Incorporating Near Real-time Transportable Array Data into the Regional Oklahoma Seismic Network

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Abstract

The addition of Earthscope USArray Transportable Array (TA) seismic stations for regional seismic monitoring offered significant technical challenges and provided a great deal of benefit to the monitoring capabilities within Oklahoma. The Oklahoma Geological Survey (OGS) operates 9 regional seismic stations. In April 2009 the first TA station was installed and by the end of 2010 there were an additional 39 stations operating in Oklahoma. These stations were incorporated into the Earthworm real-time system operated at the OGS. The greatest challenge was accommodating the computational resources required to handle in near real-time the additional data. The rolling nature of TA station installation was also an additional hurdle as new stations were added a system that appeared to have ample resources could quickly be overtaxed and fail. Excluding the Jones earthquake swarm there were 326 earthquakes in Oklahoma, of which 36 were felt. These additional seismic stations dramatically improved earthquake identification and locations. The OGS detected as many as 225 earthquakes in Oklahoma that may not have otherwise been detected by the regional monitoring network. The OGS was able to identify an earthquake swarm in Coal County in southeastern Oklahoma that would have gone largely unnoticed except for three felt earthquakes. In addition the greater coverage provided the ability to determine first motion focal mechanisms, which would not have been possible for the majority of events without the additional TA data and coverage. These focal mechanisms have been used as additional data to refine the regional stress field in Oklahoma. In addition the high quality recordings of the TA allow us to evaluate magnitude and attenuation relationships for Oklahoma. We are also able to better refine velocity models used in routine location of earthquakes in Oklahoma.

Introduction

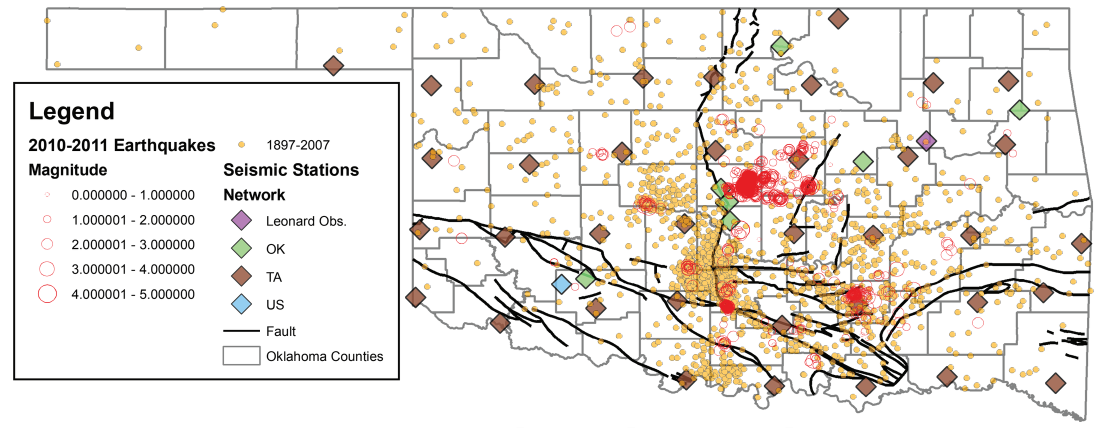
It is difficult to determine how many earthquakes would have gone undetected without the addition of the Transportable Array (TA) stations to the Oklahoma Geological Survey (OGS) earthquake monitoring system. Initially we assumed that 75% percent of earthquakes less than magnitude 2.5 would have gone undetected. This is excluding the earthquake swarm near Jones, Oklahoma, in eastern Oklahoma County, where additional instrumentation was installed. These instruments were accelerometers so they did little to improve detection of earthquakes elsewhere in Oklahoma.

There were an additional 39 stations in Oklahoma as part of TA by the end of 2010 and they are already rolling out of the western side of the state. Incorporating this large volume of data in near real-time posed many challenges. The data was accessed from IRIS using the SEEDLINK utility and brought into the EARTHWORM processing system. The greatest challenge was that as additional stations were added to the system the computer requirements did not seem to grow linearly. The additional data from the TA stations provide many opportunities to study Oklahoma seismicity in ways that had not previously been possible. We present just a few examples of the questions we are more able to address with the additional data provided by the TA for regional earthquake monitoring.

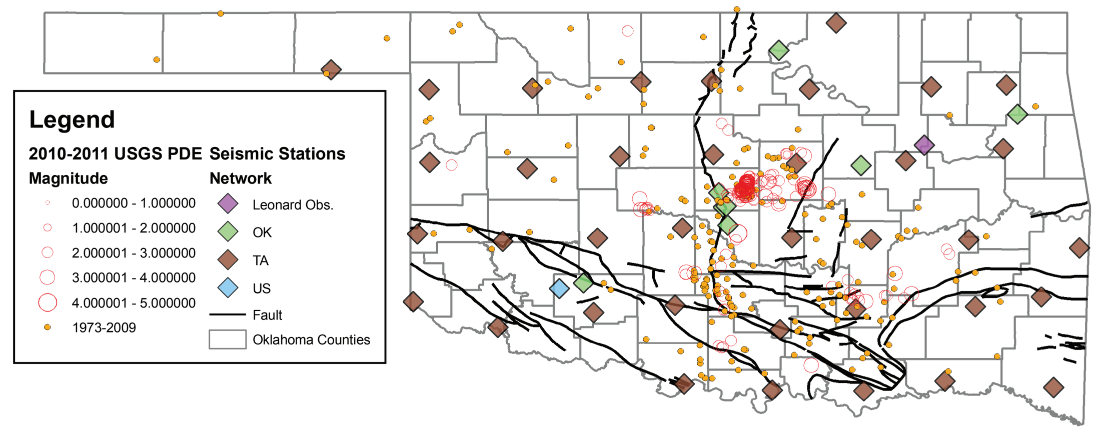
Oklahoma Seismicity

From the beginning of 2010 to March 31, 2011 the OGS located more than 1,424 earthquakes in Oklahoma. More than 850 of these earthquakes occurred in the Jones Oklahoma Swarm. Excluding earthquakes in Oklahoma County the OGS recorded 565 earthquakes more than 40 of which were reported felt. These numbers far exceed anything observed prior to 2010. From 1977 when a seismic network was installed through 2007 the OGS recorded 1,750 earthquakes. The most earthquakes to occur in a single year before 2010 was 167, and there is on average only 3 felt earthquakes in a year.

OGS Earthquake Catalog



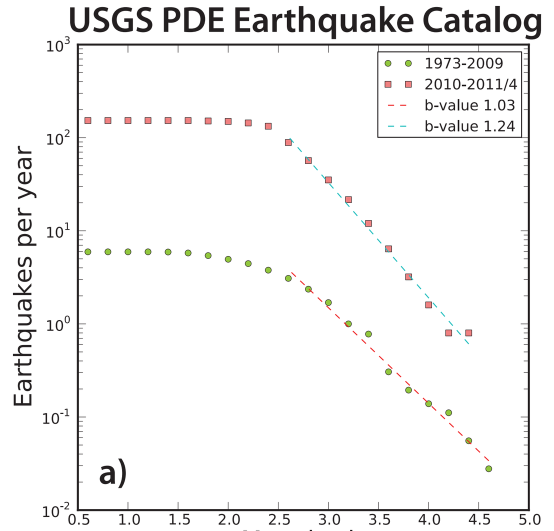
USGS PDE Earthquake Catalog

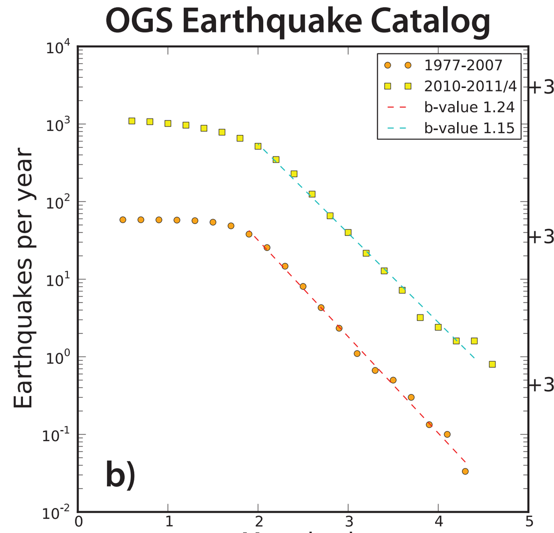


Catalog Statistics

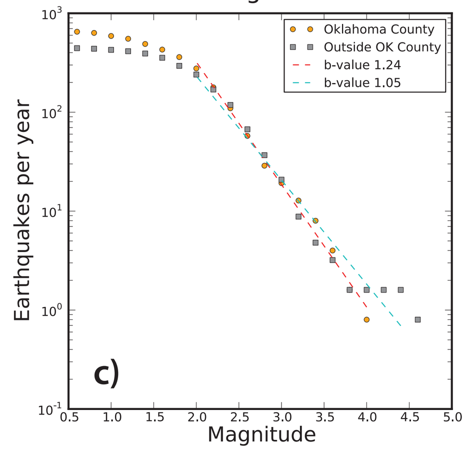
One method to address the magnitude of completeness is to examine number of earthquakes of a given magnitude over different time periods. The magnitude of completeness is defined where the earthquake occurrence rate flattens out and diverges from the linear b-value trend. In response to the Jones Swarm the USGS did add a few TA stations in Oklahoma to their routine processing.

- Both the USGS PDE and the OGS catalog show a significant and comparable rate increase.
- The Jones Swarm alone cannot explain the observed rate change.
- TA stations did not dramatically alter the magnitude of completeness, or the number of earthquakes detected, for either the OGS or the USGS PDE catalogs





Catalog (Years) d)	Number of Earthquakes	a	b	Maximum Magnitude (500 yr return period)
OGS (1977-2007)	1750	3.989	1.243	5.4
OGS (2010-2011.25)	1424	5.041	1.149	6.7
USGS PDE (1973-2009)	214	3.257	1.028	5.8
USGS PDE (2010-2011.25)	191	5.230	1.236	6.4
OGS (2010-2011.25) Oklahoma County	859	4.987	1.239	6.2
OGS (2010-2011.25) Outside Oklahoma County	565	4.469	1.052	6.8

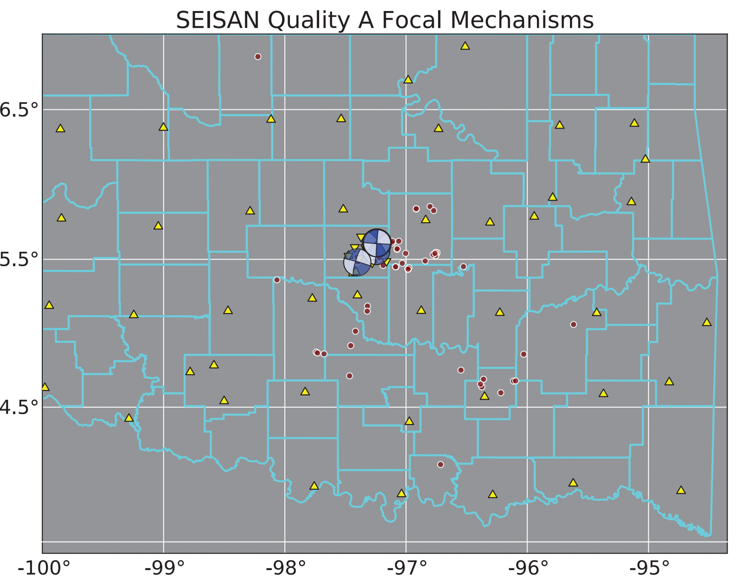


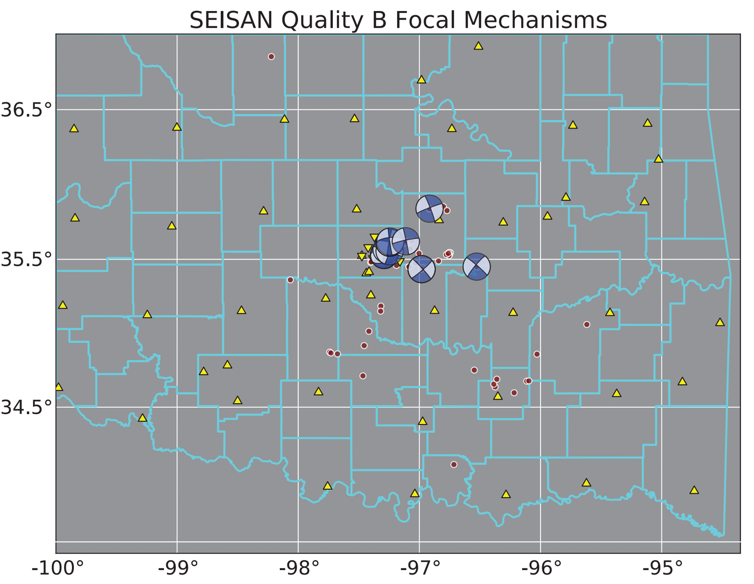
$$\log N = a - bM$$

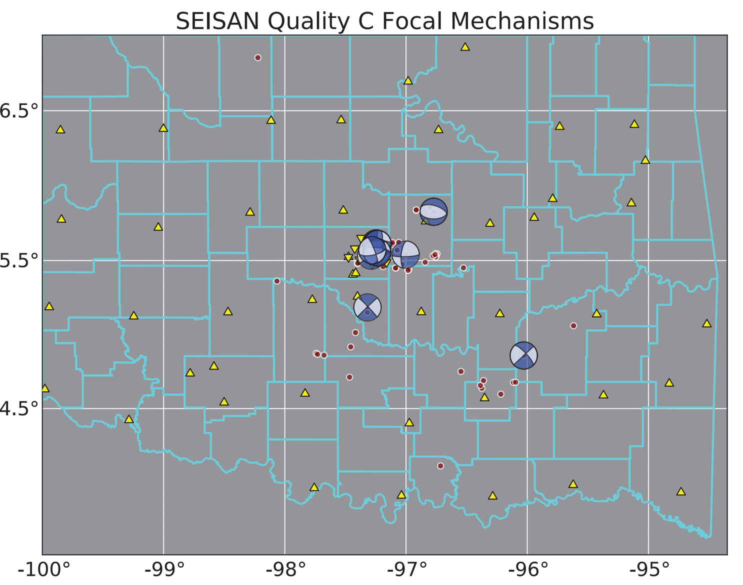
The different time periods for the catalogs were assessed determining b-values following the equation above (Gutenberg & Richter, 1944), with no declustering on the catalogs. a) Earthquake occurrence rate and b-value determinations for USGS PDE catalog from 1973-2009 and 2010-2011-3-31, b) Earthquake occurrence rate and b-value determinations for the OGS catalog from 1977-2007 and from 2010-2011-3-31, c) Earthquake occurrence rate and b-value determinations for 2010-2011-3-31 for earthquakes within Oklahoma County and for the remainder of Oklahoma, d) Comparison of b-value relationships and the predicted maximum magnitude earthquake for a 500 year return period.

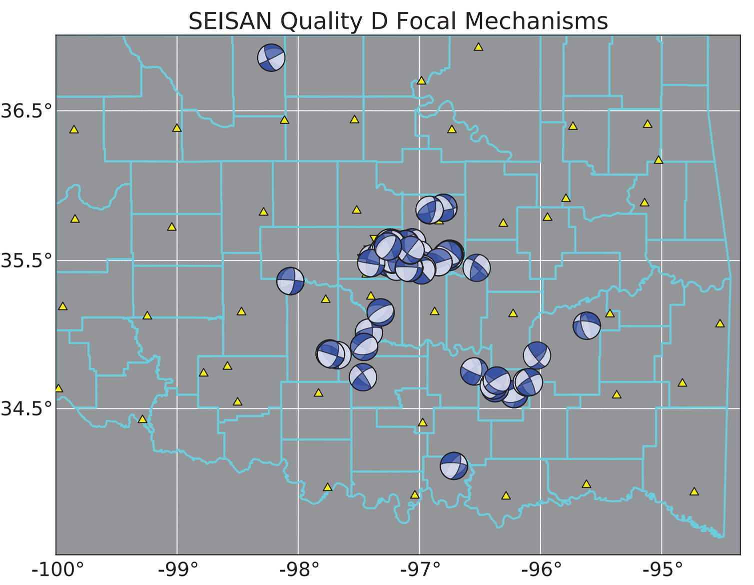
Regional Stress Field

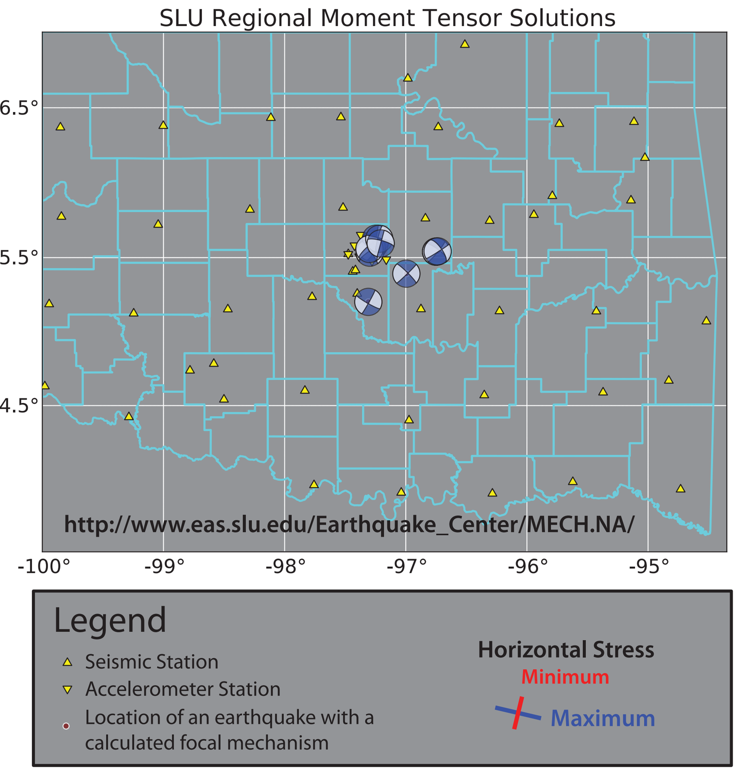
First motion focal mechanisms were calculated using HASH and assigned qualities from Hardebeck & Shearer (2002). Regional moment tensor (RMT) solutions from the Saint Louis University (SLU) catalog are shown as a comparison, and the first motion focal mechanisms are in good agreement with the RMT solutions.

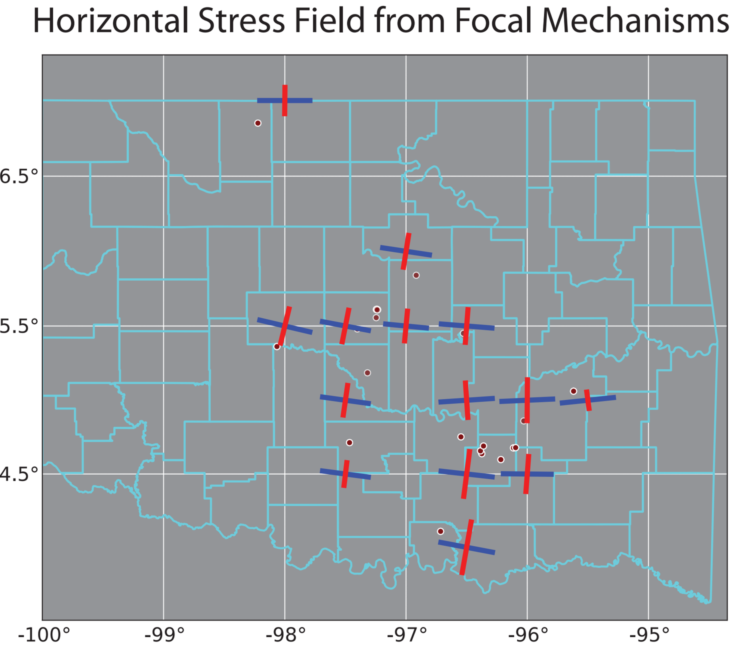






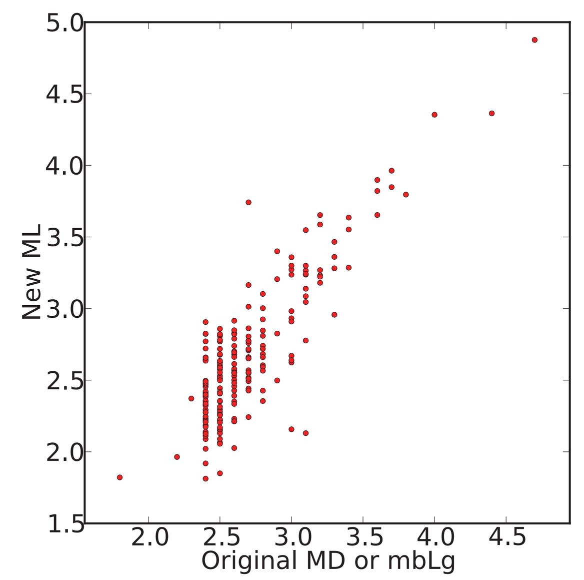




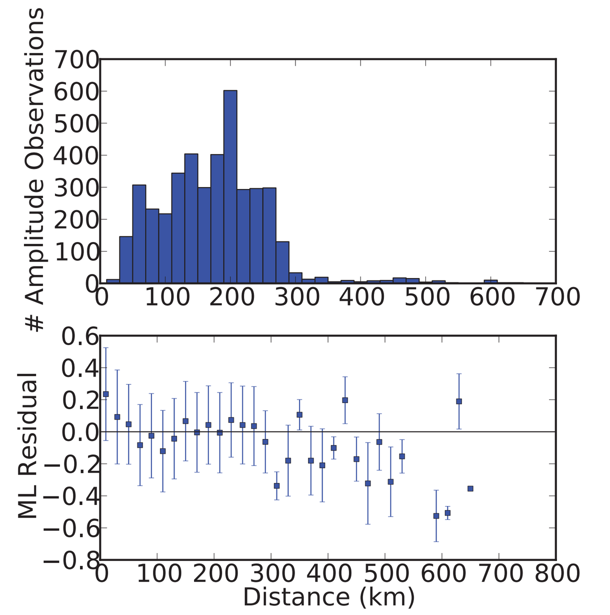


Red circles with a white border indicate the location of an earthquake which had a calculated focal mechanism of any quality, yellow triangles indicate seismic stations, inverted yellow triangles indicate accelerometers, county lines are shown in cyan.

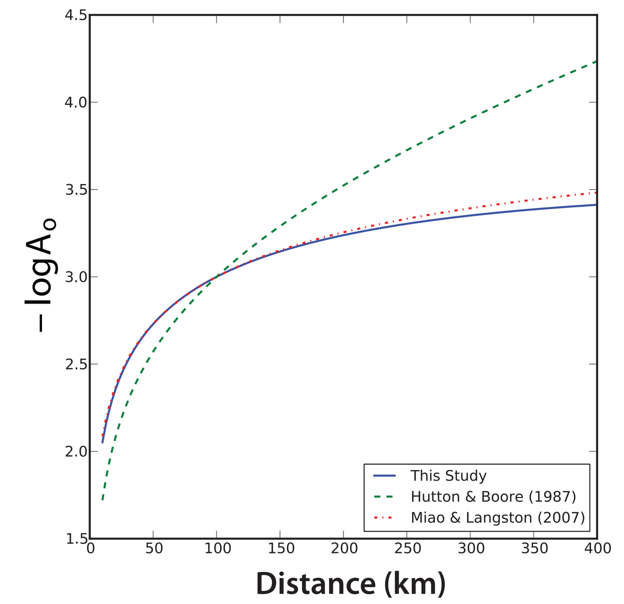
The regional stress field was calculated using SATSI (Hardebeck & Michael, 2006) for generating a spatially damped stress field. The data was gridded to 0.5 degrees. In order to calculate the regional stress field all quality A focal mechanisms were added to the input data. Then for each subsequent quality the data were only added if there were not any higher quality data contained within the grid cell. We selected a moderate damping value, which allows for variation between cell neighbors, but still provides a fairly smooth grid. 69 first motion focal mechanisms were used to model the regional stress field.



New calculated ML compared to reference. The scatter is about a line of 45 degrees indicating that for the most part the relationship is consistent with reference magnitudes.



Nearly all amplitude observations are within 300 km distance from a hypocenter, with a systematic overestimation of ML at stations with distances less than about 25 or 30 km.



Our attenuation model for local magnitude is nearly identical to the one determined for the New Madrid region of the Central US (Miao and Langston, 2007). The attenuation relationship also demonstrates that the distance attenuation in Oklahoma is much less than that for Southern California (Hutton & Boore, 1987).

Determining a Local-Magnitude Scale and Distance Attenuation

We determined a local-magnitude scale ML originally defined by Richter (1935). We closely follow the methodology of Miao and Langston (2007) except we do not invert for station residuals. This choice causes our ML relationship to have more uncertainty than it would if we included station residuals into the least squares solution for attenuation parameters. It was also recognized by Uhrhammer & Collins that the actual gain for a Wood-Anderson torsion seismometer was 2080 instead of the theoretical 2800. For this study the value of 2800 was used to allow a simpler comparison to other studies, which used the theoretical gain. We selected the maximum magnitude for any earthquake and assigned that to the reference magnitude, from which we created our ML relationship. We calculated the ML relationship iteratively by determining the parameters for our attenuation relationship and then removing all stations that had a mean residual greater than 0.3, and stations with less than 10 observations. This left us with 4,114 amplitude observations, which were again inverted for the attenuation coefficients.

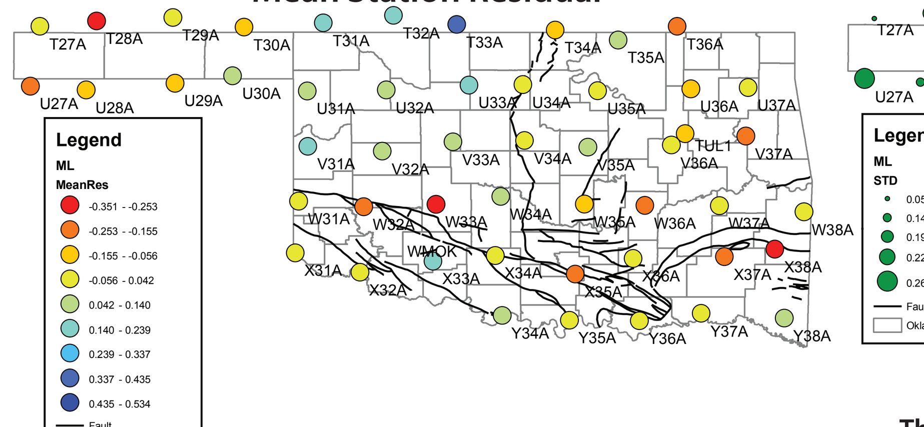
$$M_L = \log A - \log A_o$$

Distance Attenuation Relationship

$$-\log A_o = n\log(r/100) + K(r - 100) + 3.0$$

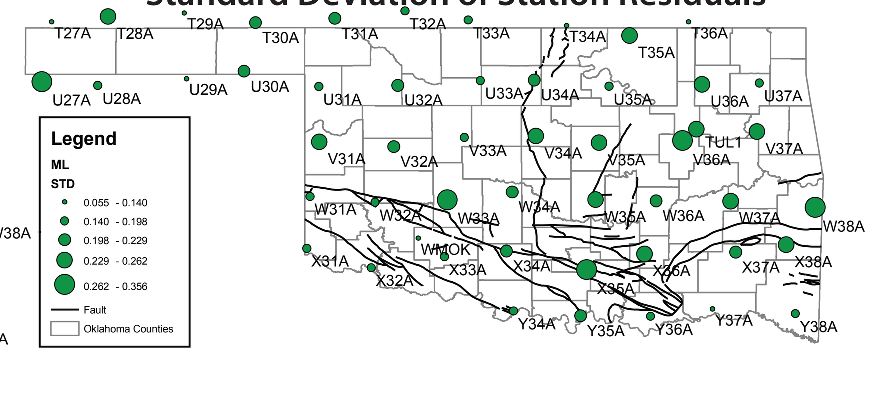
$$-\log A_o = 1.006 \pm 0.162\log(r/100) - 0.000644 \pm 0.000479(r - 100) + 3.0$$

Mean Station Residual



Station residuals are the calculated ML at a station minus the calculated ML for the earthquake. Stations with positive mean residuals, cooler colors, show either less attenuation than the calculated attenuation relationship or site amplification effects. Stations with negative mean residuals have higher attenuation or site de-amplification effects. The station residuals show low attenuation in northwestern Oklahoma and high attenuation in northeastern Oklahoma and along major geologic province boundaries in southern Oklahoma.

Standard Deviation of Station Residuals



The standard deviation of stations residuals is primarily a function of the number of observations. Stations with the greatest number of observations tend to have the largest standard deviations.

Conclusions

- There is a clear change in the number of earthquakes occurring since about the beginning of 2010.
- Adding the TA stations into the real-time and routine earthquake processing may not have improved the detection threshold for earthquakes in Oklahoma it certainly improved hypocenter location accuracies.
- The additional stations also allowed us to generate many first-motion focal mechanisms, from which we were able to model the regional stress field.
- The additional TA stations allow for better resolution of the attenuation and velocity characteristics within the region.
- The TA provided an incredible resource for high quality seismic instrumentation with greater density than is possible with a regional network.

Questions and Further Work

- What is causing the marked increase in observed seismicity in Oklahoma, and how long will the transient last?
- What are the implications of the rate observed rate increase to earthquake hazards and our understanding of seismicity in the stable continent?
- How will declustering the catalogs affect the observed rate change?
- Calculate moment tensors for smaller magnitude earthquakes not in the SLU RMT catalog.
- Examine the influence of using MD in the calculation of ML.
- Examine what the relationship between MD and mbLg may be for the OGS catalog.
- Use mbLg and ML amplitude measurements to generate a 3D model for Q in Oklahoma.
- Generate a 3D velocity model for use in routine earthquake locations in Oklahoma.

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