Final Technical Report

December 1, 2003-January 31, 2007

WESTERN GREAT BASIN SEISMIC NETWORK OPERATIONS

External Grant Award 04HQAG0004

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Abstract
Grant support from U.S. Geological Survey Cooperative Agreement 04HQAG0004 was used to gather data using the Western Great Basin Seismic Network, support data exchanges with other networks, locate earthquakes, and publish catalog and web information. ANSS support contributes to the operation and maintenance of 131 seismic stations, 50 of which include strong-motion sensors. Over 26,000 earthquakes were located during the Cooperative Agreement, almost half being aftershocks of the largest event, an ML 5.6 September 18, 2004 earthquake. Sixty-nine events had M_L 3.5, or an average of about 2 per month. The largest earthquake well-felt in urban Nevada occurred on June 26, 2005, and had an M_L 4.9. *ShakeMap* has been installed and now operates at version level 3.1. Remote review capabilities for *ShakeMap* were developed using the Antelope PHP interface. Another new development was a Matlab-Antelope analysis tool to estimate focal mechanism parameters using a selectable weighting of P-to-S amplitude ratios and first motions. More and better constrained focal mechanisms are being produced in routine analysis. Hypoinverse was also ported to the real-time environment as a prompt relocation estimator. Education and outreach has been furthered through an active web page and tours and educational contact with the Seismological Lab. A K-12 seismic network and associated teaching curriculum were developed with outside funds but further joint interests by growing seismic and scientific awareness in the community and by exchanging data with the monitoring community. UNR has maintained advisory contact with seismic safety, emergency management, and engineering interests through regular meetings of the Nevada Earthquake Safety Council. UNR has also supported activities of the IMW region, and the ANSS National Implementation Committee.

Seismic Risk in Nevada

Regional monitoring has been undertaken in Nevada because approximately a quarter of the Pacific-North American relative plate motion crosses through the monitored region. This motion, totaling 10-14 mm/yr, is broadly associated with recognized active faults, a number of which are identified in the USGS Quaternary Fault Database as potentially hazardous. The distribution of faults is such that most of the state of Nevada and all the monitored region in California are included in the contours of moderate to high hazard zone as defined by the standard of 10% in 50 years of an acceleration of 0.08 g. The western portion of the state includes regions that can expect over 0.32 g with the same probability. In rural Nevada the risk is primarily in small communities and transportation and utility corridors.

Urban monitoring in Nevada focuses on two urban areas, the Las Vegas Valley and the Reno-Carson City corridor. Both have notable potential for earthquake losses based on FEMA estimates. Risk to the Las Vegas area is due to moderate seismic hazard and a high-value built environment. The Reno-Carson City urban corridor has a smaller population but it is exposed to higher seismic shaking potential because most of the regional shear passes nearby, some on mapped active faults, and some in less well understood shear zones.

Seismic Monitoring in Nevada

UNR operates and maintains 131 stations using ANSS funding (Figure 1). Of these, 50 include strong-motion recording either as dedicated stations or recorded along with three-component weak-motion sensors. Beside the ANSS-supported stations, a network of over 40 stations is operated and maintained under support from the Department of Energy in a 50 km radius array around Yucca Mountain (Figure 1, stations around 37N, 116.5W). Both networks are recorded in a single, shared acquisition and processing stream using Antelope Real-Time System software. While DOE support is focused on their mission, ANSS monitoring in Nevada is aided by improved network sensitivity in southern Nevada, shared costs of backbone telemetry, shared costs for event processing, and improved personnel training and support.

The Seismic Catalog

Over 26,000 earthquakes in and near Nevada were located by UNR during calendar years 2004 through 2006 (Figure 2). Of these, 5500 were inside the 65 km radius of explicit interest for Yucca Mountain. These totals exclude events recognized as near Mammoth, CA, as this is part of the CISN/Northern California Seismic Network authoritative region. During the three years 207 events had M_L>=3.0 and 69 with M_L>=3.5. Sixteen, ranging in magnitude from 2.1 to 5.6 were reported as felt. Nearly half of the total number of earthquakes occurred in 2004, as aftershocks of an M5.6 event of 18 September 2004. M3+ events are concentrated in the western part of the monitoring region, but distributed with lower density over most of the state.

Nevada Station Coverage

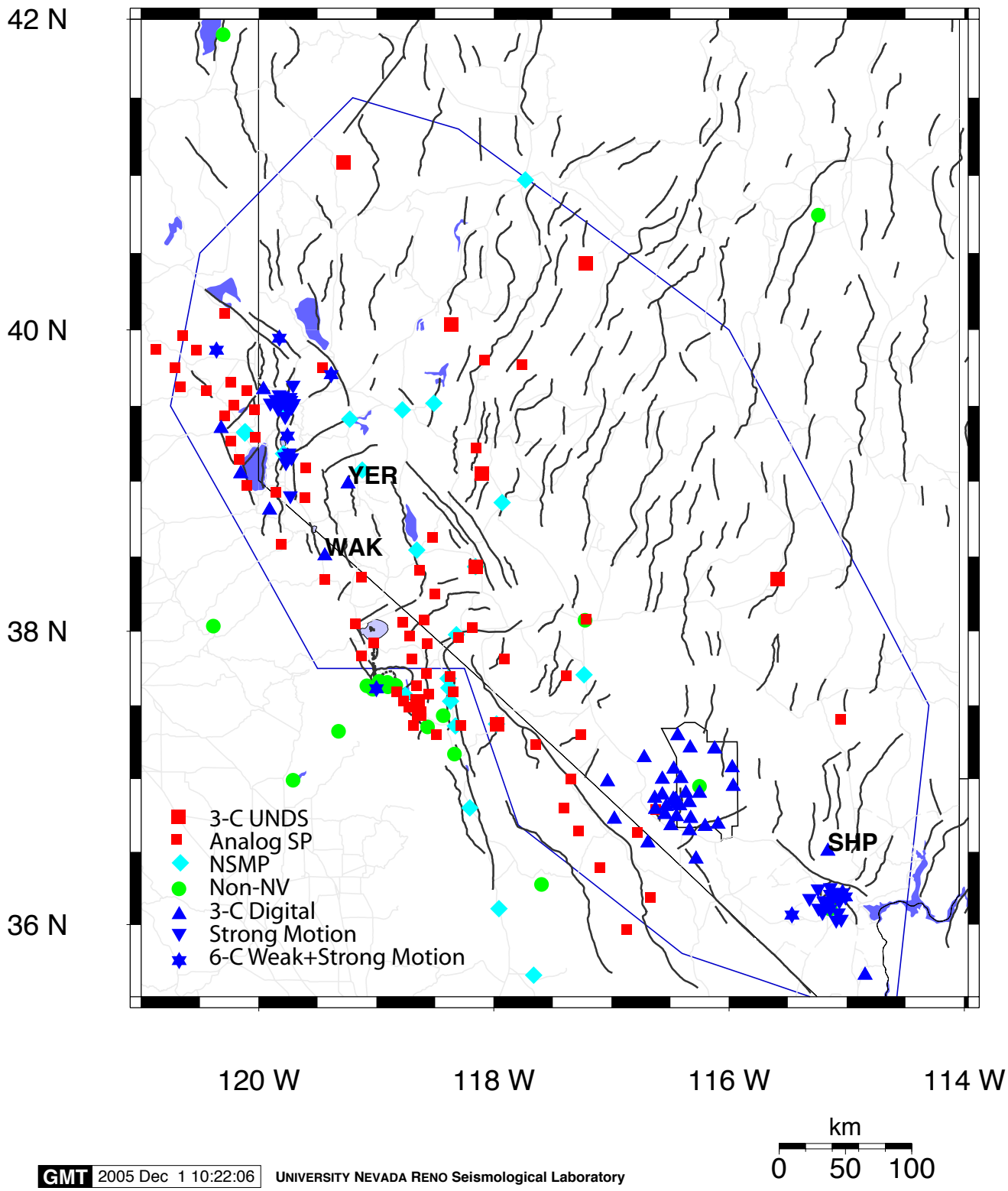
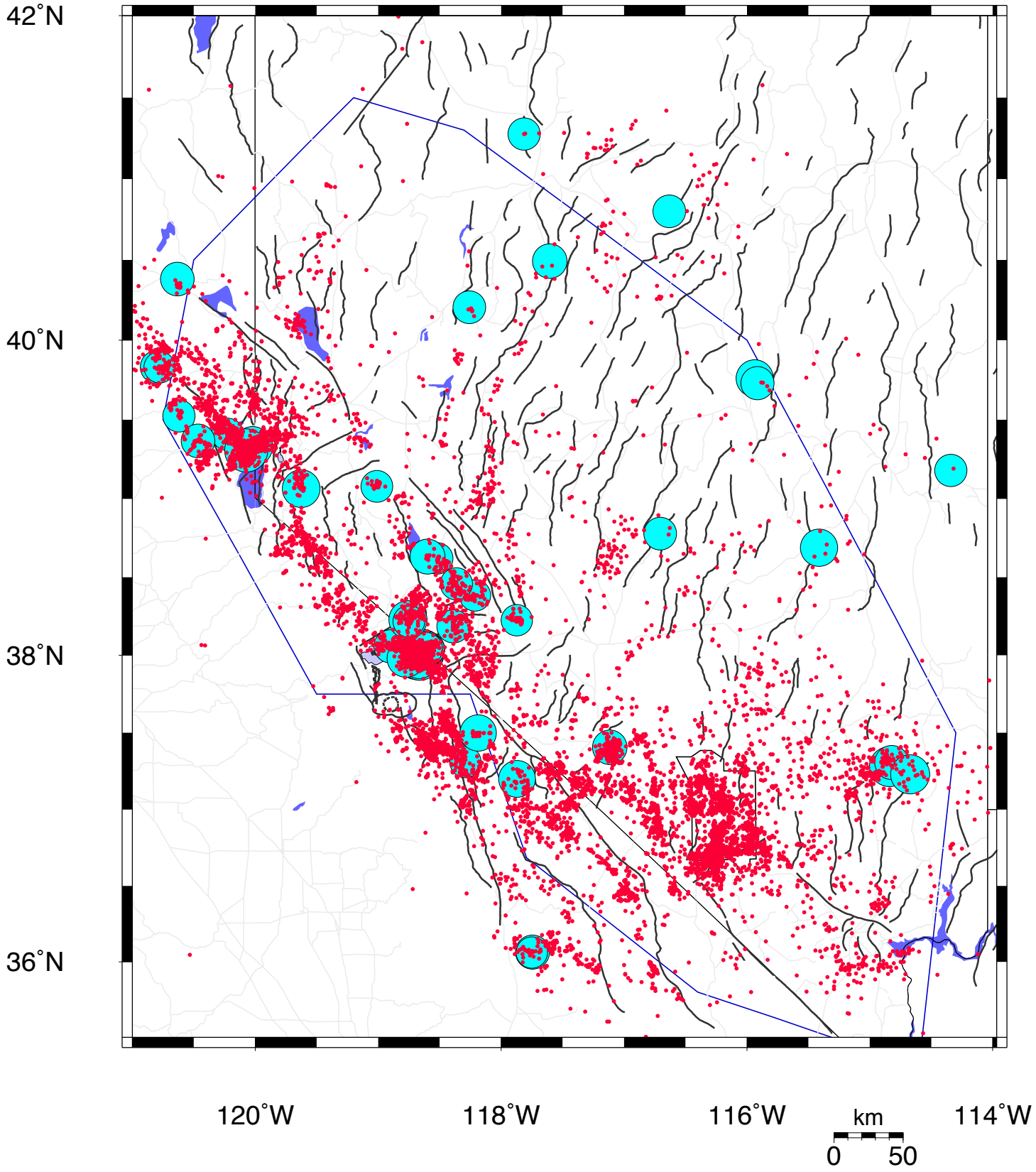


Figure 1

Nevada Seismicity, Dec 1, 2003 to Dec 21, 2006



GMT 2006 Dec 22 10:46:48 UNIVERSITY NEVADA RENO Seismological Laboratory

Figure 2

Figure 1. *Station coverage in Nevada. Small red squares mark short-period analog stations. Larger red squares are three-component stations digitally recorded at 16-bit resolution but transmitted over the analog microwave telemetry system. Blue triangles are 3-component digital sites, almost all with S-13 short-period seismometers. The concentrated cluster around 37N, 116.5W is the Southern Great Basin Digital Seismic Network installed and funded by the Yucca Mountain Project. Green circles are operated by others (netcodes US, LB, BK). Upside down blue triangles have strong-motion instrumentation; stars are formed where weak and strong motion sensors are co-located. Cyan diamonds are NSMP stations. UNR records the NSMP station on the UNR campus in real time.*

Figure 2. *Seismicity map for the period from October 1, 2004 to September 30, 2005. Red dots mark earthquakes; magnitude-scaled cyan circles indicate those M_L 3.5 or larger. Black lines are faults. The polygon encircling most of the seismicity is the UNR authoritative catalog region. The QDDS boundary coincides on the west with the California-Nevada border. Several fault systems of western Nevada and eastern California can be seen in alignments of seismicity.*

Earthquakes located in Nevada are forwarded in real time to QDDS for inclusion in *recenteqs*. Reviewed solutions are also sent to QDDS. The final catalog of reviewed solutions is sent in bulk to the ANSS combined catalog, typically in month-sized blocks, after completion of analysis and review. Improvements in analysis hardware and student staffing especially over the summer have reduced the analysis backlog, so that relocations are now routinely done within a few days or less.

Data Exchanges

UNR maintains active data exchanges with southern and northern CISN centers, the Anza network, Utah, and the NSN. UNR stations provide primary station coverage for CISN for much of the eastern Sierras by this exchange. Two UNR stations are presently being used by the USArray Transportable Array, and over 200 Transportable Array stations are being imported. Three-component data from non-Yucca Mountain stations are exported to the IRIS DMC and available in real-time.

ShakeMap

ShakeMaps have been produced at UNR since 2004. *ShakeMap* operated with version 3.0.1 until late calendar 2006 when it was upgraded to version 3.1. Some care was taken when upgrading to version 3.0 to ensure consistency between base topographic and map coverages to look and work like the CISN implementation. Primary *ShakeMap* duties operate on an ANSS-funded Sun V-240 server, with a hot backup system also running on a second, single processor server, both rack-mounted and on the UPS. The system has been triggered automatically by the primary Antelope acquisition system. In the fall of 2006 the system was converted from a cron-based model to triggering directly following the Antelope system event location and magnitude (origin row) of the event, saving approximately 5 minutes from the processing time. *ShakeMaps* are now routinely produced and pushed to UNR and USGS web servers in less than five minutes from the origin time. The system is exercised regularly by triggering on M 2.8 and larger events. A *Nagios* monitor has also been implemented to warn if any of the USGS servers are unavailable, if it appears that versions among servers are out of sync, or if a map has gone too long without review. The capability to interact with *ShakeMap* and conduct remote review of significant events was developed in the fall of 2006 by the UNR Seismic Systems Analyst using the Antelope PHP

interface and mobile devices (e.g., Blackberry). The system operates on a non-public web server to ensure access during periods of high demand on the main UNR web server. The application includes ability to examine waveform images and confirm/review/rerun *ShakeMap* remotely.

Network Operations and Development

Primary data acquisition at UNR employs the Antelope Real Time System software. The system is integrated around a single, generalized data ring into which seismic data, parametric information, state-of-health, and database row elements are deposited and shared by clients. Acquisition clients include *k22orb* (for Etna and K2 strong-motion dataloggers), *q3302orb* (for Kinemetrics Q330's), *ref2orb* (for Reftek 72A dataloggers), *rt2orb* (for Reftek 130 dataloggers), and *adsend2orb* (for the Earthworm digitizer). Data imports and exports to and from other networks are also on this ring. The real-time and post-processing environments are built around a relational database. Automatic detection and picking is done in multiple frequency bands. Associations are done on a nested grid, with local, regional and teleseismic locations. Post-processing is implemented through graphical picking and location interfaces integrated with the database. We use program *dblocsat2* with several region-specific 1-D models in post-processing. The database is also viewable via a GUI that includes full relational joining, subsetting, and analysis tools.

A preliminary comparison of network performance with the ANSS Performance Standards was conducted in September 2006. An example figure documenting location quality is shown in Figure 3. Since September, significant progress has been made in time-to-ShakeMap and time-to-hypocenter metrics, and tools have been built to meet time-to-review standards. UNR already meets most standards, and expects no trouble with the remaining standards for products we produce. A complete review is planned for the next Cooperative Agreement.

UNR is integrating Earthscope Transportable Array (TA) stations into seismic network operations. Figure 4 shows the improvement in station coverage especially in central and eastern Nevada with the Transportable Array stations. As seen in Figure 2, this area experiences moderate earthquakes but the detection level and location quality both would be improved by additional station coverage. The upper inset map shows a quick-look estimate of the improvement achieved by a preliminary configuration of network joint monitoring – approximately five times as many events were located during a 29 day period. The lower inset figure shows the magnitude-frequency relationship within the bounds of central and eastern Nevada. The magnitude-frequency relationship shows the normal shape, with a completeness level of M ~2.0. Without USArray completeness is M ~3. The b-value of 1.09 could be a bit inflated by quarry blasts based on estimates elsewhere in the state. The projection of this curve to the magnitude of an event that would on average happen once per year, M1, gives an expected earthquake of near M 4.7, near the level at which minor non-structural damage could occur.

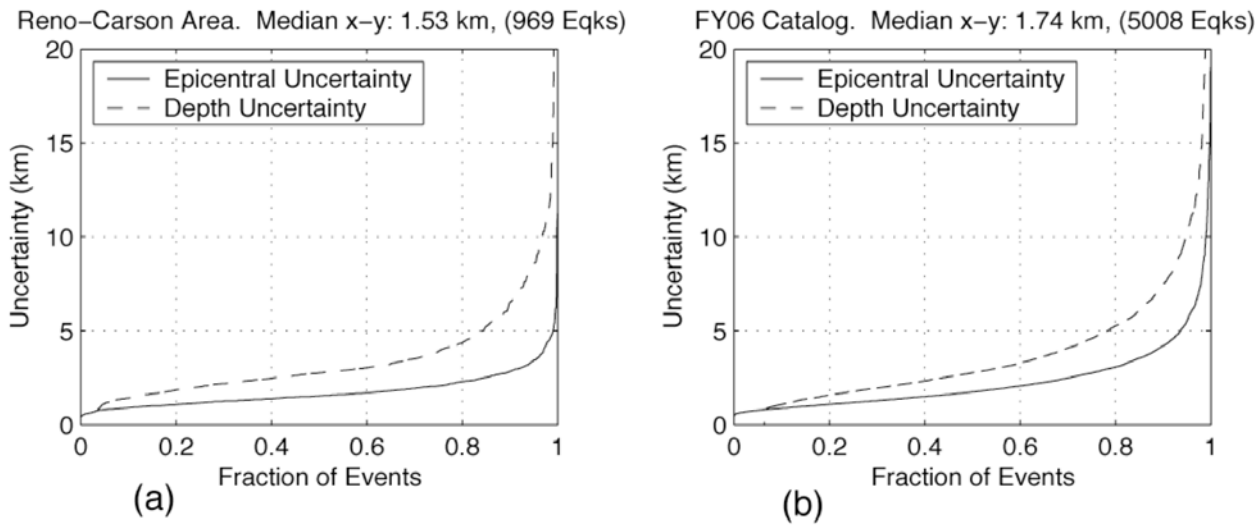
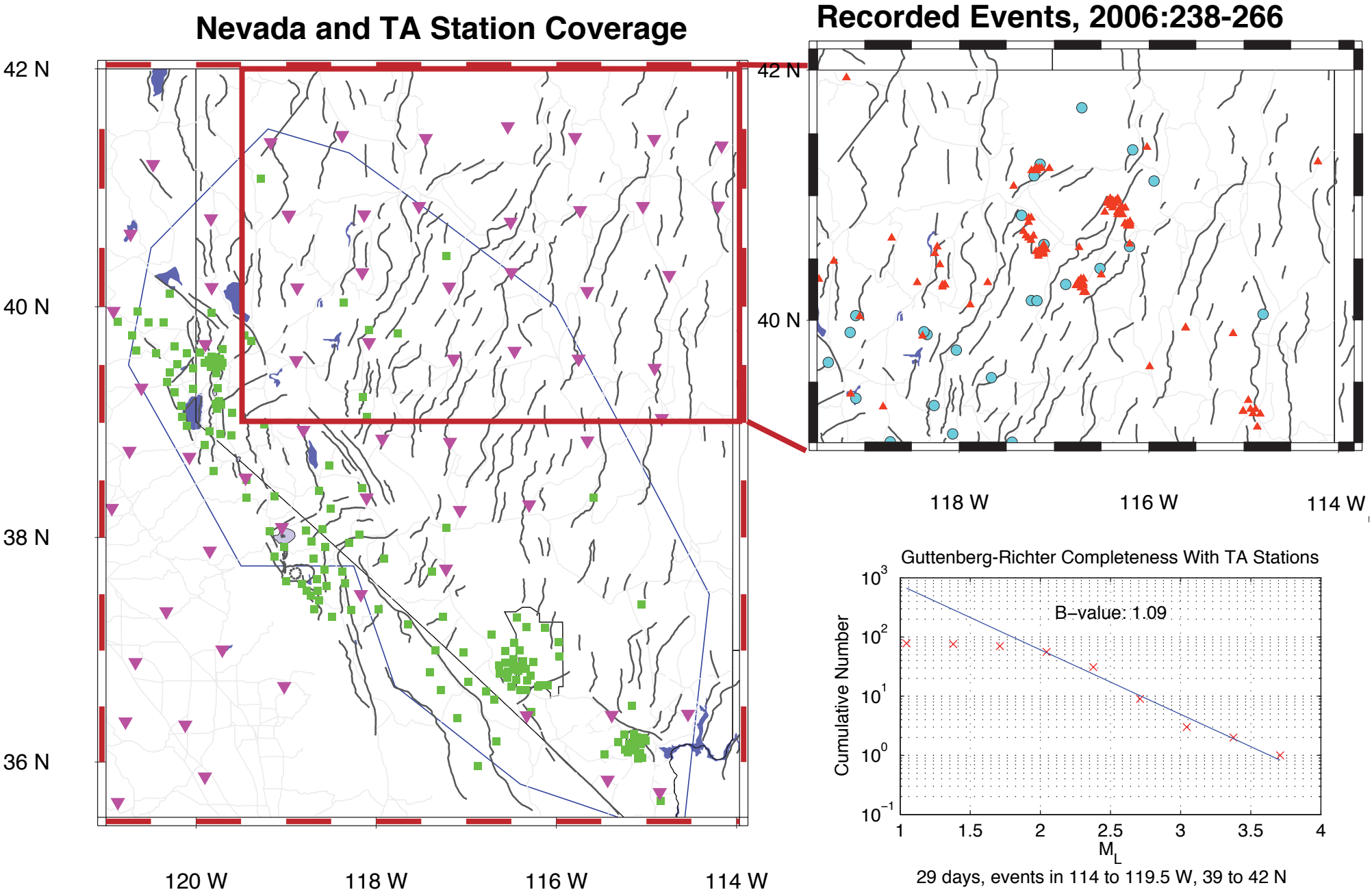


Figure 3: Formal uncertainties for relocated events with at least 8 associated phases. Data from October 1, 2005 through August 31, 2006 were used. The horizontal axis is the fraction of events relative to the total for the subplot. Median 90% epicentral uncertainty is 1.74 km for FY06 events and 1.53 km around the Reno-Carson City urban area. Dashed lines show depth uncertainties.

New capabilities developed recently include an operational *Matlab* Antelope-based application for earthquake focal mechanisms. The system is integrated with *DataScope* tables and uses the Antelope *Matlab* API. The application allows the analyst to use any combination of 3-C digital waveform P and S-wave body wave amplitudes with first-motion information to estimate focal mechanism parameters. The code allows us to develop focal parameters for smaller earthquakes and poorer gap coverage than is provided by *FPFIT*. An analyst's session with a particular event is fully documented and recoverable from database table entries, allowing reprocessing of events and review. The application was developed by Leiph Preston.

Hypoinverse was ported as a real-time relocation tool into the Antelope real-time event processing stream. The application uses the Antelope Perl API to read directly from the Antelope ORB and apply Antelope tools that drive relocations in *Hypoinverse*. *Hypoinverse* provides a community-recognized location interface and establishes other phase criteria screening to corroborate and improve real-time event locations within Antelope 4.6. The implementing script also includes links to images of event waveforms, a tar file of SAC format event waveforms for remote access, links to Mapquest and TopoZone with event epicenters in broadcast emails designed for public use. These automatic event emails are also distributed in near-real time to Nevada K-12 science teachers and classrooms.

Figure 4. *Left: Nevada network stations are green squares. Purple: Transportable Array presently monitored. Above-right: events with NV stations; Red = NV+TA coverage. 29 day comparison: 134 vs. 26 events. Trends are mostly gold district blasts.*



Above: Green: Nevada network stations; Purple: Transportable Array presently monitored. Above Right: Blue = events with NV stations; Red = NV + TA coverage. 29 day comparison: 134 vs. 26 events. Trends are mostly gold district blasts.

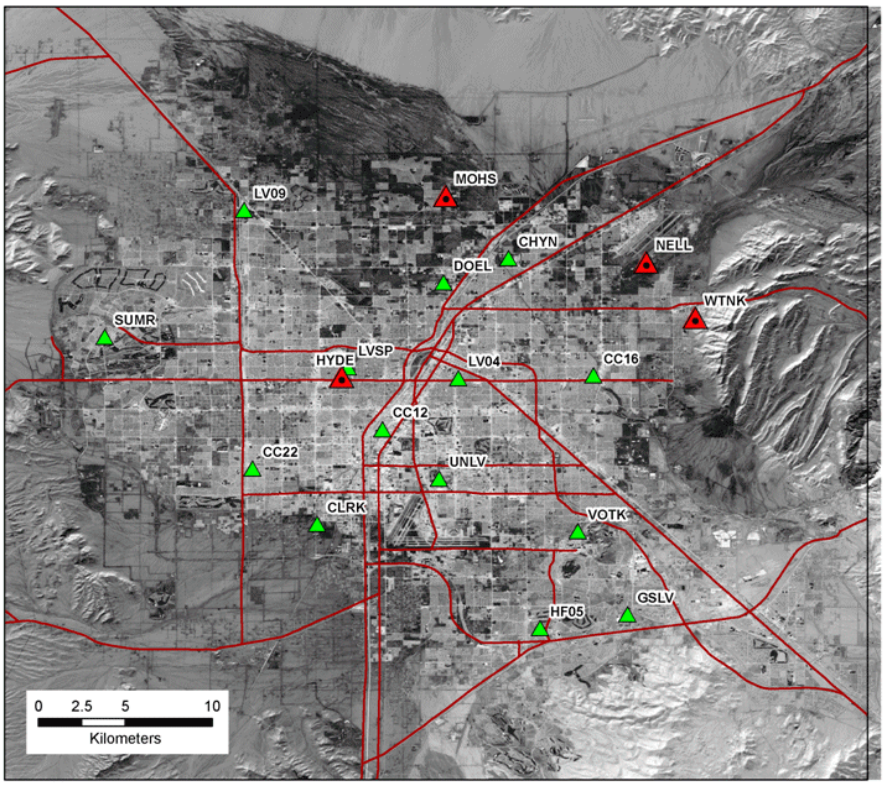
Hardware and Seismic Sites

During this Cooperative Agreement ANSS supported the installation of four new stations and the improvement of five others. Four broadband instruments were installed in FY2005 in the Las Vegas Valley area (Figure 5), three at new sites with co-located strong-motion sensors, and one that upgraded an existing strong-motion site (Figure 5, station WTNK). The broadband sensors, two recorders, and primary support for station installation were funded by Lawrence Livermore National Laboratory (LLNL), in a cooperative venture with ANSS. The LLNL mission required broadband recordings of basin response and surface-wave propagation in the urban area. One site, on the metamorphic lower-plate rocks of west Frenchman Mountain overlooking the valley, serves as a rock reference. Recordings to date have already confirmed that ground motions are higher and continue at high amplitudes for longer in the valley (Figure 6). The fourth new station was installed in a county government building in the Las Vegas Valley. Station upgrades to four stations in the greater Reno area added strong-motion components to existing digital three-component stations. All data are telemetered in real time and available for ShakeMap generation.

ANSS funding also supported infrastructure improvements for computation, storage, and telemetry. We added two network servers to support *ShakeMap* generation and file service, approximately a terabyte of live disk storage, and substantial improvements for network switching and high-speed data transfers for analysis. Telemetry improvements include the installation of a multi-point radio on the UNLV campus to support real-time telemetry from some outlying stations. We also purchased a Motorola Canopy backhaul radio pair that will be used with infrastructure supported by others to provide a redundant, non-public IP telemetry path back to UNR from the Las Vegas Valley. This will improve reliability in the event that there is an earthquake in the Las Vegas area and the public internet is disrupted.

Figure 5. *Las Vegas area ground motion monitoring network. Red triangles are joint broadband/strong-motion stations installed in a cooperative venture between ANSS and LLNL. Green stations are dedicated strong motion stations. All but two were provided through ANSS investments.*

Figure 6. *Example broadband recordings at the NELL and WTNK stations (Figure 5). Sensors are CMG-3ESP's on Reftek RT130 digitizers. Station WTNK is on rock on the west side of Frenchman Mountain. Amplitude and coda length are clearly larger at station NELL in the basin sediments. The deepest part of the basin, based on gravity modeling, is east of LV04 and west of WTNK.*



60 sec Broadbands/ANSS Strong Motion

ANSS Strong Motion (Kinemetrics K2's and Reftek MEM's)

Figure 5

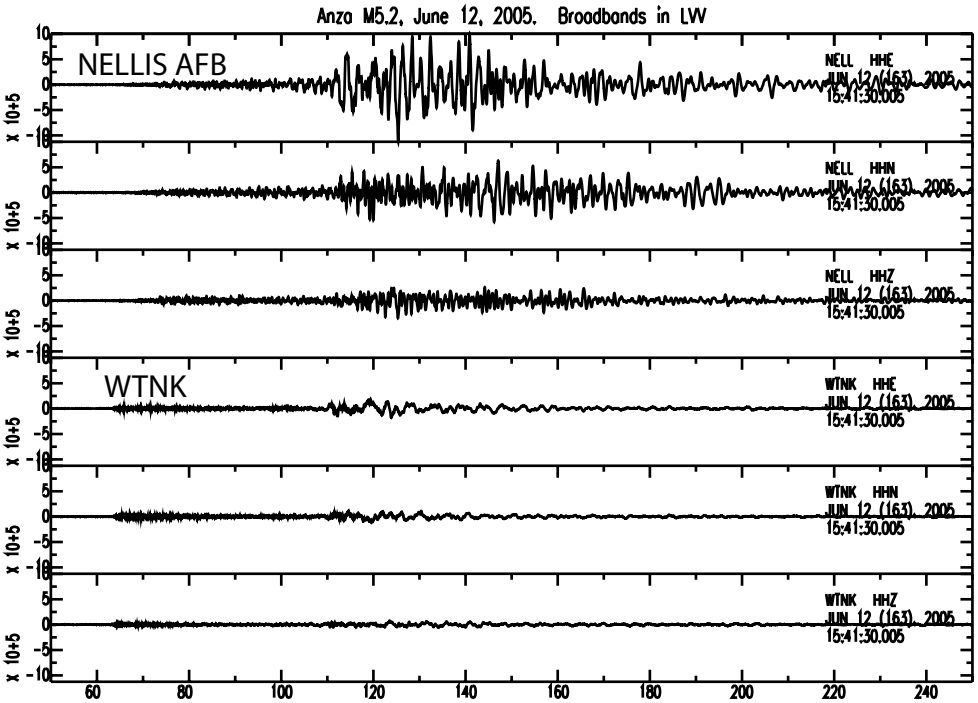


Figure 6

Advisory Committee Activities

The Nevada Earthquake Safety Council (NESC) is the primary resource for general guidance and mission oversight of the Nevada Seismological Laboratory. While convened with the broader issues of safety in mind, the NESC meets several times per year and receives a report from the Lab on current activities and plans. The NESC has been asked to advise the NSL when, in their judgment, a more formal Advisory Board should be convened. This structure balances the need for regular contact with representatives of the engineering and safety community with the fact that, due to funding limitations, there has been little need for Advisory Board guidance on new station siting and allocation. In IMW Regional activities, Nevada representatives supported the February 2006 Network Operations Workshop and August 2006 IMW joint Working Group and Advisory Committee meeting. Nevada priorities identified in the latter meeting and at the November 2005 National Steering Committee meeting include an upgrade to digital microwave telemetry infrastructure and the addition of broadband sensors. UNR has also supported the activities of the National Implementation Committee and related Working Groups.

Public Interaction, Education, and Outreach

UNR maintains an active education and outreach program through the UNR web site and local educational tours. During the three years of the Cooperative Agreement the Seismological Lab has hosted an average of over 100 educational tours per year in the Seismological Lab facilities, promoting safety and scientific understanding of earthquakes in Nevada.

In a collateral effort, a network of K-12 seismic stations has been developed and implemented where schools can receive live data feeds from available Nevada and IRIS stations, as well as operate their own networked seismographs if interested. One private school in Reno had vaults constructed by a contractor in order to host broadband and strong-motion sensors. ANSS funding was not used for the K-12 network effort.

Yearly credited classes have been conducted through the University of Nevada Reno in Geology, Tectonics and Seismology in conjunction with the UNR Raggio STEM Research Center for K-12 science teachers (course concept: TEAC – The Earth as A Classroom). The course involves two pre- and one post-session day-long classroom meeting and a one week field course. The field component covers the active tectonics of the Eastern Sierra Nevada, the Walker Lane Belt and the Mammoth Lakes area. The program is funded under a competitive solicitation through the State of Nevada. To date 37 Nevada K-12 science teachers have participated in the course.

Data Availability

Data for weak-motion stations supported by ANSS are exported to the IRIS DMC and available there in SEED format by standard methods. As noted above, real-time data are also available and freely shared with ANSS participants. Event exports of all data are made in the course of routine analysis, and held in CSS 3.0 database tables and SAC format and available on request.

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(Asterisks indicate student authors)

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