Background seismicity rates from interevent-time statistics:

Spatial patterns appear stationary through time

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Background earthquake rate

Assumes two earthquake classes:

1) Background events: occur as direct response to loading (e.g. tectonic, magmatic.)

2) Triggered events: caused by other earthquakes.

Background earthquake rate

Important for:

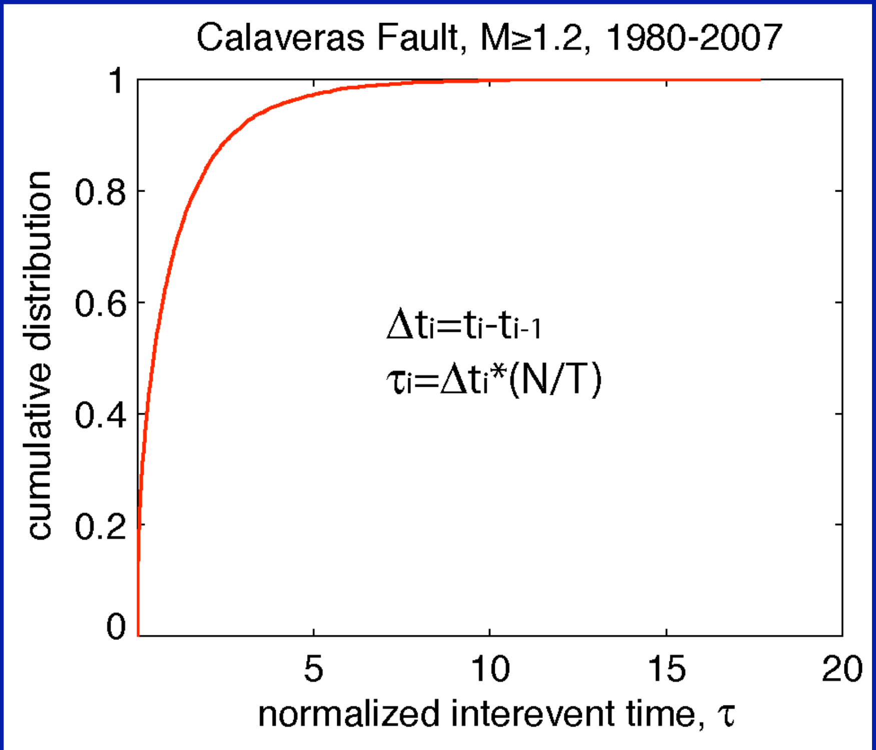
- Time-independent seismic hazard assessment.
- Background rate changes related to loading rate changes => fault physics; time-dependent seismic hazard.
- Background rate changes related to stress shadows => static versus dynamic stress triggering debate.

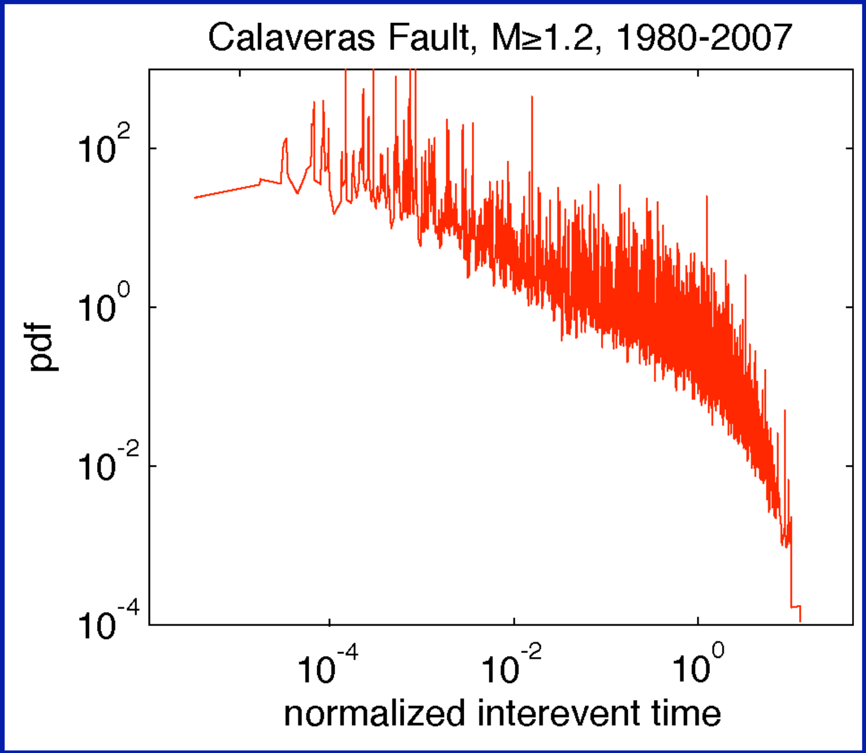
Background earthquake rate

Difficult to measure:

- Background rate obscured by triggered events.
- Standard declustering methods (Reasenberg, Gardner & Knopoff) rely on two unknown, subjectively adjustable parameters: the length-scale and time-scale that define a "triggered" event.
- A poster today: Van Stiphout "How far can we trust declustering algorithms?"

Earthquake interevent-time distribution





- Time between successive events i and i+1: $\Delta t_i = t_{i+1} - t_i$.
- N earthquakes, catalog duration T, given area and magnitude range.
- Normalize by average interevent time, $\tau_i = \Delta t_i * (N/T)$.

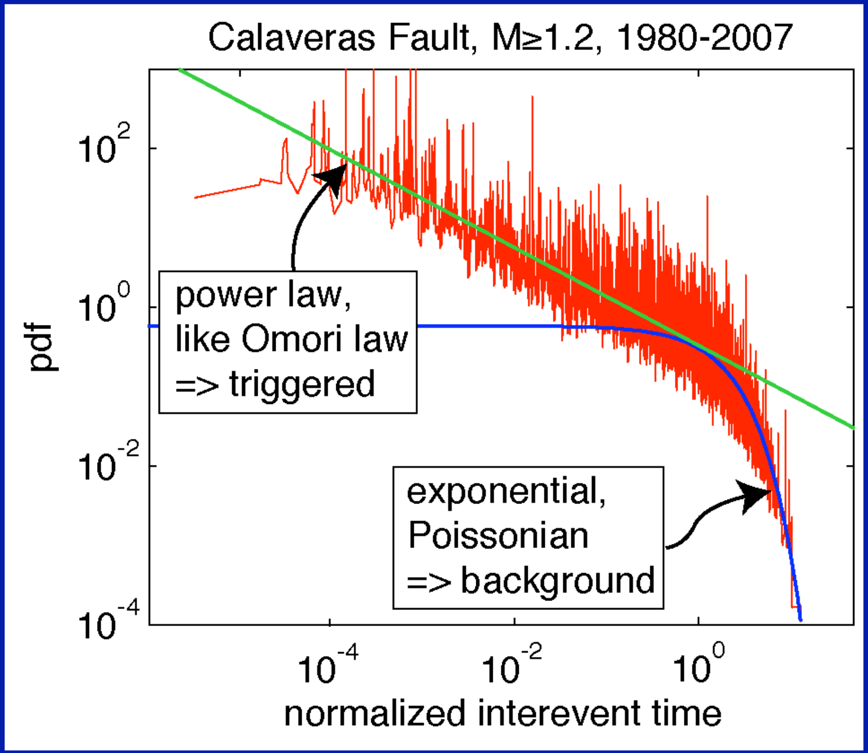
Earthquake interevent-time distribution

Short interevent times:
    clustered => power law.
Long interevent times:
    Poissonian => exponential.

Gamma distribution combines power law and exponential:

$$p(\tau) = \frac{\tau^{\gamma-1} e^{-\gamma\tau}}{\left(\frac{1}{\gamma}\right)^{\gamma}\Gamma(\gamma)},$$

γ=background fraction



Gamma distribution formulation from Hainzl et al., BSSA 2006, following Corral, PRL, 2004.

Earthquake interevent-time distribution

Method of Hainzl et al., BSSA 2006: Background fraction found *objectively* and *easily* from mean and variance of interevent-time distribution:

$$\gamma_{obs} = \frac{\text{mean}(\tau)}{\text{var}(\tau)}.$$

Follows from gamma distribution:

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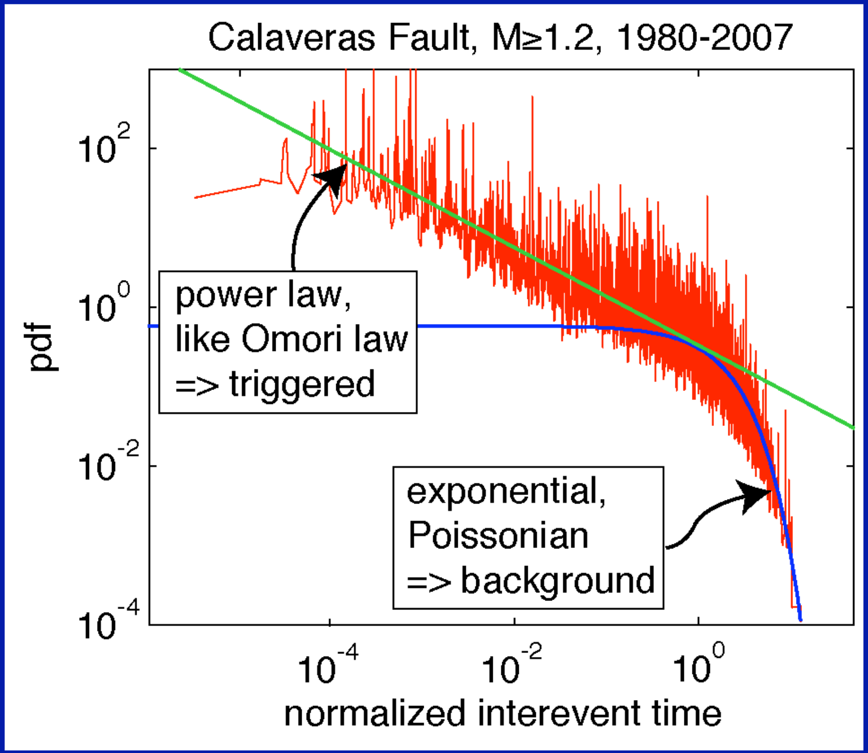

Earthquake interevent-time distribution

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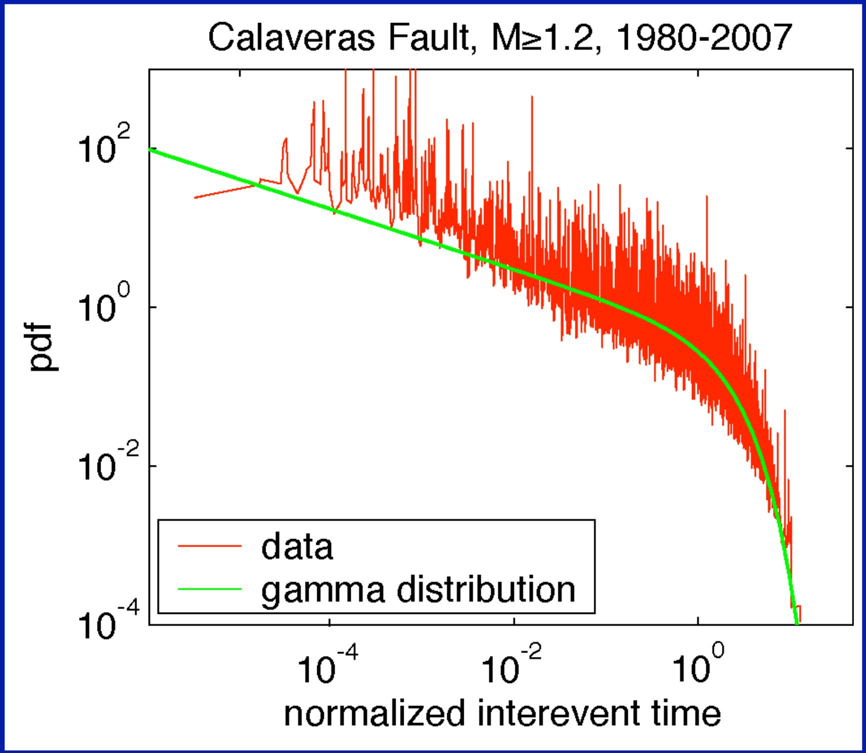


Gamma distribution is a poor fit to our data!

Earthquake interevent-time distribution

Theoretical distribution:

Gutenberg-Richter: $N(M) = 10^{a-b(M-M_{\min})}$

Modified Omori: $r(t,M) = A(M) * (t+c)^{-p}$

Productivity: $A(M) = k10^{b(M-M_{\min})}$

$$P(\tau \le \tau_1) = \gamma P_{back}(\tau \le \tau_1) + (1-\gamma) P_{aft}(\tau \le \tau_1)$$

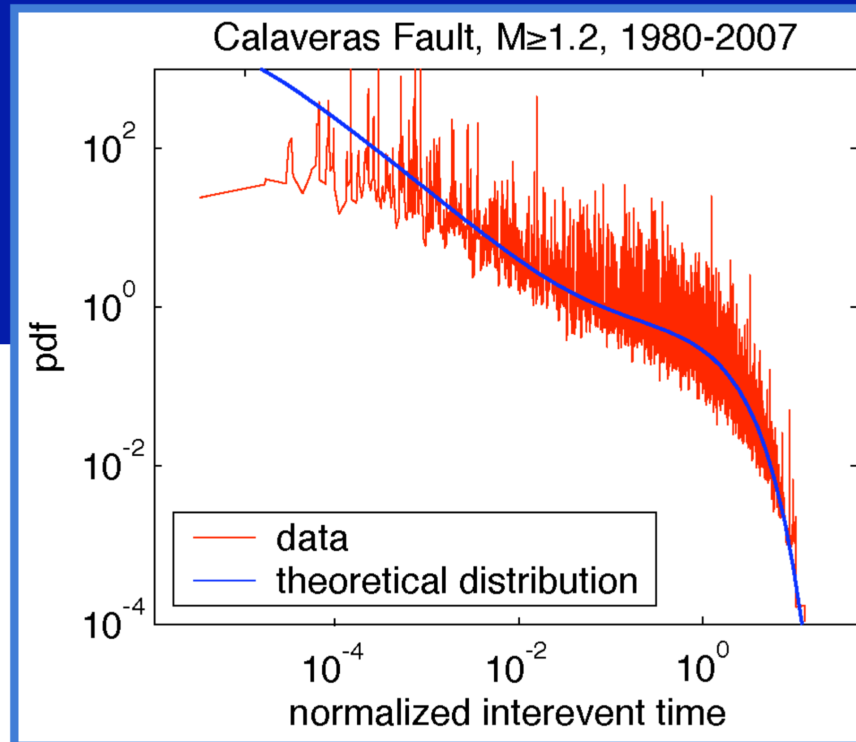
where:

$$P_{back}(\tau \le \tau_1) = 1 - \exp(-\gamma \tau_1)$$

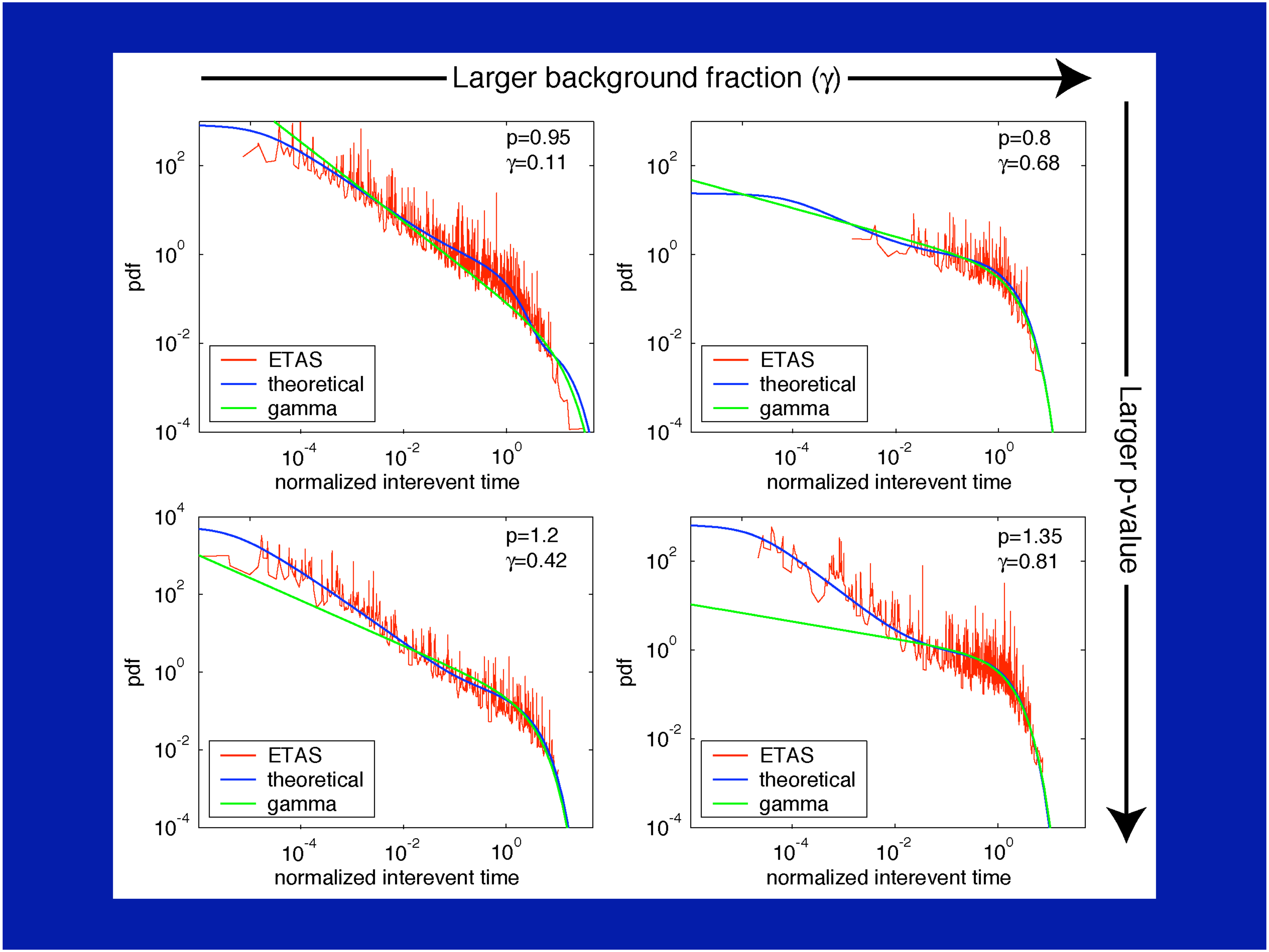
and:

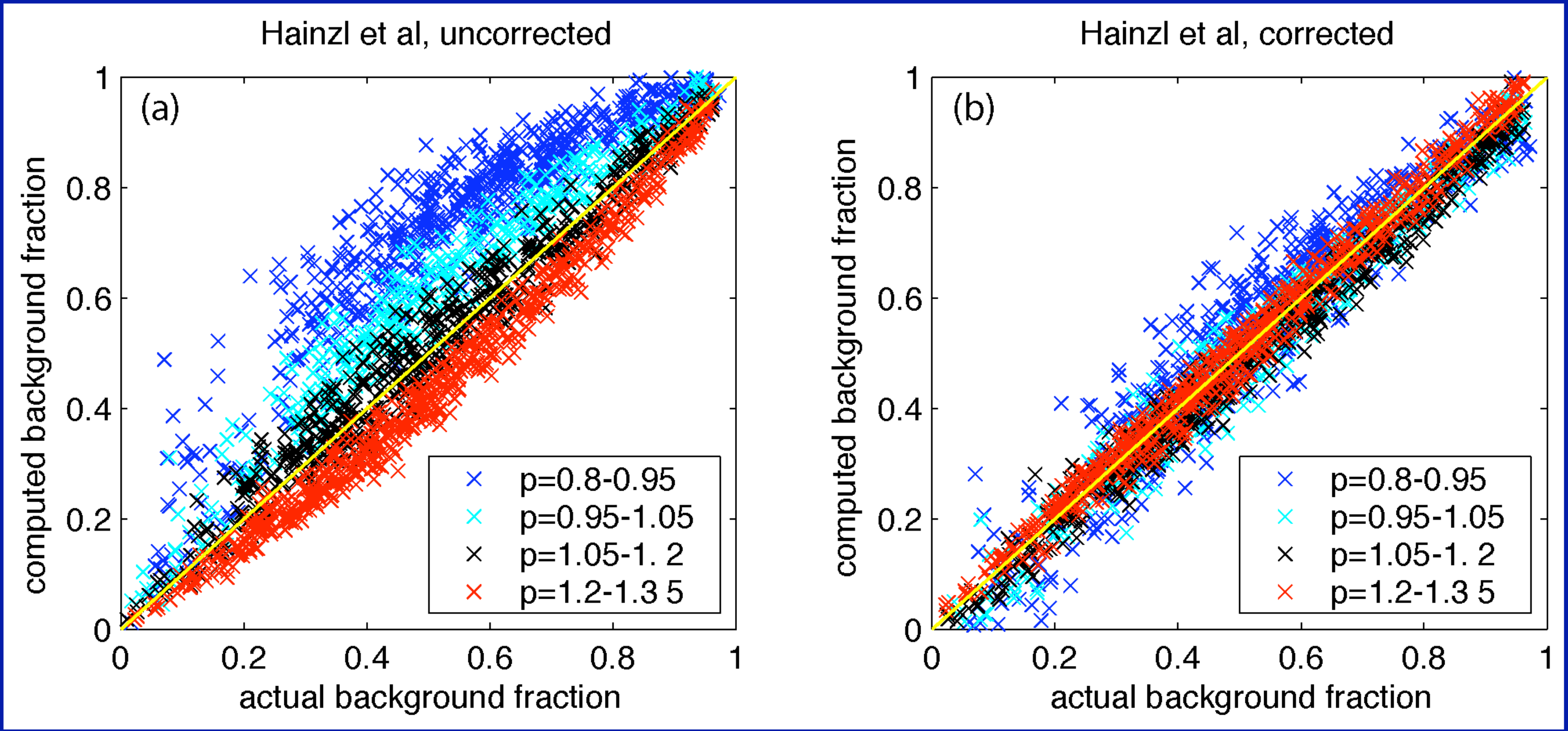
$$P_{aft}(\tau \le \tau_1) = 1 - \frac{\exp(-\tau_1)(1-p)}{(M_{max} - M_{min})\left[(T+c)^{(1-p)} - c^{(1-p)}\right]} *$$

$$\int_{t=0}^{T} \int_{M=M_{min}}^{M_{max}} (t+c)^{-p} \exp\left(-\frac{\tau_1 k}{\lambda}(2-\gamma)(t+c)^{-p} 10^{b(M-M_{min})}\right) dM dt$$



Another form of the theoretical distribution from Gutenberg-Richter and Omori laws was derived by Saichev and Sornette, JGR 2007.

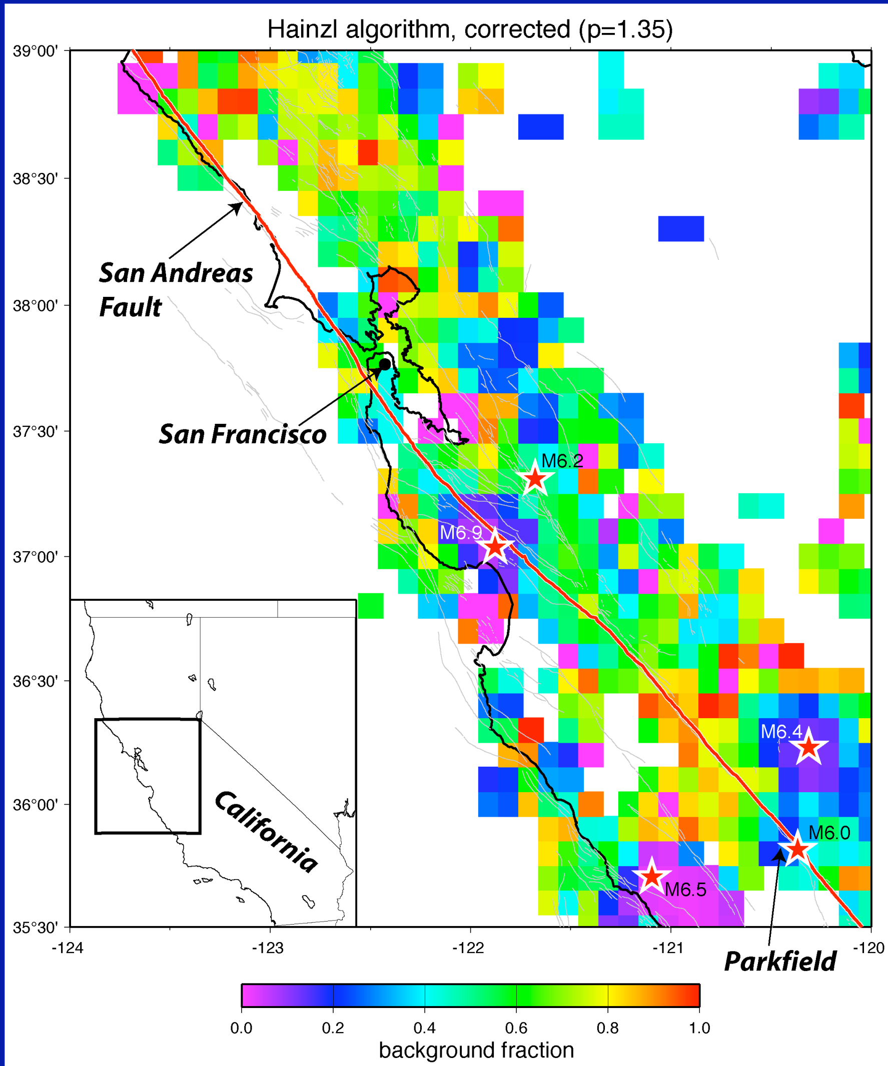

Larger background fraction (γ)
Larger p-value
p=0.95
γ=0.11
p=0.8
γ=0.68
p=1.2
γ=0.42
p=1.35
γ=0.81
pdf
normalized interevent time
ETAS
theoretical
gamma

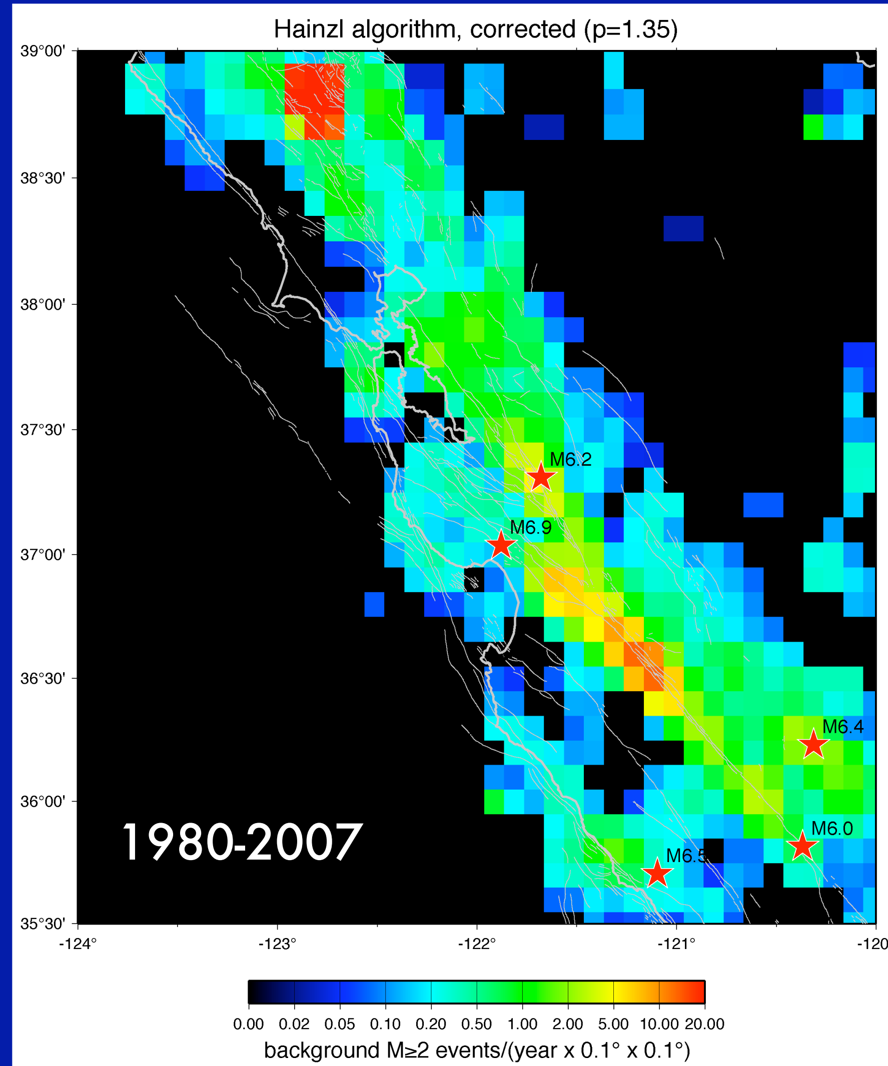


2000 ETAS simulations: Hainzl et al method works well, but requires a correction based on *direct* p-value (not usually known for real data.)

$$\gamma_{corrected} = \gamma_{obs} - 0.88 + 0.74p + (2.89 - 2.53p)(\gamma_{obs} - 0.5)^2.$$

Northern California



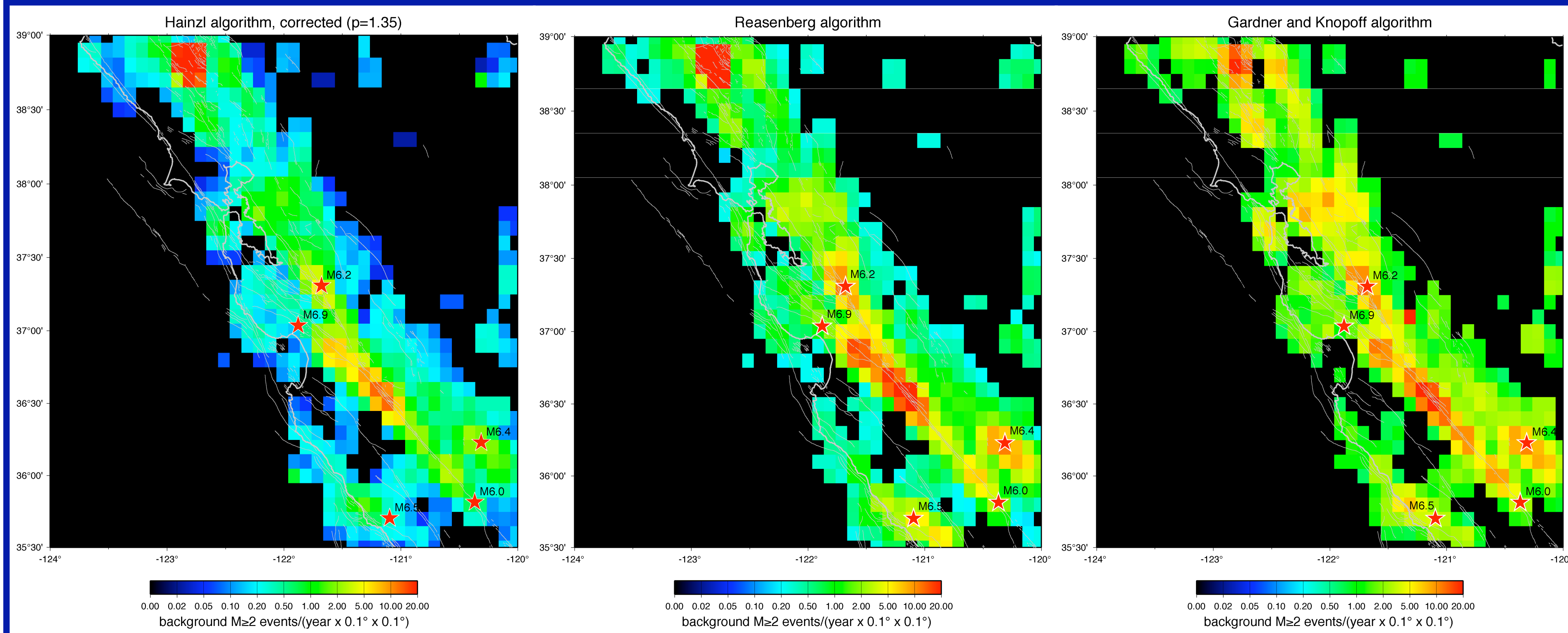


Subjective, using recommended parameters:

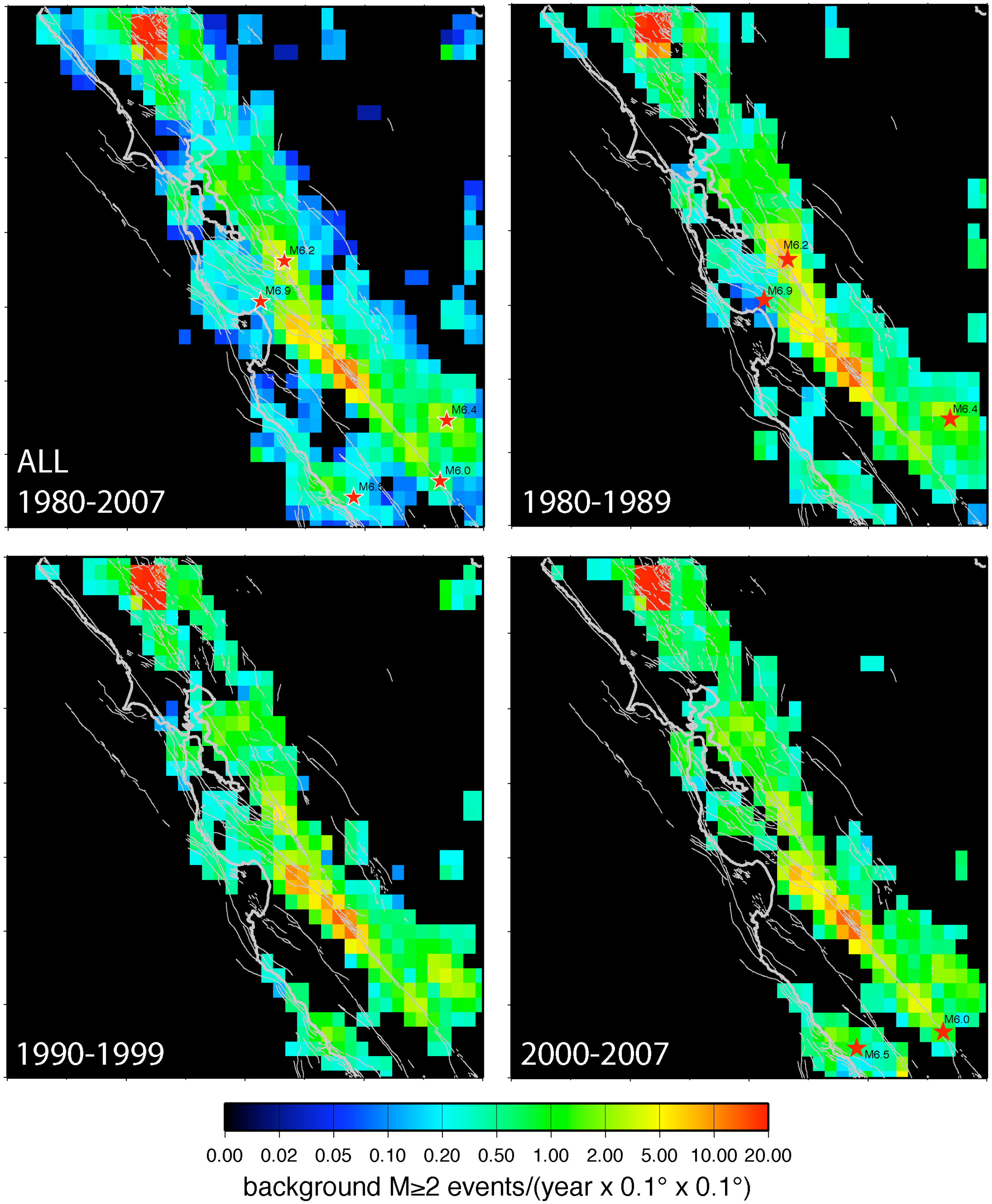
Objective

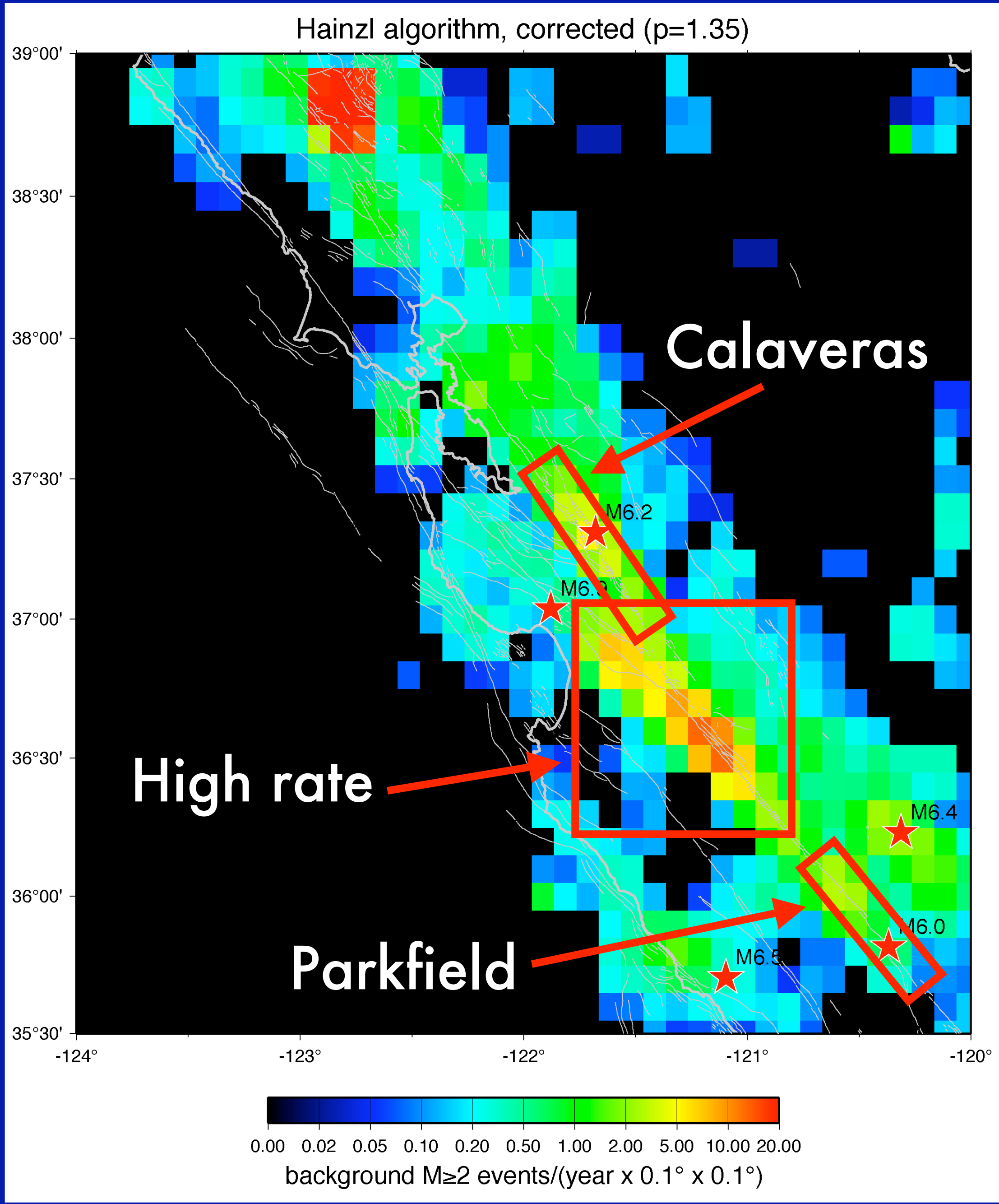
Reasenberg

Gardner & Knopoff

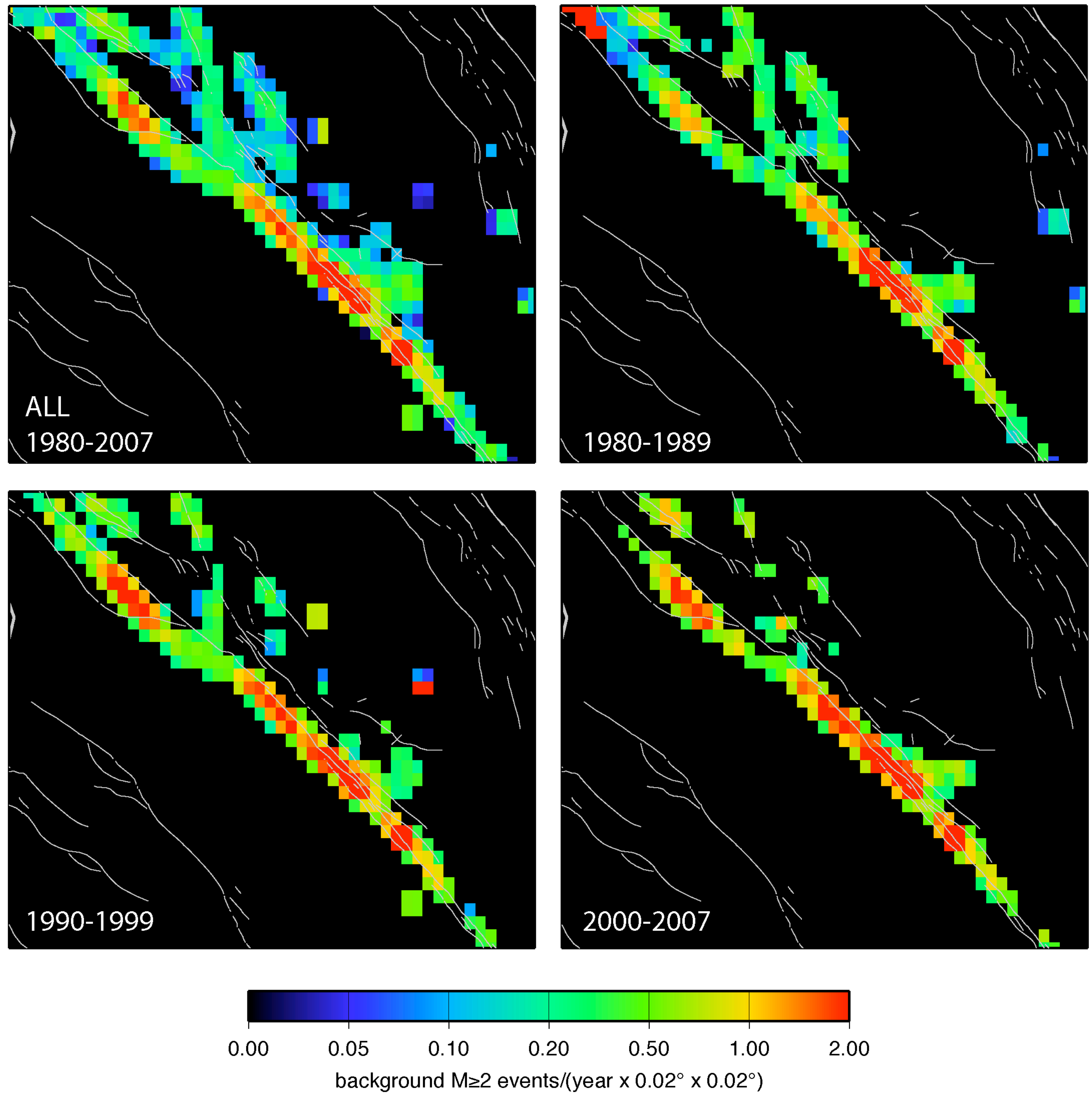


Method used for US seismic hazard maps.

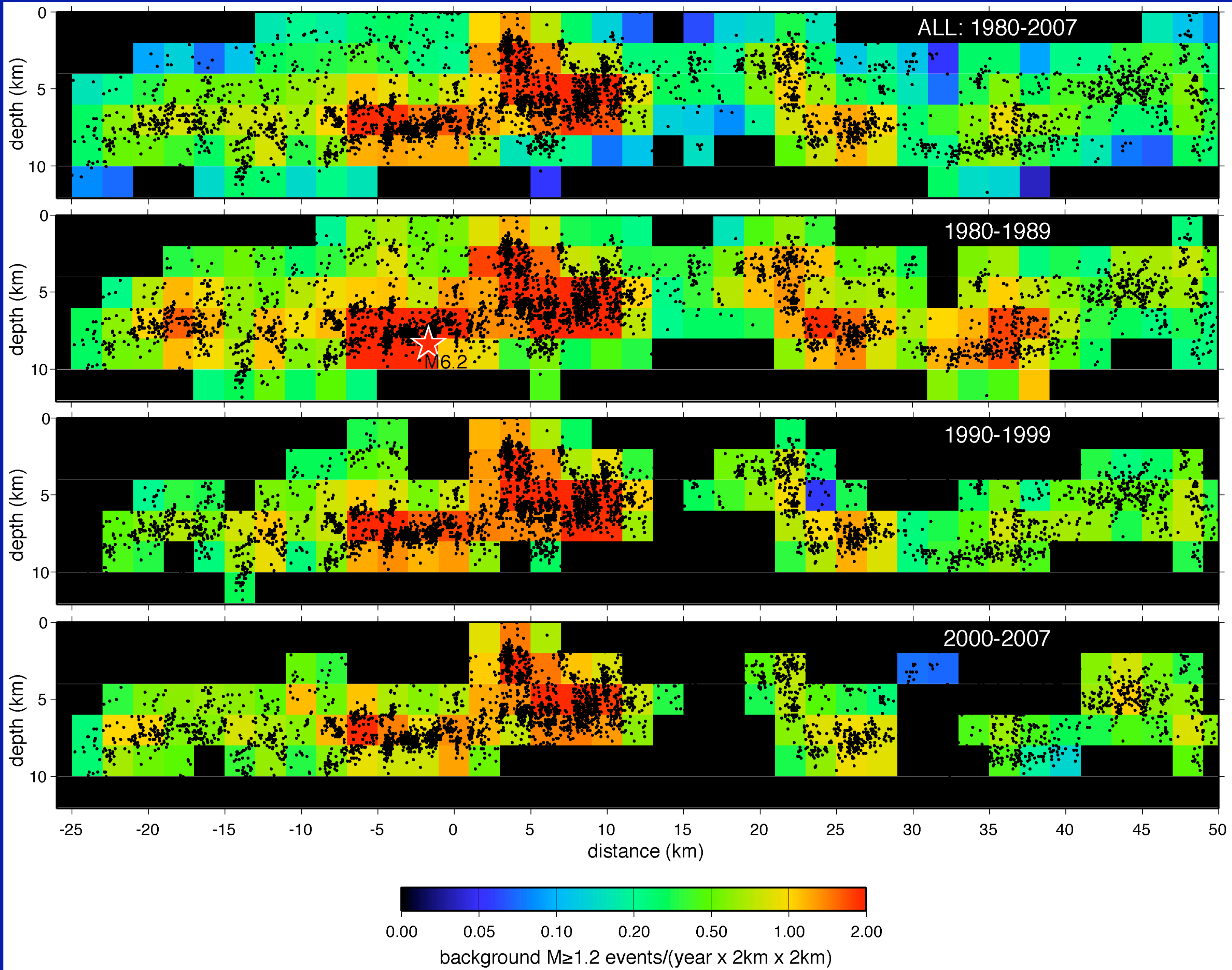

ALL
1980-2007
M6.2
M6.9
M6.4
M6.0
1980-1989
M6.2
M6.9
M6.4
1990-1999
2000-2007
M6.0
M6.5
0.00
0.02
0.05
0.10
0.20
0.50
1.00
2.00
5.00
10.00
20.00
background M≥2 events/(year x 0.1° x 0.1°)



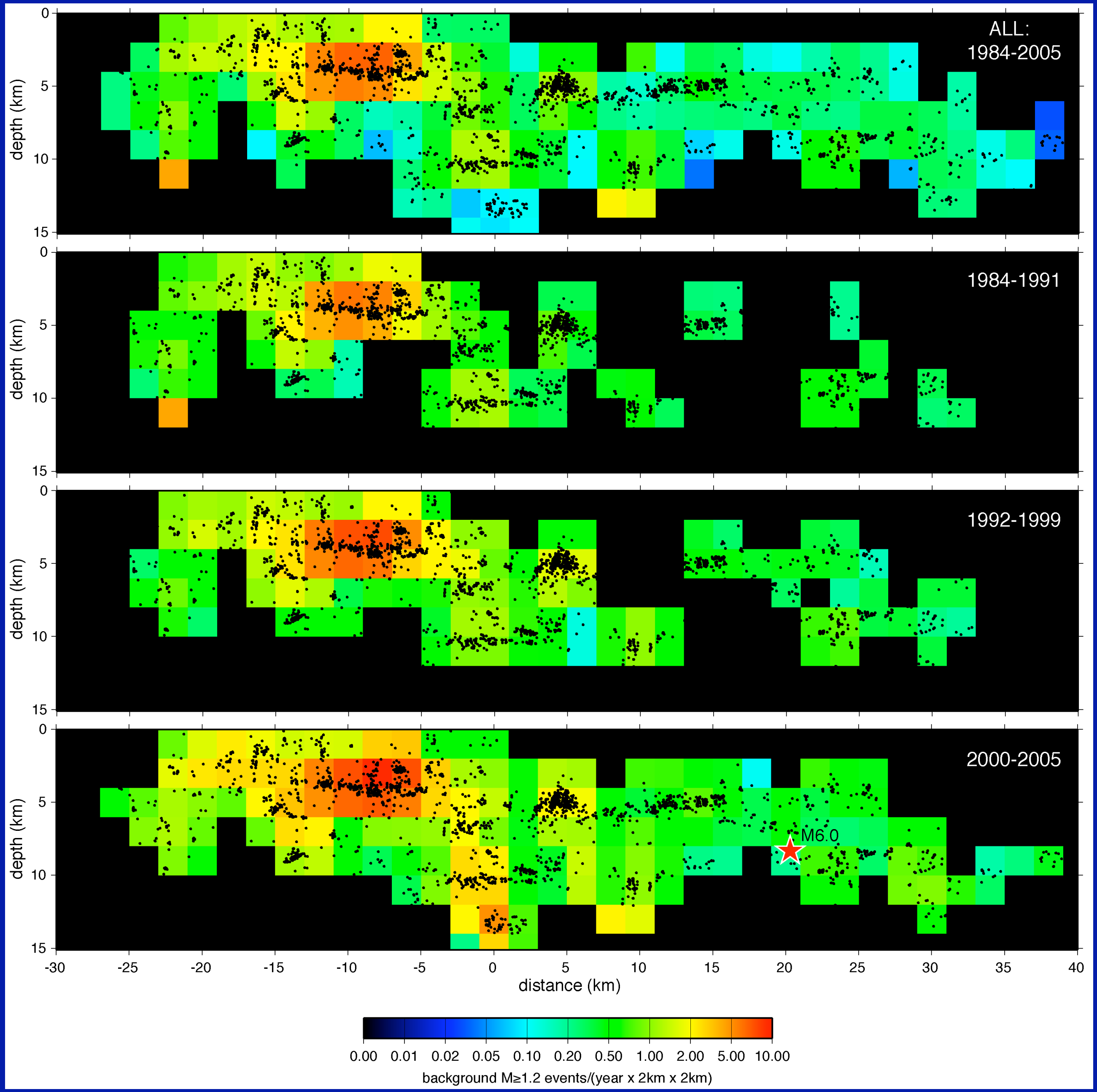
Hainzl algorithm, corrected (p=1.35)
39°00'
38°30'
38°00'
37°30'
37°00'
36°30'
36°00'
35°30'
-124°
-123°
-122°
-121°
-120°
Calaveras
High rate
Parkfield
M6.2
M6.4
M6.0
M6.5
0.00 0.02 0.05 0.10 0.20 0.50 1.00 2.00 5.00 10.00 20.00
background M≥2 events/(year x 0.1° x 0.1°)

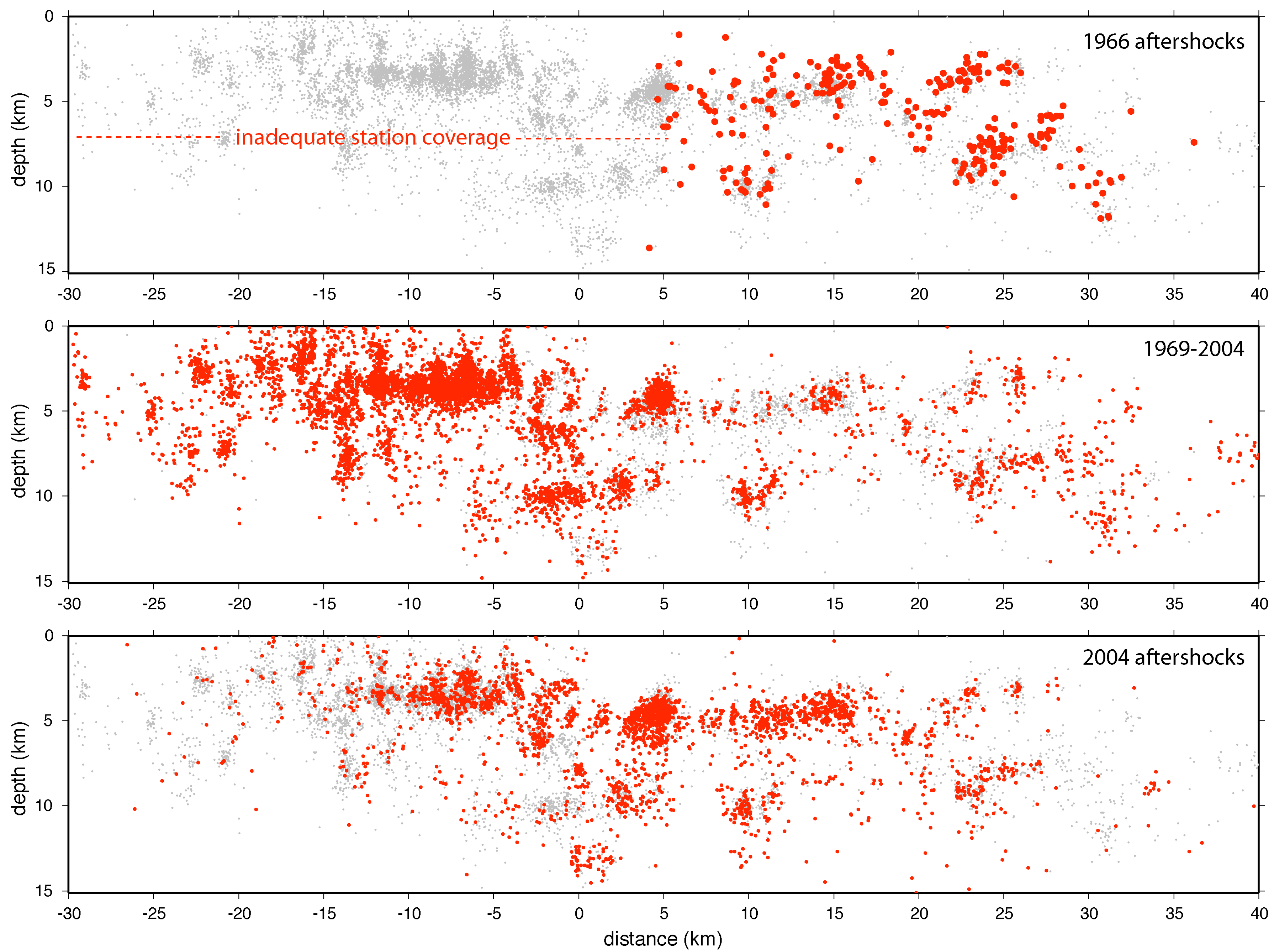

ALL
1980-2007
1980-1989
1990-1999
2000-2007
0.00
0.05
0.10
0.20
0.50
1.00
2.00
background M≥2 events/(year x 0.02° x 0.02°)

Calaveras Fault

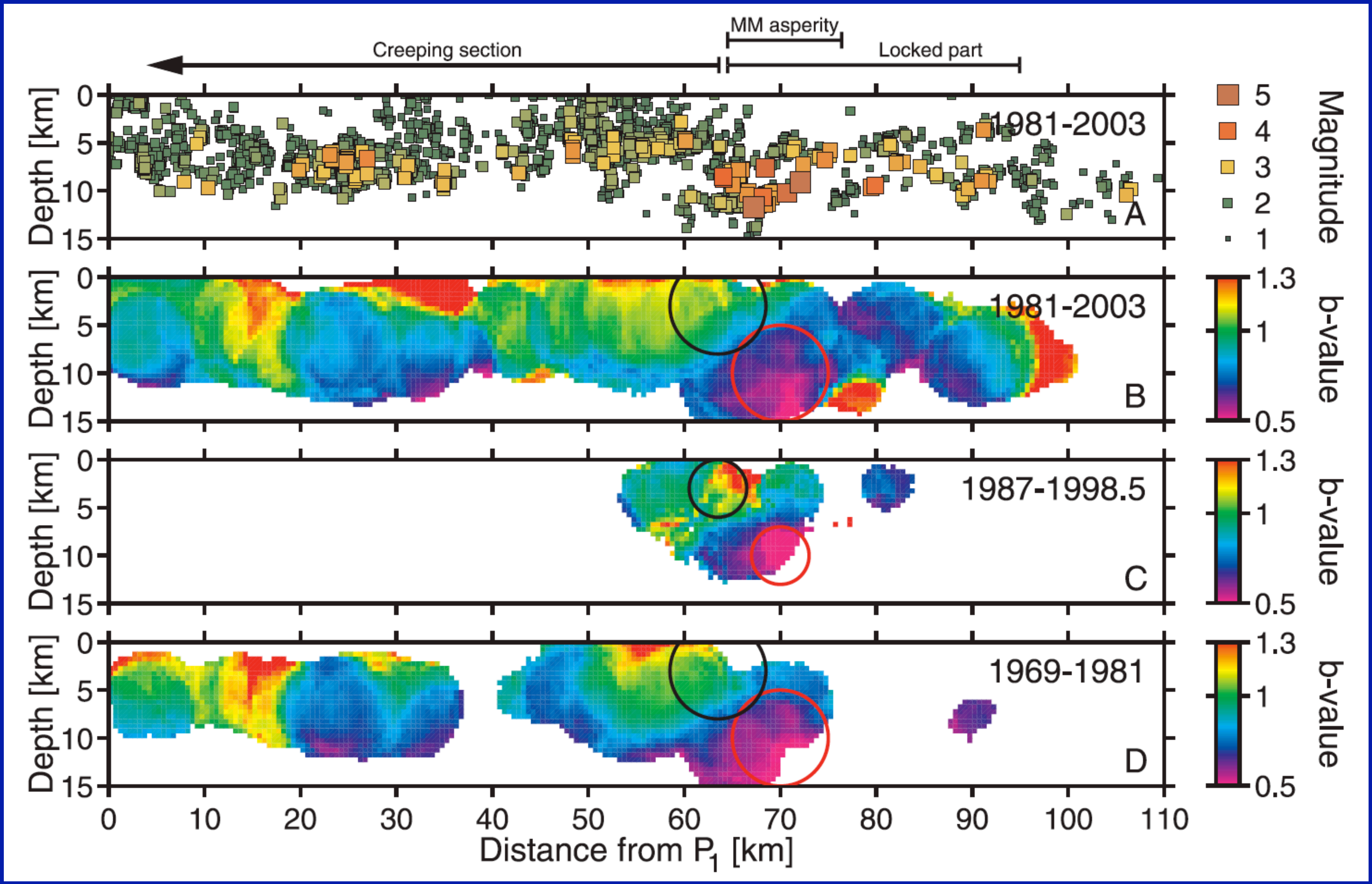


San Andreas Fault: Parkfield





1966 aftershocks
inadequate station coverage
1969-2004
2004 aftershocks
depth (km)
distance (km)
0
5
10
15
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40



Schorlemmer et al., JGR 2004

Conclusions:

- The Hainzl et al method can accurately recover the background fraction, for ETAS simulations, but requires a correction based on the *direct* p-value.

- Gamma distribution poorly fits the observed and ETAS interevent-time distributions, especially for high direct p-value.

- The background rate in Northern California is spatially variable, but appears generally stable through time.

- Parkfield seismicity is remarkably stationary: earthquake locations, background rate, and b-value.

Future Work - Methodology:

- Develop a method to use the theoretical interevent-time distribution (rather than gamma distribution) to find background fraction and direct p-value.

- Develop a quantitative measure of uncertainty for the estimated background rate. Explore sources of error such as catalog incompleteness.

Future Work - Applications:

- Quantify the stability of background rate through time.
- New background rates for seismic hazard estimates.
- Search for temporal changes in background rate, especially in areas of changing stressing rate:
  - Volcanic areas: does background rate change due to loading from magma movement?
  - Subduction zones: does background rate change due to loading from episodic slow-slip events?
  - Stress shadows: do they exist?
- Etc…