

Wastewater Injection, Hydraulic Fracturing, & Earthquakes in Southern Kansas



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Andrea Llenos, Steve Walter*

With Thanks To:





Earthquake History in Kansas

1867 MMI-VII near Manhattan

1906 MMI-VII near Manhattan

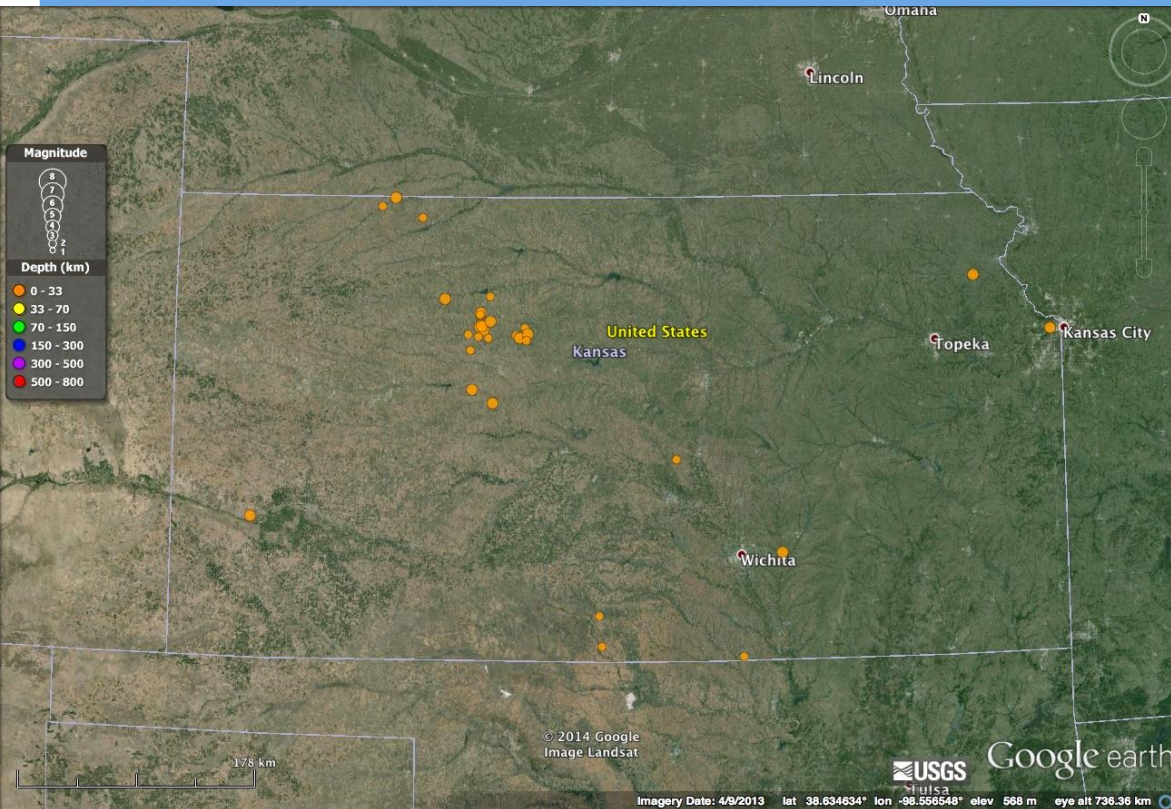
1987 Sleepy Hollow (EOR?)

1989 Palco M4.0 (SWD?)

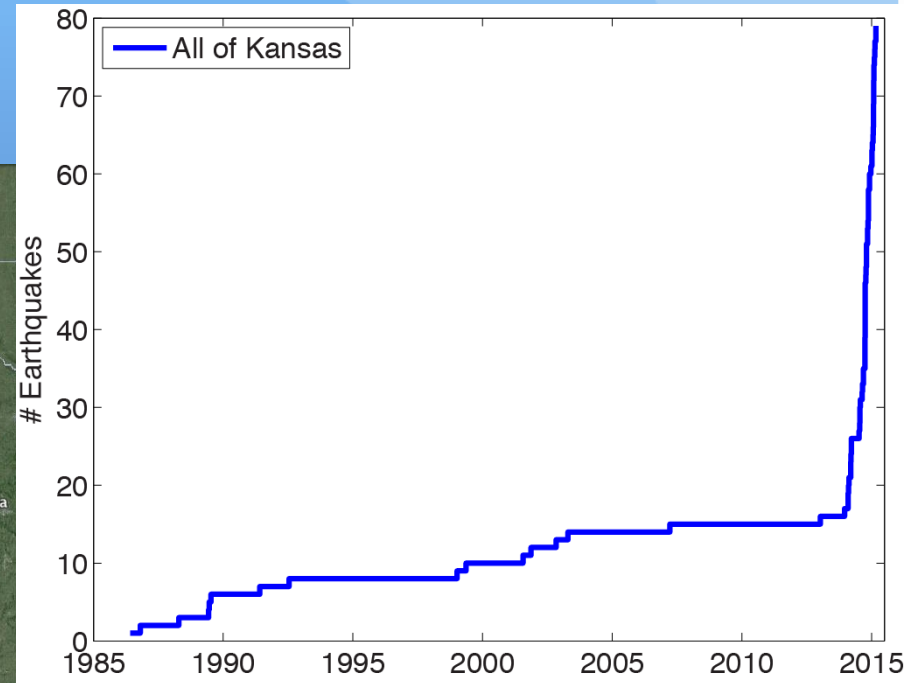
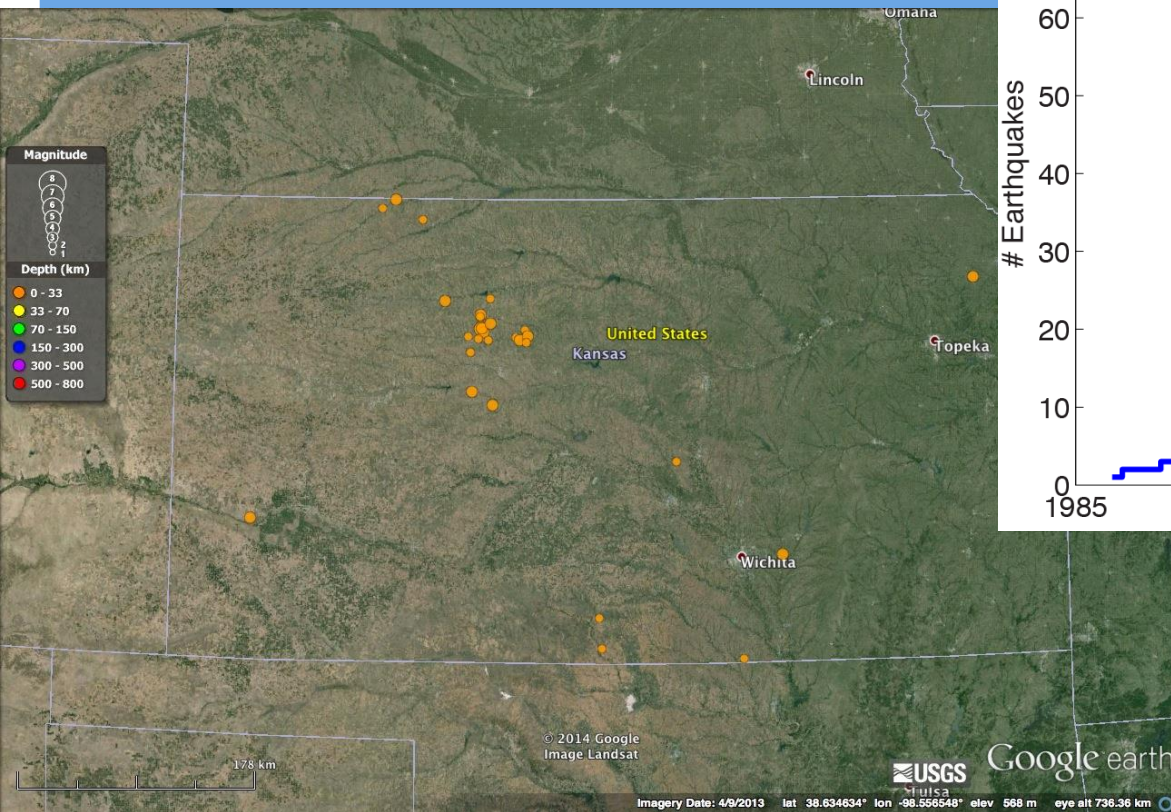
2014 Oct 2 M4.3 near
Anthony DYFI - MMI-VI

2014 Nov 12 M4.8 near
Conway Springs DYFI - MMI-VI

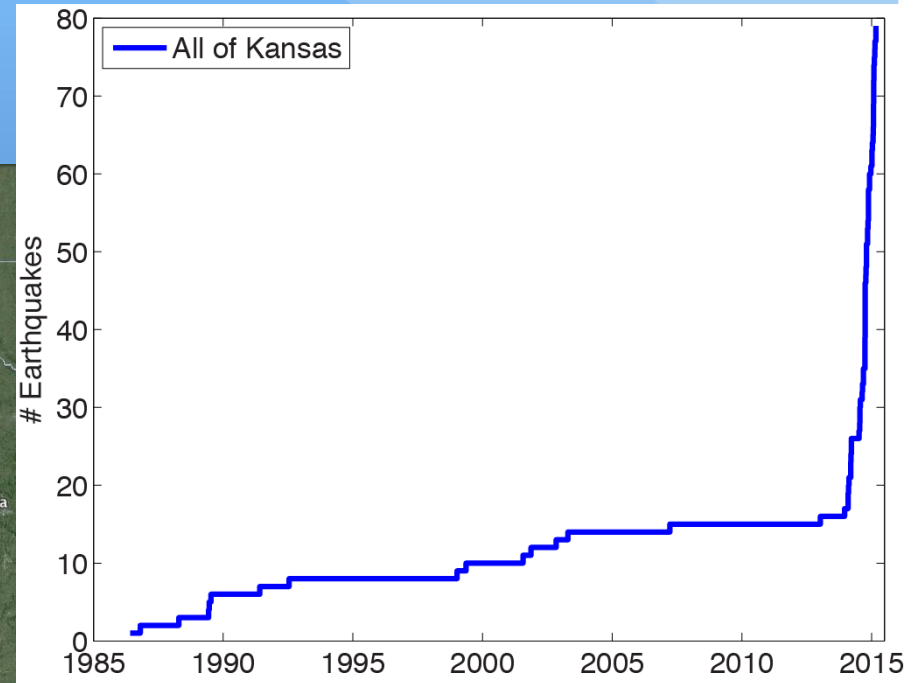
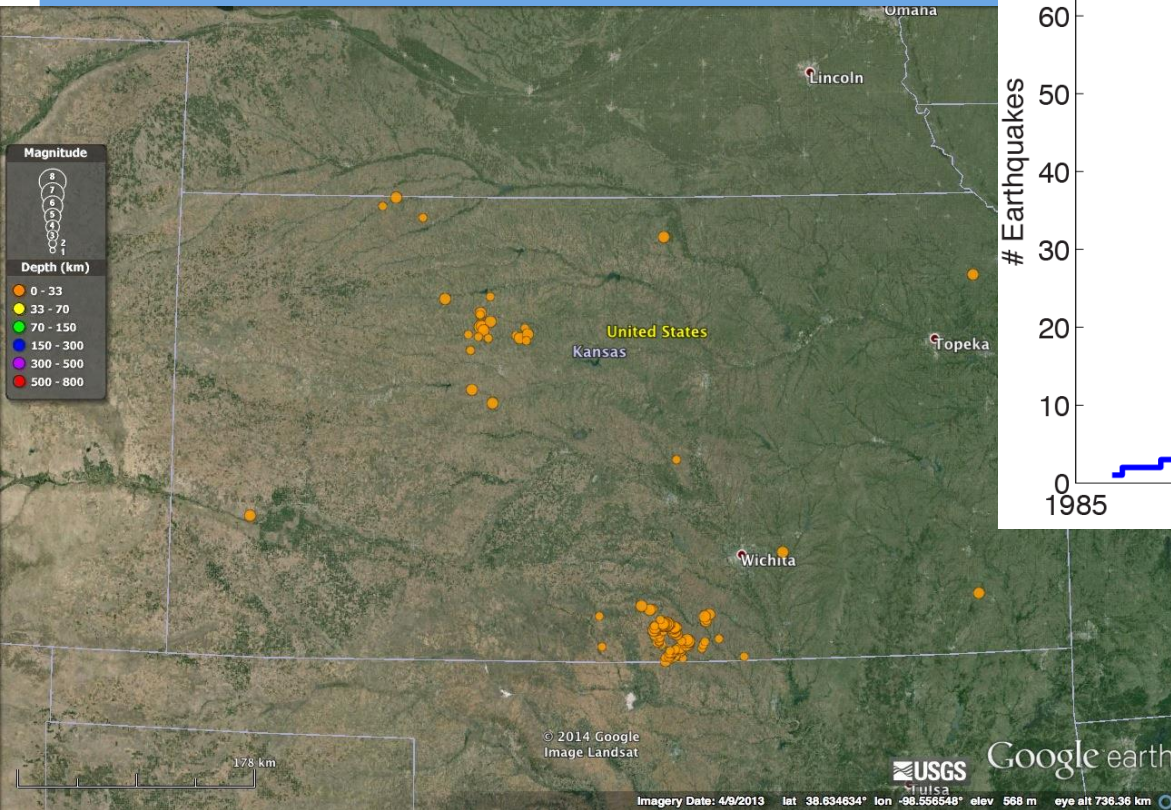
64 $M \geq 3$ Earthquakes
2012 - 3/10/2015



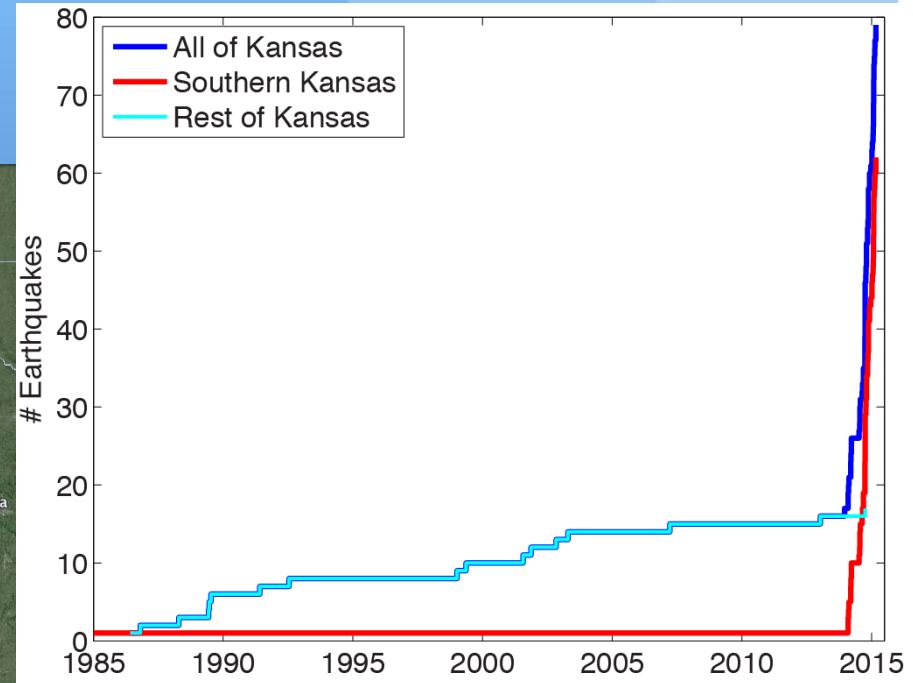
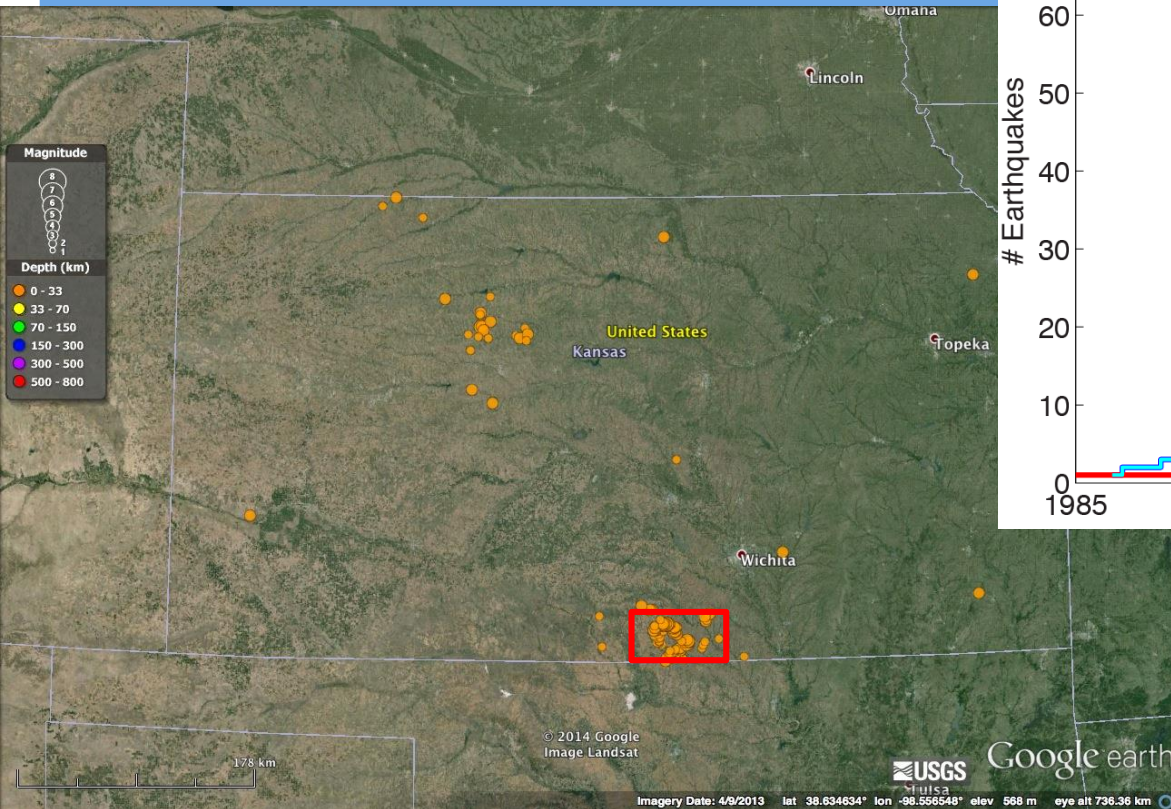
Earthquake History in Kansas (1973-2012)



Kansas Earthquakes (1973-present)



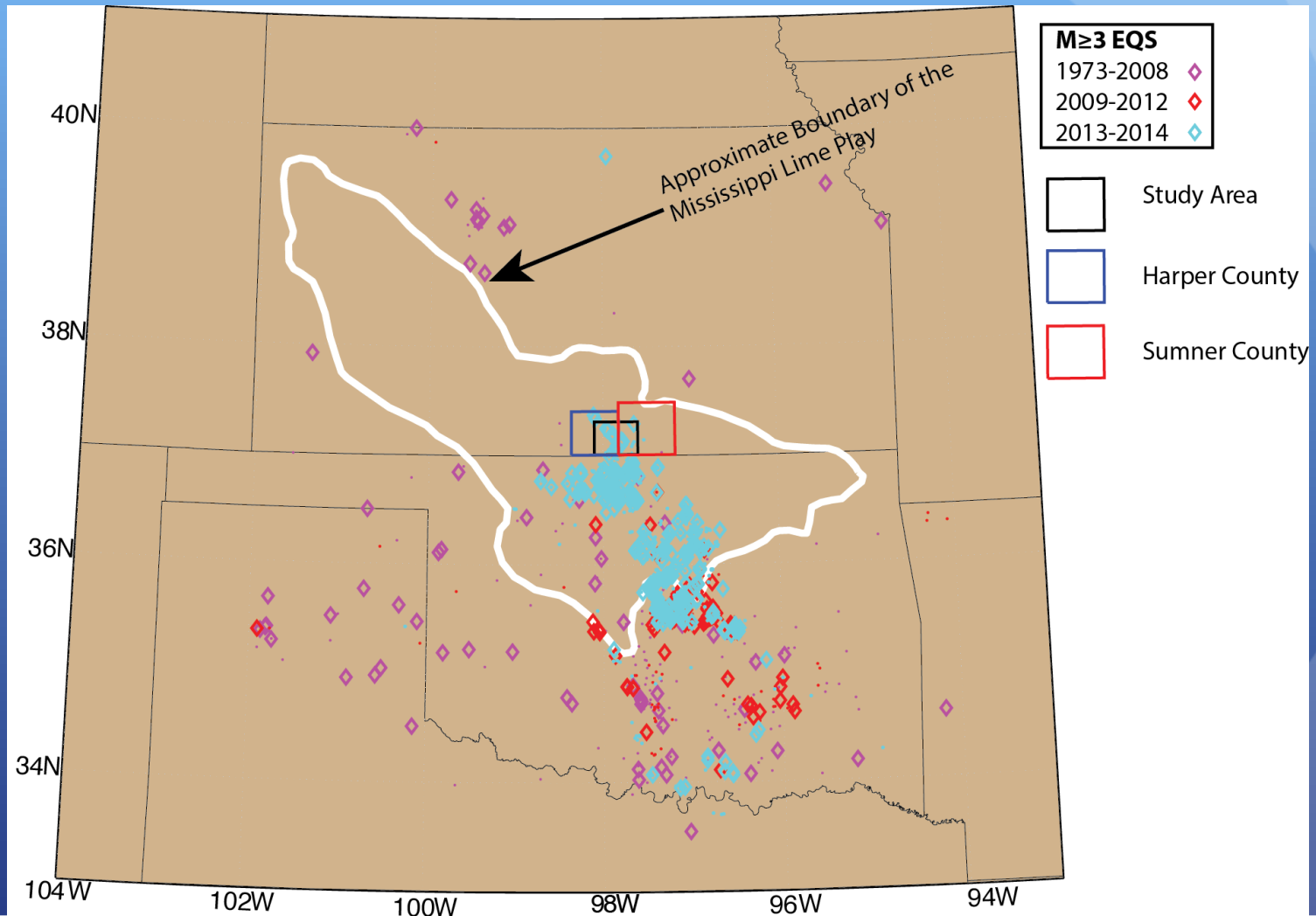
Kansas Earthquakes (1973-present)



1985-Present
79 $M \geq 3$ Earthquakes

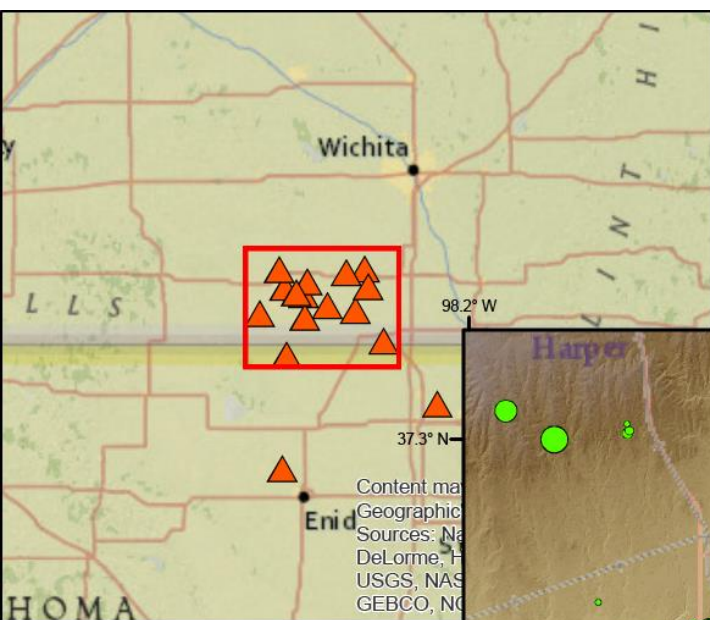
Dec 2013 - 3/10/15
64 $M \geq 3$ Earthquakes
62 in So. Kansas

Earthquake Rate has increased throughout Mississippi Lime



Southern Kansas Network Seismicity

Earthquakes since 1 July 2014, $M_L > 2.0$

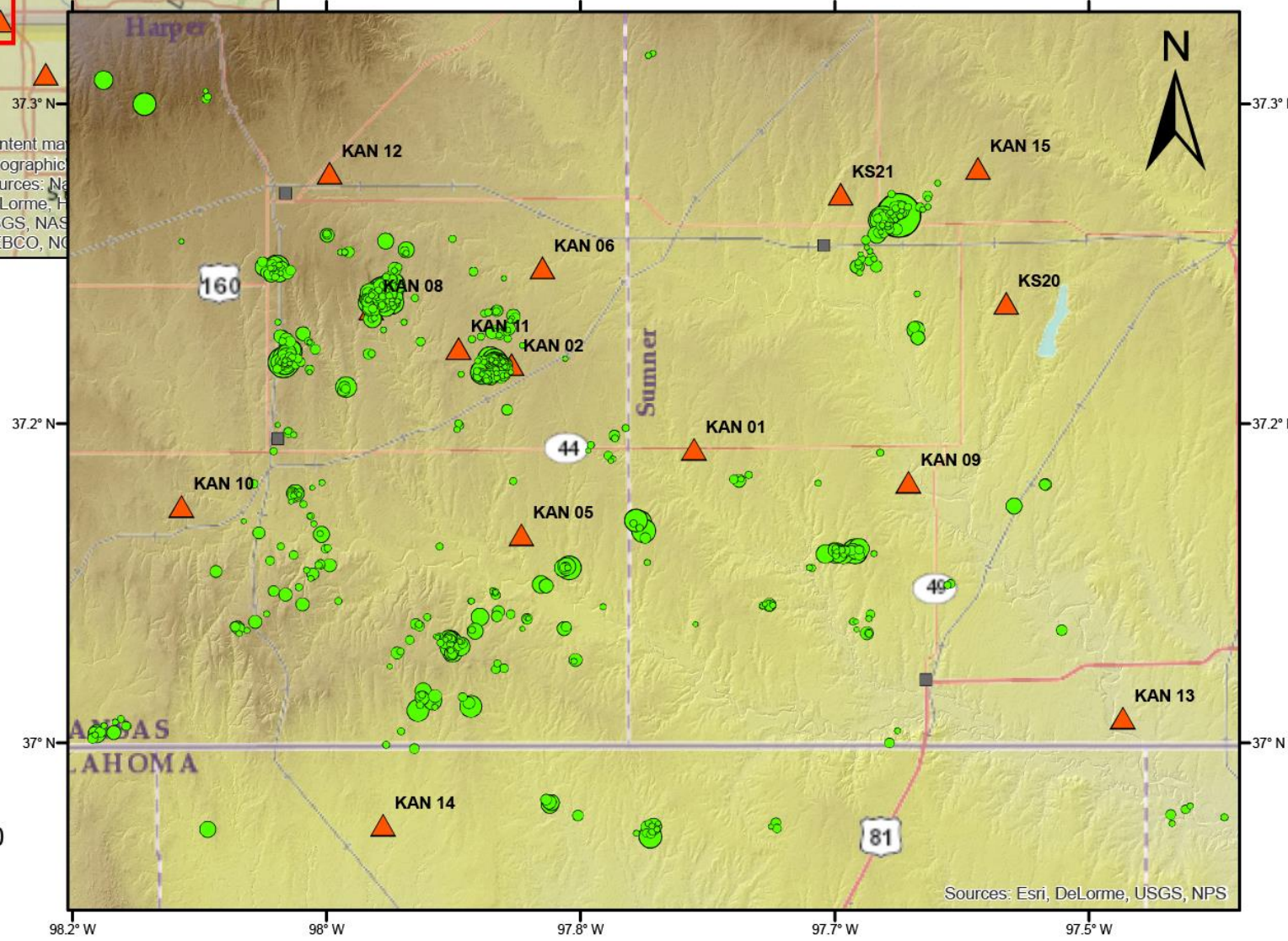
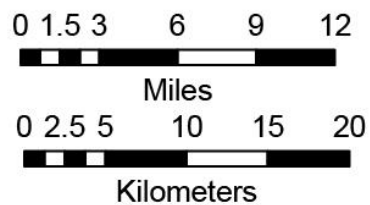


Content ma
Geographic
Sources: Na
DeLorme, H
USGS, NAS
GEBCO, NC

Magnitude



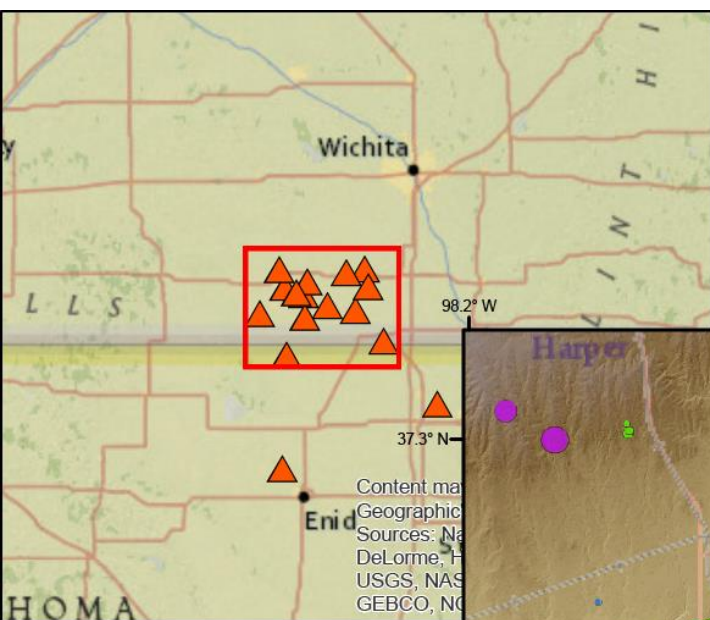
- ▲ Stations
- Towns



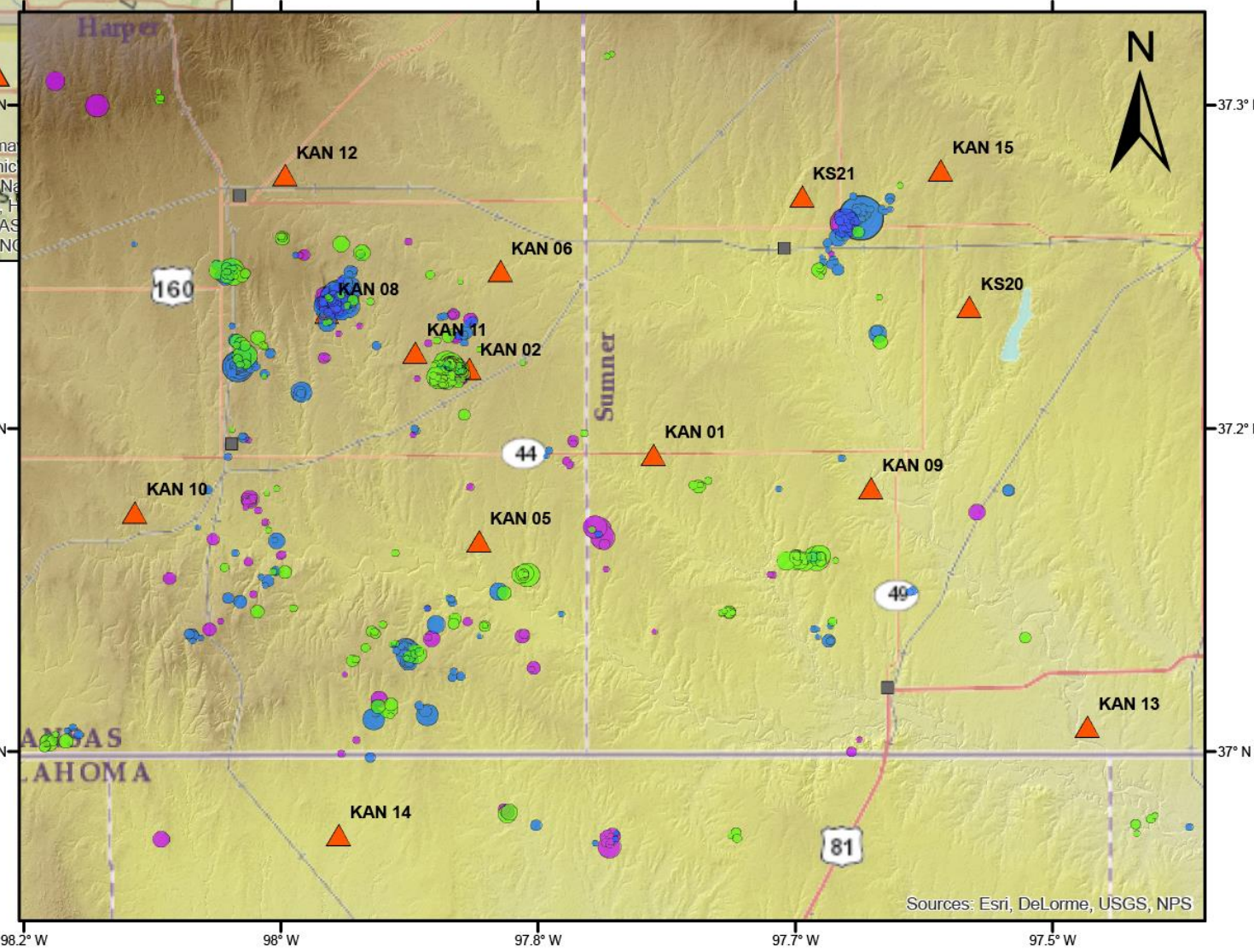
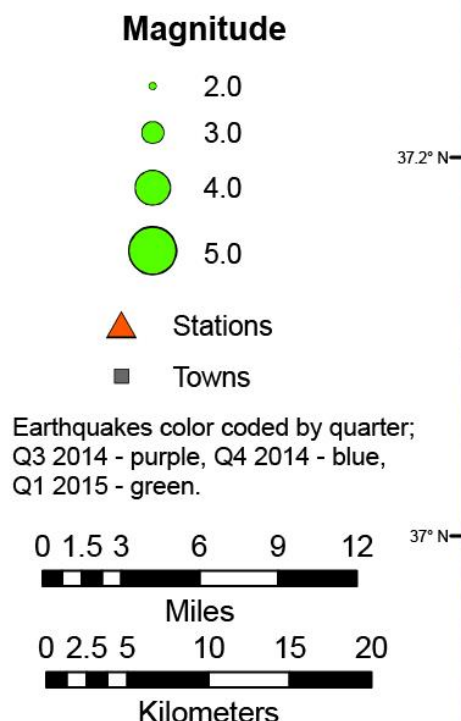
Sources: Esri, DeLorme, USGS, NPS

Southern Kansas Network Seismicity

Earthquakes since 1 July 2014, $M_L > 2.0$



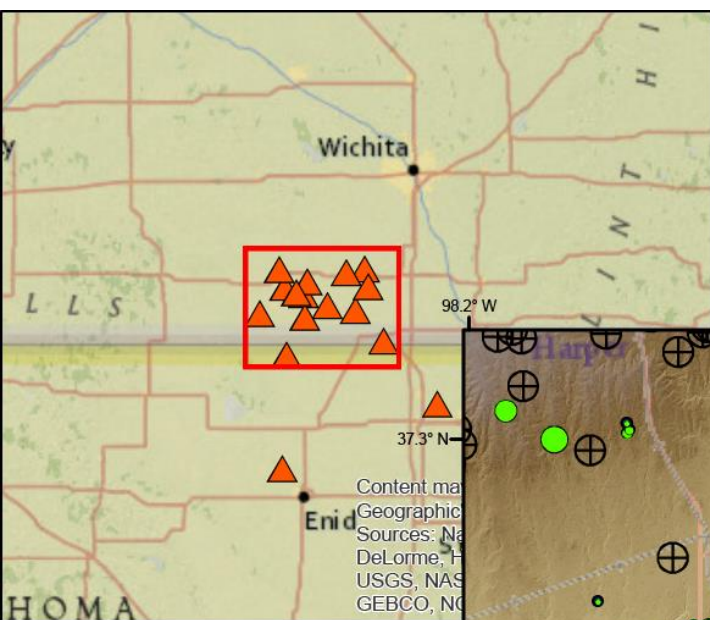
Content map
Geographic
Sources: Na
DeLorme, H
USGS, NAS
GEBCO, NC



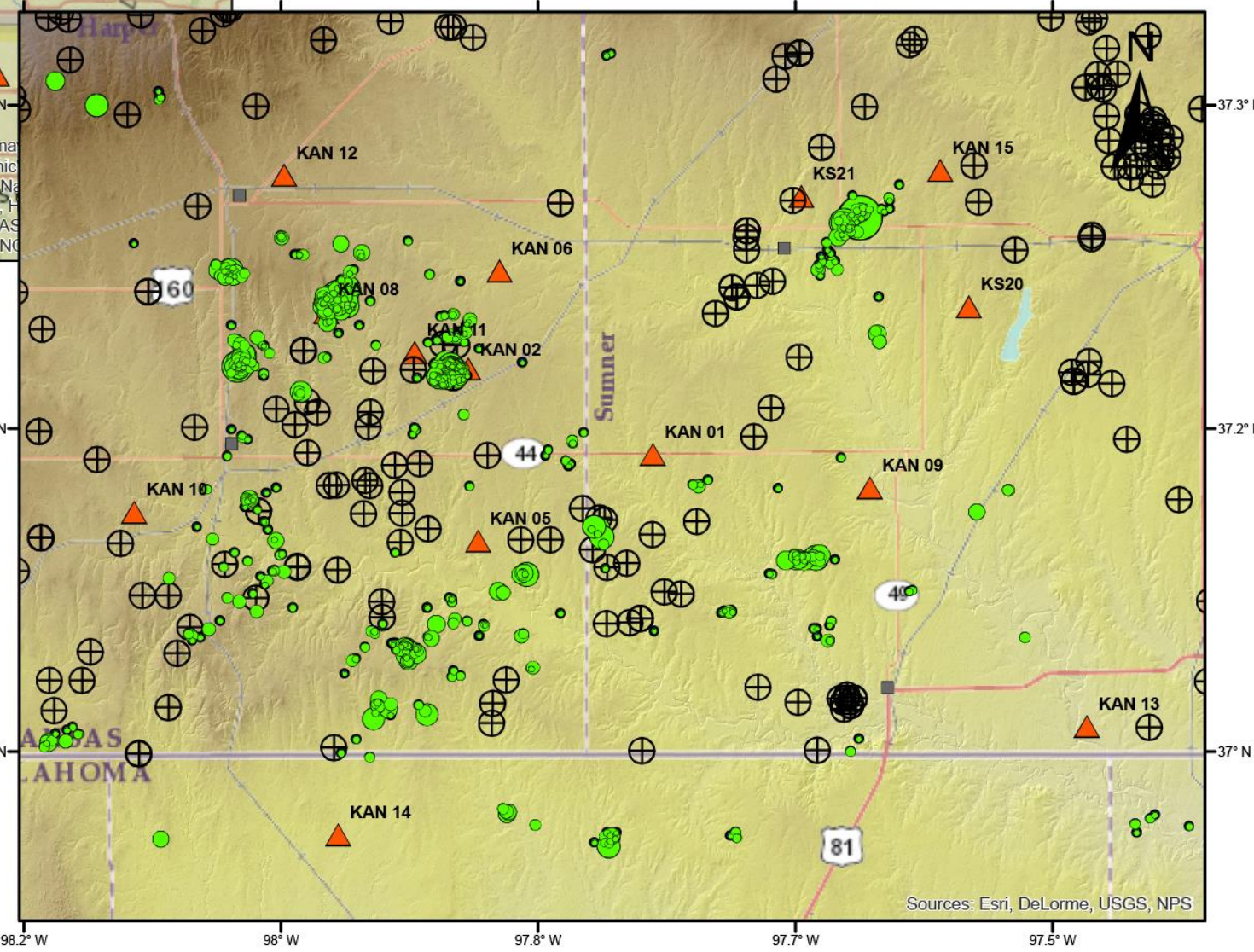
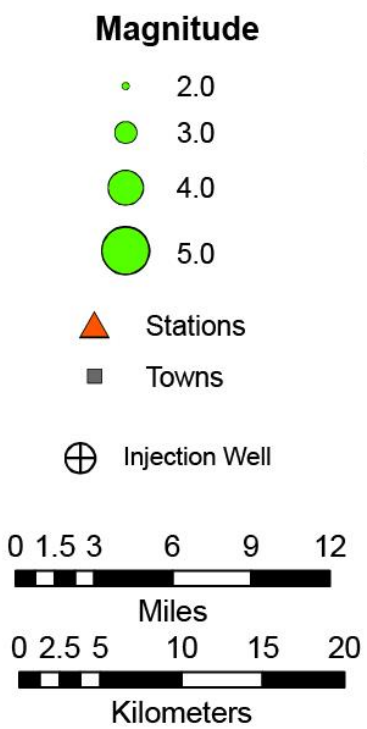
Sources: Esri, DeLorme, USGS, NPS

Southern Kansas Network Seismicity

Earthquakes since 1 July 2014, $M_L > 2.0$

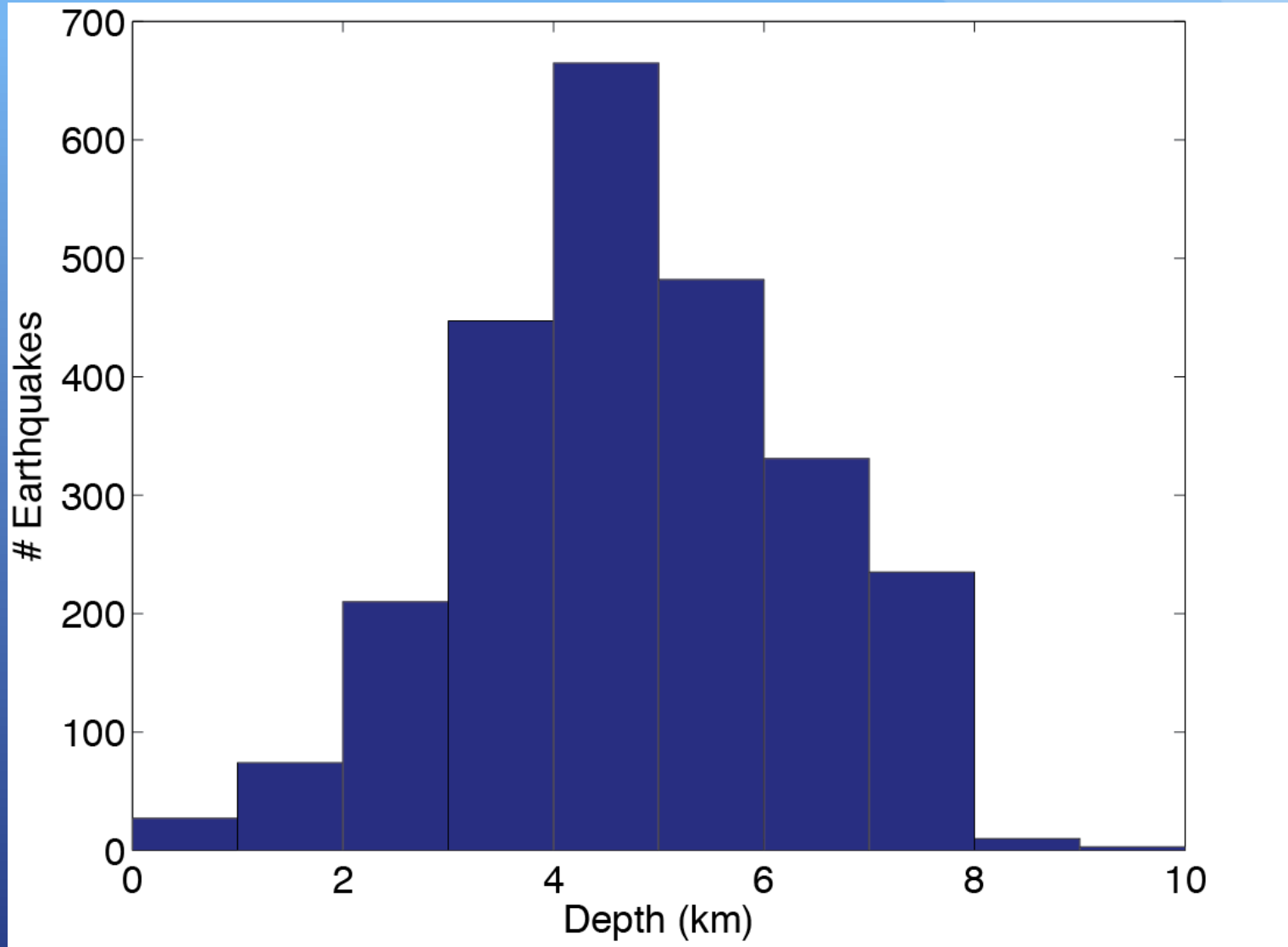


Content ma
Geographic
Sources: Na
DeLorme, H
USGS, NAS
GEBCO, NC



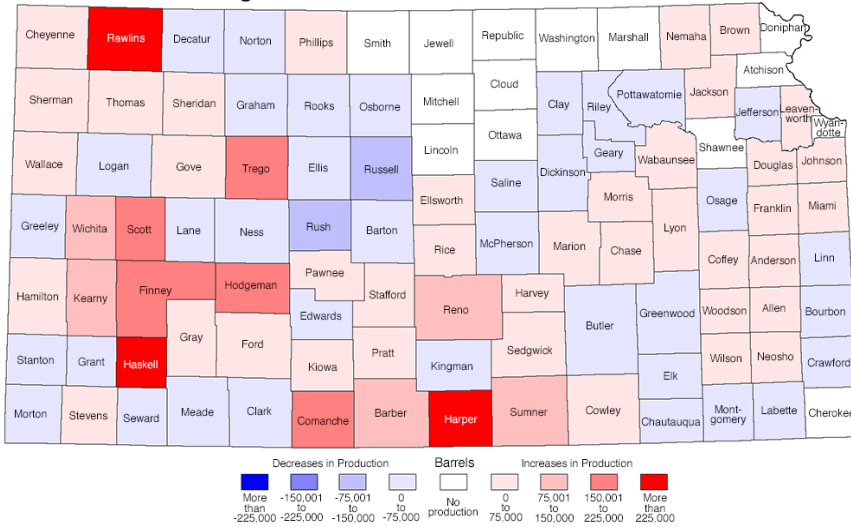
Sources: Esri, DeLorme, USGS, NPS

Earthquakes are in Shallow Basement

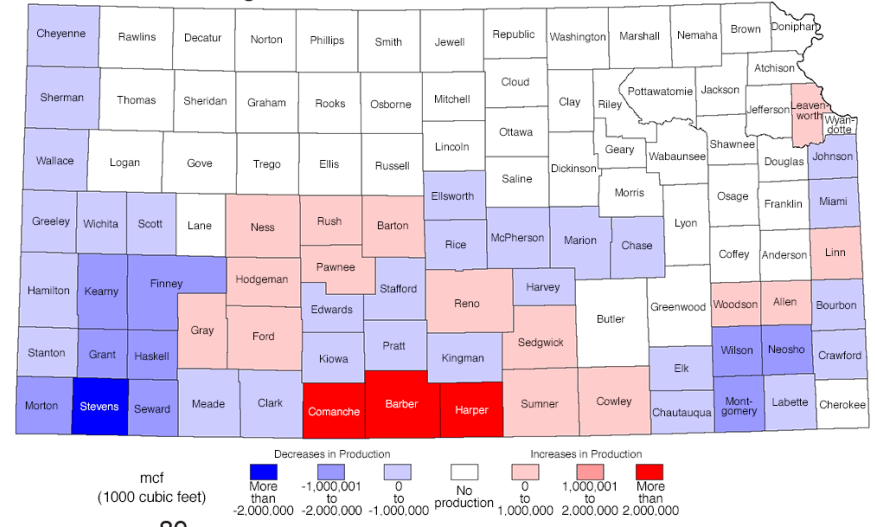


Is Wastewater Injection Causing Earthquakes in Kansas?

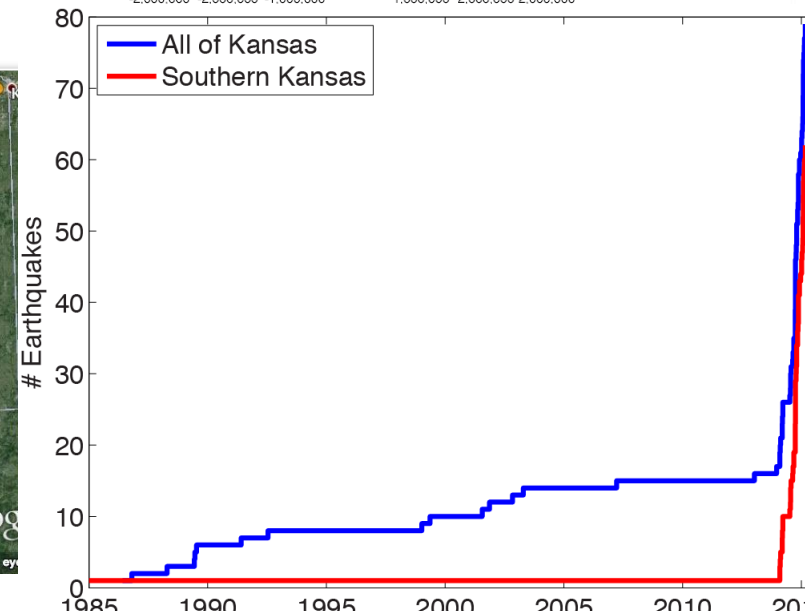
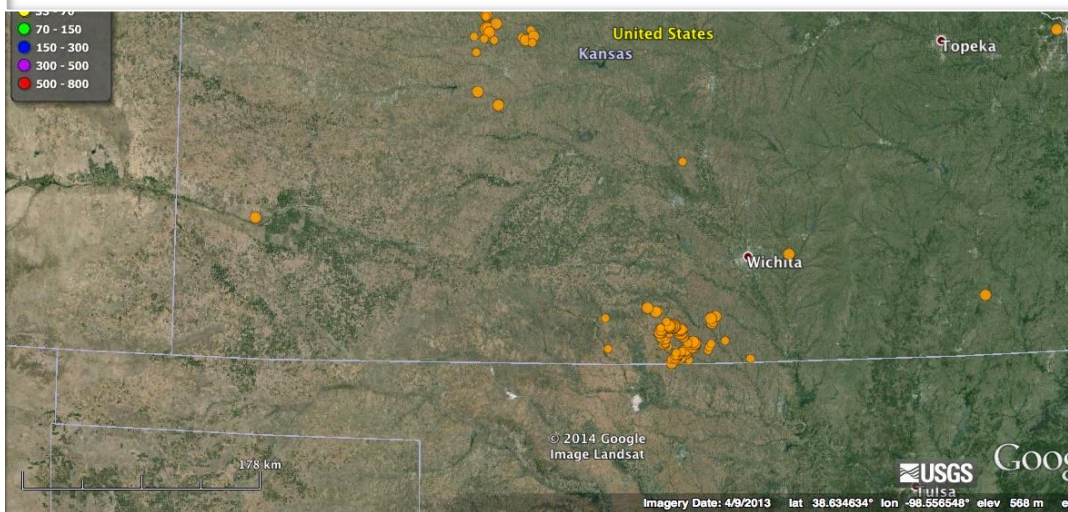
Change in Oil Production, 2012 to 2013



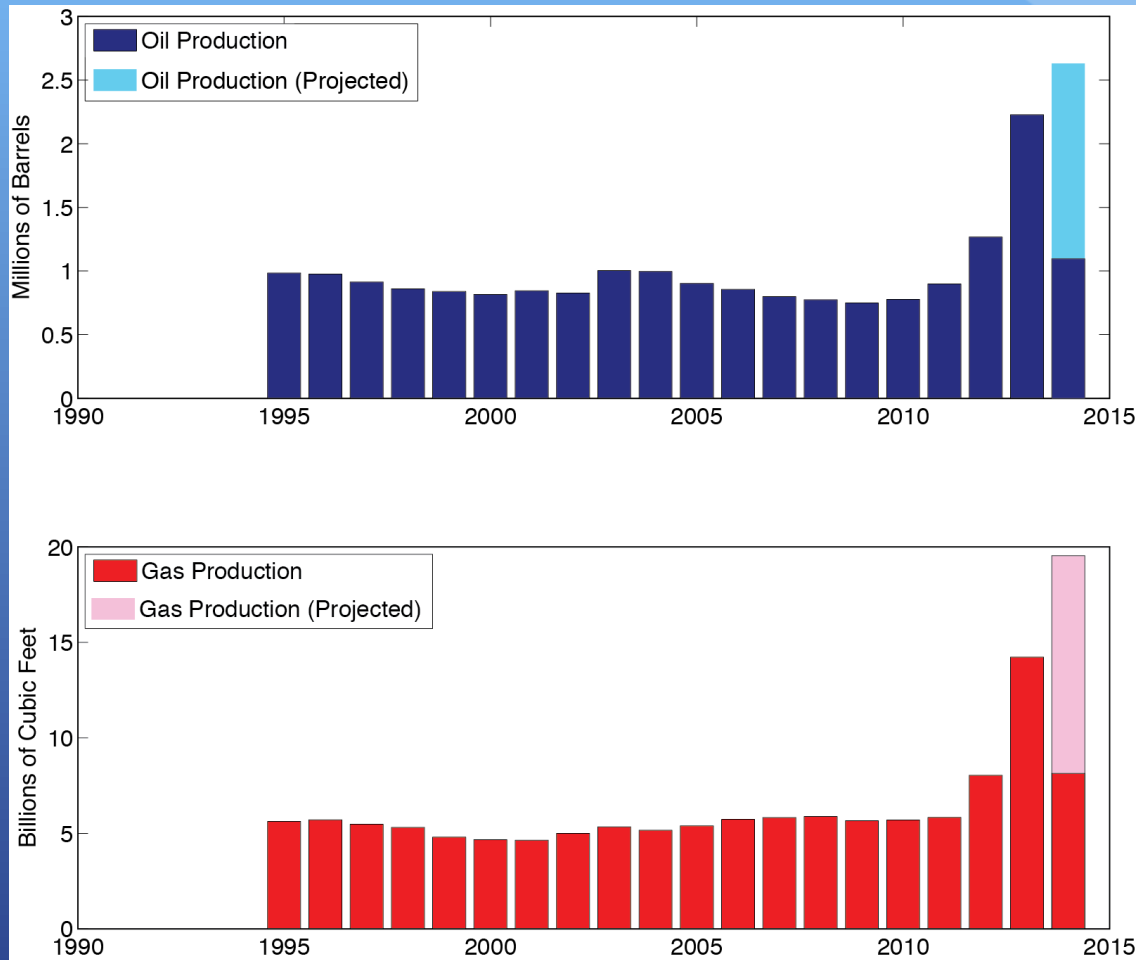
Change in Gas Production, 2012 to 2013



Kansas Geological Survey

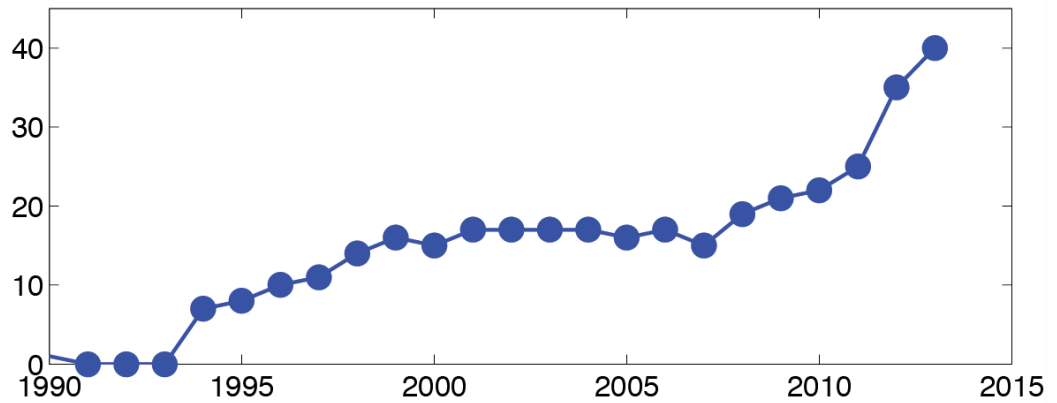


Is Wastewater Injection Causing Earthquakes in Kansas?

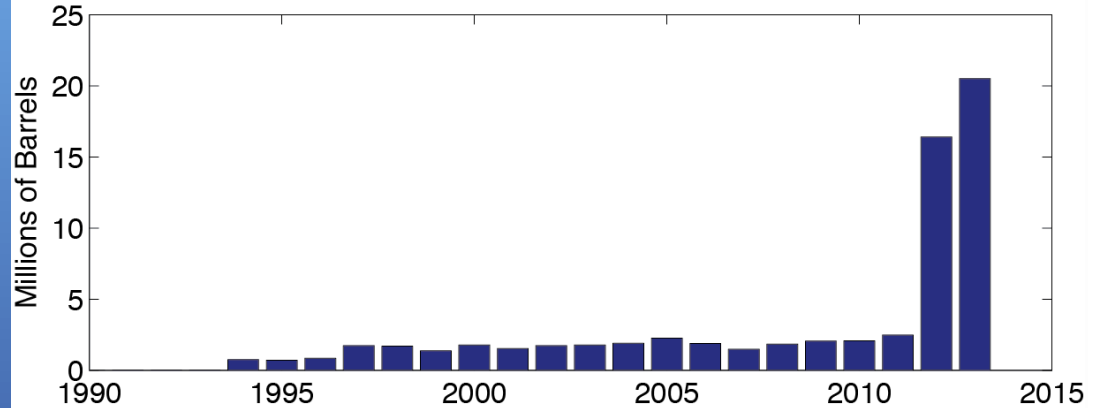


Is Wastewater Injection Causing Earthquakes in Kansas?

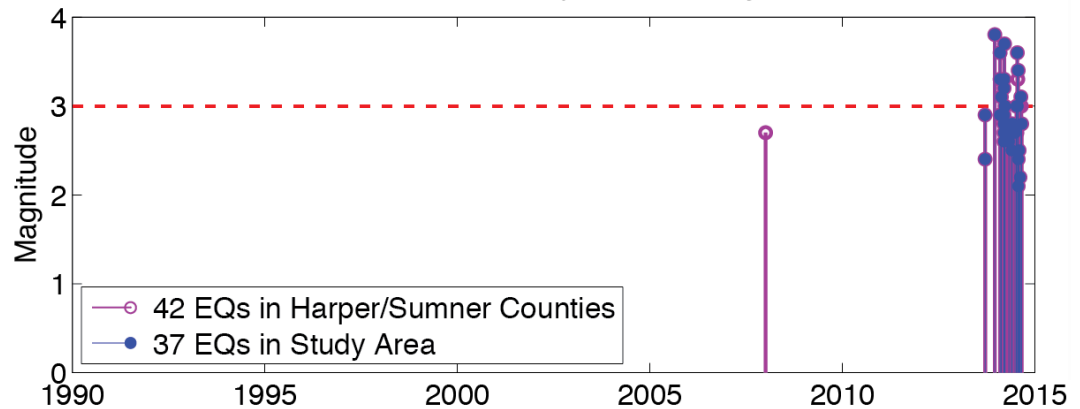
Number of Operating SWD Wells in Study Area



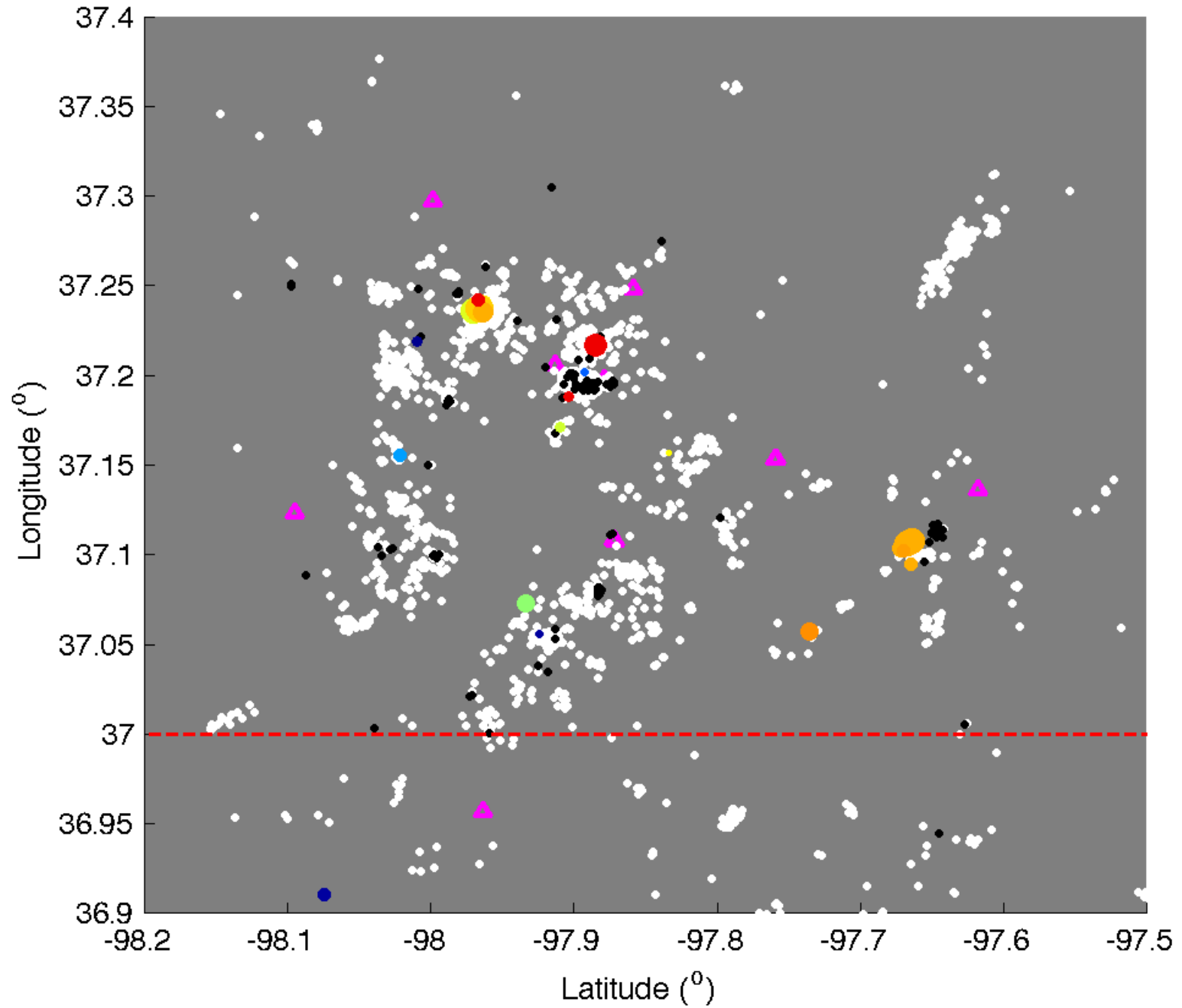
Total Yearly Injected Volume in Study Area



NEIC Detected Earthquakes in Study Area

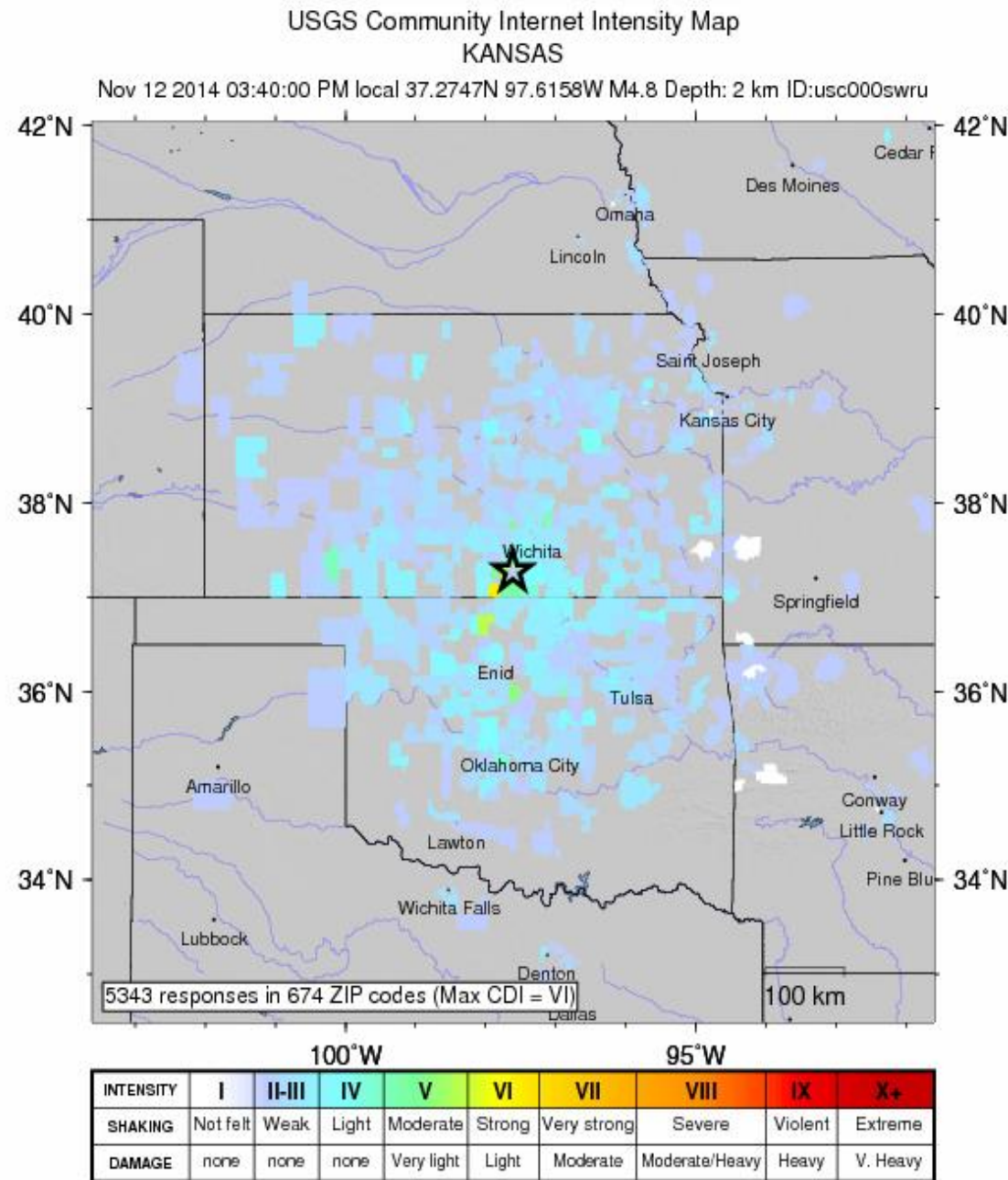


01-Jul-2014



M_w 4.8 Milan

- November 12
- Felt in at least 8 states
- Top 3 largest historical EQ in Kansas
- Light damage

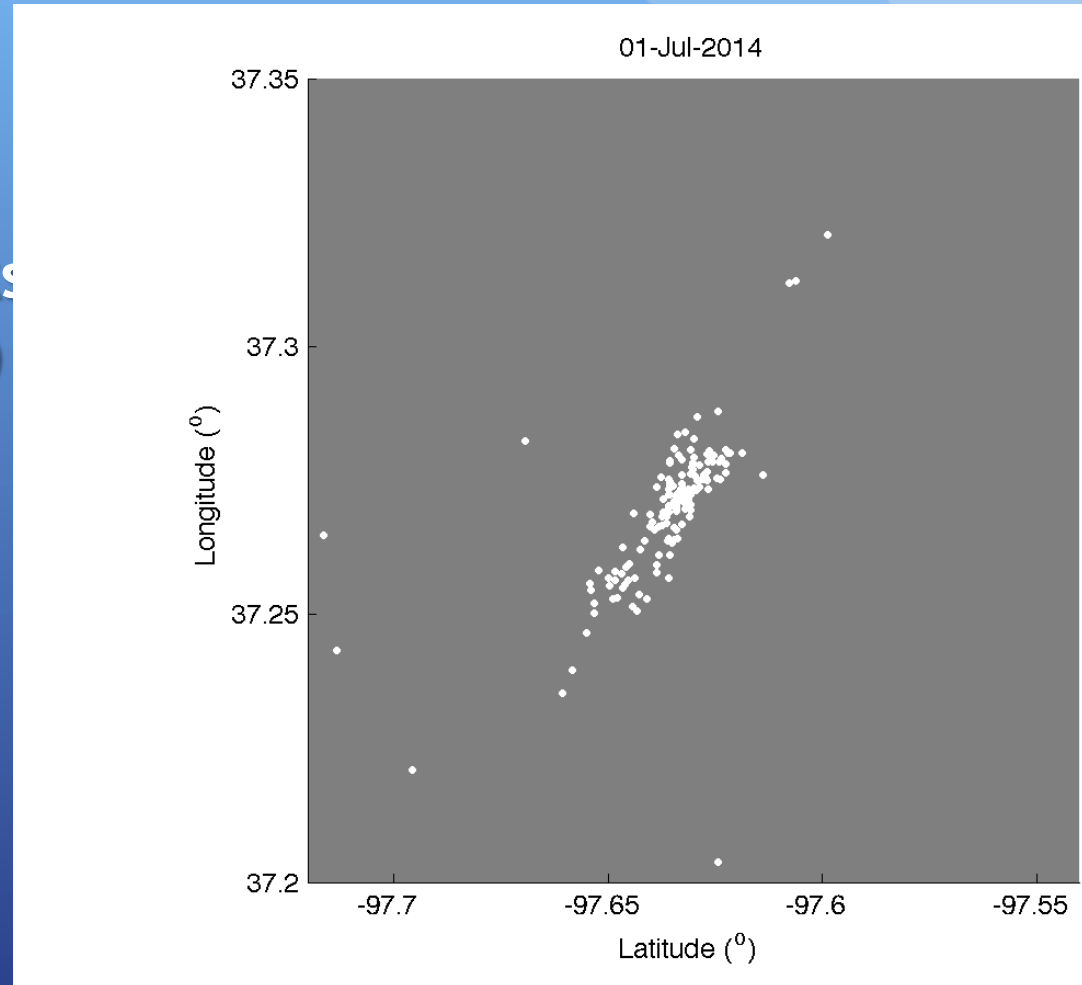


Some Damage in Milan EQ



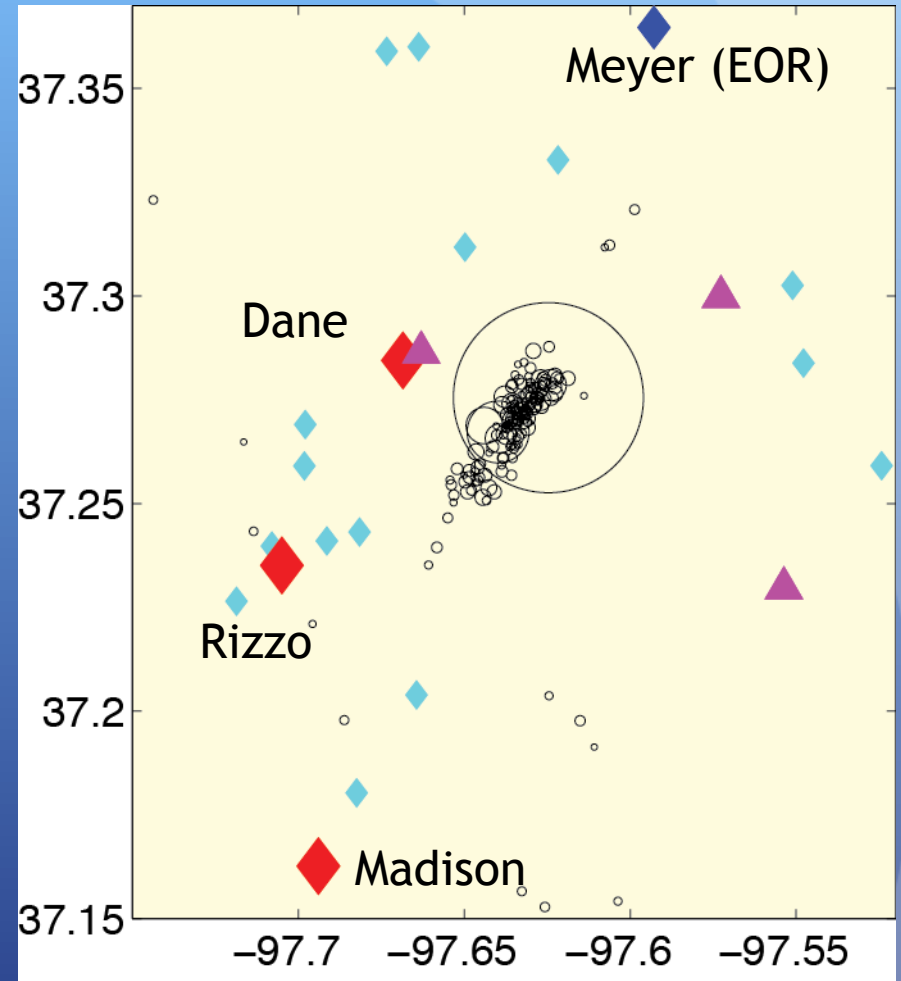
M_w 4.8 Milan Earthquake

- Some earlier EQs
 - M 3.1 Feb 15
 - M 3.4, M 3.2 July 8
- No observed foreshocks (correlation detection)
- Meager aftershock sequence
 - M_{\max} 3.0 (3 weeks)
 - 32 $M \geq 2$ earthquakes 5 weeks



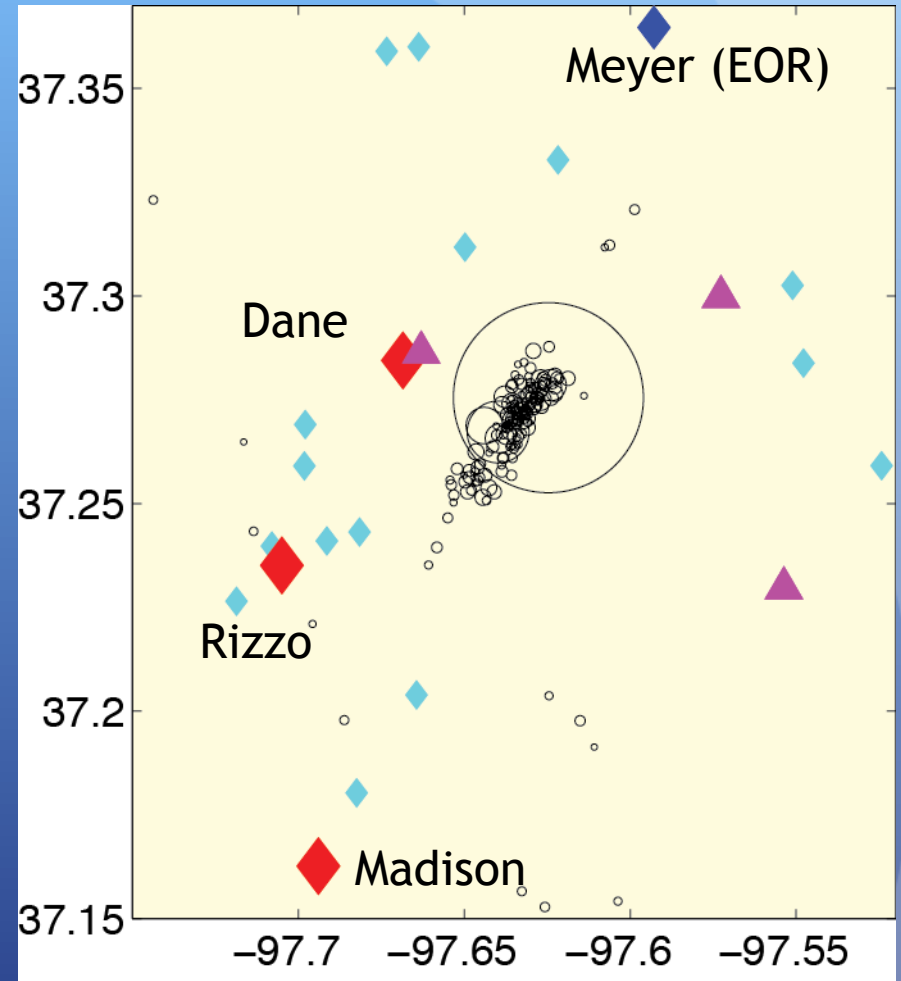
M_w 4.8 Milan Earthquake

- ~4km NE trending, steeply east-dipping structure
- Consistent w/ focal mechanism



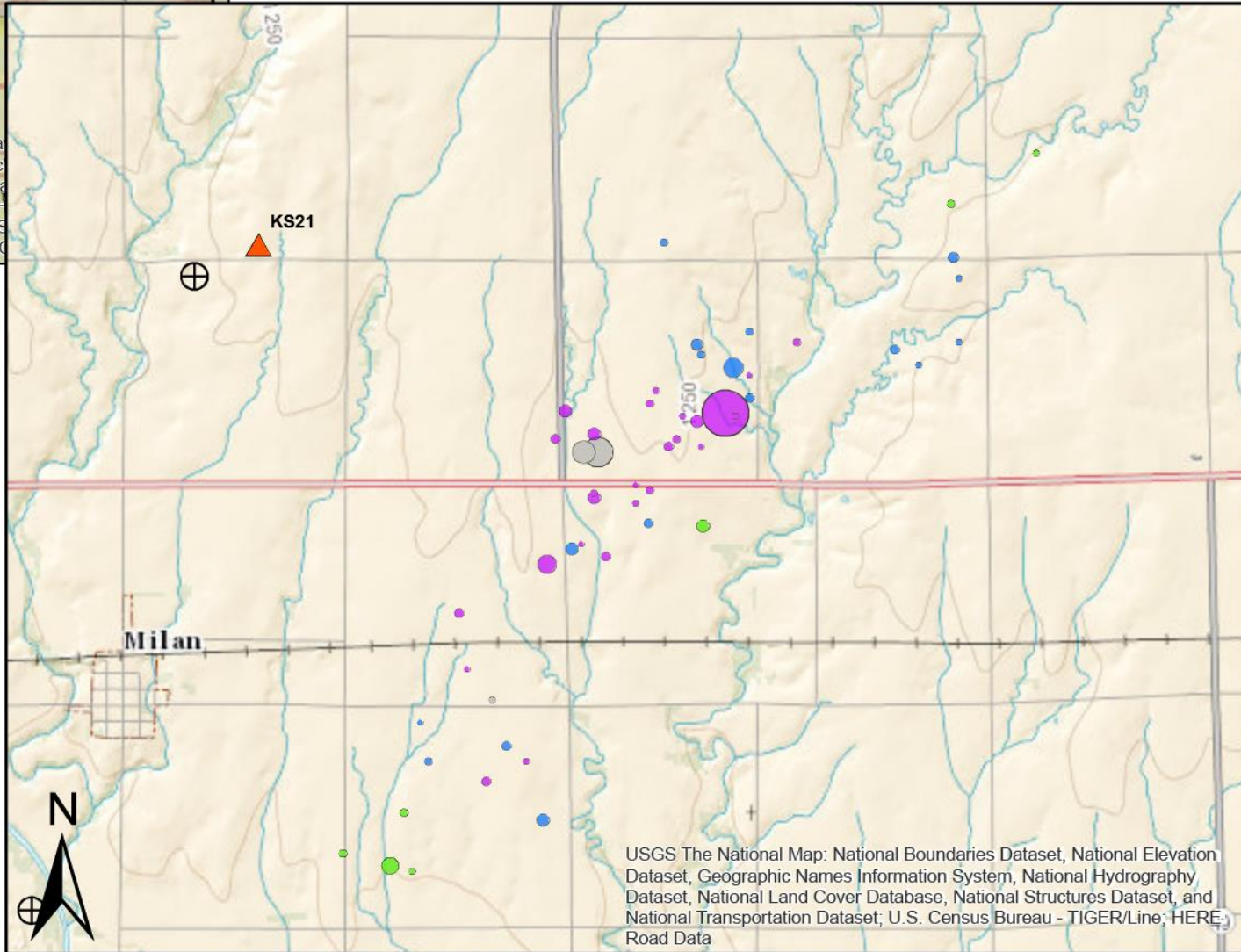
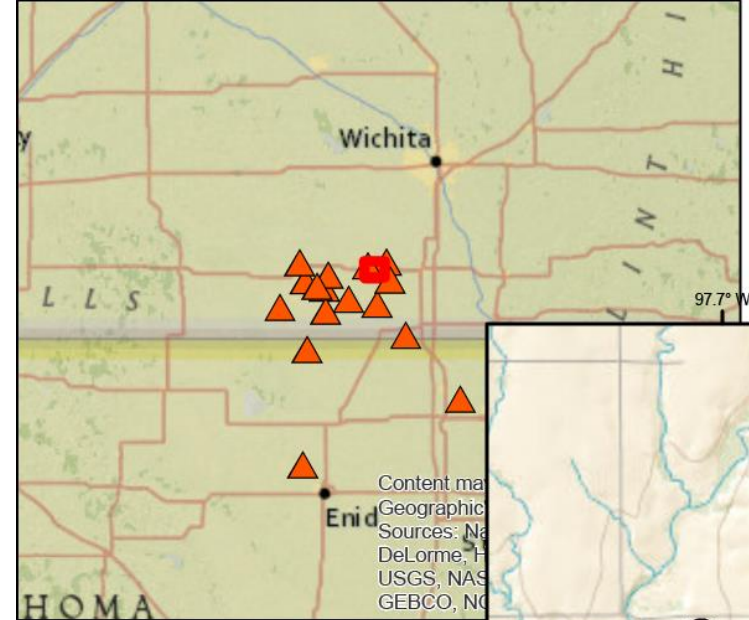
M_w 4.8 Milan Earthquake

- **Near ~20 SWDs**
 - Typically small (<20K bbl/mo)
 - Long-standing
 - 4 new wells
 - No 2014 data (all but 3 wells)
- **No clear temporal correlation w/ SWD**
 - Madison not disposing 2014
 - Dane (~100k/mo) - May 2014
 - Rizzo (100k-300k/mo) no significant changes at time of Nov EQ
- **No clear temporal correlation w/ well spud or completion**



Southern Kansas Network Seismicity

Earthquakes since 1 June 2014, $M_L > 2.0$



Magnitude

- 2.0
- 3.0
- 4.0
- 5.0
- ▲ Stations
- Towns
- ⊕ Injection Well

Earthquakes color coded by quarter;
Nov 2014 - purple, Dec 2014 - blue,
Jan 2015 - green, rest in grey.

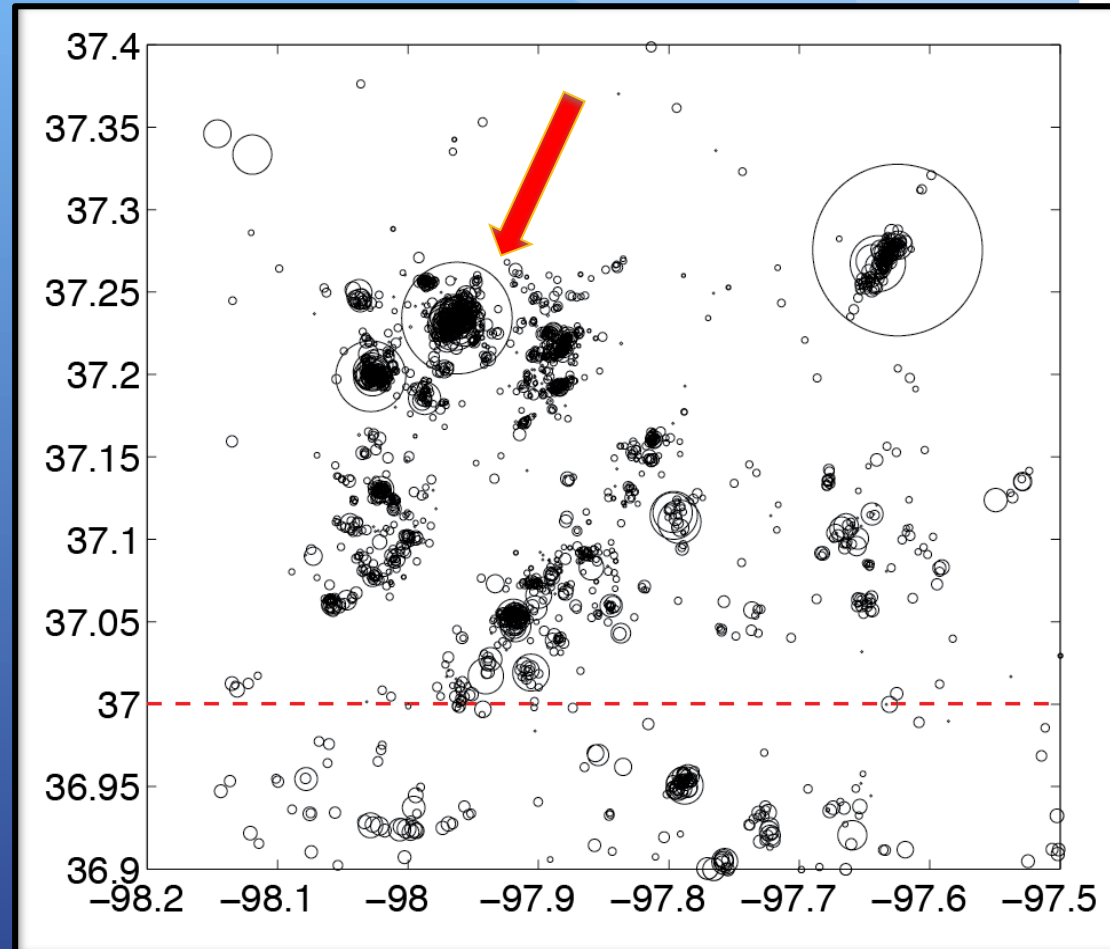


Kilometers

USGS The National Map: National Boundaries Dataset, National Elevation Dataset, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; U.S. Census Bureau - TIGER/Line; HERE, Road Data

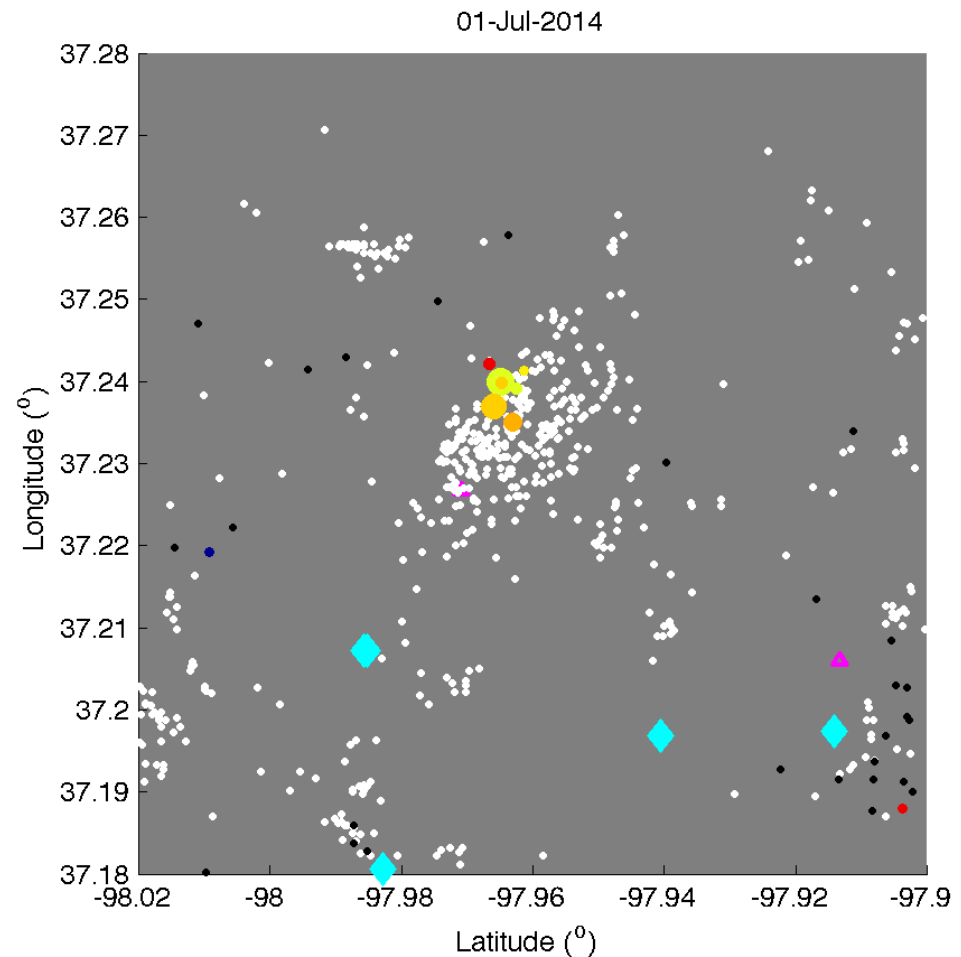
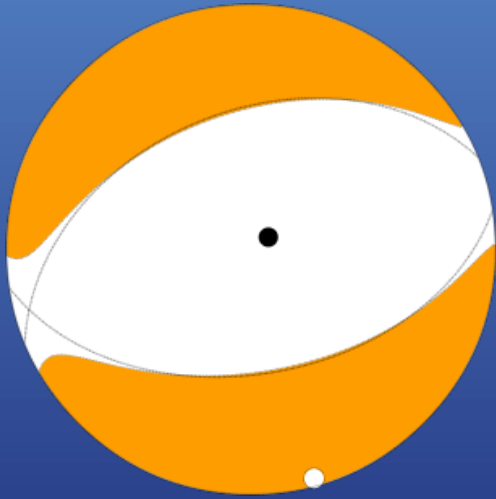
M_w 4.3 Anthony Earthquake

- Area of ongoing seismicity
- Multiple high rate wells, 300k bbl/mo
- No clear changes shortly before earthquake clusters



M_w 4.3 Anthony Earthquake

- Primarily Normal Faulting
- No strong lineations of seismicity
- Multiple High Rate Wells



Southern Kansas Network Seismicity

Earthquakes since 1 June 2014, $M_L > 2.0$

0 0.4 0.8 1.6 2.4 3.2



Miles

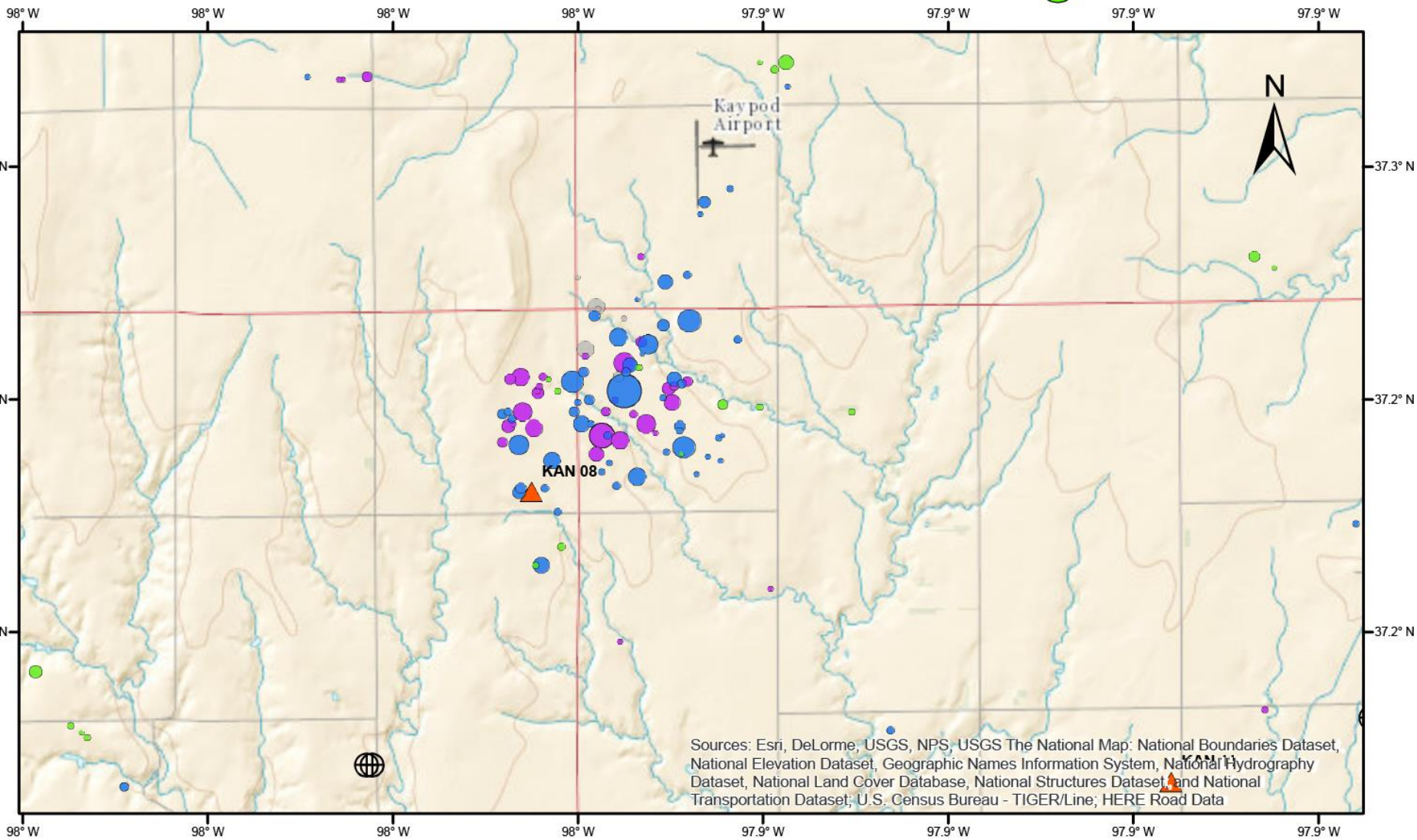
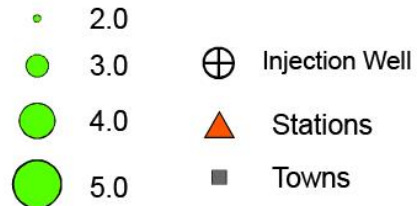
0 0.5 1 2 3 4



Kilometers

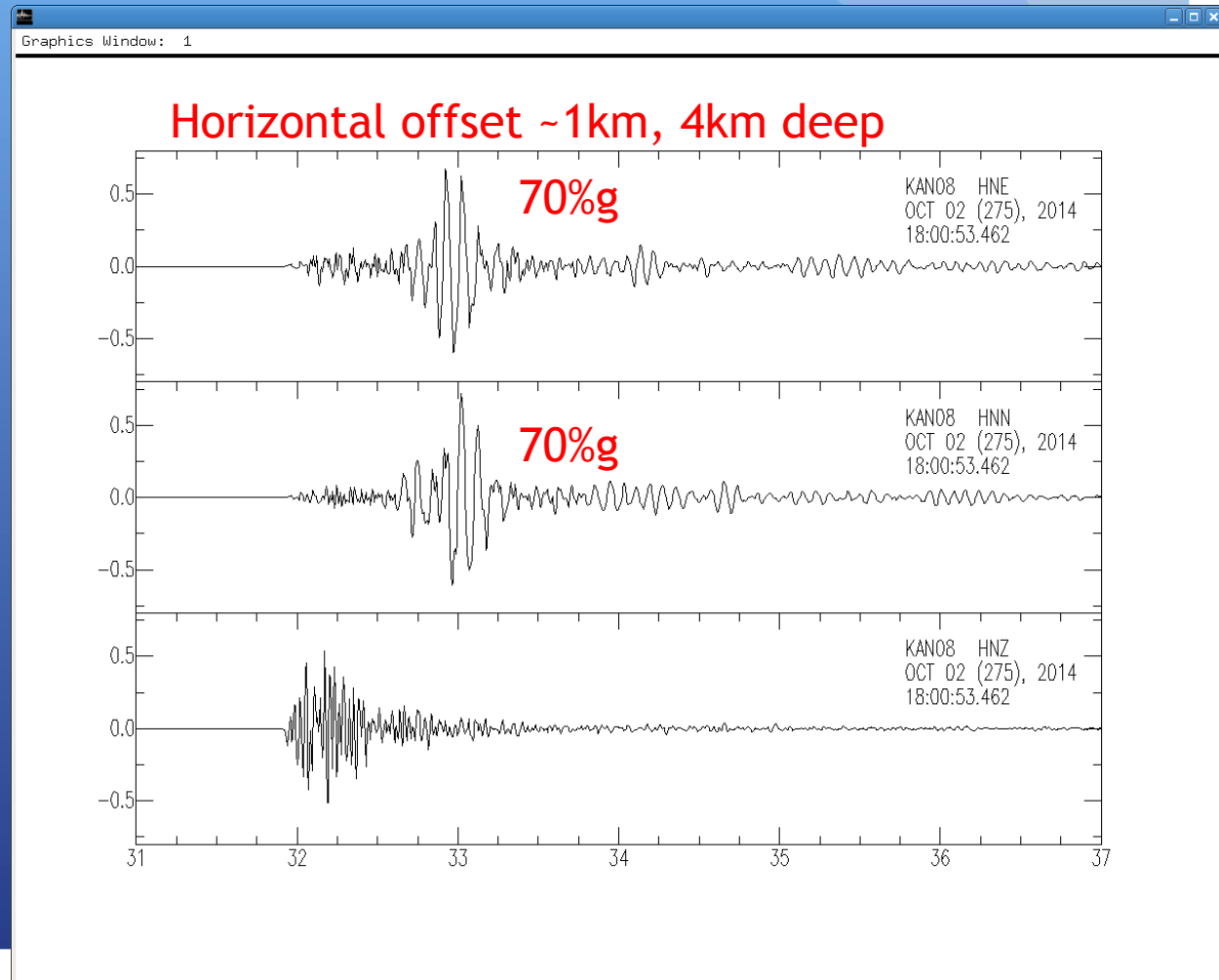
Earthquakes color coded by quarter;
Q3 2014 - purple, Q4 2014 - blue, Q1 2015 - green,
rest in grey.

Magnitude



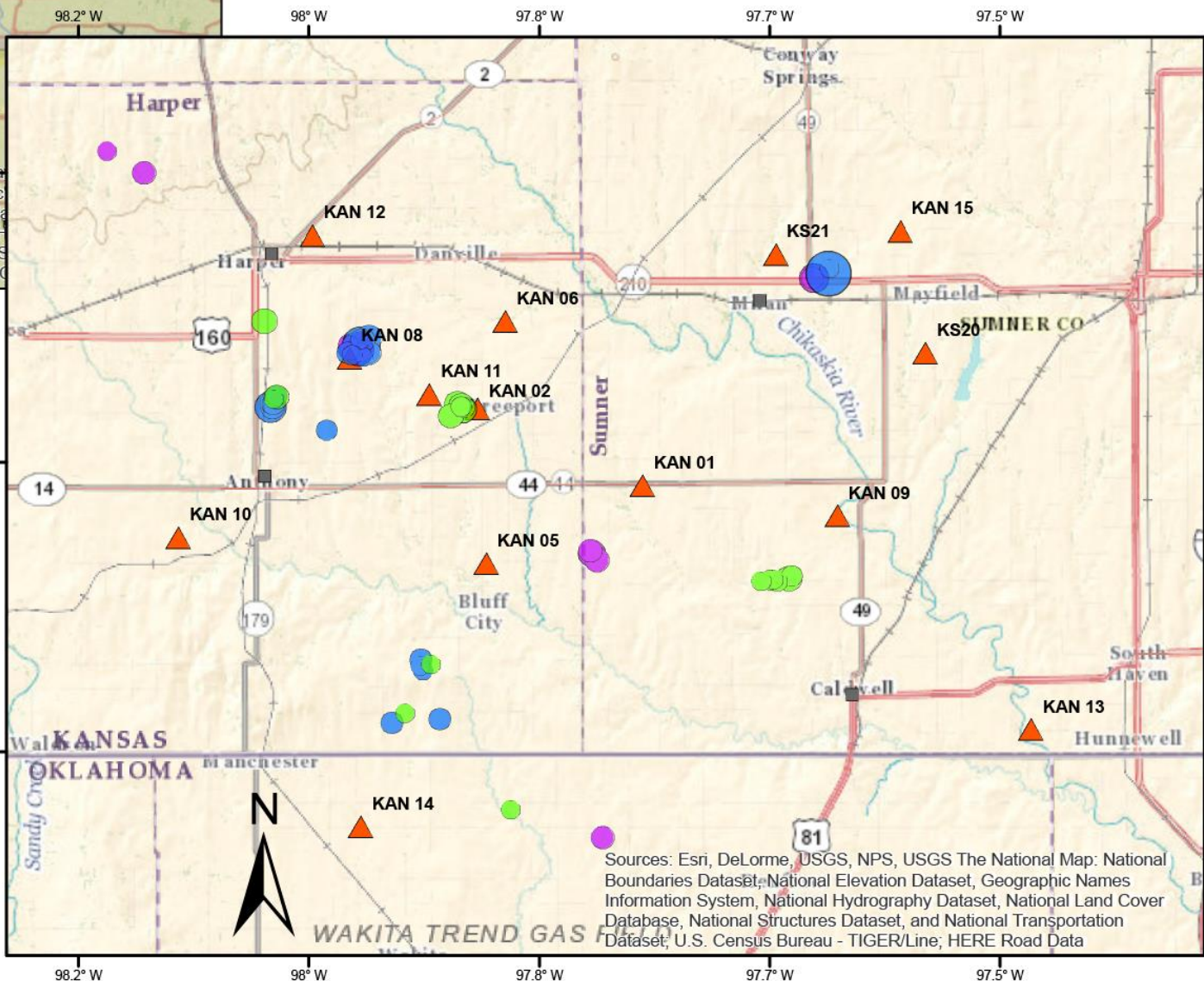
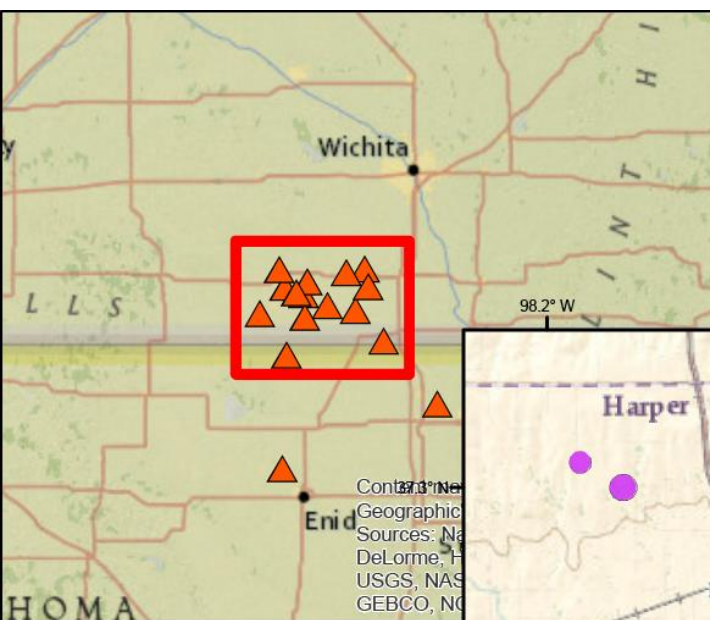
M_w 4.3 Anthony Earthquake

Strong, short
duration shaking



Southern Kansas Network Seismicity

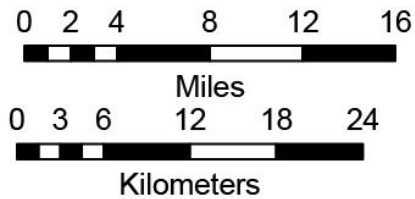
Earthquakes since 1 June 2014, $M_L > 3.0$



Magnitude

- 2.0
- 3.0
- 4.0
- 5.0
- ▲ Stations
- Towns

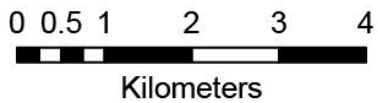
Earthquakes color coded by quarter;
Q3 2014 - purple, Q4 2014 - blue,
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Sources: Esri, DeLorme, USGS, NPS, USGS The National Map: National Boundaries Dataset, National Elevation Dataset, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; U.S. Census Bureau - TIGER/Line; HERE Road Data

Southern Kansas Network Seismicity

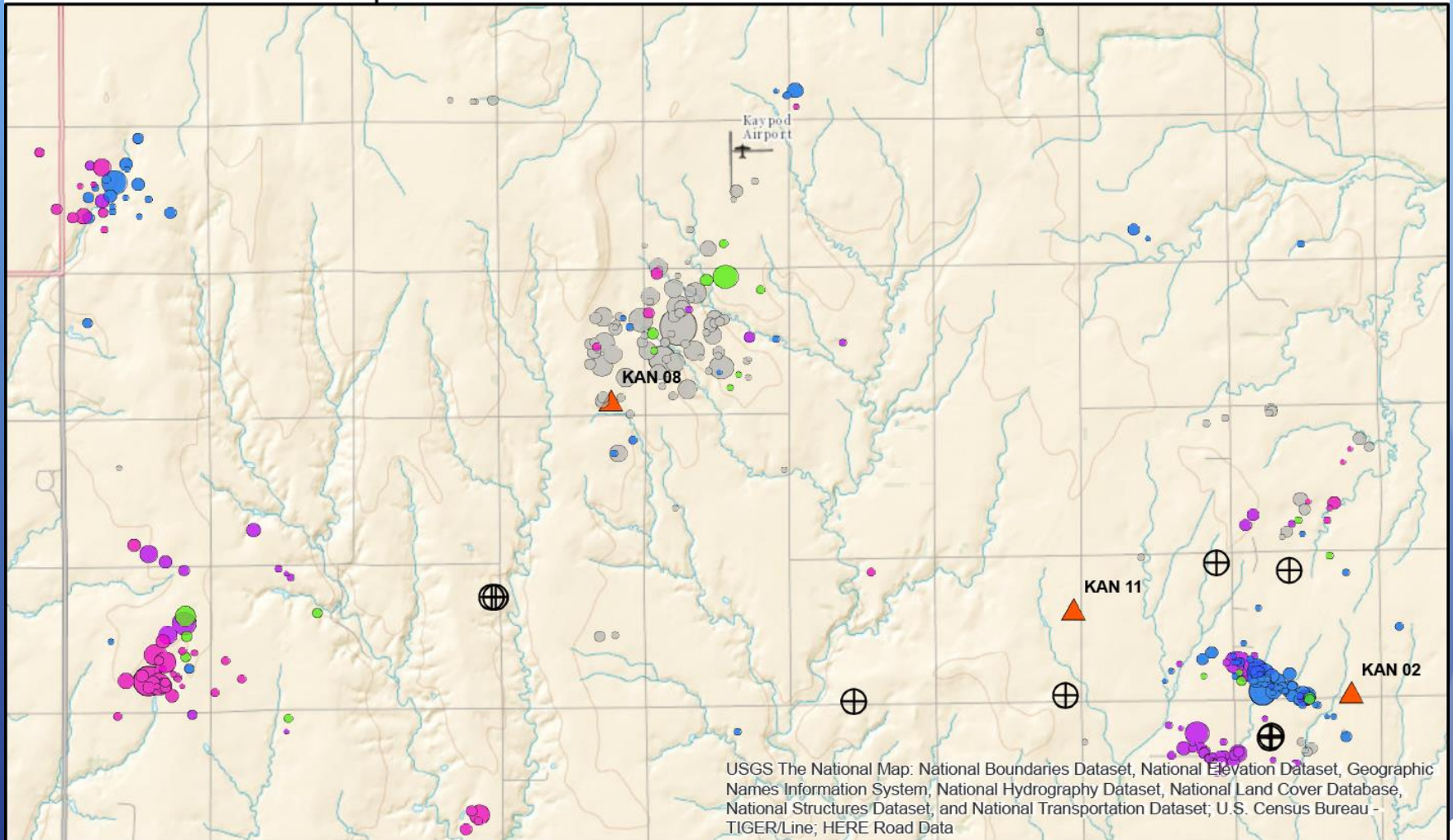
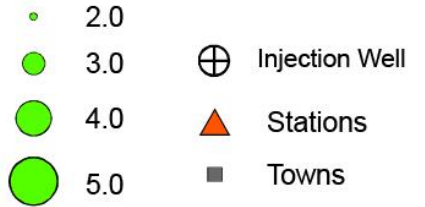
Earthquakes since 1 June 2014, $M_L > 2.0$



98° W

Earthquakes color coded by month;
Nov 2014 - pink, Dec 2014 - purple,
Jan 2015 - blue, Feb 2015 - green,
rest in grey.

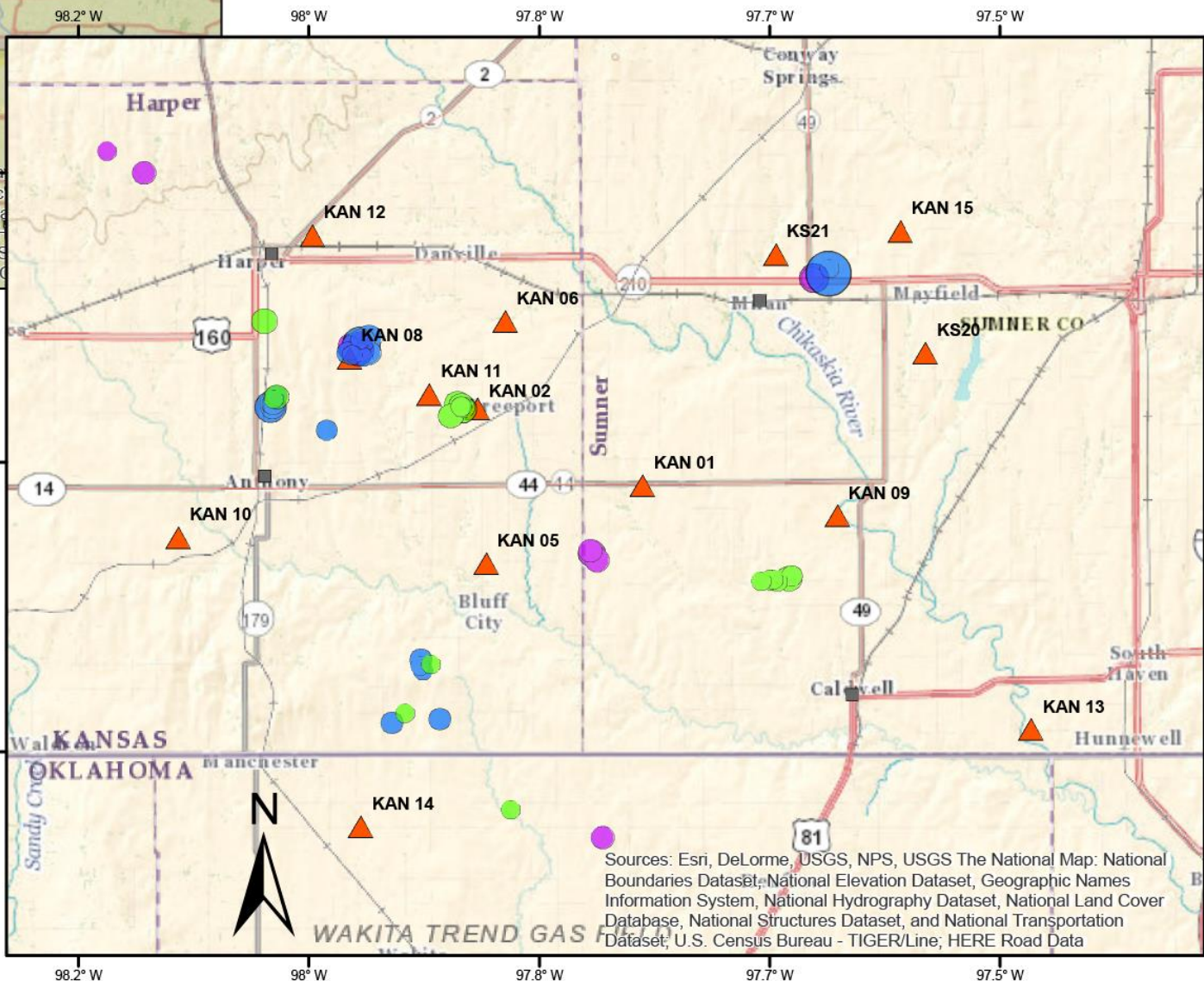
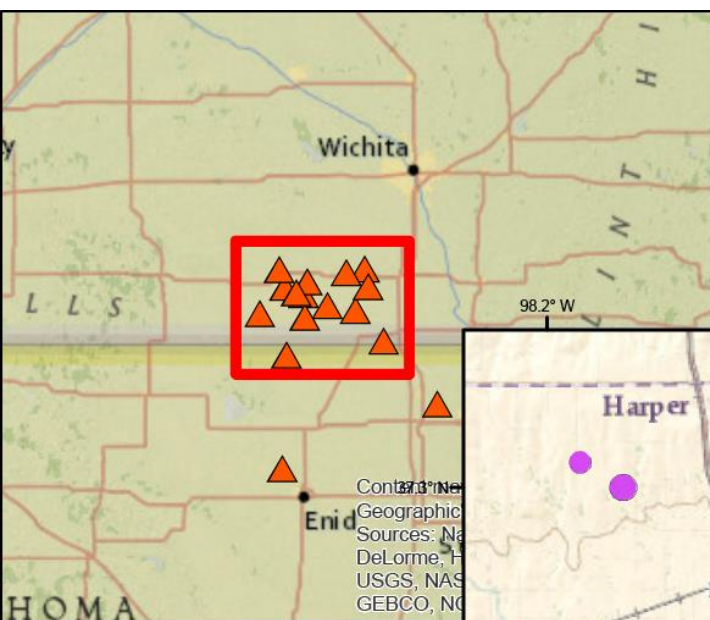
Magnitude



USGS The National Map: National Boundaries Dataset, National Elevation Dataset, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; U.S. Census Bureau - TIGER/Line; HERE Road Data

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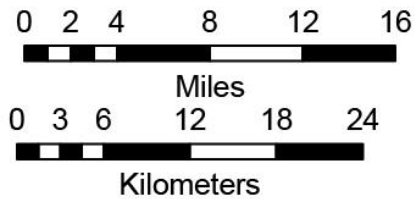
Earthquakes since 1 June 2014, $M_L > 3.0$



Magnitude

- 2.0
- 3.0
- 4.0
- 5.0
- ▲ Stations
- Towns

Earthquakes color coded by quarter;
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Southern Kansas Network Seismicity

Earthquakes since 1 June 2014, $M_L > 2.0$

97.7° W

KAN 09

Wichita

Enid

Content map
Geographic
Sources: Na
DeLorme, H
USGS, NAS
GEBCO, NC

Magnitude

- 2.0
- 3.0
- 4.0
- 5.0
- ▲ Stations
- Towns
- ⊕ Injection Well

Earthquakes color coded by quarter;
June 2014 - purple, Jan 2015 - blue,
Feb 2015 - green, rest in grey.

0 0.350.7 1.4 2.1 2.8

Miles

0 0.5 1 2 3 4

Kilometers



Doster

USGS The National Map: National Boundaries Dataset, National Elevation Dataset, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; U.S. Census Bureau - TIGER/Line; HERE Road Data

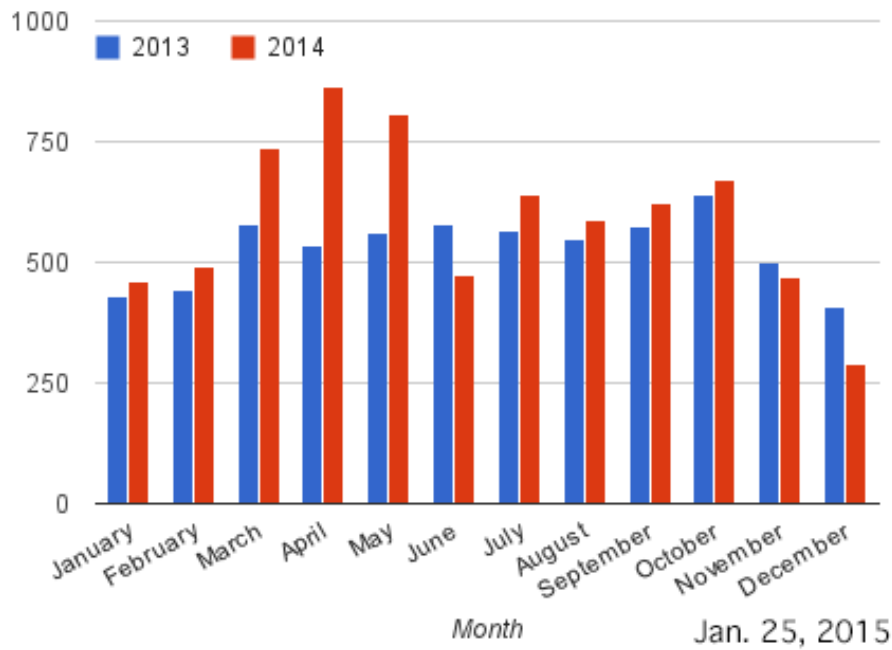
97.7° W

Preliminary Results

- Identified Over 4000 earthquakes in southern Kansas since July (Magnitude -1 - 4.8)
- Apparent fault structures identified
- M4.3 ground motions were very high (70% g)
- Earthquakes are shallow (3-7km) but below injection formation (1.5 - 1.7km)
- Some earthquakes are far from high-rate injection wells (10+ km)

Will the price of oil affect the seismicity? (it hasn't yet)

Wells permitted each month



Wells spudded each month

