIC that NEIC will produce ShakeMaps for the NM and SE regions.

We developed programs to load previously archived event directories into the AQMS archdb. Data from 1995 to 2000 were not in a suitable format to be loaded (e.g. channel naming conventions were not SEED standard). We are reprocessing all events for that time period including retiming and relocating to improve the reliability of the error estimates. We anticipate completing that project and loading these events into the database in 2015 or 2016. We can then produce QuakeML for these events and submit to IRIS and Comcat.

d. Real-time Distribution and Archiving of Waveform Data

We use earthworm exports to export requested data channels to monitoring partners in real-time. Recipients include NEIC, St Louis Univ., University of South Carolina, Virginia Tech, and the Oklahoma Geological Survey.

We use ew2ringserver and ringserver to provide seedlink ports for real-time archiving at the IRIS DMC. The USGS National Strong Motion Program (NSMP) also has access to the strong-motion ports for ringserver.

e. IT Security

CERI seismic networks IT personnel are signatories to the previous USGS Interconnection Security Agreement and anticipate endorsing its replacement.

Login accounts on all seismic network computing systems are extremely limited and generally include only IT and in some cases analysis staff. All connections are encrypted (e.g. ssh). TCP wrappers are employed to restrict domains with access and AQMS systems also use ipfilters to prevent unauthorized non/tcp connections (e.g. oracle).

f. Continuity of Operations Plan

The CERI Seismic Networks Continuity of Operations plan was written (based in large part on the plan developed by the University of Utah Seismograph Stations) and adopted in October, 2010. An update will be completed in early 2015.

g. Websites

The CERI seismic networks website (http://www.memphis.edu/ceri/seismic/) provides computed hypocenters and magnitudes, maps and lists of stations used in routine monitoring, links to products and services, and links to monitoring partners as required by the ANSS Implementation standards.

3. Performance Standards

a. Seismic Monitoring/Strong Earthquake Shaking

With the addition of the N4 network, we are able to meet performance standards for the moderate to high hazard areas (8%g contour in Figure 7). Without N4 we are not able to meet these performance targets outside the dense part of the Regional Networks. As explained in section 3.B.1.a above and shown in Figure 5, errors for events below the Mississippi Embayment sediments require a very high station density presently accomplished with the short-period network. Without these stations hypocenter uncertainty targets are difficult to achieve except when events are large enough to estimate Moment Tensors (about magnitude 3 or so).

The average station uptime for the ET and NM networks in 2013 was 95% and 100%, respectively, according to the IRIS Gap/Overlap Analysis Tool (GOAT). There is room for improvement in the ET network but we are within the 90 percentile required in the ANSS performance standards. The unusually harsh winter of 2013/2014 requires several communications reconfigurations in the ET network that are in progress (e.g. reducing reliance on the Mt Gibbs facility).

All broadband stations operated by CERI (green squares on Figures 2 and 3, and red squares on Figure 7) have collocated strong-motion sensors. These combined with the free-field strong-motion stations provide the capability for on-scale recording of strong ground motion.

b. Real-Time/Automated Product Generation

Automated earthquake locations are produced within about 2-3 minutes of origin time. We do not post automatic solutions to PDL. We currently mislocate teleseismic events within the regional network a few times per month. We plan to install the NSCN telestifle module to mitigate this problem. Even with telestifle, there are still sufficiently numerous anthropogenic events that are difficult to correctly identify and require human review of all events.

c. Preparation of Seismologist-Reviewed Products for Significant Earthquakes

For events that are well located with reasonable automatically generated magnitudes, we are able to use the AQMS Duty Review Page to post hypocenter and magnitude within about 5 minutes of origin time. Events are then re-timed by the analyst and updated within about 20 minutes. The N4 network dramatically improves preparation of reviewed hypocenter and magnitudes. Without that network events outside the densely instrumented areas of the region become more difficult to process and hence take more time.

We do not produce COSMOS V0-V3 products directly. Instead, we provide seedlink access to strong-motion channels for NSMP.

We do not produce ShakeMap directly and instead outsource that function to NEIC. NEIC production of ShakeMap for the NM and SE regions will be improved after implementation of *gmew* within AQMS.

d. Data Exchange between ANSS Networks

Data export timeliness is primarily limited by packet size. Other latencies within the network are relatively small. Packet lengths are generally 10 seconds or less depending on compression. This is well within the ANSS performance standards.

e. Data Archiving and Public Distribution

Waveform data are sent to the IRIS DMC in real-time where they are made immediately available to external users. Likewise quakeml format parametric data is sent to PDL immediately. The CERI online catalog updates every six hours with a query to the AQMS archdb.

CERI has about 5,330 events archived for NM since 1995 and about 950 for ET since 1998. These events include waveforms, hypocenters, and arrival times. We plan to implement a second AQMS archdb on Linux so that these data can be uploaded to the backup archdb and subsequently sent to Comcat. We plan to complete this upload and submission in 2015 and 2016.

Metadata is currently maintained with PDCC. We usually update changes within about a day and make these data available as described in section 3.B.2.c. We look forward to migrating to SIS when it is ready for production.

C. Delivery, Availability, and Exchange of Data and Products

As mentioned in previous sections, continuous waveform data is available in the IRIS DMC for all channels in real-time. We also use earthworm export scnl to send 33 channels to neighboring RSN's in real-time. We also export 108 channels to NEIC via a version of export_scnl modified by Dave Ketchum. Epicenters are submitted to PDL within 5 minutes for events recorded well enough to produce reliable automatic solutions and within a few hours for smaller events (e.g. less than magnitude 2.5).

We archive event-based waveforms with daily backups to an archive physically located in a different building than the primary archive. These data, while not on the public internet, are available to anyone on request.

Earthquake epicenters are available on several CERI websites:

- recenteqs, 6 months using old, but fast "Simpson" maps http://www.memphis.edu/ceri/seismic/recenteqs/ (this product will be obsolesced in early 2015).
- Interactive Google Map with 6 months of data http://folkworm.ceri.memphis.edu/REQ3/html/
- Interactive Google Map with 3 months of data and excluding OK http://folkworm.ceri.memphis.edu/REQ3a/html
- Searchable online catalog for 1974 to present http://www.memphis.edu/ceri/seismic/catalogs/

The online digital helicorder pages (http://www.memphis.edu/ceri/seismic/heli/) generate a surprising amount of public interest. 5 days are available for the vertical channel at each station used in processing (CERI operated stations as well as imported stations).