Spatial Analysis of Selected Earthquake Clusters Recorded by a Dense Network of Seismic Stations Around Stillwater, Oklahoma*

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Search and Discovery Article #51222 (2016)**
Posted February 22, 2016

*Adapted from oral presentation given at AAPG Mid-Continent Section meeting in Tulsa, Oklahoma, October 4-6, 2015

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Abstract

If the recent increase in seismicity in north-central Oklahoma is a result of the disposal of produced fluids into Underground Injection Control (UIC) Class II wells, earthquake distributions should directly demonstrate a spatial correlation. Oklahoma State University has deployed a dense network of broadband seismic stations in the immediate area of Stillwater, Oklahoma. We are using data from these stations along with data from OGS and USGS stations to locate micro-earthquakes that are generally below the threshold of detection for the regional seismic networks. Statistical spatial analysis of (micro-) earthquake locations with respect to UIC Class II injection wells will demonstrate the presence or the absence of a relationship. If the earthquakes are induced by UIC Class II injections, and depending on the availability of injection-well start-of-operation dates, volumes, and well-head pressures, it may be possible to track the spatio-temporal progression of a seismogenic pore-fluid pressure front from an injection well to preferentially-oriented faults along which greater-magnitude earthquakes occur or are likely to occur. Absent sufficiently current data on UIC Class II wells, the spatio-temporal evolution of clusters and linear trends will still provide the foundation for future analysis when the pertinent injection data become available. Whether the increase in seismicity in Oklahoma is natural or anthropogenic is potentially a serious public-safety issue.

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AAPG Mid-Continent Section Meeting

Tulsa, Oklahoma

October 6, 2015

Acknowledgements

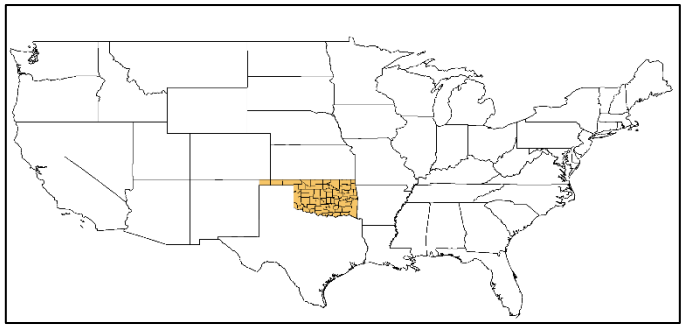
- Throughout this presentation, when I speak of the OKSTU seismic network, I refer to data from Oklahoma State University's instruments augmented by data from the Oklahoma Geological Survey (OGS) and from the United States Geological Survey (USGS), downloaded from Incorporated Research Institutions for Seismology (IRIS).

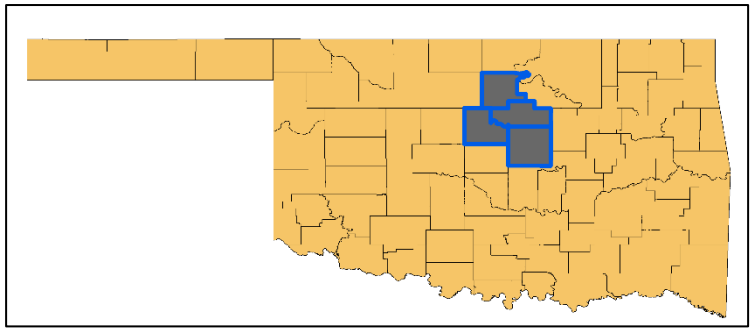
Outline

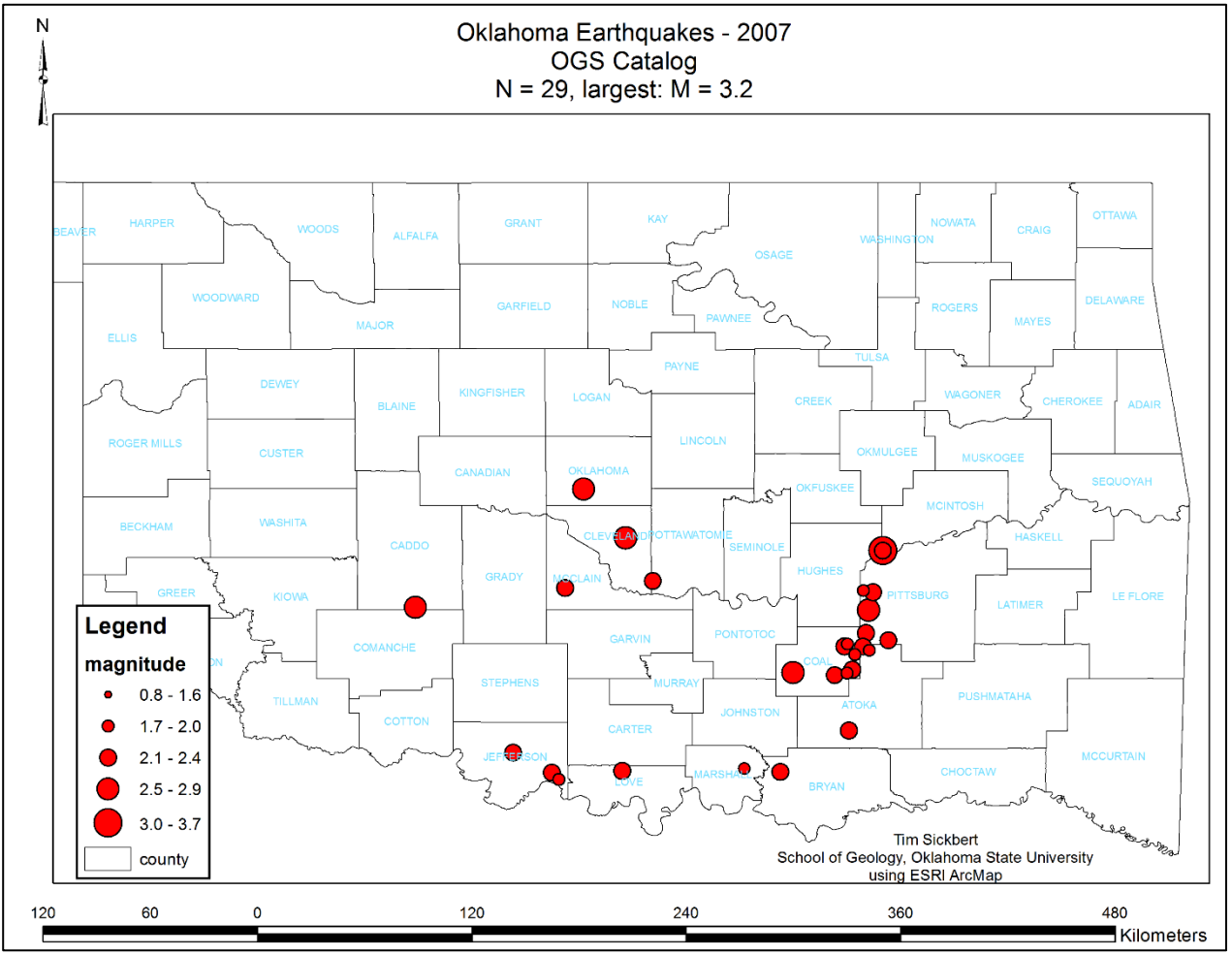
- Motivation
- Study area & other seismic networks
- Methods
- Status

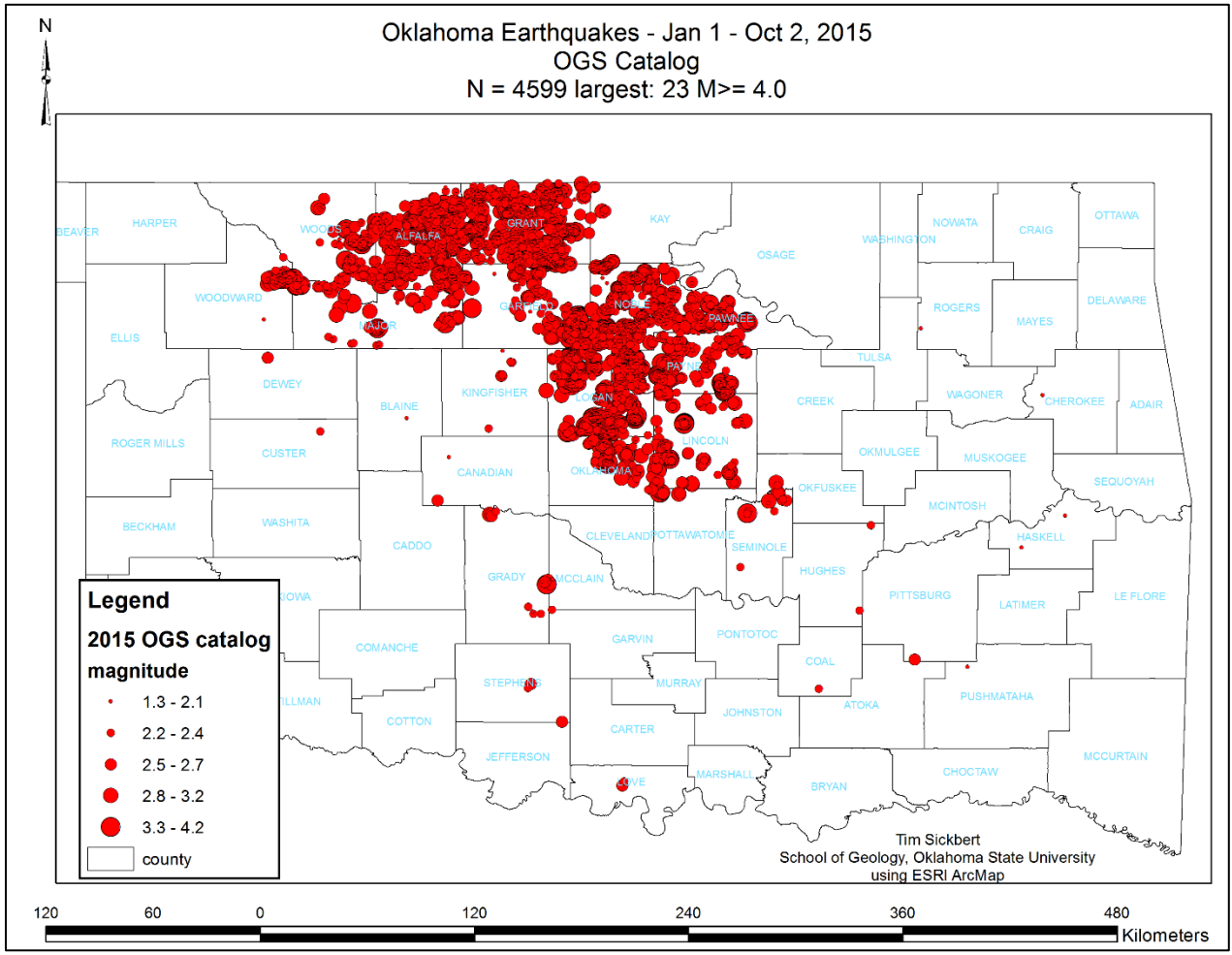
- Oklahoma UIC Class II injection well 2014 report
- Questions

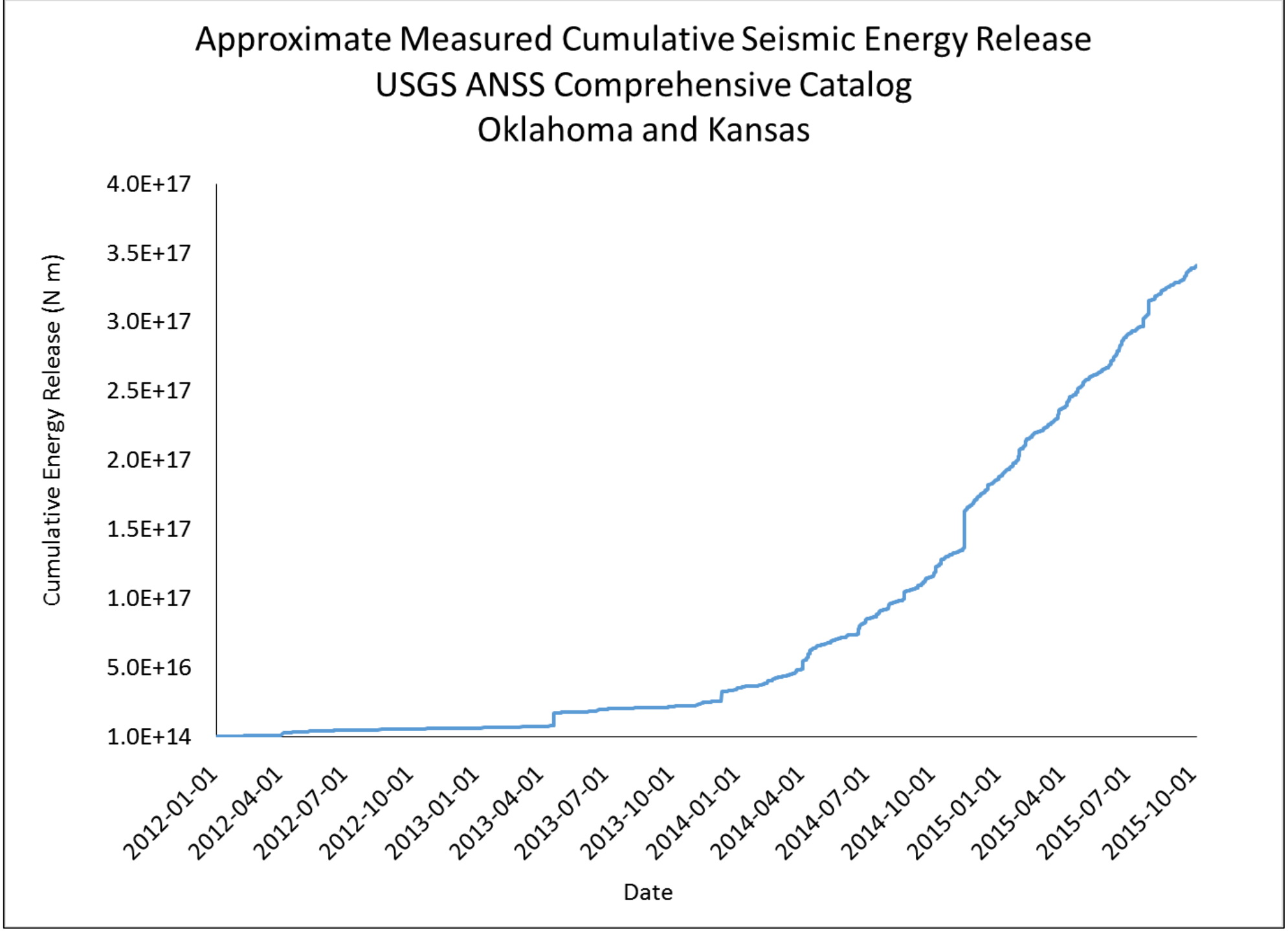
Motivation






N
Oklahoma Earthquakes - 2007
OGS Catalog
N = 29, largest: M = 3.2
Legend
magnitude
0.8 - 1.6
1.7 - 2.0
2.1 - 2.4
2.5 - 2.9
3.0 - 3.7
county
Tim Sickbert
School of Geology, Oklahoma State University
using ESRI ArcMap
120 60 0 120 240 360 480
Kilometers


N
Oklahoma Earthquakes - Jan 1 - Oct 2, 2015
OGS Catalog
N = 4599 largest: 23 M>= 4.0
Legend
2015 OGS catalog
magnitude
1.3 - 2.1
2.2 - 2.4
2.5 - 2.7
2.8 - 3.2
3.3 - 4.2
county
Tim Sickbert
School of Geology, Oklahoma State University
using ESRI ArcMap
120 60 0 120 240 360 480
Kilometers


Approximate Measured Cumulative Seismic Energy Release
USGS ANSS Comprehensive Catalog
Oklahoma and Kansas
Cumulative Energy Release (N m)
4.0E+17
3.5E+17
3.0E+17
2.5E+17
2.0E+17
1.5E+17
1.0E+17
5.0E+16
1.0E+14
2012-01-01
2012-04-01
2012-07-01
2012-10-01
2013-01-01
2013-04-01
2013-07-01
2013-10-01
2014-01-01
2014-04-01
2014-07-01
2014-10-01
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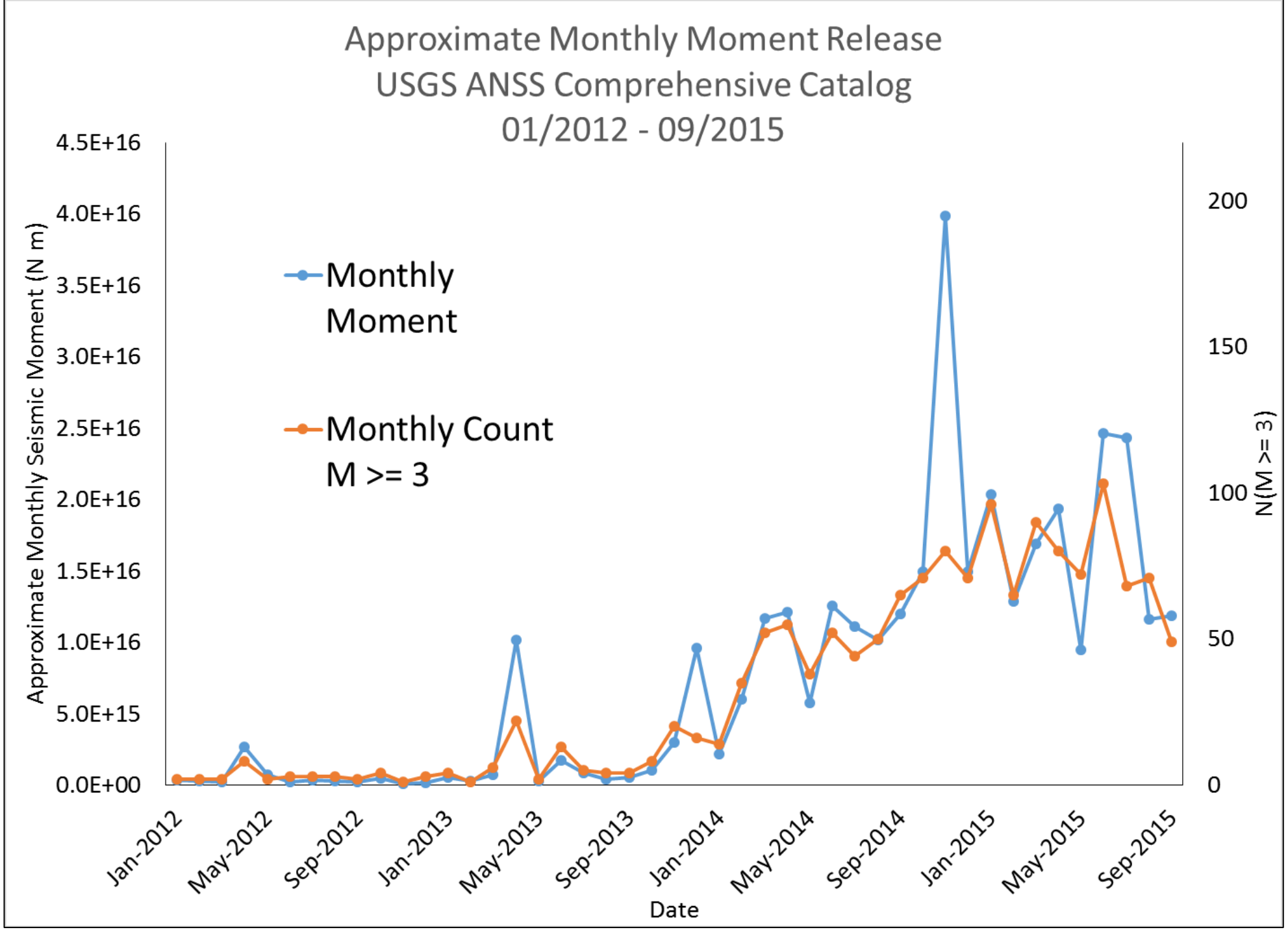
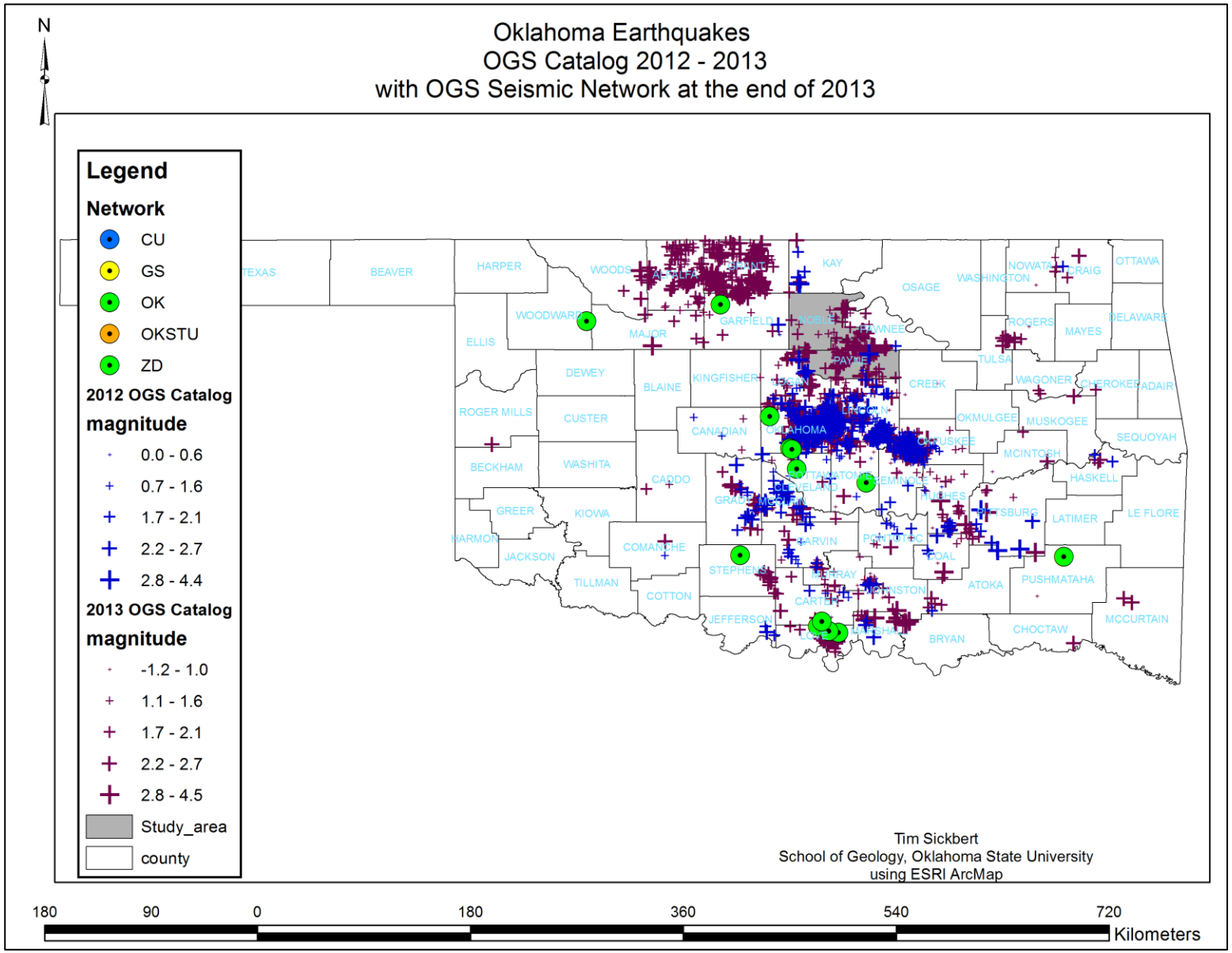
2015-04-01
2015-07-01
2015-10-01
Date


Approximate Monthly Moment Release
USGS ANSS Comprehensive Catalog
01/2012 - 09/2015
Approximate Monthly Seismic Moment (N m)
4.5E+16
4.0E+16
3.5E+16
3.0E+16
2.5E+16
2.0E+16
1.5E+16
1.0E+16
5.0E+15
0.0E+00
N(M >= 3)
200
150
100
50
0
Monthly Moment
Monthly Count M >= 3
Jan-2012
May-2012
Sep-2012
Jan-2013
May-2013
Sep-2013
Jan-2014
May-2014
Sep-2014
Jan-2015
May-2015
Sep-2015
Date

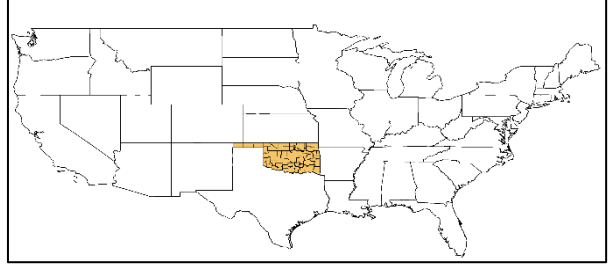
Motivation

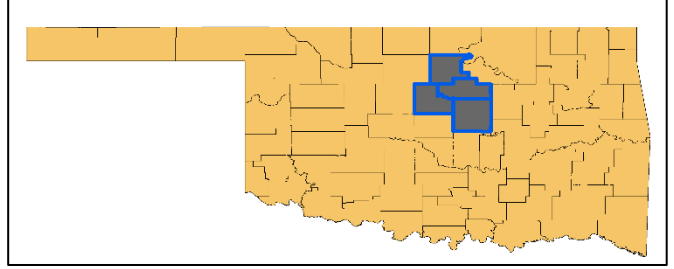
- Seismicity increased dramatically from 2012 (blue) to 2013 (maroon) in and around Payne County.
- Instrumental coverage was sparse.
- Evaluating possible cause(s), estimating the hazard, and pure opportunism to research seismology and tectonics motivated us to set up a seismological observatory.

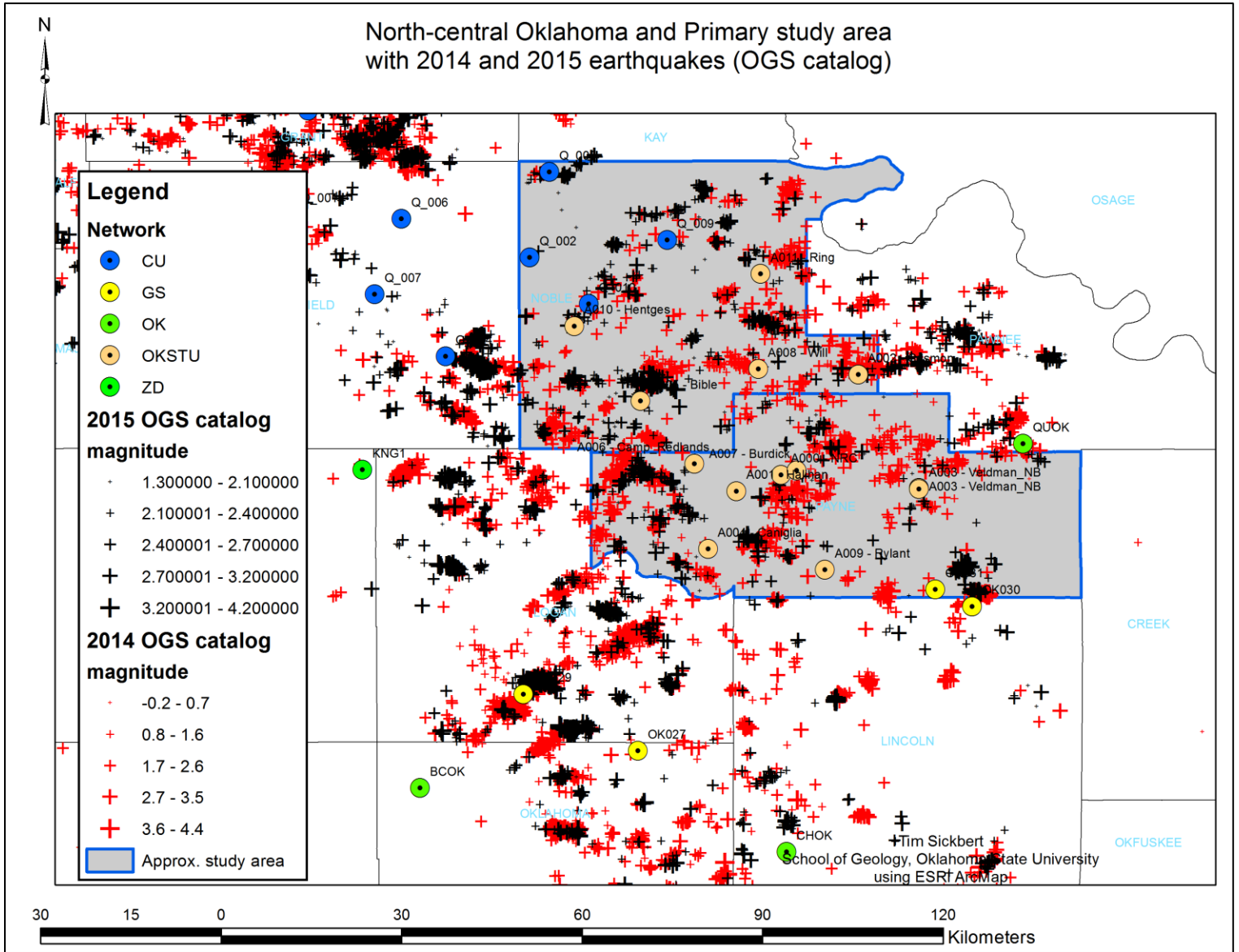


Motivation

- Since we started in early 2014
  - The rate of earthquakes has increased dramatically.
  - We have deployed the OKSTU network in and to the north-northwest of Payne County
  - OGS & USGS deployed additional instruments.
  - Dr. Katie Keranen and Catherine Lambert of Cornell have deployed a network in Noble, Garfield, and Grant counties (provisionally labeled here as CU).

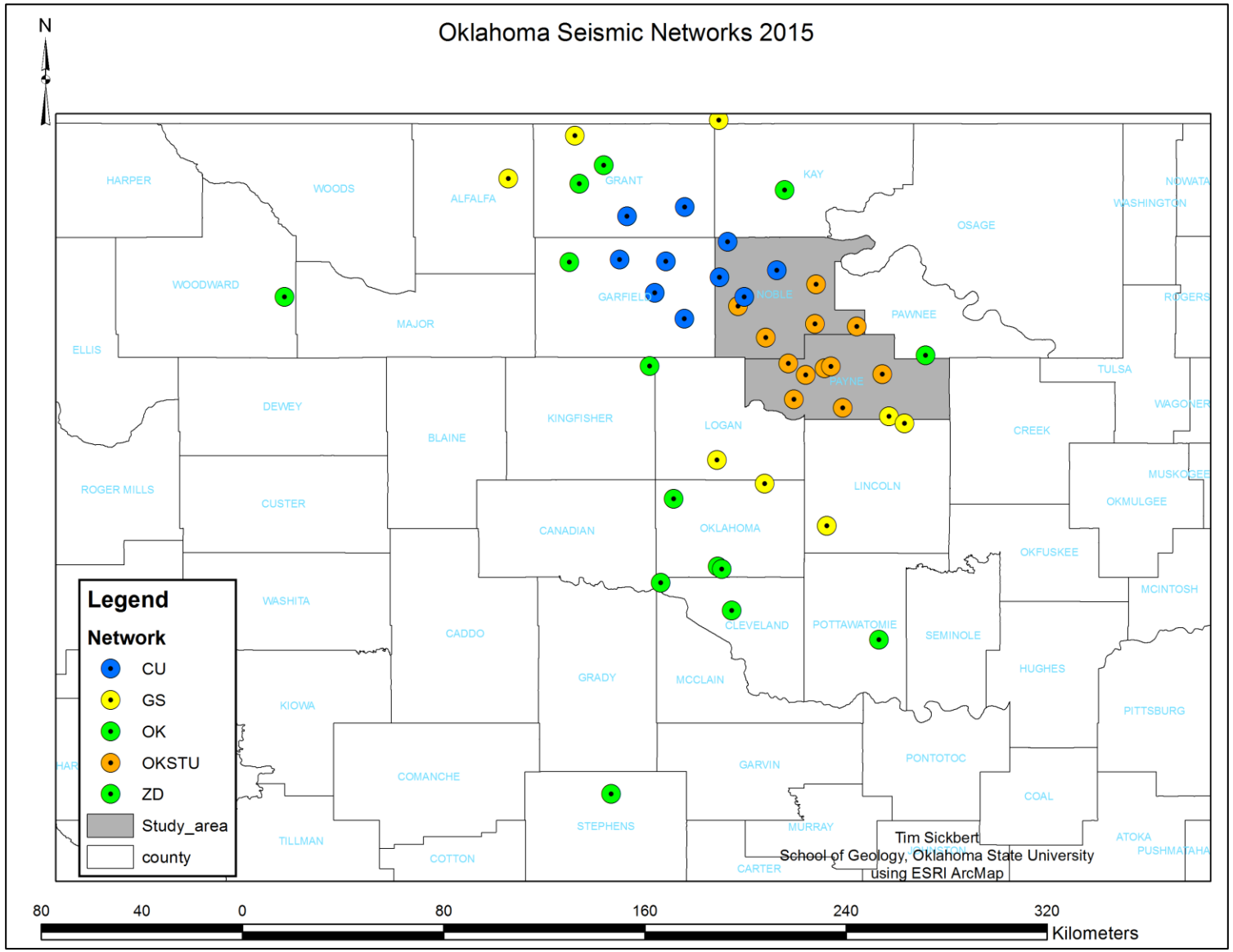






Study area & other seismic networks

- Over the period of about sixteen months, the density of seismic networks as increased dramatically.
- Coverage now allows detection and analysis of smaller events, and better location of all events.
- OKSTU data are currently not distributed. We intend to release it as soon as practical.
- I believe that the CU data is currently not distributed.
- Rumor that post-doc with Dr. Cochran of USGS will be researching southwest of Stillwater.

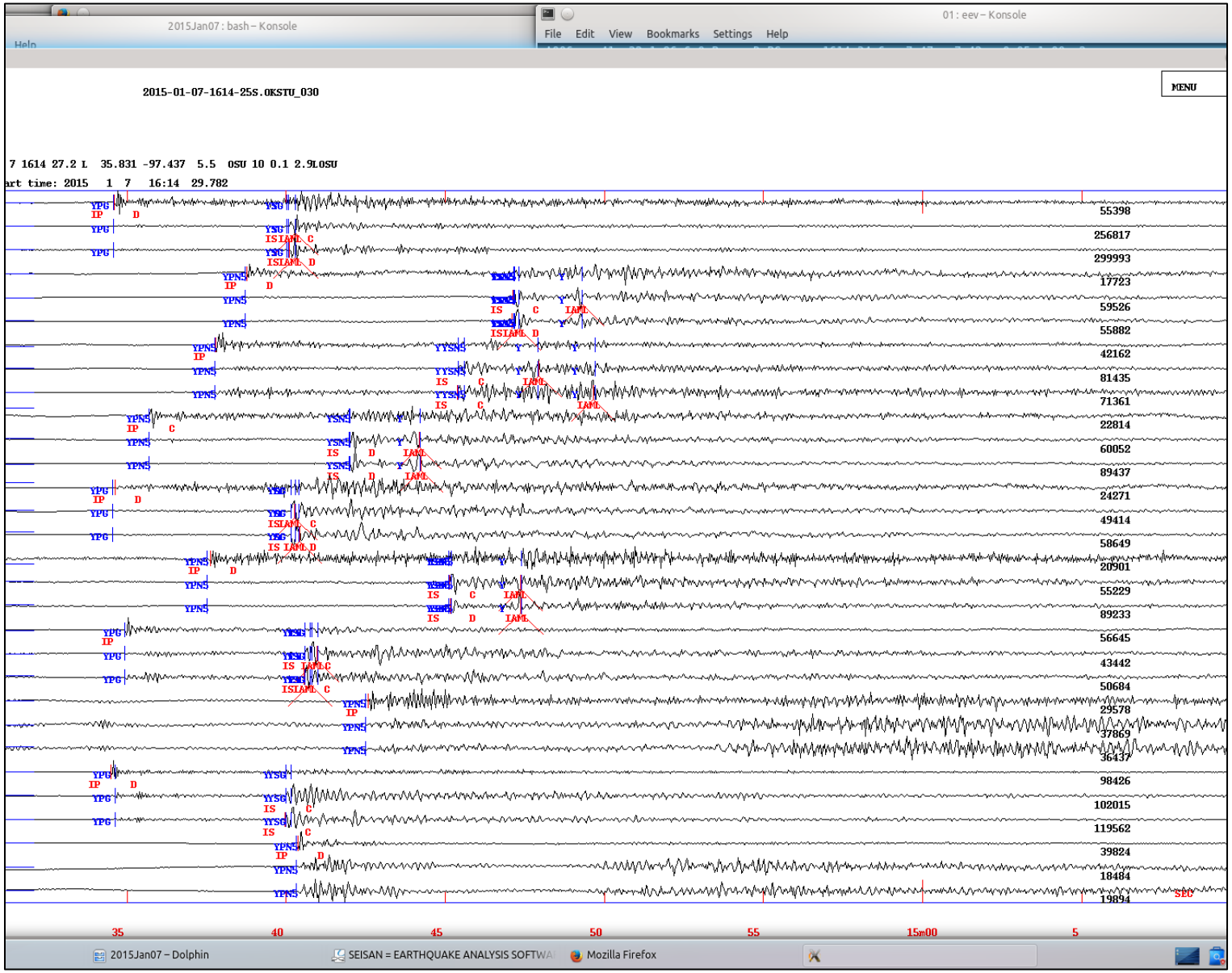


Methods
Data Collection

- Deploy and maintain a network (OKSTU) of broadband 3-component seismographs.
  - 9 Güralp CGM-6TDs in the field (30-s to 100 Hz).
  - one out for repair.
- Periodically visit each instrument and retrieve data.
- Complement the OKSTU network with OGS and USGS data available through IRIS.

Methods - Initial Processing

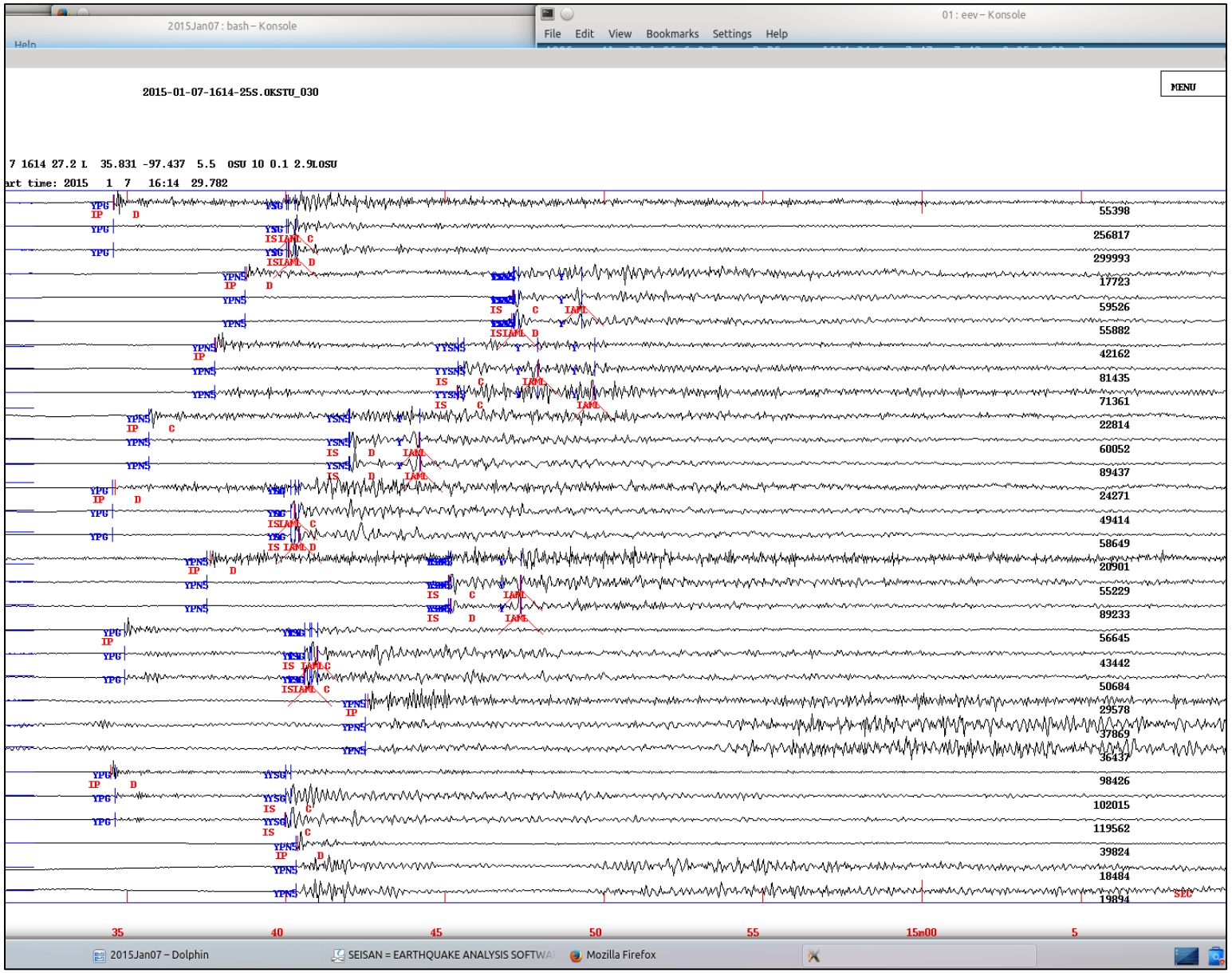
- Using SEISAN, iteratively apply classic methods of
  - location,
  - relocation, testing HYPODD, JHD, etc.,
  - refining crustal velocity model, VELEST, etc.,
  - determining focal-plane solutions using polarity,
  - estimating magnitudes,
  - determining station corrections,
  - catalog analyses for distribution of focal-plane attitudes,
  - etc.
- Currently, manual processing; later automated.



Status – Stations & Data

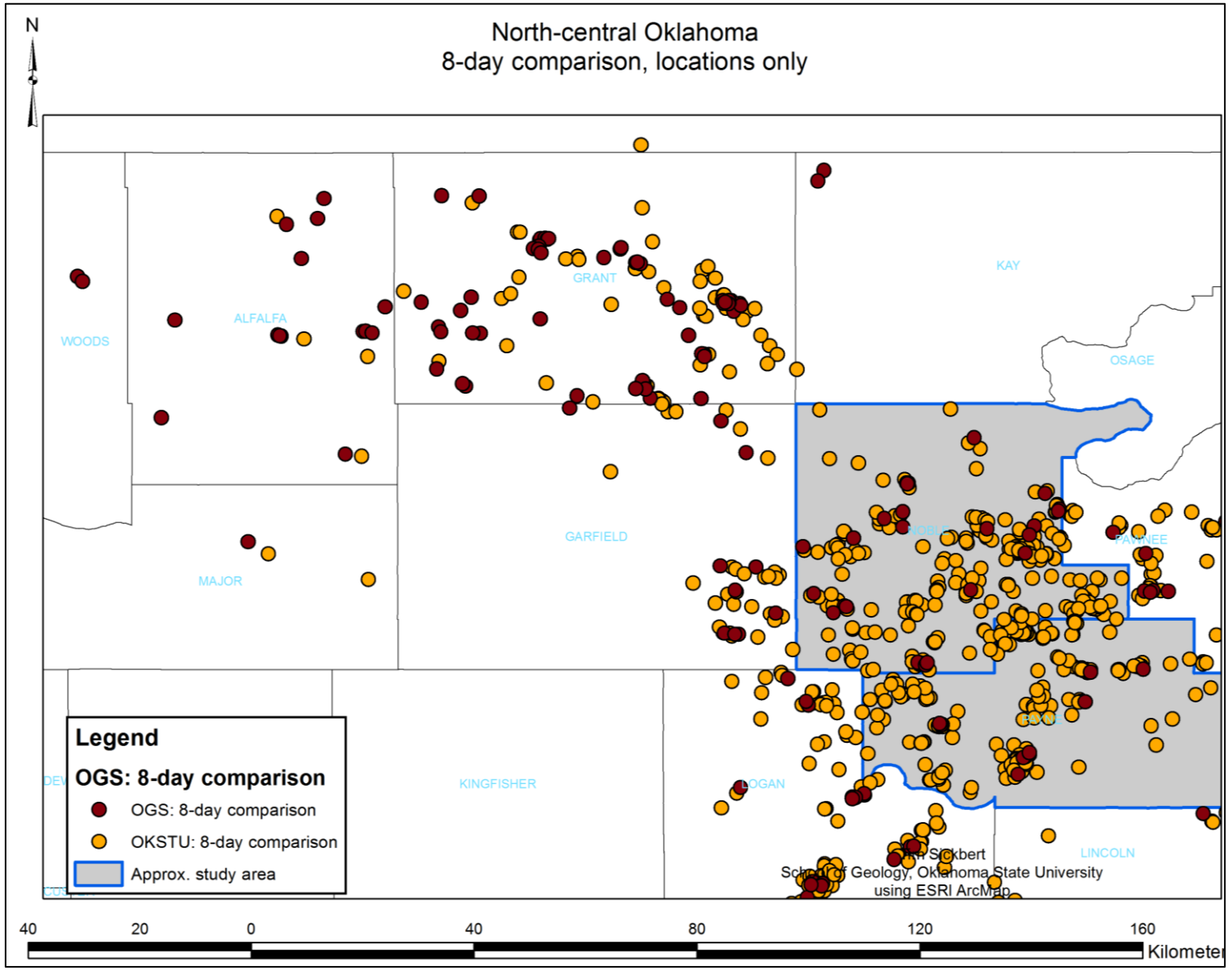
- Stations usually functional.
  - Occasional trouble with vegetation and wildlife.
  - Shifting ground has required re-seating a couple of instruments.
- Issues with
  - data continuity/completeness (dropouts).
  - data integrity (misalignment).

  The errors occur in translation programs, and are not fundamental to the data itself.



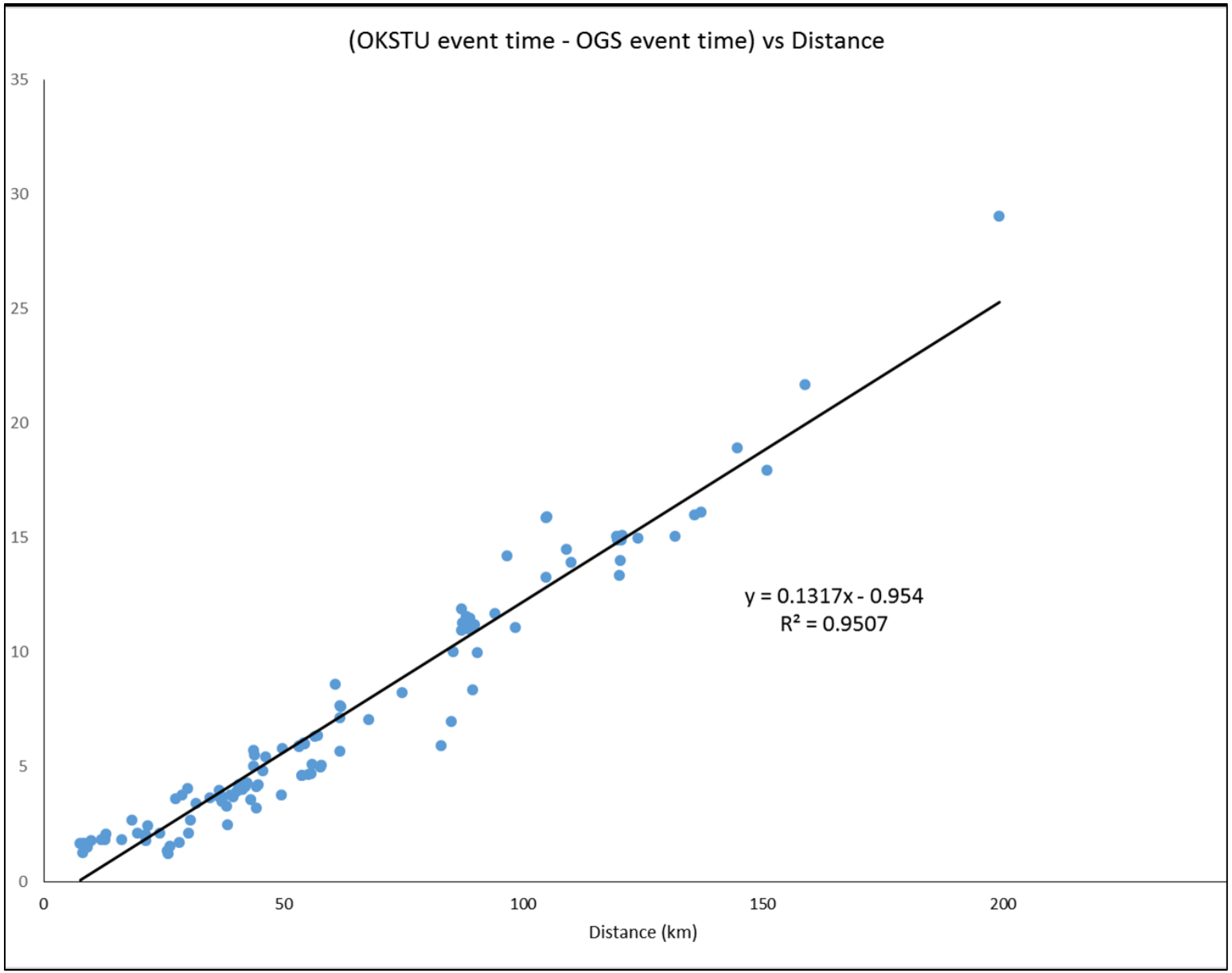
Status – Network sensitivity

- Compared 8 effectively random days from 2014 (09/24, 09/29, 10/01, 11/07, 11/13, 11/14, 12/05, & 12/06).
- OGS network located 185 events.
- OKSTU network located 795 events.
- Of these, 124 events were located by both networks.
- Differences in location between the two networks likely due to OKSTU using default IASP91 velocity model.



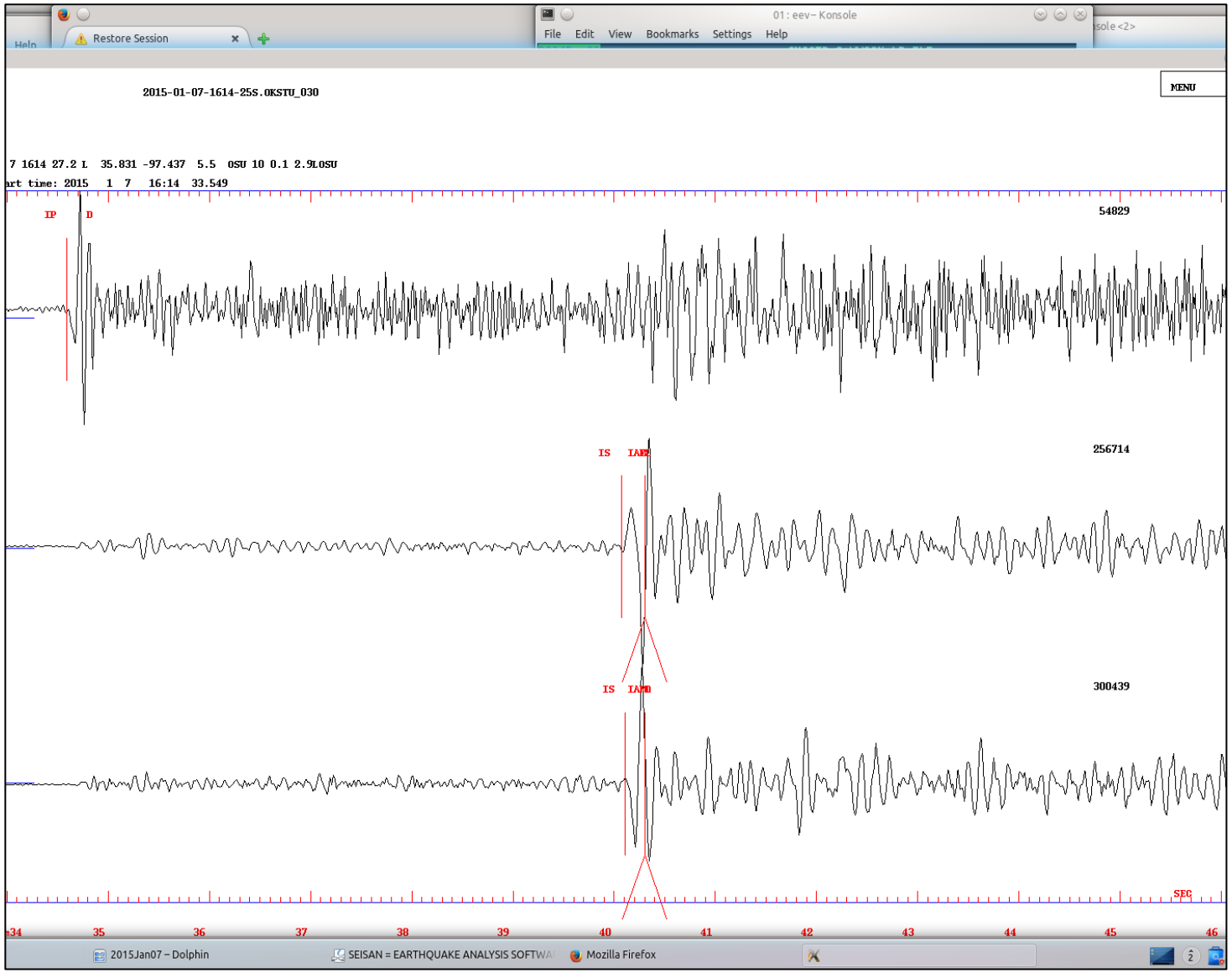
Status – Location accuracy & Event-time errors

- Event time estimated by OKSTU minus the event time in the OGS catalog.
  - All differences are positive.
  - Differences increase with distance.
  - The event time estimated by OKSTU is systematically later than the event time estimated by OGS.
  - Indicates a crustal model with velocities too low.
- This will be resolved (VELEST, etc.).



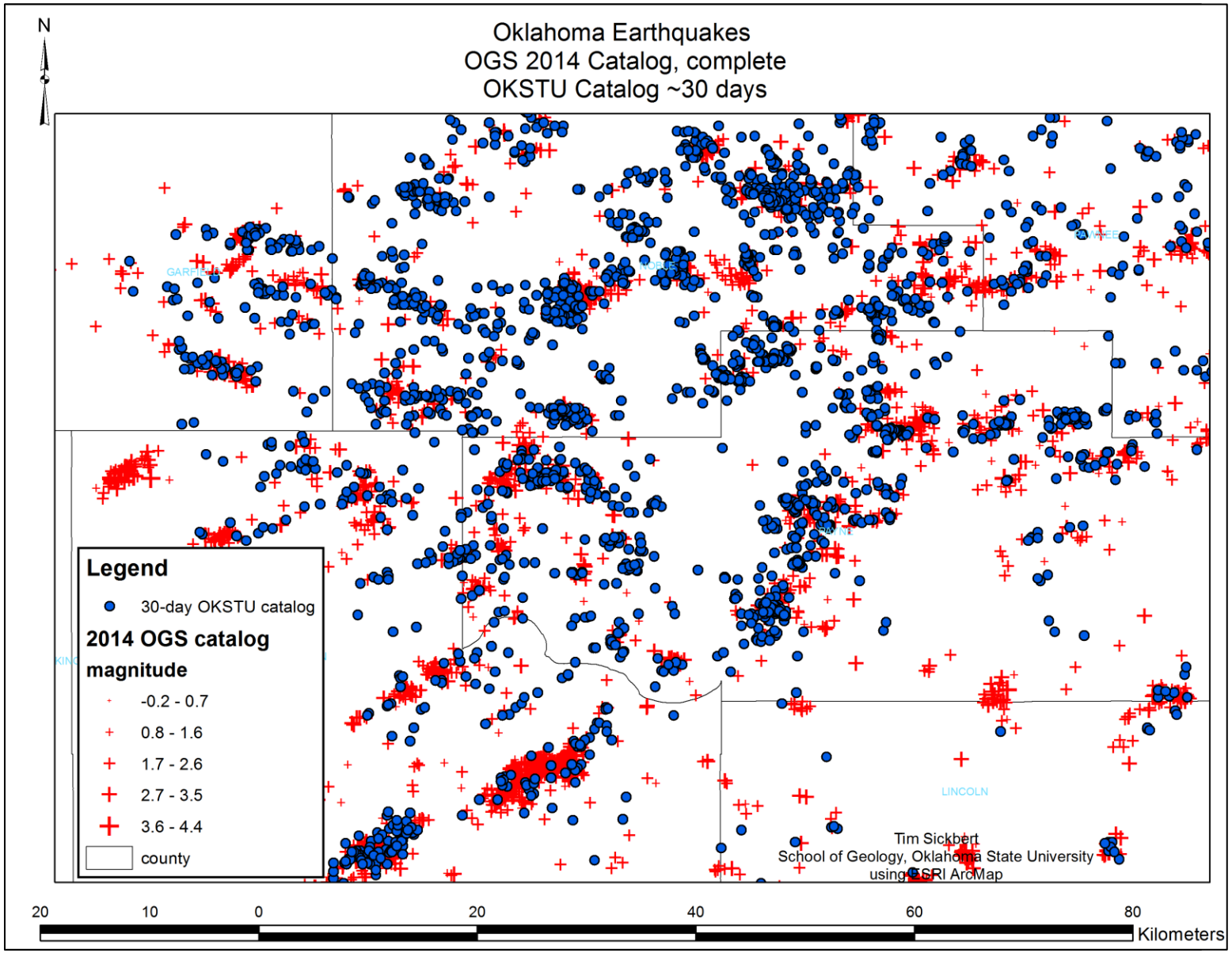
Status – Amplitude accuracy, magnitude estimation

- Currently have only a statistically non-significant number of events to compare, but:
  - average difference between OKSTU estimate and OGS catalog magnitude for 11 events is -0.1 mL.
  - future work will include determining station corrections to mitigate site effects.



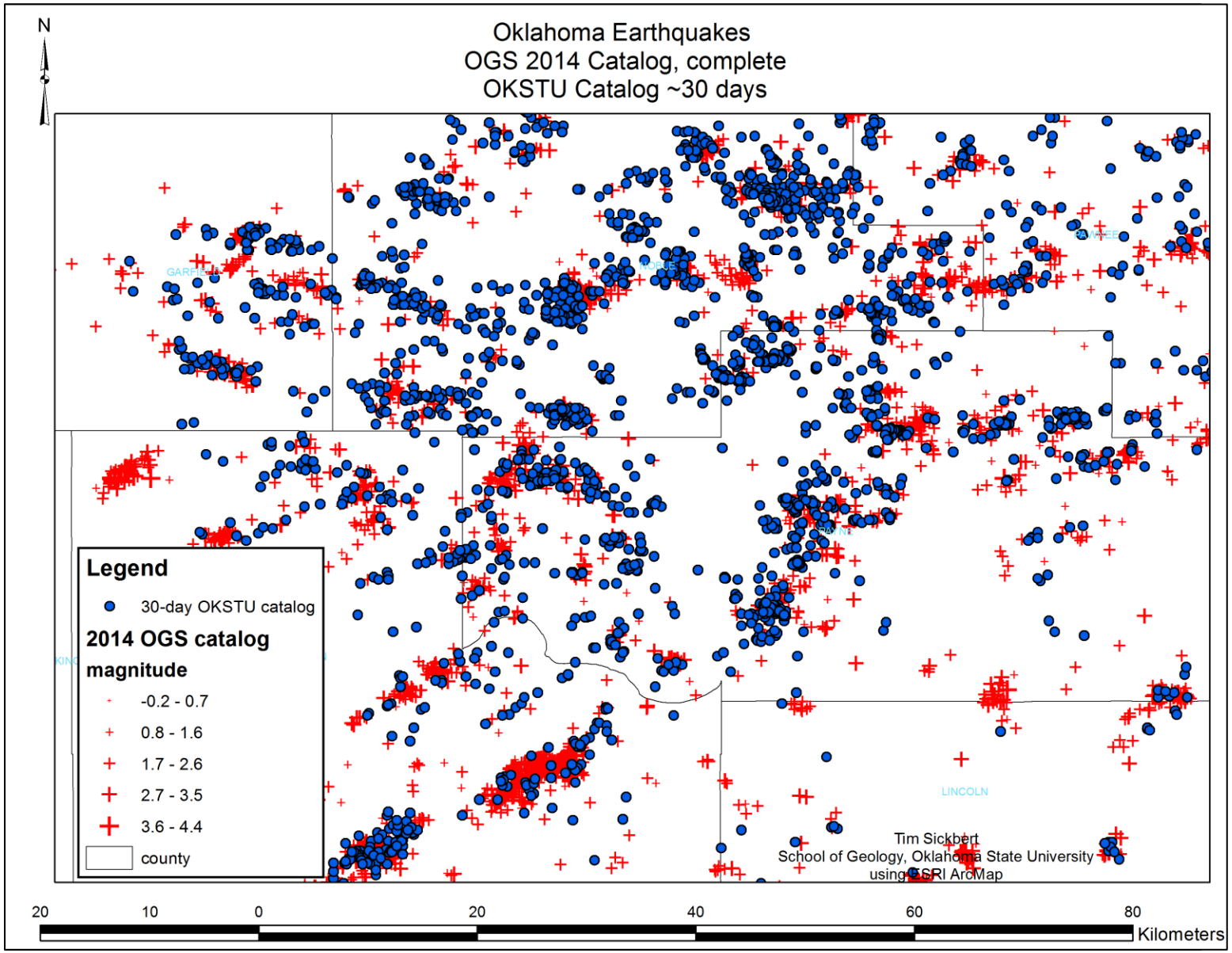
Status – Close to fully operational.

- The catalog created from the OKSTU network will be complete to a significantly lower magnitude within its area of coverage.
- Data from the OKSTU catalog will support the calculation of a higher-resolution velocity model for its area of coverage.
- The more complete catalog and refined velocity model will support high-resolution relocation of all events within the study area.
- These relocations will allow us to identify faults, especially larger faults, that may pose a significant hazard.



Spatial Analysis Contribution from OKSTU

- Provided it verifies after relocation, OKSTU network may illuminate a significant linear feature trending NE from the Langston, OK, area.
- Otherwise, fills in some gaps, supporting linear trends apparent in the maps of the OGS catalog.

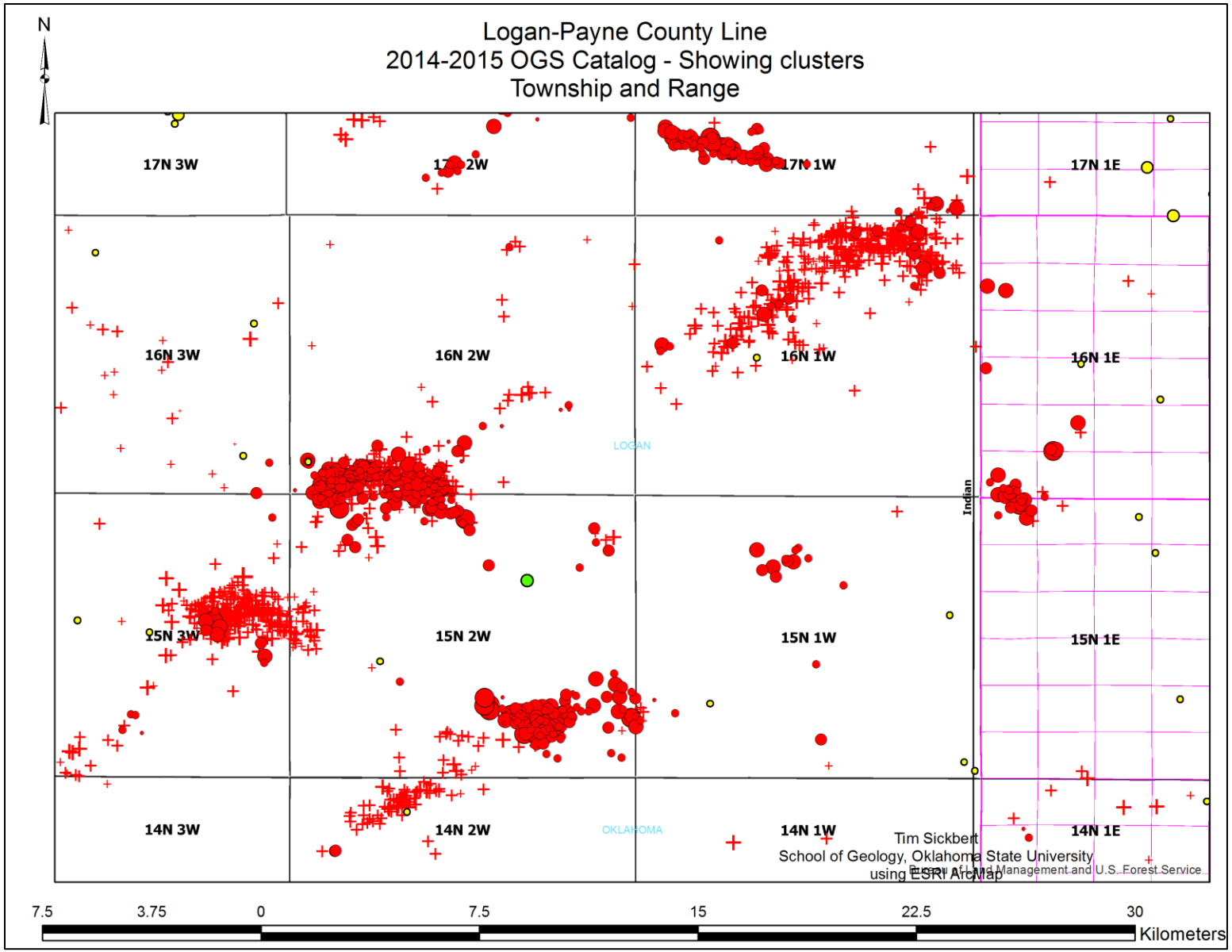


Spatial Analysis – EQ locations relative to UIC Class II

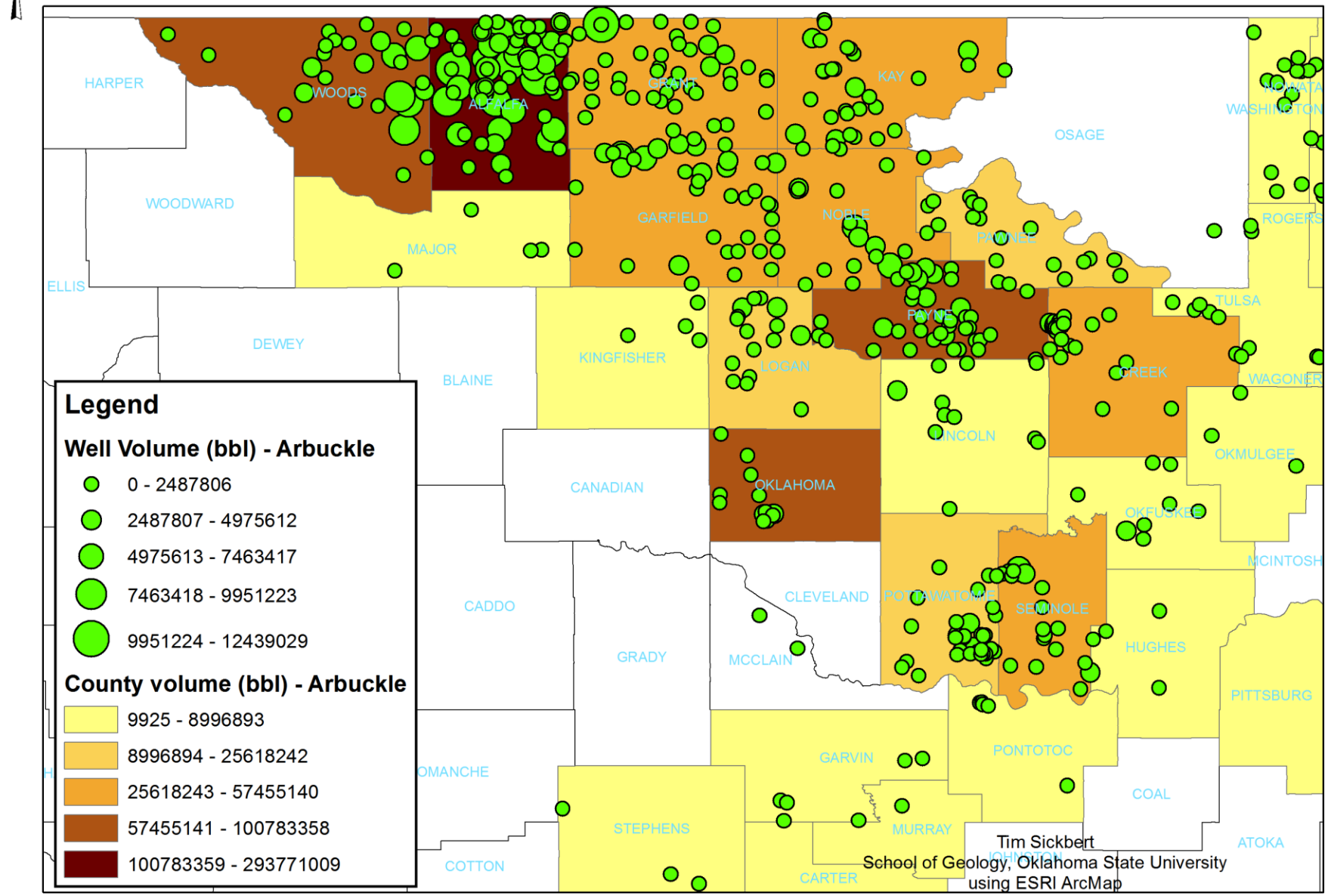
CAVEAT: Not all UIC Class II wells have geographic coordinate system (GCS) locations, but have only public-land survey system (PLSS, a.k.a., Township-and-Range) locations. Any interpretation is incomplete until all wells are reasonably located.

That said, I found no high-volume disposal wells in T15N R1W, T15N R2W, T16N R1W, or T16N R2W in the OCC 2014 UIC Class II report.

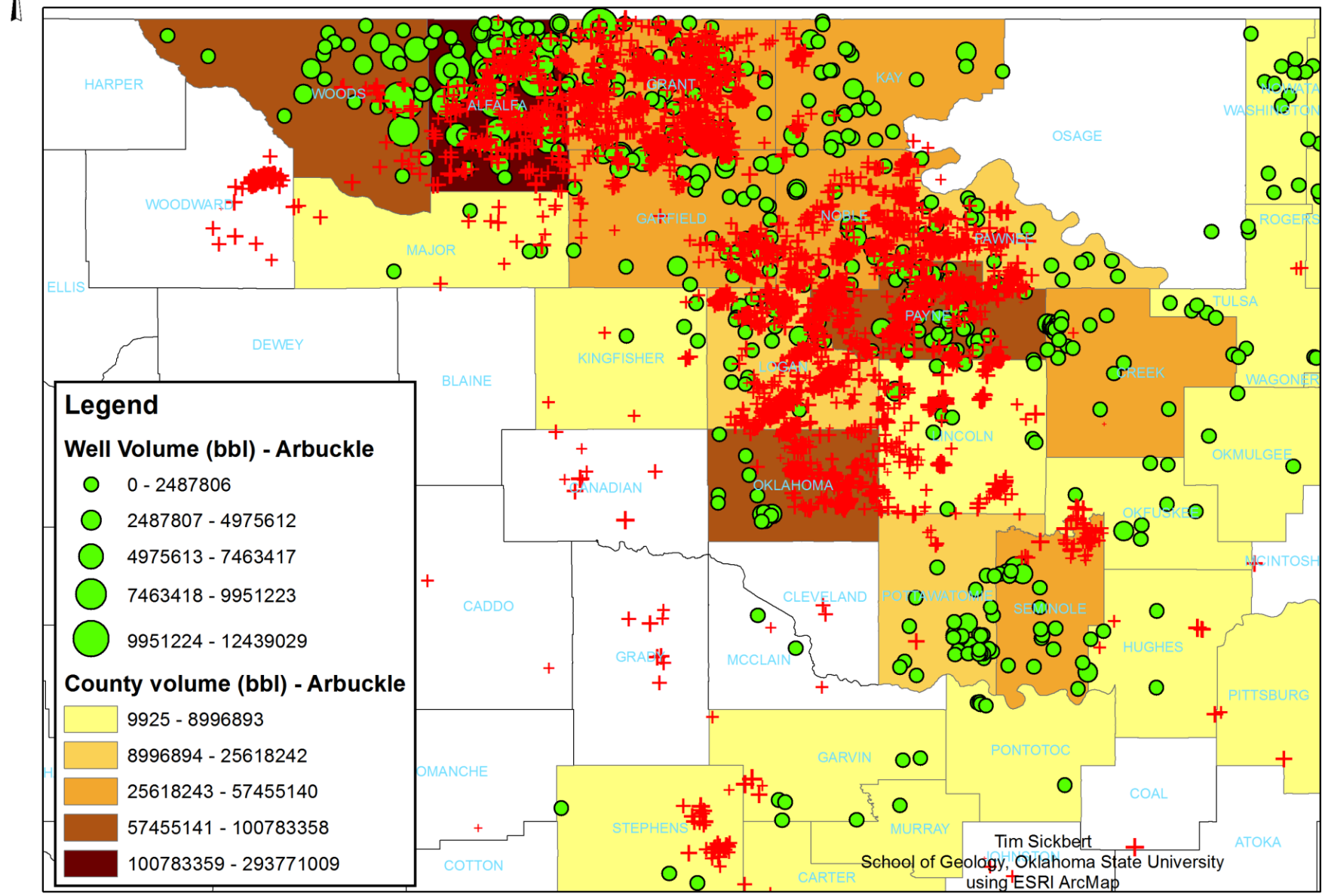
I suspect the report is incomplete. Until we establish that the report is incomplete, we have to consider the possibility of significant seismicity distant from disposal wells.



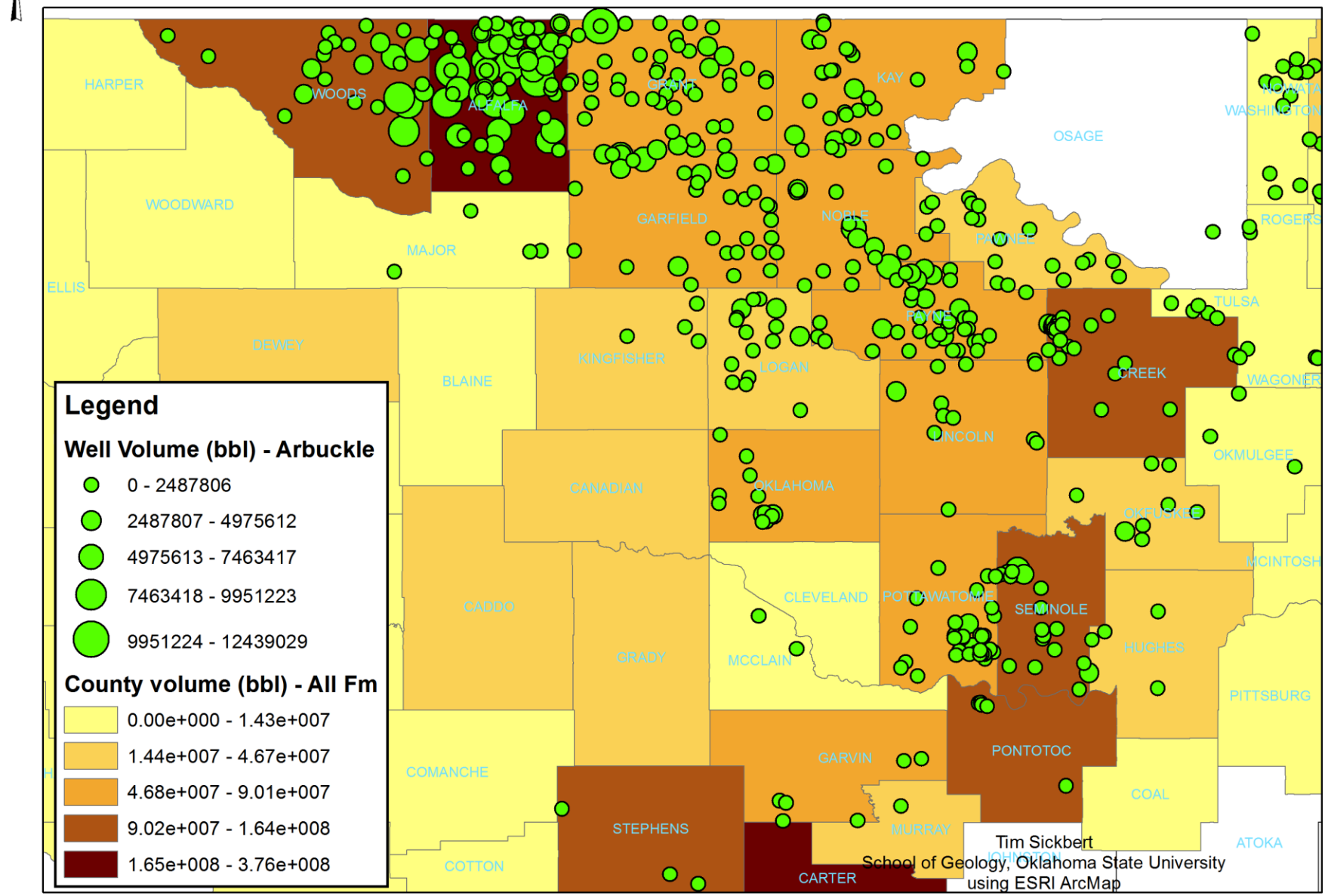
2014 Injection Volumes
Volumes Injected into the Arbuckle Fm.
data from Oklahoma Corporation Commision 1 Oct, Oklahoma Geological Survey 2 Oct 2015



2014 Injection Volumes and Earthquakes
Volumes Injected into the Arbuckle Fm.
data from Oklahoma Corporation Commision 1 Oct, Oklahoma Geological Survey 2 Oct 2015



2014 Injection Volumes
Volumes Injected - Wells: Arbuckle Fm; Counties: All formations
data from Oklahoma Corporation Commision 1 Oct, Oklahoma Geological Survey 2 Oct 2015



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Volumes Injected - Wells: Arbuckle Fm; Counties: All formations
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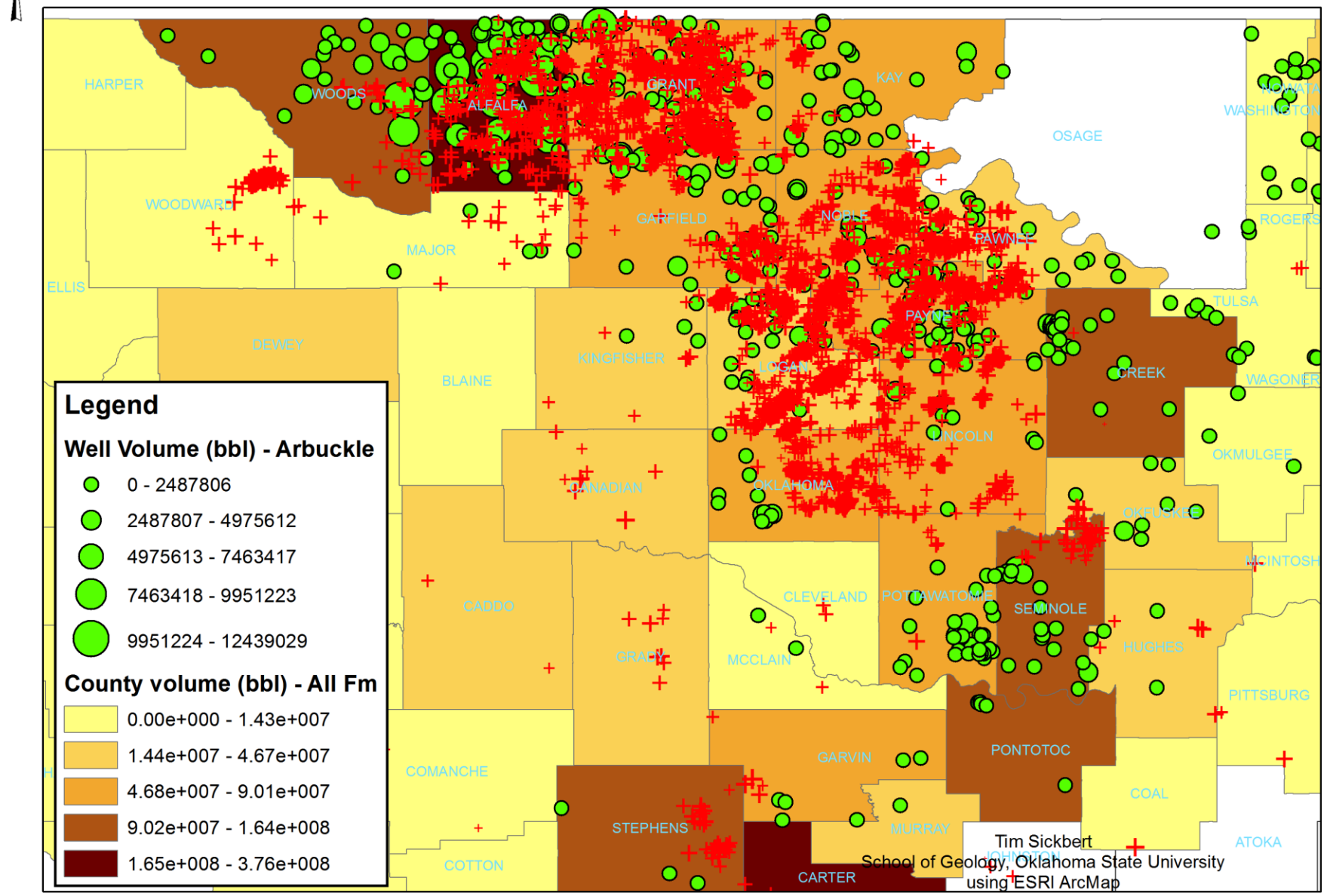

Questions?