Final Technical Report 2007-2009

Mid-America Integrated Seismic Network – CERI

USGS Cooperative Agreement 07HQAG0019

February 1, 2007 – January 31, 2010

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Prepared by M. Withers: April 30, 2010

1. Executive Summary

CERI operates 140 seismic stations (all but one are at least 3-component) to monitor earthquakes in the New Madrid and East Tennessee Seismic Zones (NMSZ and ETSZ respectively). All stations are real-time. CERI provides automated locations for the NMSZ within about 5 minutes or less for events greater than about magnitude 2.5. Of the 18 published automatically determined earthquakes for the contract period (7 in 2007, 5 in 2008, and 6 in 2009; 55 since 2002), there were 0 false alarms, 0 significant mislocations and 0 significant magnitude errors. There were also 0 missed events with magnitude greater than 2.5 within the allowed automatic polygon.

CERI also operates as the ANSS Mid-America regional processing center and exchanges data with all partners including the USGS NEIC (300 stations). Phone coordination with NEIC after felt events is routine. While not 24/7, CERI does maintain 24/7 on call capability to process events within about 20 minutes of the time we become aware of them. Events outside the automated NMSZ capable area that occur during third shift are usually processed first by NEIC then refined by CERI within about twenty minutes of receipt of the initial notification.

2. Year 1 (2007) Update

Installed two new stations in the East Tennessee Seismic Zone using existing equipment.

CCNC 36.023 -82.714

VHTN 36.399 -82.802

Added 15 channels to reference strongmotion station HDBT. Was 3-components of surface strongmotion. There are now 3-components of strongmotion and 3-components of broadband at the surface, 30 meters depth, and 60 meters depth.

Fifteen remote processing node computers were replaced with up to date hardware and operating systems.

Hardware was acquired and configuration is in progress for migrating all real-time processing to SCNL compliant earthworm version 7.

Real-time processing was brought online at HVO and Montana Tech. SeisnetWatch was configured and installed at Montana Tech.

A local magnitude scale was implemented and offline review integration software developed to begin using Ml as the preferred magnitude for New Madrid Seismic Zone earthquakes (unless an MbLg is available from NEIC or Mw from St Louis Univ.).

Software and procedures for offline review and production of ShakeMap was developed.

Installed digital environmental monitoring channels (e.g. temperature, intrusion, moisture, time failure) and developed and installed earthworm modules to produce page and email when parameters at remote nodes exceed acceptable limits.

3. Year 2 (2008) Update

Four stations in Lake county, TN were destroyed by vandalism in late 2007 (MORT, LEPT, TIPT, and GRAT). TIPT was moved (now NWCT) and is now collocated with GPS station NWCC (required a formal agreement with the TN DOC), and the others were rebuilt in early 2008. Development then required GRAT to be moved and is now CTCT.

Greg Steiner, CERI's lead engineer and technical expert, retired after 30 years of service. Numerous "brain dump seminars" were held prior to his last day on April 21 to impart as much knowledge as possible to other technical staff.

Routine data processing and analysis was removed from Withers' office workstation to a rack server.

A portable array of three CMG6TD's was deployed near Gratio, TN to monitor a small swarm. The analysis will be a student M.S. thesis.

A formal agreement was established between the University of Memphis and TDOT to allow data transfer from the I40 Hernando Desoto bridge network to the UoM using the TDOT wireless network. The technical details continue to be a moving target and have hampered establishing the link.

New stations installed in the East Tennessee Seismic Zone using existing equipment: LRVA, TVNC, WSNC, and VHTN.

Replaced North Carolina node due to structural changes in the host's building.

A portable network was installed near Mt. Carmel, to monitor aftershock activity following the M5.2 earthquake on April 18, 2008. Processing and analysis of the data is ongoing.

Published a paper in SRL using network data from the Mt. Carmel earthquake.

There were two significant problems with the Strongmotion recordings from the ANSS Guralp CMG5TD sensors: low sample rate and lack of triggers. The sensors were originally configured to stream 100 sps data and record 50 sps triggers. The IP stack in the MSS100 had a tendency to hang on noisy networks and it was empirically determined to improve stability with streaming at 50 sps and recording 100 sps triggers instead. There was a bug with the firmware used that prevented storing of waveforms with the triggers. Triggers were correctly declared but no waveforms were actually recorded in the flash. Thus only the streamed 50 sps channels were available. There are two parallel paths in process to address these problems:

1. CMG5TD's to firmware version 59914. When configuring, first set the mode to filing, then to dual.
2. Increase sample rates to 100 sps for streamed channels and 200 sps for triggered. Isolate the mss100 from networks with large amounts of broadcast traffic using a router.

Assisted installation of SLU stations near Mountain Grove, MO and Poplar Bluff, MO and with the reinstallation of UTMT and UALR.

Worked with R. Herrmann and IRIS to verify dataless seed calibration of all broadband and strongmotion stations.

Deployed portable array to Magnet Cove, AR in November and December, 2008 to monitor a sequence of small but notable activity in the region. One station is real-time.

4. Year 3 (2009) Update

Installed new 6-c broadband and Strongmotion station FPAL in northeast Alabama near Ft. Payne.

Installed and currently operate 6 station Arkansas network (network code AG) for the Arkansas Geological Survey. Data are fully integrated with ANSS processing and available in NEIC CWB.

Completed migration to earthworm v7.3 and SCNL.

Migrated most functionality of webserver (folkworm.ceri.memphis.edu) to other servers. The URL is now essentially only a placeholder to maintain the plethora of preexisting links to folkworm from sites external to CERI.

Completed migration from QDDS to EIDS.

Added 15 channels to reference Strongmotion station HDAR (3-c broadband and 3-c Strongmotion at 0, 100, and 200 feet depth). This complements an identical station on the east side of the I40 bridge over the Mississippi river (HDBT).

5. Network Summary and Description

This report addresses operation and maintenance of regional seismic networks in the Mid-America region of the Advanced National Seismic System (ANSS). This is the largest ANSS region in the contiguous United States and includes the locations of the significant 1811-1812 New Madrid and the 1886 Charleston, South Carolina, earthquakes. The geographical delineation also includes similar geological features that affect ground motion, such as the deep sediment deposits near New Madrid and the coastal plains.

Regional monitoring partners include the Center for Earthquake Research and Information (CERI) at the University of Memphis, St Louis University (SLU), the University of Kentucky (UKY), and the University of South Carolina at Columbia (USC). The region encompasses five ANSS urban monitoring targets (Memphis, St. Louis, Evansville, Charleston, and the Knoxville/Chattanooga corridor). Areas of elevated hazard (10% probability of exceeding 8% g in 50 years) as defined by ANSS performance standards (Figure 1) include the general areas of the New Madrid, East Tennessee and Wabash Valley Seismic Zones, and South Carolina.

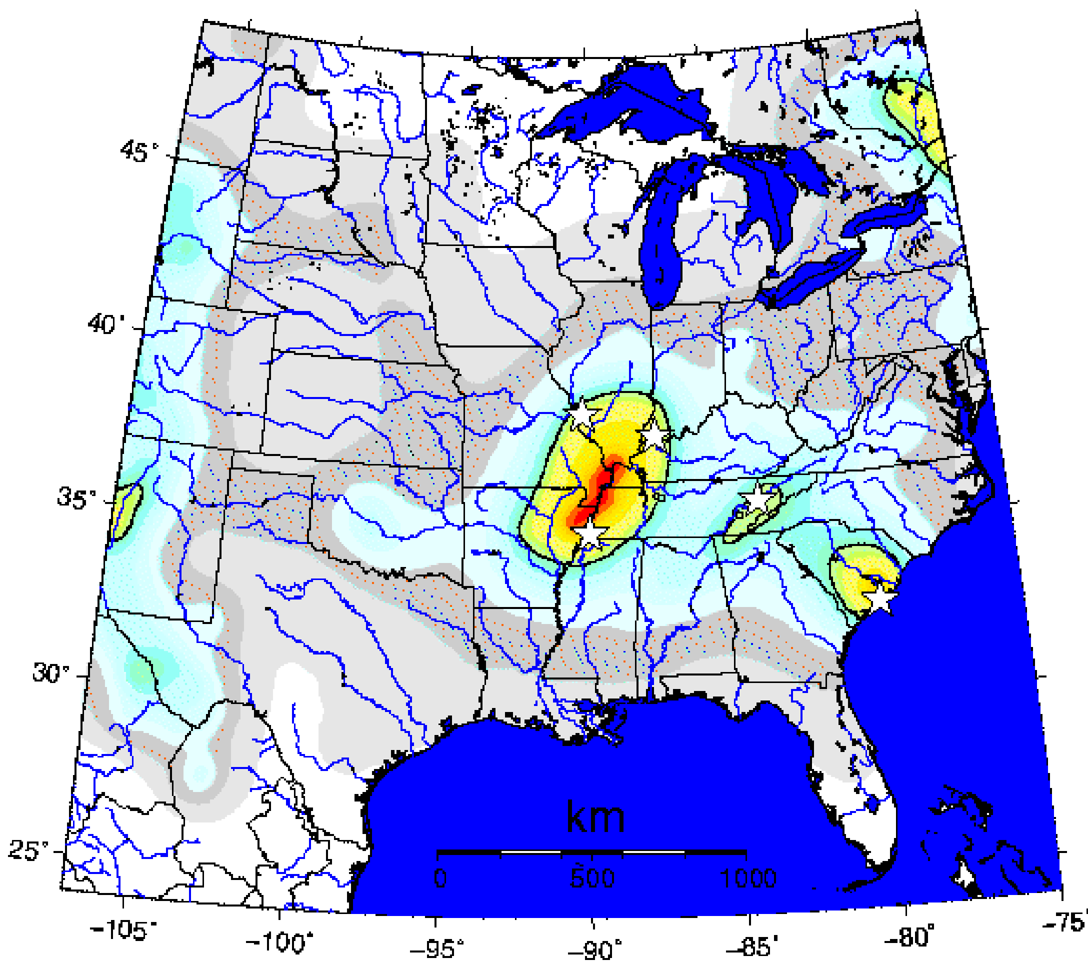

Figure 1. 2002 National Hazard Map 10% probability of exceedance in 50 years for the ANSS Mid-America region. Stars are urban monitoring

targets from USGS Circular 1188. The 8%g exceedance level is the line contour.

The regional seismic networks in the Mid-America Integrated Seismic Network (MAISN) provide raw and derived earthquake products to the ANSS system and provide local expertise on earthquake information, models, and methods. Each institution provides core operations and maintenance as well as locally specific tasks and expertise where appropriate. The purpose of the MAISN is twofold:

1. to provide scientists, engineers, public and private entities, emergency responders, and the media with rapid and reliable information about felt and damaging earthquakes within a timeframe that maximizes the utility of the information,
2. and to provide high quality data on a timely basis to the scientific and engineering communities for the purpose of improving:
   - seismic hazard estimation for urban population centers and the lifelines and critical facilities upon which they depend
   - estimation and measurement of strong ground motions, our understanding of the basic earthquake process, and seismotectonics of earthquake zones, particularly in intraplate regions.

<u>a. CERI network description</u>

The CERI seismic network consists of 140 permanent seismic stations (1 shortperiod vertical, 96 shortperiod 3-component, 16 broadband, and 27 ANSS urban strongmotion). 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 to 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 NMSZ nodes. To mitigate against fades during inclement weather (and avoid single points of failure), DSL is being added to each node.

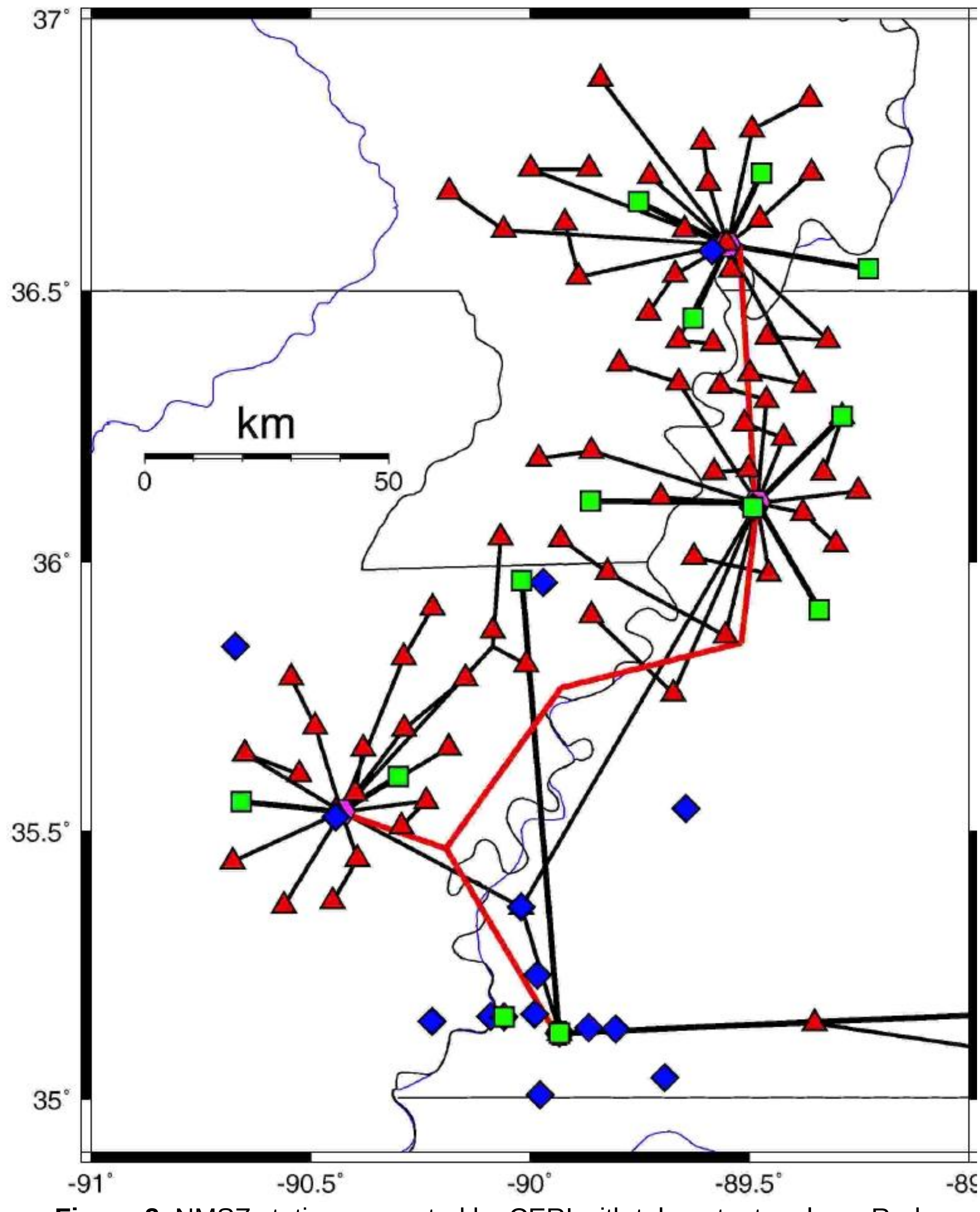

Figure 2. NMSZ stations operated by CERI with telemetry topology. Red triangles are shortperiod stations, green squares are broadband, and blue diamonds are strongmotion. Black lines are digital or analog radio. Red lines are the 2.4 GHz spread spectrum digital backbone that provides TCP/IP connectivity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

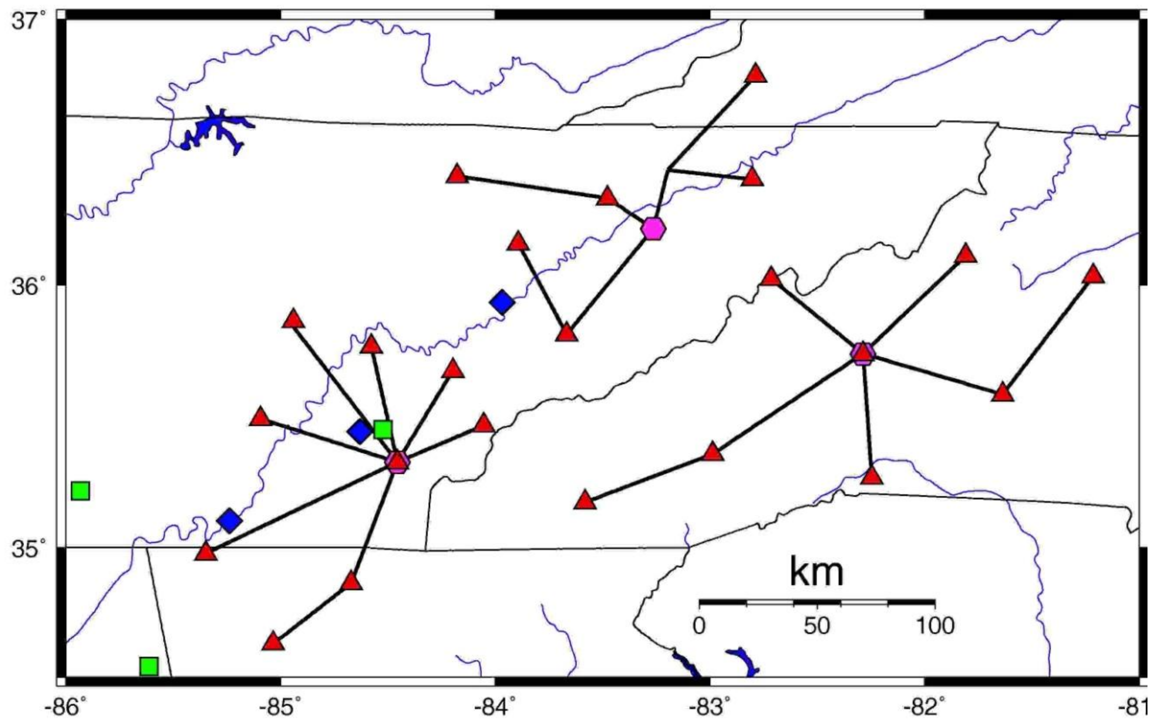

Figure 3. ETSZ stations operated by CERI with telemetry topology. Red triangles are shortperiod stations, green squares are broadband, and blue diamonds are strongmotion. Black lines are digital or analog radio. Node connectivity is accomplished via public internet or DSL.

Subnetwork triggers are analyzed daily at CERI for both the New Madrid and East Tennessee Seismic Zones (NMSZ and ETSZ respectively). 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 for teleseismic events of interest. Routine and automated event locations are shared with other networks via *EIDS*. Reviewed parameters are similarly shared and are emailed to the ENS listserve. By far the most popular tool has been the *recenteqs* webpage accounting for more than half of the 15 million hits over the past twelve months. Hypocenters are submitted weekly to the ANSS composite catalog. 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.

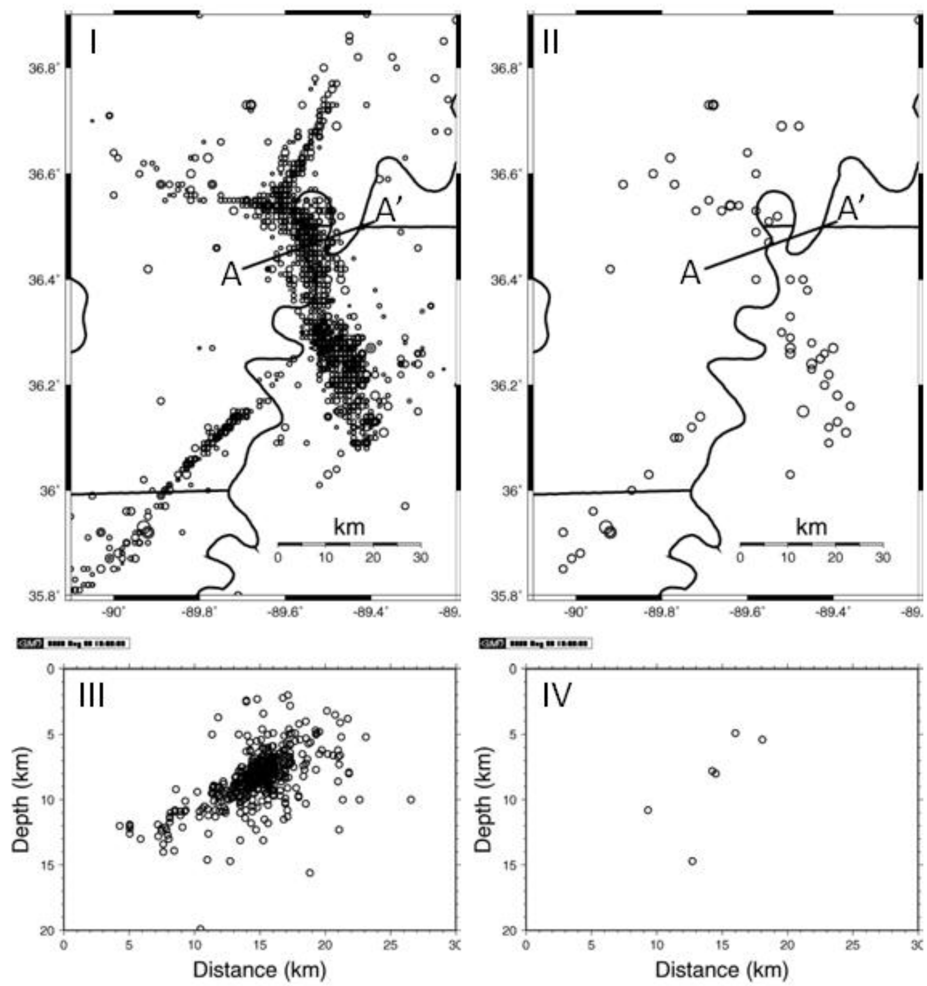

Figure 4. NMSZ Catalog epicenters 1995 to present (I). NMSZ catalog epicenters 1995 to present with magnitude greater than 2.5 (II). Cross section of hypocenters within 4 km of line A-A' (III). Cross section of hypocenters within 4 km of line A-A' with magnitude greater than 2.5 (IV).

The NMSZ network is composed of a sparse (30 km) network of broadband stations and a dense (12 km) network of shortperiod stations. The lossy 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 hard rock network. 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 New Madrid, Wabash Valley, East Tennessee, and Charleston Seismic Zones (NMSZ, WVSZ, ETSZ, and CSZ respectively). The density of the shortperiod 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 (Figure 5 right).

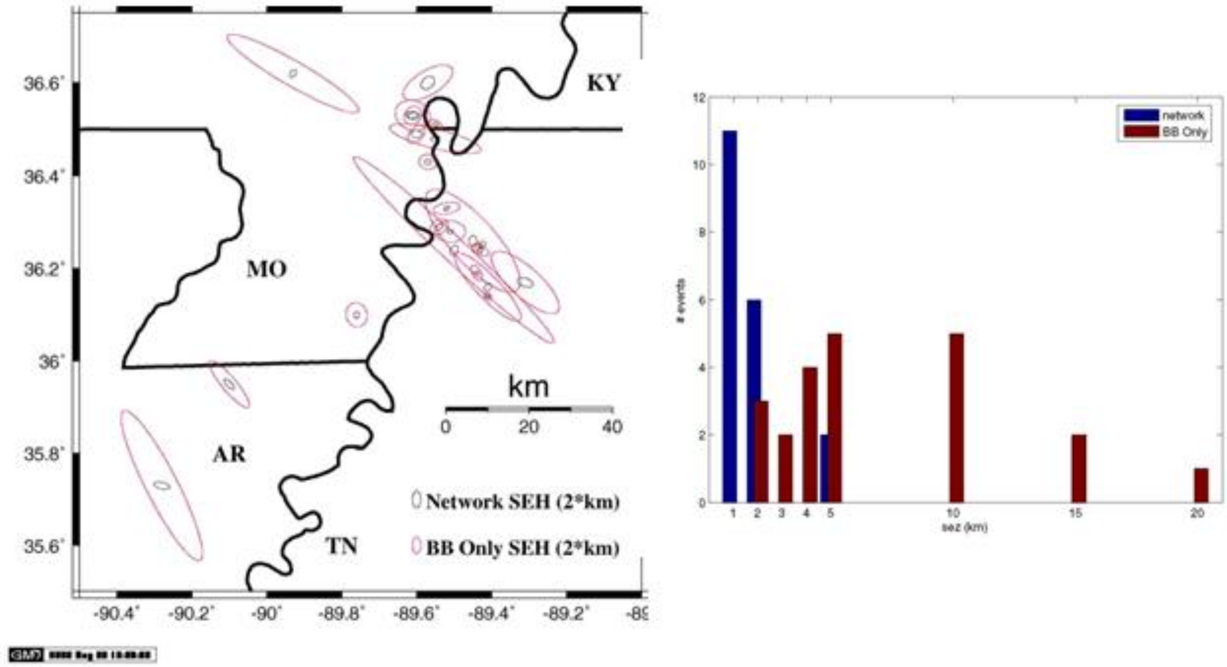

Figure 5. Epicentral error ellipses from August and September 2009 (left) earthquakes using the entire network (black) and only the broadband network (red). The bar graph on the right shows SEZ for the same earthquakes using the entire network (blue) and only the broadband network (red).

<u>b. Data Acquisition Processing</u>

Twelve remote acquisition systems and one local system in Memphis are maintained and provide several levels of redundancy. The remote systems are PC-based *earthworm* using National Instruments 12 bit digitizers. Standard short-to-long-term average ratios are employed to store triggered data streams. Additionally, a revolving continuous buffer of about 10 days provides opportunities for post-event archiving. All remote nodes include about 3 days of battery backup. The node at CERI consists of 12 computers housed in earthquake resistant racks within a physically secure, environmentally controlled room with battery and diesel generator backup and 100baseT infrastructure. Each remote node is identically configured and provides traditional triggered data as well as real-time export of select channels and station triggers. Station triggers are subnetted at the Regional Processing Center (RPC) to form subnet triggers and subsequent data files.

The NEIC inventory software is installed at CERI and awaiting completion of equipment prototypes in the mysql database. An IRIS event Data Handling Interface (event DHI) is also in operation. The inventory software provides the capability to track station metadata much more efficiently and, using ISTI developed tools, produce dataless SEED that we will send to IRIS. This will then allow archiving of waveforms at the DMC. Users may then take advantage of IRIS data searches with event-based searches getting event info from the DHI running at CERI. IRIS also attaches to earthworm waveservers to archive continuous waveforms for broadband stations. The NSMP similarly attaches to the earthworm waveservers to archive strongmotion data of interest. Earthworm modules necessary to automatically produce ShakeMap (e.g. gmew) are configured and implemented. An earthworm getfileII/sendfileII or similar transport mechanism will provide data to NEIC for production of ShakeMap. A verbal agreement made between M. Withers and D. Wald assigns NEIC as primary for ShakeMap production in this region and will include CERI produced groundmotion xml.

The 140 station NMSZ and ETSZ networks operated by CERI are augmented by an additional 105 stations operated by partner institutions. Data are imported and processed in real-time from: St Louis University, the University of Kentucky, the University of South Carolina at Columbia, North Carolina Central University, Northern Kentucky University, and the USGS NEIC.

6. Regional Operations

The regional seismic networks in the central and southeastern U.S. operate on a cooperative basis in order to meet as many requirements as resources allow. For those functions and standards not met collectively, we rely on the NEIC.

a. Routine Field and Data Center Operations

Regional network partners within the MAISN operate seismic stations (Figure 6) and facilities within their respective area of authority. While cooperation and assistance is provided between partners and operational boundaries are not definitive and include exceptions, general areas of responsibility are as follows:

- SLU: roughly north of and including Cape Girardeau, MO as well as broadband stations surrounding the active part of the NMSZ at regional distances,
- UKY: the state of Kentucky,
- USC: the state of South Carolina
- CERI: the New Madrid and East Tennessee seismic zones.

CERI operates the NEIC INV software which can be used to track station inventories and produce dataless SEED volumes. CERI is working with regional partners to keep INV updated and supply SEED volumes for any regional partner that does not. The PDF software from McNamara et al. is in operation at CERI and used to verify instrument operation. Waveform feeds are provided from regional partners to CERI via earthworm import/export modules so SeisNetWatch is operated similarly (http://webworm.ceri.memphis.edu/snw). Each regional partner may monitor seismicity within its nominal area of responsibility. CERI may provide a rapid preliminary location which is replaced by the authoritative regional network location when available. For magnitudes above the NEIC threshold, the NEIC may provide a rapid preliminary location which is replaced by CERI or the authoritative regional network location (either directly or via CERI) when available.

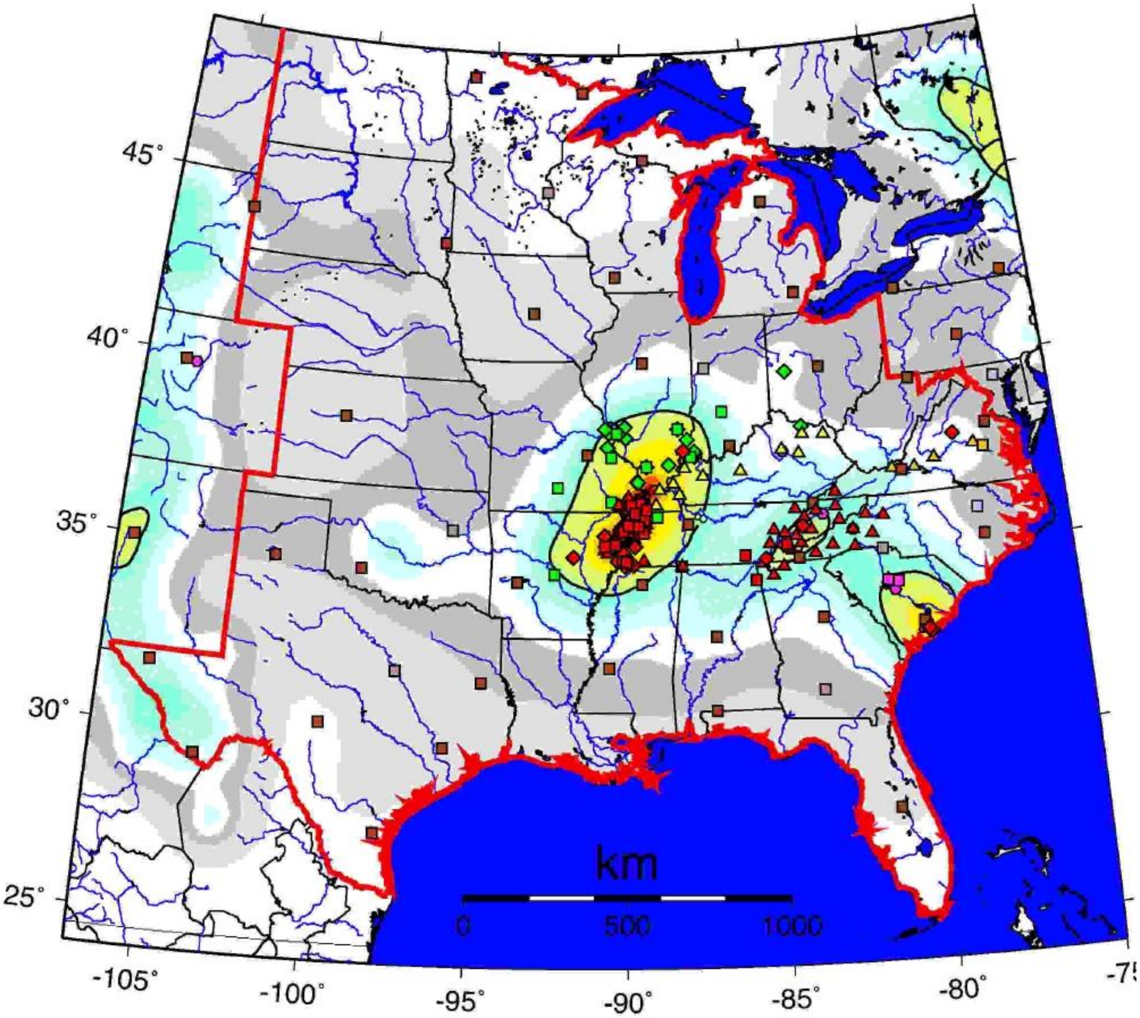

Figure 6. Station Map. Strongmotion are diamonds, shortperiod are triangles, and broadband are squares. Red is CERI, green is SLU, yellow is UKY, orange is VPI, purple is USC, brown is USNSN, and light brown is other contributor (e.g. EarthScope). The underlay is the 2002 PGA 10% probability of exceedance with the 8%g level contoured using the black line.

<u>b. Real Time Exchange and Integration of Data and Information</u>

While formal written agreements among regional partners do not currently exist, appropriate waveform exchange is established and forwarded to NEIC via earthworm import/export either through CERI or directly from the respective regional partner. Reviewed parametric data are currently exchanged via email and EIDS running at

CERI. None of the ANSS-MA regional networks are staffed 24/7 so we rely on the NEIC to meet ANSS standards for product generation during non-business hours. Due to the relatively low rate of damaging earthquakes we found that a rotating "seismologist on duty" is not a tenable option. Instead, two people at CERI responsible for routine event review (H. Withers and M. Withers) receive and respond to automated earthquake notifications 24/7/365.

c. Distribution and Dissemination of Earthquake Notifications, Data, and Information

Regional partners currently distribute reviewed earthquake hypocenter parameters via EIDS in cube format. Normally, additional parameters (e.g. arrival times and weights) are exchanged among partners using email and using standard locator output files (e.g. hypoellipse *arc* or *out* files). We will need to implement distribution of these additional parameters through EIDS and the ANSS composite catalog. CERI operates EIDS and weekly ANSS composite catalog updates (EIDS immediately after review, catalog update interval selected somewhat arbitrarily and could be more frequent). This information is available publicly via recent earthquakes, earthquakes in the news, and ENS (the ma_quake email notification was discontinued in July 2006 in favor of ENS).

CERI also operates an Event Data Handling Interface (DHI) that allows searches initiated at the IRIS DMC to include inclusion of catalogs maintained at CERI. Associated waveform data are then associated with the event at the IRIS DMC. IRIS obtains the waveform data by attaching to CERI waveservers, however event based waveform submission will be initiated when dataless SEED production becomes available using INV. Additionally all strongmotion data from real-time stations are available in CERI earthworm waveservers. The National Strong Motion Data Center operated by the NSMP also obtains data from these waveservers. Details for keeping response and metadata information at the NSMD need to be resolved presumably using mechanisms associated with INV output.

Regional network web pages will need to be updated to provide information required in the RFP (e.g. improved description of mission requirements and objectives, and the scope of coordination with other networks, etc). Withers will work with the USGS web team to update and provide appropriate hyperlinks to regional partners on the USGS EHP program pages.

d. Coordination of Monitoring Activities

Current policy at CERI is to replace the NEIC location if an improved regional network location is available. The NEIC preferred magnitude is used if available. The SLU moment magnitude when available, trumps the NEIC magnitude. This policy is not formalized either in agreements nor software but is rather implemented using communication (e.g. telephone) between analysis staff.

Core hardware at CERI includes 8 hours of battery backup and automatic switching to generator power. Long-term power disruption will not be a significant operational impediment assuming a reliable fuel supply. These systems are located in a physically secured and structurally hardened wood frame facility. It will be difficult to duplicate this operation at an alternate location with sufficient (and functioning) internet bandwidth in the event of fire or natural disaster. We have thus, in the past, relied on continued operation of regional partners and the NEIC to provide earthquake information and data in the event of catastrophe at the regional processing facility at CERI. With guidance from the USGS, improved and formalized continuity of operations plans will be developed.

e. Compilation and Distribution of Earthquake Data and Information Products

Event data for the Region are currently uploaded to the ANSS composite catalog from CERI on a weekly basis with a one week delay (delay in order to allow for months that end mid-week). The mechanism used is based on a script provided by the former CNSS and updated to use scp. An improved method should be considered perhaps using EIDS.

A continuous data buffer of about 4 weeks is available for all stations from CERI waveservers. This is not an appropriate mechanism for a 6 month buffer unless the waveserver can be modified to increase maximum file size. Continuous data are not archived locally. Six months may be accomplished using tools such as ew2mseed and acquisition of additional storage hardware. The local event based waveform archive is complete beginning in 1995. The resources necessary to maintain this event based waveform archive are trivial (less than 250GB) and CERI intends to continue archiving this dataset.

Data and Information are distributed by several mechanisms. Event information for events within the past 6 months is provided by *recenteqs* which averages about 80,000 visits per month (1,000,000+ hits per month). Events from 1974 to present are available through the ANSS composite catalog and through the CERI online catalog (available at http://www.ceri.memphis.edu/seismic/). Submissions are made to the ANSS composite catalog weekly with a one week delay (to assure inclusion of partial weeks at month boundaries). An event Data Handling Interface (DHI) also connects the CERI catalog to the IRIS DMC. IRIS extracts waveform data from CERI waveservers which IRIS will make publicly available when INV at CERI is populated (initial prototype implementation in progress) and we are able to provide dataless SEED to the DMC. Event waveforms are also made available via anonymous ftp on request. The 6,000+ ma_quake earthquake email notification list was migrated to ENS in May 2006 with assistance from Stan Schwarz at USGS Pasadena. CISN Display is operated in select emergency operations centers.

Seismic Network ANSS Performance Self Rating

Question	Explanation (if needed)
1. What is the minimum magnitude detection threshold for the best instrumented part of your network?	1.8
2. What is the typical hypocentral location accuracy for earthquakes occurring within your network? Is it the same for automated vs. reviewed?	1.5 km. Automatics use only broadband stations and analog backbone.
3. Does your network report automated earthquake locations into EIDS? If yes, how long does it take?	No, automatics reported to duty roster only
4. Does your network report analyst-reviewed earthquake locations for all quakes into EIDS (i.e., the little ones)?	1 hour to 1 day.
5. Does your network have 24/7 duty seismologists who review real-time earthquake locations above some magnitude?	All events large enough to generate automatic alarms are reviewed 24/7. Typically about 2.5 in NMSZ.
6. Describe the velocity model used to locate earthquakes in your network (1-D, multiple models, 3-D). Does it differ for automated vs. reviewed?	Multiple 1-D models depending on location. Yes, automatics and reviewed differ.
7. What software/program does your network use to locate earthquakes? Does it differ for automated vs. reviewed?	Hypoellipse for reviewed, earthworm and hypoinverse for automatics.
8. What magnitudes does your network routinely report in real time (Md, ML, Me, Mw, Ms, etc.)? How long does it take to compute them?	Md for both automatics and reviewed. Time is same as for location.
9. Does your network archive phase information at a datacenter?	No though we would if given an opportunity.
10. What is the date of the most recent event	Month files submitted weekly

Seismic Network ANSS Performance Self Rating

Question	Explanation (if needed)
you have contributed to the ANSS catalog?	with one week delay.
11. Where is the permanent archive of seismic waveform data from your network?	Local only. All channels are event archived. From 1995 to present.
14. Does your system compute focal mechanisms?	No.
15. Does your system automatically distribute email to the public in near real-time for significant events?	Yes, via EIDS and ENS.
16. Does your system automatically distribute alphanumeric pages to the public in near real-time for significant events?	Yes via EIDS and ENS.
17. Does your system automatically compute ShakeMaps and make them publicly available? If so, how long does it take?	No.
18. Is your processing system hardened? (i.e., fault-tolerant, with redundant computers, UPS, back-up generator & fuel)?	Yes.
19. What is your network's total data volume (mbytes/day)?	18,523 Mbytes/day (see note)
20. What is your network's total data volume (mbytes/year to archive)?	6,760,895 Mbytes/year

(1 channel * 1 1-c sp station + 4 channels * 96 3-c sp stations + 6 channels * 16 bb stations + 3 channels * 27 sm stations) * 4 bytes/sample * 100 samples/second * 3600 seconds/hour * 24 hours/day = 19,422,720,000 bytes/day = 18,523 Mbytes/day = 6,760,895 Mbytes/year

Note there are 299 stations processed real-time at CERI when USGS and RSN partner stations are combined with those operated directly by CERI.