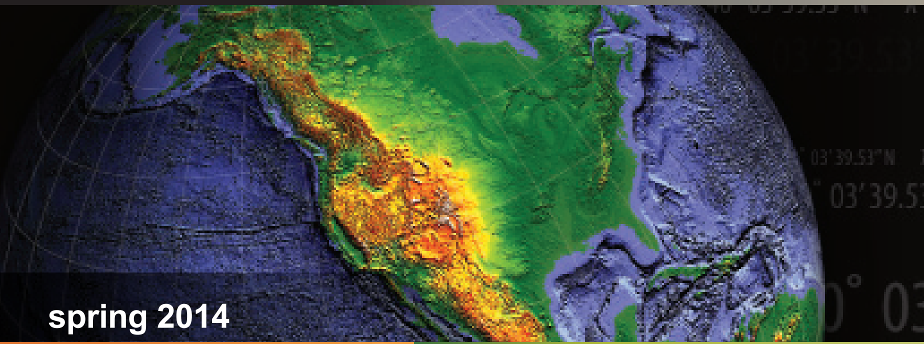


inSights

the EarthScope newsletter

spring 2014

EarthScope News

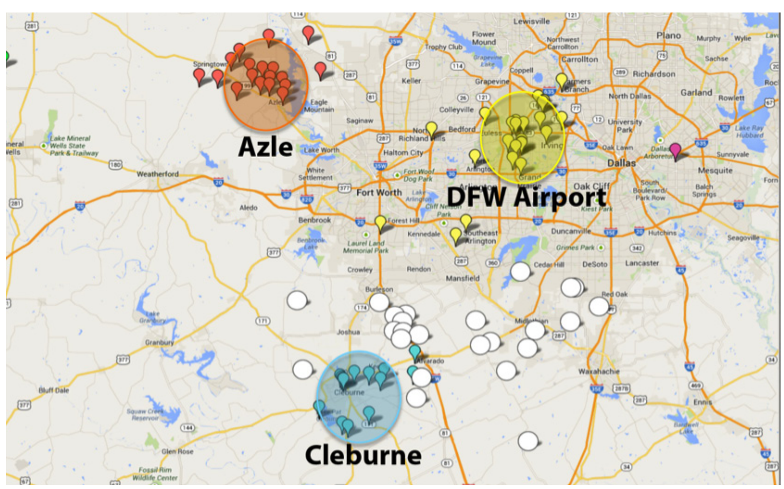
Earthquakes and Human Activities Addressing Public Concerns

North Texas Earthquake Study Group, Southern Methodist University

There is currently public, scientific, and policy concern regarding the recent increased seismicity rates in the Central and Eastern US (CEUS). Whether due to tectonic or human-induced mechanisms, characterization of the seismic sequences is important for understanding seismic hazards within the stable continent. Examples of recent tectonic and potentially human-induced mid-magnitude CEUS activity include the 2011 Arkansas Earthquake Swarm culminating in a 4.7 event on 27 February, the 5.8 Virginia Earthquake on 23 August, the 5.6 Oklahoma Earthquake on 5 November, the 4.8 Southern Texas Earthquake on 20 October, and the 4.0 Ohio Earthquake on 31 December. A combination of USArray deployments (called the CEUSN permanent station adoption) and temporary local network deployments are providing local and regional observations that result in improved locations and source information. Temporary aftershock-like deployments in these areas use a combination of long-term broadband systems and short-term high-frequency studies to provide information for detailed source studies. The foundation of such local studies is the estimate of background seismicity that is being developed from the improvements in regional coverage provided by USArray.

The possibility that recent fluid-injection into deep wells has resulted in human-induced earthquakes further motivates a detailed study of CEUS seismicity associated with these types of activities, especially in light of published linkages to recent events in Texas, Arkansas and Ohio. The National Research Council Report, *Induced Seismicity Potential in Energy Technologies* (Shemeta et al, 2012) provides a comprehensive examination of the range of human activities that have been linked to man-induced seismicity including oil/gas extraction, secondary recovery, waste water injection, geothermal and hydraulic fracturing. As noted in this report, the number of possible cases of linked seismicity are relatively small, *"Although only a small fraction of injection and extraction activities at hundreds of thousand of energy development sites in the United States have induced seismicity at levels that are noticeable to the public, seismic events caused by or likely related to energy development have been measured and felt in Alabama, Arkansas, California, Colorado, Illinois, Louisiana, Mississippi, Nebraska, Nevada, New Mexico, Ohio, Oklahoma and Texas."*

In the CEUS, regional seismicity increased from an average of 20 magnitude 3.0 and above events per year from 1970 to 2000 to more than 450 earthquakes from 2010 through 2013 (Ellsworth, 2012). This increase in seismicity raises questions about the underlying causes of the events, the methods of measuring seismicity, and the approaches to reducing risks associated with the induced events. One motivation for the CEUSN permanent station adoption has been to provide an enhanced set of seismic stations for quantifying both earthquake locations and wave propagation effects in the eastern US. The virtual network code _CEUSN has been prepared to facilitate access to this data set. *Continued next page.*



Above: Earthquakes between magnitude 2.1 and 3.7 reported by the National Earthquake Information Center in and around the Fort Worth Basin since 2008. Events in the three-labeled areas have each been found to occur on shallow faults with dimensions of a kilometer of two when supplemental data from RAMP like deployments are incorporated.

EarthScope Celebrates 10 Years

On May 15, 2014 members of the EarthScope community will host a science symposium in Washington, D.C. and present an overview of the findings and impacts from ten years of discoveries.

The event recognizes the contributions of the National Science Foundation and other agencies, organizations, and individuals who have made EarthScope a resounding success. State-of-the-art EarthScope equipment will be on display and recent Earth science discoveries will be highlighted. This talk is open to the public. Please register at esevent@iris.edu.

Thursday May 15, 2014
Science Symposium: 1:00-5:30 p.m.
Reception: 5:30 – 8:00 p.m.

AAAS Building
1200 New York Ave, NW, 1st - 2nd fl.
Washington, DC 20005
(The entrance is on the corner of 12th and H Streets, NW)

RSVP by Friday, May 9 to ESEVENT@IRIS.EDU with name and number of guests. Please specify attendance at symposium, reception, or both.

For more information, please visit www.earthscope.org/reception.

Continued from front page

The Fort Worth Basin provides an example of increased seismicity in a region of active gas production and accompanying waste water disposal. Prior to 2008, there is no reported seismicity in the region. Since then, the USGS has reported 81 events between magnitude 2.1 and 3.7, many of them felt, producing a public concern. Two studies focused on the 2008-2009 sequence of earthquakes around the DFW Airport (Frohlich et al., 2011) and the 2009-2010 sequence near Cleburne, Texas (Howe-Justinic et al., 2013). Both studies examined the temporal and spatial relationship between nearby injection wells and the earthquake sequences. For the DFW airport study, the fact that the injection well began operating shortly before the earthquakes began and that the earthquakes were close to the well, provided a plausible indication that injection was in some way related to the start of earthquakes. In the case of the Cleburne sequence, although injection wells were located within a few kilometers of the earthquakes, there was no strong timing relationship. However, because there were no reported earthquakes prior to injection, the study was not able to reject injection as a possible cause. This is a weaker conclusion than in the DFW study. These two studies relied on RAMP instrumentation provided by IRIS PASSCAL in order to make near-source measurements of earthquakes as small as magnitude 0.5 in order to provide refined locations for purposes of imaging small faults. Routine locations provided by the USGS based on permanent instruments have associated errors that make association of the events with buried faults difficult. The combined use of portable and permanent instrumentation as supported by EarthScope and PASSCAL provides a unique opportunity to assessing these unusual events.

Although models are currently under development, both of the Fort Worth Basin studies suffered from a lack of a physical explanation (a model) for how fluid injection at specific sites could have resulted in the earthquake evolution over the observation period. Neither study contained a detailed understanding of the fault geometry, subsurface geology, and subsurface stress regimes. Neither study investigated similar natural sequences or similar injection histories without associated earthquakes. Neither study was able to continue instrumentation beyond the short term RAMP time periods. Without this understanding, neither study was able to suggest the future probability of larger events needed to develop the hazard associated with this fault. Therefore, seismologists are limited to using relatively crude statistical methods based on the observation history in similar tectonic regions in the U.S.

Increased public awareness and concern about seismicity in regions with little or no historical experience has most recently been illustrated with a third earthquake sequence of 27 NEIC events in the Fort Worth Basin near Azle, Texas. Although the earthquakes have been small with the largest M 3.6, there have been many felt events and concerns by local residents. The detailed assessment of these events that began in November 2013 has been possible with the deployment of portable equipment supplied by the USGS and PASSCAL among others. Real-time data telemetry has enhanced the study, providing the opportunity to adapt the configuration of the network to maximize the collection of high quality seismic data. Detailed subsurface information may provide an opportunity to move closer to a physical understanding of these events and their relationship to both production and disposal activities in the region. Public concern in this particular instance has reinforced the need for education and outreach activities in order to provide some basis for local communities to assess the earthquakes and their associated hazard.

Increased seismicity has been associated with areas where there has been increased development of unconventional tight shale gas and oil reservoirs (Shemeta et al., 2012). Technologies associated with horizontal drilling and hydraulic fracturing have made this resource recovery economically advantageous. Felt seismic events associated with these activities, including wastewater injection, are rare. Water is typically recovered with the gas that must be either disposed of or recycled. In 2011, there were eight case studies linking earthquakes to these waste water wells in the US out of roughly 30,000 US waste water injection wells (Shemeta et al, 2012). The vast majority of injection wells have no nearby detected earthquakes. The question is why? Understanding why a particular injector is associated with earthquakes while another similar well in similar conditions has no earthquakes remains a critical question whose answer lies in a multidisciplinary approach encompassing seismic monitoring, imaging, and an comprehensive understanding of local material properties and fluid flow.

Transportable Array Contributes to the Central and Eastern US Network

Perle Dorr, IRIS

The National Science Foundation is funding the creation of a Central and Eastern US Network (CEUSN) for the purpose of obtaining long-term seismic observations. The IRIS-operated portion of the CEUSN will consist of about 160 stations. Most of these stations were originally installed as part of the EarthScope Transportable Array and will be left in place beyond their initial two-year recording period. In a few key locations, where the Transportable Array stations have already been decommissioned, seismometers will be re-installed. When the CEUSN stations are taken together with other contributing stations, there will be over 300 broadband seismometers recording in the central and eastern United States.

The intent of the CEUSN is to provide data critical to address both seismic hazard in the central and eastern United States as well as basic research questions in this region and beyond. CEUSN data will enable researchers and federal agencies to better understand basic geologic questions, background earthquake rates and distributions, seismic hazard potential, and associated societal risks. A committee representing federal, state, and university interests prepared and prioritized a list of stations to be retained that best augment existing facilities and optimize multiple observing objectives. Broadband and strong motion sensors at CEUSN stations will record at 100 samples per second, but will record 200 samples per second if an event is detected. The CEUSN is expected to operate through 2018 or longer. More information can be found on the CEUSN web page www.usarray.org/ceusn.

Project Highlight: Stability of PBO GPS Monument Types

Beth Bartel, UNAVCO

The primary mission of the EarthScope Plate Boundary Observatory is to measure regional tectonic motion and transient deformation as accurately as possible. To do so, the network's GPS antennas must be installed on stable monuments that are firmly coupled with the substrate—not just to the surface, where the monument can be influenced by local surface processes like freeze-thaw cycles and soil moisture. But how stable can we get? And what is the tradeoff between stability and cost? Recently, UNAVCO installed additional GPS monuments at five PBO sites throughout the U.S. to test the stability of both common and new monument types.

The deep-drilled braced monument, a monument consisting of legs drilled to ~11 m or ~35 feet below the surface, has been touted by researchers as the most stable monument type. Yet the deep-drilled braced monument is also prohibitively expensive, costing around $20K and requiring at least 1-2 days, 4 people, and a drill rig to complete. Is the cost worth it? PBO engineers installed two additional monument types at sites in Washington, California, and Georgia, creating 10-meter monument triangles at each site. Sites were chosen to represent a variety of geographic, hydrologic, and geologic conditions. The monuments types installed depend on the substrate. At sites with bedrock, UNAVCO also installed a short-drilled braced monument, consisting of stainless steel legs drilled to a depth of ~5 feet, and a pillar. These sites include P453 in Wilbur, Washington and P804 at the Rock Ranch, Georgia. At sites with no bedrock available—the most worrisome when it comes to stability—UNAVCO installed a short-drilled braced monument, which consists of stainless steel legs driven to refusal, and a concrete pillar. Sites with these monument types include P401 in Forks, Washington; P591 in California City, California; and P565 in Delano, California.

Concrete pillars, installed at each site, can be made with materials available locally in most places in the world, can cost as little as $100, and can be installed by hand without the use of heavy machinery. The geodetic community believes them to be generally less stable than the other monument types described here, but until now, the relative stability between these monument types had not been quantified.

The last of the multi-monument test sites was completed in August of 2013. At least two years of data from each study site will be needed to properly isolate relative monument movement from other noise sources. However, initial results indicate that in the unconsolidated sandy soil of the Mohave Desert, at site P591, a shallow driven-braced monument, installed by hand at a cost of a few hundred dollars, is as stable as a deep drilled-braced monument costing $20K (0.17 mm RMS for the horizontal position components). By contrast, the concrete pillar is showing signs of instability, with clearly discernible motions of up to 2 mm between it and the deep drilled-braced monument. When measuring plate motion, millimeters matter.

These initial results were presented at the 2013 AGU Fall Meeting and ongoing analyses using these and GPS reflectometry measurements were also presented at the 2014 UNAVCO Science Workshop. The study will inform future GPS/GNSS monument installations by identifying the most cost-effective monument style that is appropriate for its particular geological setting.

Hot New Science

In each inSights, we will highlight a few recent publications of EarthScope results. Please submit your latest publications to earthscope@asu.edu

Meqbel, M. N., Egbert, G. D., Wannamaker, P. E., Kelbert, A., & Schultz, A. (2014). Deep electrical resistivity structure of the northwestern U.S. derived from 3-D inversion of USArray magnetotelluric data. *Earth and Planetary Science Letters,* 1, 1–15. doi:10.1016/j.epsl.2013.12.026

Wei, M., Kaneko, Y., Liu, Y., & McGuire, J. J. (2013). Episodic fault creep events in California controlled by shallow frictional heterogeneity. *Nature Geoscience*, 6(7), 566–570.

Parker, E. H., Hawman, R. B., Fischer, K. M., & Wagner, L. S. (2013). Crustal evolution across the southern Appalachians: Initial results from the SESAME broadband array. *Geophysical Research Letters*, 40(15), 3853–3857.

Chu, R., Leng, W., Helmberger, D. V., & Gurnis, M. (2013). Hidden hotspot track beneath the eastern United States. *Nature Geoscience*, 6(11), 963–966.

Chu, R., Helmberger, D., & Gurnis, M. (2012). Upper mantle surprises derived from the recent Virginia earthquake waveform data. *Earth and Planetary Science Letters.*

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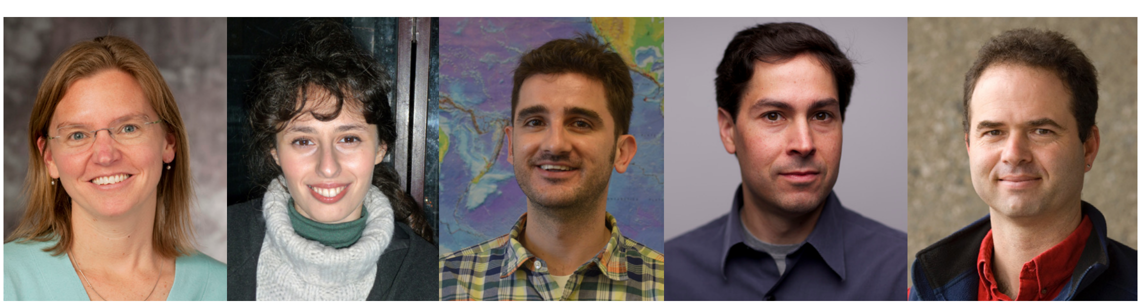
EarthScope Speaker Series 2014-2015

The EarthScope National Office is pleased to introduce the lecturers for the 2014-2015 EarthScope Speaker Series, supported by the National Science Foundation. The five outstanding speakers for this series include: Anne Egger (Central Washington University), Anna Kelbert (Oregon State University), Vedran Lekic (University of Maryland, College Park), David Schmidt (University of Washington), and Mark Simons (Caltech).

Academic institutions are invited to apply for a Speaker visit for the 2014-2015 academic year. Complete information about the EarthScope Speaker Series, including speaker biographies and an online application form can be found on the EarthScope website at www.earthscope.org/speakers. Please direct any questions about the Series to earthscope@asu.edu.



Anne Egger | Anna Kelbert | Vedran Lekic | David Schmidt | Mark Simons