Caltech

USC University of Southern California

ISC Induced Seismicity Consortium

Injection induced seismicity in California and Oklahoma: Implications for upper crustal stresses

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The Leading Edge, Special Volume, Injection Induced Seismicity, eds. Robert Habiger & Greg Beroza

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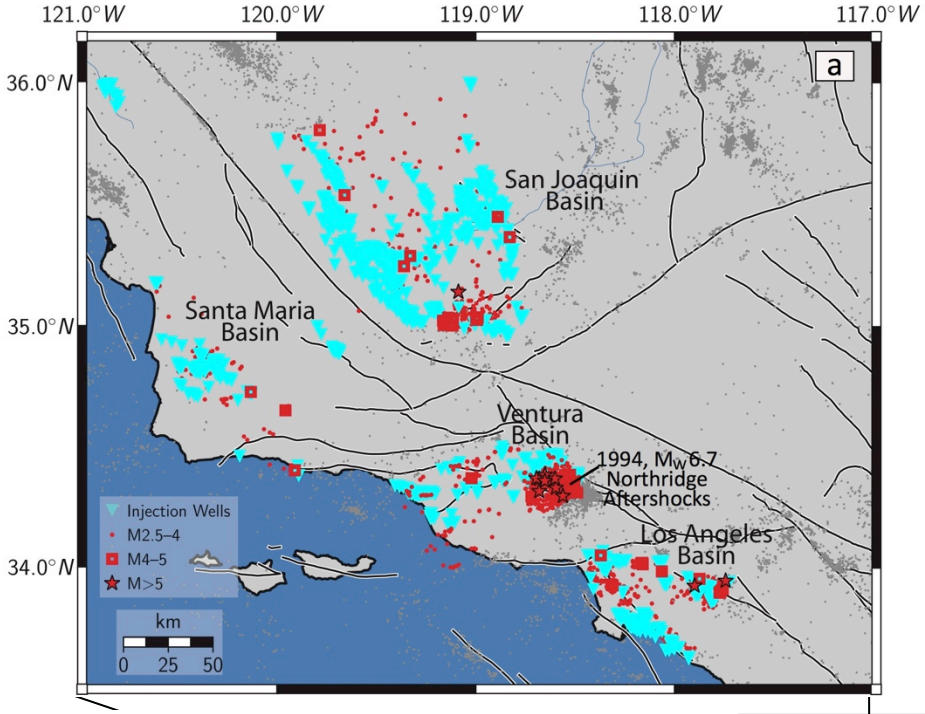
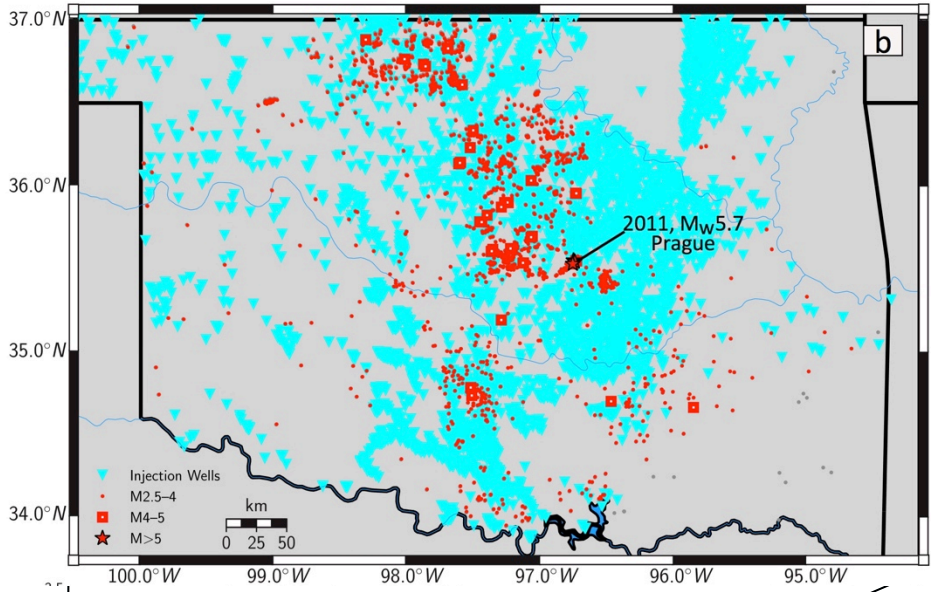
The international society of applied geophysics

Research Objectives:

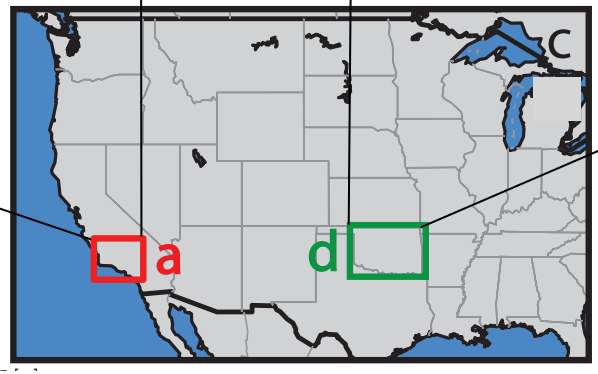
1. What are the differences/similarities in injection operations in CA and OK
2. Are there statistically significant differences in seismicity rates

Motivation I: Higher well-density in CA compared to OK



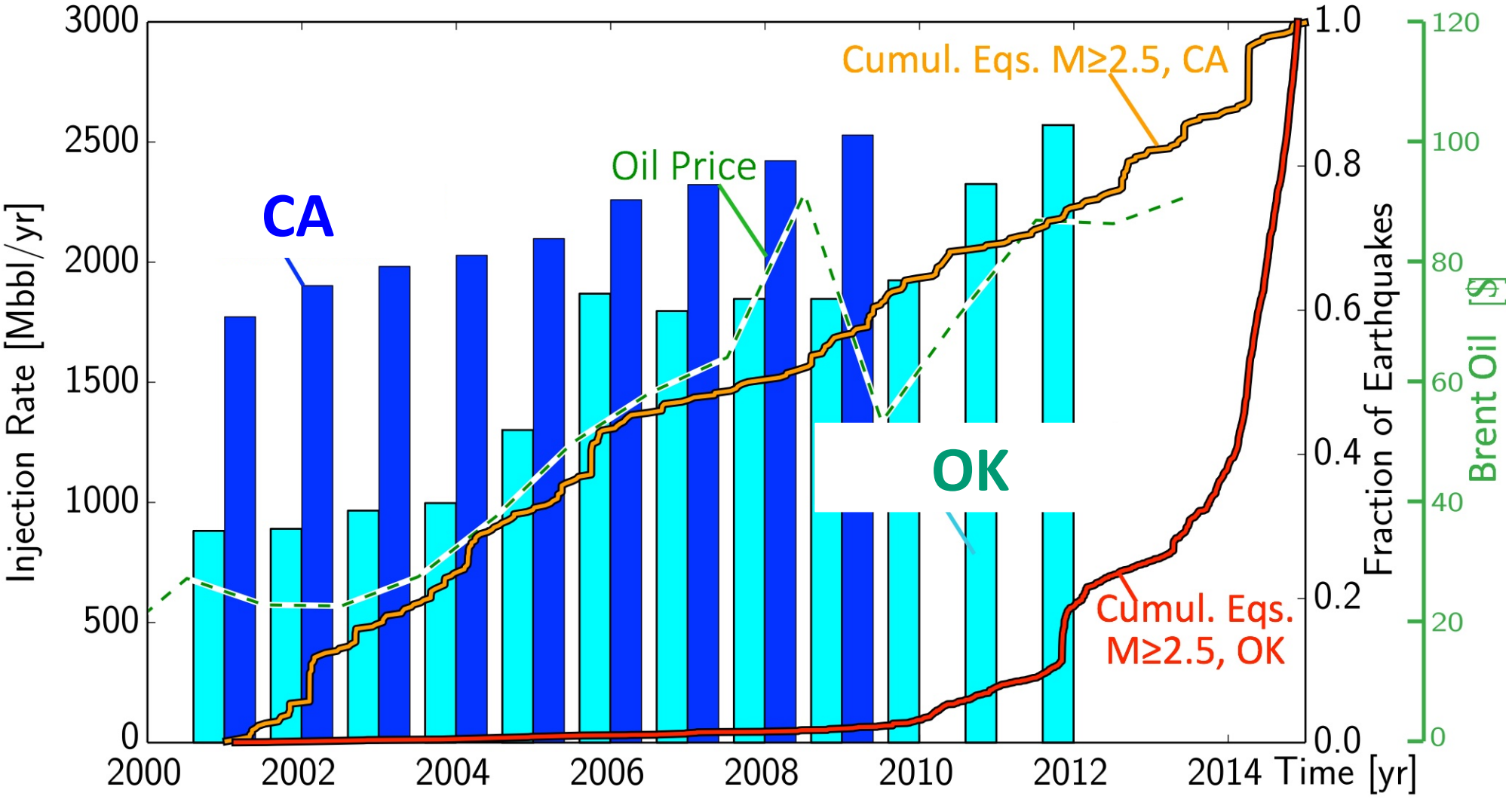


Well density: 0.7 km^2



Well density: 0.05 km^2

Motivation II: Higher injection volumes in CA than in OK



Outline

1. Fluid injection rates in CA and OK
2. Spatial-temporal variations in background seismicity rates
3. Minimum well-earthquake distance

1. Fluid injection rates in CA and OK

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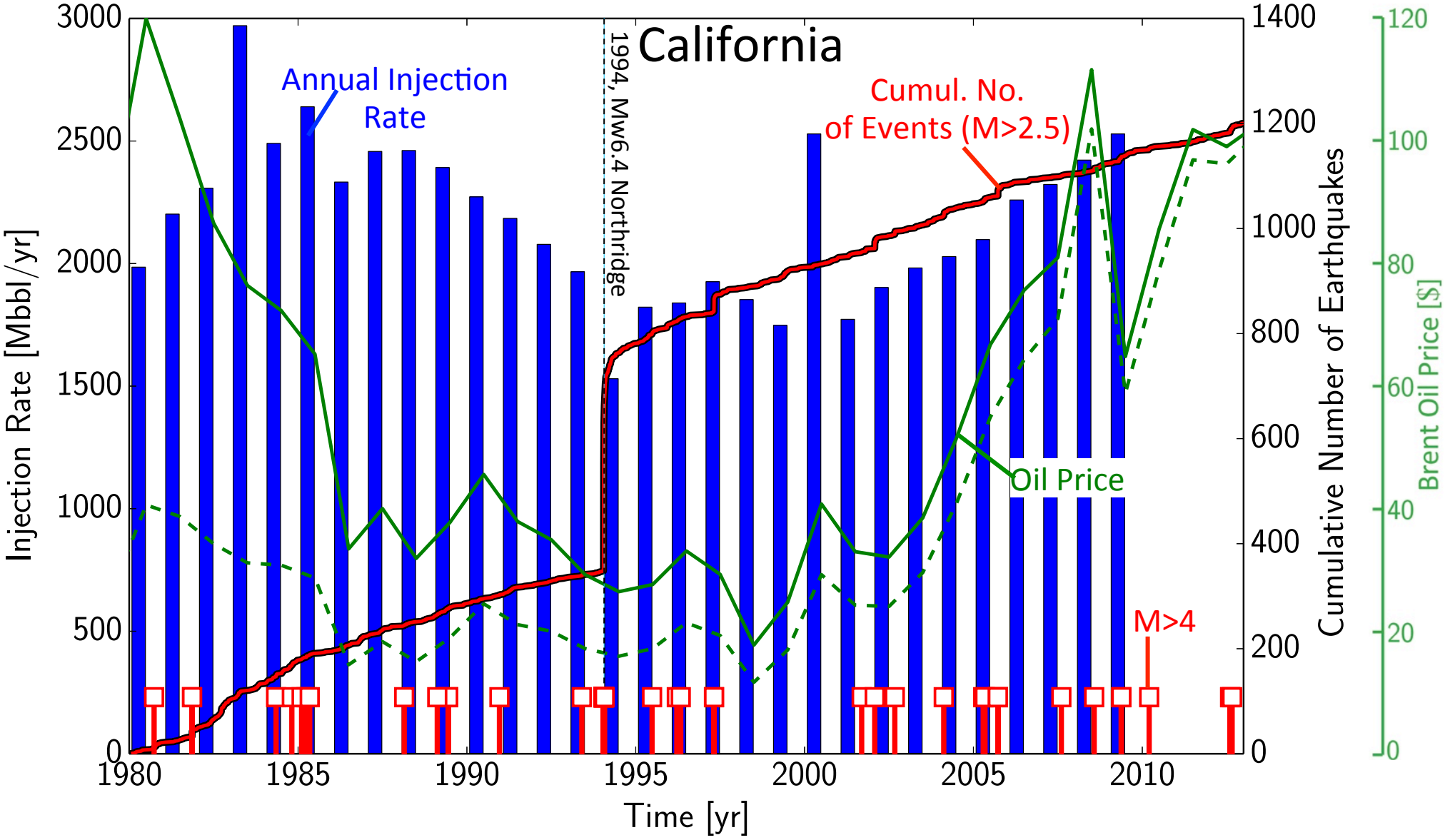
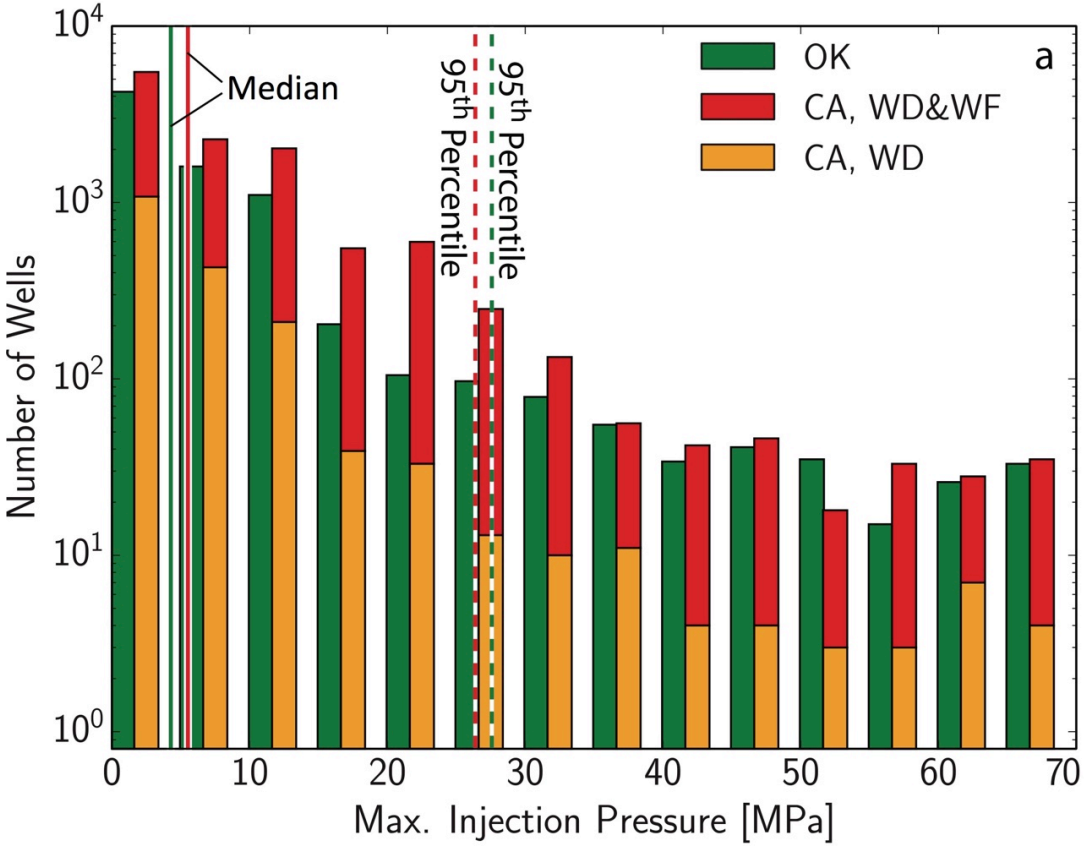
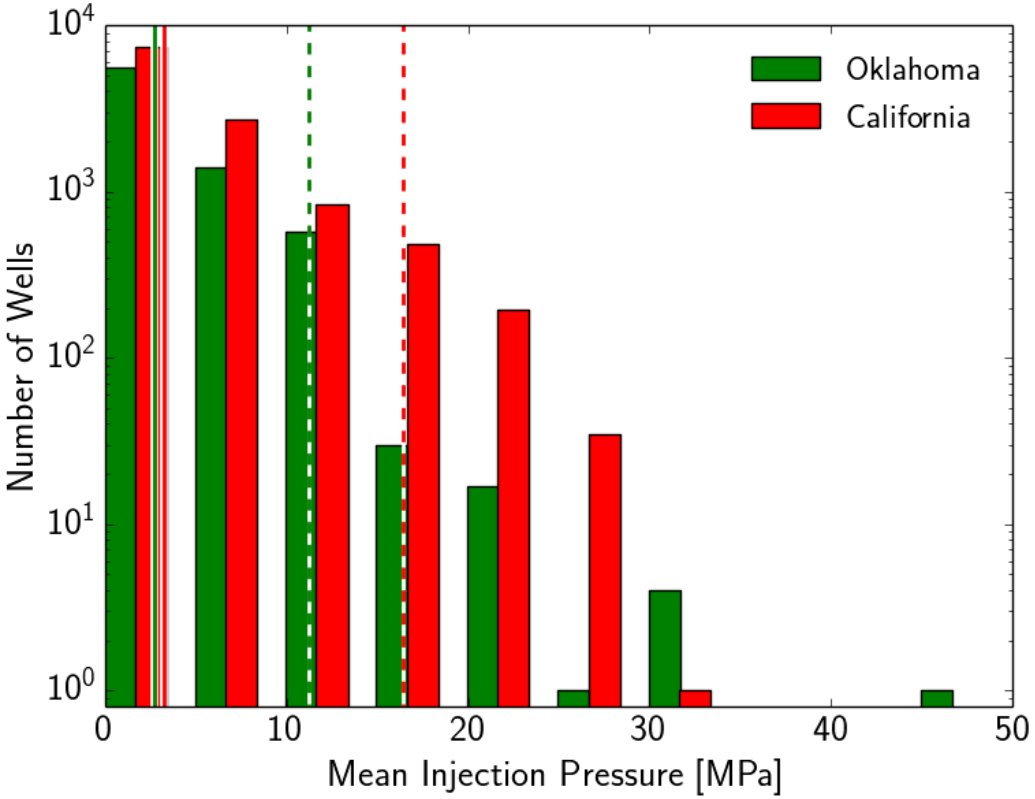
Annual injection rates and changes in seismicity rates

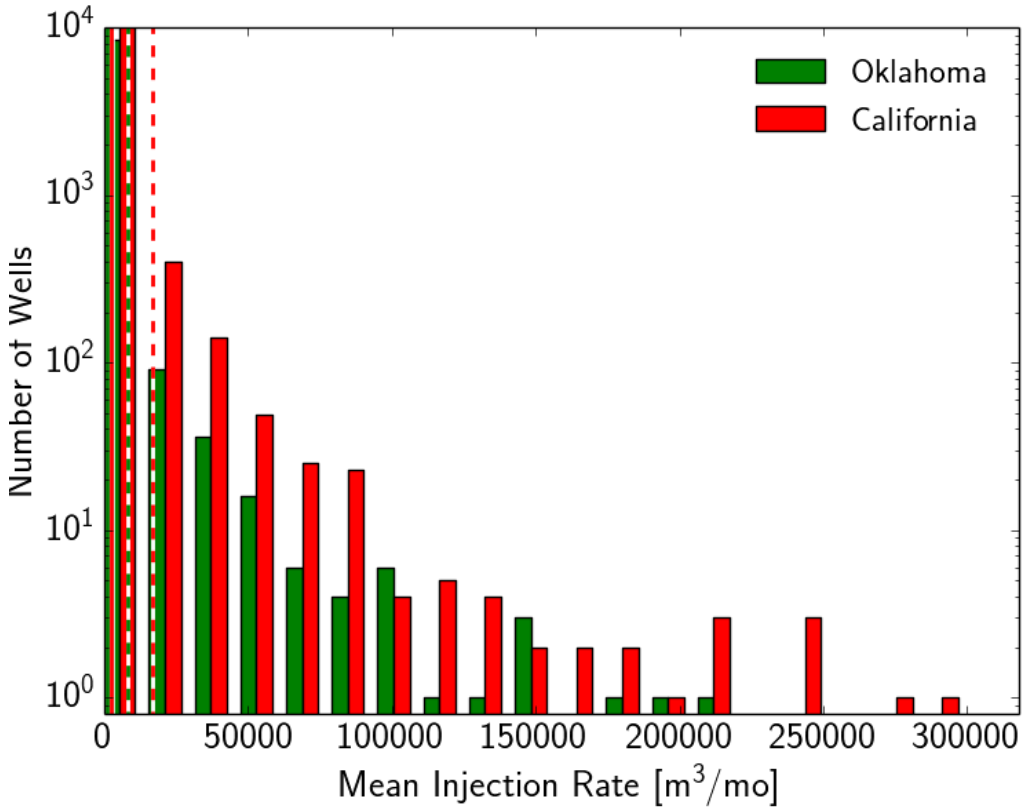


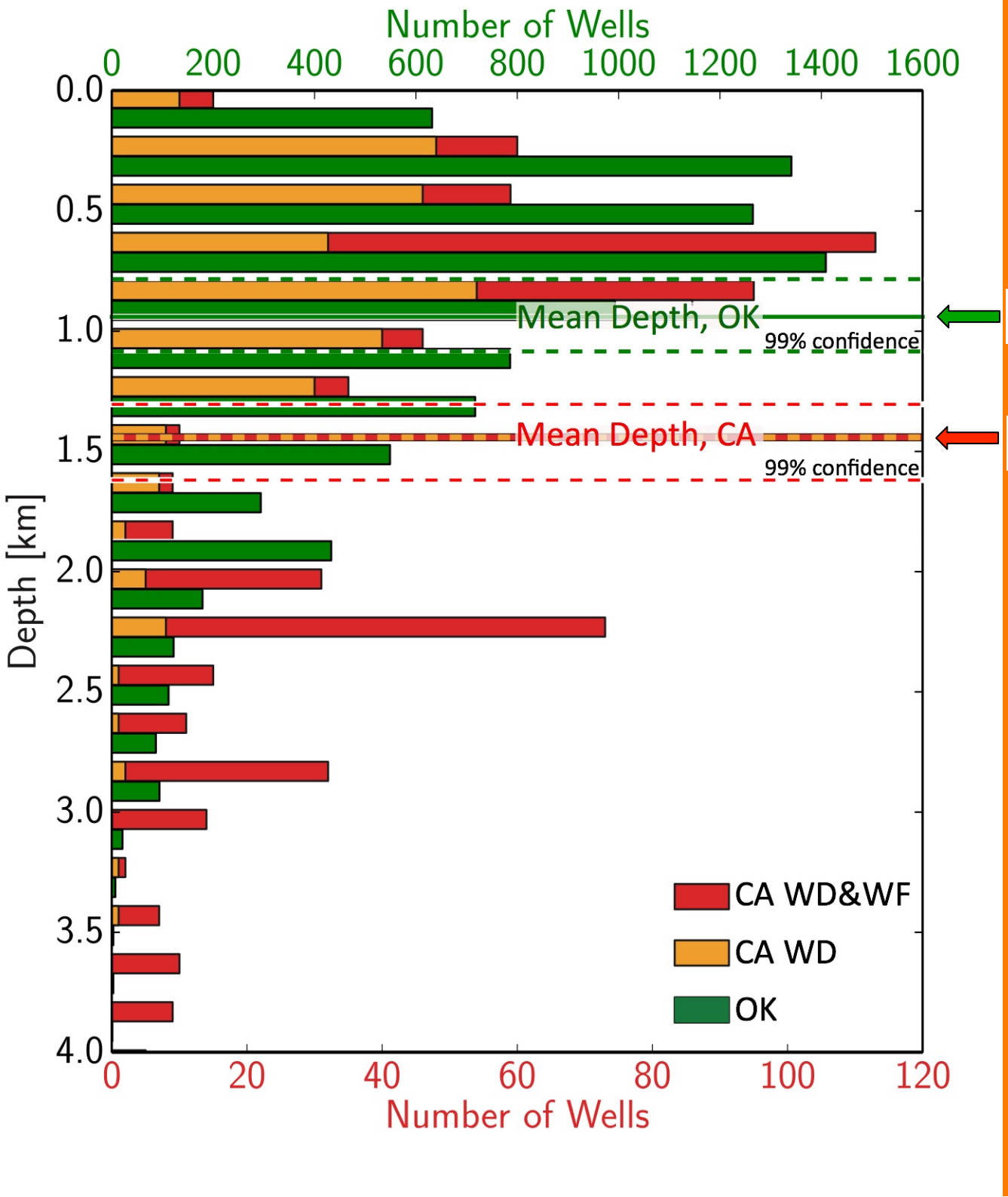
Peak injection pressures and rates are comparable in CA and OK



Mean injection pressures and rates are comparable in CA and OK







Oklahoma

California

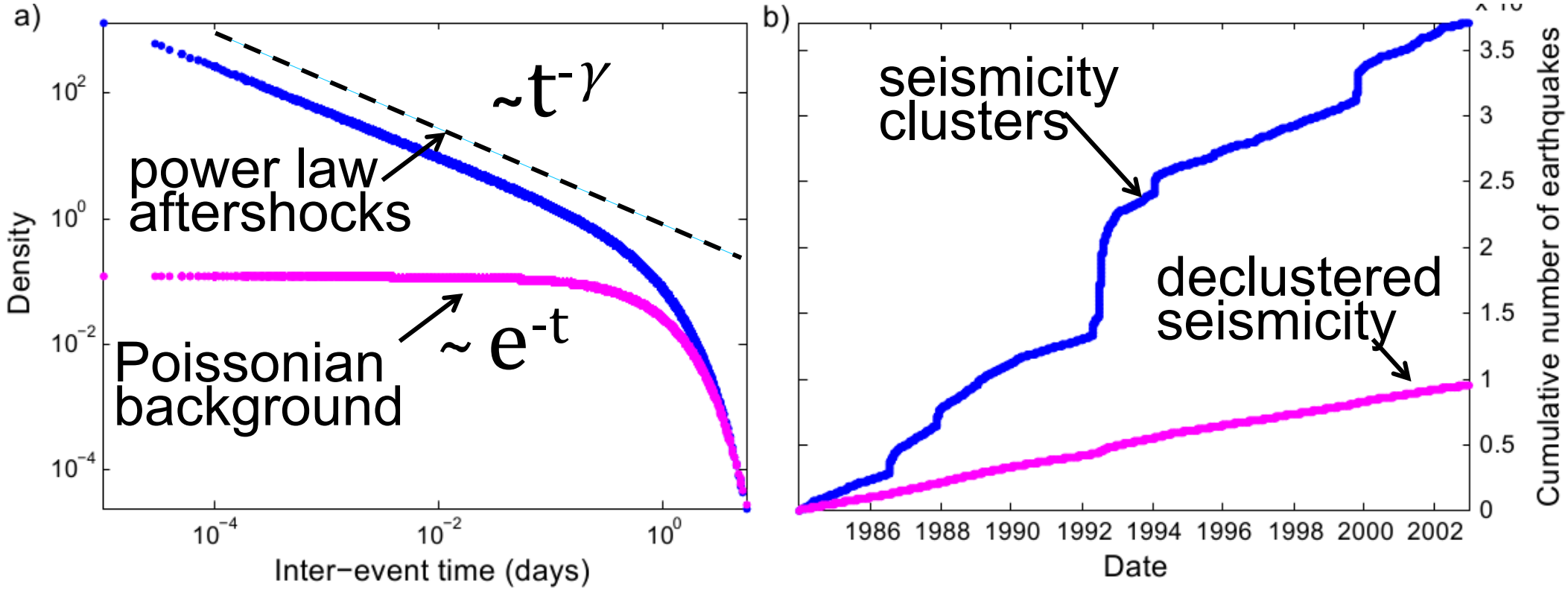
Injection depth in OK and CA

1. Fluid injection rates in CA and OK

2. Spatial-temporal variations in background seismicity rates

3. Well-earthquake distances

Background seismicity rates: Non-parametric estimate based on interevent time distribution

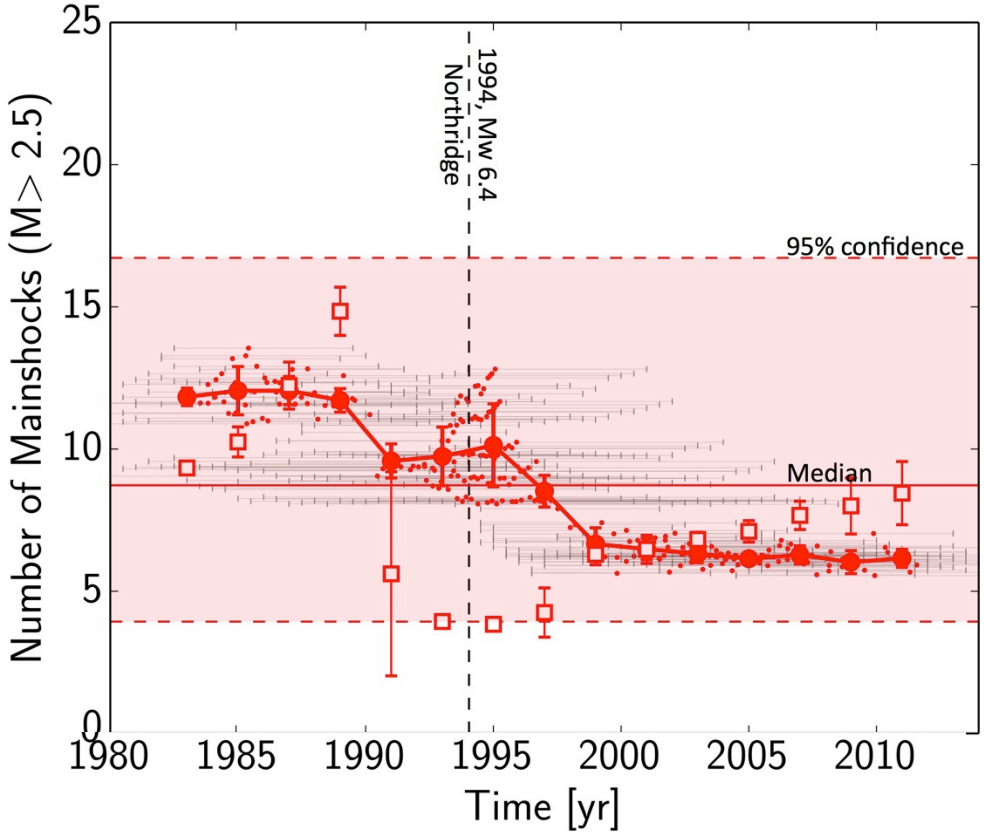


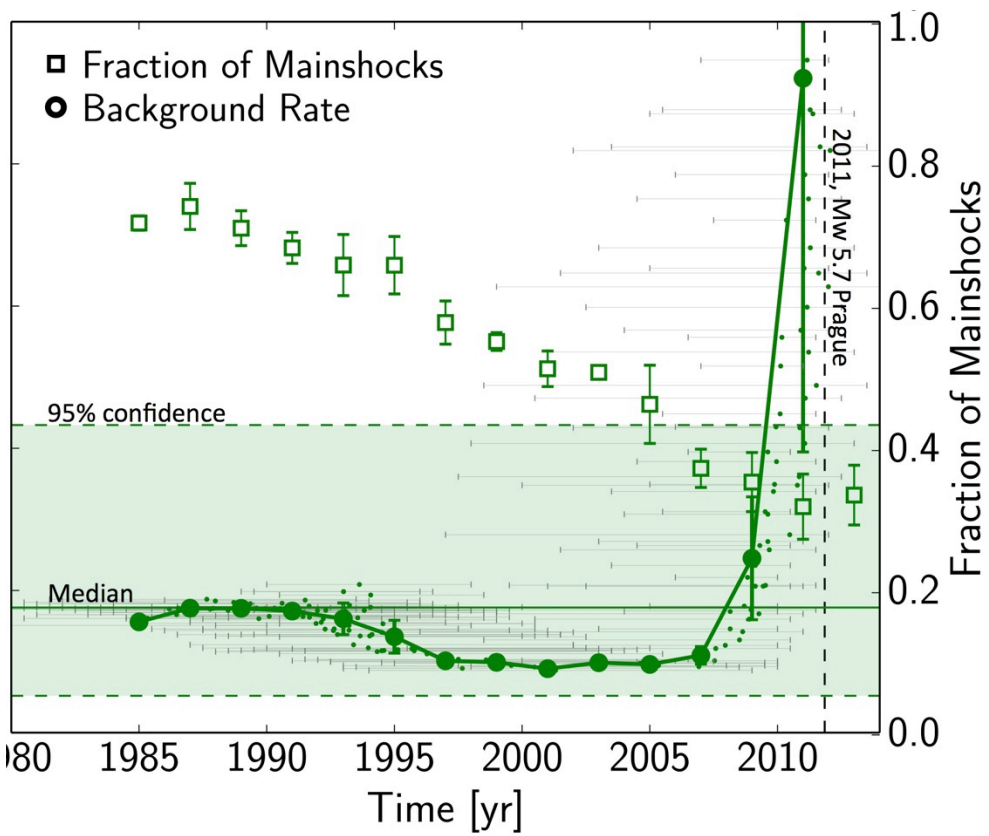
Gamma distribution of normalized interevent times

$$p(\tau) = C \cdot \tau^{\gamma-1} e^{-\tau/\beta}$$

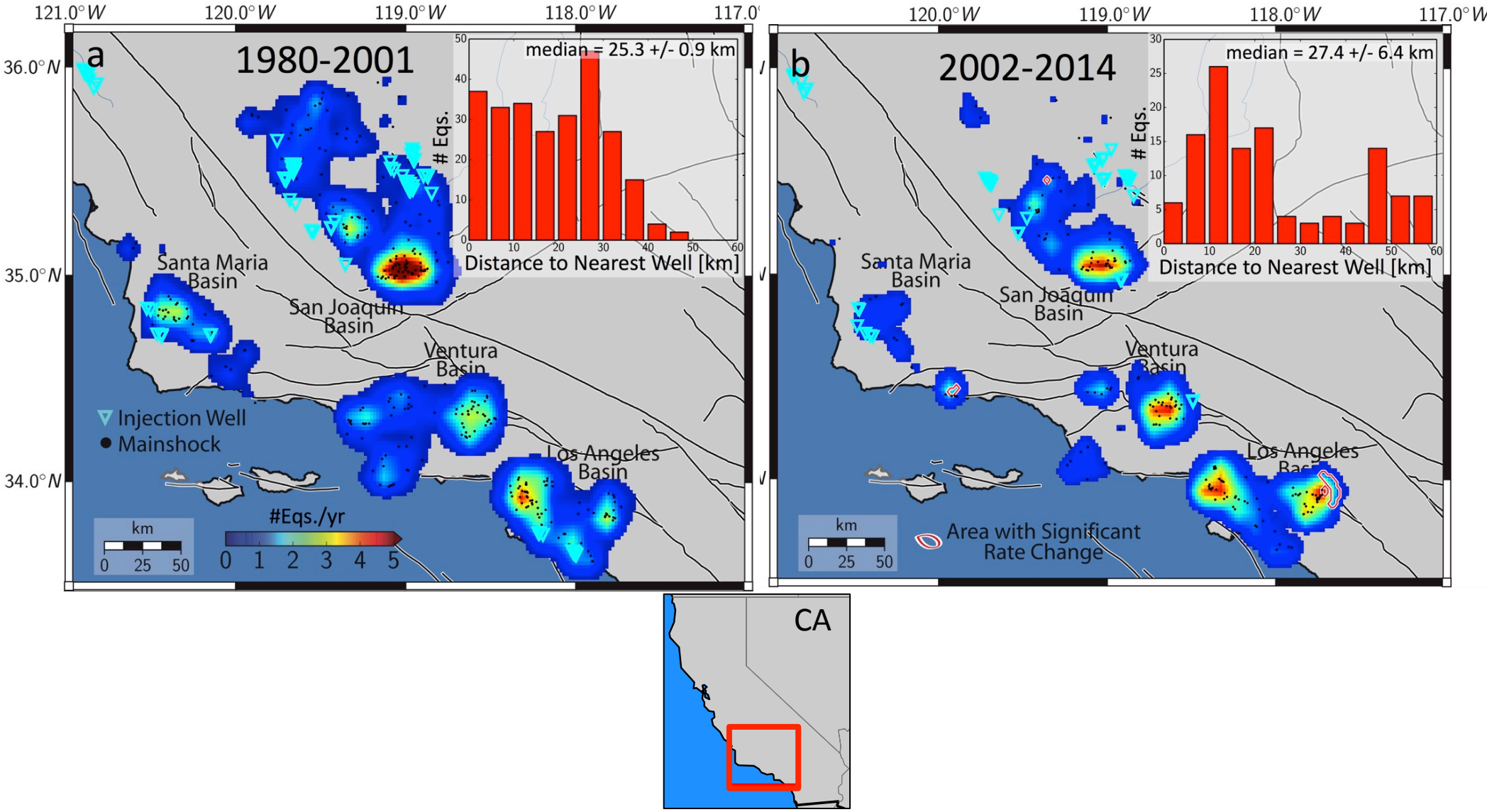
Corral, 2004; Hainzl, et al 2006,
van Stiphout, et al. 2012

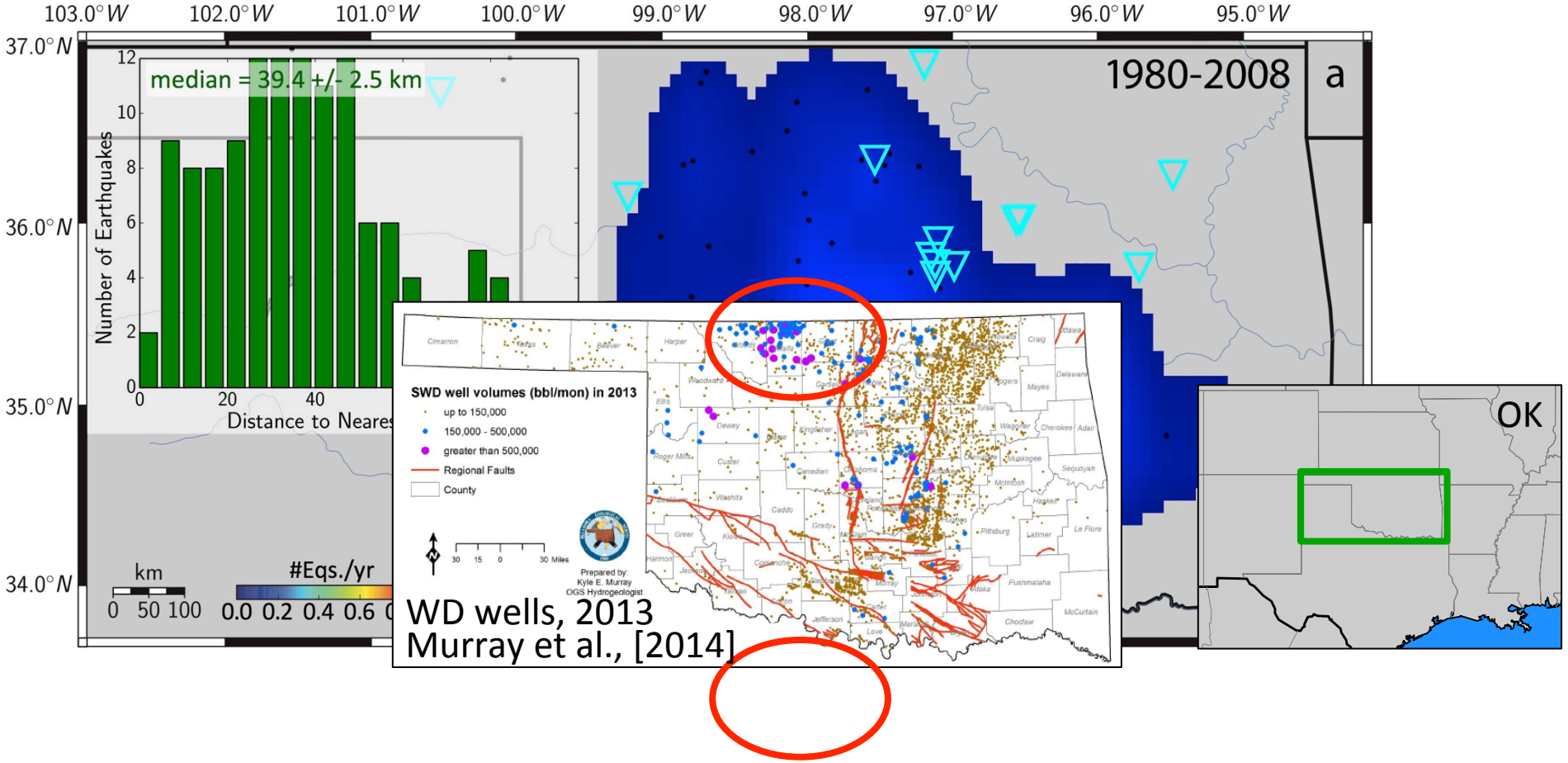
Background seismicity rates in CA and OK





Spatial variation in number of mainshocks in CA



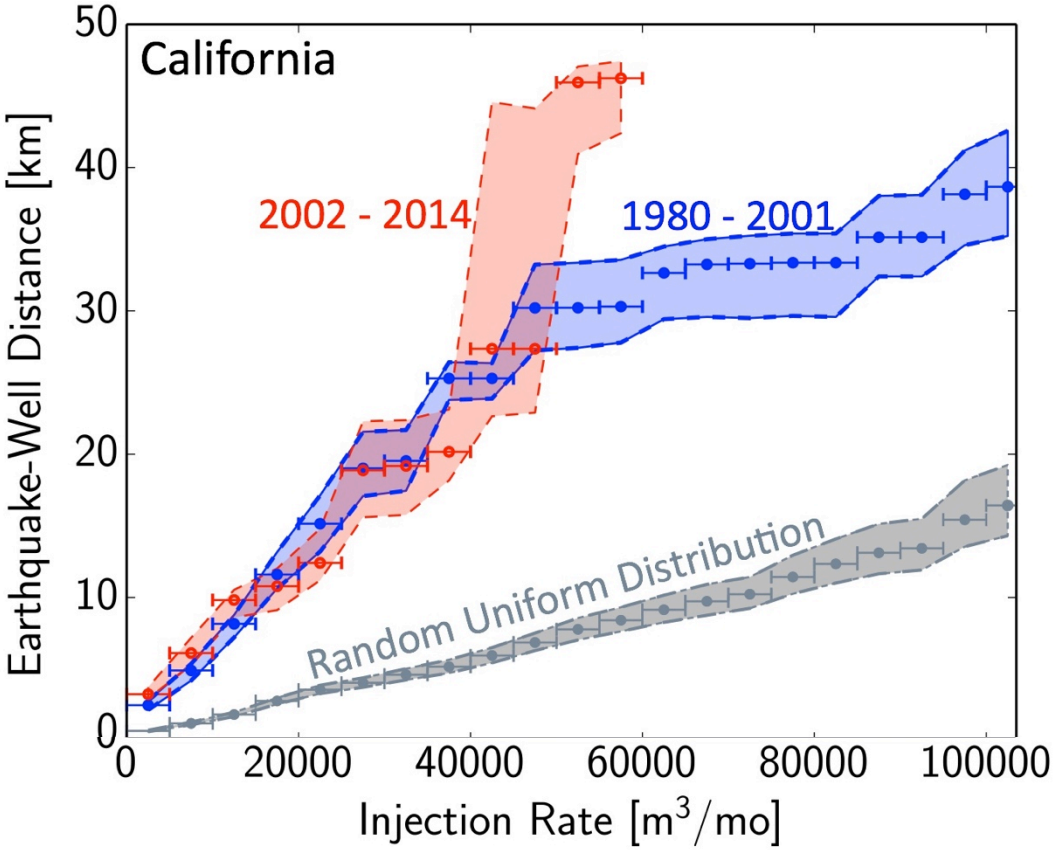

103.0° W
102.0° W
101.0° W
100.0° W
99.0° W
98.0° W
97.0° W
96.0° W
95.0° W
37.0° N
36.0° N
35.0° N
34.0° N
median = 39.4 +/- 2.5 km
Number of Earthquakes
Distance to Neares
1980-2008
a
km
0 50 100
#Eqs./yr
0.0 0.2 0.4 0.6
SWD well volumes (bbl/mon) in 2013
up to 150,000
150,000 - 500,000
greater than 500,000
Regional Faults
County
30 15 0 30 Miles
Prepared by:
Kyle E. Murray
OGS Hydrogeologist
WD wells, 2013
Murray et al., [2014]
OK

1. Fluid injection rates in CA and OK

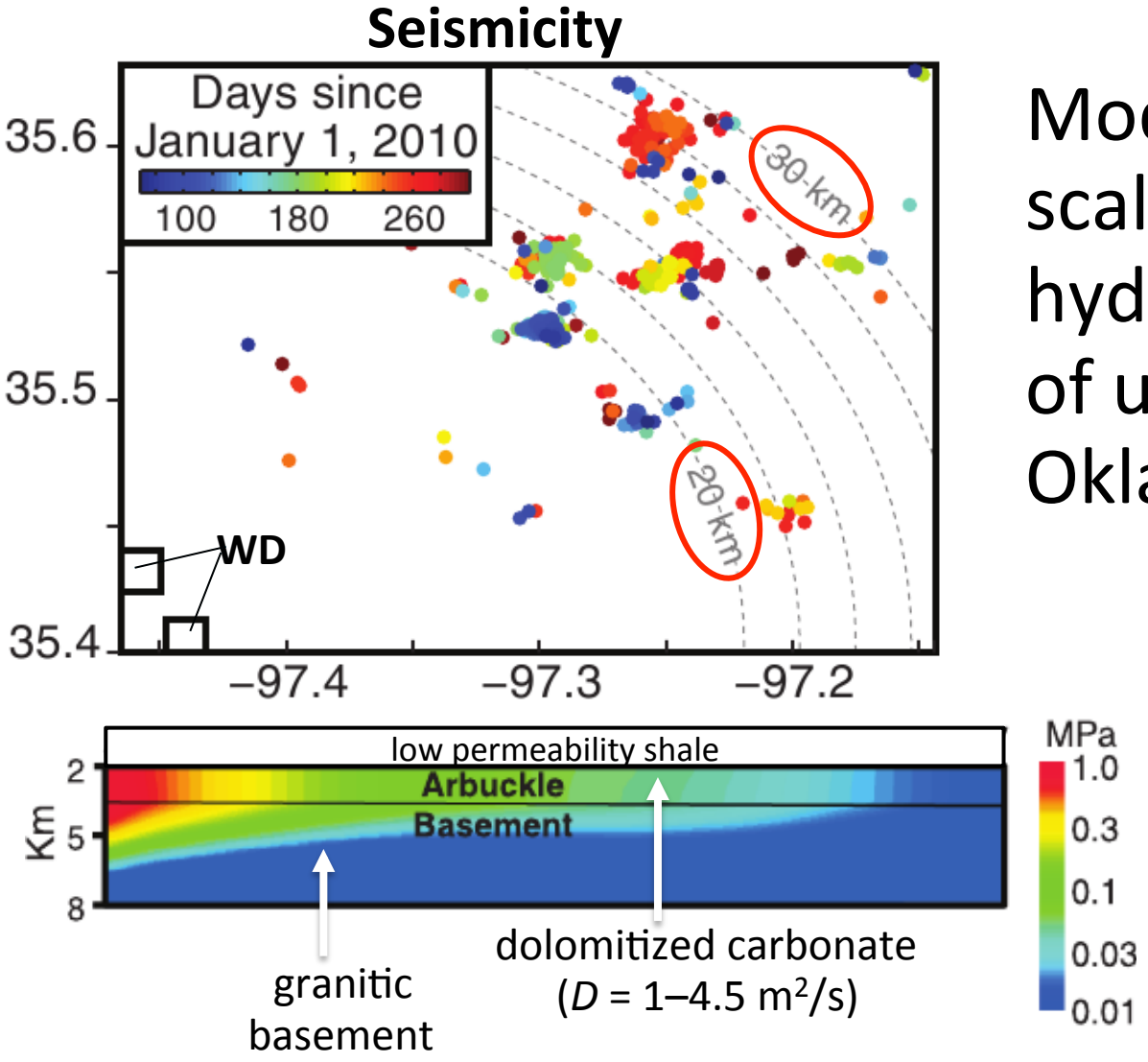
2. Spatial-temporal variations in background seismicity rates

3. Minimum well-earthquake distance

Earthquakes occur closer to wells in OK after 2009



Jones earthquake swarm: Possibly induced by distant, high-rate injection wells



Model assumes large-scale (20-35 km) hydraulic connectivity of upper crust in Oklahoma

Keranen et al., 2014

What controls induced seismicity potential?

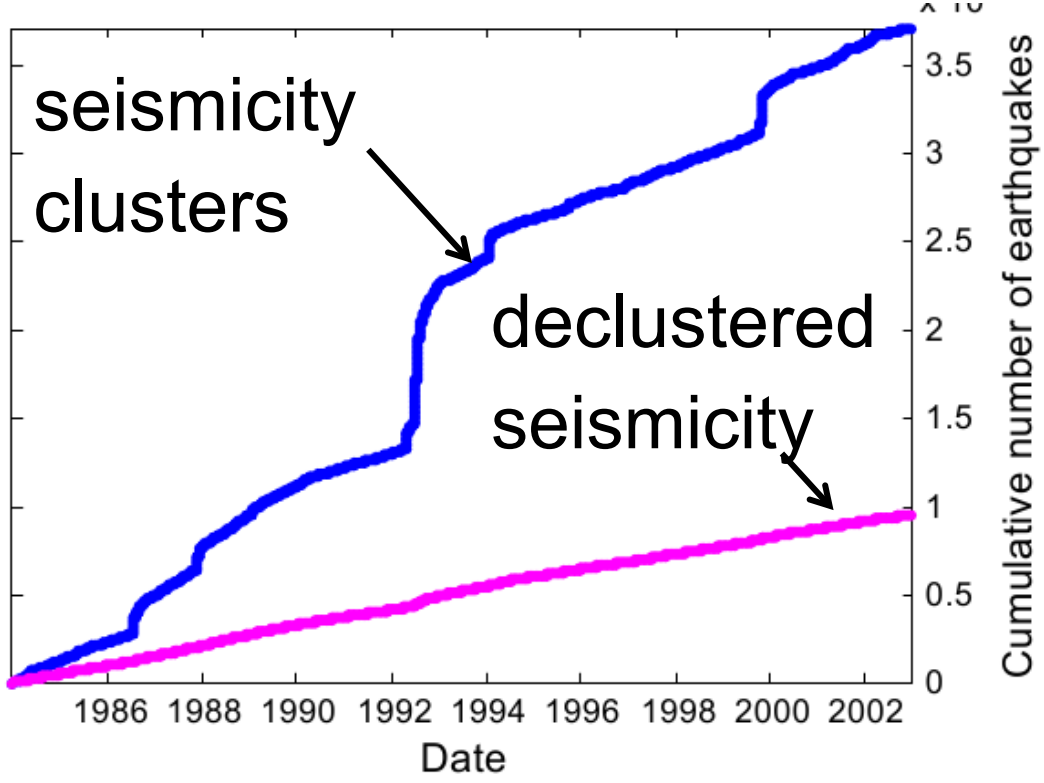
- Tested injection parameters (volume, rates, pressure, depth) have little control on seismicity
- Net production rate?
- Proximity to failure → Is crust critically stressed in OK?
- Geologic setting: Distance to basement, hydraulic connectivity

Future Research

- Geologic difference between hydrocarbon basins in California and Oklahoma
- Fault orientations and stress fields
- Influence of different strain rates in plate boundary vs. intraplate regions

- Thank you -

Background seismicity rates: Non-parametric estimate based on interevent time distribution



Corral, 2004; Hainzl, et al 2006,
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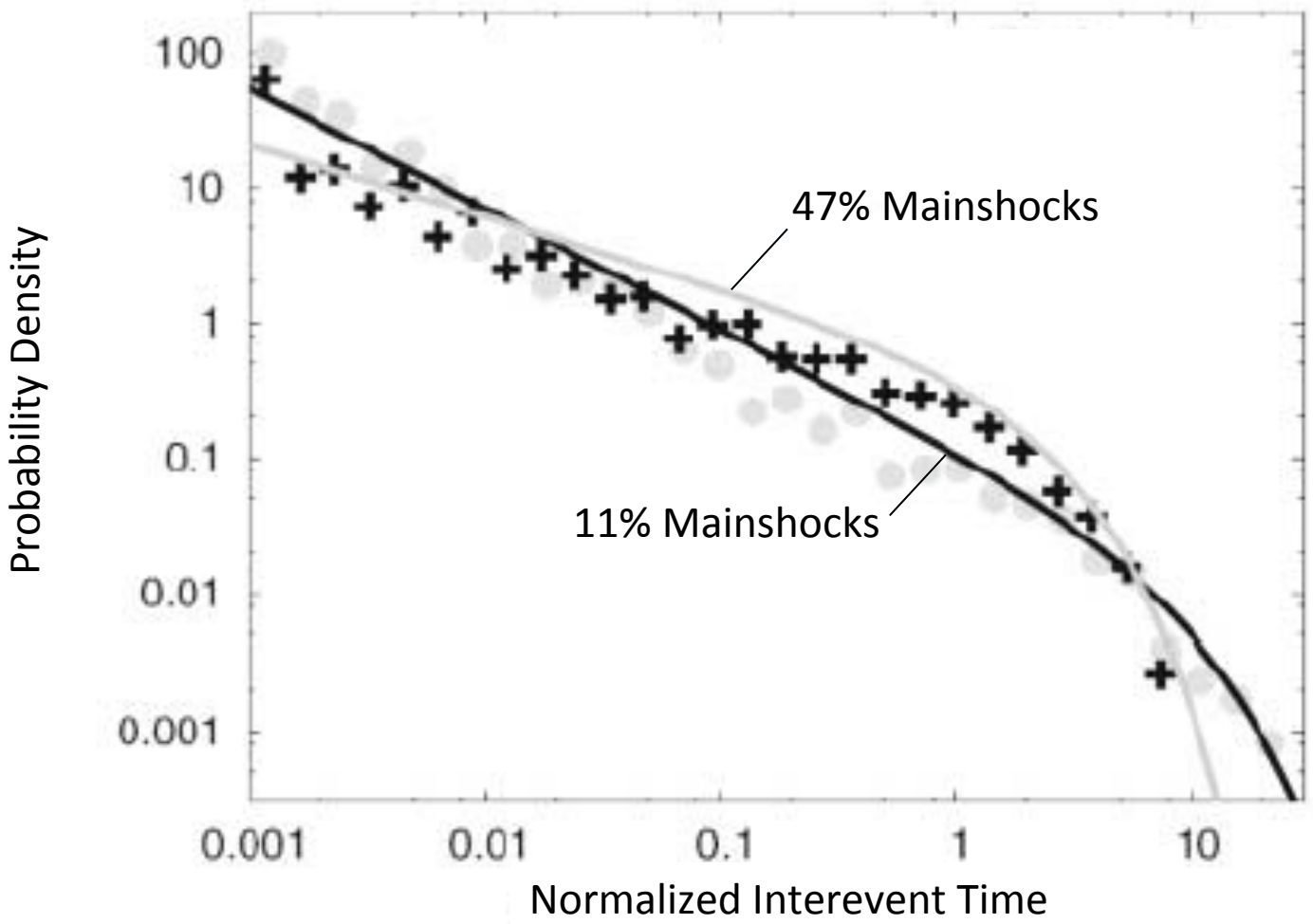
Non-parametric estimate of background seismicity rates



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Corral, 2004; Hainzl, et al 2006

Complications with induced seismicity predictions

- Poro-elastic effects, elastic stress changes due to fluid load
- crustal stress and strength distributions are heterogeneous
- aseismic slip transients
- secondary triggering, dynamic and static stress transfers

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