Final Technical Report
USGS Cooperative Agreement for Seismic Network Operations

Reporting Period:	February 1, 2010 – January 31, 2015
Cooperative Agreement Number:	G10-AC00092
C.A. Start Date & End Date:	February 1, 2010 – January 31, 2015
Seismic Network Web Site:	http://www.eas.slu.edu/eqc/
Network Code:	NM
Network Name:	Cooperative Mid-America Seismic Network
ANSS Region:	MA
Operator Address:	Saint Louis University Dept. Earth and Atmospheric Sciences 3642 Lindell Boulevard St. Louis, MO 63108
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1. Executive Summary

The Saint Louis University component of the Mid-America Integrated Seismic Network provides a broad regional coverage in a zone of historical significant historical earthquakes. The degree of seismic hazard is illustrated by the 2014 PGA map (Fig. 1. left), which shows significant levels of hazard for the area to include the major metropolitan areas of Memphis, TN and St. Louis, as well as Evansville, IN on the northeast to Little Rock, AR on the southwest. The figure on the right, indicates significant earthquakes, mostly with M > 3.5, which were analyzed to determine regional moment tensors. Until the exceptional activity in Oklahoma in in 2014, the majority of the solutions were within the region of elevated seismic hazard.

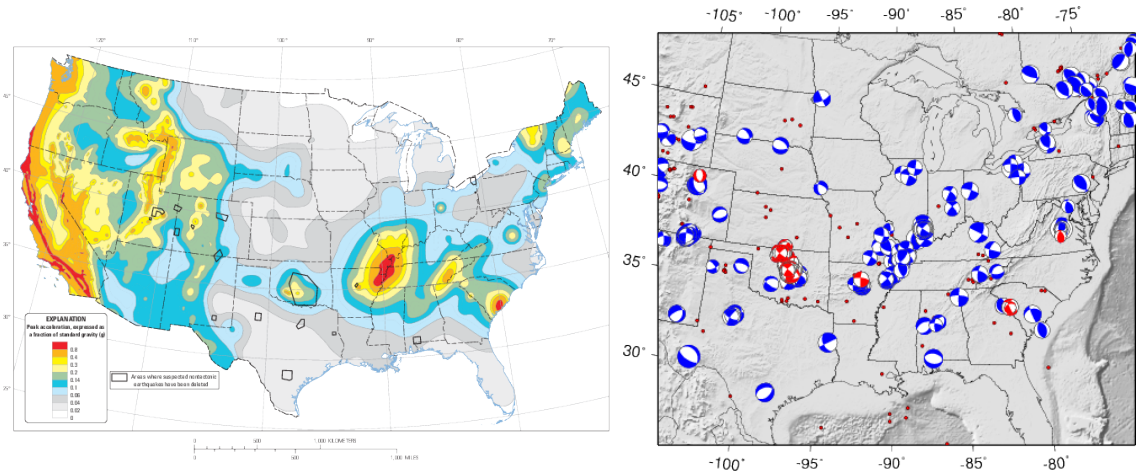

Fig 1. Left) the 2014 2% 50 year PGA map for the continental US. Right) SLU-USGS regional moment tensor catalog 1962-2014; the mechanisms shaded in red have occurred so far in 2014.

Current earthquake monitoring in the Central US is mostly the result of USGS funding through cooperative agreements with Saint Louis University (SLU) and the University of Memphis. As shown in Figure 2, the SLU network focuses on the St. Louis and Evansville urban areas and at the same time provides a broad regional backbone coverage to the University of Memphis coverage of the New Madrid Seismic Zone and activity in Arkansas. Modern digital earthquake monitoring is also provided by the Arkansas Geological Survey stations in that state (AG network), and recently by the new N4 network that represents the transfer of selected US Array Transportable Stations to the USGS. The combination of these overlapping networks is not redundant, but rather provides the necessary robustness to ensure that levels of monitoring will always provide the necessary ANSS products irrespective of any technical problems.

The Saint Louis University seismic stations form a Tier II network whose purpose is to provide high quality, calibrated digital data streams that are forwarded in real time to the CERI data center at the University of Memphis and to the USGS National Earthquake Information Center in Golden, Colorado. All digital data streams and corresponding metadata are archived at the IRIS Data Management Center in Seattle, Washington. As a Tier II network, Saint Louis University does not provide real-time location and notification services.

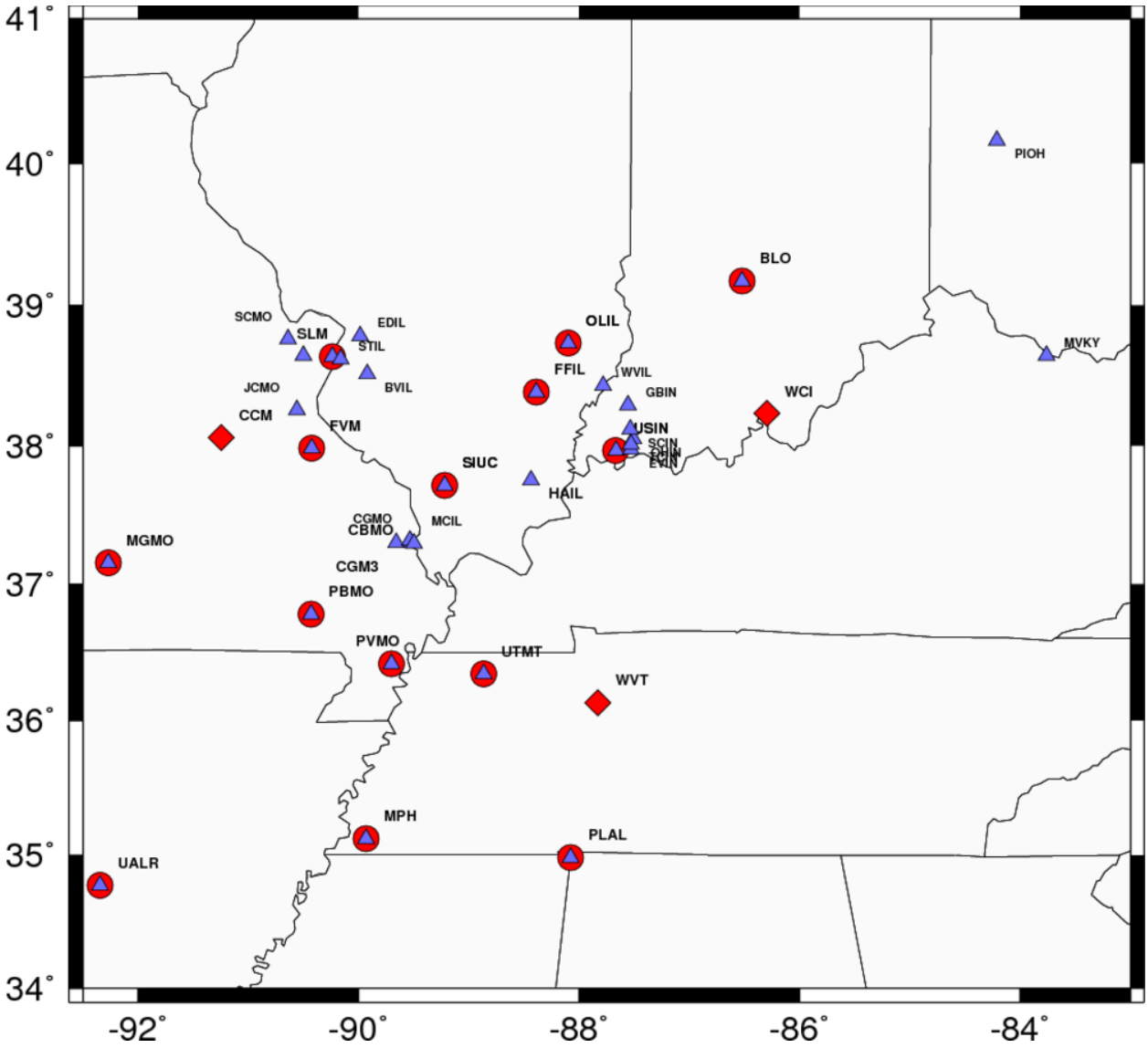

Fig. 2. Locations of SLU digital seismic stations. Red circles are broadbands; blue triangles are accelerometers. CCM, WVT and WCI are IRIS stations supported independently. SLU records a few analog streams for public relations.

2. Summary of yearly accomplishments

The following sub-sections provide a review of activities during each of the 5 years of this completed cooperative agreement.

2.1 Year 1 (FY 2010)

SLU quickly implemented ARRA upgrades at most sites. For most sites, this represented just an upgrade of the data-logger to a Q330 and the installation of the accelerometer (Episensor) at the site.

The ARRA upgrades also provided rack mounted servers to update data acquisition and data forwarding.

The FVM station, not part of the ARRA upgrade, was in the process of being upgraded. The problem was in finding a suitable replacement for an ISDN line for data communication since the additional equipment would require greater bandwidth; the station is now being converted to use a cell model. The other site using ISDN, PVMO, has been upgraded and uses DSL now. The MGMO station transmission problems due to the use of spread-spectrum over a path that was affected by an intervening road and agriculture now uses a shorter link since the host institution has provided an internet drop at a nearby meteorological station. The CMG5-TD accelerometer at MVIL in metropolitan St. Louis must be moved because of campus construction.

We have implemented SEEDlink on the rack mounted servers with a view of replacing the current Earthworm method of data forwarding. The objective is to acquire all Q330 data streams (broadband and accelerometer) and CMG5-TD data streams in one data buffer for more automatic and reliable data forwarding to ANSS data centers and to the IRIS archive.

Currently all Q330 data streams are archived at IRIS.

2.2 Year 2 (FY 2011)

The Saint Louis University Earthquake Center web page was redesigned.

The previous web page was initially designed in 1995 and was subsequently expanded to present general information about earthquakes and detailed information about network performance. The new web page URL is

http://www.eas.slu.edu/eqc/

This web page follows the preferred design for the Saint Louis University web pages, and is organized to provide quick access to information. The major headings are

Earthquakes – links to USGS/ANSS recent locations, SLU moment tensors, significant regional earthquakes, earthquake damage photos from our archive, and posters for download

Seismology at Saint Louis University - biographies of seismologists and a history of earthquake monitoring 1909-2011.

Seismic Network – links to ANSS, SLU and CERI. Sidebars provide links to details about the network. The usual helicorder plots are still there, but new pages present "Today's real time seismograms"? And "Yesterday's real time seismograms."

The latter two displays are very useful for a quick evaluation of data quality and significant earthquakes. All accelerometer channels are displayed together with all BH broadband channels. Channels with no helicorder image are indicate by a large red square annotated with "NO DATA."

Publications – links to information posters and theses

Research – link to North American group velocity tomography

Field Deployments – currently a place holder

Software – currently links to the free Computer Programs in Seismology package

Geophysics Degrees -

Students – a history of students

The following changes were made to station operation:

CGMO – closed. This instrument was in the old vault in the science building on campus. Several years ago, there was a spill of americium in a chemistry lab directly above the seismic vault. The Southeast Missouri State University in Cape Girardeau, Missouri, decided to clean everything. We removed the CMG3-5TD accelerometer and are looking for a place to install the sensor.

MVMO – closed. This site on the campus of Maryville University, St. Louis, Missouri, was always a problem. The decision to build student housing on the athletic fields caused this station to be moved. We are negotiating to install CMG3-5TD instrument about 3 km east on the campus the CBC High School.

FVM – We finally switched added an accelerometer to the existing broadband, replaced the older Q380 with a Q330 and now use a cell modem instead of ISDN.

SIUC – The instrument was removed from the noisy (air handling noise at 16 and 18 Hz) geology building basement to a site about 2 km south. This move was part of the ANSS upgrade.

OSAR – This station of the University of Arkansas, Little Rock, consists of a Q330 with hi/lo gain episensor channels. SLU forwards the data stream from the Q330 to CERI and IRIS through SEEDLINK.

The following changes were made to the SLU data collection center operation:

Data transfer to CERI using SEEDLINK. NEIC still gets data through Earthworm.

A CWB (continuous wave buffer) was locally installed to provide rapid access to the last 14 days of all data streams. The purpose is primarily for QC purposes.

A special web page was created for the August 23, 2011 Virginia earthquake. Links are provide to SLU moment tensors, and an up-do-date tabulation of aftershock locations. The most recent being 2011/11/27 09:26:43.

http://www.eas.slu.edu/eqc/eqc20110823.html

2.3 Year 3 (FY 2012)

There were no major changes in station operation during 2012. We received a replacement for the Episensor at FVM which will be installed soon.

The next figures present some interesting recordings.

A major tornado caused significant damage and fatalities early in the morning of February 29, 2012 at Harrisburg IL. The CMG-5TD accelerometer at the Southeast Illinois College (HAIL) recorded the passage of the tornado until internet and power were lost. The College sustained minor damage to some buildings and lost a greenhouse. The accelerogram is shown in Figure 3. It seems as if the tornado has already passed because the amplitudes seem to decrease. It is our hope that the single board computers to be installed at the CMG-5TD sites will preclude such data termination of interesting signals. Access to this station was restricted for many months because of local damage,

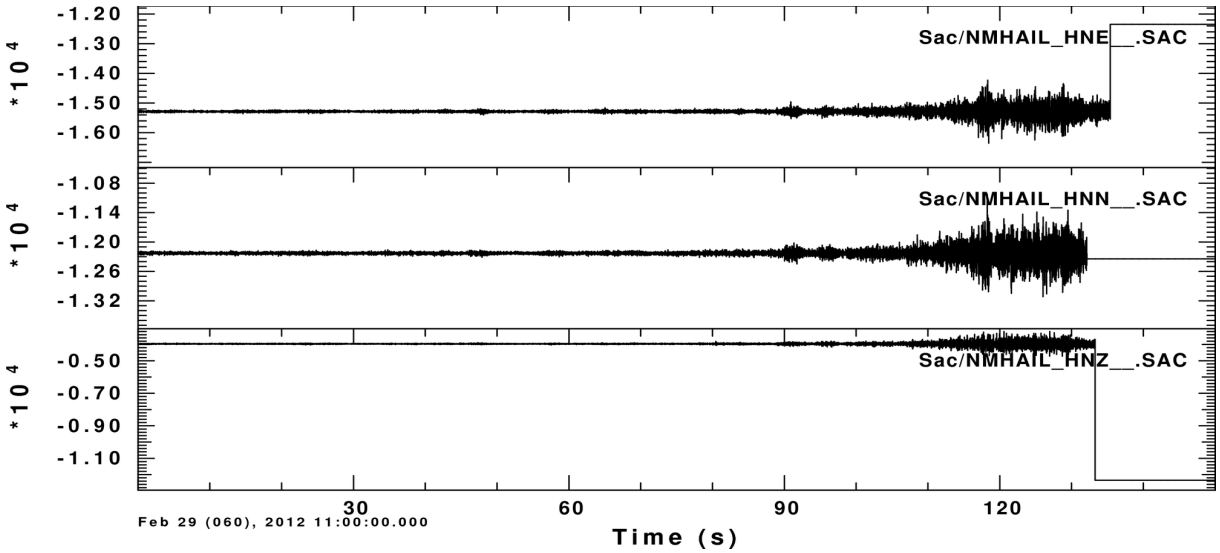

Fig. 3. Accelerogram recording at HAIL. The step at the end is a zero fill that indicates the end of the digital data. The units are digital counts.

Besides plotting instrument responses and checking noise, we watch for teleseisms whose ground motions are large enough to be observed on the CMG-5TD accelerometers, which are not as sensitive as the Episensors at other sites. We focus on the Mw=6.3 Queen Charlotte Islands region of Canada earthquake of October 28, 2012 at 03:04:11. Figure 4 shows some of the deconvolved ground velocity (m/s) recordings in the 0.1 – 0.2 Hz band near the P-wave arrival. In the arc distance range of 31 – 35 degrees, we do not expect the P-wave amplitude to change much. The accelerometer channels are indicated as HNZ and the broadband channels are denoted as HHZ or LHZ. In the left frame, SCMO, JCMO, EDIL, STIL and BVIL are CMG-5TD accelerometers while MGMO and FVMO have broadband sensors and Episensors for accelerometers. In the right frame, PVMO, BLO and USIN have broadband sensors and Episensors while GBIN and SCIN are CMG-5TD's. Although GBIN (right frame, third one down from the top) looks as if it is malfunctioning or has incorrect metadata, a similar comparison for the surface arrivals shows an excellent comparison. This highlights the need to be

careful and to use high signal-to-noise arrivals for comparison. We were surprised that this worked so well for just an Mw=6.3 earthquake at 30 degrees.

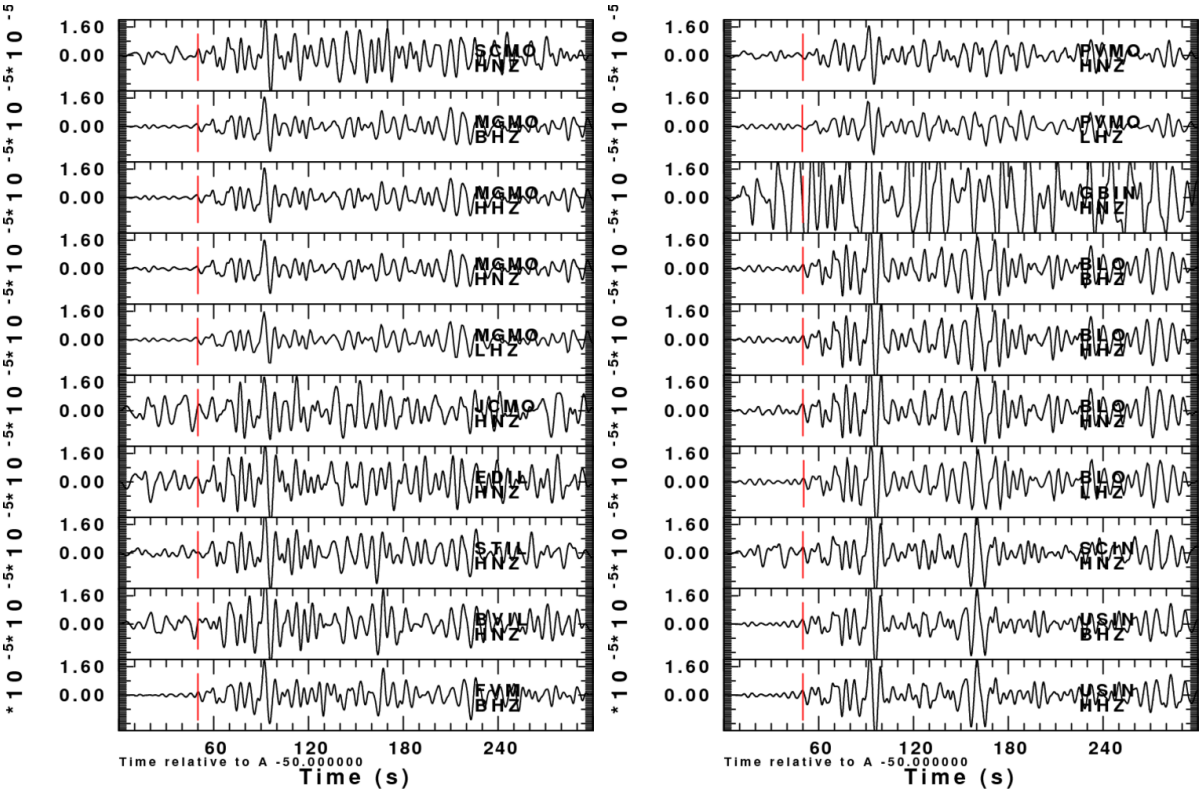

Fig. 4. Comparison of deconvolved ground motions. The red tic indicates the predicted P-wave first arrival time. Amplitudes are ground velocity in m/s.

2.4 Year 4 (FY 2013)

We installed a long planned broadband/strong motion station at Fairfield, IL (FFIL, 38.381N 99.389W). The dataless have been distributed to NEIC and to IRIS. The reason for installing this station in the Wabash Valley is the historical record of significant earthquake about every 10 years. In April, 2008, the ANSS stations in the Wabash Valley provided significant data for scientific papers and for ground motion scaling studies.

We have begin site preparation for the installation of CMG-5TD accelerometers at Christian Brothers College High School in St. Louis and at the Southern Illinois College extension site in Carmi, Illinois. The first site is about 2 miles east of the Maryville University site that had to be closed because of university construction. The Carmi site is in the Wabash Valley Seismic Zone and will be well positioned for the next earthquake there.

Preparatory work is being done at the station FVM. The instrument vault is about 300 meters from the communication tower, and the underground cabling is failing after 40 years. We hope to make progress on this before the end of this award period. However, since this may involve the installation of a new trench, we will ask that the use of carryover funds be permitted. We are working on a new power system and the infrastructure to convert to fiber.

We have replaced the Guralp CMG-3EPS broadband sensors at PBMO (Poplar Bluff, MO) and SIUC (Southern Illinois University Carbondale) with Nanometrics Trillium 120's.
In order to obtain data from GBIN, at the Toyota plant, we have located a position from which to transmit the data. We are still awaiting final approval.

We are systematically upgrading the CMG-5TD sites by adding an SBC (single board computer) running Scream under LINUX. This provides redundant data storage at the site including the 200 Hz channel and also permits continuous 100 HZ data streams to be transmitted to St. Louis University without gaps. Two systems have been upgraded with the result that uptime has been improved.

2.5 Year 5 (FY 2014)

Operations have proceeded as expected. The strong motion station MVMO was removed because the university repurposed the site for a dormitory. We began negotiations with the Christian Brothers College High School about 6 km away for a new siting.

3. Operations

Although archive percentages at IRIS are quite high (> 98%) (IRIS GOAT interface http://www.iris.edu/data_available/NM?timewindow=2014-2014) except for a few stations, we have had significant problems with real-time latency recently in 2014. Simply stated we are being affected by an increasingly urbanized technological society. The land use problem has caused us to close stations and then to re-site the sensors as hosts have reutilized their property. An urban strong motion station at Maryville University in St. Louis was closed when the site near an athletic field was selected for a new dormitory.

Although having to relocate stations is inconvenient, our current problem is due to the fact that the internet information highway, long known to be dangerous, is affected by excessive traffic. As mentioned above, most of our field installations have a local router to connect the public internet to the field systems and also to permit communication between the dataloggers and local storage systems (Baler for Quanterras an SBC for CMG3-5TDs). These routers seem to be overwhelmed by high volumes of network traffic or by scanning from the hosting network and/or external sources. We are in the process of evaluating replacement routers that will filter incoming packets to exclude those from addresses that are not ours. This problem appears not only on direct internet connections but also with traffic on the commercial cell phone network at a few sites.

The university is requiring us to physically move the Earthquake Center to another building. After the move Macelwane Hall will be solely used by the Department of Biology. The reason for this change is to permit an increase in undergraduate enrollment in the College of Arts and Sciences by giving Biology needed space. Current planning moves us to Ritter Hall which will have significant improvements to infrastructure to meet our department's needs for reliable internet access,

uninterruptible power and cooling in support of real-time meteorological forecasting and the Earthquake Center. As the specifics develop for a move in late Spring of 2015, we will make plans for a relatively uninterrupted impact on Earthquake Center data acquisition and forwarding by running systems in parallel and then switching computers. Of course if we must change our computer subnets, and we hope that this is not necessary, the transition may take longer because of the need to interact with each field system individually. Although there may be an interruption in data forwarding, all continuous and triggered data are stored independently at the field stations, so no archivable data will be lost during the move.

One advantage of the move is that our labs in support of the network will be physically adjacent to each other and that the labs be designed to be true labs with adequate storage and functionality. The public area of the Earthquake Center will be more accessible to visitors than the current third floor location of Macelwane Hall. Finally, the move presents us with a unique opportunity to clean up our labs.

As indicated above, SLU does not operate a Tier I network and data center, but rather supports the Tier I Mid-America region network. Except for a few small events, SLU does not locate earthquake or forward phase information. This is a function of the regional hub at the University of Memphis. The SLU effort is directed toward collecting and forwarding high-quality data streams to the University of Memphis, NEIC and to the IRIS DMC.

The SLU Earthquake Center website (http://www.eas.slu.edu/eqc) serves as a means for public education and awareness about earthquakes in the region and a place to describe the operation of the seismic network. The structure of the web pages also assists seismic network management by providing descriptions to stations as well as metadata. Finally the pages act as an effective means to disseminate research products that are related to the national and international earthquake problem.

Details about the current seismic network can be found at http://www.eas.slu.edu/eqc/eqcnetwork.html. This page is shown in Figure 5. The related sub-links in the left column are as follow:

- Network Description – provides a map showing the locations of all stations and a listing providing links to detailed descriptions that include site photos, links to dataless SEED and plots of instrument response history.
- Today's real time seismograms – these are plots of real time data for all recorded channels. The condition of No Data is also indicated
- Yesterday's real time seismograms – these are similar plots. These plots exists to show the public seismograms, but also provides a fast visual inspection of data streams.
- Seismograms for the last 7 days
- Network operations – this provies information on how to get data less seed, seismic data as well as other notes on network operation.

EARTHQUAKE CENTER

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Seismic Network

The Saint Louis University seismic network is supported through a cooperative agreement with the United States Geological Survey to provide a stream of calibrated digital seismic data as a component of the Advanced National Seismic System.

The seismic network uses two types of sensors: acceleration and broadband. The difference is that the first is a low sensitivity instrument designed to capture very large earthquake motions on scale, while the second provides on-scale recordings of small local and large distance earthquakes.

The Saint Louis University component of the ANSS monitors a broad region of the central United States where significant earthquakes have occurred in the past 200 years. In addition accelerometers operated in urban areas to record motions of engineering significance.

ANSS - Advanced National Seismic System

Seismic networks monitoring US earthquakes that are supported by the U.S. Geological Survey operate according to the standards of the ANSS.

- http://earthquake.usgs.gov/monitoring/anss/

In the Central United States, the two moniforing networks are the

- Saint Louis University Earthquake Center
- Center for Earthquake Research and Information at the University of Memphis.

You can find more information about the Center, seismology, and many other earthquake-related topics by visiting the Center's homepage, or by contacting Dr. Robert Herrmann.

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Fig. 5. Earthquake Center web page for the seismic network..

4. Personnel

Robert B. Herrmann is the Principal Investigator for this project. His interests are in earthquake hazard, including seismic network operation, earthquake source parameters, ground motion scaling, and development of computer software in support of these topics. His web page is http://www.eas.slu.edu/People/RBHerrmann.

Eric Haug, Electronics Engineer, is responsible for all technical aspects of the SLU broad-band systems, including installation, maintenance, monitoring data acquisition, programming and managing the data archiving. He has an M. S. E. E. and has designed seismic data acquisition equipment, both the electronics and digital computer implementation. He has 30 years experience of low level (kernel) UNIX programming to the project. He has been working with the seismic networks at Saint Louis University for more than 40 years. He is currently paid roughly half time by university funds to ride herd on the department's computer systems.

Melanie Whittington, Data Technician, is responsible for routine observatory operation, e.g., daily monitoring of computer performance, data ingress as wekk as being a focal point for public

information. She verifies the archiving of the digital data in SEED at the IRIS DMC. Melanie has been working with the network for over 30 years, and has recently improved our home page with a collection of photographs from damaging earthquakes. ≈

R. Wurth, Computer Technician, is the departmental technician responsible for PC's, meteorological instrumentation and other general services to the department. Bob maintains broadband stations as well as the ANSS Urban Hazard accelerometers installed during 2002 and 2003. He is a qualified electronic technician who works well with the seismic network staff at the University of Memphis.

As of February, 2015, Dr. Linda Warren and Dr. Lupei Zhu are co-PI's on this project.