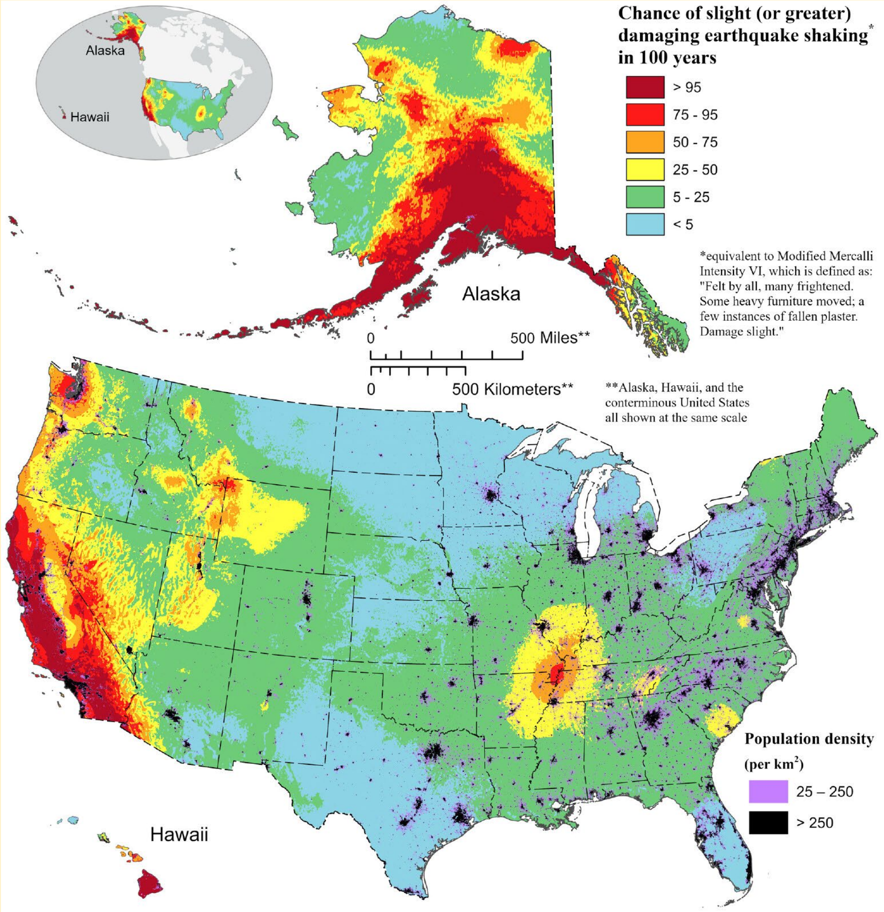
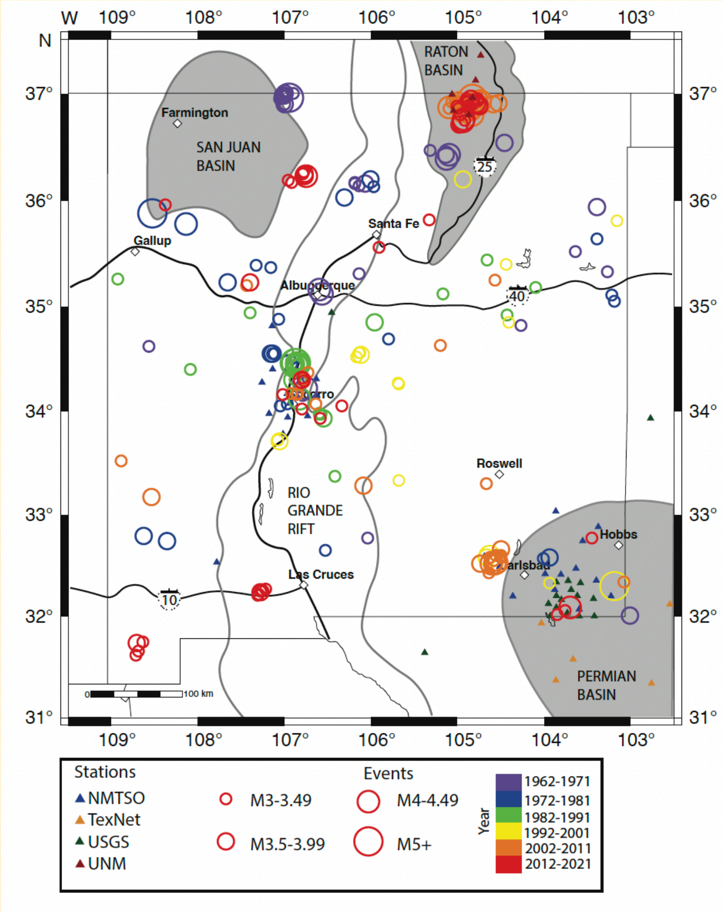
Optimizing automated earthquake detection methods in Delaware basin, southeastern New Mexico





Urbi Basu[1,2], Susan Bilek[1], Mairi Litherland[2]

[1]New Mexico Institute of Mining and Technology

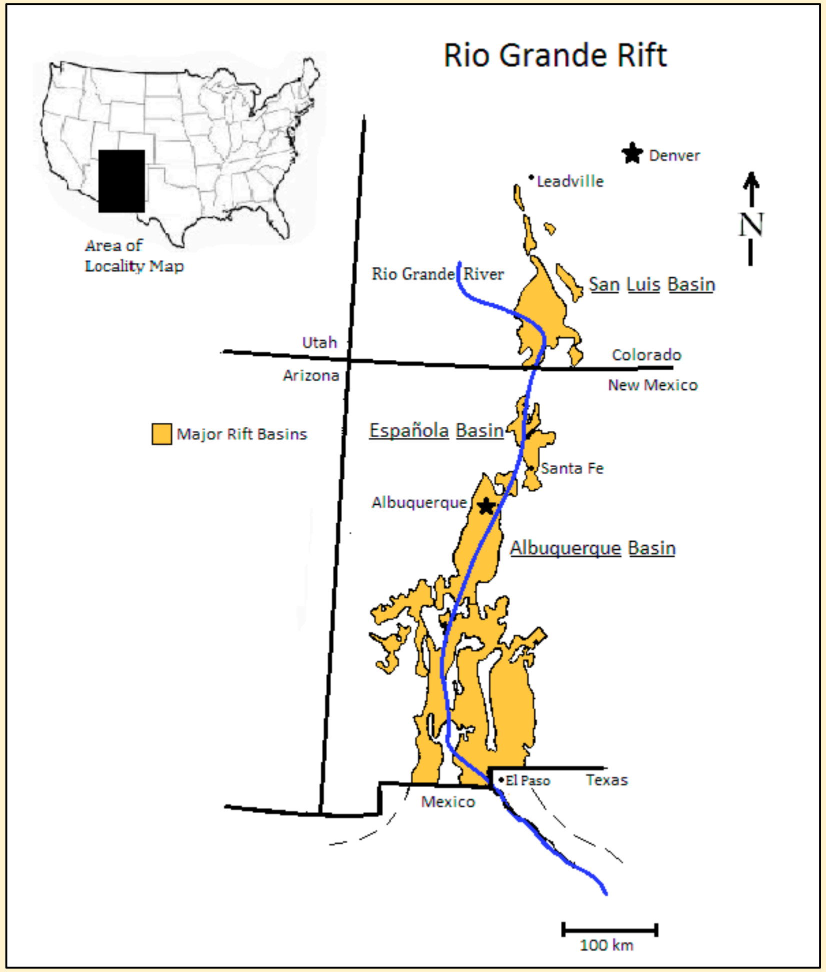
[2]New Mexico Bureau of Geology and Mineral Resources

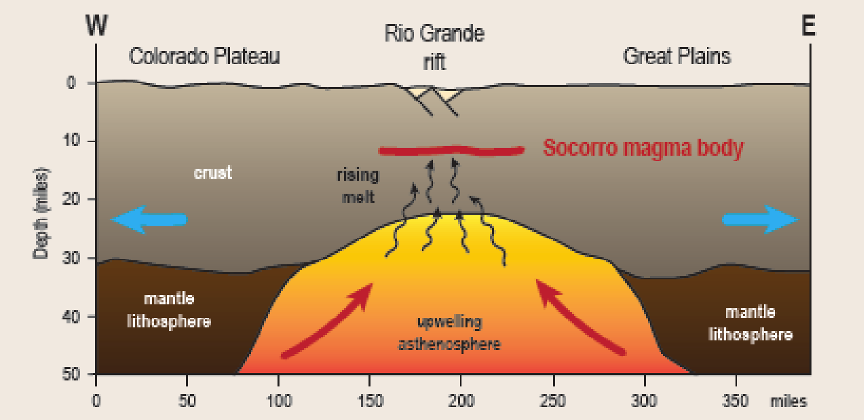
EARTHQUAKES IN NEW MEXICO

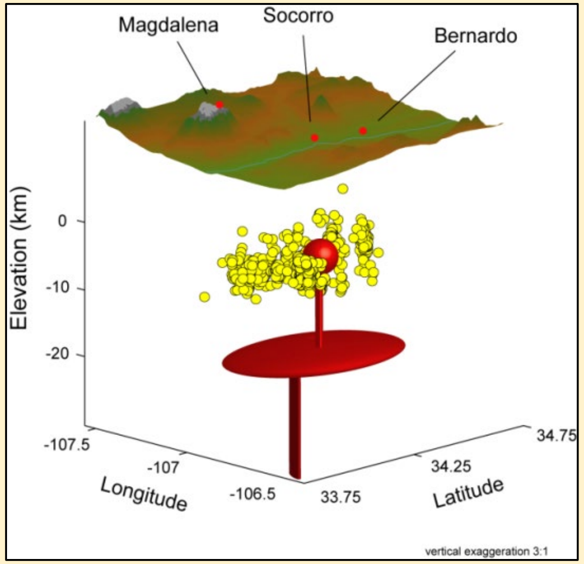
- Tectonic activity from Rio Grande Rift, E-W extending rift that extends from Colorado to northern Mexico

- **Socorro magma body**
  - Shallow, thin sill of magma at ~19 km depth
  - 1906 ~M6.2 earthquake in Socorro
  - Socorro Seismic Anomaly Region with ~50% of state's tectonic seismic activity

- **<u>Recent activity from induced seismicity</u>**

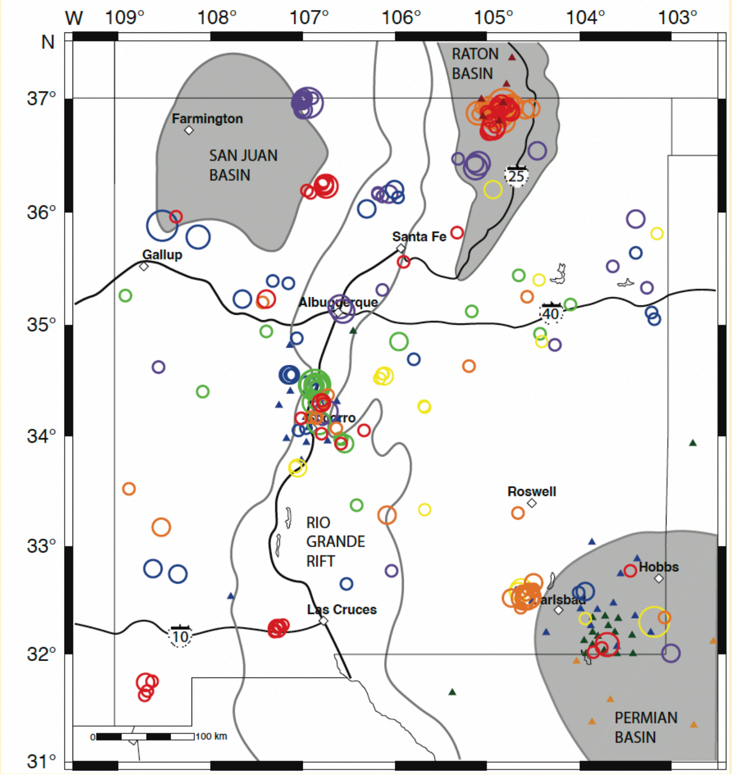




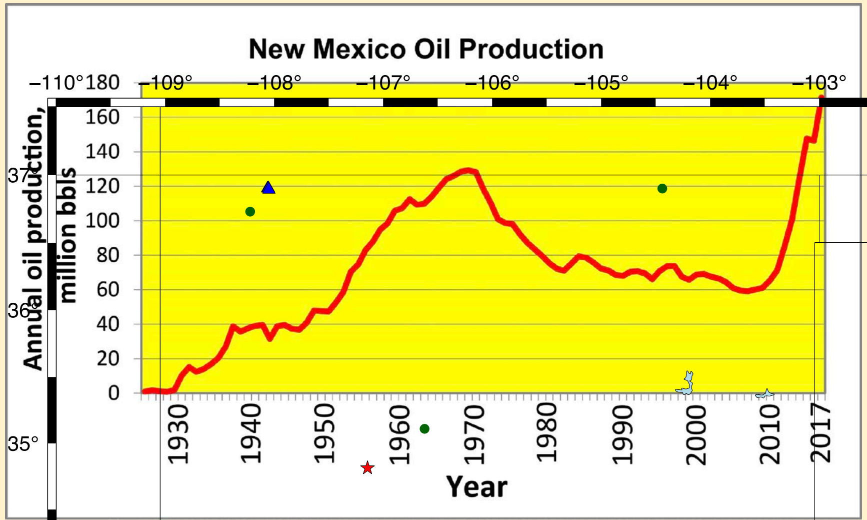


INDUCED SEISMICITY

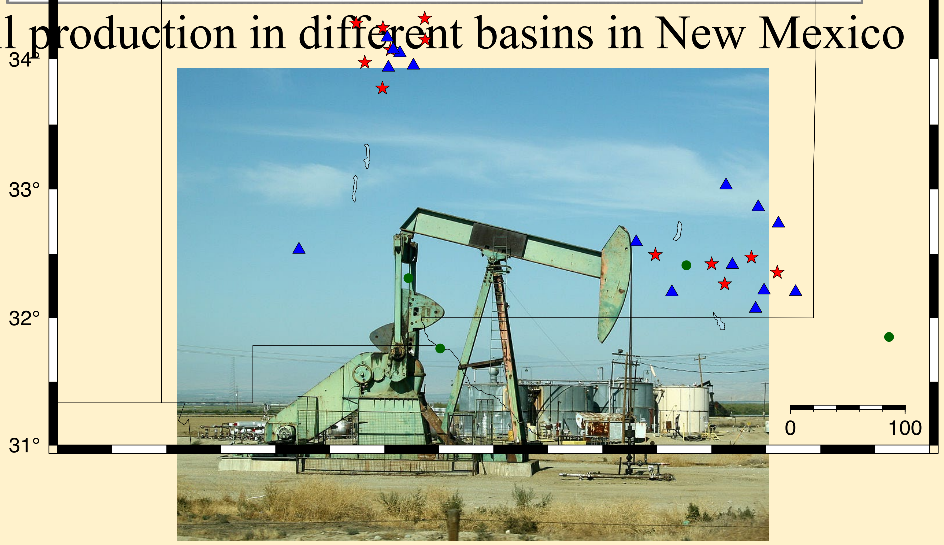
- Human activities such as oil and gas production, mining, geothermal extraction, and carbon sequestration can produce earthquakes
- Oil and gas production in New Mexico has increased significantly in recent years, which has led to an increase in induced earthquakes
- **Existing seismic network**



Map showing the earthquakes (M>3.0) from the USGS and NMTSO catalog from 1962-2021 (Litherland, 2023)

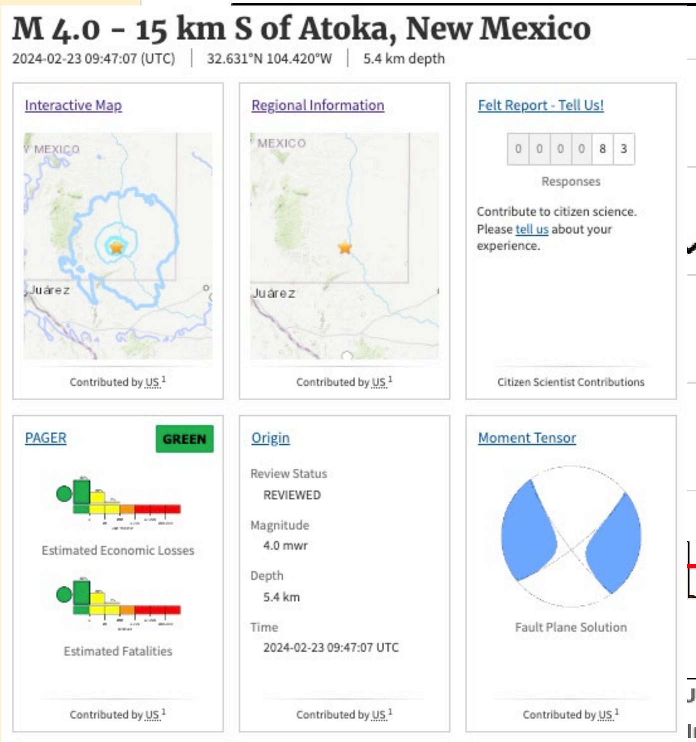


Oil production in different basins in New Mexico

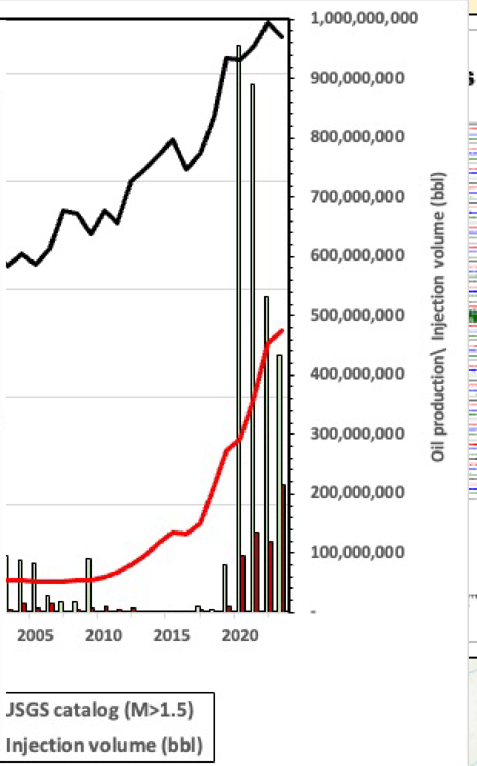


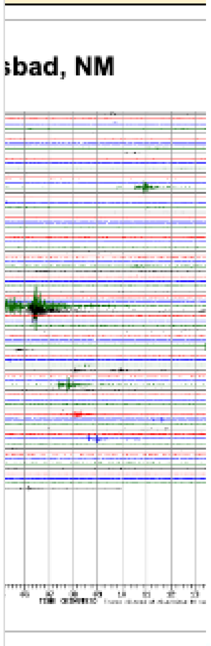
BACKGROUND

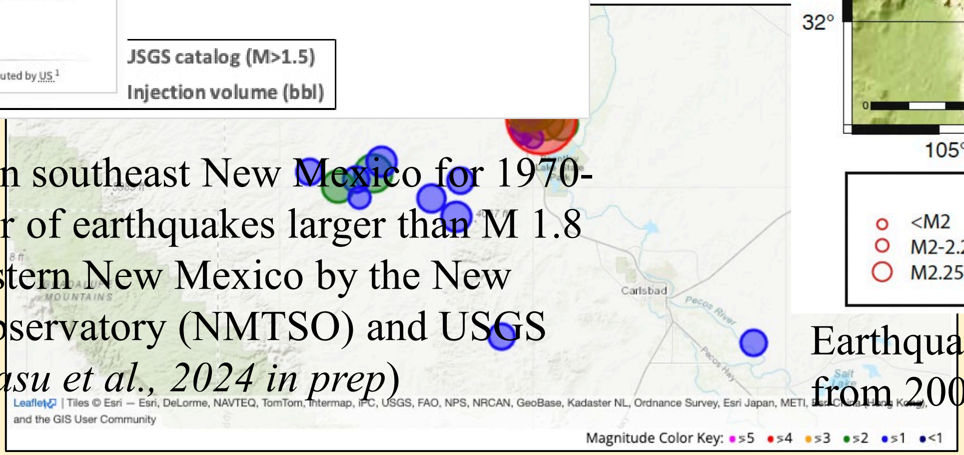
- South eastern New Mexico – Part of the Delaware basin with significant oil and gas extraction activities since the 1960's
- Substantial increase in seismicity since 2010 associated with an increase in oil and gas production and wastewater disposal



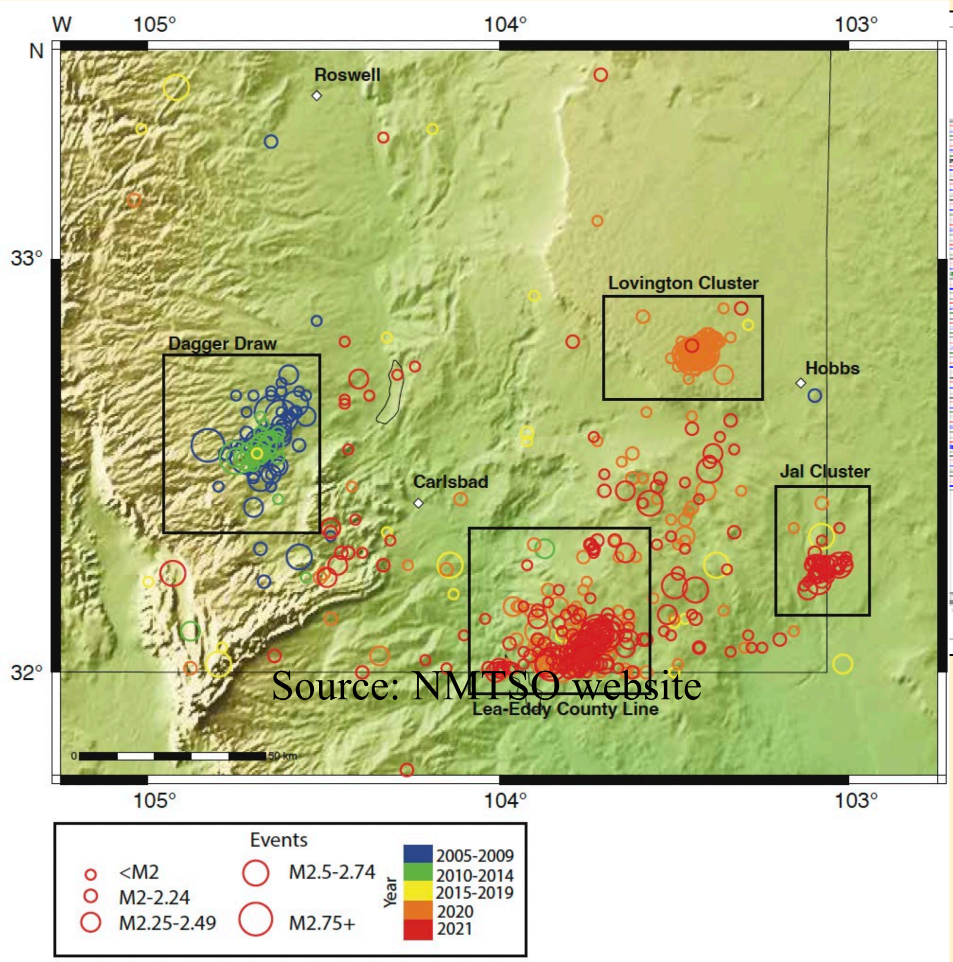
Source: USGS website



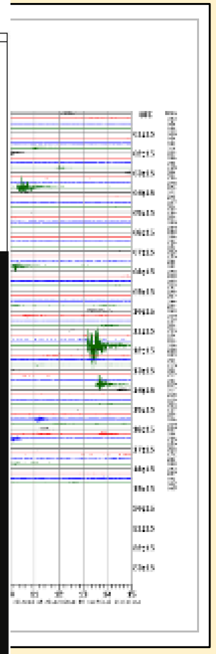




Oil production and seismicity in southeast New Mexico for 1970-2023. Histograms show number of earthquakes larger than M 1.8 and M 1.5 recorded in southeastern New Mexico by the New Mexico Tech Seismological Observatory (NMTSO) and USGS ComCat from 1970 to 2023 (*Basu et al., 2024 in prep*)



Source: NMTSO website



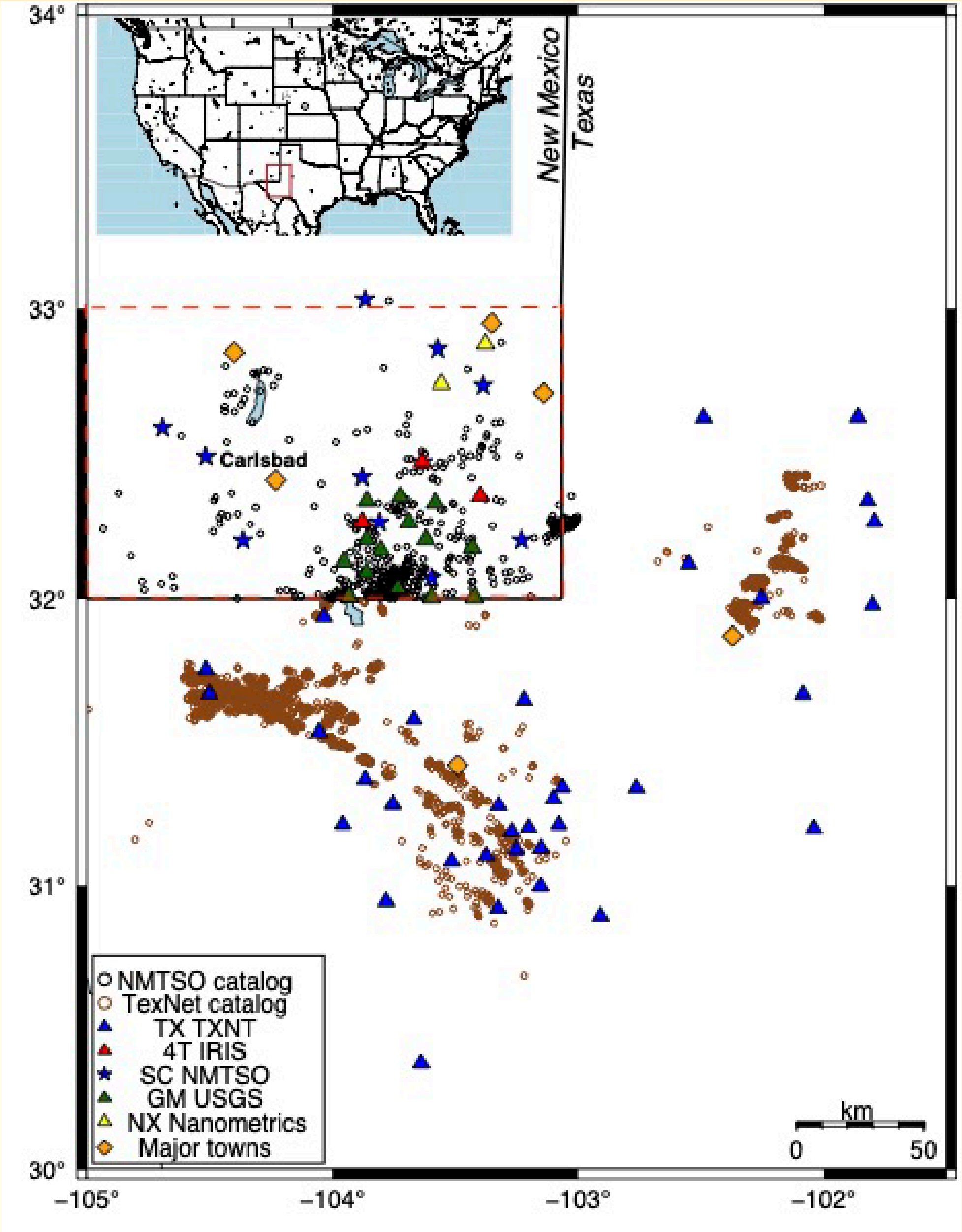
Earthquakes larger than M 1.8 recorded by the NMTSO from 2005 to 2021 (Litherland, 2023)

Source: NMTSO website

PROJECT OBJECTIVE

- Test multiple template matching and machine learning tools (EQTransformer and PhaseNet) to improve automated earthquake detection capabilities for the south-eastern New Mexico region
- Recommend automated earthquake detection workflow for real time monitoring at the New Mexico Tech Seismological Observatory (NMTSO)
- Reduce manual review effort for earthquake detection and location at the NMTSO

- Southeast New Mexico: 485 events in the NMTSO catalog and 37 events in the USGS catalog larger than M1
- Broader region including a portion of west Texas and southeast New Mexico, there are 4859 events in the TexNet catalog and 3317 earthquakes in the USGS catalog larger than M1
- Maximum of 64 seismic stations
- The NMTSO catalog will serve as the baseline for comparison with the new automated catalogs.



Study region showing earthquake activity for the year 2021 and seismic stations used in the study (*Basu et al., 2024 in prep*)

DATASET AND METHODOLOGY

- Automated earthquake detection workflow divided into three sections:

  Phase auto picking → Event association → Initial earthquake location

P and S phase auto picking

Template matching

- Cross-correlation based scanning algorithm to identify events of similar signature (Aster and Rowe, 2000; Rowe et al., 2002, Stankova et al., 2008)
- Comparison of a previously identified earthquake (master event) to a continuous time series at the same station
- 33 event templates with magnitude > 2.0
- Correlation coefficient thresholds ranging from 0.5 -0.3 tested to minimize the number of false positive and false negatives

EQTransformer

PhaseNet

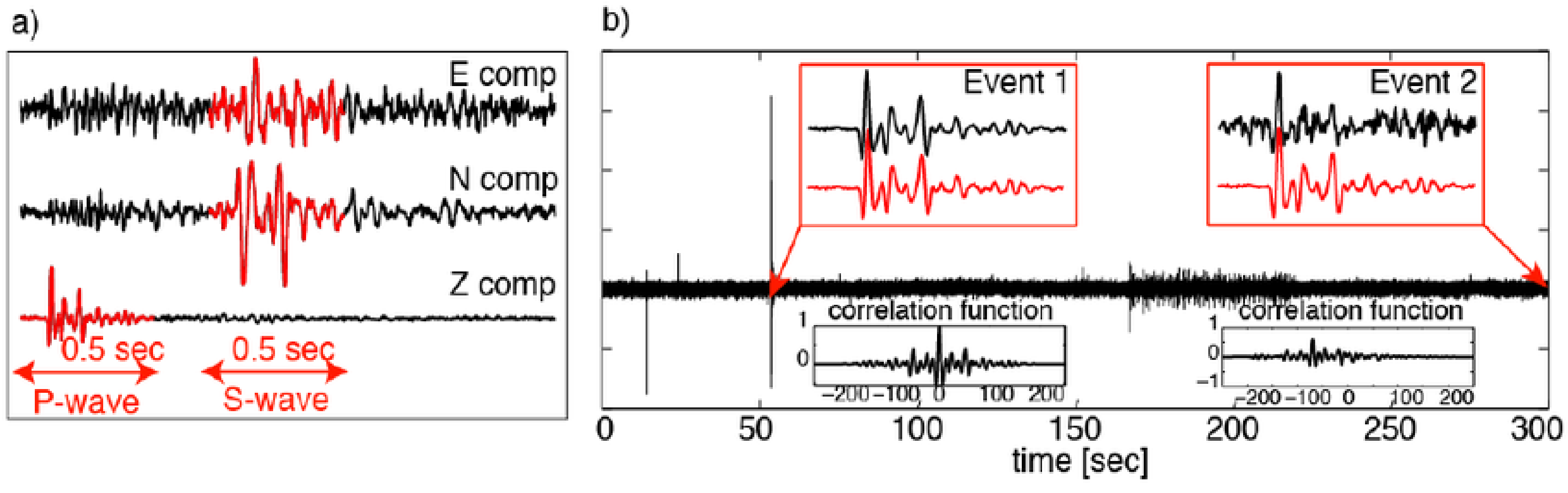


Illustration of template matching method (Goertz-Allmann et al., 2014)

DATASET AND METHODOLOGY

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- Automated earthquake detection workflow divided into three sections:

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P and S phase auto picking

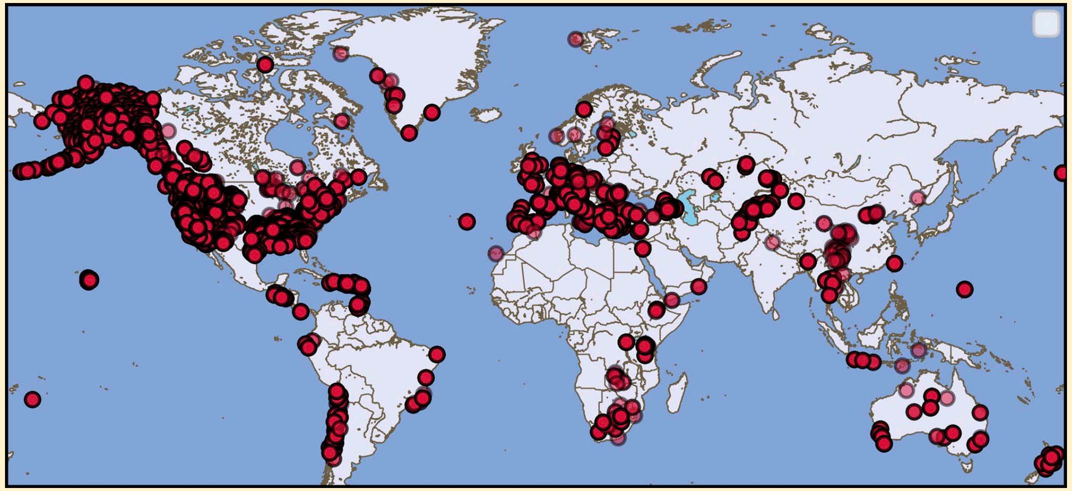
Template matching

EQTransformer

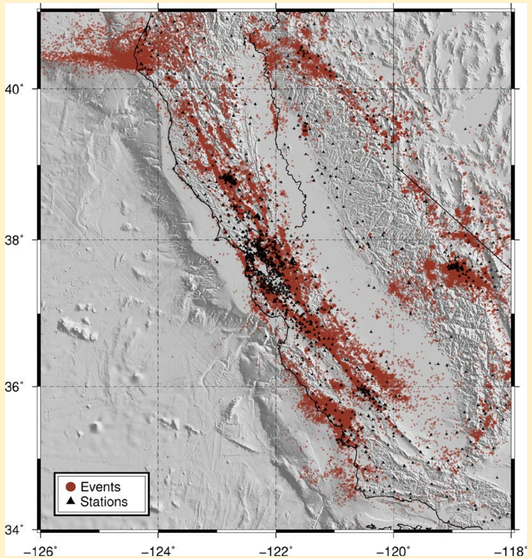
- Machine learning tool designed for automated phase picking that utilizes neural network approach for automated earthquake detection
- Uses a globally trained dataset for detecting earthquakes from continuous waveform data

PhaseNet

- Machine learning based seismic phase auto picker
- Model trained by manually labelled P and S arrival times from the Northern California Earthquake Data Center
- No existing earthquake information from study region needed



Training and test dataset for EQTransformer (Mousavi et al., 2020)



Training dataset (Zhu and Beroza, 2018)

DATASET AND METHODOLOGY

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- Automated earthquake detection workflow divided into three sections:

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P and S phase auto picking

Template matching	**EQTransformer**	**PhaseNet**

Event association

- P and S phase arrival times, number of phase picks and travel time residuals used to associate automated detections into initial earthquake locations at grid points

Initial earthquake location

Refined the initial grid earthquake locations using the least-squares location method VELEST

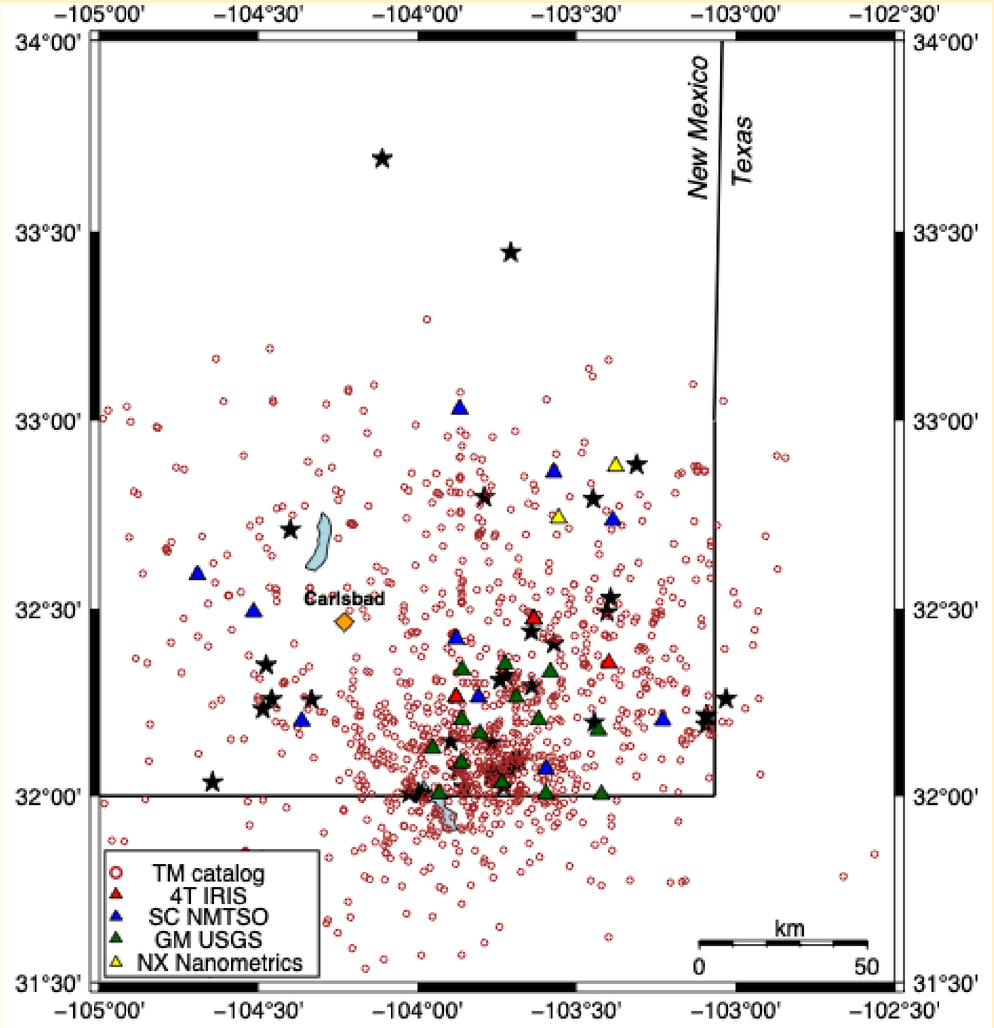
RESULTS

TEMPLATE MATCHING RESULTS

- Each of the automated detection methods produced an increase in the number of detected events during 2021, both within only southeast New Mexico as well a broader region extending into west Texas

Detection tool	Total events	False positive (%)	Number of missed events (≥ 5 *stations*)	Number of missed events (≥ 3 *stations*)
Template matching	1044	15	168	307
EQTransformer	19540	13	64	188
PhaseNet	63378	30	33	110

Comparison of the automated detections from the three automated catalogs

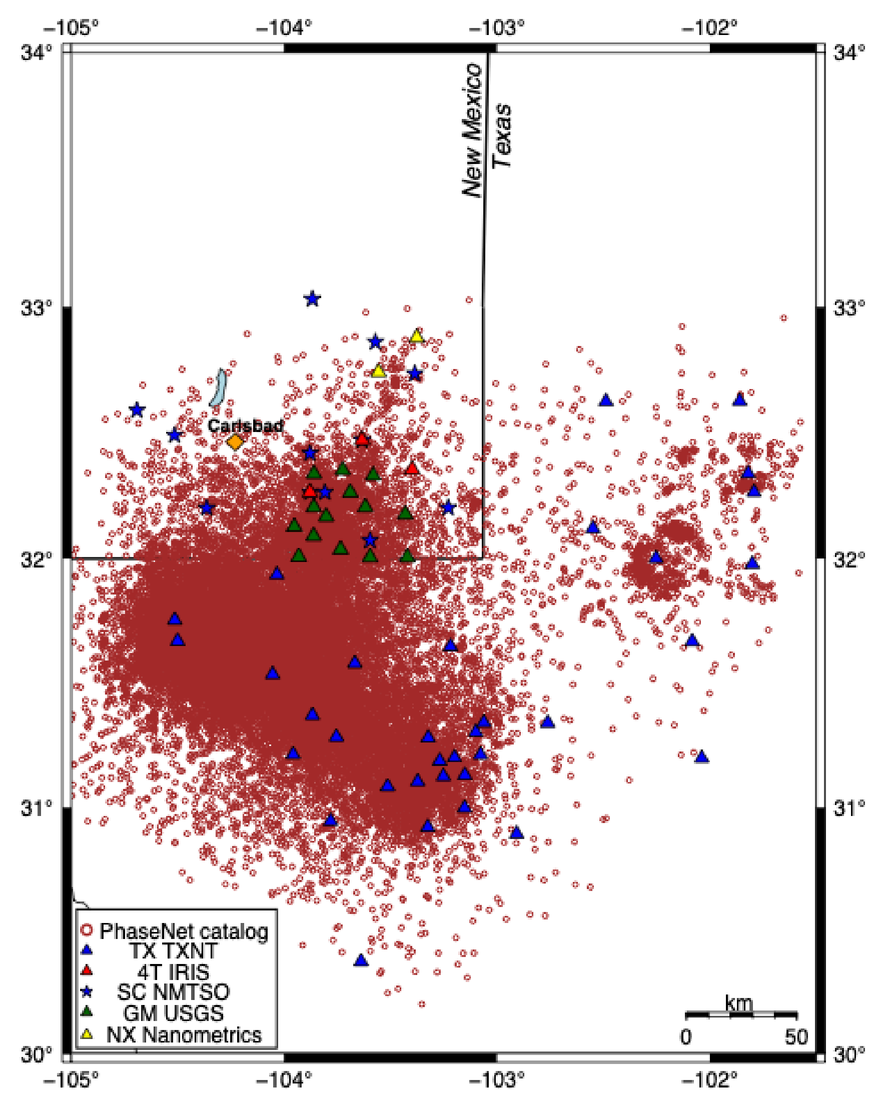


Earthquakes detected from Template matching – REAL – VELEST workflow. The black stars indicate the earthquake templates used as master events in the study (*Basu et al., 2024 in prep*)

RESULTS

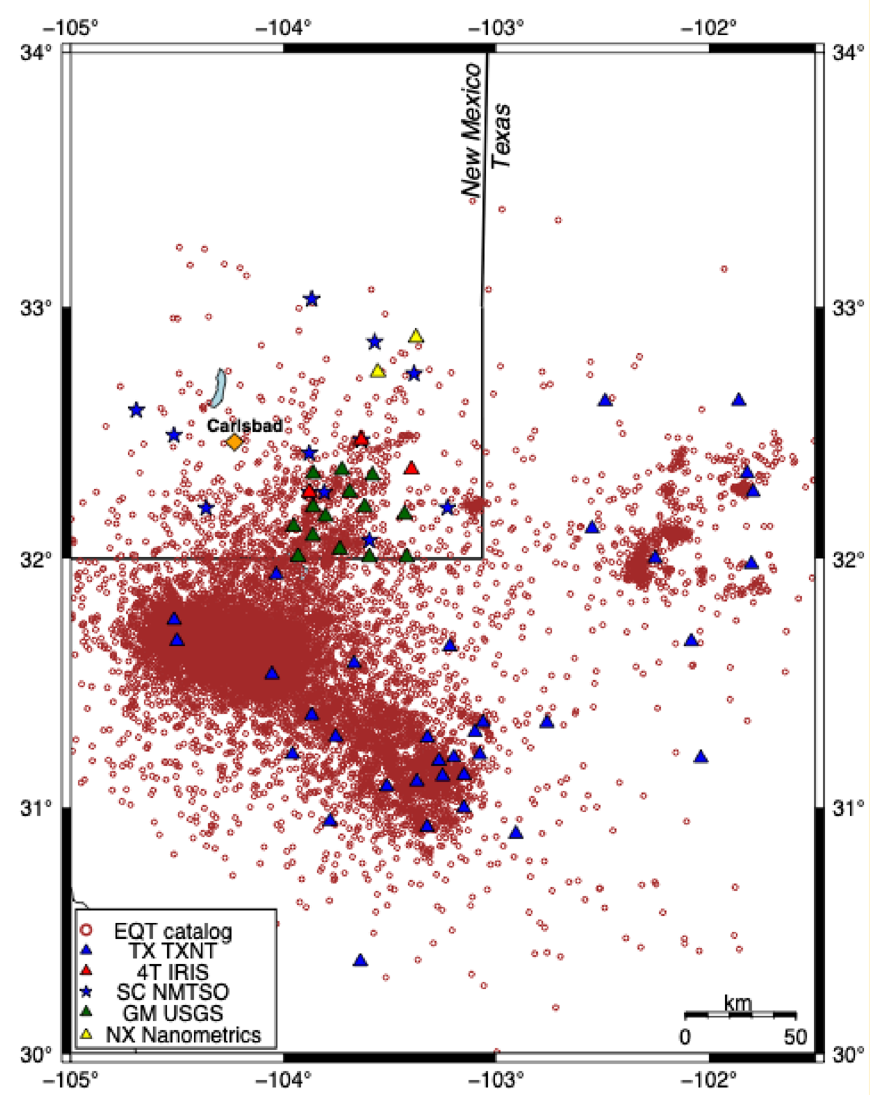
MACHINE LEARNING BASED AUTO DETECTOR RESULTS

PhaseNet



Initial locations of earthquakes detected from PhaseNet–REAL – VELEST workflow (*Basu et al., 2024 in prep*)

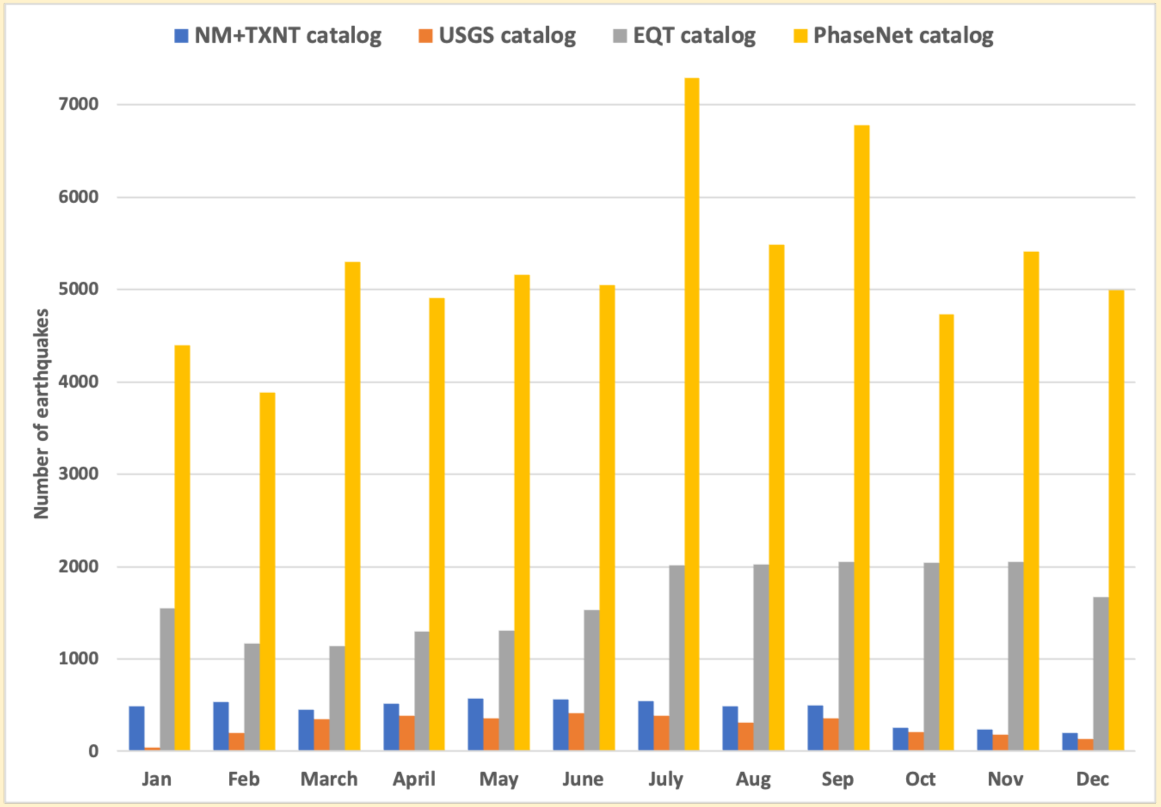
EQTransformer



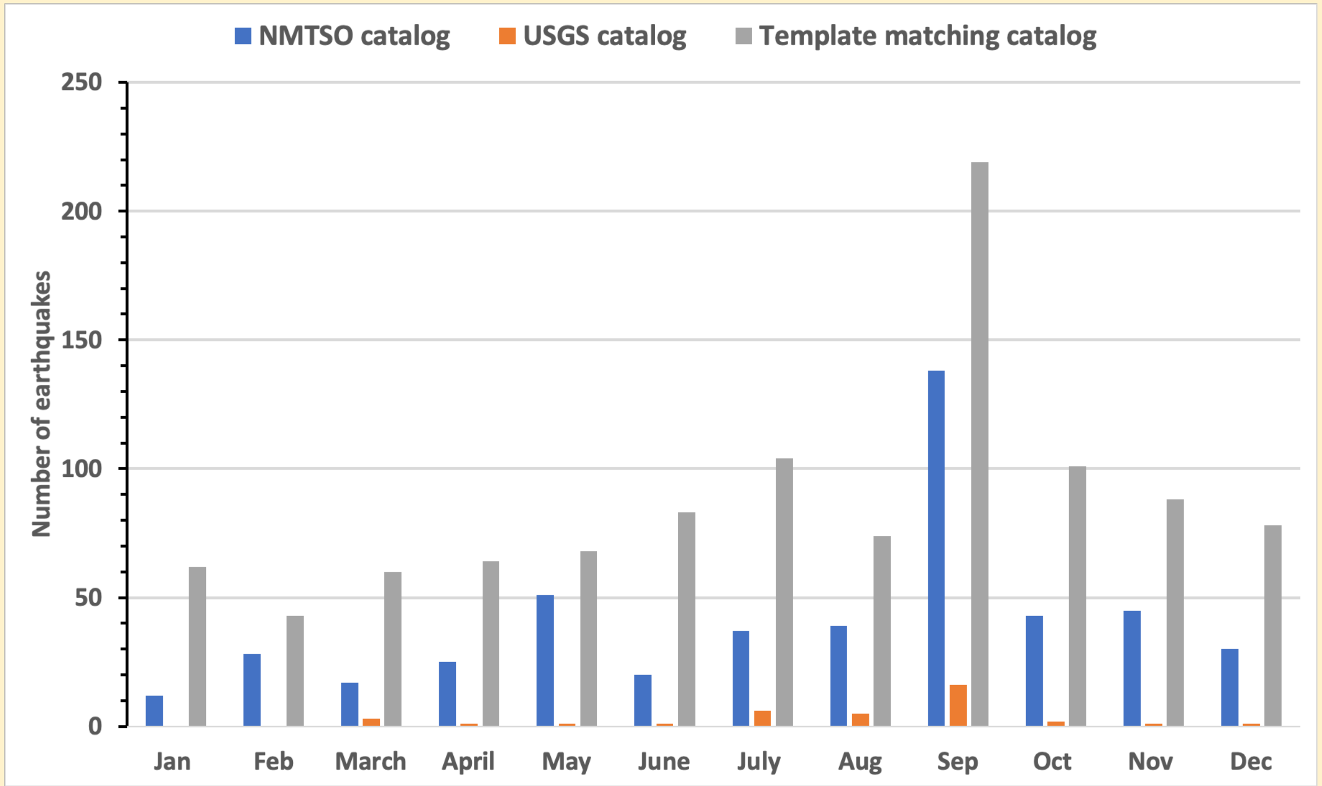
Initial locations of earthquakes detected from EQTransformer – REAL – VELEST workflow (*Basu et al., 2024 in prep*)

RESULTS

- Evaluation of the earthquake count of the different catalogs
- The overall monthly seismicity trend is similar between the NMTSO and three automated detection catalogs
- Increase of monthly trends in the EQTransformer and PhaseNet catalogs is positively correlated with high magnitude earthquakes (M > 2.5) in the later half of 2021



Comparison of the monthly earthquake count from machine learning automated catalogs (*Basu et al., 2024 in prep*)



Comparison of the monthly earthquake count from the NMTSO, USGS catalogs with the template matching results for southeast New Mexico (*Basu et al., 2024 in prep*)

RESULTS

- Evaluation of the earthquake count of the different catalogs
- The overall monthly seismicity trend is similar between the NMTSO and three automated detection catalogs
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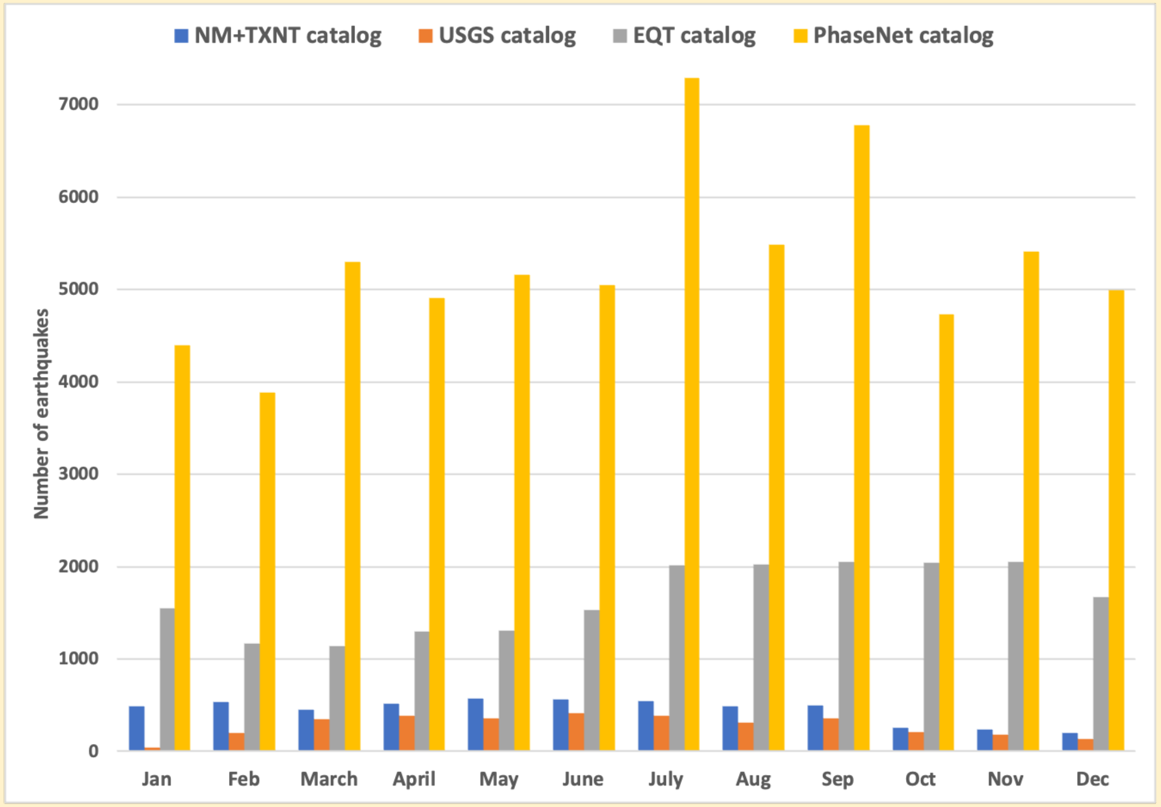

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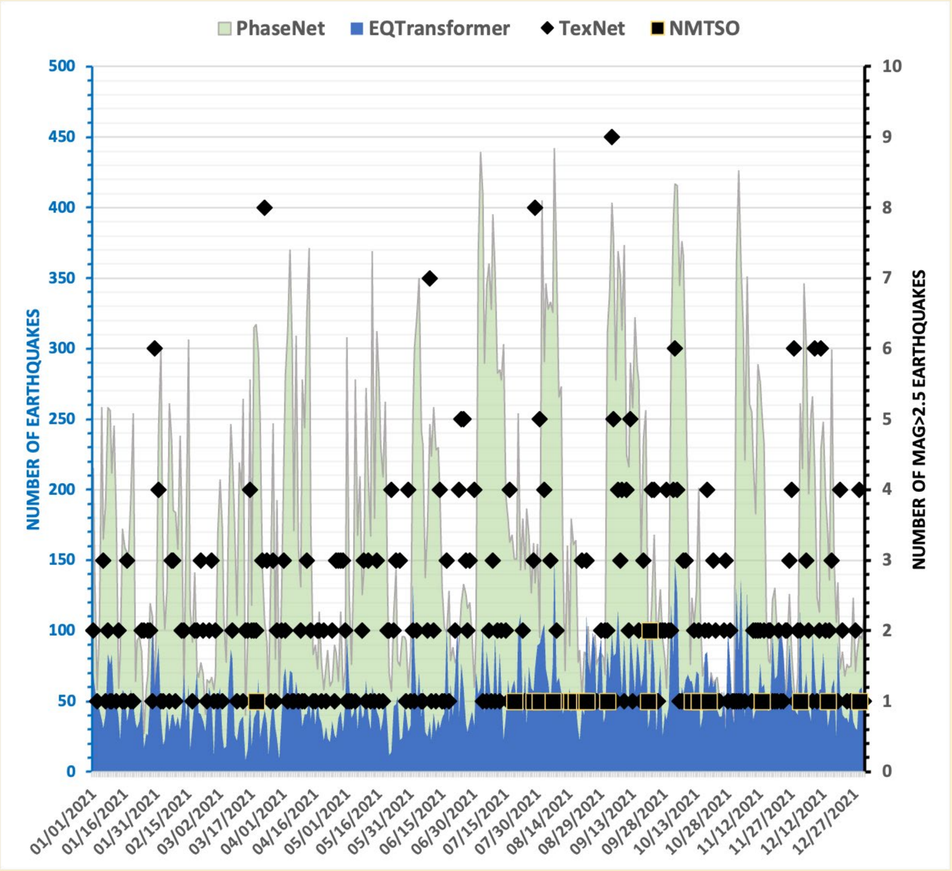

Daily earthquake count from EQTransformer and PhaseNet catalogs (*Basu et al., 2024 in prep*)

CONCLUSION

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Performance criteria	Template matching	EQTransformer	PhaseNet
Missed detections	168	64	33
Overall detection number	~ Two times as compared to NMTSO catalog	~ Four times as compared to (NMTSO+ TexNet) catalog for study region	~ Twelve times as compared to (NMTSO+ TexNet) catalog for study region
False positive rate	15%	13%	30%
Requirements of existing templates	Yes	No	No
Ease of implementation	Difficult	Moderate	Easy

NEXT STEPS

✓ **Implementing the automated tools in real time earthquake monitoring workflow**

- Earthquake relocations
- Use machine learning tools to detect more earthquakes from previous years **AND** in other parts of New Mexico
- Improving the seismic velocity model for better earthquake locations


Thank you