Waste water injection and possibly induced seismicity in central California

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Outline

1. Objectives of the ISC:
   An overview

2. Induced seismicity in central CA:
   a) Identification criteria
   b) Fluid migration and the role of fault structure

ISC purpose:

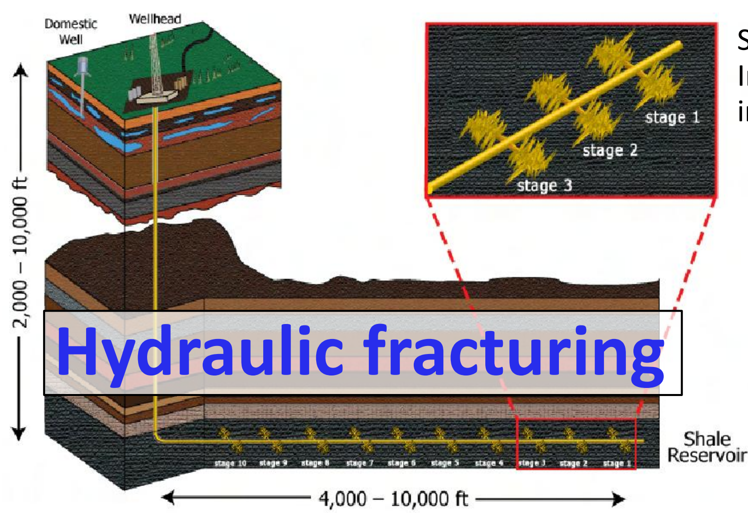
- Unique combination of expertise in **earthquake seismology** and **petroleum engineering**
- Interaction between members of **industry, regulatory agencies** and **academia**
- Advance understanding of **subsurface fluid injection** using **empirical** and **theoretical approaches**

ISC Induced Seismicity Consortium

USC University of Southern California

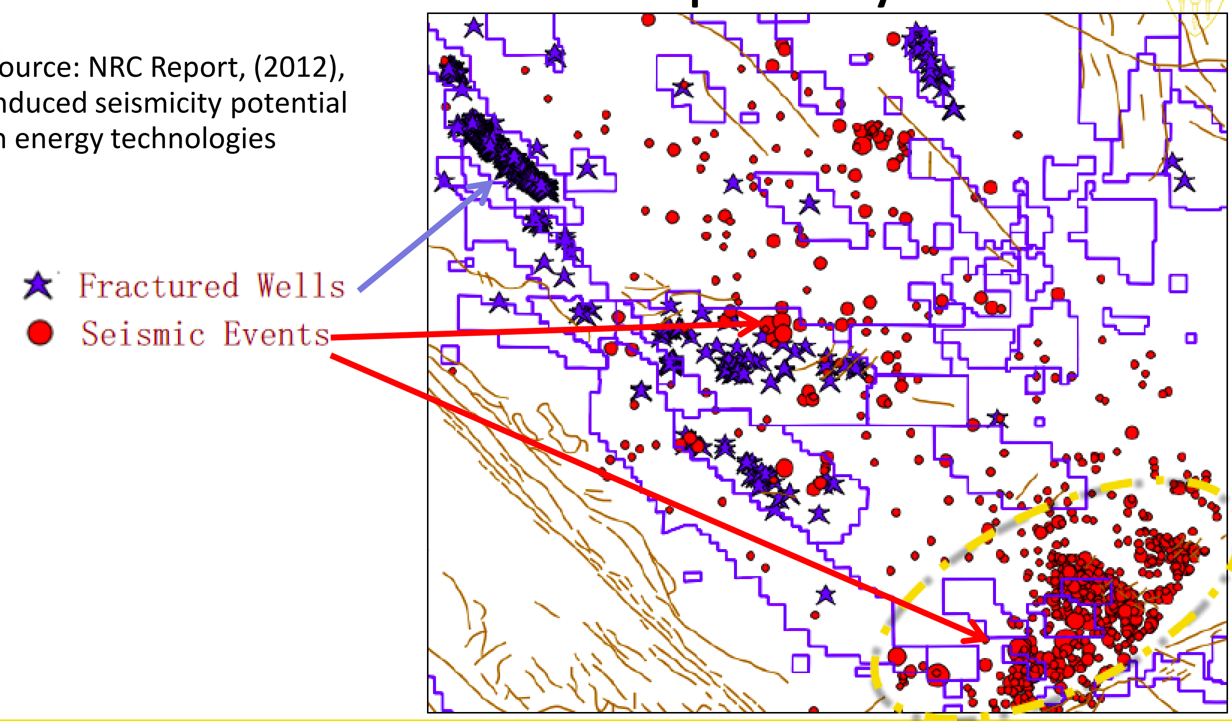
USC Viterbi School of Engineering

Hydraulic fracturing and WD wells

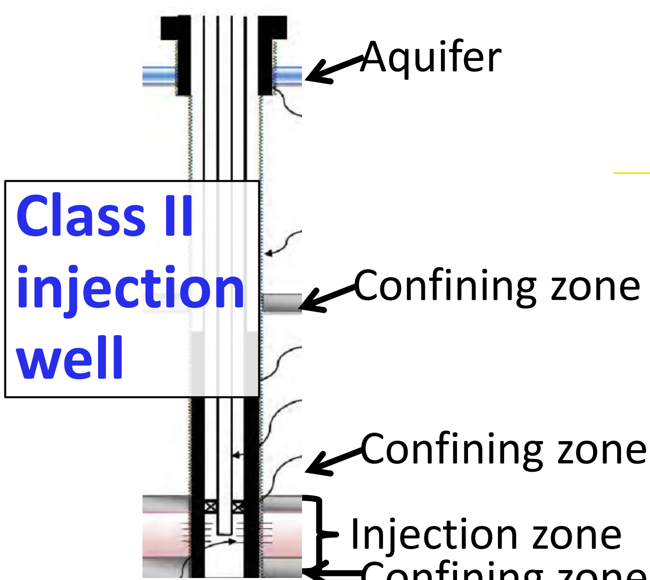


Source: NRC Report, (2012), Induced seismicity potential in energy technologies

San Joaquin Valley



Chen Q., Tiwari A., Aminzadeh F. (2014)
Pacific Section American Association of Petroleum Geologists Convention,Bakersfield CA



Original source: D.Dillion

1. larger volume
2. longer duration
3. vertically confined injection zone

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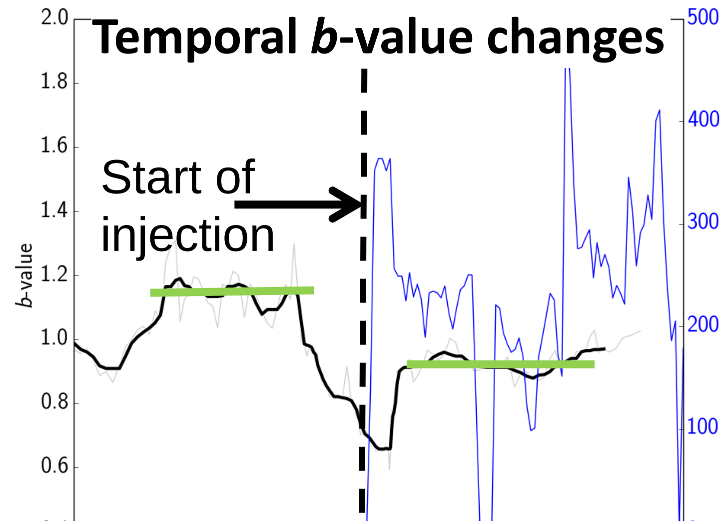
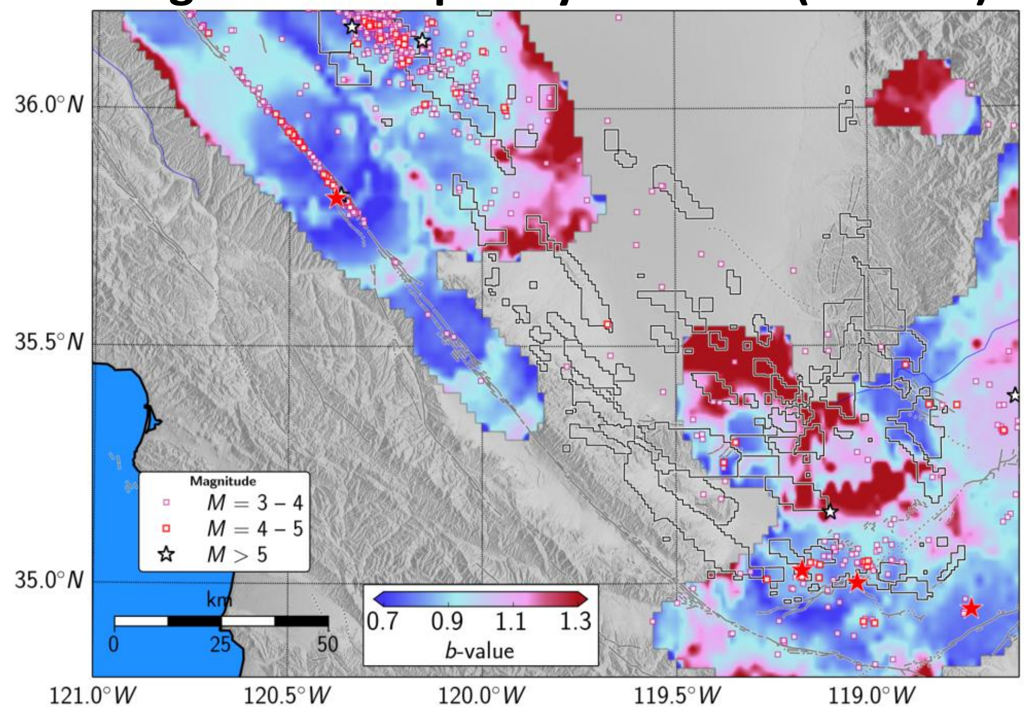
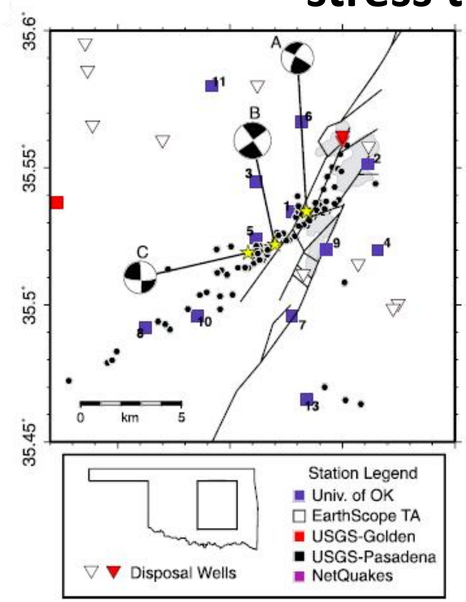
Differences in spatial-temporal clustering between tectonic and induced earthquakes

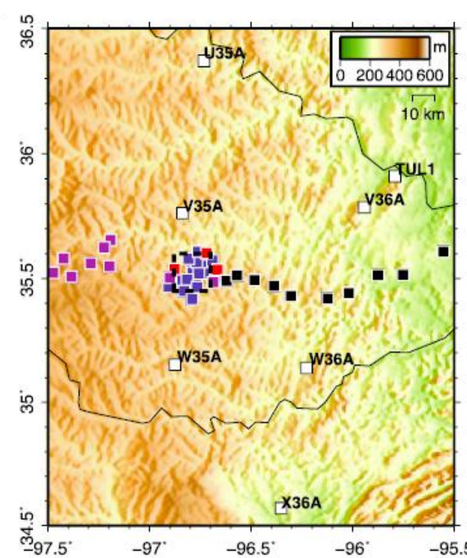


Magnitude-frequency statistics (*b*-value)



Induced seismicity, earthquake triggering & stress transfer in OK





Sumy, et al. 2014

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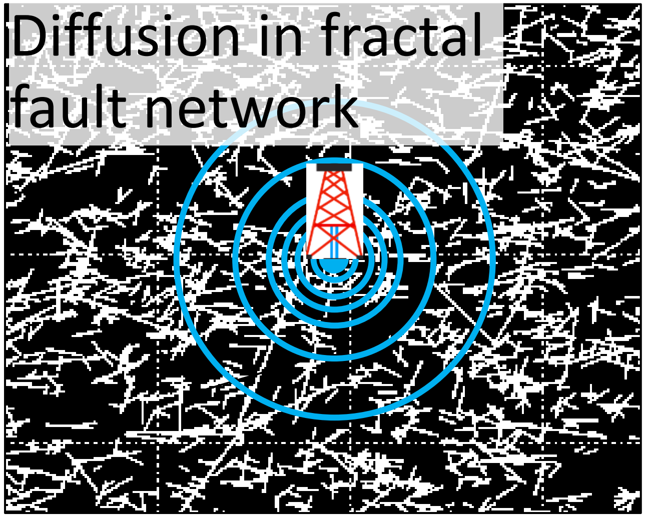
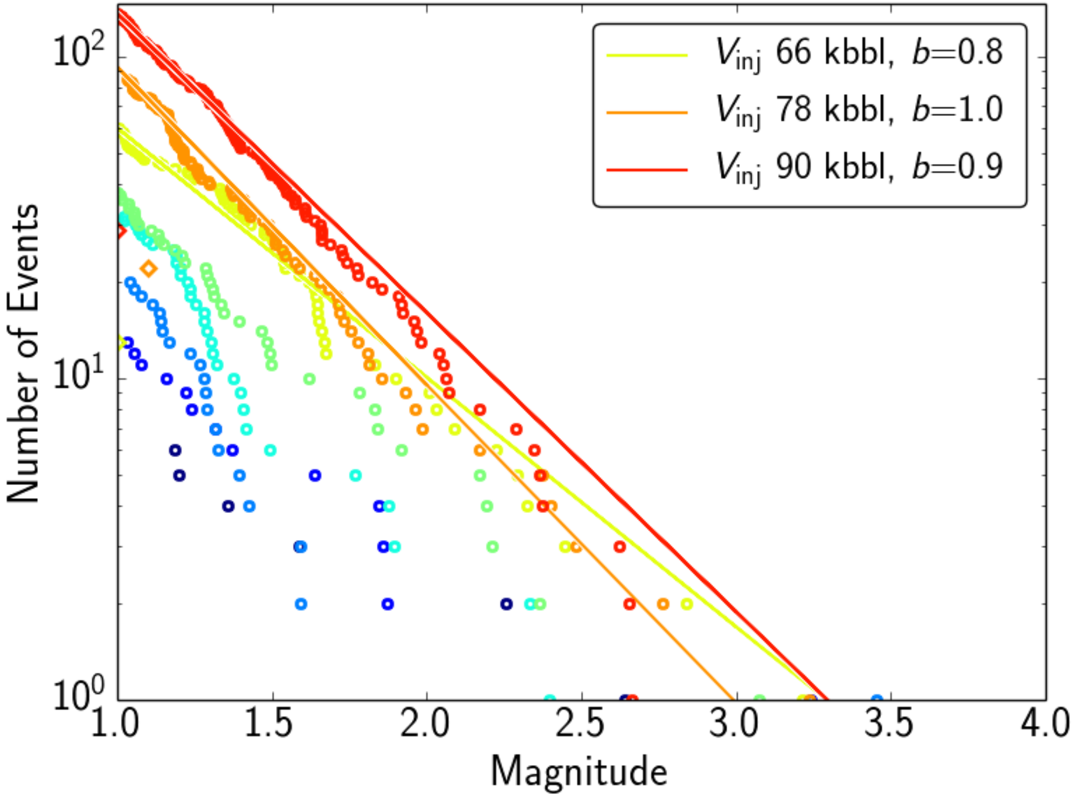
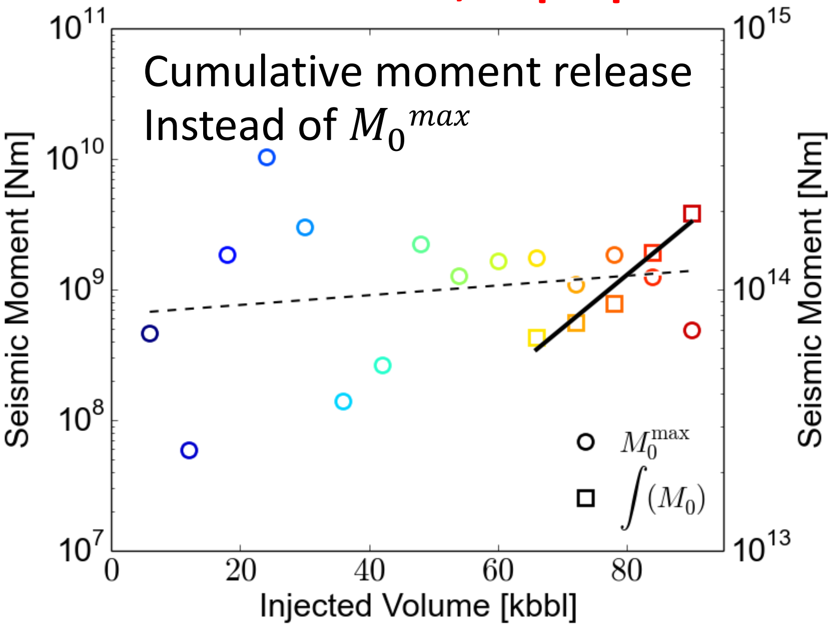
Maximum expected magnitude as fct. of injected volume

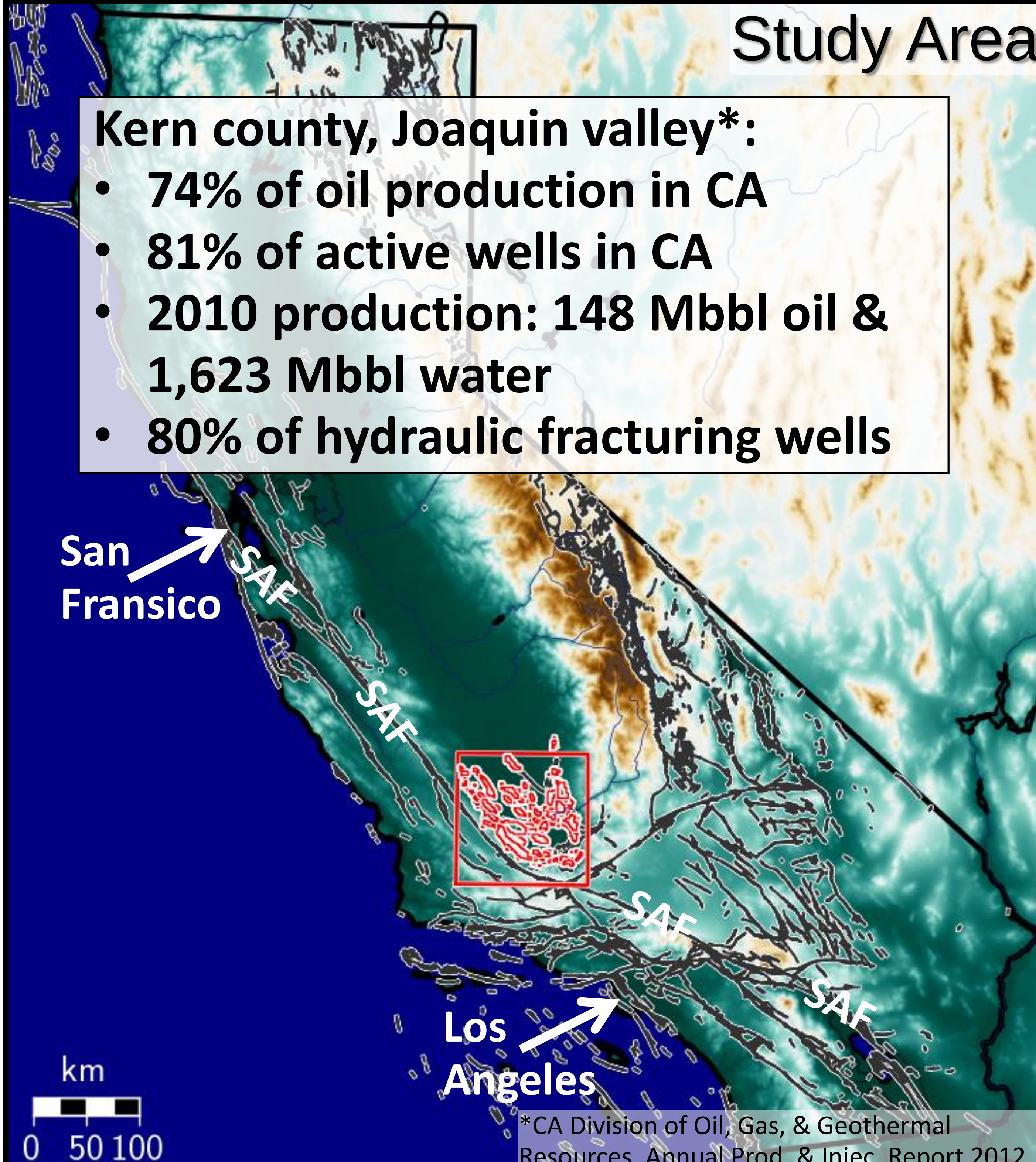




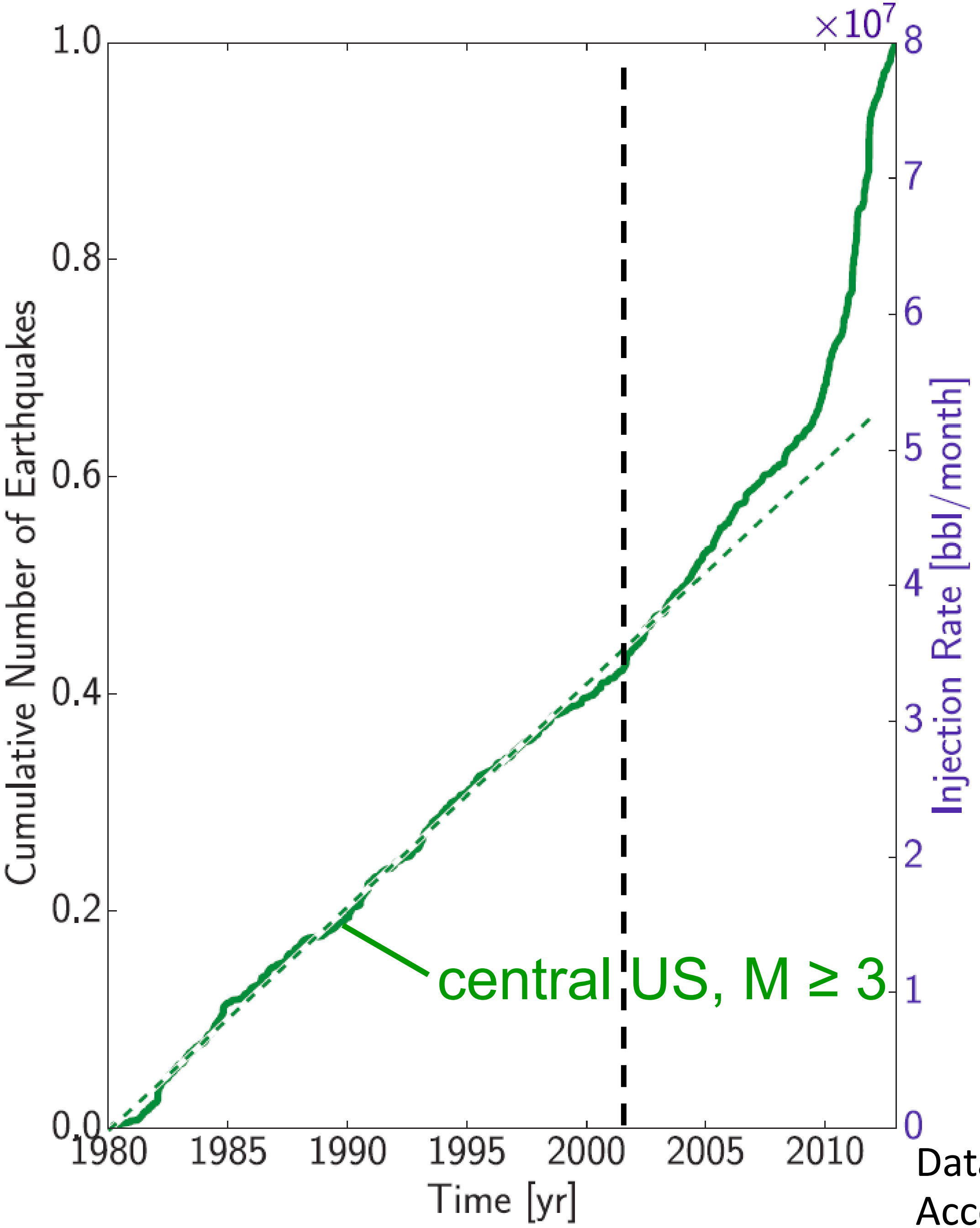
Hosseini et al., in prep.

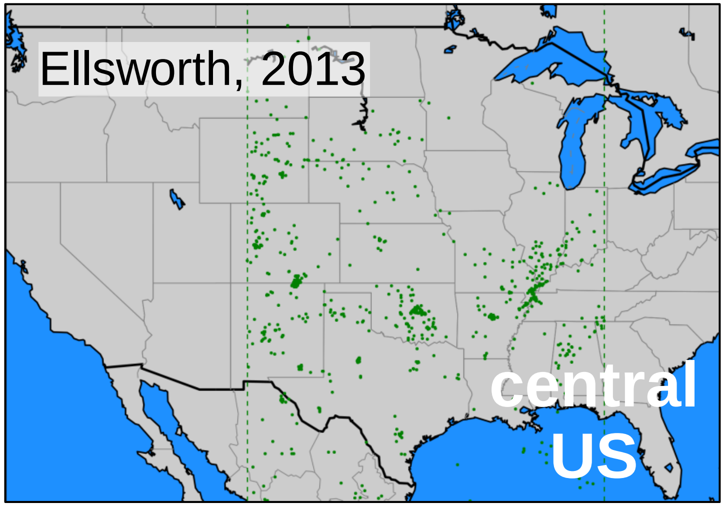


2. Potentially induced seismicity in central California


Study Area
Kern county, Joaquin valley*:
• 74% of oil production in CA
• 81% of active wells in CA
• 2010 production: 148 Mbbl oil & 1,623 Mbbl water
• 80% of hydraulic fracturing wells
San Fransico
SAF
SAF
SAF
SAF
Los Angeles
km
0 50 100
*CA Division of Oil, Gas, & Geothermal Resources, Annual Prod. & Injec. Report 2012

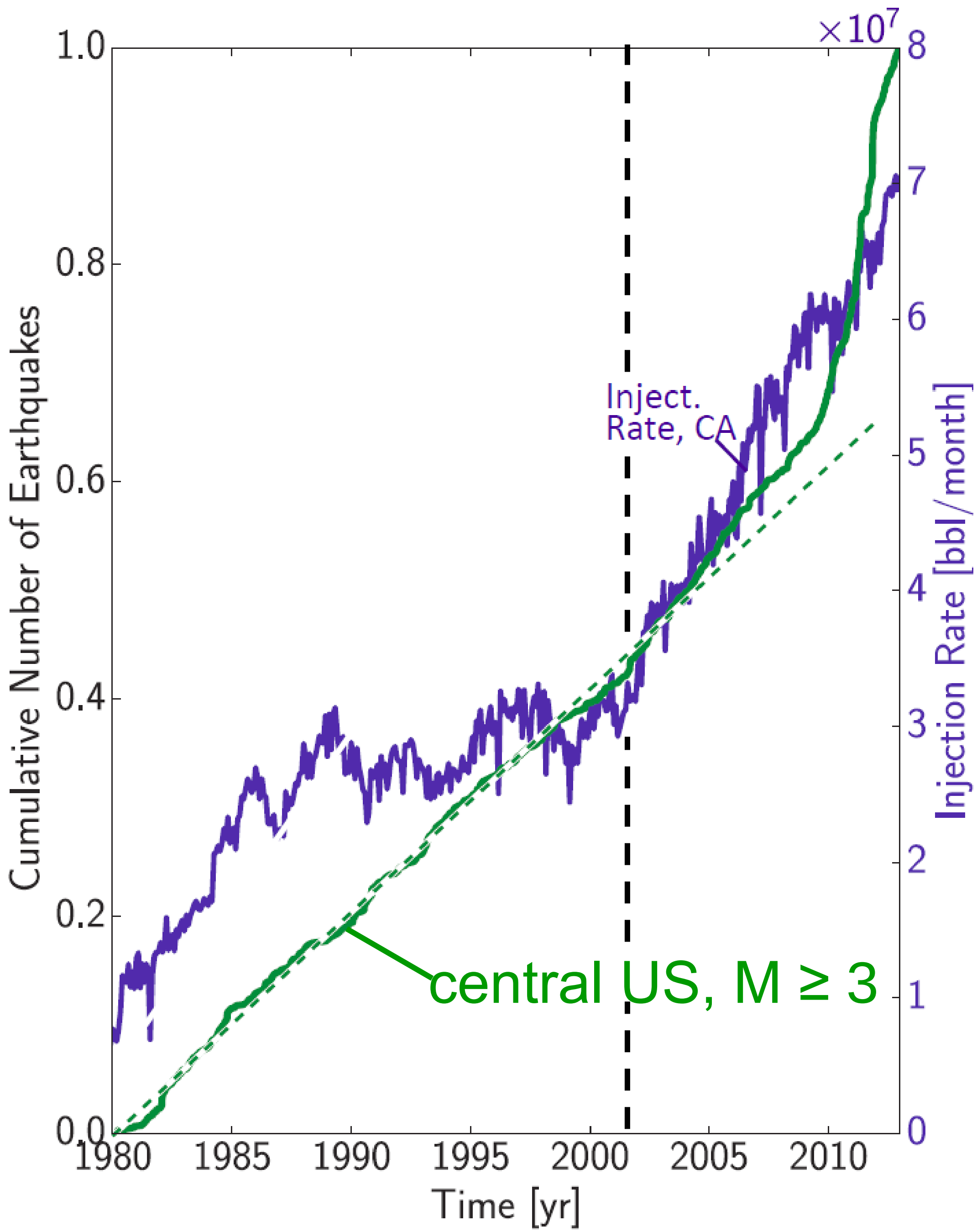
A comparison between fluid injection and seismicity in central US and CA

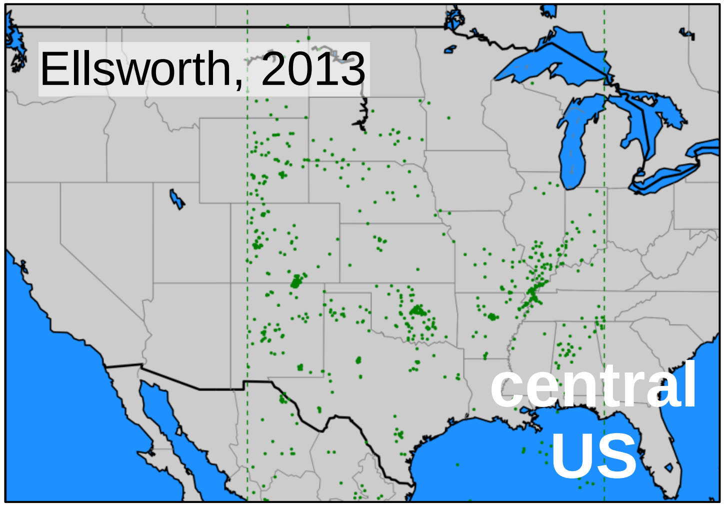




Data: ANSS earthquake catalog
Accessed through Northern California Data Center

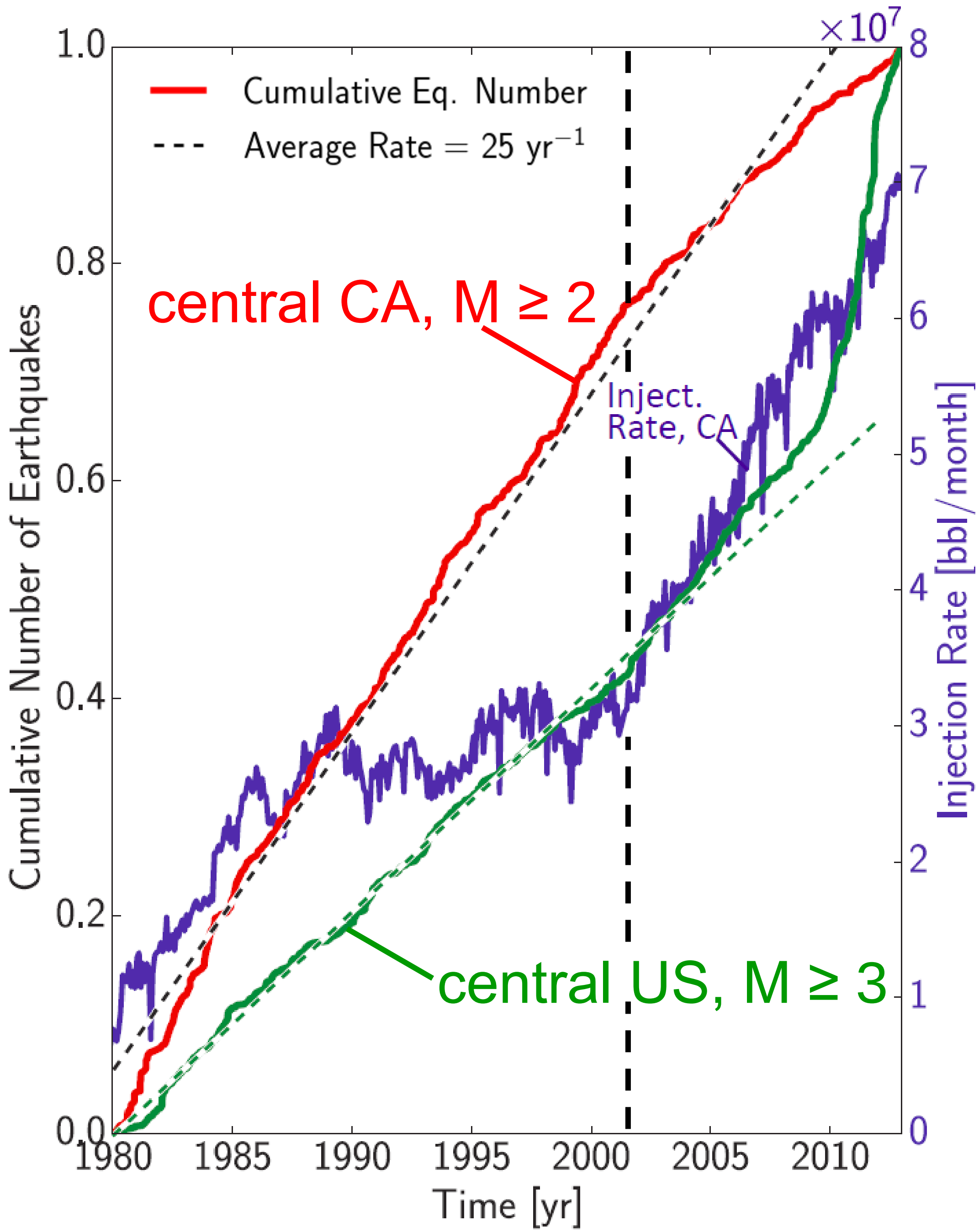
A comparison between fluid injection and seismicity in central US and CA

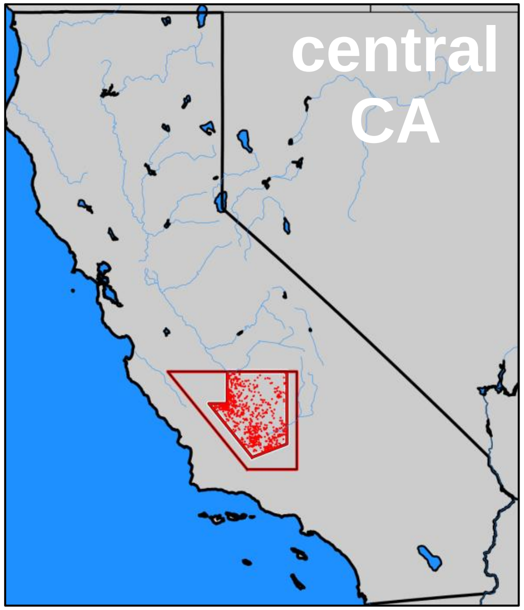


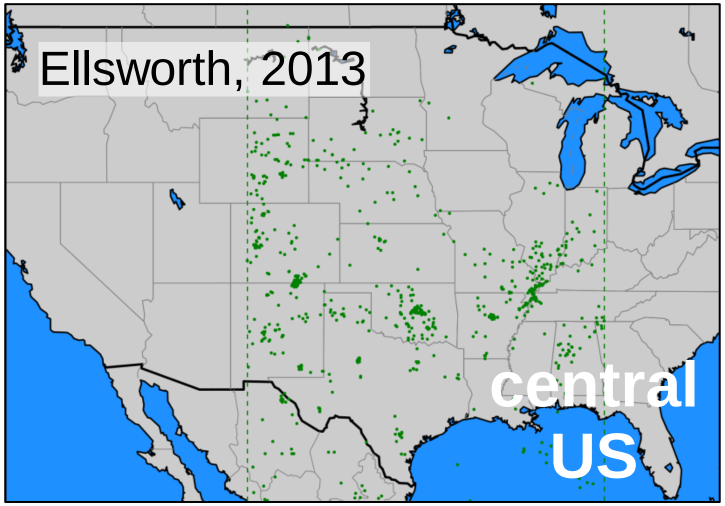


Injection Data: California Division of Oil, Gas, & Geothermal Resources

A comparison between fluid injection and seismicity in central US and CA







2b. Identification criteria

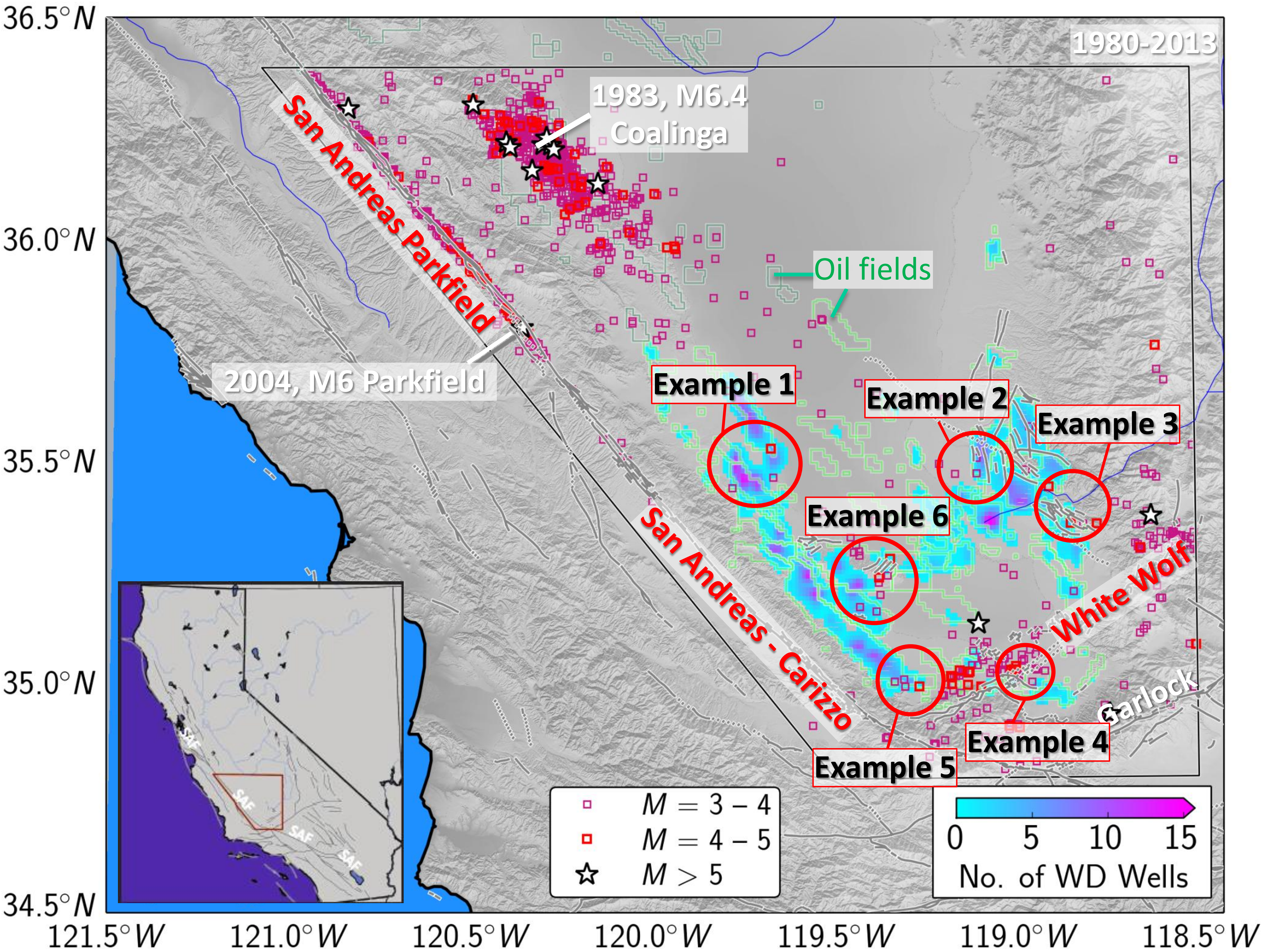
Identification criteria: Quantitative expansion of Davis & Frohlich, 1993

1. Spatial, temporal correlation

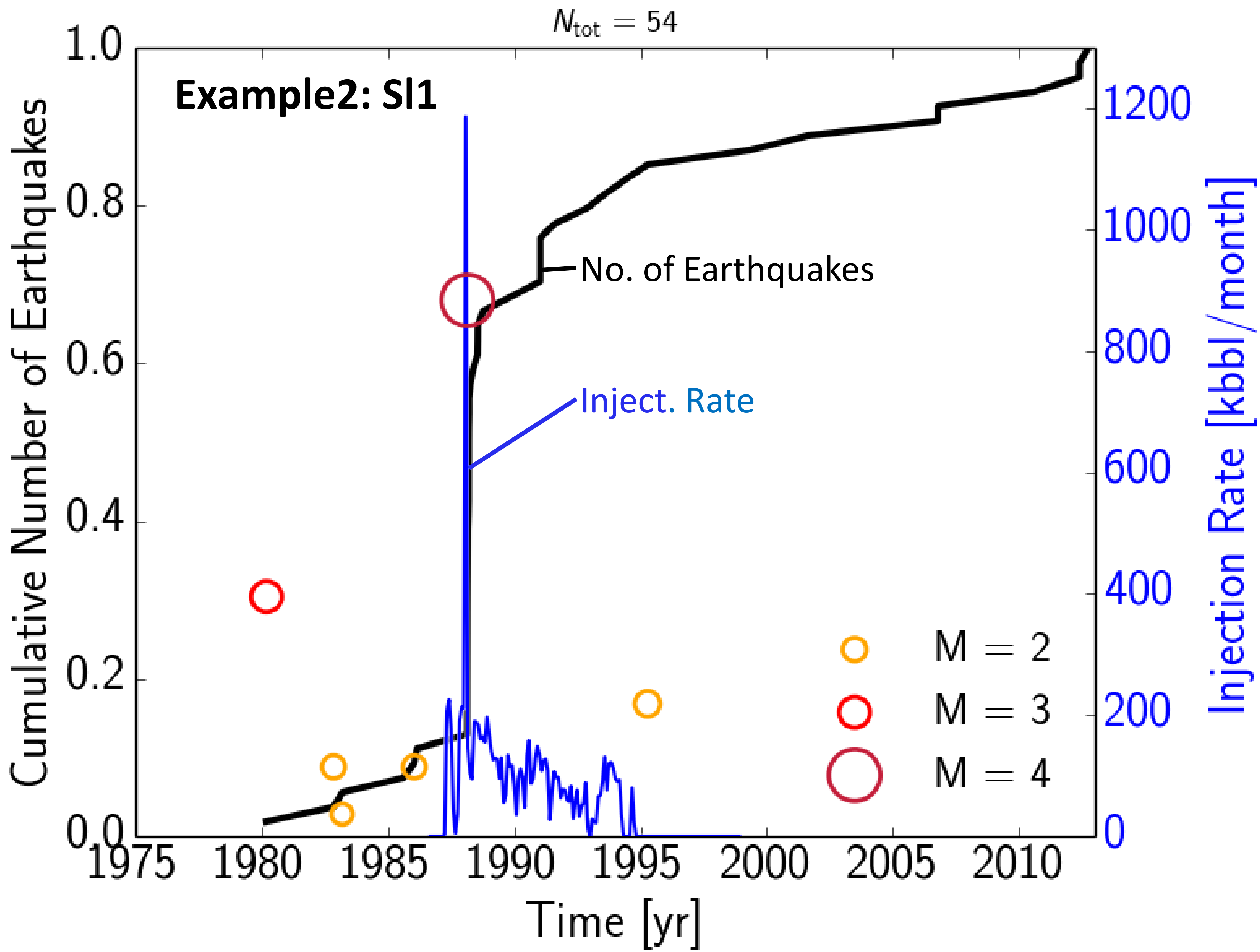
2. Different from background seismicity, first events within a particular area

3. ? Pressure changes caused by injection are high enough to encourage seismicity ?

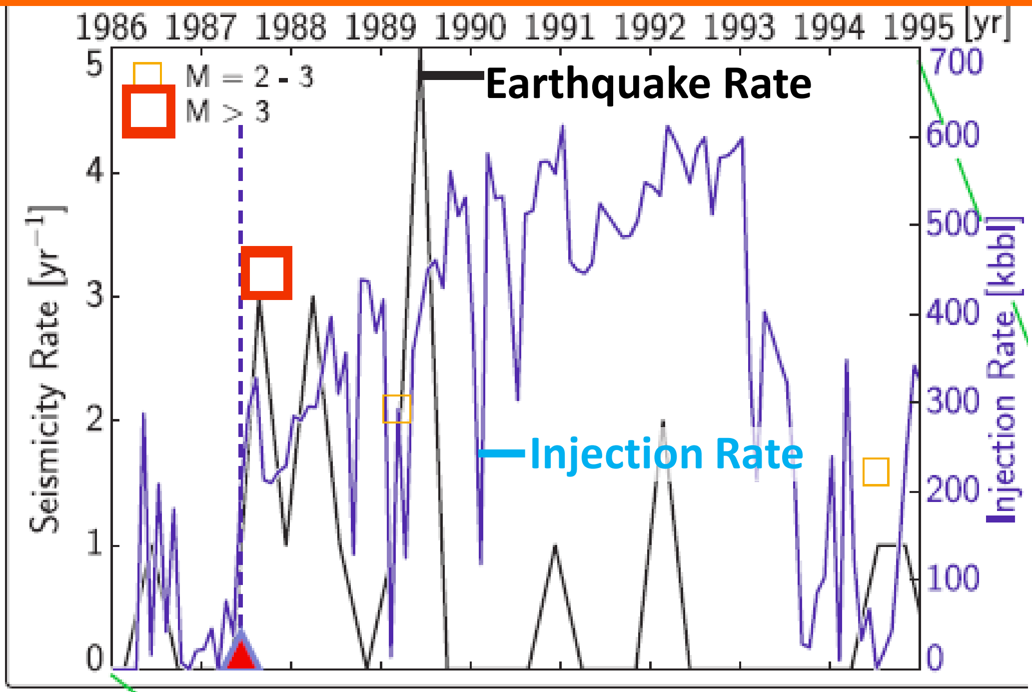
Spatial correlation: WD wells and M>3 events

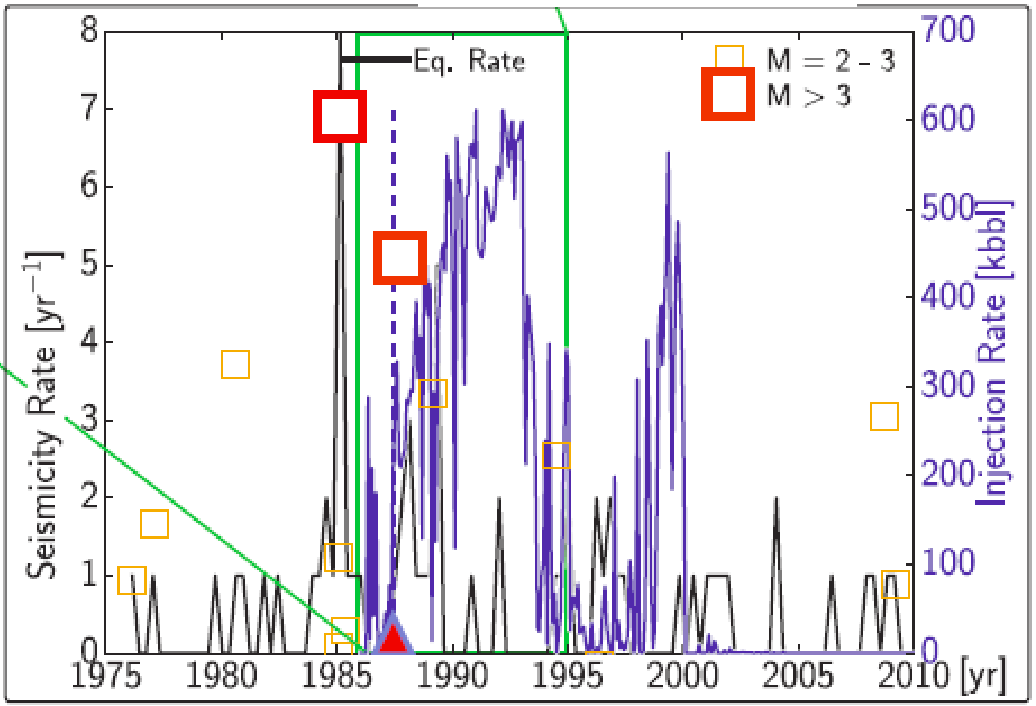


Temporal correlation



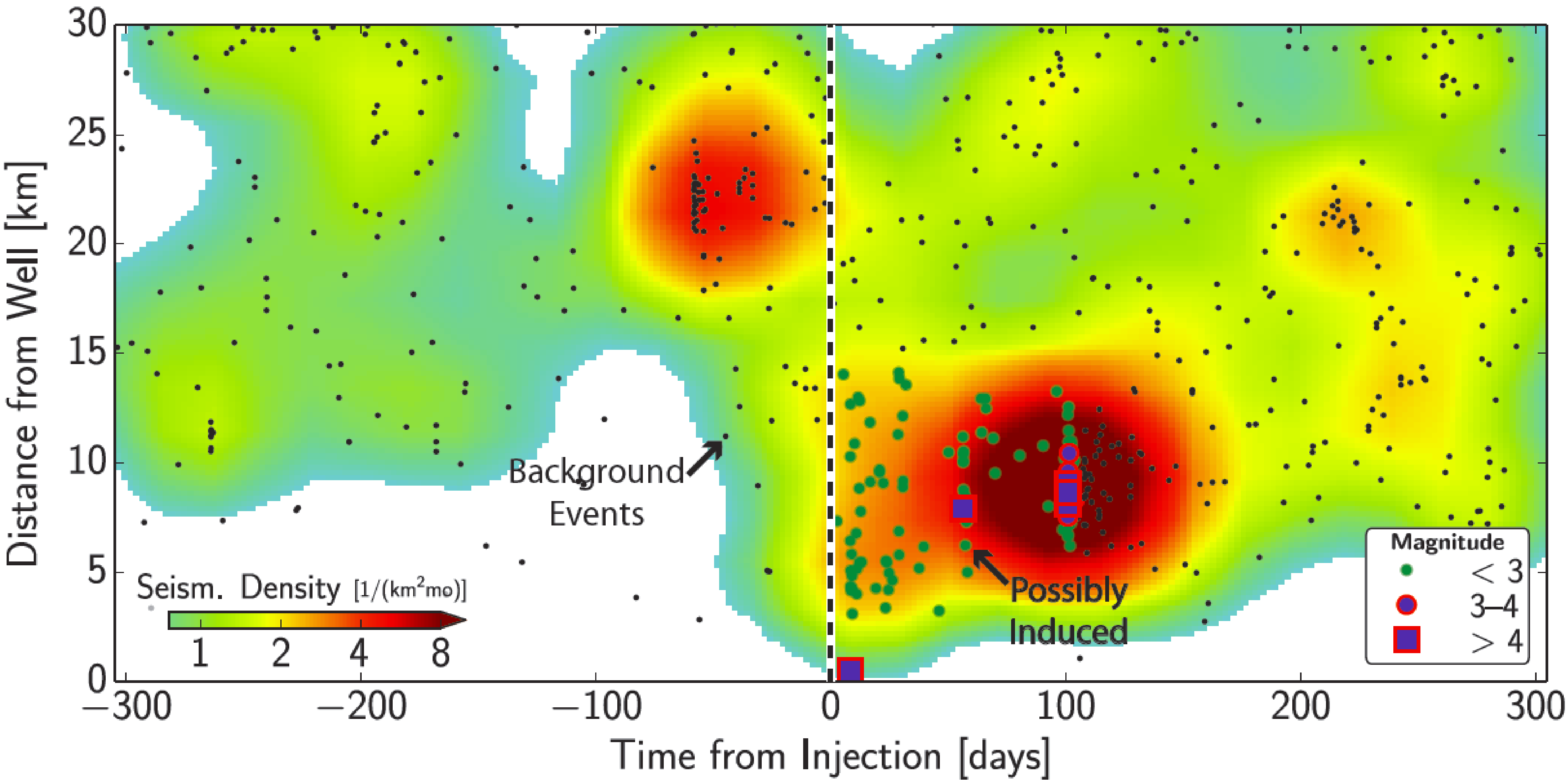
Background injection and seismic activity





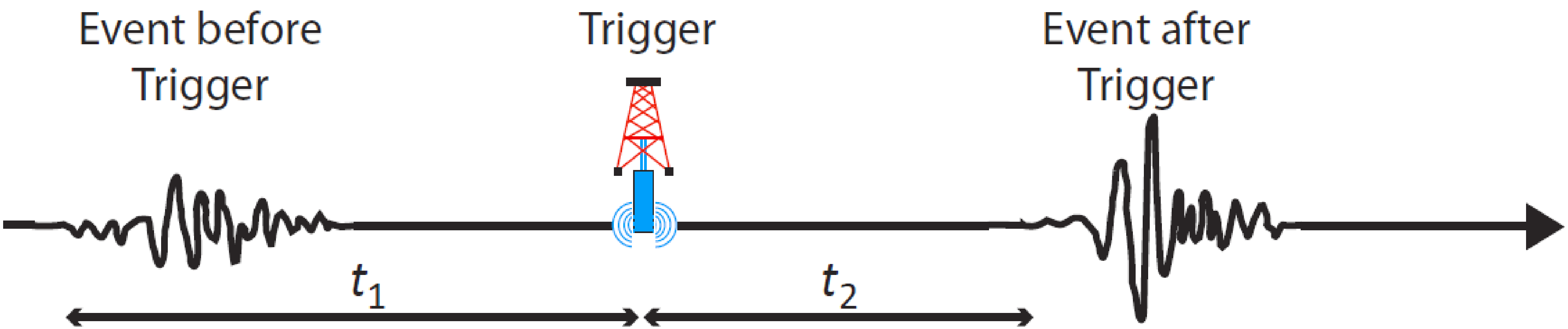
Rate-change compared to background

- Poisson background probability
- Probability of random coincidence of injection peak and seismic activity
- Significant rate-change



Rate changes: Do injections clock-advance the following seismic events?

Inter-event time ratio: $R = t_2/(t_1+t_2)$



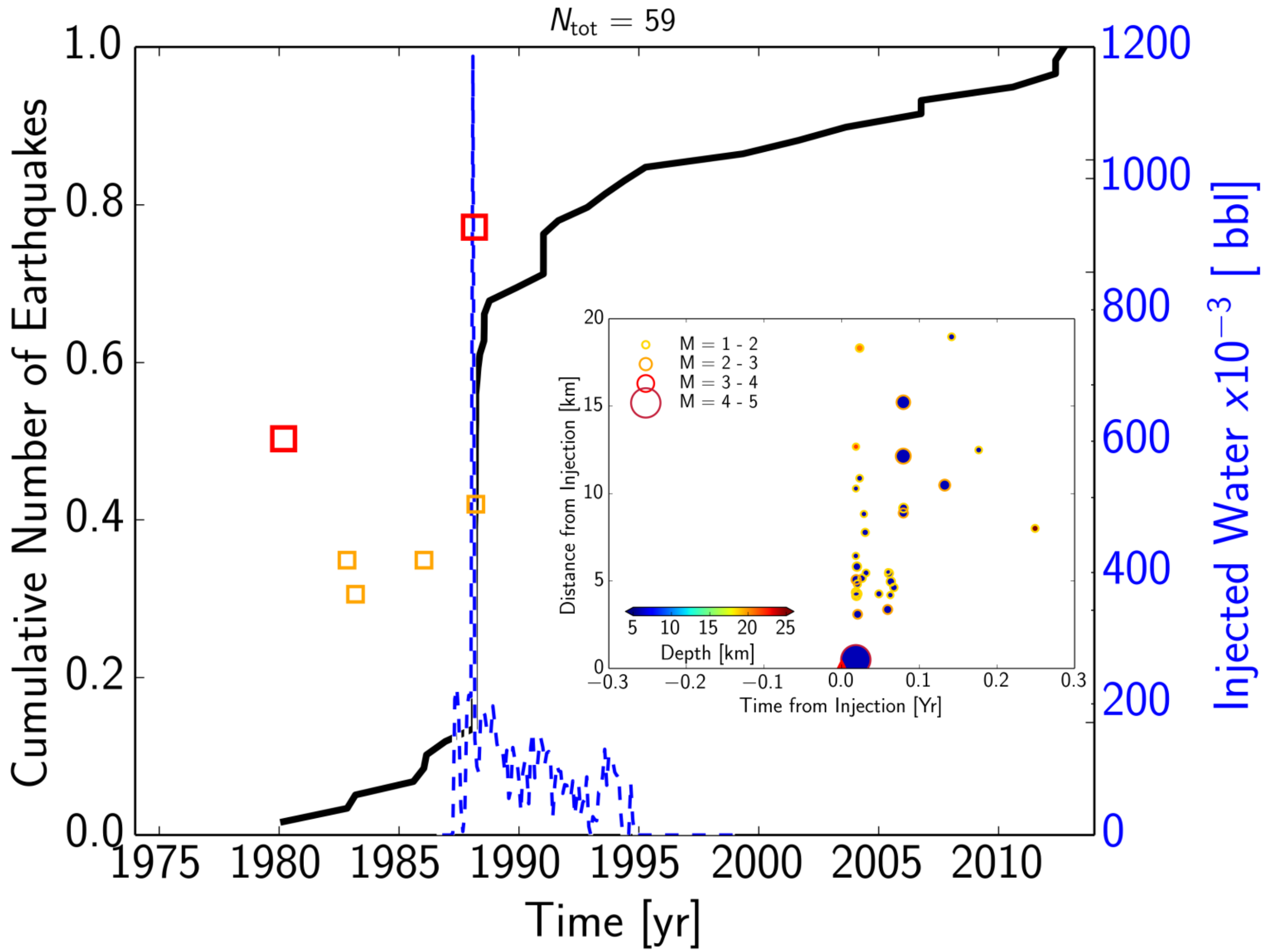
- largely insensitive to space/time window
- insensitive to secondary aftershocks
- even small rate changes are detectable
- suitable for plate-boundary and intra-plate regions

Felzer & Brodsky, 2005 Van Der Elst & Brodsky, 2010

Probabilistic assessment: Example 1

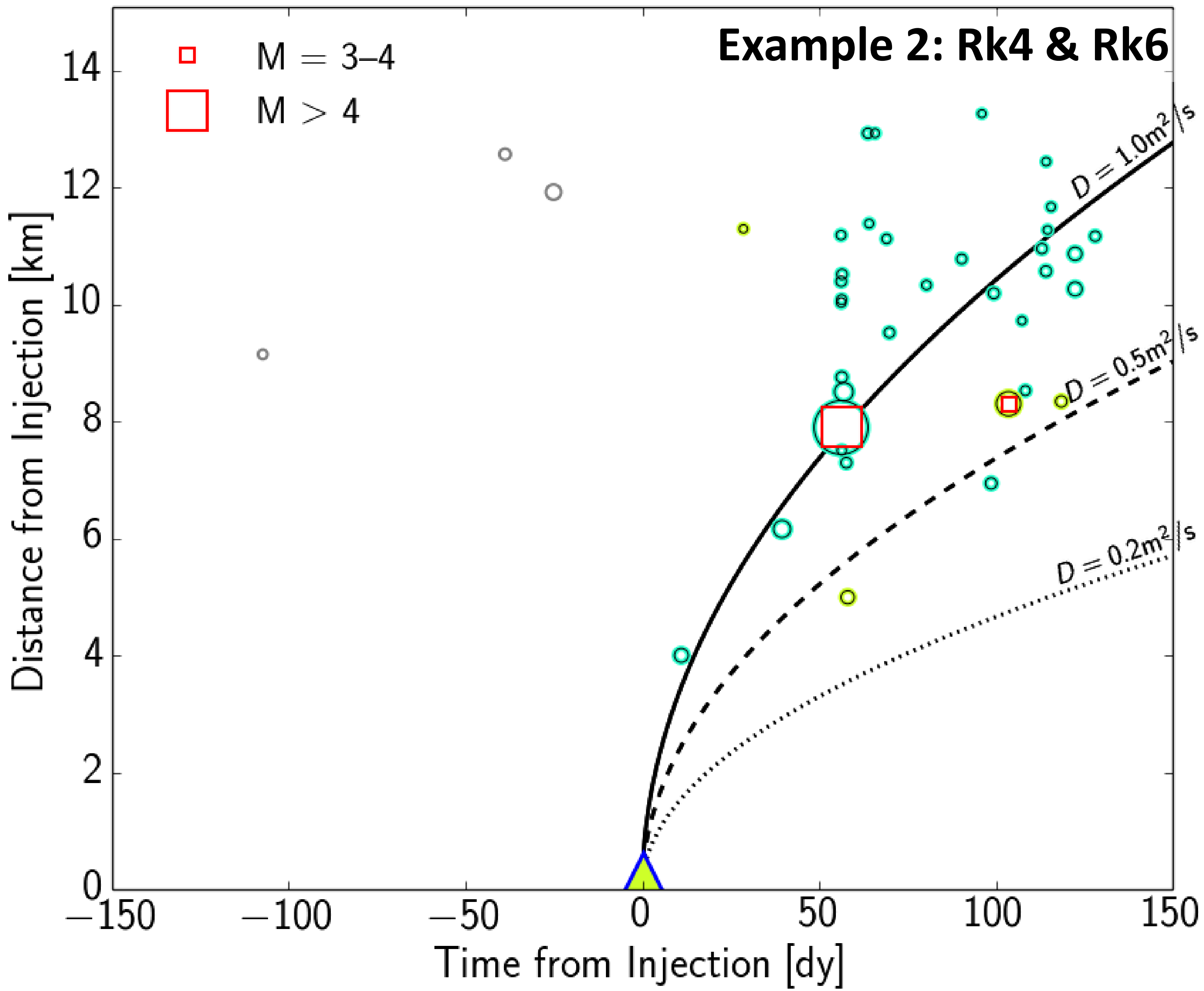
P_{ran}	P_{poi}
0.01	$7*10^{-3}$

R-ratio
0.37 (0.42), p = 0.01



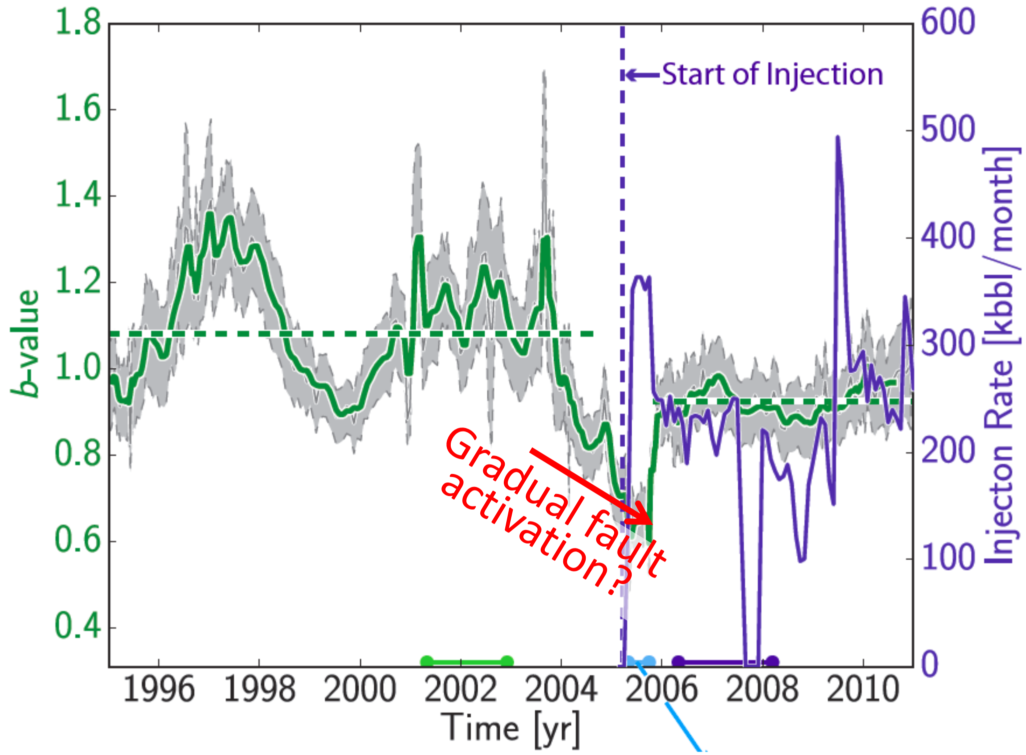
2c. Migration patterns and fault structure

Event migration: Pore pressure diffusion

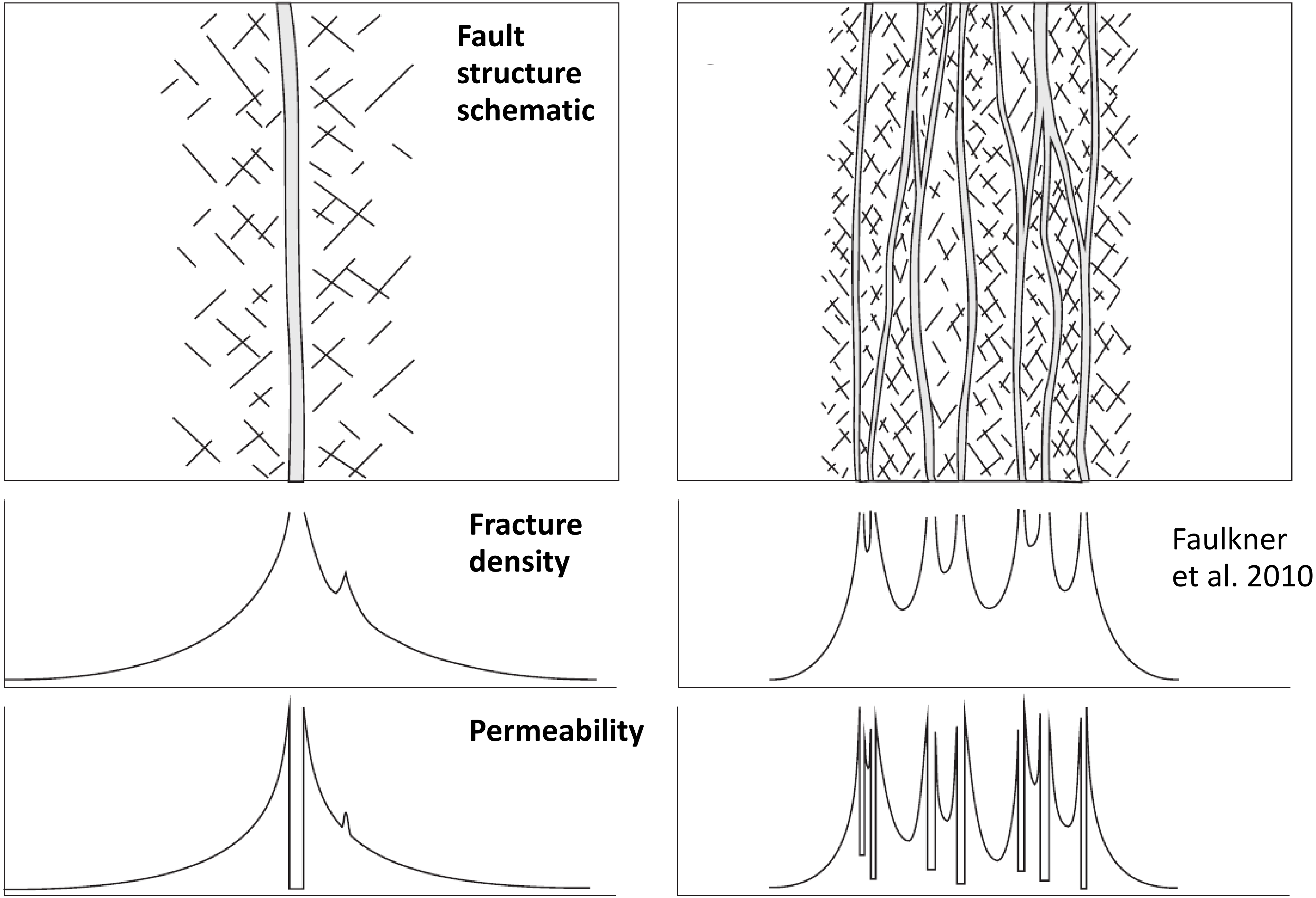


b-value variations during injection

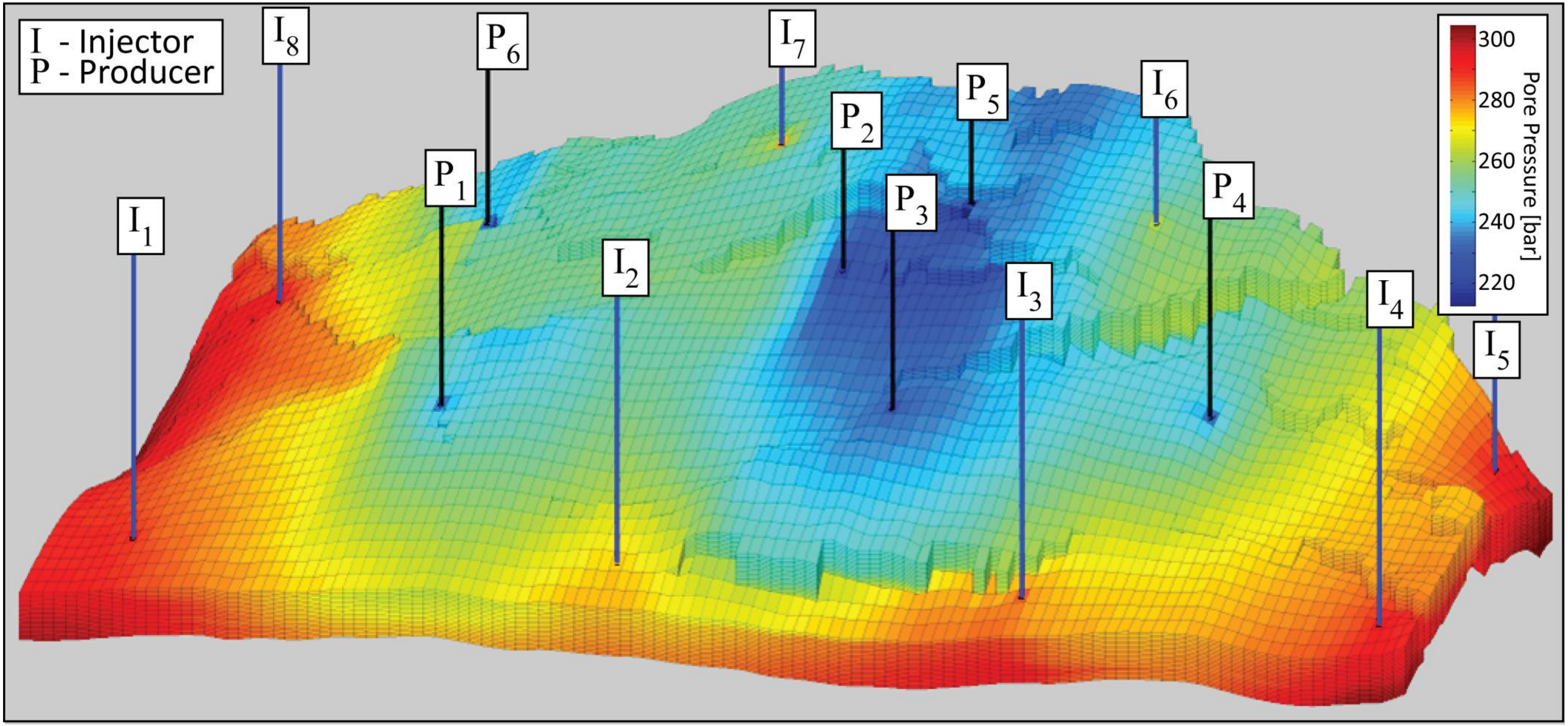
Example 3: Jn05



Coupling between fault structure and permeability



Realistic reservoir and fault structures: Faults as fluid conduits and barriers



Hosseini et al., in prep.

Conclusion

1. We **developed a method to detect likely induced events** based on correlations between injection and seismic activity

2. Induced seismicity may show pronounced **foreshock activity over diffusive space-time scales**

3. **Fault structures** may **control** diffusive processes and **maximum reach of injections**

Future work

1. Both high and low *b*-values observed during injection … ? → statistical and physical models needed

2. Potential for fault activation as a function of injection operations and distance

3. Probability of exceeding, e.g., M>4 as a function of tectonic setting and injection volumes

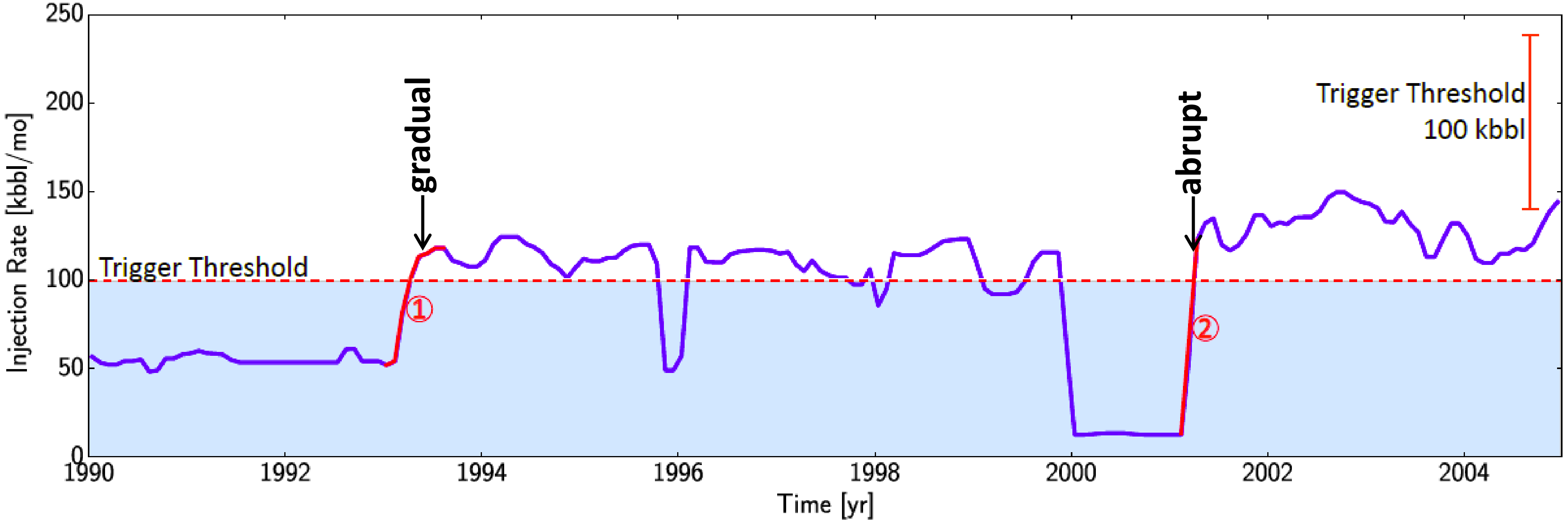
- Thank you -

Additional Slides

Temporal correlation: a-priori defined injection activity

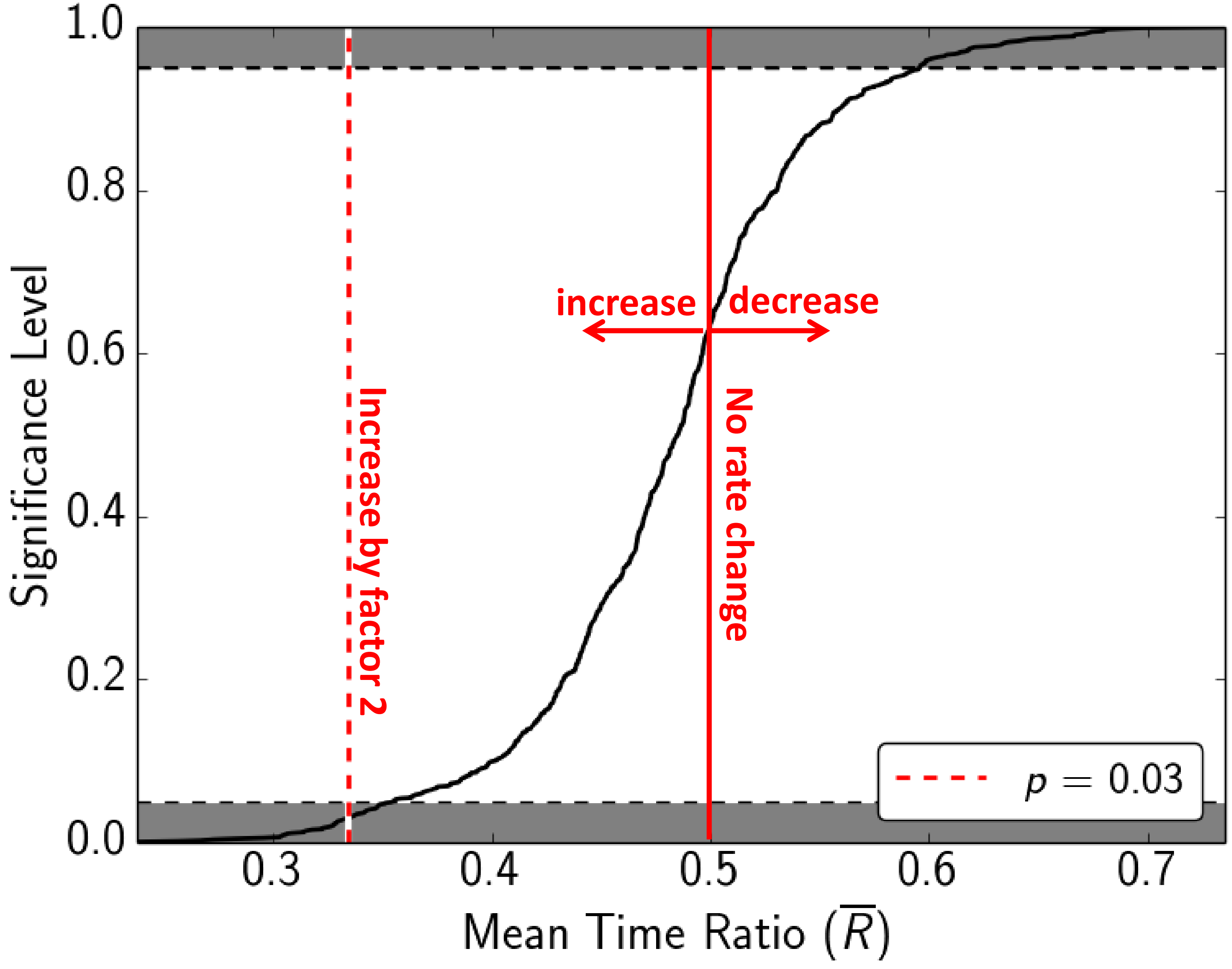
Triggering type/criteria:
gradual (3 mo.) vs. abrupt (1 mo) increase in injection rates

Threshold: 10-600 kbbl



Rate changes: Do injections clock-advance the following seismic events?

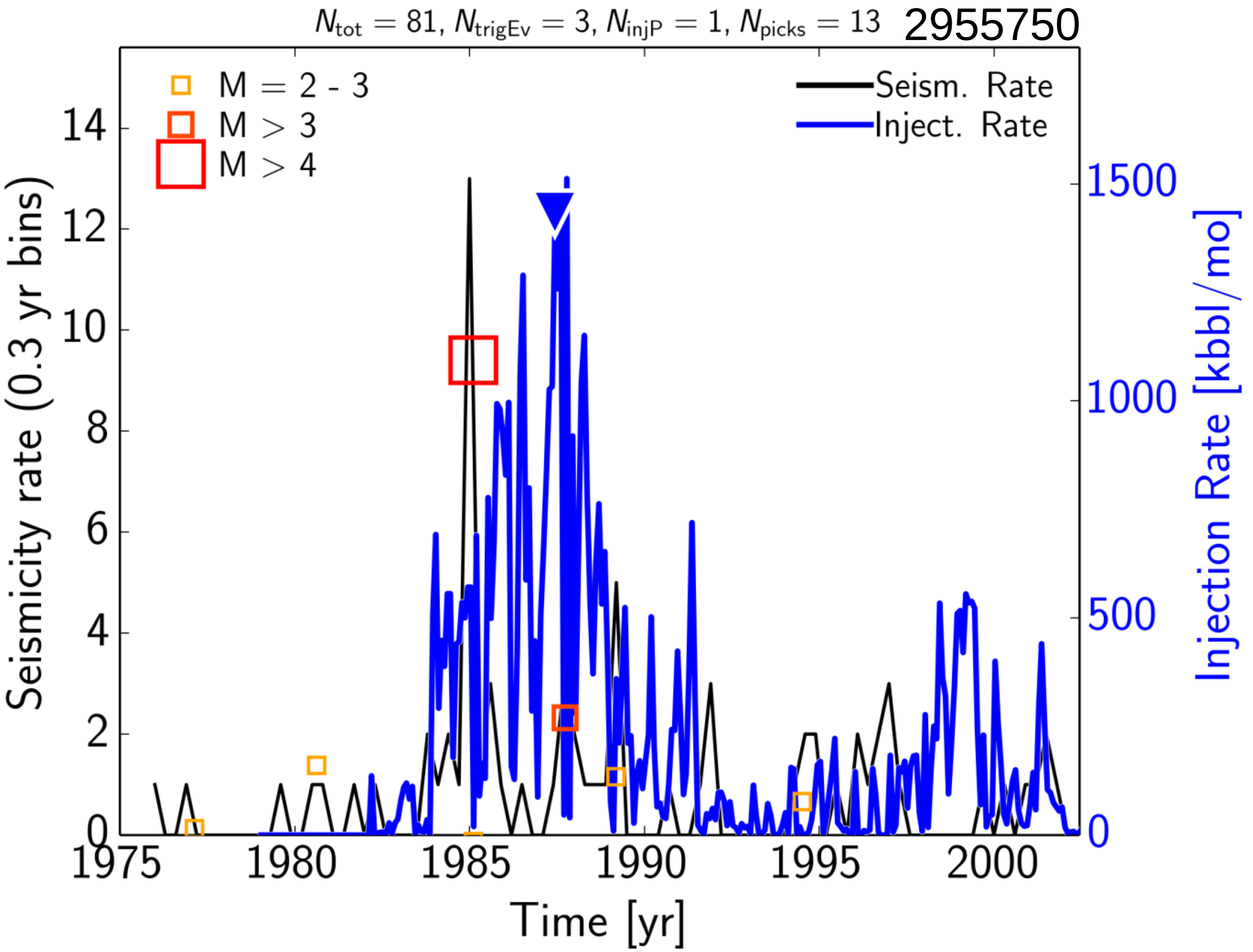
Percentile rate change compared to background



Probabilistic assessment: Example 2, no detection

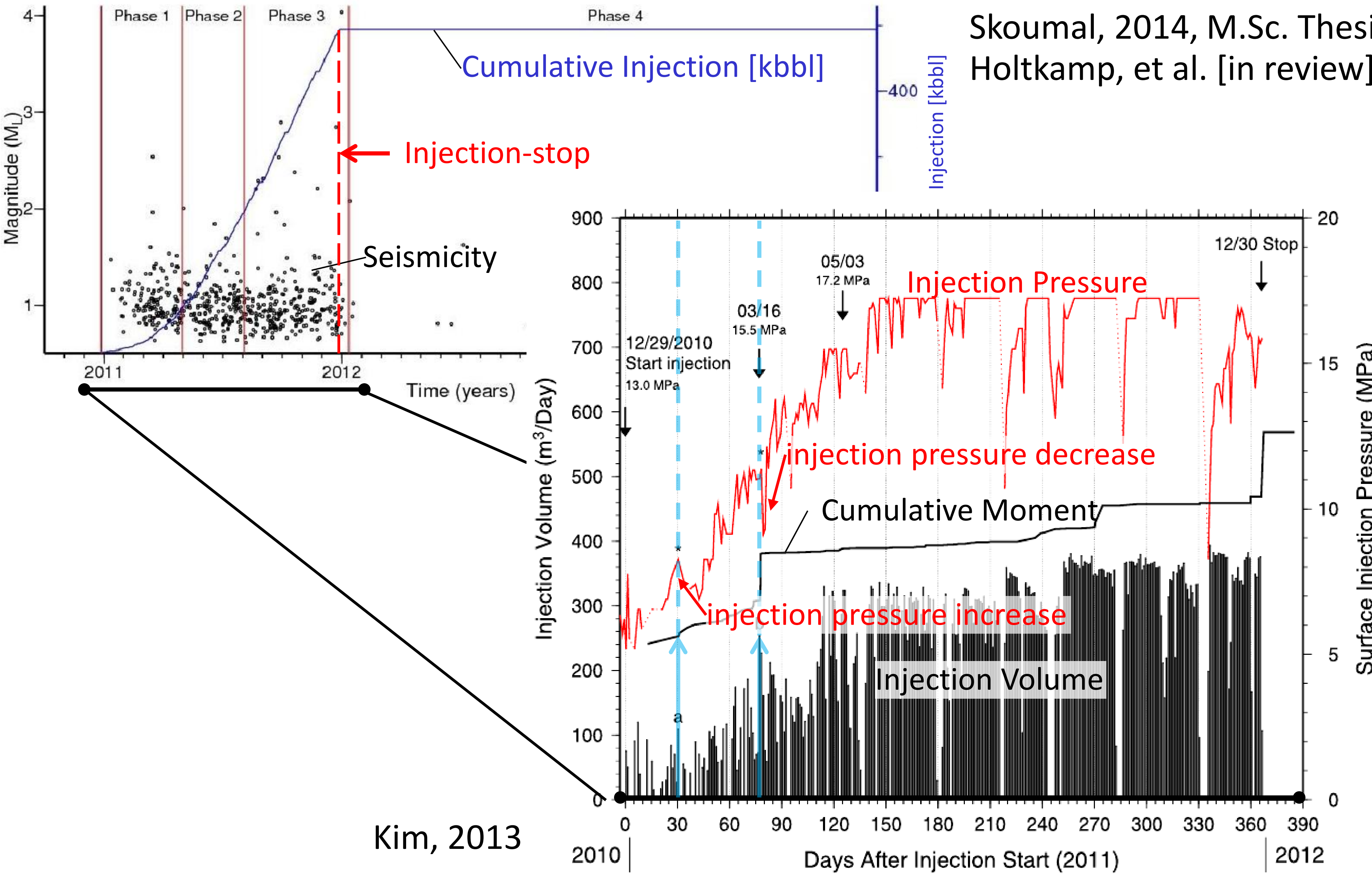
P_{ran}	P_{poi}	R-ratio
0.11	0.01	0.43 (0.48), p = 0.14

- long injection activity
- no significant rate change



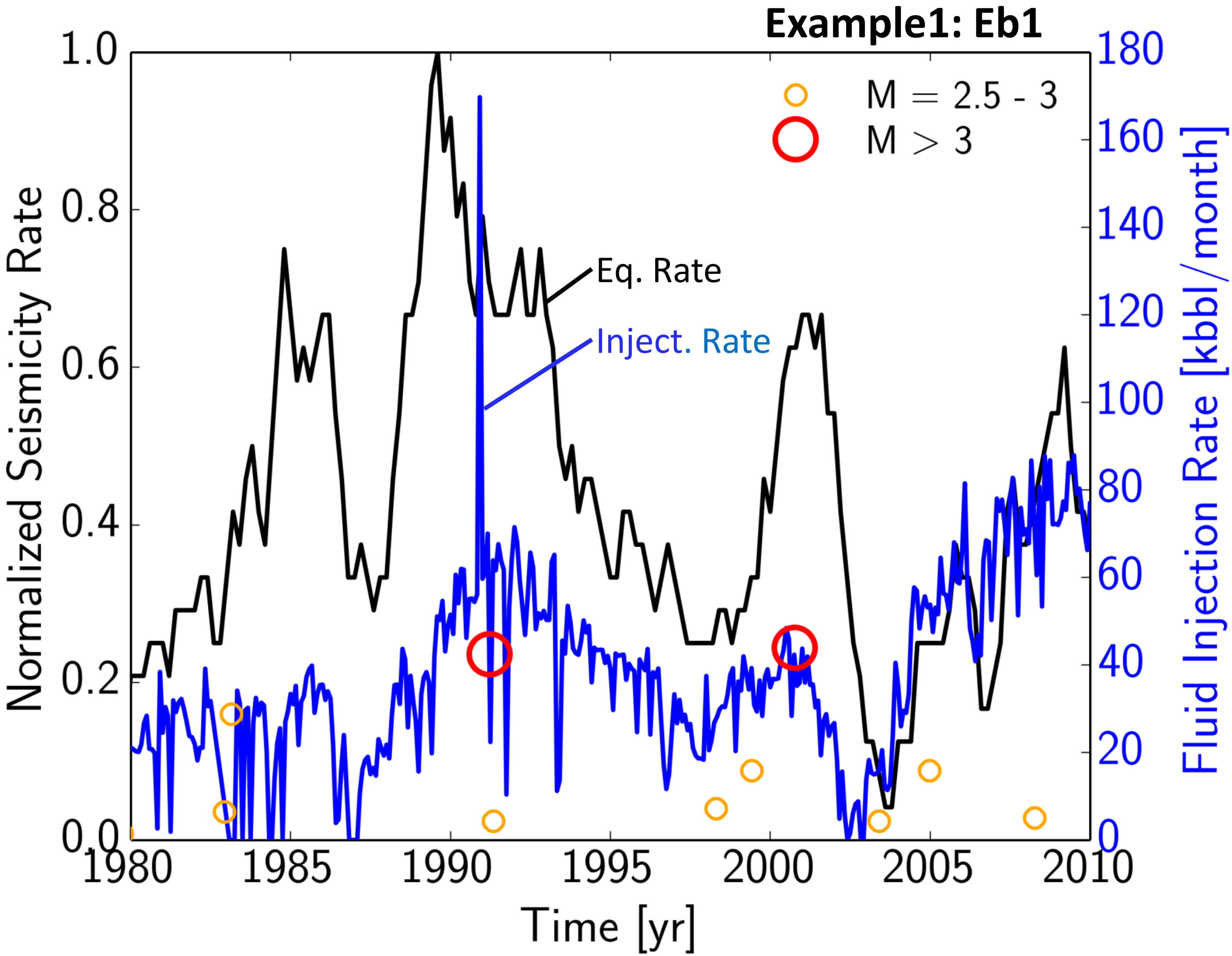
Well-head pressure and injected fluid-volume
Ohio

Skoumal, 2014, M.Sc. Thesis
Holtkamp, et al. [in review]



Kim, 2013

Temporal correlation: Injection and seismicity rates



Probabilistic assessment

Earthquake sequence	P_{ran}	P_{poi}	*R*-ratio
1: LH1	0.03	$7*10^{-3}$	0.37 (0.42), $p = 0.01$
2: KR4	$1*10^{-3}$	$2*10^{-5}$	0.40 (0.45), $p = 0.10$
3: KR6	$1*10^{-3}$	$2*10^{-5}$	0.43 (0.48), $p = 0.12$
4: JT1	0.02	0.04	0.37 (0.45), $p = 0.02$