Investigations Undertaken (October 1, 2004 – September 30, 2005):

The cooperative agreement identified here, 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 and (2) a regional earthquake-recording and information center on the University of Utah campus in Salt Lake City.

At the end of September 2005, UUSS operated and/or recorded 216 stations (100 short-period, 85 strong-motion, and 31 broadband, with 20 stations having multiple sensor types); a total of 517 channels were being recorded. 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 report period, project efforts involved: (a) continued development of a real-time earthquake information system in the Wasatch Front area as an element of an Advanced National Seismic System (ANSS); (b) timely study of new data acquired with our modernized network; (c) ongoing network operations; and (d) miscellaneous related activities.

Results:

Real-Time Earthquake Information System. Since FY2000, in incremental steps, we have successfully (1) integrated weak- and strong-motion monitoring within a modernized regional/urban seismic network and (2) developed an effective real-time earthquake information system. Accomplishments in FY 2005 included the following:

ShakeMap — During FY2005, ShakeMaps were automatically produced and posted to our Web site for three earthquakes (3.0 ≤ Mr ≤ 3.3) in our standard Wasatch Front ShakeMap area (~73,000 km²). ShakeMap development work focused on (1) expanding ShakeMap capabilities to the entire Utah region (~300,000 km²), (2) installing ShakeCast, and (3) developing ShakeMap scenarios for emergency managers. Two main prerequisites for expanding ShakeMap to the entire Utah region are a site-condition map of Vs30 (average shear-wave velocity in the upper 30 m) for the whole region and a geographically expanded distribution of strong-motion instruments. A geology-based Vs30 map in GIS format for the Utah region was created with the help of the Utah Geological Survey (UGS), based on eight surface geology units whose mean Vs30 values were calibrated by ~150 Vs30 measurements within the Wasatch
Front area (most from the Salt Lake Valley). Although not ideal, the extrapolation of geology-correlated Vs30 data to areas outside the Wasatch Front was the only mapping approach available in the absence of Vs30 data elsewhere. Expanded geographic coverage of strong-motion recording outside the Wasatch Front area, at least in skeletal form, was achieved as part of the “USMEP05” project (described below). In late FY2005, we tested our expanded ShakeMap capabilities for the Utah region on our backup server; near-real-time ShakeMaps were successfully created offline for three earthquakes ($M_L \leq 3.8$) in southern Utah during the test period. Because new strong-motion stations in the general area were not yet recording in real time, these ShakeMaps were unconstrained by instrumental data.

Also during FY2005, Utah’s seismic network became the first outside of California to run ShakeCast, and we now routinely exchange information with the USGS ShakeCast server in Southern California. Another notable accomplishment during FY2005 was the generation of sixteen ShakeMap scenarios. A poster (Pankow and Burlacu, 2005) at the SSA 2005 meeting in Reno summarized many of the scenario results for potential earthquakes in both the Wasatch Front region and southern Utah. In August 2005 we participated in a UGS earthquake exercise for which we provided a sequence of three scenario ShakeMaps requested by the exercise’s planning committee: an M7.0 main shock on the Weber segment of the Wasatch fault followed by an M6.5 aftershock near Bountiful, north of Salt Lake City, followed by an M6.0 sympathetic rupture in the western part of the Salt Lake Valley. Two lessons learned are: (1) the number of JPEG images sent via e-mail need to be limited and (2) e-mail alerts should include links to ShakeMap not only on our own Web site but also on the USGS Web site. Both lessons were communicated to the ANSS ShakeMap Working Group.

**Utah Strong-Motion Expansion Project 2005 (USMEP05)** — USMEP05 is a cooperative multi-agency project to expand, at least in a limited way, Utah’s continuously-telemetered strong-motion network to earthquake-prone cities and towns in Utah outside the Wasatch Front. The participating entities include UUSS, the USGS ANSS program, the USGS National Strong-Motion Program (NSMP), the Utah Department of Emergency Services and Homeland Security (DES), and the Utah Geological Survey (UGS). The project was motivated by a desire of DES, a major user of ANSS products in Utah, to be able to use ShakeCast to integrate UUSS ShakeMaps into Hazus in near-real time for damaging earthquakes anywhere in Utah. The practical importance of having instrumental data to constrain ShakeMaps was emphasized by experience from the 2003 San Simeon, California, earthquake (see, for example, [http://www.cisn.org/docs/CISN_SanSimeon.pdf](http://www.cisn.org/docs/CISN_SanSimeon.pdf)). To achieve rudimentary real-time strong-motion coverage of population centers in Utah outside the Wasatch Front area, ANSS funding was secured to upgrade eight existing NSMP stations along Utah’s main seismic belt—which basically follows the I-15 corridor, including a swath of growing cities and towns in southwestern Utah—and to add two new stations in eastern Utah with state funds (for details, see [http://www.seis.utah.edu/usmep05](http://www.seis.utah.edu/usmep05)). Five of the eight NSMP stations were originally installed in the mid-1990s as part of a cooperative project between UGS and NSMP with one-time instrumentation funding from the Utah Legislature. As part of USMEP05, NSMP provided new accelerographs for these five stations (the other three already had Kinemetrics Etna accelerographs with dial-up telemetry), and UUSS took the lead (with ANSS funds) to re-site, permit, and upgrade all eight stations, establish continuous real-time telemetry, and integrate them into UUSS’s regional/urban seismic network as “ANSS Cooperative” stations. As of September 30, 2005, the installation of all eight stations had been completed, and continuous real-time data streams were being recorded from six of the stations. All ten USMEP05 strong-motion stations will be fully operational by the end of 2005.

**Urban Strong-Motion Network in Wasatch Front area** — Excluding the USMEP05 stations, our real-time strong-motion ("SM") network at the end of FY2005 included 87 three-component accelerometers located at 76 ANSS-funded stations, seven ANSS contributing stations (funded by the state of Utah), and
four ANSS cooperative stations (NSMP stations with real-time telemetry to UUSS). Five of these 87 stations do not lie within our standard Wasatch Front area. In addition, we use an import protocol to automatically receive from NSMP both parametric data (in XML format) and waveform data from 10 other NSMP strong-motion stations in the Wasatch Front area that have telephone connections to Menlo Park, CA. One new ANSS-funded station was added to our SM network during FY2005—a urban station on the grounds of the Utah State Capitol in Salt Lake City, currently undergoing a $200 million renovation and seismic retrofit scheduled for completion in late 2007.

For robustness, our real-time SM network uses diverse telemetry, including dedicated circuits, public Internet, and point-to-multipoint digital telemetry using spread-spectrum radio links. For the latter, the growing number of SM stations in the Wasatch Front area led us to use Time Division Multiple Access (TDMA) configurations instead of point-to-point for many practical reasons (e.g., equipment costs, bandwidth use, and factors at our central recording site such as space, power, and the number of antennas). Although TDMA digital radio has no ongoing service cost and allows greatest control by the network operator, it is our most complex telemetry option; problems have typically arisen from the demuxing software and the equipment it runs on. As part of a status report on Utah’s ANSS SM network for the 2005 annual SSA meeting (Arabasz et al., 2005), we analyzed trade-offs among telemetry options in terms of cost, reliability, and expected performance during a large earthquake. We also analyzed the comparative reliability of government-furnished SM instrumentation in our network. During FY2005 we continued to try to remedy, in cooperation with the manufacturer, major shortcomings of some government-furnished accelerographs that make up a large part of our inventory of SM instrumentation and which we received during 2002–2005 as “beta-status” rather than “production” instruments. Persistent problems, whose resolution depends on the issue of new firmware, variously relate to the IP stack, FTP server, Ethernet interface, PPP firmware, and serial interface.

**Earthworm** — We continued improvements to our 13-machine Earthworm system (hardware and software) for real-time earthquake monitoring and automated alerts. Work done on this system during FY2005, in addition to routine maintenance and monitoring of the system performance, included: modifications to accommodate new stations and changes in instrumentation and/or telemetry at existing stations; transfer of radio telemetry software Wigate from a PC to a SUN workstation; and selective installation of Earthworm v6.2, which is now running on all of our Earthworm machines except for (1) the PC which digitizes data from analog telemetry stations and (2) the machines on the primary system which interact with the Oracle database. We also worked with Paul Friberg of Instrumental Software Technologies, Inc., and others, to define and test some improvements to the Earthworm module for determining local magnitudes; the improvements were included in Earthworm v6.3, which was released on September 30, 2005.

**Accomplishments in Ongoing Network Operations.** Noteworthy accomplishments during the report period included the following:

**Revision of coda magnitudes in the UUSS catalog, 1981-2002**—We have been carrying out quality control checks on revised coda magnitudes (M<sub>C</sub>) in the UUSS earthquake catalog, 1981-2001. The revised M<sub>C</sub>s are superior to the old ones because they are calculated using (1) gain-corrected signal durations measured to a fixed threshold instead of the pre-event noise level, (2) improved coda magnitude equations calibrated against local magnitude (M<sub>L</sub>), and (3) a modified version of Hypoinverse which does not discard negative magnitudes. However, instability in the gain corrections, which we began routinely applying to our duration measurements in 2002, can sometimes lead to erroneous coda magnitudes.

As a check on the revised M<sub>C</sub>s, we compared them to the magnitudes (M<sub>C</sub> or M<sub>L</sub>) in the old UUSS
catalog. Based on the distribution of these magnitude differences, we decided to check all of the revised \( M \)s that differ from the old magnitudes by 1.0 units or more. A total of 861 events, representing 1.7% of the catalog, fall into this category. Of the 195 revised \( M \)s checked before the end of the report period, about half were in error by \( = 1.0 \) magnitude units. These quality control checks are continuing and should be completed by the end of 2005.

Near-real-time data exchange with other networks — Throughout the report period, we continued to exchange waveform data in near-real-time with the National Earthquake Information Center, the Idaho National Laboratory, the Montana Bureau of Mines and Geology, Brigham Young University-Idaho, Northern Arizona University, the U.S. Bureau of Reclamation, and the University of Nevada, Reno. These data exchanges are done via the Internet using Earthworm import/export software modules.

Assistance to other seismic networks — During FY2005, technical help to other seismic networks included: (1) help to operators of the Puerto Rico seismic network in setting up a Windows PPP server to communicate with REF TEK 130 seismic recorders and providing GIS guidance and software to help generate geology and Vs30 files for ShakeMap; (2) remote maintenance and troubleshooting of the Northern Arizona University (NAU) Earthworm system and relaying of NAU’s data streams to the IRIS DMC; (3) providing Mike Stickney, the operator of Montana’s regional seismic network, with response files and changes to previously-provided UUSS software to enable him to use digital data from the Butte, Montana, simulated Wood-Anderson seismograph for computing local magnitude, \( M_L \); (4) helping Aaron Frodsham, the operator of Brigham Young University-Idaho’s Earthworm system, to troubleshoot firewall-related difficulties in exporting seismic data to other networks; (5) providing Webicorder displays for the USGS’s Teton Region ANSS seismic network in northwestern Wyoming; and (6) providing scripts to Mitch Withers at CERI (University of Memphis) for automating ShakeMap using Earthworm.

Archiving waveform data — All digital waveform data collected by the University of Utah regional seismic network during the report period were submitted to the IRIS DMC in SEED format.

Submission of earthquake catalog data to ANSS information outlets — During the report period, Earthworm automatic (non-human-reviewed) hypocenters and magnitudes for earthquakes of magnitude 3.0 and larger in our authoritative regions (Utah and Yellowstone National Park)—2.5 and larger in the Wasatch Front urban corridor—were automatically submitted to the QDDS. Analyst-determined hypocenters and magnitudes for all earthquakes in our authoritative regions were submitted to the QDDS as they were completed, using software that we further improved during the report period. These same data were automatically submitted to the ANSS catalog four times per day during the Monday-Friday work week. Events of \( M \geq 1.0 \) submitted to the QDDS are automatically posted on the ANSS RecentEqs Web pages.

Miscellaneous

Coal-mining-induced seismicity — During FY2005 we continued studies of mining-induced seismicity (MIS) associated with underground coal mining in east-central Utah (Arabasz et al., 2005b,c). UUSS currently has partnerships with the Univ. of Utah Dept. of Mining Engineering, the U.S. Bureau of Land Management (BLM), and mine operators at three coal mines in Utah’s Book Cliffs mining district. MIS is of direct concern for mine safety, particularly as new mining goes to greater depth, and it also is of great interest to federal agencies such as BLM that are responsible for maximizing the recovery of federal coal resources in the region as well as safeguarding off-site structures on federally-managed land from the potential ground-shaking hazard of MIS. Above each of the three mines in the Book Cliffs area, UUSS
cooperatively operates one 4-component seismograph (3-component accelerometer plus a vertical-component short-period velocity sensor) with continuous telemetry to our network operations center. The instrumentation provides mine operators with continuous Webicorder records online, improved locations of MIS at the mine sites, and ground-motion data for the larger events. The accelerometers also provide valuable ShakeMap control in central Utah.

First-motion focal mechanisms — As part of a senior thesis by J. Mark Hale (Hale and Pankow, 2005), we have installed and configured HASH (Hardebeck and Shearer, 2002; Bull. Seism. Soc. Am. 92, 2264–2276) to facilitate routine generation of first-motion focal mechanisms, when possible, for earthquakes of M3.5 or larger in the Utah region. In areas of enhanced station coverage, such as the Wasatch Front, we will attempt to routinely generate such mechanisms for earthquakes of M2.5 or larger.

ANSS Implementation Activities — Beyond our direct involvement in ANSS seismic-network operations in Utah, indirect activities during FY2005 aimed at advancing ANSS implementation included: our involvement in the ShakeMap Working Group and assistance to other ANSS seismic networks (mentioned earlier); coordination of ANSS advisory committees and other planning in the Intermountain West (IMW) Region; service on the ANSS National Implementation and Technical Integration committees; chairing a working group to develop an evolutionary architecture for ANSS; and activism in securing Congressional support for increased ANSS funding. UUSS secured funding from IRIS for a new six-component broadband/strong-motion seismograph near Cedar City in southwestern Utah and is taking the lead in siting and installing it. The station will be operated as a cooperative UUSS/USGS station under ANSS and will be part of the national backbone network jointly serving ANSS and the National Science Foundation’s EarthScope/USArray project. The station is scheduled to be completed by the spring of 2006.

Utah Earthquake Hazards Working Groups — In March 2005 we presented two invited talks at a meeting of the Utah Ground Shaking Working Group. Four seismologists in our network group are serving on this 17-member working group, which is planning the development of the next generation of ground shaking hazard maps in Utah. Two are also serving on a Utah Quaternary Fault Parameter Working Group. Both working groups are sponsored by the USGS and the Utah Geological Survey. These activities enable close coordination between our UUSS/ANSS urban strong-motion network and researchers addressing local seismic hazard issues.

Network Seismicity. Figure 1 shows the epicenters of 1,469 earthquakes (ML ≤ 4.1) located in part of the University of Utah study area designated the “Utah region” (lat. 36.75°–42.5° N, long. 108.75°–114.25° W) during the period October 1, 2004 to September 30, 2005. The seismicity sample includes thirteen shocks of magnitude 3.0 or greater and sixteen felt earthquakes (1.3 ≤ ML ≤ 4.1). The largest earthquake within the Utah region during the report period was a shock of 4.1 on November 6, 2004 (23:54 MST) located 31 km (19 miles) west of Naturita, CO (epicenter labeled in Figure 1). ShakeMaps were generated using our network data for three earthquakes (3.0 ≤ ML ≤ 3.3) during the report period; see <http://www.seis.utah/shake/archive/>. Community Internet Intensity Maps were generated by the USGS for eleven Utah region shocks; see <http://pasadena.wr.usgs.gov/shake/imw/archives.html>.

Non-technical Summary:

This cooperative agreement provides major support for urban and regional seismic monitoring in Utah and neighboring areas. During the report period we operated and improved a real-time earthquake information system in Utah's seismically hazardous Wasatch Front urban corridor. By September 2005, more than 80 strong-motion stations were operating in our urban network as part of the Advanced
National System (ANSS) to meet needs for emergency response and earthquake engineering. More than 1,400 earthquakes were located in our study region during the report period; 13 had a magnitude of 3.0 or larger, and 16 were reported felt. The largest local earthquake was a shock of magnitude 4.1 on November 6, 2004 near the Colorado-Utah border. Many of our activities during the report period were to help build elements of the ANSS in Utah, in the Intermountain West region, and nationally.

**Reports and Publications:**


Availability of Data:

All seismic waveform data archived by the University of Utah Seismograph Stations can be retrieved from the IRIS DMC using their SeismiQuery Web tool at <http://www.iris.washington.edu/SeismiQuery> (delivered in a variety of formats). 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) via anonymous ftp <ftp.seis.utah.edu/pub/UUSS_catalogs>, (2) by e-mail request to webmaster@seis.utah.edu, or (3) 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.quake.utah.edu>. The contact person for data requests is Relu Burlacu, tel: (801) 585-7972; e-mail: burlacu@seis.utah.edu.
Figure 1. Earthquakes in the Utah Region, October 1, 2004 through September 30, 2005. Shocks of magnitude 3.0 and larger are plotted as stars; those less than magnitude 3.0, as circles. Base map of Quaternary faults from the Utah Geological Survey; Wasatch fault shown in bold.