Oklahoma Geological Survey Coordination of Mid-Continent Carbon Management: Induced Seismicity and Subsurface Fluid System

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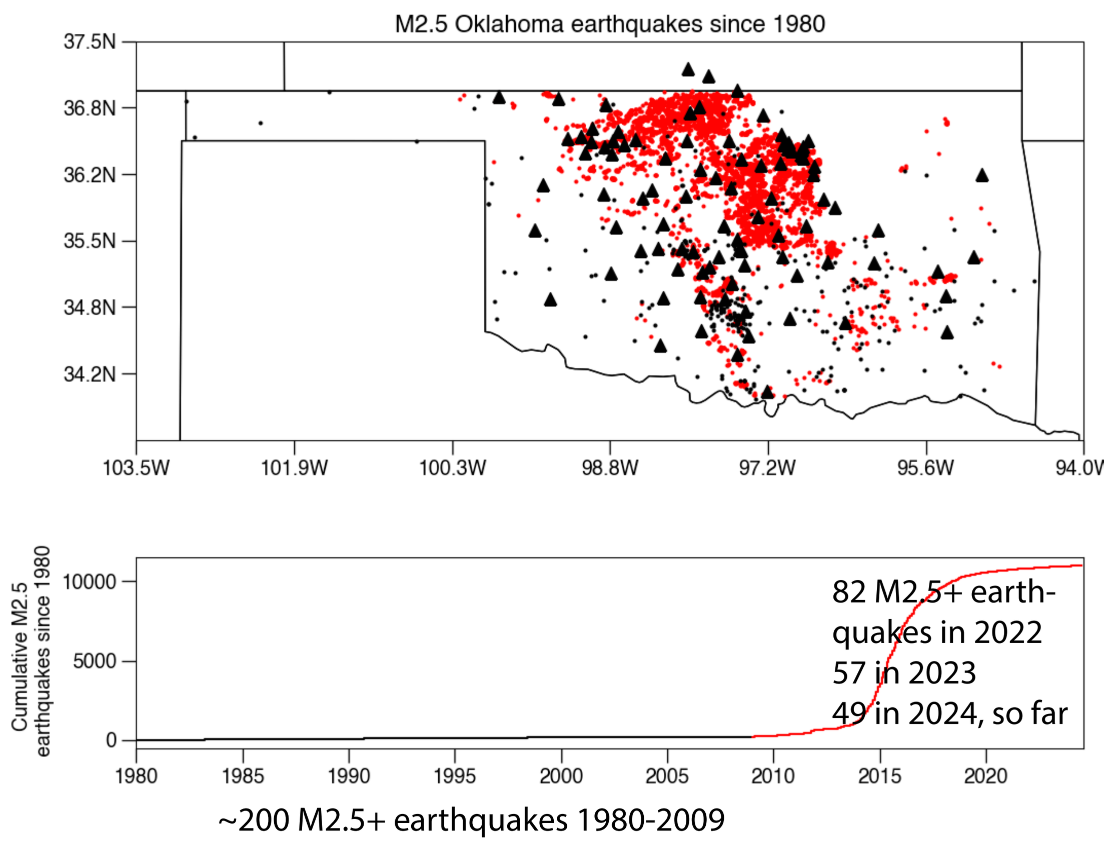
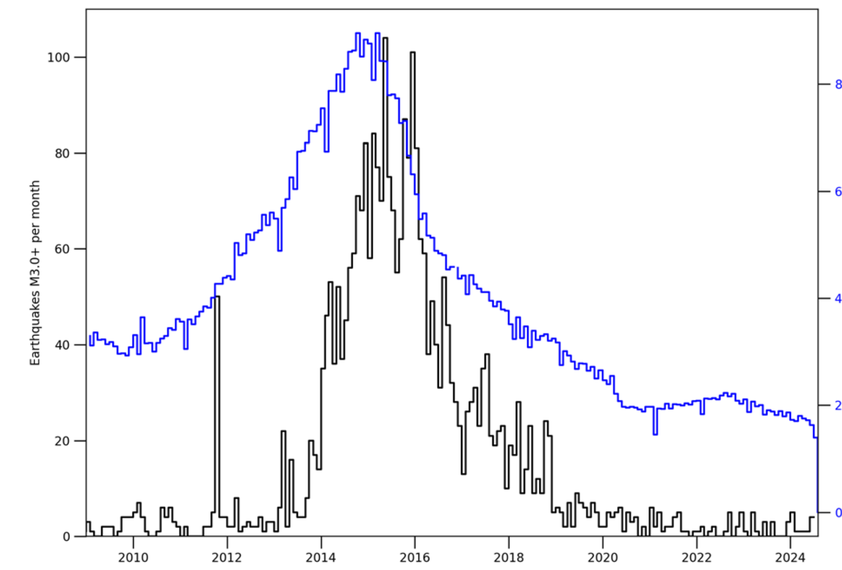
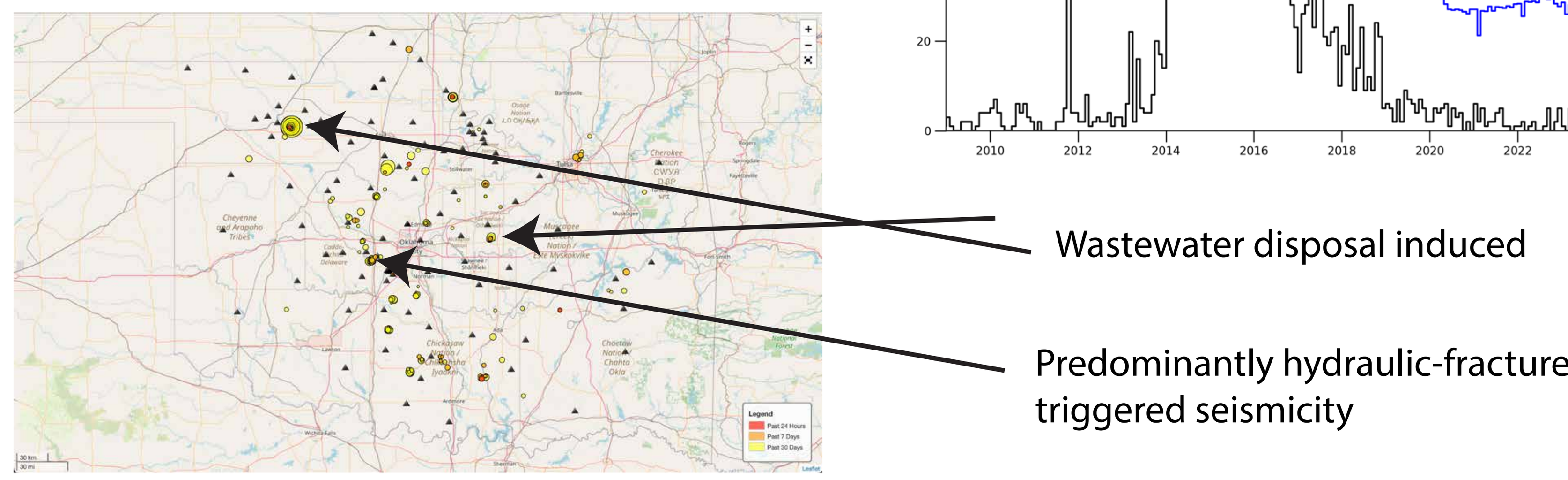


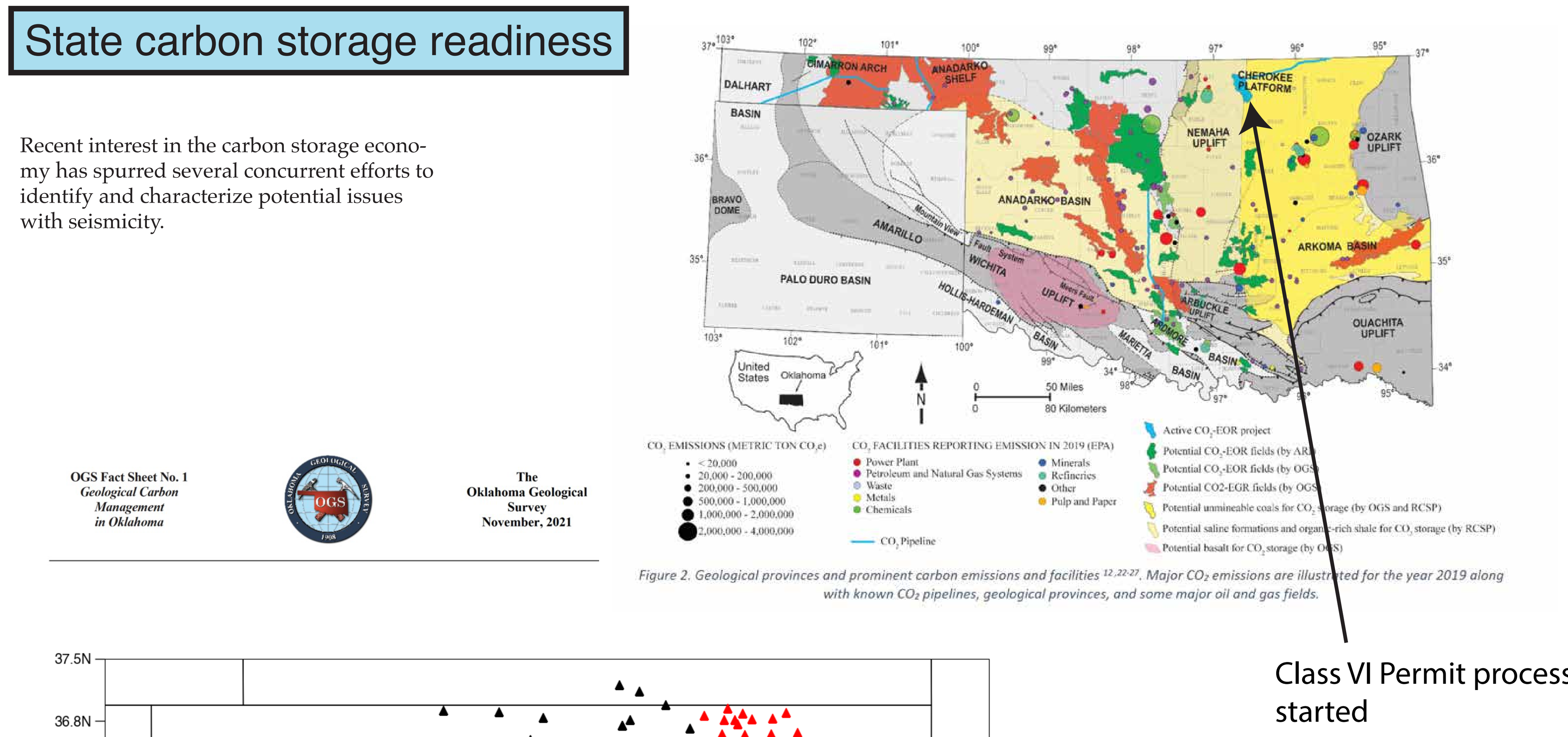
Oklahoma has experienced a significant increase in seismicity in the last decade (LEFT), that is largely attributable to wastewater disposal into the Arbuckle Group, directly above basement rocks (RIGHT). The figure at right is an updated version of the plot originally shown in Walter et al. (2020). In the last month (BOTTOM), there have been several earthquake clusters spanning the state, not always concentrated in areas of high volume wastewater disposal.

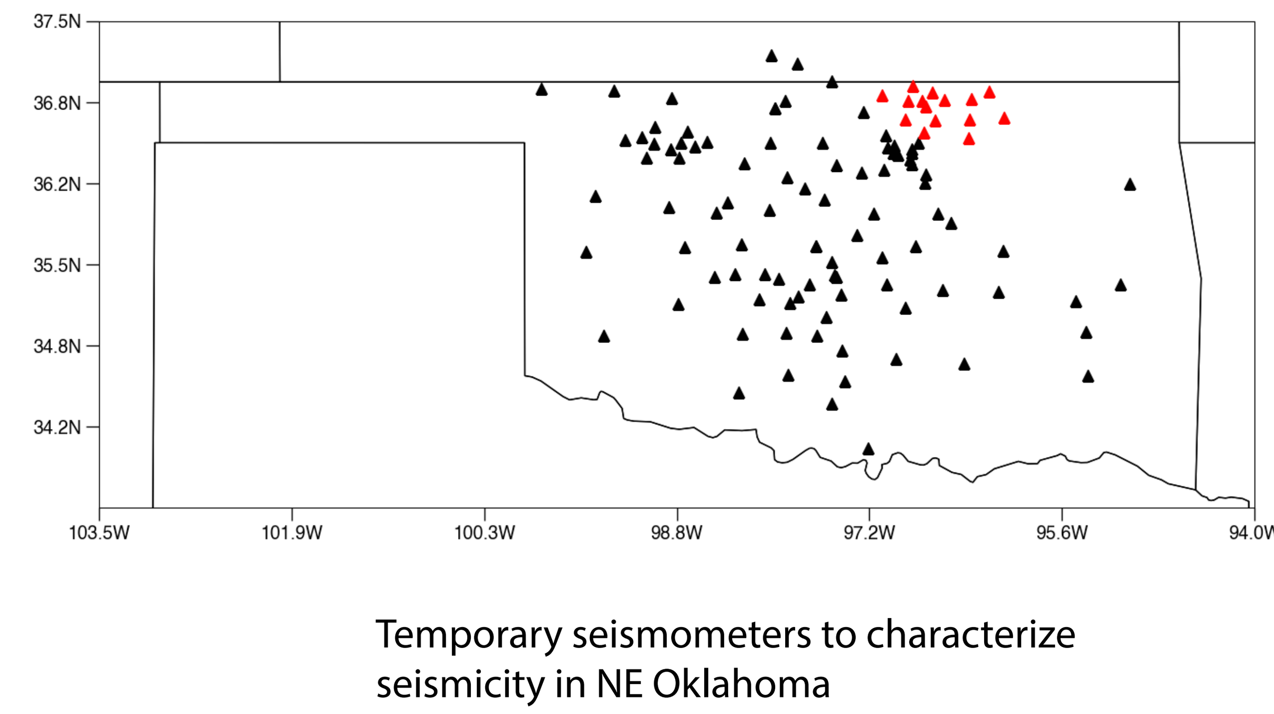




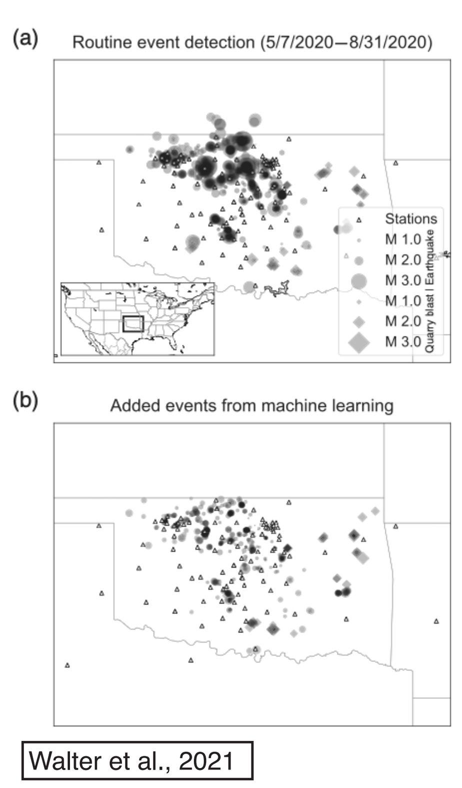
State carbon storage readiness

Recent interest in the carbon storage economy has spurred several concurrent efforts to identify and characterize potential issues with seismicity.



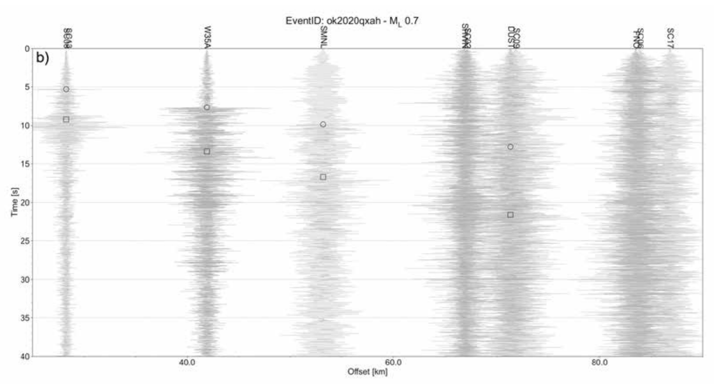


Machine-learning (ML) enhancement



Since May 2020, OGS has intergrated machine-learning pickers into the daily workflow for producing a reviewed catalog during regular business days. Our software package (easyQuake - see panel below) is run nightly and those detections are reviewed within our GUI Seiscomp analysis software during the business day by OGS analysts.

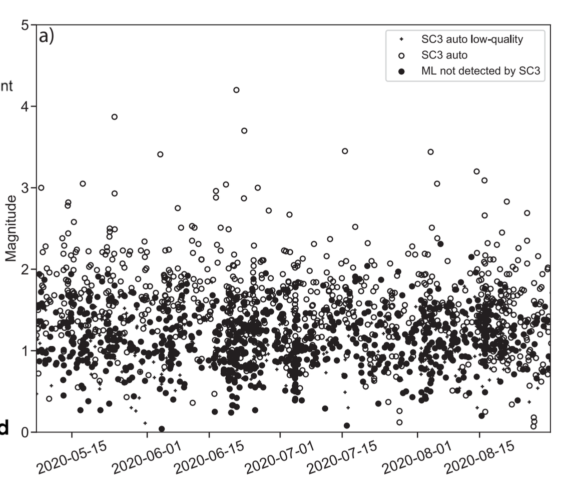
easyQuake - https://www.github.com/jakewalter/easyQuake

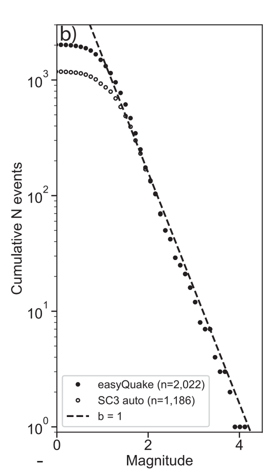


1. Detect – Choose machine-learning picker, either the generalized phase detector (Ross et al., 2018), EQTransformer (Mousavi et al., 2020), or PhaseNet (Zhu and Beroza, 2019)
2. Associate and locate - Modified PhasePApy 1D associator (Chen and Holland, 2016)
3. Magnitude - Compute preliminary magnitude
4. Full QuakeML file event files
5. Input it into SeiscomP system for analyst review or output various file formats for relocation or focal mechanism determination

WORK FLOW	Continuous mode	Event mode
1. Download data	download_mseed	download_mseed_event
2. Run machine-learning phase detection	detection_continuous	detection_association_event
3. Associate phase picks for event detection	association_continuous	
4. Combine all associated events in project folder and locate with hypoinverse	combine_associated	
5. Compute local magnitudes and form a fully-populated QuakeML file, with P-wave first motion polarity	magnitude_quakeml	magnitude_quakeml
(Optional) Output hypoDD file	quakeml_to_hypodd	quakeml_to_hypodd
(Optional) Output hash input files for focal mechanism	quakeml_hashpy	quakeml_hashpy

Can be run on data collected already or direct it to download data from FDSN servers

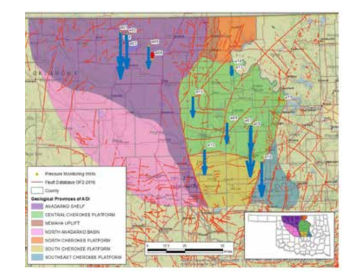


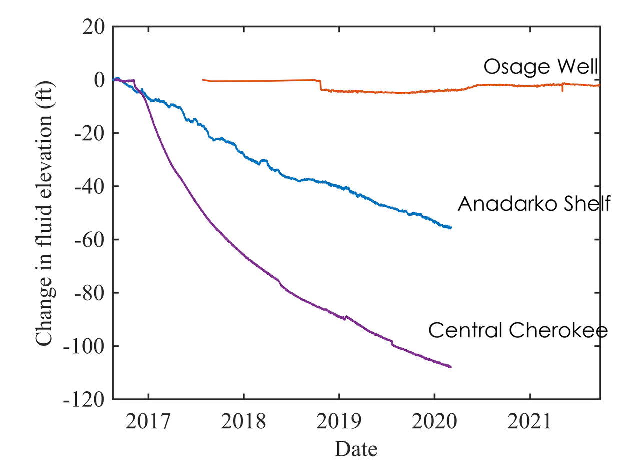


Pressure

We also operated pressure transducers in shut-in Arbuckle wells to track relative head changes over time.

See Benjamin Allen's work, currently in revision at JGR Solid Earth





Keys to successful geostorage

Volume – long-term operation and large volumes

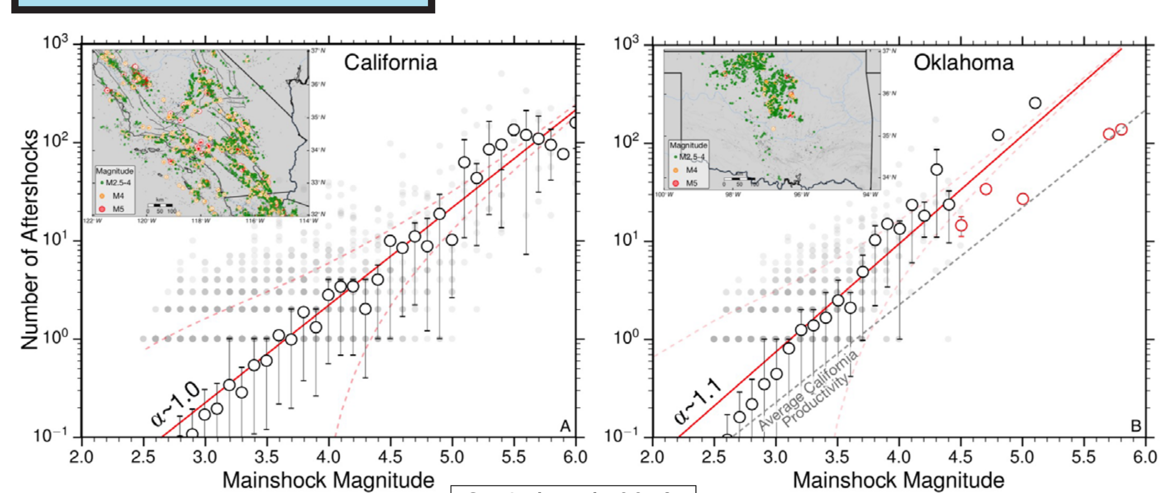
Geology and faults – planning operations to avoid large faults that are oriented for slip

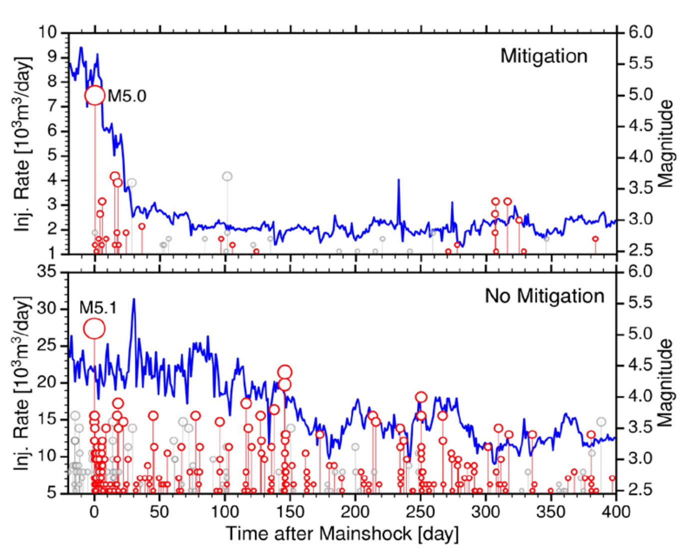
Rapid mitigation – traffic light pauses or disposal shut-in may be effective on hours to days timescales

Clear industry/public agency communication channels and proactive planning can keep the social license to operate intact. When events happen, a clear understanding of the "reaction" (mitigation)

Clear need for comprehensive borehole and surface monitoring by trusted (public) agencies

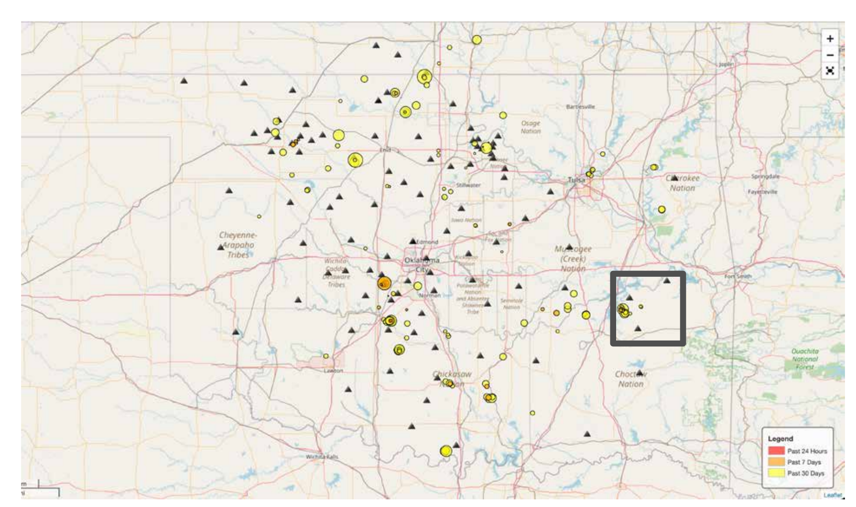
Fast mitigation

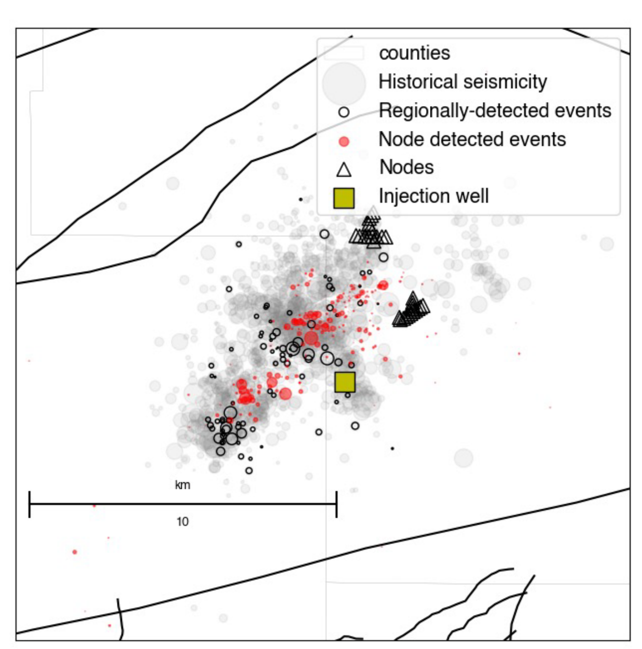


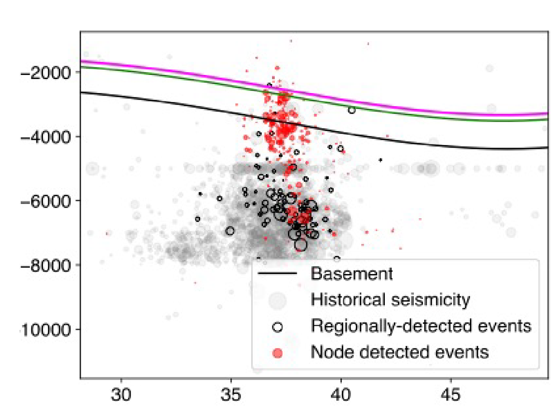


The Oklahoma Corporation Commission commonly halts injection near M4.0+ earthquakes. We found (Goebel et al., 2019) that the aftershock efficiency is decreased after those actions. Modeling suggests that the poroelastic stress decreases due to the rapid shut-in. Thus, rapid shut-in can mitigate ongoing seismicity, thus reducing the seismic hazard.

Case study: Large-N array and ML detection



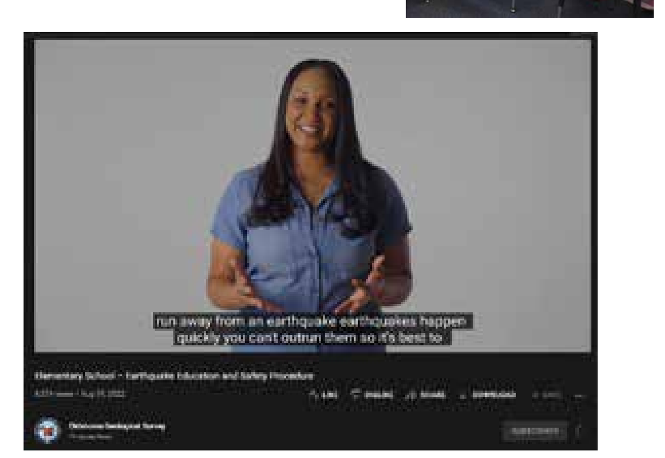




We piloted a new effort to install three-component nodes (large-N) that are capable of recording for a little over a month. Combining the new deployment strategy with ML detection applied to the collected data has yielded valuable insight into the structural features of ongoing wastewater disposal seismicity. These techniques could be used to study complex or double events (e.g. Ogwari et al., 2022). In addition, microseismicity remains an invaluable tool to deduce caprock failure. Thus, nodal temporary deployments could be a pivotal strategy for state-level monitoring efforts.

Outreach

Schools throughout Oklahoma already conduct earthquake drills due to present and past participation in Great Central US Shakeout. We speak at schools/groups about twice per month on the science we conduct, past decade of induced seismicity, and the future seismic hazard. Broad public outreach would be needed for large regional geostorage efforts. For this effort, we specifically plan to engage Native Nations across the state.



In Fall 2022, we created several PSAs targeted at different age levels with what to do in an earthquake. These included Oklahoma contextual information. Scan the code below to see!

References

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Acknowledgements

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