FINAL TECHNICAL REPORT

Regional and Urban Seismic Monitoring: Wasatch Front, Utah, and Neighboring Intermountain West

February 1, 2010–January 31, 2015

U.S. Geological Survey Cooperative Agreement No. G10AC0085

Seismic Network Web Site:	http://www.seis.utah.edu
Network Code:	UU
Network Name:	University of Utah Regional/Urban Seismic
Network ANSS Region:	Intermountain West (IMW)

Principle Investigator:	Keith D. Koper
Email Address:	koper@seis.utah.edu
Phone:	801-585-3669
Co-Principal Investigator:	Kristine L. Pankow
Email Address:	pankow@seis.utah.edu
Phone:	801-585-6484
Operator Address:	Dept. of Geology & Geophysics University of Utah 115 South 1460 East, Room 211 FASB Salt Lake City, UT 84112-0102

April 30, 2015

TABLE OF CONTENTS

1. ABSTRACT

This report is the final technical report for USGS Cooperative Agreement No. G10AC00085, covering the period from February 1, 2010, through January 31, 2015. This cooperative agreement, combined with funding from the State of Utah, provided major support for the operation of (1) the University of Utah Seismograph Stations' (UUSS) regional and urban seismic network, an ANSS Tier-1 network, and (2) a regional earthquake-recording and information center on the University of Utah campus in Salt Lake City.

On January 31, 2015, UUSS operated and/or recorded 294 stations (78 broadband, 114 strong-motion, and 102 short-period, with some stations having multiple sensor types); a total of 907 channels were being recorded. Of the 294 stations, 142 stations (465 channels) were operated and maintained in the Utah region (36° 45'–42° 30' N, 108° 45'–114° 15' W) with full or partial support from the USGS as part of the Advanced National Seismic System (ANSS). These include 13 broadband stations, 92 strong-motion stations, and 37 short-period stations. USGS support is focused on the seismically hazardous Wasatch Front urban corridor of north central Utah but also encompasses neighboring areas of the Intermountain Seismic Belt.

During the five-year period January 2010–December 2014, we detected and analyzed nearly 32,000 seismic events, including local earthquakes, teleseismic and regional earthquakes, and blasts. Approximately 19,000 earthquakes were located within and near our regional seismic network—including 7,429 within the Utah region, of which 5,091 were within the Wasatch Front area (38° 55'–42° 30' N, 110° 25'–113° 10' W). Eighty-seven earthquakes of magnitude 3.0 and larger occurred in the Utah region during the report period, and 95 earthquakes were documented as felt. The largest earthquake was a shock of magnitude (M_L) 4.9 that occurred at 23:59 UTC on April 15, 2010, 8 km (5 mi) northeast of Randolph, Utah.

2. INTRODUCTION

The University of Utah Seismograph Stations (UUSS) capitalizes on a state-federal partnership to conduct research, education, and outreach related to earthquakes, seismic monitoring, and seismic safety in the Utah region. As a founding member of ANSS, UUSS shares in the mission of providing prompt and accurate information related to seismic events, including their effect on the built environment. Notable UUSS partner agencies include the Utah Geological Survey, the Utah Seismic Safety Commission, and the Utah Department of Emergency Management.

Seismic hazard in Utah is highest along the north-south trending intermountain seismic belt, although significant seismicity occurs throughout the state. Seismic risk in Utah is severe because 2.2 of Utah's 2.9 million residents live in the Salt Lake City-Provo-Orem urban corridor, directly adjacent to the Wasatch Fault. Paleoseismic studies have reported the occurrence of at least 20 M~7 earthquakes along the central segments of the Wasatch fault in the last 6,000 years.

UUSS operates and maintains a combined urban-regional network of 237 seismic stations, which generate 768 distinct channels of data, to monitor Utah seismicity. The continuous 100 sps data are archived locally at the UUSS Earthquake Information Center (EIC) as well as at the IRIS DMC in Seattle, WA, from which they are publicly available.

The Utah network is designed to be robust with respect to power and telemetry failures. Redundancy is provided by 6 overlapping data collection nodes and 13 mountaintop relay sites. A hot-backup site for the UUSS EIC exists in Richfield, Utah, approximately 250 km south of Salt Lake City, and additional backup is provided by the NEIC in Golden, CO via the Denver Federal Center.

Since 2012, UUSS has used the state-of-the-art ANSS Quake Monitoring System (AQMS) to detect and locate seismicity in the Utah region. In a typical year, UUSS locates over 1,500 earthquakes in the Utah region: 1 in the M4 range, 18 in the M3 range, and 130 in the M2 range, with 20 earthquakes reported as felt. For earthquakes larger than about M3.5, full moment tensors are estimated by inverting broadband, regional distance waveforms. UUSS also routinely computes ShakeMaps for events larger than M3.

With additional support from the USGS Volcano Hazards Program, UUSS maintains a second seismic network in and around Yellowstone National Park. Operations for the two networks are integrated, with, for instance, both using the same instance of AQMS. The Yellowstone network is smaller than the Utah network (UUSS operates and maintains 27 stations corresponding to 96 channels in Yellowstone), however the seismicity rate is significantly higher than in Utah. In a typical year, UUSS locates over 2,500 earthquakes in the Yellowstone region.

3. NETWORK OVERVIEW

Figures 1 and 2 together with Tables 1 and 2 summarize essential information for the University of Utah's urban/regional seismic network. The regional distribution of conventional broadband and short-period stations is effectively shown in Figure 1. Figure 2 shows our real-time urban strong-motion network in the Wasatch Front urban corridor and in the SW Utah.

- **294** — Number of stations (907 channels) we operate and/or record (Table 1): 78 broadband (BB), 92 strong-motion (SM), 22 NetQuakes (NQ), and 102 short-period (SP) stations, with some stations having multiple sensor types.
- **237** — Number of stations (768 channels) we operate and maintain (Table 1): 43 BB, 92 SM, 22 NQ, and 80 SP stations. All data are contributed to ANSS. We import data from 57 stations (139 channels) and, excluding data export to the IRIS DMC, we export data from 98 stations (194 channels) to other seismic networks and NEIC.
- **142 —** Number of stations (465 channels) we operate and maintain with full or partial ANSS support (Table 2): 13 BB, 70 SM, 22 NQ, and 37 SP stations. Currently, all our ANSS O&M stations are within the Utah region.

4. SEISMICITY OVERVIEW

During the five-year period January 2010–December 2014, we detected and analyzed nearly 32,000 seismic events, including local earthquakes, teleseismic and regional earthquakes, and blasts. Approximately 19,000 earthquakes were located within and near our regional seismic network—including 7,429 within the Utah region, of which 5,091 were within the Wasatch Front area (38° 55'–42° 30' N, 110° 25'–113° 10' W).

Eighty-seven earthquakes of magnitude 3.0 and larger occurred in the Utah region during the report period, and 95 earthquakes were documented as felt. The largest earthquake was a shock of magnitude (M_L) 4.9 that occurred at 23:59 UTC on April 15, 2010, 8 km (5 mi) northeast of Randolph, Utah.

From January 1, 2010 through December 31, 2014, ninety-five earthquakes in the Utah region were documented as felt and/or generating a ShakeMap (Table 4). During this same period, we issued thirty seven press releases immediately after earthquakes in the Utah region that were either felt by many or were larger than a set threshold magnitude of 3.5. Mining-induced seismicity accounted for about 43 percent of the earthquakes located in the Utah region during this period. A total of 3,160 shocks ($M \leq 3.9$) were located in known areas of underground coal-mining within an arcuate zone extending counterclockwise from east of Price to 100 km southwest of it (Fig. 3).

5. ANSS PERFORMANCE

Data Management Practices

Data management practices in our regional/urban seismic network are consistent with ANSS data policy, and we have agreed to adhere to the "Advanced National Seismic System Elements of Data Policy" adopted by the ANSS National Implementation Committee in December 2003. In particular:

- All digitally-recorded waveforms from stations we maintain and operate (channel types EH, EN, HH, HN, EL) are archived at the IRIS DMC. From 1981 to the beginning of continuous archiving, the archived waveforms are the recorded segments containing seismic events.
- Continuous archiving of waveform data at the IRIS DMC from our broadband stations began on June 19, 2001, and from our strong-motion stations on April 19, 2001. Since June 2002, continuous waveform data from all stations we maintain and operate (EH, EN, HH, HN, EL) have been submitted to the IRIS DMC on a daily basis. Currently, the IRIS DMC retrieves data from our Earthworm System wavetanks several times per day.
- All UUSS instrument responses, dating back to the start of digital recording in 1981, are archived at the IRIS DMC in SEED format.
- All UUSS station locations are available at the IRIS DMC and at http://www.seis.utah.edu/EQCENTER/QUARTERLY/quarterly.htm as part of our quarterly reports.
- For our UUSS strong-motion stations, information including site-class, building type, and telemetry are available at http://www.seis.utah.edu/MONRESEARCH/SEIS_NET/urban_net.htm
- Our standard practice is to calibrate new and changed broadband stations with a step-function calibration (Guralp models following Pechmann et al., 1999), before including their responses in a dataless SEED volume. For the Kinemetrics K2s, we use a calibration procedure similar to that for the broadband instruments. For all other strong-motion stations, we develop the response files using information provided by the manufacturers and verify that

the response remains stable by comparing repeated step-function tests. Response files for the analog stations are constructed from the nominal responses for each individual component; some *in situ* calibrations were done on analog telemetry stations using a random binary sequence method (Berger et al., 1979).

- Our network promptly reports automated and analyst-reviewed earthquake locations into the QDDS using EIDS. Note: on June 30, 2014 UUSS has implemented the Product Distribution Layer (PDL) for earthquake data dissemination. The earthquake catalog updates are automatically submitted to the CNSS/ANSS catalog four times per day (Monday through Friday).
- The automatic locations and magnitudes are very reliable for real earthquakes. However, we generate a few false alarms per year, and closely spaced events are not always distinguished.

- ShakeMaps are posted to both our Web site and the USGS Web site within 7 to 9 minutes of the event and JPEG images of the intensity maps are emailed to critical users within this same time window.

All seismic waveform data archived by the University of Utah Seismograph Stations can be retrieved from the IRIS DMC (for information about data availability and request tools please check the IRIS webpage at http://www.iris.edu/data/). Alternatively, the data can be obtained upon request directly from our office (typically delivered to the user in SAC ASCII or binary format). Earthquake catalog data for the Utah region are available (1) by e-mail request to webmaster@seis.utah.edu, or (2) via the Advanced National Seismic System's composite earthquake catalog, <http://www.ncedc.org/anss/catalog-search.html>. See also the University of Utah Seismograph Stations homepage at http://www.seis.utah.edu. The contact person for data requests is Relu Burlacu, tel: (801) 585-7972; e-mail: burlacu@seis.utah.edu.

Elements of our current UUSS response plan include:

- the designation of a primary duty seismologist
- e-mail alarms to UUSS-staff and designees at the Utah Geological Survey and State of Utah Department of Homeland Security
- a duty seismologist checklist
- contact information for NEIC in the event that operations fail at UUSS
- immediate deployment of at least one or two digital seismographs with real-time data streaming in the epicentral area if the magnitude or regional station coverage suggest additional data is needed

While this plan has served us well in the past, we recognize the need to review and update our procedures and to exercise them routinely. As part of updating our plan we have been discussing formal coordination with NEIC. Major elements of this coordination will include: 24/7 backup (actions depend on functional status of the RSN), post-event response coordination, and post-event coordination of field recording.

Progress on ANSS Integration

We use different mechanisms (Earthworm import/export modules, slink2ew, Edge) to exchange waveform data with NEIC, NSMP, and seven neighboring networks (network codes AR/AE, IE, LB, MB, NN, RC, and RE). Automatic phase picks are exported in near-real-time to the USGS/NEIC via Earthworm export. UUSS analyst phase picks are archived internally (in the AQMS database since Oct. 2012) and are available on request.

Ground motions (for ShakeMap) automatically determined by AQMS are exported in near-real-time to the USGS/NEIC via a Product Distribution Layer (PDL). Analyst-determined amplitudes for local magnitude determinations are archived internally at UUSS.

Automatic locations are currently reported into the EIDS for $M_L \geq 3.0$ events in the Utah region and $M_L \geq 2.5$ events in the Wasatch Front urban corridor. Based on entries in the AQMS database tables origin and alarm_action for sixteen earthquakes that have met these criteria since we switched to AQMS data processing on Oct 1, 2012, it appears that the EIDS messages with M_Ls are typically sent out 4.0 ± 0.5 min. after the origin time. All automatic event locations and magnitudes reported via the EIDS are promptly reviewed by a seismologist and, if necessary, revised or removed.

For each automatically located seismic event, our Earthworm system attempts to compute two automated magnitudes: a coda-duration magnitude, M_C (calibrated to M_L), and an M_L. An M_L is automatically reported to the EIDS system for seismic events that meet the criteria given in the previous paragraph.

For $M_L \geq 3.5$ events in the Utah region, we attempt to determine a full moment tensor solution using software developed at U.C. Berkeley. We also determine focal mechanisms from P-wave first motions for selected events of interest and for research projects. These focal mechanisms are not currently archived at a public datacenter.

Shakemaps are automatically generated for Utah region earthquakes of $M_L \geq 3.0$ to $M_L \geq 3.5$, depending on the location. Automatically generated ShakeMaps are posted publicly on our web site and submitted to the USGS, usually within 7-9 minutes of the origin time. The web posting could take longer if the web server is being overwhelmed with hits.

6. CHANGES AND ACCOMPLISHMENTS IN NETWORK OPERATIONS

Changes and accomplishments for project years 1-4 are reproduced here as they were described in previous annual progress reports. Minor editing, such as removing web links and figures, has been done. Changes and accomplishments for project year 5 have not been reported previously.

6.1. Changes and accomplishments for Year 1 (Feb. 1, 2010 - Jan. 31, 2011)

New Stations and Station Upgrades

At the beginning of Year One we maintained and operated 129 stations with full or partial ANSS support. Changes during this first year include: (1) Upgrading 7 broadband stations and 6 short-period stations as part of the ARRA agreement (upgrades vary from station to station, but include upgrading sensors and data loggers, adding accelerometers, and upgrading radios); (2) Adding instrumentation consisting of a Kinemetrics Basalt recorder, a 3-component accelerometer, and a vertical-component short-period seismometer to 3 adopted EarthScope Transportable Array vaults as part of ARRA (new station names HCSU, RRCU, and CRLU) and utilizing telemetry solutions to make it cost neutral to ANSS; and (3) Relocating ANSS strong-motion station HCO (new station name HFSU).

We received a total of 10 NetQuakes strong-motion instruments from the USGS during Year One (and 2 in the previous year). To prioritize siting of these instruments, the Utah Advisory Committee for Urban Strong-Motion Monitoring met on May 13, 2010. The Committee selected locations to supplement the ANSS Wasatch Front strong motion network, based primarily on local geology, recent urban development, and the existing station distribution. Of the 12 NetQuakes we have received, 7 were installed during Year One (additionally, one was installed during 2009). Of the seven installed this year, one is on loan, at the request of the USGS, to Wyoming to capture ground motion data from persistent earthquake activity in the Gros Ventre area near Jackson Hole, WY.

Using non-USGS funds, we have purchased 10 QuakeCatcher strong motion accelerometers (http://qcn.stanford.edu). Plans for these sensors include instrument testing by collocating with existing network instruments and densifying seismic coverage on the University of Utah campus. We have made arrangements to have one instrument located in the Marriott Library, which was recently seismically retrofitted, and one in the Park Building, which houses the University of Utah's central administration.

Starting May 1, 2010, digitization of analog short-period stations moved from our UUSS network center to seven mountain top locations and an eighth site on the University campus. This move coincided with the switching of event triggering from the obsolete University of Washington HAWK system, running on a Masscomp computer, to Earthworm *CarlTrig* modules, running on SUN computers. The Masscomp system was decommissioned on May 14, 2010.

Major Accomplishments (and Partnering)

Our efforts and accomplishments during Year One of the cooperative agreement were dominated by three activities: (1) planning, installation and data integration for the ARRA upgraded stations; (2) work on upgrading our UUSS data-processing system to ANSS Quake Monitoring System (AQMS) hardware/software; and (3) web and product development.

Tectonic Summaries for the Utah region (the UU network authoritative region) were submitted to the USGS for review on March 24, 2010, and the finalized version was provided to the USGS on June 29, 2010. The summaries are for seven distinct areas within the Utah region: the Intermountain Seismic Belt (ISB), Northern Utah, ISB Southern Utah, Eastern Basin and Range, Western Colorado Plateau, Middle Rocky Mountains and Wyoming Basin, Western Paradox Basin, and Area of Coal-Mining-Induced Seismicity.

Webpage Developments—In 2009, we began a more formal approach to our web presence and development. The first step, accomplished late 2009, was to move the UUSS webpages to a load-balanced web farm. During Year One, we have added a web-test environment and a separate web-development environment. In other efforts, we have implemented an internal web-based ticketing system for work requests. We have also made significant improvements to the web content. These changes include: Modernizing the catalog of historical earthquake information "Personalizing the Earthquake Threat", updating the strong motion webpages, and increasing the number of available webicorders.

Upgrading of our UUSS data-processing systems to AQMS — In Year One we continued to work towards making AQMS the operational data processing system at UUSS. Owing to the complicated nature of the software, the overall progress was rather slow. One accomplishment was integrating the metadata information into the AQMS database. Due to specifics of the UUSS response files stored in dataless SEED volumes, we have worked with Instrumental Software Technologies, Inc. (ISTI), a USGS contractor, to format the information for AQMS. This process was time consuming, as some of the initial software solutions did not produce the expected results.

In parallel with working on AQMS, we configured, tested, and implemented *CarlTrig* modules. CarlTrig is an Earthworm event-detection algorithm that is also used in AQMS. With the Masscomp system decommissioned, the *CarlTrig* modules are now used as part of the operational system to generate triggered events, which are subsequently processed by the seismic analysts.

We tested and configured the location program Hypoinverse-2000 for off-line use at UUSS, to be implemented into AQMS. We completed software changes for computation and reporting of negative magnitudes, with an option for reporting the mean magnitude for an earthquake instead of the weighted median magnitude.

Steps Toward Greater Coordination with NEIC — Greater coordination between NEIC and regional seismic networks, including ours, is a key imperative for ANSS system performance. This coordination includes 24/7 backup by NEIC, with emphasis on continuity-of-operations planning, post-event coordinated response, and post-event coordination of field recording. We continue to build on past years of coordination with NEIC. In Year One of this project, we have worked closely with the ShakeMap group to develop a mechanism for Global ShakeMap to backup the Utah ShakeMap. These efforts have included providing necessary configuration and local Utah geology and station files to NEIC and then testing the new PDL system for transferring event parametric data. We are also in continuing discussions with NEIC for transferring waveform data to NEIC in realtime. These discussions are on hold until NEIC has completed computer and infrastructure upgrades.

Characterizing Vs30 in the St. George and Cedar City areas — In June 2009, we collected microtremor data with small arrays of broadband seismographs at eight sites in southwestern Utah near the rapidly growing urban areas of St. George and Cedar City. Sites for the experiment were chosen to sample different geologic surface units and to be close to new state-funded ANSS-contributing strong-motion stations. There were no geotechnical data available to characterize site-response conditions near these stations. From the eight sites, we were able to determine velocity profiles for six using spatial autocorrelation (SPAC; Aki, 1957), multi-mode spatial autocorrelation (MMSPAC; Asten, 2006), and modeling of horizontal-to-vertical spectral ratios as Rayleigh wave ellipticity. The study was Simin Huang's Master's Thesis and is now being prepared for publication.

Infrasound arrays and partner projects — During the report period, we continued our infrasound studies in collaboration with scientists from Southern Methodist

University and LANL (with funding from the Air Force Research Laboratory) and installed six new infrasound arrays collocated with existing seismic stations.

Improved Network Operations

In order to accommodate the increase in the number of stations/channels, using mostly our state funds, we have added three enclosures and 25 146-GB disks to the overall Earthworm storage system.

EIDS— We have tested and implemented the EIDS system (the replacement for QDDS) at UUSS, in collaboration with the USGS. We are using the EIDS client to populate the earthquake information web pages on the UUSS web site.

SeisNetWatch, NAGIOS, and MRTG — To monitor state-of-health information, we have updated the ISTI SeisNetWatch software. We are currently running version 1.71 of the Network Station Info (NSI) server and version 1.83 of the GUI client software. We continue to use Nagios, an open-source host, service, and network monitoring program, to monitor critical systems (e.g., telemetry links, sensors, computer hardware) in our network. Email and pager notifications are configured to alert staff members when there are problems. We also rely on MRTG (multi-router traffic grapher) to monitor local network traffic (LAN) as well as telemetry traffic and health (error rates) both locally and for our Earthworm nodes. This tool allows us to see short-term performance statistics, as well as long-term trends in network behavior.

New Initiatives

Moment Tensors—We have worked with the University of California, Berkeley, to implement a full moment tensor inversion code (both deviatoric and isotropic components; Minson and Dreger, 2008). After the Crandall Canyon Mine collapse, we realized the need for in-house expertise in computing non-standard moment tensors. We have begun creating a moment tensor catalog for Utah events. Over the next year, we hope to incorporate the moment tensor calculation as part of our routine earthquake response. Our newest full-time hire at UUSS, Katherine Murphy Whidden, is dedicating 0.5 of her time to this effort.

PDF/PSD Work—Recently, UUSS has developed the capability to perform spectral analysis on long segments of ambient seismic noise. The methodology is modeled after McNamara and Buland (2004), and allows for quantitative comparison of noise levels across a wide range of site conditions and instrument types. The comparisons can be made against global reference curves to assess the overall quality of recording sites, and especially to assess the effectiveness of the ARRA related upgrades. We have found that some UU noise pdfs stored at IRIS were constructed with incorrect metadata, and that they will not be recalculated by IRIS because the current Quack system processes data only as it arrives in near real time. Another advantage of our technique is that it analyzes the cross-spectra of three-component data allowing polarization properties of the noise to be quantified as a function of time and frequency (Koper and Hawley, 2010).

Mass Storage—A new initiative being undertaken at UUSS is the development of a robust mass-storage system that can be efficiently and simultaneously accessed by multiple users. Currently, UUSS relies on IRIS to archive continuous data from our network; only segmented data containing waveforms of seismic events are saved on-site. With the new system, we will be able to rapidly access all digital data ever recorded by UUSS, enabling new types of operational and scientific research to be carried out by

UUSS personnel. For example, with the new archive we will be able (1) to locate seismic sources using continuous backprojection methods that do not rely on picked P-arrivals, (2) to perform long-term, longitudinal studies of ambient noise recorded across Utah, and (3) to create high-resolution (possibly 4D) velocity models of the Utah region via cross-correlation of ambient noise. We plan to purchase the mass storage device with non-USGS funds obtained from the University of Utah.

Other

Quarterly Earthquake Summaries — Within 30–60 days of each calendar quarter we submitted to the USGS and distributed to stakeholders a report on *Earthquake Activity in the Utah Region, Preliminary Epicenters*. Besides an earthquake catalog and seismicity map, the reports include a narrative summary, a table of earthquakes felt and/or generating a ShakeMap in the Utah region, and an up-to-date table and maps for operating stations in the University of Utah Regional/Urban Seismic Network. The reports are available online.

6.2. Changes and accomplishments for Year 2 (Feb. 1, 2011 - Jan. 31, 2012)

New Stations and Station Upgrades

At the beginning of Year Two we maintained and operated 132 stations with full or partial ANSS support. (Instrumentation from stations BYU, GRD, JVW, MGU, and VES was removed due to construction activities at these locations and will be relocated at a later time.) Changes during this second year include: (1) Upgrading 1 broadband station and 8 short-period stations as part of the ARRA agreement (upgrades vary from station to station, but include upgrading sensors and data loggers, adding accelerometers, and upgrading radios); (2) Adding instrumentation consisting of a Kinemetrics Basalt recorder, a 3-component accelerometer, and a vertical-component short-period seismometer to 1 adopted EarthScope Transportable Array vault as part of ARRA (new station name PCCW) and utilizing telemetry solutions to make it cost neutral to ANSS; (3) Relocating a state-funded strong-motion station in Moab, Utah (MBUT; new station name MGCU); and (4) Helping NSMP install 10 SM stations in Utah. Note: during this reporting period, UUSS personnel also completed the ARRA upgrades for the Yellowstone Seismic Network. All the ARRA upgrades were finalized in time and the ARRA Final Technical Report was sent to USGS on November 28, 2011.

NetQuakes — We received a total of 12 NetQuakes strong-motion instruments from the USGS in 2009 and 2010 to be installed in the Utah region. (An additional instrument was received and deployed near Jackson Hole, WY to capture ground motion data from earthquake activity in the Gros Ventre area.) Following the recommendations of the Utah Advisory Committee for Urban Strong-Motion Monitoring for selecting locations to supplement the ANSS Wasatch Front strong-motion network (based primarily on local geology, recent urban development, and the existing station distribution), 8 instruments were installed in 2009 and 2010, with the last 4 NetQuakes installed during Year Two. In November 2011, we received an additional 10 NetQuakes, and are scheduled to install the first from this batch on December 15, 2011.

Major Accomplishments (and Partnering)

Our efforts and accomplishments during Year Two of the cooperative agreement were dominated by two activities: (1) installation and data integration of the ARRA upgraded stations, and (2) upgrading our UUSS data-processing system to the ANSS Quake Monitoring System (AQMS).

Upgrading our UUSS data-processing systems to AQMS **—** In Year Two we continued to work towards making AQMS the operational data processing system at UUSS. Owing to the demands of the ARRA upgrades, repeated AQMS software changes, and difficulties related to maintaining an Oracle database without a specialized DBA, the overall progress was slower than anticipated. The AQMS design for UUSS consists of four machines—two real-time (RT) and two post-processing (PP), allowing for redundancy and fail-over. One of the RT-PP pairs is configured and currently operational. We have started testing locating earthquakes with multiple velocity models in AQMS, similar to the legacy system. Also, we integrated the metadata for seismic stations outside our network that are used in data processing into the database and enabled the acquisition of data from NSMP dial-up stations and NetQuakes. Additionally we have implemented alarms similar to our current production system and have installed and integrated ShakeMap v3.5.

In related work, we met with Mike Stickney in November to address the implementation of the Montana network data (Tier II) into the UUSS AQMS system. We agreed on some of the elements necessary for integration and constructed a list of specific tasks; however, it was understood that the main priority is to get AQMS operational in Utah.

Steps Toward Greater Coordination with NEIC — Greater coordination between NEIC and regional seismic networks, including ours, is a key imperative for ANSS system performance. This coordination includes 24/7 backup by NEIC, with emphasis on continuity-of-operations planning, post-event coordinated response, and post-event coordination of field recording. We continue to build on past years of coordination with NEIC. In Year One, we worked closely with the ShakeMap group to develop a mechanism for Global ShakeMap to backup the Utah ShakeMap. In Year Two, the emphasis was on constructing a plan for transferring waveform data to NEIC in real-time. On September 1, 2011 we met with Harley Benz and Dave Ketchum and developed a plan for transferring the UUSS data to NEIC.

Ground Motion Simulations **—** We completed a collaborative project with San Diego State University to carry out 3D numerical simulations of ground motions (0-10 Hz) from M 7 surface-rupturing earthquakes along the Salt Lake City segment of the Wasatch fault (Roten et al., 2011a,b). Significant features of the predicted ground motions from six different rupture scenarios include a strong sensitivity to the rupture propagation direction, large nonlinear soils effects, average peak horizontal ground accelerations ranging from 0.3 to > 0.6 g over the eastern two-thirds of the Salt Lake Valley, and reasonably good agreement with recently-developed empirical ground motion prediction equations. This work was funded by the USGS external research program and the Swiss National Science Foundation.

Infrasound arrays and partner projects — During the report period, we continued our infrasound studies in collaboration with scientists from Southern Methodist University and LANL (with funding from the Air Force Research Laboratory). Nine infrasound arrays are currently incorporated into the seismic network. Work included analysis of the Tushar Mountain earthquake (for more details, see description of the earthquake sequence below).

Funding for a multifaceted project related to mining seismicity — UUSS and the University of Utah Department of Mining Engineering received joint funding from the National Institute for Occupational Safety and Health (NIOSH) to: (1) analyze mining induced seismicity (MIS), including hypocentral locations and source analysis, (2) provide a geotechnical model of the Trail Mountain Mine, (3) analyze InSAR measurements of subsidence and possible correlations with MIS, (4) evaluate pillar stress changes with seismic interferometry, and (5) train graduate students in ground-control related research.

Education and Outreach **—** One important accomplishment related to UUSS education and outreach activities is overhauling the "Earthquakes in the Intermountain West" travelling exhibit. This exhibit was developed for the benefit of the community and serves as a tool to present information about historical and current local, national, and international earthquakes. It also provides information on how to create an emergency preparedness plan.

Improved Network Operations

SeisNetWatch, NAGIOS, and MRTG **—** To monitor state-of-health information, we have updated the ISTI SeisNetWatch software. We are currently running version 1.71 of the Network Station Info (NSI) server and version 1.83 of the GUI client software. We continue to use Nagios, an open-source host, service, and network monitoring program, to monitor critical systems (e.g., telemetry links, sensors, computer hardware) in our network. Email and pager notifications are configured to alert staff members when there are problems. We also rely on MRTG (multi-router traffic grapher) to monitor local network traffic (LAN) as well as telemetry traffic and health (error rates) both locally and for our Earthworm nodes. This tool allows us to see short-term performance statistics, as well as long-term trends in network behavior.

Moment Tensors **—** We have calculated the full moment tensor (Minson and Dreger, 2008) for 51 earthquakes occurring in Utah and the surrounding region from 1998 to mid-2011. The moment magnitudes range from 3.3 to 4.7. This moment tensor catalog represents 75% of $M_L \geq 3.5$ earthquakes reported in the University of Utah Seismograph Stations catalog during the study time period. Focal mechanisms are predominantly normal to normal-oblique, and there are several strike-slip earthquakes. Two events are found to have large and significant implosive components and are associated with known mine collapses. Full moment tensor capability will allow us to respond quickly in the event of a future mine collapse. A paper describing the catalog is in preparation and we expect to submit the work for publication in the remaining part of Year Two.

Mass Storage — Over the past year UUSS purchased a new mass-storage device to be used as an archive of continuous UUSS seismic and infrasound data. Since September 2011 the archive has been filling up with data in real-time and plans are underway to backfill the archive with all digital data ever produced by UUSS. We partnered with Dave Ketchum of NEIC/USGS to install the continuous waveform buffer (CWB) software used by researchers at NEIC. This software provides efficient storage and retrieval of the waveform data, enabling new types of operational research and quality control to be carried out by UUSS personnel.

Other

Tushar (Circleville) Earthquake—On January 3, 2011, an M_w 4.6 earthquake occurred in the Tushar Mountains of central-southwestern Utah, eight miles southwest of the town of Circleville. Full moment tensor inversion indicates an oblique-normal focal mechanism with a dominant double-couple component. As of December 1, 2011, a total of 101 aftershocks ranging from Mc -0.7 to M_L 3.6 have been recorded. The aftershocks of the Tushar sequence are nearly all located east of the mainshock, suggesting that the nodal plane striking NE and dipping steeply to the southeast is the fault plane. A temporary three-component seismometer was deployed in the aftershock zone on January 8, 2011. The portable data are being analyzed as part of a University of Utah Masters Thesis. In addition to the seismic recording, the mainshock also generated epicentral infrasound that was recorded on 6 infrasound arrays incorporated into the Utah Regional Seismic Network. Analysis and modeling of the infrasound data are summarized in Arrowsmith et al. (2011).

Quarterly Earthquake Summaries **—** Within 30–60 days of each calendar quarter we submitted to the USGS and distributed to stakeholders a report on *Earthquake Activity in the Utah Region, Preliminary Epicenters*. Besides an earthquake catalog and seismicity map, the reports include a narrative summary, a table of earthquakes felt and/or generating a ShakeMap in the Utah region, and an up-to-date table and maps for operating stations in the University of Utah Regional/Urban Seismic Network. The reports are available online.

6.3. Changes and accomplishments for Year 3 (Feb. 1, 2012 - Jan. 31, 2013)

New Stations and Station Upgrades

At the beginning of Year Three we maintained and operated 131 stations with full or partial ANSS support. (Note that instrumentation from stations HOC and LMU was removed due to construction activities and fire, respectively, and will be relocated at a later time.) Changes during this third year include: (1) upgrading 4 strong-motion stations (LEVU, MHD, WCU, and WMUT) by replacing the Episensors with instruments from the ANSS Depot (the original ones had serial numbers indicative of potential noise problems); and (2) installing three new stations, two BB+SM (BSUT and VRUT) as part of a state initiative, and one SM+SP (TCVU) in collaboration with the U.S. National Park Service. We have also installed a total of 21 NetQuakes strong-motion instruments, with the last 7 installed during Year Three.

AQMS

AQMS was established as the primary data-processing system on October 1, 2012. Making this transition was the top UUSS priority for calendar year 2012. Work leading up to AQMS implementation included: (1) solving problems related to our specific hardware architecture of two real-time and two post-processing machines, including replication involving the four Oracle databases and alarm configurations; (2) rigorous testing of newer versions of *Hypoinverse* and *Jiggle* software; for both algorithms, we worked intensively with the developers to fix bugs and implement requested changes ensuring continuity in the UUSS earthquake catalog; (3) configuring an expanded set of velocity models that includes the region from Montana to southern Utah—the Montana model was implemented in consultation with Mike Stickney; (4) refining and configuring alarms that included sub-regions; (5) testing and working with ISTI to add a signal-to-noise ratio (SNR) test for the calculation of amplitudes used in producing ShakeMaps (for small earthquakes the SNR test was shown to be necessary); and (6) training all analysts and duty seismologists in AQMS specific tasks.

In closely related work, we upgraded ShakeMap to version 3.5, and configured AQMS to generate automatic first-motion focal mechanisms using the *FPFIT* software. We continue to work with Mike Stickney regarding the implementation of the Montana network data (Tier II) into the UUSS AQMS system. Progress related to adding Montana included configuring the Montana velocity model, introducing the alarms to Mike Stickney, and reinitiating talks with ISTI regarding the software requirements for adding Montana into the UUSS AQMS system. In the next step, ISTI will need to provide updated code for testing at UUSS and Montana.

Greater NEIC coordination

Greater coordination between NEIC and regional seismic networks, including ours, is a key imperative for ANSS system performance. This coordination includes 24/7 backup by NEIC, with emphasis on continuity-of-operations planning, post-event coordinated response, and post-event coordination of field recording. We continue to build on past years of coordination with NEIC. In Year Three we began exporting all UUSS waveform data from our hot-site in Richfield, Utah to NEIC, via the Denver Federal Center. Additionally, as part of the Utah ShakeOut (discussed more in the *Continuity and Response Planning* section) we had an extensive conference call with NEIC personnel regarding earthquake response coordination. Specific items addressed included producing talking points, requests for additional instrumentation, and help with dealing with the media.

UUSS Director Keith Koper also visited NEIC for several days in summer 2012, while NEIC research scientist Morgan Moschetti visited the University of Utah for several days in November 2012. During Moschetti's visit, groundwork was laid for a future UUSS-NEIC collaboration involving ambient noise imaging of the Salt Lake Basin and possible identification of the underlying Wasatch fault.

Regional Moment Tensors

We published a catalog of regional moment tensors for 48 earthquakes that occurred in the Utah region during 1998-2011 (Whidden and Pankow, 2012). The method that was employed (Minson and Dreger, 2008) is capable of estimating the full moment tensor, including a test that assesses the significance of any isotropic component. This capability is critical for the Utah region because of the prevalence of mining induced seismicity, including collapses. All 48 events were tested for the statistical significance of the isotropic component, and two events, both known mine collapses, were found to have significant implosive components. The remaining events are constrained to be deviatoric (double couple and/or compensated linear vector dipole) and have predominantly normal and strike-slip mechanisms. We evaluated three velocity models and determined that the Western United States model (Herrmann *et al.* 2011) works best for moment tensor calculation in Utah. We continue to calculate moment tensors for earthquakes in the Utah and Yellowstone monitoring regions and are actively working towards calculating moment tensors in real time. We have also begun evaluating methods for determining moment tensors for small ($M<3$) events in Utah, particularly in the coal-mining region.

Strong Motion Noise Analysis

In Year Three we carried out an analysis of ambient noise recorded on all UU strong motion sensors for the calendar year 2011. Over 2.2 million PSDs were calculated for hour-long segments of data and analyzed in a method analogous to McNamara and Buland (2004), but with less smoothing at middle and short periods. Several subtle instrumentation problems were discovered and a new reference ambient noise model was developed that is more useful for evaluation of strong motion seismometers than the Peterson (1993) broadband model.

Evaluation of PGA/PGV vs. NGA

In Year Three we completed an analysis of instrumentally recorded peak ground acceleration (PGA) and peak ground velocity (PGV) recorded in Utah since 2000 (Pankow, 2012). Ground motions within 200 km of a UU strong-motion station were analyzed for all $3.0 \leq M_L \leq 5.5$ earthquakes. The PGA and PGV values were compared to modified NGA relations and a ShakeMap relation for small earthquakes. In the Utah region, it was found that the Chiou *et al*. (2010) model for southern California best fits the recorded ground motions. As a result, ShakeMap has been updated to use the Chiou and Youngs (2008) NGA relation for large earthquakes, and Chiou *et al*. (2010) for smaller events.

Mass Storage

In Year Three we completed the back-fill of our CWB data storage system with continuous digital data from all USSS broadband and short-period channels going back to 2001. We are currently back-filling broadband channels from the Intermountain west region (Yellowstone, Montana, Tetons, Idaho, Arizona, etc.), and soon after will begin loading segmented, event-based waveform data from the pre-2001 era. Real time UUSS data continues to be archived locally on the CWB system and we intend to thoroughly compare completeness statistics between our local depository and IRIS. Initial tests have shown some subtle, though potentially important, discrepancies.

Analysis of Mining Seismicity

During the report period, we continued a collaborative project with the University of Utah, Department of Mining Engineering to study mining induced seismicity (with funding from NIOSH). Related activities include: relocating seismicity around the Trail Mountain mine using both master events and relative relocations (Boltz *et al.,* 2012); reanalysis of the Crandall Canyon sequence using both log books from the rescue efforts (Kubaki *et al.,* 2012b) and waveform cross-correlation (Kubaki *et al.,* 2012a) to expand the catalog of seismic events before and after the collapse. We are also working to infer moment tensors for the smaller (M<3) mining events. As a result of this project, this year we were able to purchase one new broadband instrument, and are planning to purchase a second broadband next year. These instruments will be installed near active mining areas in central Utah and will be completely integrated into the UUSS network.

Infrasound arrays

During the report period, we continued our infrasound studies in collaboration with scientists from Southern Methodist University and LANL (with funding from the Air Force Research Laboratory**)**. Nine infrasound arrays are currently integrated into the seismic network. As part of this project, we recorded, documented, and modeled the infrasound signals generated by the January 2011 M4.5 Tushar Mountain earthquake (Arrowsmith *et al.*, 2012).

The Working Group on Utah Earthquake Probabilities

Two UUSS seismologists are active members of the Working Group on Utah Earthquake Probabilities (WGUEP), which has been organized by Ivan Wong of URS Corporation under the auspices of the Utah Geological Survey and the U.S. Geological Survey (Wong *et al.,* 2012). This group has met eight times, each time for 1 ½ to 2 days, beginning in 2010 and with two meetings in 2012. The goal of the working group is to estimate probabilities of potentially damaging earthquakes in the Wasatch Front region, including (1) time-dependent probabilities of $M \geq 6.5$ events on the five central segments of the Wasatch fault and the two southern segments of the Great Salt Lake fault, (2) time-independent probabilities of $M \geq 6.5$ earthquakes on other less well studied faults and fault segments, and (3) time-independent probabilities of background earthquakes of $5.0 \leq M \leq 6.5$. In support of this effort, we are working to create a consensus earthquake catalog—not only for the WGUEP study area but also for the entire Utah region—that unifies the UUSS catalog and the USGS National Seismic Hazard Mapping Project catalog. Achieving uniform estimates of moment magnitude, M_W, is a key part of the work. Efforts undertaken during 2012 include work on: (1) a more rigorous analysis of the relation between UUSS catalog magnitudes and M_W (Pechmann and Whidden, 2012); (2) the compilation and evaluation of non-UUSS size estimates for Utah earthquakes, both pre-instrumental and instrumental, and their relations to M_W; (3) improving equations for estimating M_W of historical Utah earthquakes from maximum intensity and felt area; and (4) to ensure unbiased calculations of earthquake rates, statistical studies to assess uncertainties associated both with observed magnitudes and magnitude transformations.

National Seismic Hazard Mapping Project Workshops

Two UUSS seismologists gave presentations at the "Workshop on Update of Intermountain West Part of the U.S. National Seismic Hazard Maps," which was held on June 13-14, 2012, at the University of Utah. One person also attended the Western U.S. National Seismic Hazard Map GPS Workshop, which was held on October 18-19, 2012, in Newark, California.

Quarterly Earthquake Reports

During Year Three we continued to produce quarterly reports. These reports, on *Earthquake Activity in the Utah Region, Preliminary Epicenters*, are generated within 30–60 days of each calendar quarter and are submitted to the USGS and distributed to stakeholders. In addition to an earthquake catalog and seismicity map, the reports include a narrative summary, a table of earthquakes felt and/or generating a ShakeMap in the Utah region, and an up-to-date table and maps for operating stations in the University of Utah Regional/Urban Seismic Network. The reports are available online from the UUSS home page (www.seis.utah.edu).

Continuity of Operations

Beginning in 2007, we initiated development of a formal plan for continuity of operations. The plan can be divided into two parts: (1) continuity of data collection and (2) continuity of routine and response operations. To improve data recovery, the entire schema for our seismic network has been redesigned. The major changes include digitizing the analog-telemetry stations at eight distributed sites, collecting the digital data at six data collection nodes dispersed throughout the state, and sending all data to both the University of Utah and to a hot site in a state-owned backup facility in Richfield, Utah. Data transmission from the nodes and hot site is done through the State of Utah microwave network (internet protocol) and the Utah Education Network. As discussed in a previous section, all UUSS data are now being archived at UUSS using CWB, as well as at IRIS. Additionally, in March of 2012 we began forwarding all UUSS data to NEIC via the Federal Center from the backup facility in Richfield using Edge software.

During Year Three of this project, advances in continuity of data collection include expanding the use of SEEDLink and slink2ew to additional datalogger models, adding UPS to some data collections sites, and expanding the way we monitor data flow and machine performance using Nagios. We also installed Edge software at the remote nodes. This allows easy back-filling of data if there is a telemetry outage. It also allows us to store longer windows of data at the remote nodes. In preparation for IT changes that will affect data collection, we have also been experimenting and starting to research the effects of the change to IPv6. We have been in contact with vendors and are being proactive in preparing for the change in standards.

For continuity of routine operations and response operations, we overhauled the UUSS Continuity of Operations Plan originally developed in 2007 and have also developed an Emergency Operations Plan. These plans were updated and developed in preparation for the 2012 Utah ShakeOut exercise. The new plans were tested during ShakeOut. Appendix 1 contains the post-exercise analysis. A number of items were identified as action items. We have made progress in addressing many of these items and have planned a tabletop/functional exercise for Tuesday, December 18, 2012. We will use this exercise to evaluate the progress made since April.

6.4. Changes and accomplishments for Year 4 (Feb. 1, 2013 - Jan. 31, 2014)

New Stations and Station Upgrades

At the beginning of Year Four we maintained and operated 130 stations with full or partial Advanced National Seismic System (ANSS) support. Changes during this fourth year include: (1) upgrading 10 strong-motion stations (CRLU, FLU, HCSU, HTU, LTU, NPI, NPI, PTU, RBU, SAIU, and SNUT) by replacing the Episensors with instruments from the ANSS Depot (the original ones had serial numbers indicative of potential noise problems); and (2) installing one new station, a broadband+strong-motion station (SWUT) as part of a state initiative. Instrumentation from stations GMV, OF2, and RIV was removed owing to site construction and will be replaced, and possibly relocated, at a later time. We also installed one new NetQuakes instrument during Year Four, which brings our total number of such installations to 22.

AQMS

During Year Four, UUSS used the ANSS Quake Monitoring System (AQMS) as the primary data-processing system. Efforts were directed towards several major operational aspects: (1) maintaining the specific hardware of two real-time and two post-processing machines and the integrity of the four Oracle databases, including the replication processes; (2) adding testbed and development AQMS systems for testing different software/hardware configurations and another (redundant) system at the backup recording site (hotsite) in Richfield, Utah; (3) testing of USGS Edge software for waveform data import/export and implementation of this software for export of UUSS waveform data to the Incorporated Research Institutions for Seismology (IRIS) data center; (4) testing and implementation of coda magnitude (M_C) determinations using short-period digital telemetry data from recently upgraded analog telemetry stations, (5) testing of newer versions of *Earthworm* and *Jiggle* software to ensure continuity and accuracy in the UUSS earthquake catalog and data processing; (6) maintaining the database metadata information and related configuration files using the UUSS dataless SEED volume; (7) refining and configuring alarms, including specific configurations for the Montana region (MB network); and (8) continued discussions with all analysts and duty seismologists in AQMS-specific tasks to ensure proper response to significant and felt earthquakes.

We continued to work with Mike Stickney regarding the implementation of the Montana network data processing (Tier II) into the UUSS AQMS system. Our engineer Jon Rusho visited Montana over the summer to assist in the set-up of computers designed to run Earthworm and Edge software needed for the AQMS transition. He also helped to install Jiggle for testing purposes. A second trip is scheduled for later this calendar year to continue the integration process.

Greater NEIC Coordination

Greater coordination between the National Earthquake Information Center (NEIC) and regional seismic networks, including ours, is a key imperative for ANSS system performance. This coordination includes 24/7 backup by NEIC, with emphasis on continuity-of-operations planning, post-event coordinated response, and post-event coordination of field recording. We continue to build on past years of coordination with NEIC.

Helping Other Seismic Networks

In partnership with Northern Arizona University (NAU), we helped with upgrades to the NAU seismic network that included new discriminators, new digitizers, and updates to the data acquisition system. We also assisted with updating metadata information. Data are now being archived at NAU and at the IRIS DMC using Edge.

Regional Moment Tensors

During Year Four, seven moment tensors have been calculated at UUSS for earthquakes in and around Utah. The earthquakes range in magnitude from M_w 3.6-4.8, and in depth from 2-80 km. The 80 km deep M_w 4.8 earthquake occurred in the upper mantle beneath western Wyoming and is the subject of ongoing study at UUSS. We have enhanced the format of our moment tensor output and trained all duty seismologists to use our regional moment tensor inversion code.

Infrasound Arrays

During the report period, we continued our infrasound studies in collaboration with scientists from Southern Methodist University and LANL (with funding from the Air Force Research Laboratory**)**. Nine infrasound arrays are currently integrated into the seismic network. As part of this project, we recorded infrasound signals generated by two large rock avalanches that occurred on April 10, 2013, MDT at the Bingham Canyon copper mine near Salt Lake City. The infrasound and seismic signals from these rock avalanches, and some small earthquakes that they induced, will be the subject of three presentations (two with UUSS authors) at the 2013 American Geophysical Union Fall Meeting in San Francisco.

The Working Group on Utah Earthquake Probabilities

In support of the UGS-USGS Working Group on Utah Earthquake Probabilities, UUSS has devoted considerable effort to developing a unified moment magnitude earthquake catalog for the Utah region for the time period 1850 through September 2012. This catalog is a "unified" catalog in the sense that it synthesizes existing UUSS and USGS catalogs and uses multiple size measurements to obtain a best estimate of the moment magnitude, M_w, for each earthquake. For this project we have developed 18 conversion relations between M_w and an assortment of shaking-intensity size measurements and instrumental magnitudes that have varied with time and reporting agency. The new earthquake catalog will be used to compute unbiased recurrence rates, duly accounting for magnitude uncertainty and for background earthquakes below the threshold of surface faulting.

Professional Outreach

UUSS personnel played key roles in the 2013 Seismological Society of America Annual Meeting held in Salt Lake City in April. UUSS provided a co-chair and two members of the program committee, two of the six speakers at the town hall meeting, five co-chairs of special sessions, and eight first-author technical presentations. UUSS has also been involved in helping the Utah Museum of Natural History with a visiting exhibit on natural disasters. Several seismologists from UUSS have participated in both training museum docents and answering questions from the public at the museum.

Quarterly Earthquake Reports

During Year Four we continued to produce quarterly reports. These reports, on *Earthquake Activity in the Utah Region, Preliminary Epicenters*, are generated within 30–60 days after each calendar quarter and are submitted to the USGS and distributed to stakeholders. In addition to an earthquake catalog and seismicity map, the reports include a narrative summary of earthquake activity during the quarter, a table of earthquakes that were felt and/or large enough to generate a ShakeMap in the Utah region, and an up-to-date table and maps of operating stations in the University of Utah Regional/Urban Seismic Network. The reports are available online from the UUSS home page (www.seis.utah.edu).

Continuity and Response Planning

UUSS has made several improvements to the network infrastructure during the past year to reduce the likelihood of data loss during telemetry and/or power outages.

- Edge/CWB data archiving has been configured at the Richfield, Utah, hotsite, with a capability of storing up to 190 days of data. This setup allows us to back-fill data at the main facility in case of major disruptions.

- Our mountaintop telemetry sites have been upgraded to include UPS backup power in addition to generator power, and remote power-cyclers to allow us to remotely reset equipment rather than drive to the site. Small Linux computers have also been installed to augment our acquisition systems, allowing the buffering and preservation of data if the digital microwave links fail.

- Nearly half of our strong-motion instruments are either Kinemetrics K2 or Etna digitizers with Episensors. These systems have proven themselves reliable over many years, but they have minimal ability to buffer data during a telemetry outage. We are currently experimenting with supplementary data buffering on Raspberry Pi Linux computers running a minimal Earthworm system plus ew2ringserver and ringserver from IRIS. These computer systems would allow us to store more data on site and retrieve it after a telemetry outage. The Raspberry Pi computers are about the size of a credit card, and can be installed in a small footprint device that can be directly mounted on or adjacent to the K2/Etna. The upgrade per K2/Etna is estimated to cost less than $100 per site.

During Year Four UUSS had the opportunity to test various aspects of our continuity of operations plan. Some examples include:

- The University of Utah has been upgrading the campus electrical infrastructure, which necessitated several extended power outages. Our building UPS and generator systems have handled these outages well. However during one outage, part of the campus network infrastructure went down. We were able to continue processing at our hotsite during this outage.

- The Utah Education Network (UEN), the network interconnecting schools, colleges and universities within the State of Utah as well as providing the primary network connectivity for the State of Utah government, began a series of network upgrades throughout Utah during 2013. UUSS heavily utilizes UEN and State network connections for data flow. These upgrades have resulted in extended outages at several institutions throughout Utah. The UUSS network design, with distributed acquisition nodes, was able to weather most of these outages without loss of data.

6.5. Changes and accomplishments for Year 5 (Feb. 1, 2014 - Jan. 31, 2015)

Basin and Range Province Seismic Hazards Summit III (BRPSHSIII)

UUSS was one of seven co-sponsors of the Basin and Range Province Seismic Hazards Summit III (BRPSHSIII) meeting, which was held in Salt Lake City, Utah, from January 12-17, 2015. This meeting was convened by the Utah Geological Geological Survey and the Western States Seismic Policy Council to discuss recent earthquake-hazards research and to evaluate its implications for hazard reduction and public policy in the Basin and Range Province. A UUSS seismologist served on the program committee for this meeting and was the primary organizer of the session on “Ground Motions from Normal-Faulting Earthquakes.” UUSS personnel also gave three presentations at the BRPSHSII meeting (Koper, 2015; Arabasz et al., 2015; Dinter and Pechmann, 2015) and conducted a tour of UUSS as part of the field trip on the last day of this meeting. The meeting presentations will be included in the BRPSHSIII Proceedings Volume as digital slide shows or posters.

Working Group on Utah Earthquake Probabilities (WGUEP)

As part of a Working Group on Utah Earthquake Probabilities (WGUEP; see Wong *et al*., 2014, 2015), UUSS seismologists contributed more than a man-year of effort in data compilation and analyses. These efforts included the development of a moment magnitude catalog for the Utah region, calculations of earthquake recurrence rates based on this catalog, the lead role in a comparison of seismic moment rates estimated from crustal deformation measurements ("geodetic moment rates") with geological/seismological moment rates predicted by the WGUEP model, analysis of focal depth variations, and work on characterizing the Oquirrh-Great Salt Lake fault zone. The two UUSS WGUEP members also contributed to other aspects of the project, in part during 12 Working Group meetings of 1-2 days each from 2010 to 2015. The WGUEP report (Wong et al., 2015) will be published by the Utah Geological Survey after revisions based on the recently completed USGS review.

The most substantial UUSS contributions to the WGUEP were the development of a uniform moment magnitude earthquake catalog for the Utah region (1850–September 2012) and the use of this catalog to compute recurrence rates for earthquakes below the threshold of surface faulting in the Wasatch Front and surrounding Utah region. Full details are documented in an appendix (Arabasz *et al*., 2015) to the WGUEP report. The new catalog unifies existing UUSS and USGS catalogs for the Utah region and incorporates results of a systematic review and editing of the historical earthquake record, thus facilitating authoritative earthquake hazard and risk analyses. To obtain a best estimate of the moment magnitude, **M**, for each earthquake, Arabasz et al. (2015) developed eighteen region-specific conversion relationships to **M** (based on general orthogonal regressions) for an assortment of instrumental magnitudes and shaking-intensity size measures. They also used a refined state-of-the-art methodology to correct the earthquake recurrence rates determined from the moment magnitude catalog for the bias caused by magnitude uncertainty. Their analysis of Utah region seismicity likely incorporates more thorough and rigorous treatments of the earthquake record, magnitude estimates, and magnitude uncertainties than heretofore attempted for any ANSS network region in the western U.S. outside of California.

The geodetic analysis showed that the rate of crustal deformation is consistent with the WGUEP earthquake rate model except in the southernmost fifth of the WGUEP study region, an area that encompasses the Levan and Fayette segments of the Wasatch fault. In this area the geodetic moment rate is a factor of six higher than the geological/seismological moment rate, with no overlap in the uncertainty ranges. The cause of this moment rate discrepancy is currently unknown.

Bingham Canyon Landslides

Work continued this year on the analysis of the seismic and infrasound data generated by the April 10, 2013, Bingham Canyon landslide. Research efforts focused on three main directions: (1) understanding the dynamics of the landslide; (2) analysis of earthquakes induced by the slide; and (3) detection of infrasound from additional smaller scale landslides. The research team consists of UUSS staff members Dr. Kris Pankow, Dr. Keith Koper, and Mark Hale; Dr. Jeff Moore (UU Geology and Geophysics), UU Mining Engineering graduate student Tex Kubacki, and Sean Ford (Lawerence Livermore National Laboratory). Results related to the induced earthquakes by the landslide were presented in an Invited Talk at the 2014 Geological Society of America meeting in Vancouver. Results were also presented by Dr. Kris Pankow at the Southern

Methodist University (Dallas, TX) Department of Earth Sciences Seminar Series in October.

Challis, Idaho Earthquake Sequence

In late March 2014 an energetic sequence of earthquakes began occurring near Challis, ID, in an area 20-30 km to the northwest of the M6.9 1983 Borah Peak earthquake fault zone. Many events in the sequence were felt by local residents. UUSS partnered with the U.S. Geological Survey, the Idaho Geological Survey, Boise State University, Montana Bureau of Mines and Geology (MBMG), and Idaho National Laboratories to install a temporary network of 5 seismic stations (broadband and strong-motion) near the source region in mid-April, with two additional stations in early July. The addition of these stations decreased the minimum distance between events and closest stations, from over 70 km to under 12 km, for nearly all events. All, but one station, were removed in September in preparation for the winter season.

Initial processing results were presented at the 2014 Fall American Geophysical Union Meeting in a study led by Mike Stickney (MBMG); UUSS contributing authors included Dr. Kris Pankow, Dr. Keith Koper, and Katherine Whidden. The locations and focal mechanisms determined in this initial analysis suggest that the 2014 sequence occurred on a northwestern continuation of the Lost River Fault, which ruptured in the 1983 Borah Peak earthquake.

Partnering with Montana

In 2014, UUSS made a major effort to incorporate Montana Bureau of Mines and Geology (MBMG) earthquake data into the ANSS Quake Monitoring System (AQMS) located at the University of Utah. Together with MBMG staff, computer hardware and software were upgraded; Earthworm configuration files were optimized; station metadata were updated and imported into the database; and an end-to-end data exchange was set-up. By the end of 2014, MBMG were fully integrated into AQMS. MBMG will be migrating to AQMS for operations in 2015.

MSSSTC Interns/GSL Seismicity

Mindy Timothy and Kristel Hansen worked at the UUSS facility during the summer of 2014 to complete the research component of their Masters of Science for Secondary School Teachers degree. For their research projects, they analyzed the relationship between changes in water level at the Great Salt Lake (Mindy) and Utah Lake (Kristel) and earthquakes from the UUSS earthquake catalog, for possible effects of induced seismicity. During their activity at UUSS, they were mentored by Katherine Whidden and Dr. Kris Pankow. The results of their analyses prompted additional research that was presented at the 2014 Fall American Geophysical Union Meeting.

Removal of Infrasound Arrays

2014 brought the end of funding for many of the infrasound arrays in Utah. As a result, six of the nine arrays were decommissioned. In partnership with Southern Methodist University, we continue to operate the arrays BRPU, PNSU, and NOQ.

Mining-Induced Seismicity (MIS)

In continued work on MIS, Dr. Kris Pankow and Dr. Keith Koper worked with GG graduate student Jared Stein and UU Mining Engineering graduate students Derrick Chambers and Tex Kubacki to detect and discriminate seismic sources in the mining environment and to improve the three-dimensional locations. Results from these studies have included a catalog of MIS with an improved magnitude of completion and locations for the time bracketing the 2006 Crandall Canyon Mine collapse; discrimination of surface blasting and MIS for southwestern Wyoming using the EarthScope Transportable Array; and relative relocation of seismic events in the Wasatch Plateau to determine if depth can be used to discriminate MIS. Results from this work have been published in the Journal of Geophysical Research, presented at the 2014 Fall American Geophysical Union Meeting, and will be also presented at the 2015 Society for Mining, Metallurgy, and Exploration Meeting.

In related work, Dr. Kris Pankow worked with UU Mining Engineering graduate student Meagan Shawn Boltz, who developed a three-dimensional finite difference model (FLAC3D™) for the Trail Mountain Mine located in central Utah. Results from this model were compared to MIS recorded at the mine from October 2000–April 2001. Conclusions of the study included the observation that peaks in the maximum shear stress are followed by peaks in the seismic moment. However, it was found that stresses alone are not a sufficient indicator of the occurrence of future MIS, in space or time.

7. REFERENCES CITED

Arabasz, W.J., J.C. Pechmann, and R. Burlacu (2015). A unified earthquake catalog and background seismicity rates for the Wasatch Front and surrounding Utah region, *Basin and Range Province Seismic Hazards Summit III*, January 12-17, 2015, Salt Lake City, Utah (poster presentation).

Dinter, D.A., and J.C. Pechmann (2015). Paleoseismology of the northern segments of the Great Salt Lake fault, *Basin and Range Province Seismic Hazards Summit III*, January 12-17, 2015, Salt Lake City, Utah (poster presentation).

Koper, K. (2015). Earthquake early warning in the Intermountain West, *Basin and Range Province Seismic Hazards Summit III*, January 12-17, 2015, Salt Lake City, Utah (keynote address, day 2).

Wong, I., W. Lund, C. DuRoss, P. Thomas, W. Arabasz, A. Crone, M. Hylland, N. Luco, S. Olig, J. Pechmann, S. Personius, M. Petersen, D. Schwartz, and R. Smith (2014). New time-independent and time-dependent seismic source models for the Wasatch Front, Utah for the National Seismic Hazard Maps, *Seism. Res. Lett.* **85,** 481.

Wong, I., W. Lund, C. DuRoss, P. Thomas, W. Arabasz, A. Crone, M. Hylland, N. Luco, S. Olig, J. Pechmann, S. Personius, M. Petersen, D. Schwartz, R. Smith, and S. Bowman (2015). Earthquake probabilities for the Wasatch Front region in Utah, Idaho, and Wyoming, Final Technical Rept., U.S. Geol. Surv. Award Nos. G11AP20010, G11AP20004, G13AP00003, and G13AP00002, 212 pp. (excluding appendices), in revision following USGS review.

8. BIBLIOGRAPHY OF RELATED PEER-REVIEWED PUBLICATIONS AND STUDENT THESES

Arrowsmith, S., R. Burlacu, K. Pankow, B. Stump, R. Stead, R. Whitaker, and C. Hayward (2012). A seismoacoustic study of the January 3, 2011 Circleville earthquake, *Geophys. J. Int.* **189**, 1148-1158.

Boltz, M. S. (2014). Mining-induced seismicity and FLAC3D modeling at the Trail Mountain Mine, *M.S. Thesis*, University of Utah, Salt Lake City, Utah.

Boltz, M., K. Pankow, and M. K. McCarter (2014). Fine details of mining-induced seismicity at the Trail Mountain Mine coal mine using modified hypocentral relocation techniques, *Bull. Seism. Soc. Am.* **104**, 193-203.

Dyal, K. (2012). Microseisms at Dugway Station, *M.S.S.S.T. Thesis*. University of Utah, Salt Lake City, Utah.

Gammans, C. N. L. (2013). Low-angle normal faulting in the Basin and Range-Colorado Plateau transition zone during the January 3, 2011 Circleville, UT earthquake sequence, *M.S. Thesis*, University of Utah, Salt Lake City, Utah.

Hale, J. M. (2013). Infrasound signal characteristics of small earthquakes, *M.S. Thesis*, University of Utah, Salt Lake City, Utah.

Hansen, K. (2014). An investigation of Utah Lake and reservoir induced seismicity, *M.S.S.S.T. Thesis*, University of Utah, Salt Lake City, Utah.

Kanu, C., R. Snieder, and K. Pankow (2014). Time-lapse monitoring of velocity changes in Utah, *J. Geophys. Res. Solid Earth* **119**, 7209–7225.

Kubacki, T. M. (2014). Changes in mining induced seismicity before and after the Crandall Canyon Mine collapse, *M.S. Thesis*, University of Utah, Salt Lake City, Utah.

Kubacki, T., K. D. Koper, K. L. Pankow, and M. K. McCarter (2014). Changes in mining induced seismicity before and after the 2007 Crandall Canyon Mine collapse, *J. Geophys. Res. Solid Earth* **119**, 4876–4889.

Linville, L. M. (2014). Dynamic earthquake triggering potential across Earthscope's Transportable Array, *M.S. Thesis*, University of Utah, Salt Lake City, Utah.

Pankow, K.L., J. R. Moore, J.M. Hale, K.D. Koper, T. Kubacki, K. M. Whidden, and M. K. McCarter (2014). Massive landslide at Utah copper Mine generates wealth of geophysical data, *GSA Today* **24**, 4-9.

Roten, D., K. B. Olsen, and J. C. Pechmann (2012). 3-D simulations of M 7 earthquakes on the Wasatch fault, Utah, Part II: Broadband (0-10 Hz) ground motions and nonlinear soil behavior, *Bull. Seism. Soc. Am.* **102,** 2008-2030.

Roten, D., K. B. Olsen, J. C. Pechmann, V. M. Cruz-Atienza, and H. Magistrale (2011). 3-D simulations of M 7 earthquakes on the Wasatch fault, Utah, Part I: Long-period (0-1 Hz) ground motions, *Bull. Seism. Soc. Am.* **101,** 2045-2063 [correction to the author list added in **102,** 453].

Thomas, G., K. D. Koper, R. Burlacu, and D. Drobeck (2013). A model of ambient seismic noise recorded by the Utah regional network of strong-motion seismometers, *Seism. Res. Lett.* **84**, 759-771.

Timothy, M. (2014). Comparison of seismicity rates to the Great Salt Lake elevation fluctuations, *M.S. Thesis*, University of Utah, Salt Lake City, Utah.

Whidden, K. M. and K. L. Pankow (2012). A catalog of regional moment tensors in Utah, *Seism. Res. Lett.* **83**, 775-783.

9. FIGURES

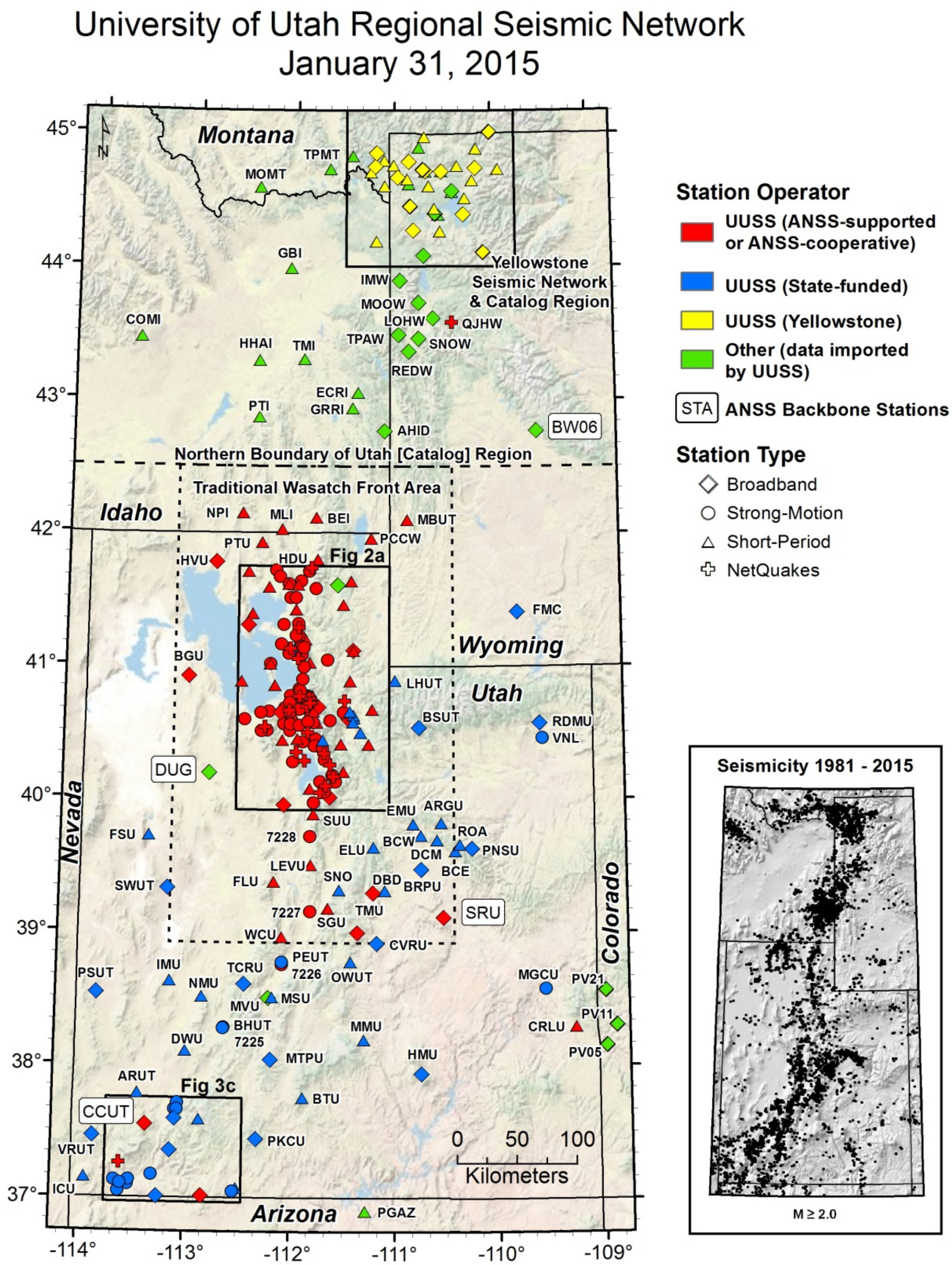

Figure 1. Seismic stations operated and/or recorded as part of the University of Utah regional/urban seismic network. Inset dashed rectangle outlines our traditional Wasatch Front study area; our authoritative Utah catalog region extends from 36.75° to 42.5° N. Smaller map (right) shows representative seismicity for the same area.

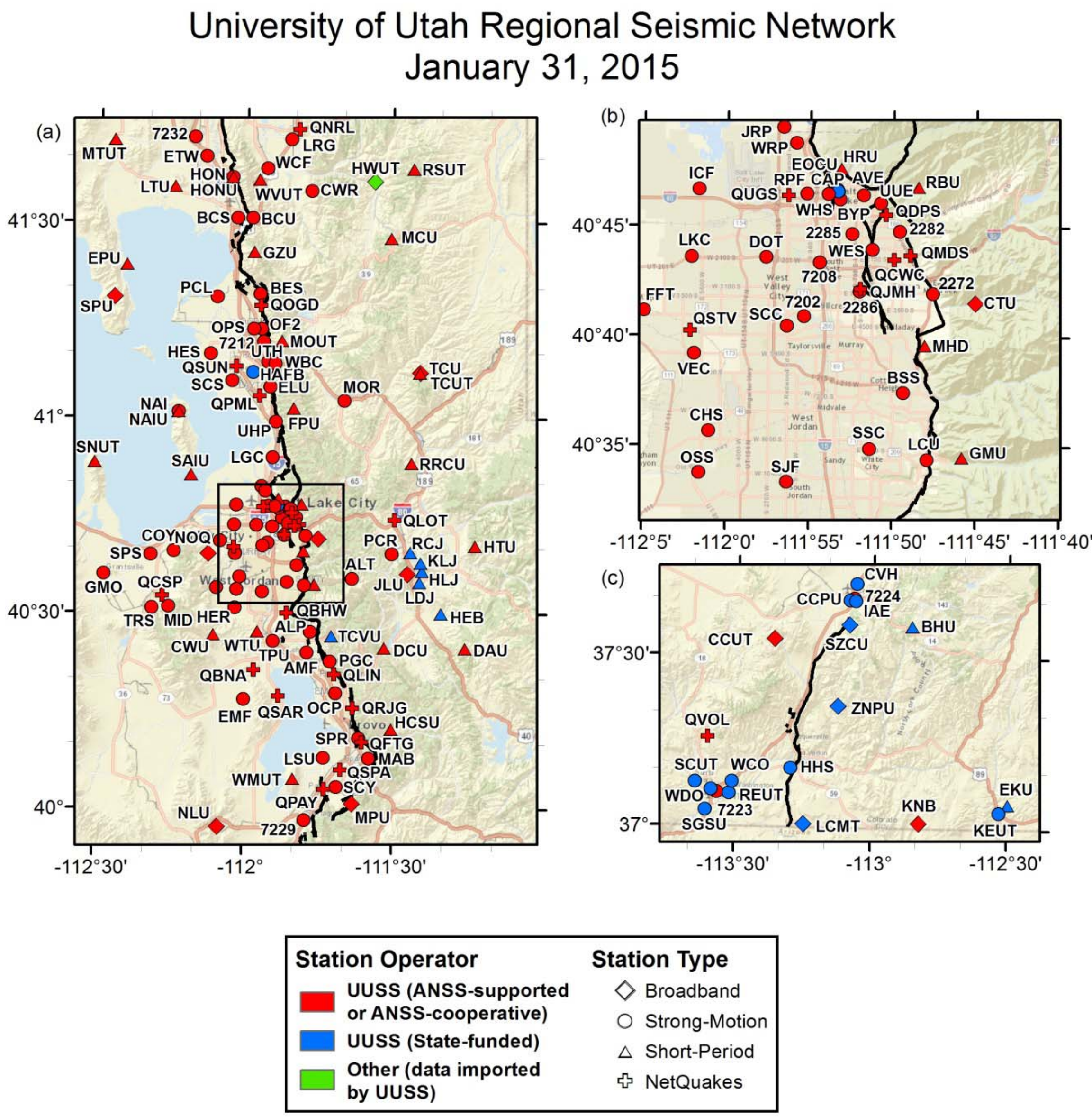

Figure 2. Close-ups of densely populated regions from Figure 1.

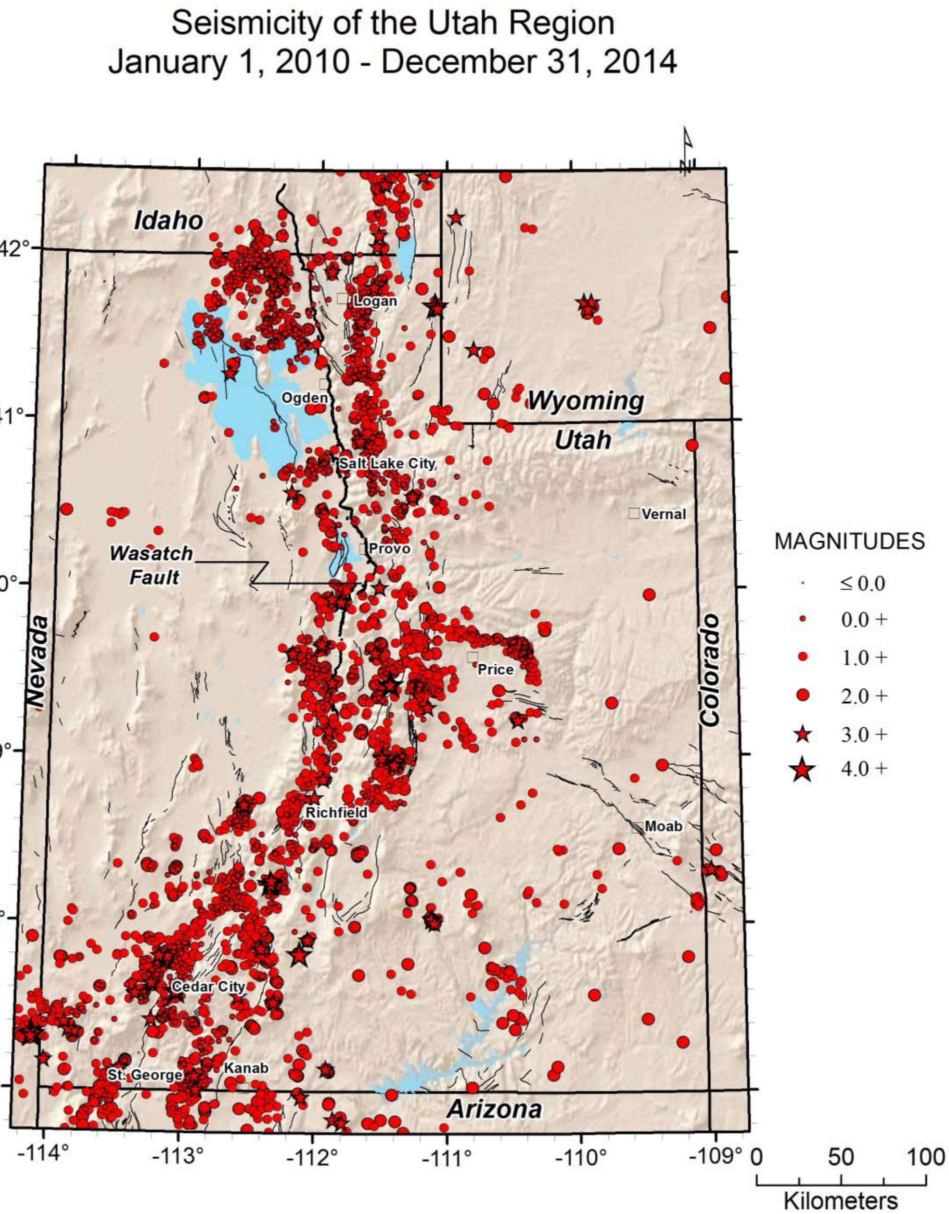

Figure 3. Epicenter map of earthquakes located by the University of Utah Seismograph Stations in the Utah region; base map of Quaternary (geologically young) faults from the Utah Geological Survey. The Wasatch fault is shown in bold.

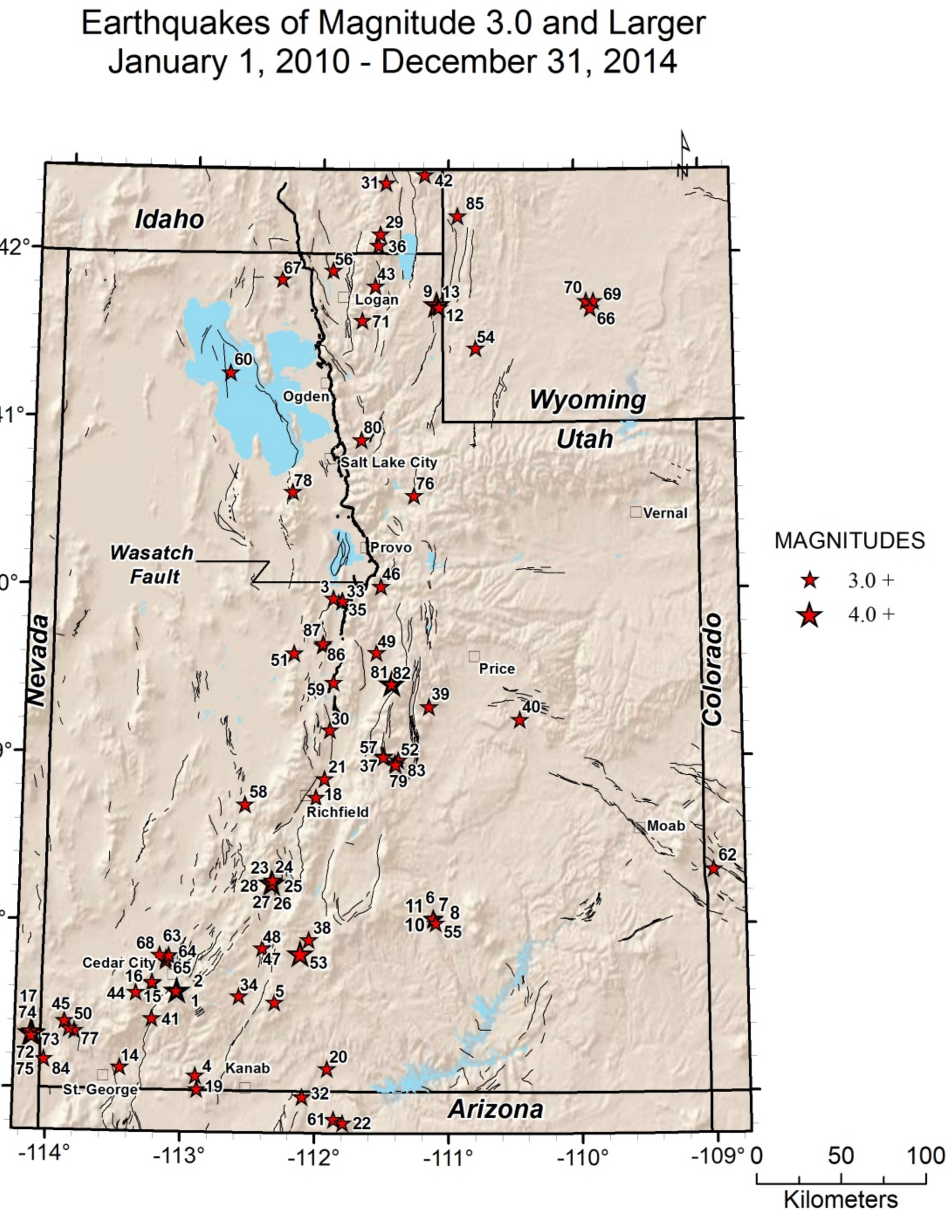

Figure 4. Epicenter map of earthquakes of magnitude 3.0 and larger in the Utah region during the period January 1, 2007 – December 31, 2009 (base map as in Figure 3). Epicenters, keyed to Table 3, are labeled by number.

Table 1. Overview of the University of Utah Regional/Urban Seismic Network January 31, 2015

Networks Forming Part of Regional Operation:	CODE	Stations/channels
Utah Region Seismic Network	UU	194/629
ANSS-NSMP stations with real-time telemetry maintained and operated by University of Utah	NP	15/45
Yellowstone National Park Seismograph Network (YSN)	WY	28/94

TOTAL Stations/Channels Operated: 237/768

Import data from:	CODE	Stations/channels
Montana Regional Seismic Network	MB	6/6
Idaho National Engineering and Environmental Laboratory Seismic Network	IE	7/7
Western Great Basin/Eastern Sierra Seismic Network University of Nevada, Reno	NN	3/9
US Bureau of Reclamation Paradox Valley Seismic Network	RE	4/12
US National Seismic Network	US	12/36
USGS National Strong Motion Project (via EW module getfile; triggered data from instruments in Wasatch Front area)	NP	Variable (.evt and xml files)
Sandia National Laboratory—Leo Brady Network	LB	2/6
USGS Albuquerque Seismological Laboratory	IU	1/3
Northern Arizona University Seismic Network	AR	3/3
Arizona Broadband Seismic Network	AE	2/6
Intermountain West	IW	8/24
PBO Borehole Seismic Network	PB	6/18
USArray Trabsportable Array	TA	3/9
Total Stations/Channels Imported:		**57/139**

TOTAL Stations/Channels Recorded: 294/907

Export Data To:	Stations/Channels
Brigham Young University (Idaho) Seismic Network (formerly Ricks College)	21/29
Montana Regional Seismic Network	8/8
Idaho National Engineering and Environmental Laboratory Seismic Network	7/7
Northern Arizona University Seismic Network	7/21
Yellowstone Volcano Observatory/USGS	29/53
USGS/NEIC	Export HYP, MAG, SMII messages
USGS/NEIC	26/76
IRIS Data Management Center	248/539
Total Stations/Channels Exported:	**346/733**

Table 2. Summary Statistics for UU Regional/Urban Seismic Network
(as of January 31, 2015)

Total no. of stations operated and/or recorded	294
Total no. of channels recorded	907
No. of short-period (SP) stations	102 (37 ANSS)
No. of short-period (SP) stations with metadata	102
No. of broadband (BB) stations	78 (13 ANSS)
No. of broadband (BB) stations with metadata	78
No. of strong-motion (SM) stations	114 (92 ANSS)
No. of strong-motion (SM) stations with metadata	114
No. of stations maintained & operated by network	237
-same, with full metadata	237
No. of stations maintained & operated as part of ANSS	142
-same, with full metadata	142
Total data volume archived (mbytes/day)	*
* *Estimated UU data volume being recorded in the IRIS DMC in MiniSeed format is ~8000 mbytes/day*	

Table 3. Earthquakes in the Utah Region of Magnitude 3.0 and Larger: January 1, 2010 – December 31, 2014

No.	Date	Origin Time	Latitude	Longitude	Depth	Mag	No	Gap	Dmn	Rms
1	100104	16:24:03.11	37º 35.92′	113º 02.33′	6.8	4.1W	25	49	8	0.39
2	100105	04:55:24.70	37º 35.58′	113º 02.77′	7.2*	3.3W	16	53	17	0.28
3	100123	15:48:45.53	39º 56.82′	111º 53.45′	1.1*	3.0W	31	58	11	0.26
4	100212	22:37:09.51	37º 05.51′	112º 53.54′	11.9	3.0W	11	102	10	0.35
5	100409	20:58:29.75	37º 32.08′	112º 18.44′	1.6*	3.0	17	125	10	0.25
6	100414	18:58:45.15	38º 02.02′	111º 06.76′	2.7*	3.9W	28	117	34	0.29
7	100414	22:39:52.98	38º 02.40′	111º 07.08′	5.0*	3.1W	18	129	35	0.26
8	100415	10:48:36.53	38º 02.62′	111º 06.78′	2.6*	3.2W	30	117	35	0.23
9	100415	23:59:38.97	41º 42.20′	111º 05.65′	7.9*	4.9W	29	88	29	0.23
10	100428	17:40:02.24	38º 02.09′	111º 06.88′	5.0*	3.2W	24	121	34	0.22
11	100502	15:00:00.83	38º 02.24′	111º 06.81′	4.9*	3.6W	18	129	24	0.26
12	100527	06:16:55.91	41º 41.33′	111º 05.23′	0.4*	3.1W	22	88	29	0.22
13	100611	11:06:14.54	41º 41.00′	111º 04.54′	0.1*	3.0W	25	88	30	0.21
14	100708	16:31:17.49	37º 08.10′	113º 27.22′	7.1*	3.2W	19	119	23	0.24
15	100818	12:51:43.79	37º 38.68′	113º 13.58′	3.0*	3.0W	24	76	13	0.30
16	100818	12:52:31.97	37º 38.27′	113º 13.33′	6.4	3.8W	21	79	13	0.26
17	100917	14:56:29.22	37º 18.52′	114º 07.24′	2.8*	3.0W	16	132	25	0.27
18	101022	20:39:29.27	38º 45.53′	112º 00.64′	1.3*	3.0W	19	104	24	0.23
19	101106	20:39:05.14	37º 00.62′	112º 52.73′	11.2*	3.0W	20	177	32	0.39
20	101108	01:02:05.67	37º 08.43′	111º 54.46′	0.9*	3.0W	15	116	53	0.41
21	101119	11:38:11.43	38º 52.18′	111º 56.85′	9.0	3.0W	23	75	16	0.23
22	101124	14:58:21.75	36º 49.08′	111º 47.48′	5.8*	3.0W	16	128	69	0.31
23	110103	12:06:36.88	38º 14.84′	112º 20.39′	5.4*	4.6W	25	46	27	0.23
24	110103	20:23:45.14	38º 14.27′	112º 20.29′	1.8*	3.2W	28	45	26	0.24
25	110106	03:18:09.11	38º 15.67′	112º 19.99′	3.4*	3.1W	27	48	28	0.23
26	110106	22:31:04.37	38º 15.73′	112º 20.03′	2.9*	3.5W	24	47	28	0.15
27	110107	22:51:07.83	38º 15.42′	112º 19.83′	0.9*	3.3W	16	74	27	0.24
28	110112	08:46:29.67	38º 14.31′	112º 20.43′	4.7*	3.6W	20	47	26	0.22
29	110112	22:04:53.63	42º 07.21′	111º 32.56′	3.2*	3.1	19	154	20	0.23
30	110120	21:59:12.94	39º 09.73′	111º 54.57′	9.9*	3.2W	29	55	23	0.24
31	110126	05:10:11.08	42º 25.44′	111º 29.96′	5.8*	3.7W	25	80	41	0.25
32	110623	03:14:02.42	36º 58.34′	112º 05.66′	6.6*	3.3W	19	110	38	0.42
33	110705	03:22:06.63	39º 55.82′	111º 49.26′	6.5	3.2W	46	54	5	0.23
34	110705	14:59:04.35	37º 34.16′	112º 34.48′	9.6*	3.0W	19	52	25	0.24
35	110722	07:05:35.17	39º 55.92′	111º 49.39′	5.2	3.3W	37	77	6	0.24
36	110726	03:38:26.94	42º 03.13′	111º 33.51′	1.1*	3.7W	31	71	29	0.26
37	110728	22:34:55.71	39º 00.04′	111º 29.90′	0.7*	3.0W	17	83	24	0.23
38	110928	06:31:20.97	37º 54.58′	112º 03.23′	6.9*	3.5W	23	94	19	0.35
39	111110	04:27:45.45	39º 18.15′	111º 09.07′	5.6	3.9W	30	55	5	0.23
40	111112	05:15:11.43	39º 13.53′	110º 27.27′	12.9	3.2W	28	111	14	0.26
41	111120	18:32:51.41	37º 25.72′	113º 13.53′	4.5*	3.0W	17	75	12	0.25

Table 3. Earthquakes in the Utah Region of Magnitude 3.0 and Larger:
January 1, 2010 – December 31, 2014

NO.	DATE	ORIGIN TIME	LATITUDE	LONGITUDE	DEPTH	MAG	NO	GAP	DMN	RMS
42	111201	08:00:05.27	42º 28.33′	111º 11.43′	6.4*	3.0W	14	127	33	0.23
43	111219	16:51:21.26	41º 48.55′	111º 34.99′	4.4*	3.0W	33	86	23	0.21
44	120104	17:18:55.64	37º 34.92′	113º 20.84′	1.0	3.0W	21	110	4	0.36
45	120124	06:01:29.24	37º 24.15′	113º 52.50′	1.2*	3.0W	13	196	29	0.26
46	120204	11:27:03.69	40º 01.09′	111º 31.50′	8.8*	3.6W	29	78	27	0.23
47	120212	03:06:09.53	37º 51.31′	112º 24.26′	0.5*	3.2W	25	101	28	0.24
48	120212	04:18:59.69	37º 51.35′	112º 24.29′	0.1*	3.5W	28	101	28	0.24
49	120216	08:20:58.48	39º 37.47′	111º 33.25′	4.5*	3.0W	36	56	26	0.21
50	120229	22:36:22.34	37º 21.55′	113º 50.50′	1.3*	3.0W	15	163	24	0.26
51	120325	23:07:51.06	39º 37.08′	112º 11.52′	3.0*	3.0W	28	59	27	0.26
52	120329	17:22:06.32	38º 58.94′	111º 23.13′	6.3*	3.4W	21	75	23	0.16
53	120412	03:29:22.60	37º 49.54′	112º 06.91′	5.1*	4.1W	21	118	25	0.25
54	120502	13:10:07.46	41º 26.42′	110º 47.20′	22.0*	3.1W	24	99	58	0.25
55	120622	05:37:15.20	38º 00.81′	111º 05.78′	0.2*	3.0W	27	125	27	0.27
56	120713	19:53:16.96	41º 54.07′	111º 54.97′	2.5*	3.5W	27	76	17	0.16
57	120731	10:27:28.39	39º 00.41′	111º 29.82′	0.9*	3.6W	26	40	23	0.20
58	120814	07:17:35.85	38º 42.71′	112º 32.99′	0.4*	3.1W	21	66	14	0.17
59	121104	06:04:20.01	39º 26.76′	111º 53.14′	12.7	3.1W	28	69	9	0.17
60	121106	09:13:57.72	41º 17.16′	112º 43.30′	9.2*	3.1W	57	131	23	0.18
61	130107	15:36:43.07	36º 50.30′	111º 51.38′	6.4*	3.0W	18	125	60	0.15
62	130124	04:46:39.57	38º 19.43′	108º 59.43′	1.2*	3.9M	27	81	11	0.24
63	130207	19:29:55.58	37º 48.24′	113º 06.35′	2.4*	3.1W	24	55	11	0.18
64	130207	20:02:21.87	37º 47.30′	113º 07.45′	2.1	3.4W	23	52	10	0.17
65	130208	02:47:02.96	37º 46.39′	113º 07.74′	0.2	3.7W	24	68	9	0.17
66	130503	06:17:06.71	41º 40.50′	109º 52.56′	2.5*	3.0W	15	156	95	0.28
67	130529	13:32:41.22	41º 50.79′	112º 19.35′	0.9	3.1W	37	76	9	0.19
68	130814	05:47:37.06	37º 48.48′	113º 10.39′	11.0*	3.0W	23	59	24	0.13
69	130928	08:54:21.09	41º 43.07′	109º 51.04′	-3.2*	3.1W	21	185	95	0.16
70	131015	00:03:26.92	41º 43.11′	109º 54.52′	-3.1*	3.4W	21	162	90	0.17
71	131017	16:19:19.95	41º 36.20′	111º 41.03′	11.4	3.6W	42	57	8	0.14
72	140128	16:20:11.47	37º 19.54′	114º 07.29′	7.2*	4.1W	24	84	26	0.19
73	140129	01:30:27.54	37º 19.42′	114º 06.75′	7.0*	4.0W	26	84	26	0.15
74	140129	01:39:00.63	37º 19.94′	114º 07.46′	7.0*	3.0W	22	111	27	0.14
75	140129	01:39:15.49	37º 20.04′	114º 07.57′	8.7*	3.0W	9	184	27	0.10
76	140314	16:03:51.17	40º 33.67′	111º 16.13′	14.0	3.2W	42	61	9	0.16
77	140404	09:38:19.53	37º 20.73′	113º 47.98′	-0.7*	3.5W	25	65	14	0.16
78	140420	03:22:51.68	40º 34.81′	112º 12.99′	7.4	3.2W	60	67	6	0.15
79	140516	16:54:07.28	38º 57.41′	111º 24.33′	8.3*	3.0W	29	42	20	0.14
80	140612	04:34:04.95	40º 53.43′	111º 40.99′	11.9	3.3W	54	47	16	0.18
81	140629	00:56:22.24	39º 26.47′	111º 26.16′	8.8	4.2W	50	36	16	0.20
82	140629	04:52:46.20	39º 26.20′	111º 26.39′	8.8	3.1W	50	37	16	0.27
83	140820	04:05:15.02	38º 58.01′	111º 24.60′	5.7*	3.3W	29	75	21	0.17
84	141110	14:47:20.76	37º 10.39′	114º 01.25′	11.2	3.0W	23	118	9	0.27

Table 3. Earthquakes in the Utah Region of Magnitude 3.0 and Larger: January 1, 2010 – December 31, 2014

No.	Date	Origin Time	Latitude	Longitude	Depth	Mag	No	Gap	Dmn	Rms
85	141206	09:32:16.56	42º 13.73′	110º 55.62′	-2.7*	3.0W	15	72	39	0.35
86	141229	06:08:18.46	39º 39.84′	111º 58.31′	3.8*	3.7W	44	54	22	0.17
87	141229	06:56:46.66	39º 40.51′	111º 58.18′	2.3*	3.2W	47	58	13	0.19

number of earthquakes = 87

* indicates poor depth control
W indicates Wood-Anderson data used for magnitude calculation

Table 4. Earthquakes Felt and/or Generating a ShakeMap in the Utah Region
January 1, 2010 to December 31, 2014

2010					
Date	**Time†**	**Felt Information‡**	**Latitude**	**Longitude**	**Magnitude§**
January 04	09:24 MST 16:24 UTC	Utah. *CIIM*. Felt (III) at Cedar City (?), UT and (II) at New Harmony, La Verkin, Central, St. George, Monroe (?), UT, Las Vegas (?), NV and Sedona (?), AZ.	37º 35.92′	113º 02.33′	M_L 4.1
January 04 January 05	21:55 MST 04:55 UTC	Utah. *CIIM*. Felt (II) at Cedar City and Hurricane, UT.	37º 35.58′	113º 02.77′	M_L 3.3
January 05	01:08 MST 08:08 UTC	Utah. *CIIM*. Felt (IV) at Woods Cross (?), UT, (III) at Saratoga Springs, Lehi and Herriman, UT and (II) at Eagle Mountain, American Fork, Draper, Pleasant Grove, Lindon, Orem, Alpine, Provo, Salt Lake City and Ogden (?), UT.	40º 21.68′	111º 54.65′	M_L 2.9
January 23	08:48 MST 15:48 UTC	Utah. *CIIM*. Felt (III) at Fort Duchesne (?), UT and (II) at Payson, Santaquin, Lehi and Magna (?), UT.	39º 56.82′	111º 53.45′	M_L 3.0
February 12	15:37 MST 22:37 UTC	Utah. *CIIM*. Felt (II) at Monroe (?), UT and Las Vegas (?), NV.	37º 05.51′	112º 53.54′	M_L 3.0
April 14	12:58 MDT 18:58 UTC	Utah. *CIIM*. *ShakeMap*. Felt (IV) at Torrey, UT, (III) at Boulder, Salt Lake City (?), Ogden (?), UT and (II) at Teasdale, Hanksville, Saint George (?), Eagle Mountain (?), Herriman (?), Bloomfeld (?), NM and Las Vegas (?), NV..	38º 02.02′	111º 06.76′	M_L 3.9

April 15	04:48 MDT 10:48 UTC	Utah. *CIIM*. Felt (III) at Salt Lake City (?), Logan (?), UT, and (II) at Torrey, Draper (?), Sandy (?), Park City (?), Kaysville (?), Ogden (?), Lewinston (?), UT and Malad City (?), ID.	38º 02.62′	111º 06.78′	M_L 3.2

April 15	17:59 MDT 23:59 UTC	Utah. *CIIM*. *ShakeMap*. Felt (VI) at Randolph, UT, (IV) at Woodruff, Dutch John, UT and Cokeville, WY, (III) at Garden City, Logan, Providence, Franklin, Lewinston, Trenton, Coalville, Cornish, Fielding, Salt Lake City, Pleasant Grove, Whiterocks, Payson, UT, Colorado Springs (?), CO and Puyallup (?), WA and (II) at Fish Haven, Hyde Park, Hyrum, Richmond, Huntsville, Paradise, Smithfield, Wellsville, Eden, Mendon, Clarkston, Collinston, Henefer, Ogden, Brigham City, Morgan, Garland, Layton, Willard, Hill AFB, Tremonton, Roy, Farmington, Kaysville, Clearfield, Hooper, Syracuse, Centerville, Bountiful, Park City, Woods Cross, Magna, Midway, Midvale, Sandy, West Jordan, South Jordan, Draper, Riverton, American Fork, Bingham Canyon, Herriman, Provo, Lehi, Orem, Grantsville, Tooele, Eagle Mountain, Lapoint, Santaquin, Saint George, UT, Fish Haven, Paris, Montpelier, Preston, Weston, Malad City, Arimo, McCammon, Inkom, Pocatello, Blackfoot, Boise (?), ID, Evanston,	41º 42.20′	111º 05.65′	M_L 4.9

		Kemmerer, Big Piney, Rock Springs, Jackson, Lander, WY, Evergreen (?), Milliken {?}, Brighton (?), Colorado Springs (?), CO, Mesquite (?), NV, Irvine (?), Huntington Beach (?), CA, , Des Moines (?), IA.			
April 20	02:57 MDT 08:57 UTC	Utah. *ShakeMap.*	37º 54.15′	113º 10.68′	M_L 2.9
April 28	11:40 MDT 17:40 UTC	Utah. *CIIM*. Felt (II) at Boulder, UT.	38º 02.09′	111º 06.88′	M_L 3.2
May 2	09:00 MDT 15:00 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Hanksville, UT and (II) at Boulder, Teasdale, Torrey, Loa, Roy (?), UT.	38º 02.24′	111º 06.81′	M_L 3.6
May 27	00:16 MDT 06:16 UTC	Utah. *ShakeMap.*	41º 41.33′	111º 05.23′	M_L 3.1
June 10	10:58 MDT 16:58 UTC	Utah. *CIIM*. Felt (IV) at Midvale, UT,(III) at Lehi, Salt Lake City, UT and (II) at Riverton, Herriman, South Jordan, Draper, Sandy, Saratoga Springs, Kaysville, Logan, UT and Solana Beach (?), CA.	40º 28.42′	111º 58.99′	M_L 2.7
June 11	05:06 MDT 11:06 UTC	Utah. *ShakeMap.*	41º 41.00′	111º 04.54′	M_L 3.0
July 8	10:31 MDT 16:31 UTC	Utah. *CIIM*. *ShakeMap*. Felt (II) at Washington, St. George, Santa Clara, Ivins, Hurricane, Ogden (?), UT and Fredonia (?), AZ.	37º 08.10′	113º 27.22′	M_L 3.2
August 8	11:36 MDT 17:36 UTC	Utah. *CIIM*. Felt (II) at Cedar City, UT.	37º 48.56′	113º 06.26′	M_L 2.8

August 18	06:52 MDT 12:52 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Washington, St. George, UT and (II) at Central, Beryl, Milford, UT and Rock Springs (?), WY.	37º 38.27′	113º 13.33′	M_L 3.8
August 24	05:41 MDT 11:41 UTC	Utah. *CIIM*. Felt (III) at Salt Lake City (?), UT.	37º 38.77′	113º 13.25′	M 2.2
October 22	14:39 MDT 20:39 UTC	Utah. *CIIM*. *ShakeMap*. Felt (II) at Monroe, Richfield, Saint George (?), UT, Elko (?), NV, Scottsdale (?), AZ.	38º 45.53′	111º 22.52′	M_L 3.0
November 5	11:31 MDT 17:31 UTC	Utah. *CIIM*. Felt (II) at Morgan, Ogden, UT.	41º 01.57′	111º 43.66′	M_L 2.8
November 17 November 18	23:14 MST 06:14 UTC	Utah. *CIIM*. Felt (III) at Joseph, Monroe, Sevier, UT, (II) at Saratoga Springs (?), UT.	38º 36.23′	112º 13.94′	M_L 2.9
2011					
Date	**Time†**	**Felt Information‡**	**Latitude**	**Longitude**	**Magnitude§**
January 03	05:06 MST 12:06 UTC	Utah. *CIIM*. Felt (IV) at Kingston, Joseph, Panguitch, and Modena (?), UT, (III) at Marysvale, Beaver, Sevier, and Beryl (?), UT, and (II) at Greenville, Antimony, Monroe, Torrey, Loa, Parowan, Richfield, Cedar City, Milford, Kanab, Saint George, Saratoga Springs, Draper, Tooele, Sandy, Salt Lake City, Centerville, and Garden City (?), UT, Page, Flagstaff, AZ, Mesquite, Henderson, Las Vegas, NV, Eagle (?), ID and National City (?), CA.	38º 14.84′	112º 20.39′	M_L 4.6
January 03	13:23 MST 20:23 UTC	Utah. *CIIM*. Felt (IV) at Beaver, UT, (III) at	38º 14.27′	112º 20.29′	M_L 3.2

		Monroe and Teasdale, UT and (II) at Nephi, UT.			
January 05 January 06	20:18 MST 03:18 UTC	Utah. *CIIM*. Felt (II) at Salt Lake City (?), UT.	38º 15.67′	112º 19.99′	M_L 3.1
January 06	15:31 MST 22:31 UTC	Utah. *CIIM*. Felt (II) at Beaver (?), AZ.	38º 15.73′	112º 20.03′	M_L 3.5
January 07	15:51 MST 22:51 UTC	Utah. *CIIM*. Felt (II) at Beaver, UT.	38º 15.42′	112º 19.83′	M_L 3.3
January 12	01:46 MST 08:46 UTC	Utah. *CIIM*. Felt (II) at Marysvale and Cedar City, UT.	38º 14.31′	112º 20.43′	M_L 3.6
January 20	14:59 MST 21:59 UTC	Utah. *CIIM*. Felt (III) at Centerfield and Saratoga Springs (?), UT and (II) at Gunnison, South Jordan, La Verkin, Saint George, UT and Lakeside (?), AZ	37º 46.58′	111º 54.57′	M_L 3.3
January 25 January 26	22:10 MST 05:10 UTC	Idaho. *CIIM*. Felt (III) at Thatcher, Grace, Paris and Preston, ID and Salt Lake City (?), UT and (II) at Bern, Montpelier, Soda Springs, Lava Hot Springs, Downey, Bancroft, Pocatello, Ellis (?), Boise (?), ID and Torrington (?), WY.	42º 25.44′	111º 29.96′	M_L 3.7
February 11 February 12	19:38 MST 02:38 UTC	Utah. *CIIM*. Felt (III) at Lehi and Saratoga Springs (?), UT and (II) at Eagle Mountain, Draper, Magna, Pleasant Grove, Salt Lake City, UT.	40º 22.89′	111º 55.24′	M_L 2.4
February 13	02:25 MST 09:25 UTC	Utah. *CIIM*. Felt (III) at Saratoga Springs and Midvale, UT and (II) at Eagle Mountain, Herriman, South Jordan, Orem, West Jordan, Springville, UT and Phoenix (?), AZ.	40º 23.00′	111º 55.15′	M_L 2.7

February 13 February 14	18:09 MST 01:09 UTC	Utah. *CIIM*. Felt (III) at Draper and Saratoga Springs, UT and (II) at Lehi, Riverton, Eagle Mountain, Herriman, Pleasant Grove, South Jordan, Salt Lake City, UT and Phoenix (?), AZ.	40º 23.10′	111º 55.44′	M_L 2.8
April 11 April 12	21:34 MDT 03:34 UTC	Utah. *CIIM*. Felt (II) at Cedar City, UT.	37º 46.58′	113º 06.74′	M_L 2.2
April 12	00:11 MDT 06:11 UTC	Utah. *CIIM*. Felt (III) at Cedar City, UT.	37º 46.34′	113º 06.96′	M_L 2.7
April 13	04:17 MDT 10:17 UTC	Utah. *CIIM*. Felt (II) at Cedar City, UT.	37º 45.15′	113º 07.88′	M_L 2.7
July 04 July 05	21:22 MDT 03:22 UTC	Utah. *CIIM*. Felt (III) at Payson, UT and (II) at Mona, Santaquin, Provo, Nephi, Sandy, Salt Lake City, Richfield, and Monroe, UT.	39º 55.82′	111º 49.26′	M_L 3.2
July 05	08:59 MDT 14:59 UTC	Utah. *CIIM*. Felt (III) at Alton, and Brian Head, UT and (II) at Panguitch, Escalante, and Provo (?), UT.	37º 34.16′	112º 34.48′	M_L 3.0
July 22	01:05 MDT 07:05 UTC	Utah. *CIIM*. Felt (III) at Santaquin, Salem, Spanish Fork, Cedar Valley, Nephi, and Mount Pleasant, UT and (II) at Mona and Payson, UT.	39º 55.92′	111º 49.39′	M_L 3.3
July 25 July 26	21:38 MDT 03:38 UTC	Idaho. *CIIM*. Felt (IV) at Garden City, UT, (III) at Saint Charles, Franklin, ID, Providence, Salt Lake City (?), UT and (II) at Fish Haven, Preston, Montpelier, ID, Richmond, Lewinston, Hyde Park, Smithfield, Logan, Collinston, Farmington, Centerville, Bountiful, Salem (?), UT.	42º 03.13′	111º 33.51′	M_L 3.7

August 12	16:07 MDT 22:07 UTC	Utah. *CIIM*. Felt (II) at Riverton, Herriman, South Jordan, Draper, West Jordan, Lehi, Sandy, Salt Lake City, Magna, and Provo, UT.	40º 28.66′	111º 59.02′	M_L 2.5
September 06	08:33 MDT 14:33 UTC	Utah. *CIIM*. Felt (II) at Sandy (?), UT and Baker (?), NV.	39º 00.19′	111º 22.39′	M_L 2.9
September 28	00:31 MDT 06:31 UTC	Utah. *CIIM*. Felt (II) at Escalante, Panguitch, Saint George (?), and Salt Lake City (?), UT.	37º 54.58′	112º 03.23′	M_L 3.5
November 09 November 10	21:27 MST 04:27 UTC	Utah. *CIIM*. Felt (IV) at Huntington, UT, (III) at Price, Ferron, Helper, UT, Mancos (?), CO, and (II) at Mount Pleasant, Wellington, Provo, Moab, UT, Grand Junction (?), CO, Kemmerer (?), WY.	39º 18.15′	111º 09.07′	M_L 3.9
November 11 November 12	22:15 MST 05:15 UTC	Utah. *CIIM*. Felt (III) at Price, Salt Lake City (?), UT, Montrose (?), CO, and (II) at Feron, UT, Berthoud (?), CO.	39º 13.53′	110º 27.27′	M_L 3.2
November 28	00:02 MST 07:02 UTC	Utah. *CIIM*. Felt (III) at Salt Lake City, UT and (II) at Magna, UT.	40º 43.17′	112º 04.01′	M_L 2.1
November 29	04:42 MST 11:42 UTC	Utah. *CIIM*. Felt (II) at Lindon, Smithfield (?), UT.	38º 59.66′	111º 22.92′	M_L 2.8
December 10	09:45 MST 16:45 UTC	Utah. *CIIM*. Felt (III) at Huntington, UT.	38º 59.40′	111º 23.32′	M_L 2.9
December 19	09:51 MST 16:51 UTC	Utah. *CIIM*. Felt (III) at Logan, UT, Bellevue (?), ID and (II) at Providence, Syracuse, UT, Mountain City (?), NV.	41º 48.55′	111º 34.99′	M_L 3.0
2012					
Date	**Time†**	**Felt Information‡**	**Latitude**	**Longitude**	**Magnitude§**
January 05	12:49 MST	Utah. *CIIM*. Felt (III) at	40º 47.94′	111º 38.60′	M_L 2.8

	19:49 UTC	Salt Lake City, UT, and (II) at Park City, Bountiful, Roy, and Orem, UT.			
January 23 January 24	23:01 MST 06:01 UTC	Utah. *CIIM*. Felt (II) at Saint George, Ivins, Washington, Hurricane, and Cedar City, UT and Littlefield, AZ.	37º 24.15′	113º 52.50′	M_L 3.0
February 04	04:27 MST 11:27 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Salem and Spanish Fork, UT and (II) at Mapleton, Santaquin, Payson, Springville, Provo, Eagle Mountain, and Salt Lake City, UT.	40º 01.09′	111º 31.50′	M_L 3.6
February 11 February 12	20:06 MST 03:06 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Panguitch, UT and (II) at Kingman (?), AZ.	37º 51.31′	112º 24.26′	M_L 3.2
February 11 February 12	21:18 MST 04:18 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Panguitch and Milford (?), UT and (II) at Parowan, Escalante, Cedar City, and Payson (?), UT.	37º 51.35′	112º 24.29′	M_L 3.5
February 16	01:20 MST 08:20 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Fairview, UT and (II) at Mount Pleasant, Ephraim, Nephi, Salt Lake City, and Fielding (?), UT.	39º 37.47′	111º 33.25′	M_L 3.0
February 29	15:36 MST 22:36 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Veyo, Central, Washington, and Hurricane, UT and (II) at Saint George, Ivins, La Verkin, Parowan, UT, and Las Vegas (?), NV.	37º 21.55′	113º 50.50′	M_L 3.0
March 25	17:07 MDT 23:07 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Delta, UT and (II) at Lehi, Pleasant Grove, UT, and Kemmerer (?), WY.	39º 37.08′	112º 11.52′	M_L 3.0
March 29	11:22 MDT	Utah. *CIIM*. Felt (II) at Monroe, UT.	38º 58.94′	111º 23.13′	M_L 3.4

	17:22 UTC				
April 11 April 12	18:25 MDT 00:25 UTC	Utah. *CIIM*. Felt (III) at Draper (?), UT.	37º 46.90′	112º 21.11′	M_L 2.7
April 11 April 12	21:29 MDT 03:29 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Antimony, Bryce Canyon, Escalante, Panguitch, Torrey, Alton, Kanab, Boulder, Hurricane, Delta, Provo (?), Saratoga Springs (?), Riverton (?), Draper (?), Layton (?) , UT, Page, Fredonia, , Supai, AZ and (II) at Kingston, Brian Head, Teasdale, Cedar City, Ferron, Washington, Hite, Lehi (?), Salt Lake City (?), UT, Marble Canyon, Kaibeto, Sedona (?), Messa (?), AZ.	37º 49.54′	112º 06.91′	M_L 4.1
June 21 June 22	23:37 MDT 05:37 UTC	Utah. *CIIM*. Felt (III) at Boulder, UT.	38º 00.81′	111º 05.78′	M_L 3.0
July 13	13:53 MDT 19:53 UTC	Utah. *CIIM*. *ShakeMap*. Felt (V) at Trenton, UT, (IV) at Clarkston, Cornish, UT, (III) at Richmond, Hyde Park, Logan, Centerville (?), UT, Franklin, Preston, ID, and (II) at Lewiston, Mendon, Providence, Woods Cross (?), Salt Lake City (?), UT, Weston, ID, Jackson (?), WY.	41º 54.07′	111º 54.97′	M_L 3.5
July 18	13:44 MDT 19:44 UTC	Utah. *CIIM*. Felt (III) at Lewiston, UT and (II) at Trenton, UT.	41º 54.10′	111º 55.56′	M_L 2.3
July 31	04:27 MDT 10:27 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Salina, UT and (II) at Salt Lake City (?), Farmington, UT.	39º 00.41′	111º 29.82′	M_L 3.6
August 14	01:17 MDT 07:17 UTC	Utah. *CIIM*. *ShakeMap*. Felt (II) at Salt Lake City (?), UT.	38º 42.71′	112º 32.99′	M_L 3.1

August 21	15:21 MDT 21:21 UTC	Colorado. *CIIM*. Felt (II) at Kaysville (?), UT.	39º 30.60′	107º 02.40′	M 3.3
November 4	00:04 MDT 06:04 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Nephi, Delta, UT and (II) at Helper, UT.	39º 26.76′	111º 53.14′	M_L 3.1
November 6	02:13 MST 09:13 UTC	Utah. *CIIM*. Felt (II) at Corinne, Clearfield, Centerville, UT.	41º 17.16′	112º 43.30′	M_L 3.1
November 12	03:43 MST 10:43 UTC	Utah. *CIIM*. Felt (III) at Eagle Mountain (?), Roy (?), Payson, UT and (II) at Salem, Orem, Saratoga Springs, UT.	40º 05.10′	111º 24.42′	M_L 2.5
2013					
Date	**Time†**	**Felt Information‡**	**Latitude**	**Longitude**	**Magnitude§**
January 23 January 24	21:46 MST 04:46 UTC	Colorado. *CIIM*. Felt (IV) at Bedrock, CO, (III) at Monticello, Moab UT and Whitewater, Grand Junction, Hotchkiss, Crawford, New Castle, CO, and (II) at Nucla, Redvale, Olathe, Delta, Placerville, Montrose, Clifton, Palisade, Fruita, Ridgway, Telluride, Cortez, Paonia, Lafayette (?), CO.	38º 19.43′	108º 59.43′	M_W 3.9
February 06	11:47 MST 18:47 UTC	Utah. *CIIM*. Felt (III) at Cedar City, UT.	37º 47.48′	113º 07.42′	M_L 2.7
February 07	12:29 MST 19:29 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Farmington, Cedar City, UT.	37º 48.24′	113º 06.35′	M_L 3.1
February 07	13:02 MST 20:02 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Cedar City, UT.	37º 47.30′	113º 07.45′	M_L 3.4
February 07	13:35 MST 20:35 UTC	Utah. *CIIM*. Felt (II) at Cedar City, UT.	37º 45.89′	113º 08.11′	M_L 2.0
February 07	19:47 MST	Utah. *CIIM*. *ShakeMap*.	37º 46.39′	113º 07.74′	M_L 3.7

February 08	02:47 UTC	Felt (III) at Cedar City, Saint George, UT.			
February 07 February 08	20:19 MST 03:19 UTC	Utah. *CIIM*. Felt (III) at Cedar City, UT and (II) at Delta, Provo (?), UT and Grand Junction (?), CO.	37º 47.16′	113º 07.52′	M_L 2.8
April 19	00:14 MDT 06:14 UTC	Utah. *CIIM*. Felt (III) at Payson, Salem, Mona, Salina (?), and Willard (?), UT and (II) at Spanish Fork, Mapleton, and Springville, UT.	40º 00.07′	111º 47.59′	M_L 2.8
May 29	07:32 MDT 13:32 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Tremonton, UT and (II) at Plymouth, Portage, and Honeyville, UT.	41º 50.79′	112º 19.35′	M_L 3.1
May 31	16:34 MDT 22:34 UTC	Utah. *CIIM*. Felt (II) at Hurricane, UT.	37º 10.44′	113º 24.82′	M_L 2.8
May 31	16:45 MDT 22:45 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Washington and Hurricane, UT and (II) at Saint George, UT.	37º 10.31′	113º 24.78′	M_L 2.9
July 08	13:30 MDT 19:30 UTC	Utah. *CIIM*. Felt (II) at Salt Lake City, UT.	41º 07.89′	112º 54.38′	M_L 1.8
August 13 August 14	23:47 MDT 05:47 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Cedar City, UT.	37º 48.48′	113º 10.39′	M_L 3.0
October 17	10:19 MDT 16:19 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Hyrum, Providence, Paradise, Eden, Smithfield, and Ogden, UT, and (II) at Logan, Wellsville, Hyde Park, Huntsville, Richmond, Brigham City, Roy, Clearfield, Syracuse, Layton, and Fayette (?), UT and Blackfoot (?), ID.	41º 36.20′	111º 41.03′	M_L 3.6
November 25 November 26	21:17 MST 04:17 UTC	Utah. *CIIM*. Felt (III) at Vernal (?), UT, and (II) at Payson, Park City, Kamas, and Ogden, UT.	39º 40.48′	111º 30.76′	M_L 2.8

December 09 December 10	18:23 MST 01:23 UTC	Utah. *CIIM*. Felt (III) at Park City, Salt Lake City, and Midway, UT, and (II) at Provo, UT and Jackson (?), WY.	40º 50.99′	111º 33.22′	M_L 2.7
2014					
Date	**Time†**	**Felt Information‡**	**Latitude**	**Longitude**	**Magnitude§**
January 28	09:20 MST 16:20 UTC	Nevada. *CIIM*. *ShakeMap*. Felt (II) at Ivins and Washington, UT.	37º 19.54′	114º 07.29′	M_L 4.1
January 28 January 29	18:30 MST 01:30 UTC	Nevada. *CIIM*. *ShakeMap*. Felt (III) at Pine Valley and St. George, UT and (II) at Ivins and Washington, UT and Mesquite, NV.	37º 19.42′	114º 06.75′	M_L 4.0
March 14	10:03 MDT 16:03 UTC	Utah. *CIIM*. *ShakeMap*. Felt (IV) at Kamas, UT, (III) at Park City, UT and (II) at Heber City and Salt Lake City, UT.	40º 33.67′	111º 16.13′	M_L 3.2
April 4	03:38 MDT 09:38 UTC	Utah. *ShakeMap*.	37º 20.73′	113º 47.98′	M_L 3.5
April 19 April 20	21:22 MDT 03:22 UTC	Utah. *CIIM*. *ShakeMap*. Felt (III) at Bingham Canyon, Tooele, West Jordan, Salt Lake City, Magna, Midvale, Sandy, Grantsville, Wasatch National Forest, Willard, Fayette (?), and Garrison (?), UT, and (II) at Herriman, Riverton, Draper, Eagle Mountain, Stockton, North Salt Lake, Woods Cross, Orem, Layton, Syracuse, Clearfield, Dugway, Heber City, UT and Riverton (?), WY.	40º 34.81′	112º 12.99′	M_L 3.2
June 11 June 12	22:34 MDT 04:34 UTC	Utah. *CIIM*. *ShakeMap*. Felt (IV) at Croydon, Salt Lake City, UT,	40º 53.43′	111º 40.99′	M_L 3.3

		(III) at Bountiful, Morgan, Centerville, Farmington, North Salt Lake, Woods Cross, Park City, Henefer, Kaysville, Ogden, Midway, Pleasant Grove, Cedar Valley (?), Feyette (?), UT and (II) at Layton, Midvale, Sandy, Coalville, Magna, West Jordan, Syracuse, Clearfield, Roy, Draper, Huntsville, Riverton, Hooper, Herriman, Eden, Bingham Canyon, Orem, Tooele, Provo, Tremonton, Dugway, UT and Idaho Falls (?), ID.			
June 28 June 29	18:56 MDT 00:56 UTC	Utah. *CIIM*. Felt (IV) at Mount Pleasant, UT., (III) at Ephraim, Fairview, UT. and Grand Junction (?), CO., and (II) at Manti, Huntington, and Draper, UT.	39º 26.47′	111º 26.16′	M_L 4.2
June 28 June 29	22:52 MDT 04:52 UTC	Utah. *CIIM*. Felt (IV) at Ephraim, UT. and (III) at Mount Pleasant and Sandy (?), UT.	39º 26.20′	111º 26.39′	M_L 3.1
November 7	13:56 MST 20:56 UTC	Utah. *CIIM*. Felt (II) at Salt Lake City (?), UT.	39º 29.94′	112º 00.99′	M_L 2.7
November 10	07:47 MST 14:47 UTC	Utah. *ShakeMap*.	37º 10.39′	114º 01.25′	M_L 3.0
December 28 December 29	23:08 MST 06:08 UTC	Utah. *ShakeMap*. *CIIM*. Felt (III) at Nephi, UT and (II) at Mona, American Fork, and Hurricane (?), UT.	39º 39.84′	111º 58.31′	M_L 3.7
December 28 December 29	23:56 MST 06:56 UTC	Utah. *ShakeMap*. *CIIM*. Felt (III) at Nephi, Salt Lake City (?), UT and (II) at Mona, Eureka, UT.	39º 40.51′	111º 58.18′	M_L 3.2

† Times are listed both as Local Time—Mountain Standard Time (MST) or Mountain Daylight Time (MDT)—and as Universal Coordinated Time (UTC).

? Indicates on-line reports that appear questionable given the distance from the source

‡ *CIIM* indicates the availability of a Community Internet Intensity Map (http://earthquake.usgs.gov/earthquakes/dyfi/archives.php), compiled by the U.S. Geological Survey (USGS); *ShakeMap* indicates the availability of computer-generated maps of ground-shaking (*http://www.seis.utah.edu/shake/archive*), produced by the University of Utah Seismograph Stations (UUSS). Roman numerals correspond to the Modified Mercalli intensity scale. Unless otherwise indicated, felt information is from the USGS (1) CIIM reports and/or (2) PDE Monthly (or) Weekly Listing Files (http://earthquake.usgs.gov/research/data/pde.php).

§ Richter local magnitude (M_L) or coda magnitude (M_C) determined by UUSS. If labeled "NEIC," data are from the National Earthquake Information Center of the USGS

Table 5: Earthquake Data and Information Products

Network Products		
Does the network provide the following?	**Yes/No**	**Comments/Explanation**
Primary EQ Parameters		
Picks	Yes	Automatic phase picks are exported in near real time to the USGS NEIC via Earthworm export. Since July 30, 2014, UUSS has also provided finalized arrival time picks to the public via the NEIC web site.
Hypocenters	Yes	Hypocenters are posted at http://www.quake.utah.edu/ and on the NEIC web site.
Magnitudes (& Amplitudes)	Yes	Magnitudes are posted at http://www.quake.utah.edu/ and on the NEIC web site. Since July 30, 2014, UUSS has provided the data used to compute finalized magnitudes to NEIC to post on its web site: synthetic Wood-Anderson peak-to-peak amplitude measurements for local magnitude, M_L, and signal duration measurements for duration magnitude, M_d. ShakeMaps, which include magnitudes and peak ground motions automatically determined by AQMS, are exported in near real time to the NEIC via a Product Distribution Layer (PDL).
Focal mechanisms	Yes	See "Moment Tensors" below. We also attempt to determine first-motion focal mechanisms for selected events of interest.
Moment Tensor(s)	Yes	For events with M ≥ 3.5 in the Utah region, we attempt to determine a full moment tensor solution within a few days of the event using software developed at U.C. Berkeley. We have applied the same methodology to past M ≥ 3.5 Utah region seismic events to produce a moment tensor catalog for Jan 1998 through July 2011 (Whidden and Pankow, 2012, SRL 83, 775-783).
Other EQ Parameters/Products		
ShakeMap	Yes	Shake maps are posted to our web site at http://www.quake.utah.edu/shake/ and sent to USGS computers.
Finite Fault	No	
Supplemental Information		
Felt Reports	Yes	We provide links on our Web site to the "Did You Feel It?" webpage. We also summarize felt reports and USGS-estimated intensities in our quarterly earthquake reports.
Event Summary	No	Not routinely provided. We occasionally provide an event summary for significant earthquakes.
Tectonic Summary	Yes	We have written tectonic summaries for 7 subdivisions of the Utah region. These summaries have been incorporated into the USGS web pages for Utah region earthquakes since July 2010.
Collated Maps	No	
Refined Hypocenters (e.g. double-difference)	Yes	Not done routinely. We compute refined hypocenters (including double-difference) for sequences of special interest and for research purposes.

Network Products		
Does the network provide the following?	**Yes/No**	**Comments/Explanation**
Web Content		
Recent EQ Maps	Yes	http://www.quake.utah.edu/EQCENTER/recent.htm
Station Helicorder	Yes	http://www.quake.utah.edu/helicorder/
Station noise PDFs	Yes	http://www.iris.edu/servlet/quackquery/ http://service.iris.edu/mustang/ (both produced by IRIS)
Station Performance Metrics	Yes	http://www.iris.edu/servlet/quackquery/ http://service.iris.edu/mustang/ (both produced by IRIS)
Network Description	Yes	http://www.quake.utah.edu/ABOUT/uussanss.htm and http://www.quake.utah.edu/ABOUT/monitoring_scope.htm
Station List	Yes	http://www.seis.utah.edu/STATION_MAP/station_table.htm http://www.quake.utah.edu/EQCENTER/QUARTERLY/quarterly.htm
Station Metadata	Yes	http://www.iris.edu/mda/UU
Email Notification Services	Yes	Only to selected state and federal agencies. We direct other users to the USGS ENS Web site (https://sslearthquake.usgs.gov/ens/)
Contact Info	Yes	http://www.quake.utah.edu/ABOUT/staff.htm (general contact info provided at bottom of all higher-level pages on our Web site)
Region-specific FAQs	Yes	http://www.quake.utah.edu/REGIONAL/eqfaq.htm
Region-specific EQ info	Yes	http://www.quake.utah.edu/REGIONAL/regional.htm http://www.quake.utah.edu/
Waveforms		
Triggered	Yes	Triggered waveform data are archived in-house and are available upon request.
Continuous	Yes	All continuous waveform data are archived at the IRIS DMC and publicly available from this data center. Since September 2011, we have also archived continuous waveform data internally using the USGS Continuous Waveform Buffer (CWB) software. We have backfilled our CWB data storage system with some continuous data from broadband and short-period channels going back to 2001.
Processed	Yes	Synthetic Wood-Anderson seismograms are generated both automatically and as part of post-processing, but these processed waveforms are not archived. Other processed waveforms are generated for special projects.
Summary Products		
Catalogs	Yes	Posted on our web site at http://www.quake.utah.edu/EQCENTER/quakelists.htm and incorporated into the ANSS catalog.
Metadata		
Instrument Response	Yes	Archived at http://www.iris.edu/mda/UU and at UUSS.

Network Products		
Does the network provide the following?	**Yes/No**	**Comments/Explanation**
Site Info (e.g. surface geology, Vs30)	Yes	Vs30 information (mostly from generalized Vs30 maps) for our Utah region stations is available on our Web site at http://www.quake.utah.edu/MONRESEARCH/SEIS_NET/seisnet.htm See also the Vs30 maps at http://www.quake.utah.edu/MONRESEARCH/SEIS_NET/urban_net.htm
Descriptions:		
***Tectonic Summary*: Text and/or figures describing the tectonic setting of the event and related activity**		
***Event Summary*: Text and/or figures (press releases, collated media/disaster agencies info) that describes the earthquake and its effects**		
***Collated Maps*: Any map or set of maps that illustrates the event properties, tectonics, hazards, etc**		
***Processed Waveforms*: Specialized processing that is required by some portion of the community, e.g. processed strong motion records for the engineering community**		
***Catalogs*: Lists of parameters that describe an earthquake(s) or information used to describe an earthquake (e.q., picks, locations, amps,..)**		
***Region-specific earthquake information*: Description (text and/or maps) of historical earthquakes, faults/geology, etc.**		

Table 6: ANSS Cooperating Network Performance Self-Rating

Question	Answer	Explanation (if needed)
1. What is the minimum magnitude detection threshold for your network?	$M \geq 1.2$-1.7 for Utah's main seismic belt (see Pankow et al., 2004, BSSA 94, S332-S347). Outside the main seismic belt, the threshold has not been rigorously quantified but is estimated to be M 2.0 to 2.5.	
2. What is the minimum magnitude detection threshold for the best instrumented part of your network?	$M \geq 1.2$ (in the Wasatch Front urban corridor, along the main seismic belt; see Pankow et al., 2004, BSSA 94, S332-S347)	
3. What is the typical hypocentral location accuracy for earthquakes occurring within your network? Is it the same for automated vs reviewed?	Based on an analysis of earthquake locations from 2013 through 2014, hypocentral accuracy is better for the reviewed locations than the automatic ones. In the Utah (UT) region, the median ERH is 0.6 km for reviewed locations versus 1.0 km for automatic, and the median ERZ is 3.4 km for reviewed locations versus 7.1 km for automatic. In the Yellowstone Park (YP) region, the median ERH is 0.6 km for reviewed locations versus 0.7 for automatic, and the median ERZ is 1.1 km for reviewed locations versus 1.4 km for automatic. For the same one-year time period, 14% of the reviewed locations in the UT region and 50% of those in the YP region have good focal-depth control: DMIN ≤ DEPTH or 5.0 km and ERZ ≤ 2.0 km.	
4. Does your network report automated earthquake locations into EIDS? If yes, how long does it take?	UUSS switched from EIDS to its successor, PDL, on July 30, 2014. Automated locations are currently reported into PDL for earthquakes that meet the following criteria: $M_L \geq 4.5$ everywhere in the Utah Region, $M_L \geq 3.0$ in more than 90% of the Utah region (excluding an area in the NE corner where poorly-located blasts are a problem), and $M_L \geq 2.5$ in the Wasatch Front urban corridor. For the 25 events that met these criteria from Oct 1, 2012, through June 30, 2014, 90% of the EIDS messages were sent out within 5.7 min of the origin time. The time delays for issuing PDL messages should be aproximately the same.	
5. Does your network report analyst-reviewed earthquake locations for all quakes into EIDS (i.e., the little ones)?	Yes. All locations for earthquakes in our authoritative regions are submitted to PDL following analyst review. The delay is typically next business day. If there is significant earthquake activity, then the analysts process the largest events first. In such situations, processing delays for smaller events can be a week or longer (depending on staff resources at the time).	If yes, what is the typical processing delay?
7. Describe the velocity model used to locate earthquakes in your network (1-D, multiple models, 3-D). Does it differ for automated vs. reviewed?	As of October 1, 2012, the same velocity models are being used for both automatic and reviewed locations. Locations in the Yellowstone region are computed using a single 1-D velocity model generalized from a 3-D model. Locations in the Utah region are computed using four primary 1-D models, each assigned to epicenters in different areas. In two of these areas, alternative 1-D models are used to calculate travel times to stations located in the Colorado Plateau physiographic province.	

8. What software/program does your network use to locate earthquakes? Does it differ for automated vs. reviewed?	Automated and reviewed locations are both computed using Hypoinverse-2000. We currently use Version 1.39 (02/2013) for the automatic locations and Version 1.35 (07/2011) for the analyst locations.	
9. What magnitudes does your network routinely report in real time (Md, ML, Me, Mw, Ms etc.)? How long does it take to compute them?	For each automatically located seismic event, our Earthworm system attempts to compute two automated magnitudes: a coda-duration magnitude, M_C (calibrated to M_L), and an M_L. An M_L is automatically reported to the PDL system for seismic events that meet the criteria given in the answer to question (4). The PDL message is sent within the time frame described under (4), which we consider to be near real time. Currently, we do not report unreviewed M_Cs to the PDL system in order to reduce false alarms caused by teleseisms and telemetry problems.	
10. Does your network archive phase information at a datacenter?	Phase data from July 1962 through 1988 were submitted to NOAA some years ago. On July 30, 2014, UUSS began submitting phase data to the USGS via the PDL system along with each finalized earthquake location. These phase data, and eventually the older phase data, will be archived in the ANSS Comprehensive Catalog.	If yes, how long is the delay to report? Where is the information archived?
11. Does your network archive summary (i.e., earthquake catalog) information at a public datacenter?	Yes. Utah and Yellowstone region earthquake catalogs are publicly available as part of the ANSS catalog. The submitted catalogs date back to 1962 for the Utah region and 1973 for the Yellowstone region (the pre-1982 Yellowstone catalog is from the USGS). Updates to the ANSS catalog are automatically submitted four times per day (Monday through Friday). Earthquake catalogs for these two regions are also posted on our own Web site.	If yes, how long is the delay to report? In what year does archiving begin?
12. Does your network archive event waveforms at a public datacenter?	Archived event waveforms date back to 1981. All digitally recorded waveforms from stations we maintain and operate (channel types EH, EN, HH, HN, and EL) have been sent to the IRIS DMC. We stopped sending segmented waveform data to IRIS when we began submitting continuous data streams.	If yes, describe what type of channels (e.g., EH, HH, HN) and how long is the delay to report? In what year does archiving begin?
13. Do you archive continuous waveforms at a public datacenter?	Continuous waveform data from all stations we maintain and operate (EH, HH, EL, EN, and HN) have been submitted to the IRIS DMC on a daily basis since June 2002. Currently, the data export to the IRIS DMC is done continuously from our internal waveform data archive, the Continuous Waveform Buffer (CWB), using USGS EDGE software. Submission of continuous waveform data from our broadband stations began on June 19, 2000, and submission of data from our strong-motion stations began on April 19, 2001.	If yes, describe which channels and how long is the delay to report? In what year does archiving begin?
14. If your network archives waveforms, does it supply supporting instrument response metadata to support generation waveforms in SEED? For all waveforms?	Yes. Instrument response information is stored at the IRIS DMC in SEED format for all UUSS waveforms archived there. The archive starts in 1981.	

15. Does your network compute focal mechanisms?	For M ≥ 3.5 events in the Utah region, we attempt to determine a full moment tensor solution using software developed at U.C. Berkeley. We have applied the same methodology to past M ≥ 3.5 Utah region seismic events to produce a moment tensor catalog for Jan 1998 through July 2011 (Whidden and Pankow, 2012, SRL 83, 775-783). We also determine focal mechanisms from P-wave first motions for selected events of interest and for research projects. These focal mechanisms are not archived at a public datacenter.	If yes, what type (first motion, moment tensor). In real-time? Do you archive them at a public datacenter?
16. Does your network automatically distribute email to the public in near real-time for significant events?	We do not provide earthquake email notifications to the general public; we instead direct interested persons to the USGS ENS service. Automatic email alerts are distributed to the following State of Utah agencies following significant earthquakes in the Utah region: (a) the Utah Division of Emergency Management, for $M_L \geq 3.0$ events; (b) the Utah Geological Survey, for $M_L \geq 3.0$ events; and (c) the Dept. of Natural Resources, for $M_L \geq 5.0$ events. Email notifications are also sent to (a) and (b) after the creation of a ShakeMap in the Utah region. Following $M_L \geq 2.5$ earthquakes in the Yellowstone region, email notifications are sent to (1) three USGS scientists affilicated with the Yellowstone Volcano Observatory, including the Scientist-in-Charge, and (2) three National Park Service officials in Yellowstone Park, including the chief geologist.	If yes, Do you offer a website where they can sign up?
17. Does your network automatically distribute alphanumeric pages to the public in near real-time for significant events?	Currently, automatic alphanumeric pages are sent only to our internal staff and to a few emergency responders. Following $M_L \geq 3.5$ earthquakes in the Utah region, alphanumeric pages are sent to the earthquake specialist at the Utah Division of Emergency Management. Following $M_L \geq 2.5$ earthquakes in the Yellowstone region, alphanumeric pages are sent to (1) three USGS scientists affilicated with the Yellowstone Volcano Observatory, including the Scientist-in-Charge, and (2) four National Park Service officials in Yellowstone Park, including the chief geologist.	If yes, Do you offer a website where they can sign up?
18. Does your network automatically compute *ShakeMaps* and make them publicly available? If so, how long does it take?	Yes, for Utah region earthquakes of $M_L \geq 3.0$ to $M_L \geq 3.5$, depending on the location. Automatically generated ShakeMaps are posted publicly on our web site and submitted to the USGS, normally within 8-12 minutes after the origin time. The web posting could take longer if the web server is being overwhelmed with hits.	
19. Does your network operate a fault-tolerant system (e.g., redundant computers, UPS, back-up generator with lots of fuel)?	It is to a large extent, but improvements are still underway. We operate two redundant AQMS systems, and a third system for testing and development, at our primary recording site at the University of Utah. We also operate a backup data collection site in Richfield, Utah, 215 km from the primary site (with software for event review), and have a data access point at the Salt Lake County emergency operations center. On May 1, 2010, we replaced our centralized analog telemetry data acquisition systems by a distributed network of digitizers (eight sites) and Earthworm nodes (6 sites). This new distributed system is more resistant to major failures. Since April 2010, all of the UUSS regional seismic network facilities have been housed in a new building that was built for the Geology and Geophysics department. This building has a UPS system and back-up generator that provide backup power for the UUSS network operations center, including the air conditioning.	

20. What does your network do with the data recorded on ANSS strong motion instruments? For example, do you make it available to the engineering community through a Data Center?	Continuous waveform data from all our ANSS strong-motion instruments are archived in the IRIS DMC. In addition, we have made arrangements to enable the USGS National Strong-Motion Project data center to retrieve data from our Earthworm wavetanks and make them available to the engineering community. This data center is primarily interested in records with PGAs of 0.5% g or greater.	If so, which one?

Table 7: Locations visited by UUSS traveling earthquake exhibit

Year	City	Organization
2010	Cedar Fort	Cedar Valley Elementary School
2010	Garland	Garland Elementary School
2010	Hanksville	Hanksville Elementary School
2010	Holladay	Crestview Elementary School
2010	Holladay	Oakwood Elementary School
2010	Hyrum	Lincoln Elementary School
2010	Kearns	Bacchus Elementary School
2010	Layton	Ellison Park Elementary School
2010	Lehi	Willowcreek Middle School
2010	Logan	Ellis Elementary School
2010	Magna	Copper Hills Elementary School
2010	Midvale	Midvale Elementary School
2010	Mona	Mona Elementary School
2010	Mt. Pleasant	Mt. Pleasant Elementary School
2010	Murray	Moss Elementary School
2010	Nephi	Juab Junior High School
2010	Ogden	West Weber Elementary School
2010	Ogden	West Weber Elementary School
2010	Price	Price Library
2010	Provo	The Church of Jesus Christ of Latter-day Saints
2010	Provo	Rock Canyon Elementary School
2010	Roosevelt	Eagle View Elementary School
2010	Salt Lake City	Delta Call Center
2010	Salt Lake City	Dilworth Elementary School
2010	Salt Lake City	Hawthorne Elementary School
2010	Salt Lake City	McMillan Elementary School
2010	Salt Lake City	Washington Elementary School
2010	Sandy	Altara Elementary School
2010	Sandy	Silver Mesa Elementary School
2010	Sandy	Whitmore Library
2010	South Jordan	Eastlake Elementary School
2010	Spanish Fork	Canyon Elementary School
2010	Springville	Sage Creek Elementary School
2010	Sunnyside	Bruin Point Elementary School
2010	Washington	Riverside Elementary School
2010	West Jordan	Majestic Elementary School
2010	West Jordan	Riverside Elementary School
2010	West Valley City	Gerald Wright Elementary School
2010	West Valley City	Hunter Elementary School
2010	West Valley City	Robert Frost Elementary School
2011	Brigham City	Brigham City EPF
2011	Grantsville	Willow Elementary School
2011	Holladay	Bonneville Junior High School
2011	Kearns	Kearns Junior High School

2011	Magna	Copper Hills Elementary School
2011	Nephi	Red Cliffs Elementary School
2011	Orem	Cascade Elementary School
2011	Orem	Northridge Elementary School
2011	Salt Lake City	Backman Elementary School
2011	Salt Lake City	Beacon Heights Elementary School
2011	Salt Lake City	Delta Call Center
2011	Salt Lake City	Hawthorne Elementary School
2011	Salt Lake City	Morningside Elementary School
2011	Salt Lake City	Woodstock Elementary School
2011	Sandy	Albion Middle School
2011	Saratoga Springs	Thunder Ridge Elementary School
2011	Spring City	Spring City Elementary School
2011	West Jordan	Terra Linda Elementary School
2012	Beryl	Escalante Valley School
2012	Bountiful	Valley View Elementary School
2012	Brigham City	Foothill Elementary School
2012	Cedar City	Cedar East Elementary School
2012	Cleveland	Cleveland Elementary School
2012	Delta	Delta Elementary School
2012	Draper	Willow Springs Elementary School
2012	Fillmore	Fillmore City Library
2012	Grantsville	Grantsville Elementary School
2012	Grantsville	Grantsville Junior High School
2012	Heber	Old Mill Elementary School
2012	Holladay	Oakwood Elementary School
2012	Hyrum	Lincoln Elementary School
2012	Kamas	South Summit Elementary School
2012	Kamas	Summit County Library - Kamas
2012	Kanab	Kanab City Library
2012	Magna	Lake Ridge Elementary School
2012	Midvale	Midvalley Elementary School
2012	Mona	Mona Elementary School
2012	Ogden	Majestic Elementary School
2012	Ogden	Weber County Library - Pleasant Valley
2012	Ogden	Weber State University
2012	Orem	Northridge Elementary School
2012	Park City	Park City Library
2012	Payson	Payson City Library
2012	Pleasant View	Lomond View Elementary School
2012	Price	Creekview Elementary School
2012	Provo	Dixon Middle School
2012	Roy	Roy Elementary School
2012	Salina	North Sevier Middle School
2012	Salt Lake City	Beacon Heights Elementary School
2012	Salt Lake City	Delta Call Center

2012	Salt Lake City	Howard R. Driggs Elementary School
2012	Salt Lake City	Primary Children's Hospital
2012	Salt Lake City	Rosecrest Elementary School
2012	Salt Lake City	Uintah Elementary School
2012	Sandy	Brookwood Elementary School
2012	Sandy	Edgemont Elementary School
2012	Sandy	Union Middle School
2012	South Jordan	Elk Meadows Elementary School
2012	Spanish Fork	Canyon Elementary School
2012	Spanish Fork	East Meadows Elementary School
2012	Spanish Fork	Larsen Elementary School
2012	Spanish Fork	Spanish Oaks Elementary School
2012	Springdale	Springdale Elementary School
2012	Springville	Westside Elementary School
2012	Taylorsville	Arcadia Elementary School
2012	West Jordan	Oquirrh Elementary School
2012	West Valley City	Diamond Ridge Elementary School
2012	West Valley City	Endeavor Hall
2012	West Valley City	West Valley City Library
2013	Bountiful	Oak Hills Elementary School
2013	Brigham City	Foothill Elementary School
2013	Castle Dale	Emery County Library - Castle Dale
2013	Cedar City	Iron Springs Elementary School
2013	Elmo	Emery County Library - Elmo
2013	Huntington	Canyon View Junior High School
2013	Kamas	South Summit Elementary School
2013	Kanab	Kanab Elementary School
2013	Kearns	Entheos Academy
2013	Kearns	Kearns Junior High School
2013	Lehi	North Point Elementary School
2013	Moab	Grand County Public Library
2013	North Salt Lake	Foxboro Elementary School
2013	Orangeville	Emery County Library - Orangeville
2013	Pleasant Grove	Valley View Elementary School
2013	Provo	Centennial Middle School School
2013	Roy	Municipal Elementary School
2013	Salt Lake City	Beacon Heights Elementary School
2013	Salt Lake City	Delta Call Center
2013	Salt Lake City	Discovery Gateway
2013	Salt Lake City	Hillside Middle School School
2013	Salt Lake City	Howard R. Driggs Elementary School
2013	Sandy	Union Middle School
2013	Saratoga Springs	Thunder Ridge Elementary School
2013	South Jordan	Elk Meadows Elementary School
2013	Spanish Fork	Canyon Elementary School
2013	Spanish Fork	Larsen Elementary School

2013	Spanish Fork	Riverview Elementary School
2013	Springville	Westside Elementary School
2013	Syracuse	Cook Elementary School
2013	West Jordan	Majestic Elementary School
2013	West Valley City	Granger Elementary School
2013	West Valley City	Redwood Elementary School
2014	Alpine	Timberline Middle School
2014	Alpine	Westfield Elementary School
2014	Bountiful	Boulton Elementary School
2014	Brigham City	Adele C. Young Intermediate School
2014	Brigham City	Box Elder Middle School
2014	Cedar Fort	Cedar Valley Elementary School
2014	Highland	Highland Elementary School
2014	Highland	Ridgeline Elementary School
2014	Kearns	Kearns Junior High School
2014	Layton	Legacy Junior High School
2014	Mona	Mona Elementary School
2014	Murray	Liberty Elementary School
2014	Orangeville	Cottonwood Elementary School
2014	Orem	Suncrest Elementary School
2014	Salt Lake City	Beacon Heights Elementary School
2014	Salt Lake City	Clayton Middle School School
2014	Salt Lake City	Eastwood Elementary School
2014	Salt Lake City	Hillside Middle School School
2014	Salt Lake City	North Star Elementary School
2014	Salt Lake City	Woodstock Elementary School
2014	South Jordan	Elk Meadows Elementary School
2014	Tabiona	Tabiona School
2014	Taylorsville	Arcadia Elementary School
2014	Taylorsville	Westbrook Elementary School
2014	West Valley City	Whittier Elementary School