STATISTICAL UNDERSTANDING OF INJECTION-INDUCED EARTHQUAKES IN RATON BASIN, COLORADO & NEW MEXICO

ELIZABETH A. MENEZES, ANNE SHEEHAN, KRISTY TIAMPO, SHEMIN GE, SCOTT STOKES

CIRES and Department of Geological Sciences, University of Colorado Boulder

MAJOR WASTEWATER INJECTION SINCE '99

The Raton Basin, an underpressure coal-bed methane field, has had large volumes of fluid pumped from and injected into the subsurface as well as increased earthquake occurrences.

Prior to 2001 there was one M≥4 earthquake and after major injection began in 1999 there have been over a dozen (Rubinstein et al., 2014).

WHY STUDY INDUCED SEISMICTY

Human induced earthquakes are typically small in magnitude. However, in recent years across the central U.S. these earthquakes are increasing in frequency and magnitude (Rubinstein and Mahani, 2015).

Problem?

These induced earthquakes pose a hazard to local residents and create challenges for energy production.

10,766 EARTHQUAKES IN THIS STUDY

RESEARCH GOALS

Understand how the regional seismicity is changing due to subsurface processes and stress changes and discover how these mechanisms drive induced seismicity.

METHODS

Metric: Thirumalai-Mountain (TM)

What: Identify the equilibrium property of ***ergodicity***.

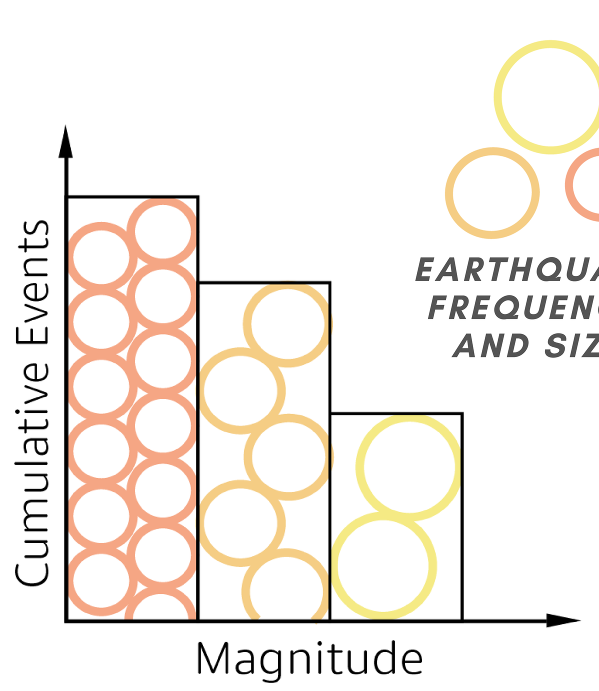
How: We take the Data Sum (integrated number of events for each timestep) and the Ensemble Average (mean of the Data Sum over a sample size based on location/box size) to calculate the variance.

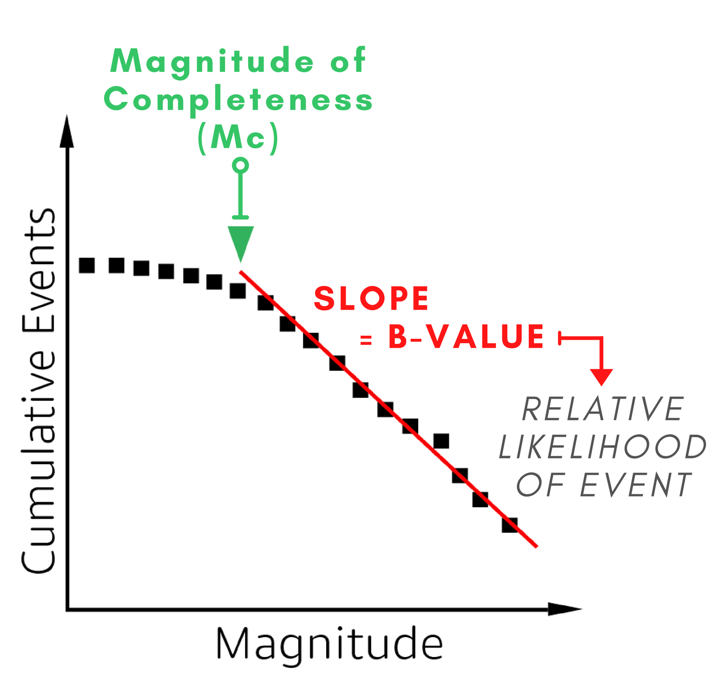
ERGODIC WHEN THE INVERSE OF THE SPATIAL VARIANCE GROWS LINEARLY WITH TIME

TIME needed to reach ergodic behavior →
ERGODICITY DIFFUSION PARAMETER →

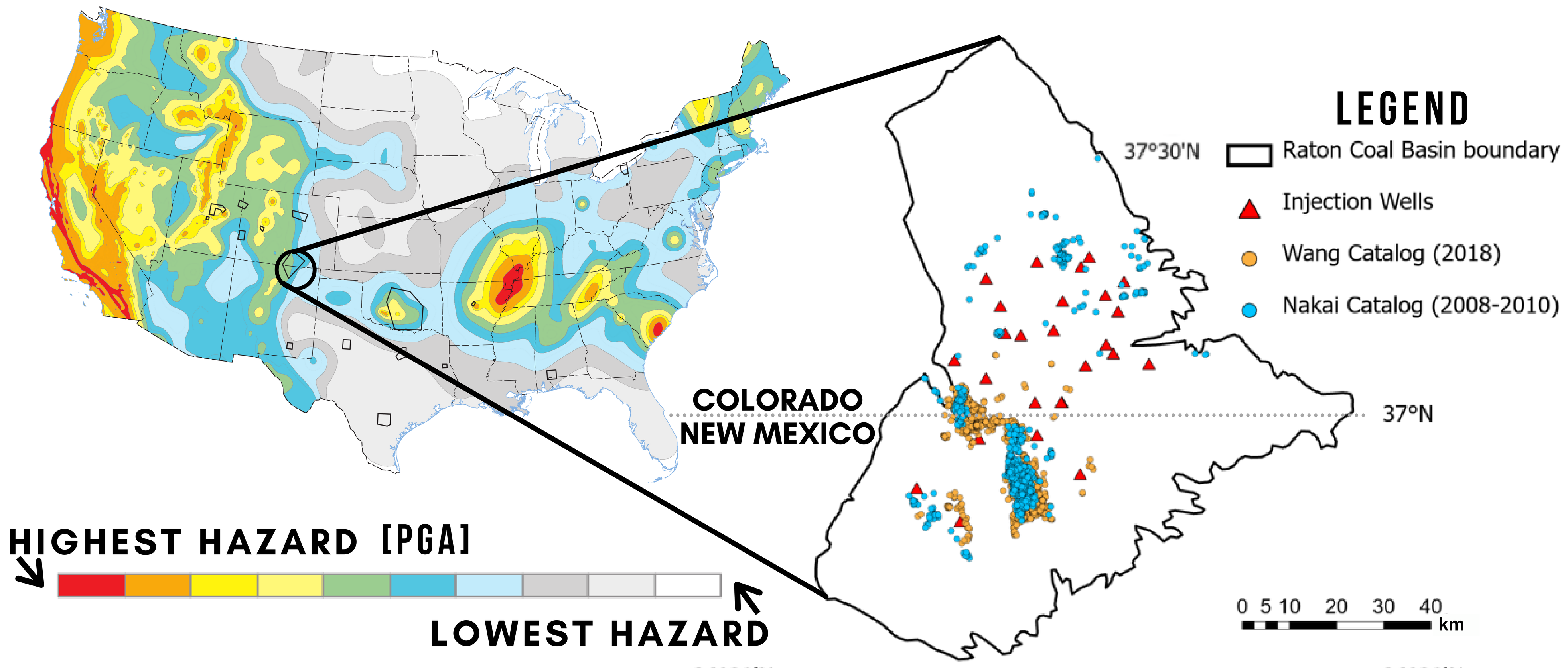
$$\frac{t}{D_e} = \Omega_e(t)^{-1}$$

Why: Know if the earthquakes' spatial or temporal average have been changing with time (Tiampo et al., 2007). Meaning that the other statistical analysis will be consistent for the time period i.e. Gutenberg-Richter (GR) distribution.





SEISMIC MAPS



USGS, 2014 - modified by E.Menezes

DATA

In this study, we used the two seismic catalogs plotted in the map above.

CATALOG	DATES	# OF EARTHQUAKES	MAGNITUDES
Nakai Catalog [1]	05/28/2008 02/17/2010	1,508	-2.14 to 3.03
Wang Catalog [2]	05/12/2018 06/15/2018	9,258	1.00 to 4.30

[1] EarthScope Transportable Array stations, Nakai et al., 2017

[2] Dense Nodal Array stations, Wang et al., 2020

DISCUSSION & CONCLUSIONS

By employing the TM metric we are able to use the associated effective ergodicity to explain the variations in the cataloged data. The linear trend of the green lines, Figure 2, illustrates that the system is in ergodic equilibrium meaning the events are consistent spatially and temporally despite the disturbances from large events in the catalog. This increases our confidence in the GR distribution and calculated b-value.

The GR distribution, Figure 1, shows both catalogs' b-value varying around 1.0. This helps to explain the expected behavior of injection induced events in the region. These findings will help to provide a scientific basis for guiding injection operation in a way that reduces earthquake occurrence.

FUTURE WORK

We plan to perform further statistical analysis by employing:

- **Interevent Time** - to observe the distribution of time between consecutive events (Langenbruch et al., 2011)
- **Nearest Neighbor Distance** - to consider the spatial distance between events, detect earthquake clusters and identify complex features in the internal structure of the clusters (Zaliapin and Ben-Zion, 2013)
- **Epidemic Type Aftershock Sequence** - to model background seismicity and investigate aftershocks (Ogata 1998)

Additionally, we will perform differential interferometric synthetic aperture radar (InSAR) analysis to measure surface deformation in the Raton Basin. We anticipate our findings will be integrated into predictive seismic and hydromechanical models.

ANALYSIS

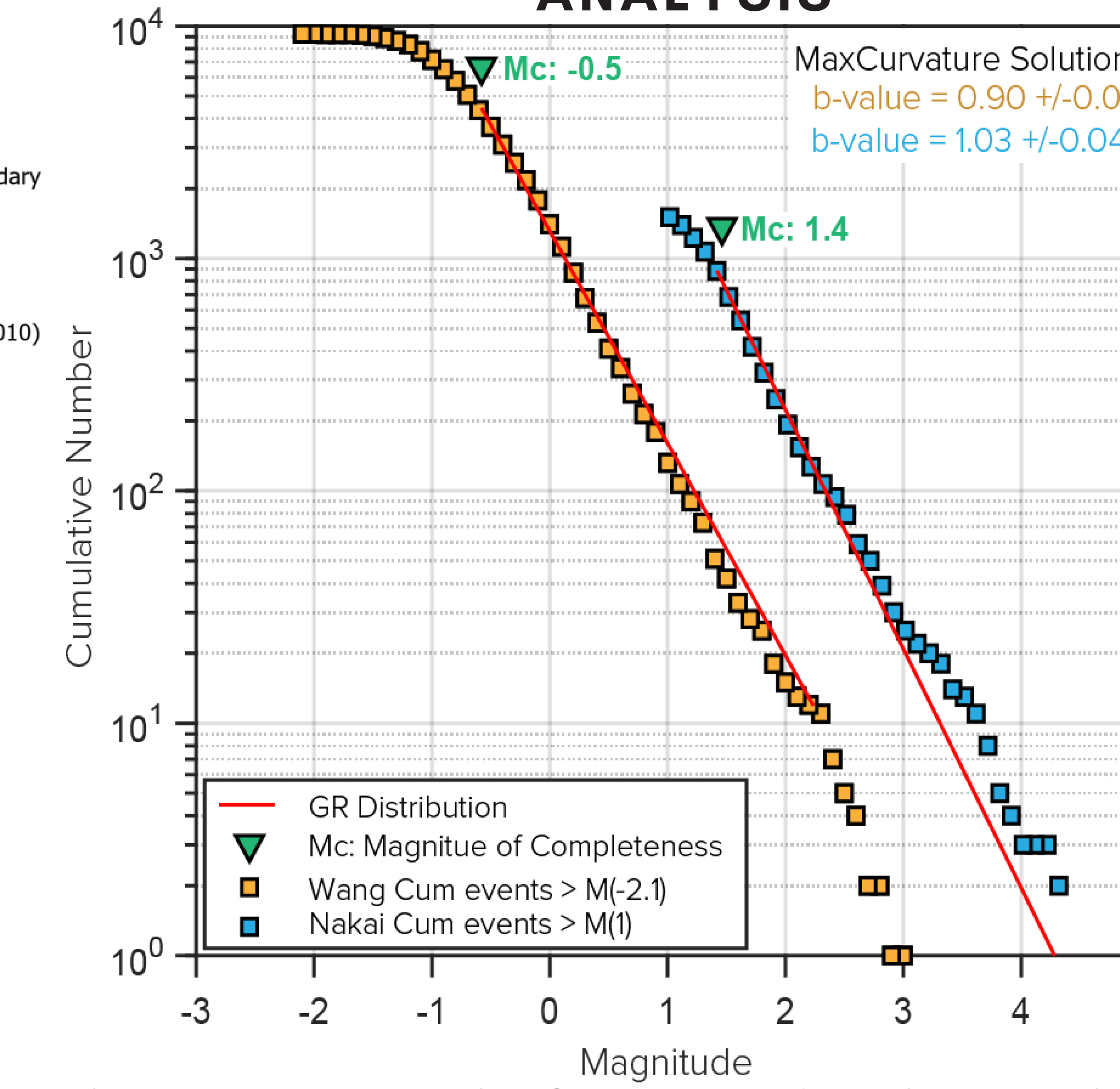


Figure 1. Magnitude frequency plot showing the Gutenberg-Richter distribution, where the b-value is calculated from the maximum curvature method. The b-value is 0.90 for the Wang catalog with a magnitude of completeness estimated at Mc -0.5 and Mc 1.4 for the Nakai catalog with a calculated b-value of 1.03.

INVERSE TM METRIC FOR SEISMICITY PLOT

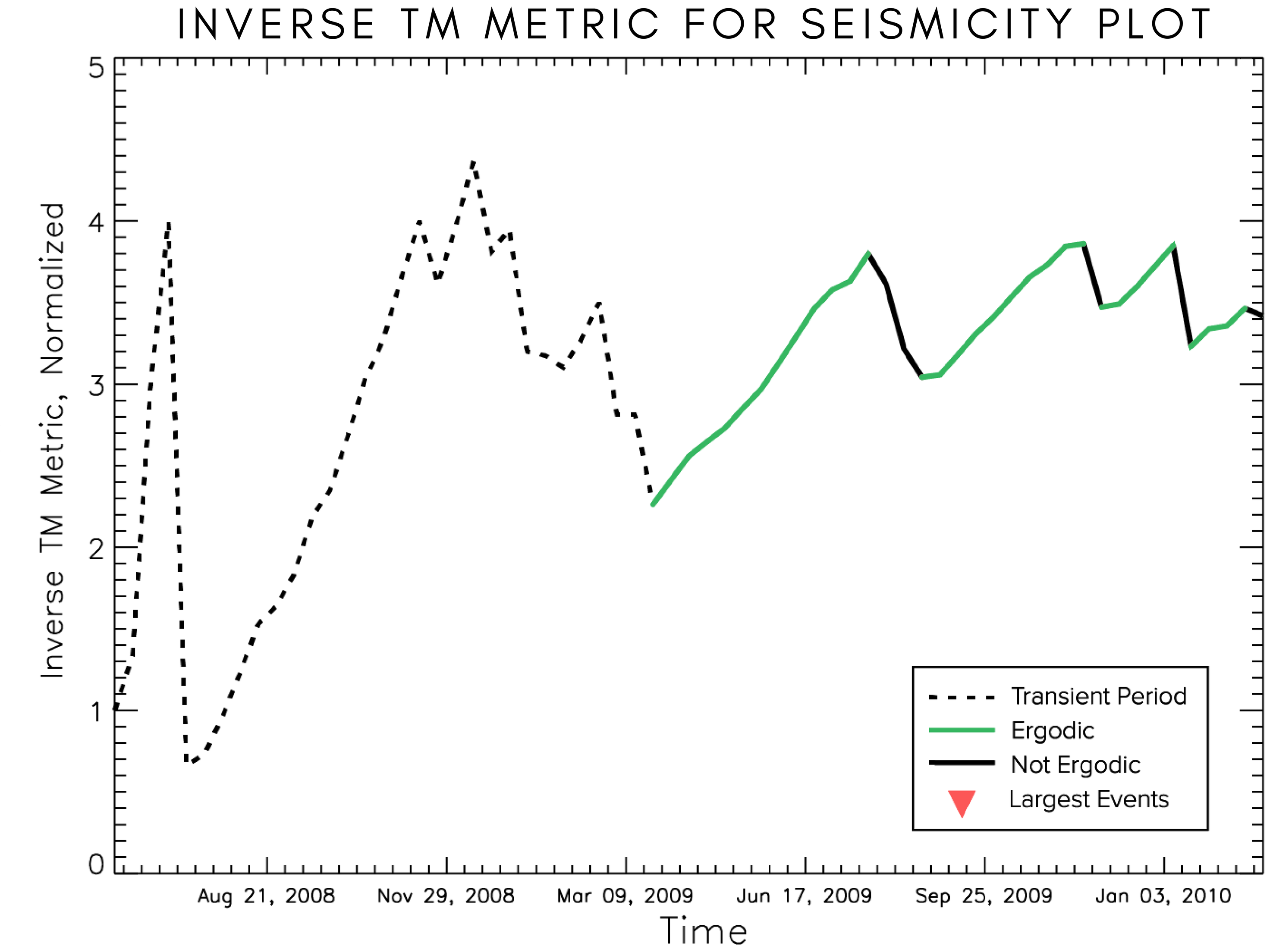


Figure 2. Inverse TM metric for the Nakai (2008-2010) catalog for the Raton Basin seismic events Mw≥1, box size equal to 0.1°, calculated for every 10 days, the arrows (left to right) locate the occurrence of events Mw4.3 & 4.2, Mw3.0 and Mw4.3. Note: The plot utilizing the TM metric calculated for the Wang catalog, is currently undergoing analysis (*not included*).