Award Number: **G09AC00493**

Title: **Upgrade Selected Western Great Basin Seismic Network Stations and Infrastructure**

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Abstract

This award provided funds to upgrade fifteen Nevada Seismic Network stations located in Nevada and Eastern California with modern dataloggers and high-quality broadband sensors and accelerometers. Among the 15 stations, nine were legacy RT72A/S-13 sites that were managed through now discontinued analog communications bands, four were formerly analog stations, and two are new sites. Of the two new stations, one replaces legacy broadband station WCN, and the other, a strong-motion recorder, is co-located at a communications site near Reno. Analog station upgrades involved a virtual rebuild, including solar, communication/enclosure tower, and radio equipment. All upgraded stations now include strong-motion sensors, which allow use of their data in ShakeMaps. All stations are now on digital, IP-based communications, and most mountaintop collection points have redundant communications paths back to the UNR Data Center. Two ARRA-furnished Basalt dataloggers were deployed to digitize a total of six analog stations at two mountaintops. ShakeMap 3.5 was deployed with support from the award, and now is in production; ShakeMap is also now the primary input for HAZUS damage estimates. Award support also allowed the implementation of moment-tensor estimation code in support of ANSS requirements for magnitudes of moderate and larger regional earthquakes. Extensive development resulted in modern web based capabilities for location/magnitude information and mapping. UNR was an early adopter of the EIDS information exchange, and this system is now the primary means of parametric information exchange with ANSS partners including the NEIC. Award support also allowed the installation and integration of Linux servers for data storage and processing, to replace aging Sun computers. These computers will help improve reliability of network operations, and allow the use of a wider range of support software solutions.

Introduction

The Western Great Basin Seismic Network (WGBSN) operates in Nevada and eastern California (Figure 1) to provide earthquake location, magnitude, and seismic hazard information to the public and as a cooperating network of the Advanced National Seismic System (ANSS). The objectives of ANSS American Recovery and Reinvestment Act (ARRA) investments in the Western Great Basin Seismic Network were to improve seismic data quality, network product development, timeliness of products, and ANSS integration. To improve seismic data quality, fifteen stations were programmed for either modernization or replacement to achieve datalogger and sensor configurations meeting ANSS performance standards. Eleven of the 15 stations were programmed to receive broadband sensors, the goal of which was to improve the quality and station density available for regional moment tensor development and to support overall western U.S. ANSS objectives. Network product development included implementation of ShakeMap 3.5 in an operational context and a follow-up path for HAZUS input. The capability to compute moment tensors for all regional events was implemented and MT results for Nevada and CA/NV border events compare very well with CISN regional and NEIC solutions. This provides a high level of confidence for finite source input to both ShakeMap and HAZUS; scenarios for evaluating HAZUS output are now routinely developed with scaled finite-source models from M > 4 regional earthquakes as essentially near real-time planning exercises. Timeliness of product delivery was supported by investments in computer infrastructure and the implementation of earthquake reporting via EIDS. NSL Data Center protocols for EIDS updates and remote event reviews, including MT solutions, were worked out and implemented during the ARRA program. Together these steps promoted system performance of the WGBSN as a cooperating partner in ANSS. ARRA upgrades had to be implemented in conjunction with spectrum relocation activities on literally all communications links affected by the ARRA program. In fact, temporary long-haul communications solutions were required prior to ARRA station upgrades. Work to accomplish ARRA objectives posed a number of engineering challenges, but had widespread benefits for all aspects of seismic network operations and resulted in important lessons learned for the future of Nevada earthquake monitoring.

Permanent Network Station Upgrades

Fifteen stations were programmed for upgrade or replacement (Figure 1). The goals of station upgrades included replacement of obsolete dataloggers, improvement of station reliability, augmentation of bandwidth in seismic recordings, improvement of strong-motion coverage, improvement in earthquake magnitude estimation, and improved coverage in eastern California.

Three types of datalogger systems were replaced. The oldest consisted of one- or two-component short-period sensors with analog voltage-controlled oscillators (VCOs), and analog UHF radio telemetry at the station, and discriminators and a multiplexed 12-bit digitizer at UNR. Also in use were custom-built 16-bit digital measuring systems on simplex UHF radio telemetry. These used an innovative (for its time) system of gain-ranging to record to higher dynamic range. The most modern dataloggers, Reftek RT72A 24-bit systems, were ~12 years old, communicating to UNR via 9600 baud UHF-frequency modems. Upgrade was important because both the field and UNR components were aging, and parts are no longer available. Also, the analog backbone telemetry system to the stations was being discontinued under federal spectrum relocation activities. ARRA upgrades of these dataloggers thus improved data quality and moved systems to supported hardware and modern digital telemetry, thus enhancing maintainability and reliability.

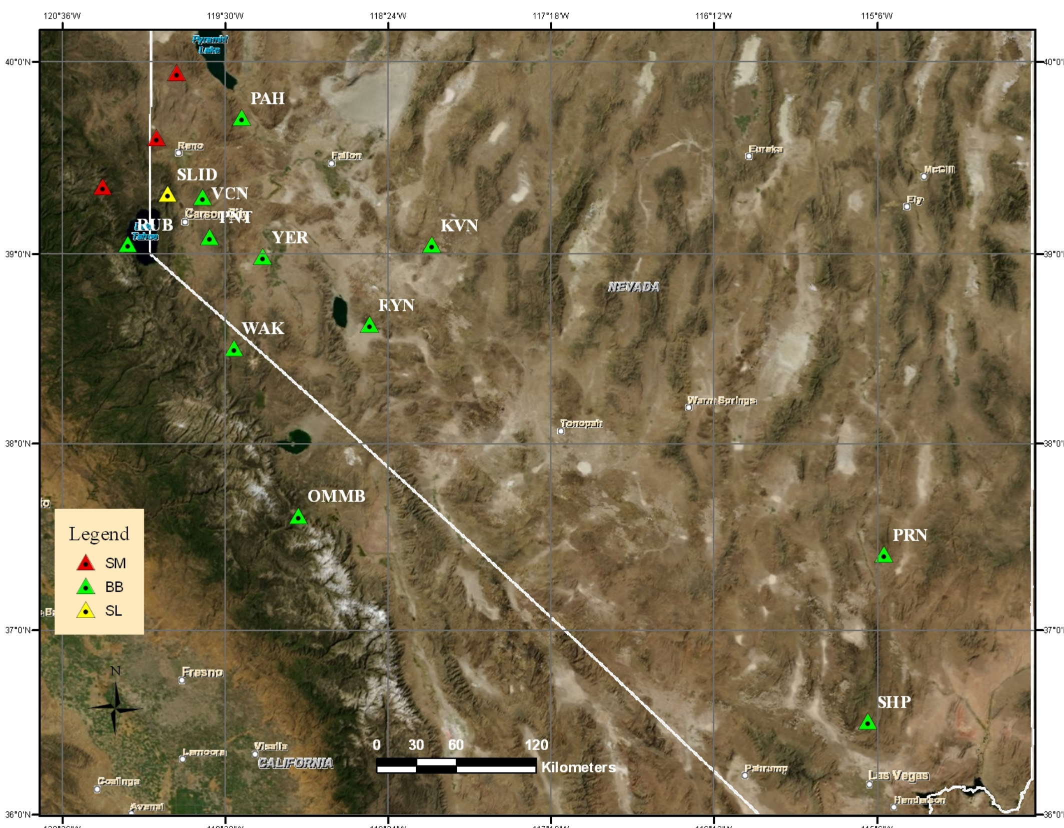


Figure 1. Green triangles: upgrade to broadband sensors and accelerometers. Red triangles: ARRA upgrade replaced dataloggers and added accelerometers; from north to south, stations WVA, PEA, and DON. Yellow triangle: Basalt recorder and strong motion sensor. IP communications were added to all stations; power system improvements were made to most sites.

Sensor upgrades to eleven sites significantly improved recording bandwidth and resolution of regional moment tensors. Prior to the upgrade, stations operated with a mixture of sensors, including ancient SL210/SL220 10-20 second free-period passive seismometers, single and multiple-component short-period passive seismometers, and a few very early-model CMG-40 intermediate period active sensors. None of these sensors had long-period noise characteristics suitable for use in regional moment tensor estimation. Stations were selected for upgrade to broadband seismometers based on rough guidelines to separate them by ~50 km or more where the network density is high, and to fill significant holes where M>3 earthquakes would otherwise be poorly recorded. Three stations with three-component S-13 1-Hz seismometer installations did not receive broadband upgrades. All ARRA upgrade stations had or received as improvements strong-motion sensors, either with as Reftek RT147 or Kinemetrics Episensor accelerometers. Strong-motion sensors ensure that ground motion is recorded on scale, and support ground-motion mapping for ShakeMap.

STATION UPGRADES:

PAH (Pah Rah Range, NV): An RT72A datalogger on analog telemetry and early model CMG-40T were replaced with a Reftek RT130 datalogger and Nanometrics Trillium 120 broadband sensor. Digital telemetry was installed to communicate with the backbone telemetry node at Virginia Peak. The Reftek MEMS accelerometer at the site was retained. Improved data quality/reliability at PAH has contributed to geothermal monitoring activities in the Pyramid Lake area.

KVN (Kaiserville, NV): This station was installed in the 1980's at about the 100' level in an abandoned inclined mine adit. As a safety measure and because of impracticalities related to cable lengths and GPS timing, the sensor and datalogger were relocated to the surface. A shallow vault was installed on rock a few meters away from the original communications mast and about 80 meters in map view from the original location. A new Rohn tower was installed with solar panels and boxes for the datalogger and batteries. This station communicates via a 900 MHz radio link to the NSL Fairview Peak communications site.

RYN (Ryan, NV): RYN was initially a single-component analog station digitized by an Earthworm digitizer at UNR. RYN was upgraded to an RT130 with broadband and strong-motion sensors. Analog simplex telemetry was replaced with a duplex spread-spectrum radio system linked to mountain top site TV Hill. A new communications tower was installed with mounted boxes for the datalogger, batteries, and solar panels. RYN replaced another station initially programmed for upgrade when detailed engineering indicted the initial plan would incur untenable long-term maintenance and support costs. A T1 circuit brings data from TV Hill to UNR enabling digital telemetry from RYN.

WAK (Walker, CA): An RT72A datalogger and three S-13 short-period sensors were replaced with an RT130 and Trillium 120 and strong-motion sensors. The replacement vault is on granite, giving the site good noise properties. It communicates via a newly installed spread-spectrum radio to Slide Mountain.

This fairly long 900 MHz shot was tested prior to WAK upgrade; fortunately this is low-noise path.

PRN (Pahroc Range, NV): This station is in southeast Nevada along the Highway 93 corridor. It was initially a two-component analog station connected via a long radio shot to western Nevada, and digitized at UNR. A new broadband vault was constructed, and broadband and strong-motion sensors installed with an RT130 datalogger. Communications were the primary challenge at PRN. Initial experiments with Freewave 900 MHz radios were unsuccessful due to the limited bandwidth of the radios and interference at the receive site. Ultimately a Microtik 4.9 GHz backhaul radio was implemented. These radios have the bandwidth and range of long-haul telemetry solutions but are lower cost and have lower power consumption. In addition, the 4.9 GHz band is reserved for emergency response uses, reducing interference. PRN is approximately a 1000 mile round trip from UNR.

RUB (Rubicon – Lake Tahoe, CA): This station is on the west side of Lake Tahoe in eastern California. The upgrade followed the pattern of WAK, replacing an RT72A and S-13's with an RT130 and Trillium 120 and strong motion sensors. This station communicates via spread-spectrum radio to Slide Mountain on the Carson Range east of Lake Tahoe. RUB is currently the only broadband station in the Lake Basin.

VCN (Virginia City, NV): VCN was installed in Virginia City as a replacement for station WCN. WCN became unsupportable due to vandalism and an aging power system. VCN was sited as a cooperative with Storey County Emergency Management, under which communications to the site could be leveraged for other applications. Station VCN includes an RT130 and broadband and strong-motion sensors. At installation the potential was recognized for above average (for Nevada) noise at the vault, and alternative new sites nearby are being considered. This site provides the only monitoring for the Virginia City underground mine workings. VCN communicates by spread-spectrum radio to McClelland Peak, which also provides direct communications between the Reno Data Center and the Nevada Division of Emergency Management (DEM) in Carson City. Upgrades to the communications system at McClelland Peak have improved data communications with Nevada DEM.

OMMB (Mammoth Lakes, CA): The Old Mammoth Mine (OMM) station was sited ~100 m inside an adit on an inactive gold property near Mammoth, California. However, mining restarted, and with GPS and IP cabling issues, an alternate site was considered preferable. A surface site on rock was identified nearby, and permitted with instrumental help from the USGS. By informal convention for relocated stations, the site was renamed OMMB. The site operates with an RT130, Trillium 120, and accelerometer, and communicates by Microtik 4.9 GHz Backhaul radio to TV Hill near Hawthorne, Nevada.

Figure 2. Radio and solar installations, station OMMB in the Long Valley area.

<u>SHP (Sheep Range, NV):</u> The Sheep Range site upgrade consisted of replacing the RT72A and S-13 1-Hz sensors with an RT130 and Trillium 120 and strong-motion sensors. This station now provides broadband coverage of the area immediately north the Las Vegas, filling a significant hole in network coverage. The new vault is on granite, providing good coupling and reduced noise. Solar panels were replaced, and a spread-spectrum radio installed for IP communication to Angel Peak west of Las Vegas.

<u>PNT (Pine Nut Range, NV):</u> Station PNT in NW Nevada initially operated as an analog short-period station. Like RYN, it was elected to replace a planned ARRA station that proved unacceptable under more detailed evaluation. Station upgrade details are as for station RYN. PNT communicates by spread-spectrum radio to McClelland Peak north of Carson City.

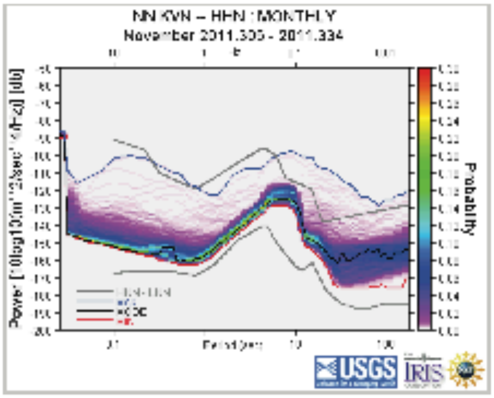
<u>YER (Yerington, NV):</u> The upgrade of station YER near Yerington, Nevada follows the pattern of SHP, with broadband and strong-motion sensors replacing a set of S-13's. This station provides coverage of the east side of the populated area of western Nevada, and now contributes to regional moment tensor calculations. It communicates by IP spread-spectrum radio to TV Hill.

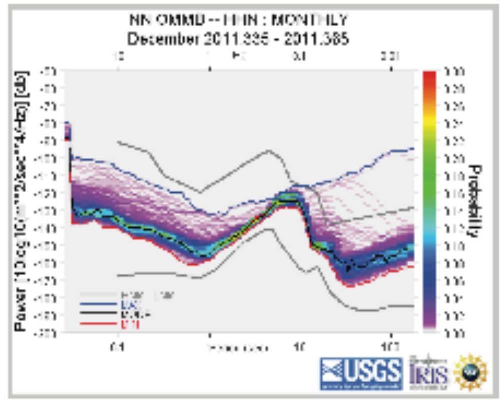
<u>WVA, DON, and PEA (Winnemucca Valley, NV; Donner Lake, CA; Peavine Peak, NV):</u> These station upgrades consisted of replacing the RT72A dataloggers with RT130's and adding strong-motion sensors. Geotech S-13 sensors were retained because in each case there is sufficient broadband station coverage from nearby stations that regional moment tensors can be developed. In the case of DON, a cell modem was employed to replace the radio set DON formerly used on the analog telemetry infrastructure.

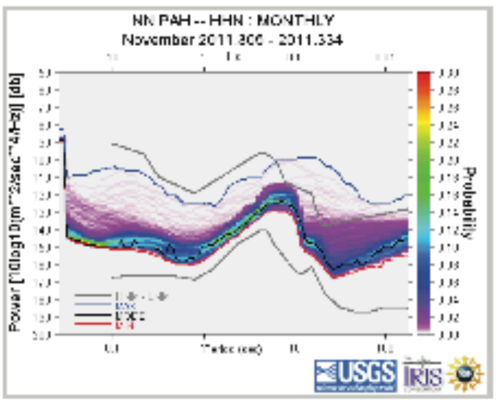
SLID (Slide Mountain, NV): SLID is the one ARRA station programmed and installed as a Basalt datalogger and accelerometer. SLID is between Reno and Lake Tahoe, and near recurring moderate seismicity north and northeast of the lake. It replaced the planned upgrade of WCK near Long Valley. SLID connects directly to IP trunk communications on Slide Mountain.

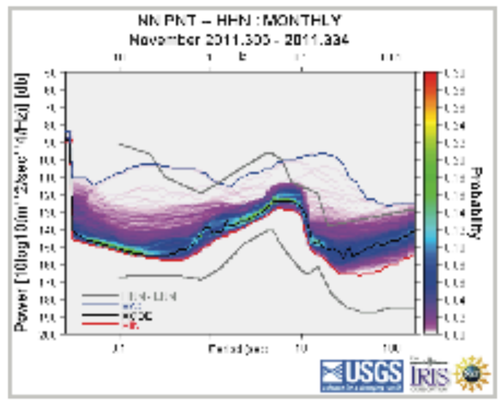
Figure 3 shows station noise power density functions for the eleven ARRA stations upgraded to broadband sensors. For brevity only the north component of each is shown, but they are representative of noise levels on other channels. Stations RYN and VCN have Reftek RT151 120 second sensors; all others are Nanometrics Trillium 120's. Station noise performance is uniformly between the Low Noise Model and the High Noise Model bounds, indicating that the vault solution used for upgrades is performing reasonably. Station RUB is in a forested area on the west slope facing Lake Tahoe. Wind noise in the trees may be responsible for its less well-resolved probability function. Complete station noise PDFs are available at: http://www.iris.edu/servlet/quackquery/ .

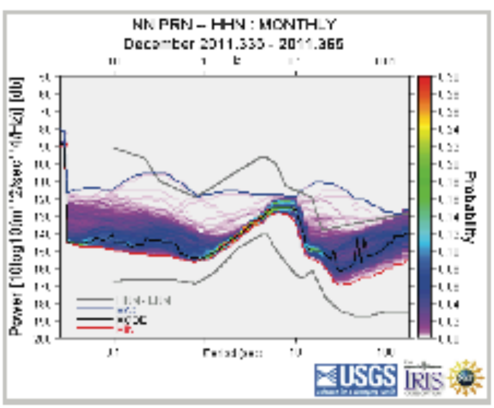
Figure 3. (Below, spanning two pages). Noise power density functions for the 11 broadband stations upgraded under this ARRA grant. The north component of each is shown, but is representative of all three components. Station names are given in the plot titles.

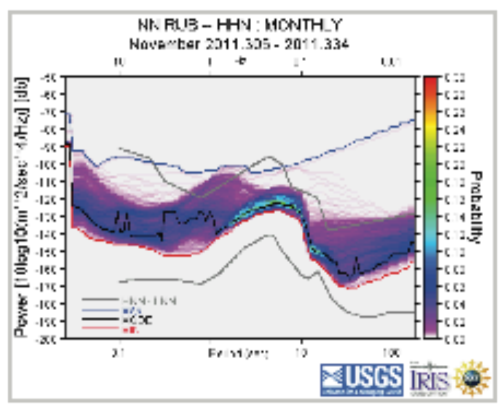

NN KVN -- HHN : MONTHLY
November 2011.305 - 2011.334
Power [10log10(m**2/sec**4/Hz)] [db]
Period (sec)
Probability
USGS
IRIS

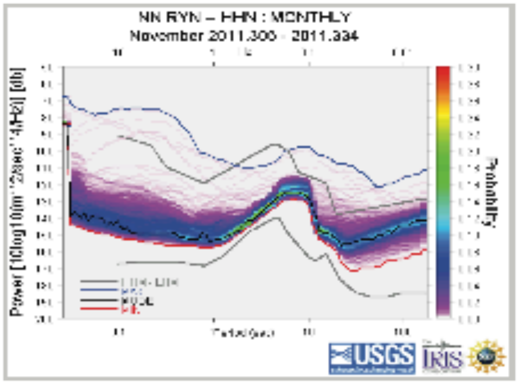

NN OMMD -- HHN : MONTHLY
December 2011.335 - 2011.365
Power [10log10(m**2/sec**4/Hz)] [db]
Probability
USGS
IRIS

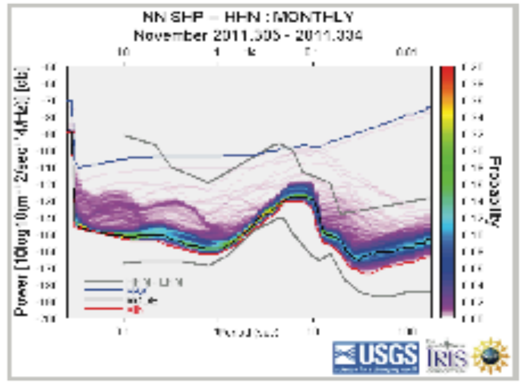

NN PAH -- HHN : MONTHLY
November 2011.305 - 2011.334
Power [10log10(m**2/sec**4/Hz)] [db]
Period (sec)
Probability
USGS
IRIS

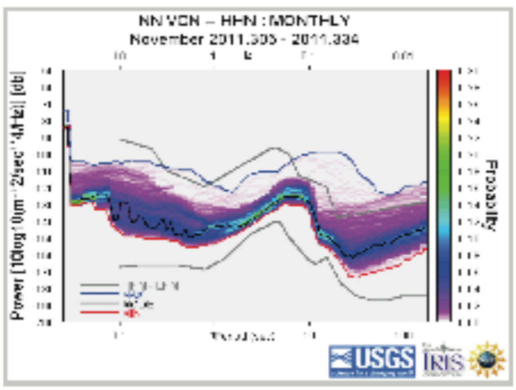

NN PNT -- HHN : MONTHLY
November 2011.305 - 2011.334
Power [10log10(m**2/sec**4/Hz)] [db]
Period (sec)
Probability
USGS
IRIS

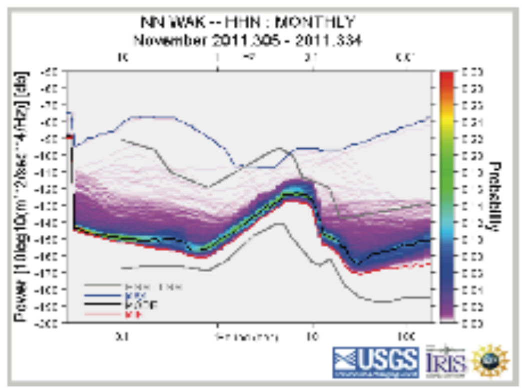

NN PRN -- HHN : MONTHLY
December 2011.335 - 2011.365
Power [10log10(m**2/sec**4/Hz)] [db]
Period (sec)
Probability
USGS
IRIS

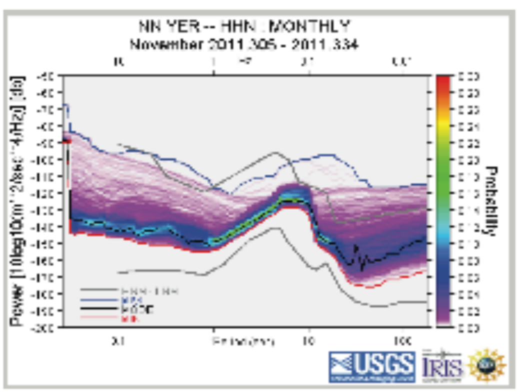

NN RUS -- HHN : MONTHLY
November 2011.305 - 2011.334
Power [10log10(m**2/sec**4/Hz)] [db]
Period (sec)
Probability
USGS
IRIS


NN RYN -- HHN : MONTHLY
November 2011.305 - 2011.334
Probability
USGS
IRIS


NN SHP -- HHN : MONTHLY
November 2011.305 - 2011.334
Probability
USGS
IRIS


NN VCN -- HHN : MONTHLY
November 2011.305 - 2011.334
Probability
USGS
IRIS


NN WAK -- HHN : MONTHLY
November 2011.305 - 2011.334
Power [10log10(m**2/sec**4/Hz)] [db]
Probability
USGS
IRIS


NN YER -- HHN : MONTHLY
November 2011.305 - 2011.334
Power [10log10(m**2/sec**4/Hz)] [db]
Probability
USGS
IRIS

NetQuakes Stations

The WGBSN received five ARRA NetQuakes recorders for deployment in western Nevada. These recorders were designed to be a low-cost means to improve station density in urban areas. NetQuakes recorders are normally installed on the concrete foundations of small 1- and 2-story buildings or garages where the site host can provide or accommodate wireless internet access. Stations are sometimes deployed in schools as a way to leverage interest in seismic safety and community engagement/outreach. ARRA NetQuakes stations have been installed as follows:

> **RENO3, Sage Ridge School (Reno), NV:** This station was installed following a small swarm of activity just west of the school beneath the Carson Range in the Mt Rose fan area. The station provides monitoring for the numerous Holocene faults along the Mt. Rose fan area in south Reno.
>
> **STYIT, Storey County:** Provided the first strong-motion coverage for Virginia City. This station has the potential to record larger collapses from historic mining activity deep beneath the town. It is hosted by the Storey County Emergency Management office and provides avenues for improved interaction with Virginia City first responders.
>
> **TCES, Tahoe Center for Environmental Science:** This station provides strong-motion coverage of the east shore of Lake Tahoe and helps promote interaction between TCES and UNR.
>
> **MCSO, Mineral County Sheriff's Office:** This station was installed during the height of the 2011 Hawthorne, Nevada earthquake swarm. Activity was regularly being felt in the town of Hawthorne, but until it was installed, there was no nearby strong-motion station for the community.
>
> **LOSN, Our Lady of the Snows:** This station is in a relatively un-instrumented district of Reno and is on an older geologic terrace surface about which little seismically is known.

ARRA upgrades provided two Kinemetrics Basalt digitizers to assist in the telemetry transition from an analog backbone to all digital communications. Northwest of Reno, four short-period analog stations, SMI, EUR, LVO, and GZY, are collected and relayed through Virginia Peak to UNR. Discriminators were installed at Virginia Peak and configured as input to the Basalt. IP communications from UNR then completed the data routing. Similar changes were implemented to record stations EBP and SJC south of Carson City at the Slide Mountain telemetry relay. Non-ARRA funds were used to buy several more Basalt digitizers for telemetry nodes in western and southern Nevada. A 36-channel version (Kinemetrics "Rock" series Granite model) inherited from the Yucca Mountain network was deployed with digitizer racks at TV Hill near Hawthorne. Between them and in conjunction with spectrum relocation activities, analog trunk-line telemetry had been eliminated from the network.

The upgrade to Rock series digitizers was accompanied by some unexpected challenges. In particular, these units digitize at 24-bit resolution, whereas the inputs resolve ground motion only to 8-12 bits. Thus the additional resolution is presently unused. The change also highlighted noise sources including significant levels (compared to the noise floor of the digitizer) of cross-talk between channels. These problems have been reduced with attention to grounding and shielding, but have not been fully resolved.

Other Upgrades

ARRA support was also received to implement non-station upgrades. The upgrades included replacement of new servers, installation and integration of ShakeMap 3.5, implementing parametric data exchange through EIDS, and improvement of magnitude estimates by implementation of moment tensor code in the real-time system.

Computing systems: New Linux computers were installed to host waveform archives and to manage the interaction of auxiliary real-time systems. Computers were selected with reliability in view – dual power supplies, dual fans, well-supported Linux operating systems. These computers replaced aging Sun servers and small-capacity disk arrays. Two 2-Tb RAIDs now host waveforms and the database archive. Hosts are continuously monitored for operational issues and off-normal conditions using Nagios-based monitors. Other renovations completed along side of the upgrade included removing two racks of microwave analog telemetry modems, Reftek 72A modems, and high-speed serial network hardware. An underperforming large UPS was replaced several smaller rack-mounted units connected to the same diesel generator. Together these changes significantly reduced the heat load in the computer room. Computer room air conditioning was not on emergency power. To address this continuity of operations issue, an emergency air conditioning system was also added to meet the new reduced heat thresholds during building power and outages.

Shakemap 3.5: ARRA support was requested to upgrade the UNR installation of ShakeMap to version 3.5 and to improve its integration into network operations. ShakeMap was installed and integrated into a suite of applications that trigger and interoperate in the real-time system. ShakeMaps have been tested as the primary input for HAZUS damage estimates for the State of Nevada; systems are operational in anticipation of the next significant event in the Nevada region. Maps are now posted automatically for M3.5 and greater to the USGS web site: http://earthquake.usgs.gov/earthquakes/shakemap/nn/shake

EIDS: To improve real-time exchange of parametric data with ANSS partners including NEIC, EIDS was implemented, using ARRA support. UNR was an early adopter of EIDS. The real-time process integration system now exchanges automatic and near-real-time reviewed locations and magnitudes as they are developed. Software systems now recognize reviewed/relocated events and automatically post updates through EIDS.

Network Metadata: Network metadata for ARRA upgraded stations and the active network were completed in part with ARRA support. These metadata include response files and recording configuration from the time of station installation. These data are available at ftp://crack.seismo.unr.edu/downloads/Dataless/NN via anonymous ftp, and also mirrored at the IRIS DMC. Data from upgraded stations are shared in real time with CISN, NEIC, and the IRIS DMC.

Moment Tensor Inversions: To improve the accuracy and quality of real-time and reviewed magnitudes, ARRA support was solicited to implement moment tensor inversion code as a real-time process. This was ready for in-house exercise by late 2009, and is now part of the real-time processing stream. Real-time MTs solutions are posted internally for review prior to distribution on NSL web pages. Figure 3 is an example of the fit to regional waveforms from an Mw 4.0 event in the 2011 Hawthorne, Nevada sequence. Staff remotely access Data Center operations systems and interactively develop MT solutions for events of M 3 and larger. MT solutions are posted to the web site during remote processing and event review (http://www.seismo.unr.edu/Earthquake). Around 50 MT solutions for events of M >= 3 have been developed since July 2010; ARRA stations have substantially reduced uncertainties in MT solutions. Waveform fits are robust and consistent with UCB solutions in the eastern California area. This addressed a significant question about magnitudes developed by the WGBSN. The MT applications use available ARRA upgraded station data, and implement DHI SOD requests to NCEDC and IRIS for any additional data within specified distances. Therefore, in principle, MT solutions can be developed for any moderate western US event where reliable velocity models are available; i.e., NSL can provide backup for CISN MTs if necessary. Waveform data for all events and waveform fits are maintained at NSL. The MT inversion is performed with Gene Ichinose's MTINV package with front-end interface developed by Gabe Plank. Figure 4, 5, and 6 below show examples of MT solutions using combined UNR ARRA and CISN stations.

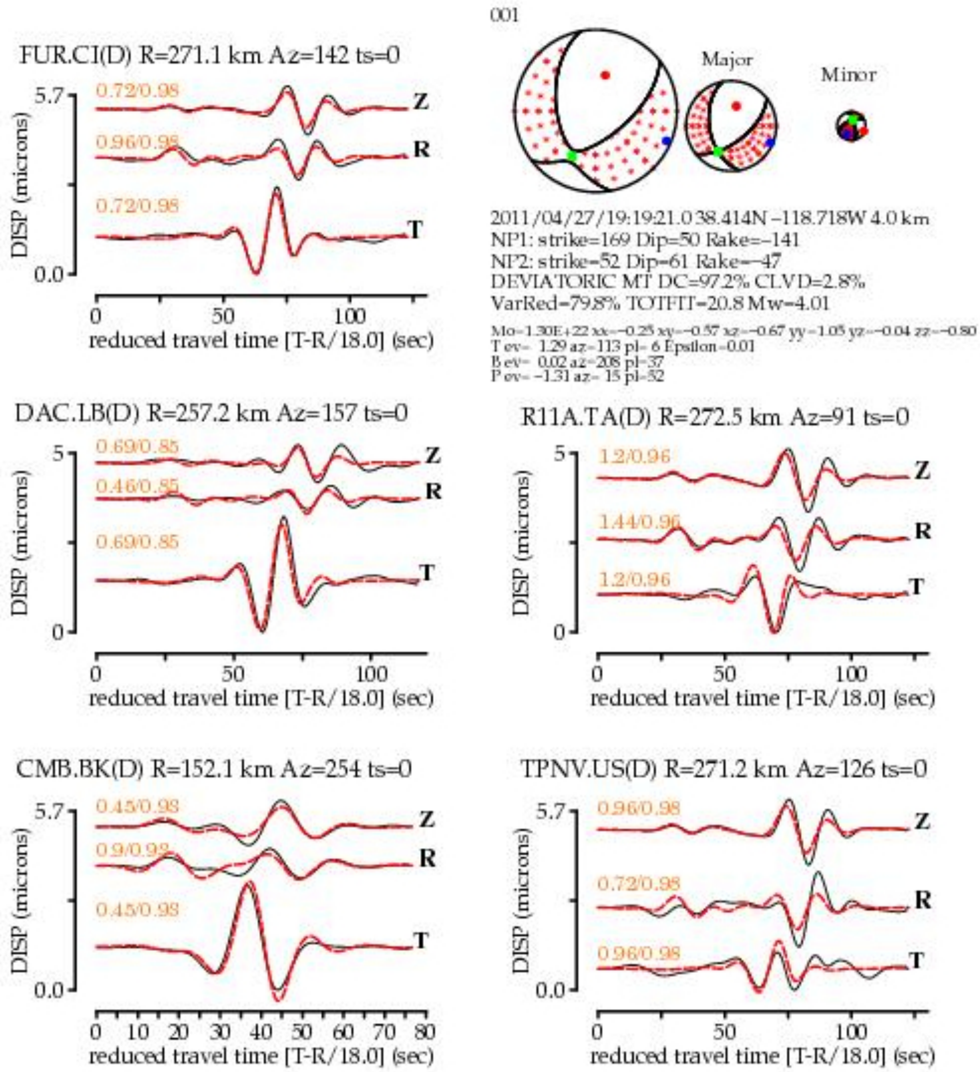


Figure 4. Example moment tensor fit developed for an Mw 4.0 event near Hawthorne, NV, May 12, 2011.

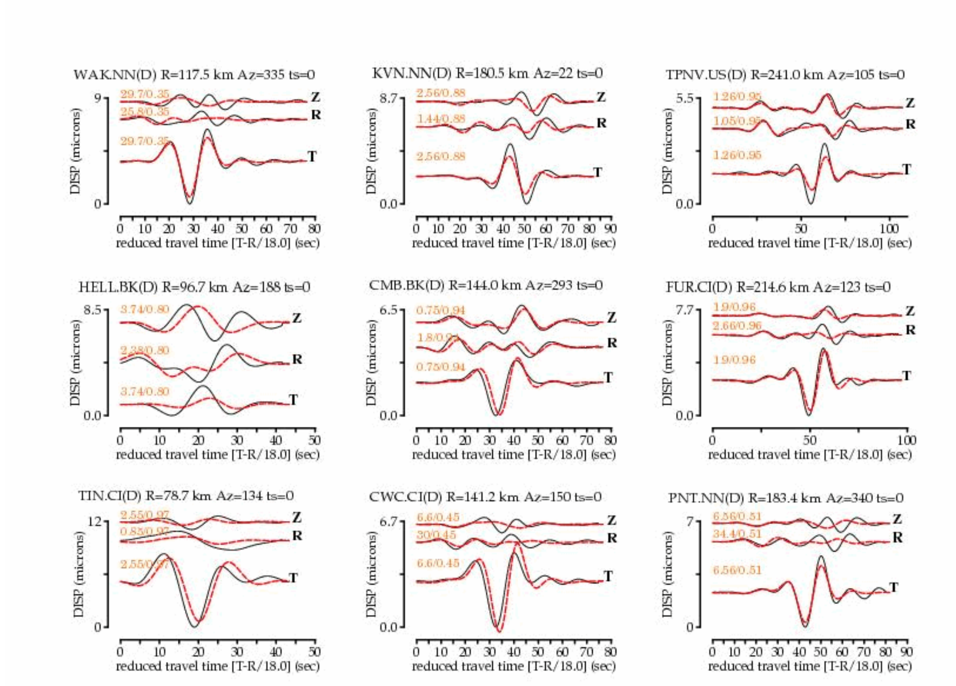


Figure 5. Waveform fits to an Mw 4.1 earthquake near Mammoth Lakes, California, August 24, 2011. Includes both UNR ARRA and CISN stations.

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All Stations defining and nondefining:

Station.Net	Def	Distance (km)	Azi (deg)	Bazi (deg)	lo-f (Hz)	hi-f (Hz)	vmodel
TIN.CI (D)	Y	78.7	134	314	0.020	0.080	TIN.CI.wus.glib
HELL.BK (D)	Y	96.7	188	8	0.020	0.080	HELL.BK.wus.glib
WAK.NN (D)	Y	117.5	335	155	0.020	0.080	WAK.NN.wus.glib
CWC.CI (D)	Y	141.2	150	330	0.020	0.080	CWC.CI.wus.glib
CMB.BK (D)	Y	144.0	293	112	0.020	0.080	CMB.BK.wus.glib
KVN.NN (D)	Y	180.5	22	202	0.020	0.080	KVN.NN.wus.glib
PNT.NN (D)	Y	183.4	340	160	0.020	0.080	PNT.NN.wus.glib
FUR.CI (D)	Y	214.6	123	304	0.020	0.080	FUR.CI.wus.glib
TPNV.US (D)	Y	241.0	105	287	0.020	0.080	TPNV.US.wus.glib
PAH.NN (D)	Y	245.1	350	169	0.020	0.080	PAH.NN.wus.glib

(V)-velocity (D)-Displacement

Author: www-data
Date: 2011/08/25 20:10:50

Figure 6. Accompanying text output for waveform fits in Figure 4 above; Mw 4.1 near Mammoth Lakes, California, August 24, 2011.