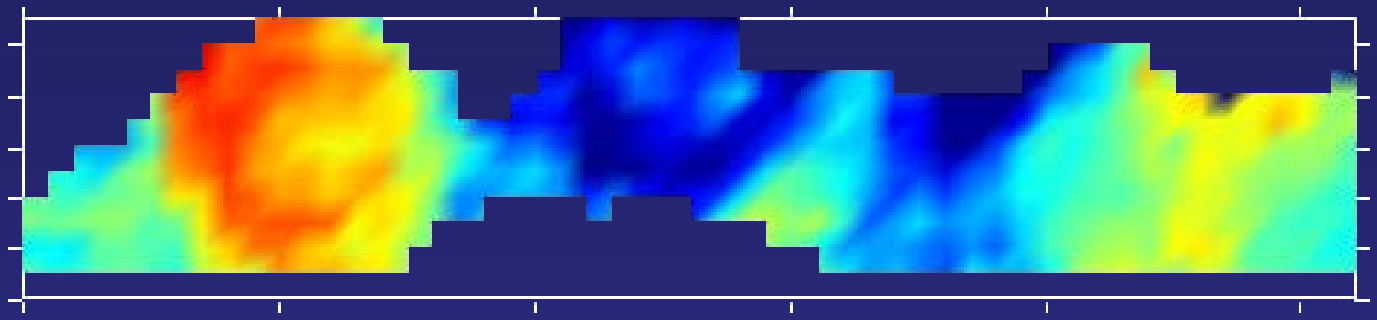
Can we map asperities using b-values?



ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Schweizerischer Erdbebendienst
Swiss Seismological Service

Thessa Tormann (ETH)
Stefan Wiemer (ETH)
Danijel Schorlemmer (USC)
Jochen Woessner (ETH)

b-value as stress sensor

Amitrano, JGR, 2003

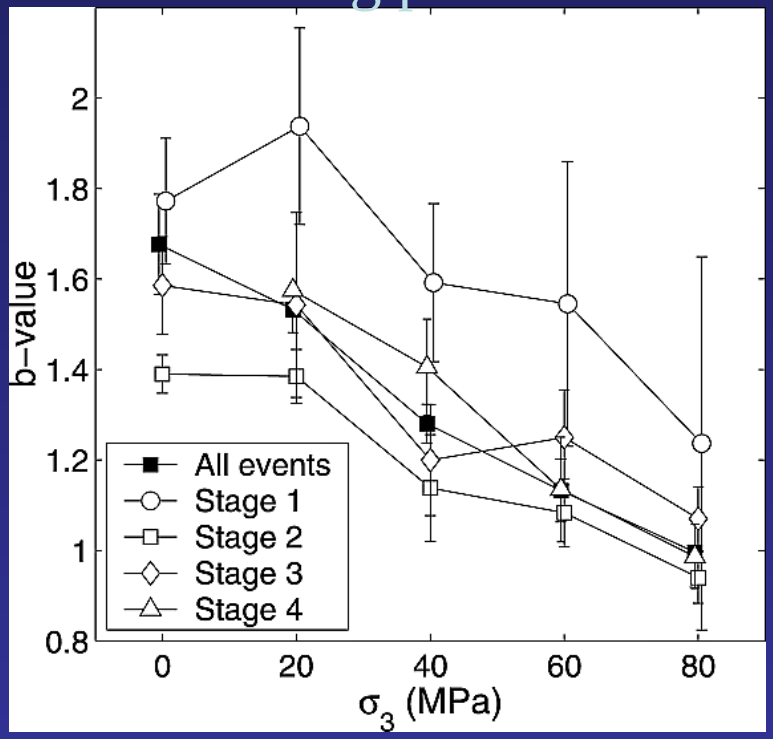
b-value as stress sensor

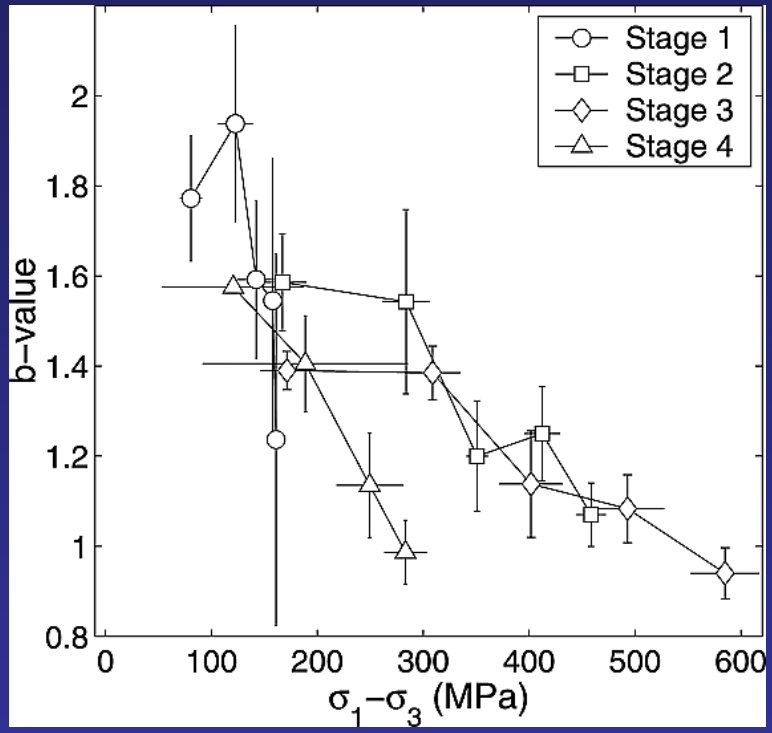
Amitrano, JGR, 2003

Laboratory study:

Acoustic Emission (AE) experiments with granite samples

Mean b-value decreases systematically with increasing confining pressure and differential stress





b-value as stress sensor

Several case studies in different regions of the world

California
- 1997: Wiemer & Wyss→ Parkfield and Morgan Hill
- 2000: Wyss et al. → San Jacinto and Elsinore
- 2001: Wyss → Hayward
- 2005: Schorlemmer & Wiemer → Parkfield
- 2007: Parsons → Calaveras

Mexico
- 2001: Zuniga & Wyss → Pacific Coast

Iceland
- 2006: Wyss & Stefansson → Southern Iceland

France
- 1999: Sylvander → French Pyrenees

Turkey
- 2000: Oncel & Wyss → Izmit
- 2002: Westerhaus et al. → Izmit

Sumatra
- 2005: Nuannin → off coast of NW Sumatra

Japan
- 2002, 2005: Wyss & Matsumura → Kanto-Tokai
- 2006: Nakaya → Kuril Trench

This list is not complete, alltogether more than 20 case studies that map spatial b-value distributions (plus several studies of b-values beneath volcanoes and in subduction zones)

b-value as stress sensor

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This list is not complete, alltogether more than 20 case studies that map Spatial b-value distributions (plus several studies of b-values beneath volcanoes and in subduction zones)

b-value as stress sensor

Outline

- General Issues of b-value Mapping
- Example Case Studies

  2005: Schorlemmer & Wiemer → Parkfield
  1997: Wiemer & Wyss→ Parkfield and Morgan Hill
  2000: Wyss et al. → San Jacinto and Elsinore
  2002, 2005: Wyss & Matsumura → Kanto-Tokai
  2007: Parsons → Calaveras

  Currently: Tormann et al. → San Francisco Bay Area

- ALM – Asperity-based likelihood model for California
- CALM – Cross-sectional asperity likelihood model for California
- Testing Perspectives

General issues of b-value mapping

Problems that each study adresses a little differently:

- Data quality
- Minimum number of events versus coverage
- Mc calculation
- Mapping radii

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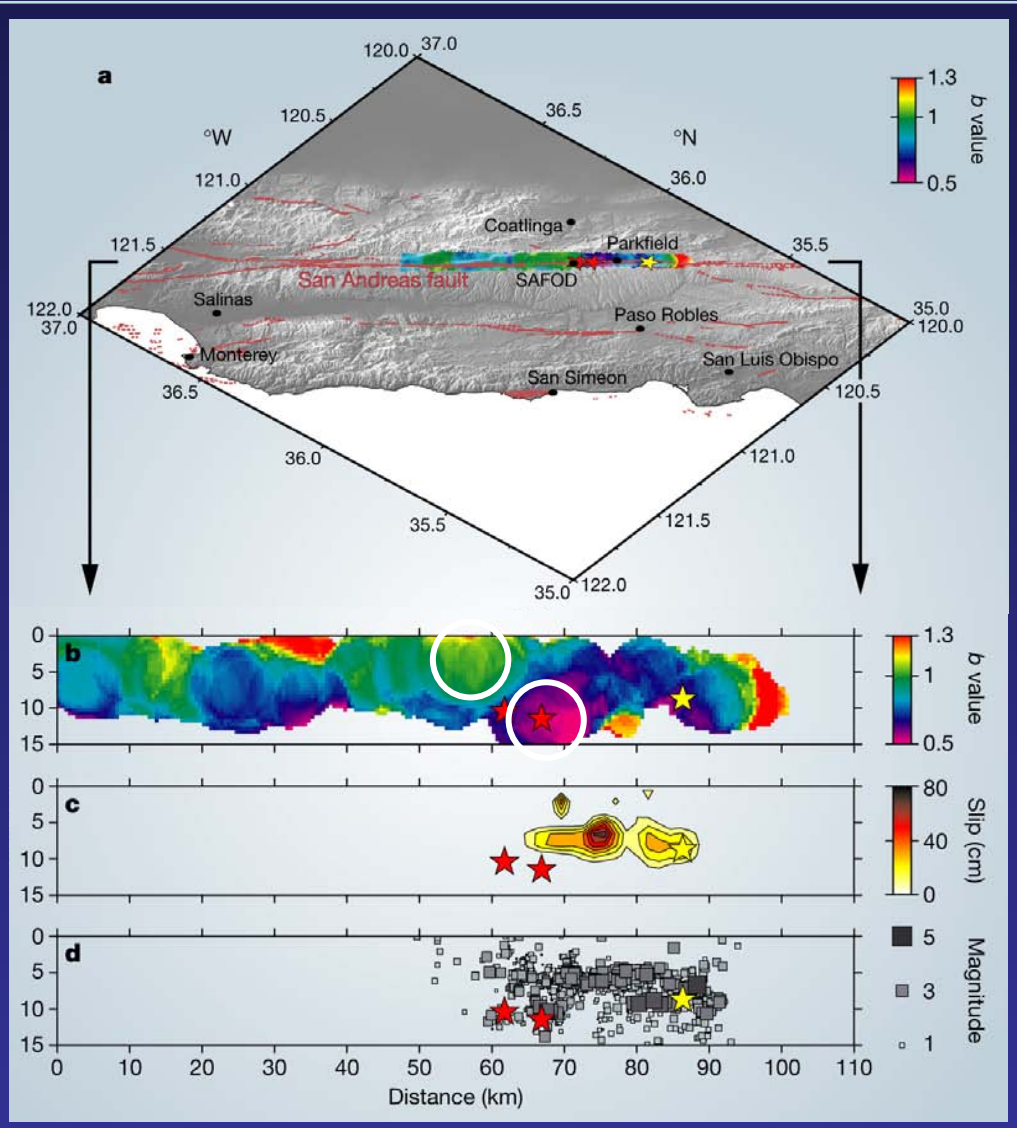
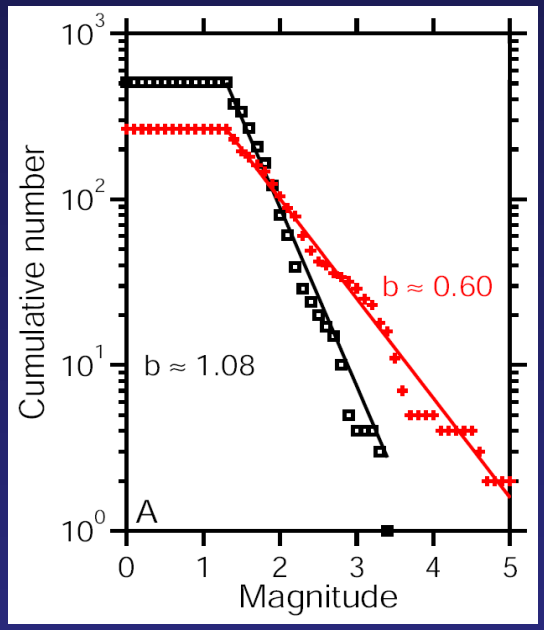
- **Data selection**
- **Temporal non-stationarity**
- **Non-linear FMDs**

Parkfield

Schorlemmer & Wiemer, Nature, 2005



NCEDC 1981 - 2003

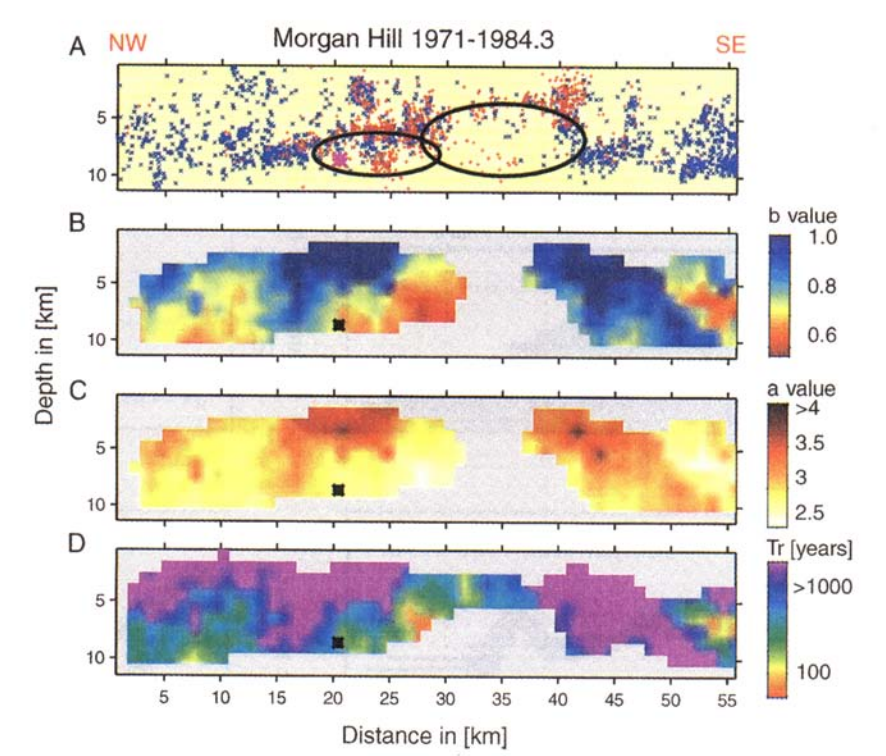


Found temporal stationary very low b-value zone

Zone correlated well with the mainshock and aftershock locations of the 2004 M6.0 event

Morgan Hill

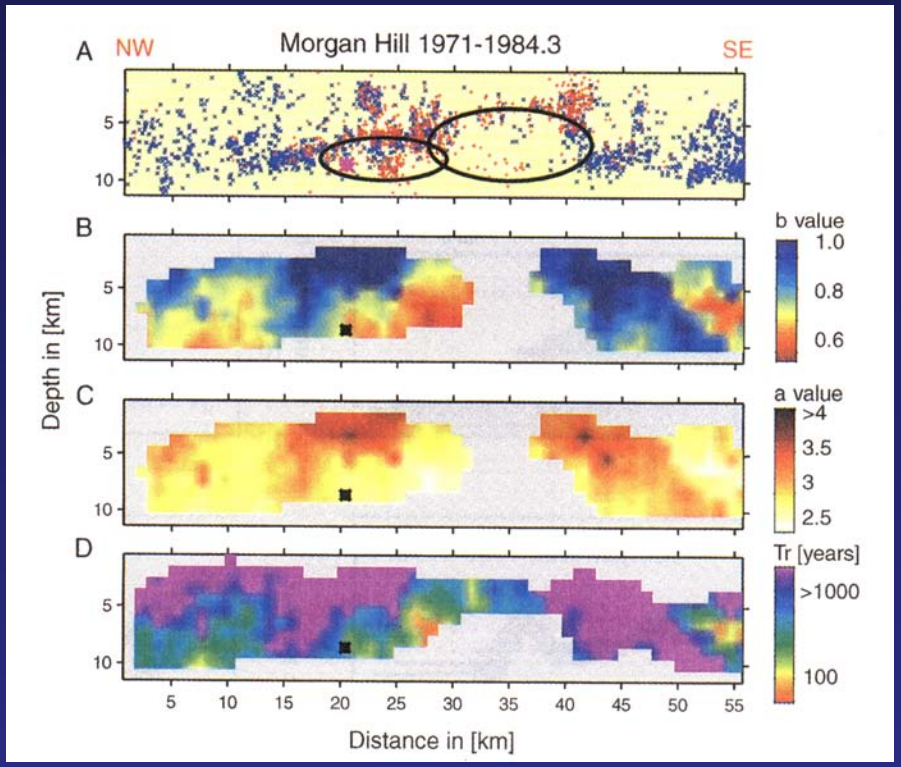
Wiemer & Wyss, JGR, 1997

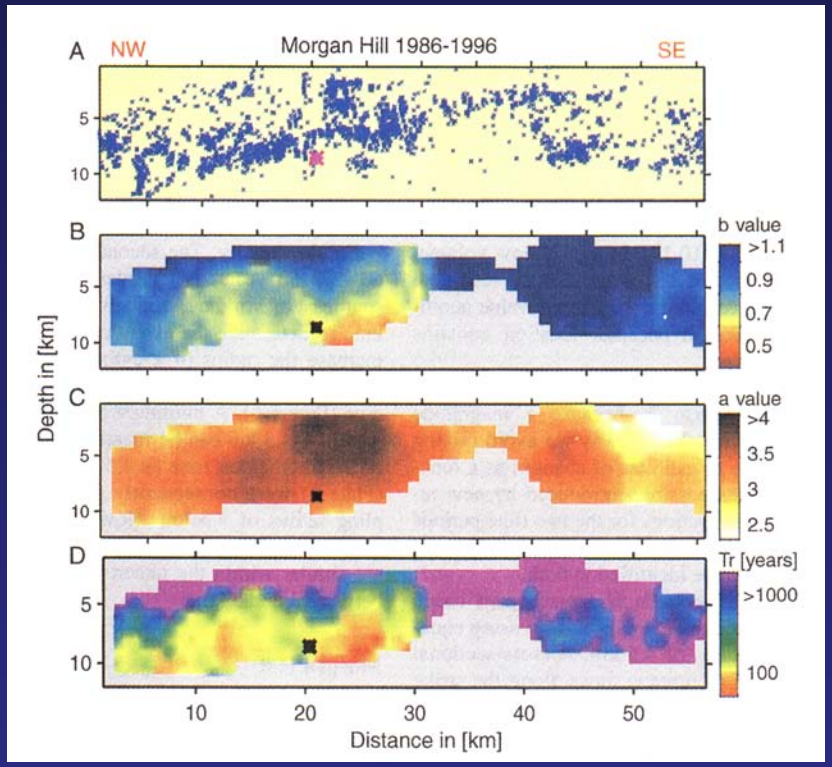


Anomalies in b-value and local recurrence time (M6+) in the nucleation area before Morgan Hill 6.2 mainshock

Morgan Hill

Wiemer & Wyss, JGR, 1997





Anomalies in b-value and local recurrence time (M6+) in the nucleation area before Morgan Hill 6.2 mainshock

b-values change a little but still show up anomalously low just south of the mainshock area

Anomaly in Tr is larger and stronger

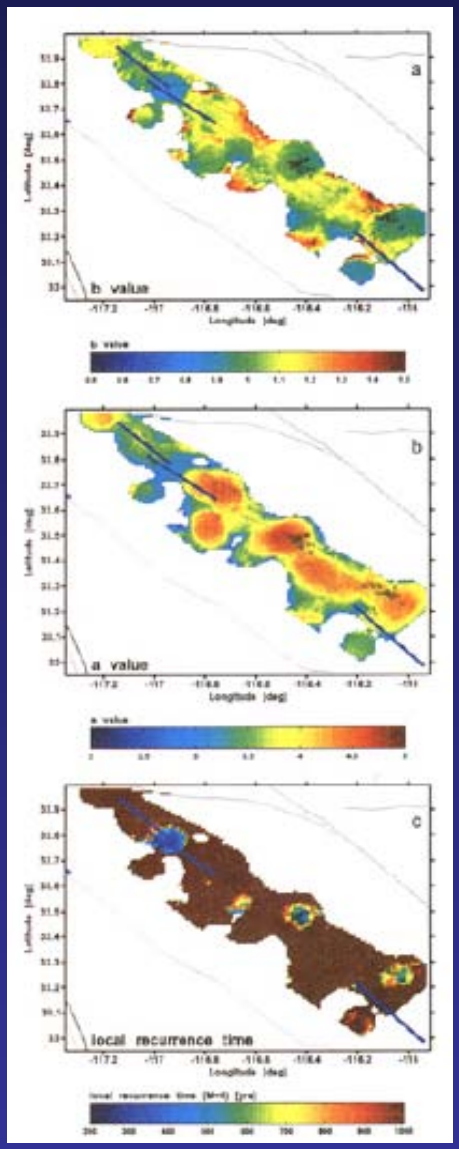
San Jacinto-Elsinore

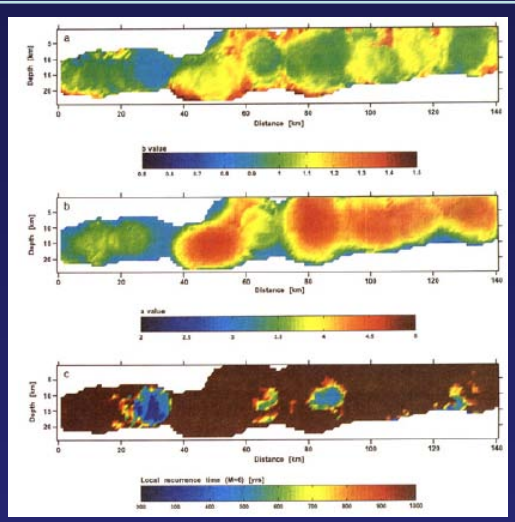
Wyss et al., JGR, 2000

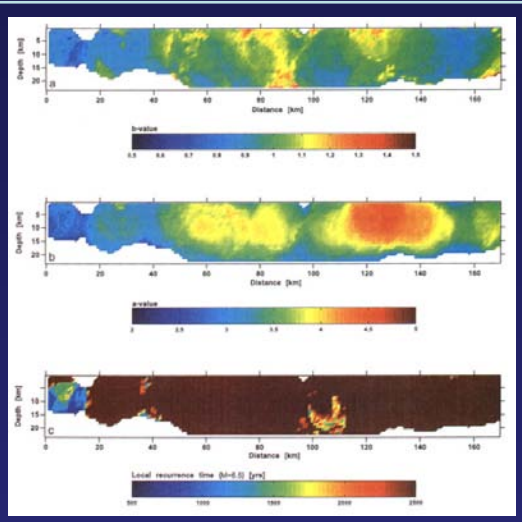
Modern catalogue 1.2<=M<=5.0 (1981-1998)
6 historic mainshocks M>=5.6
5 of historic events ruptured substantial parts of the
4 mapped asperities

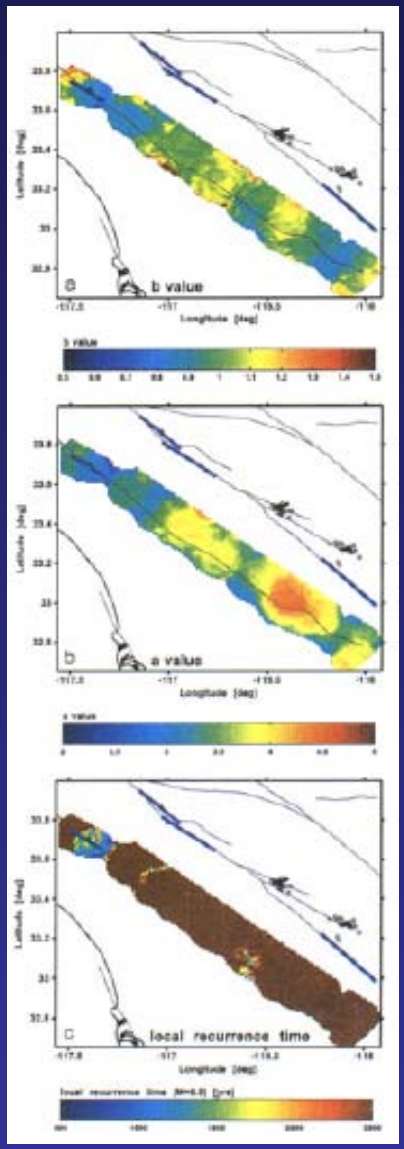
San Jacinto-Elsinore

Wyss et al., JGR, 2000









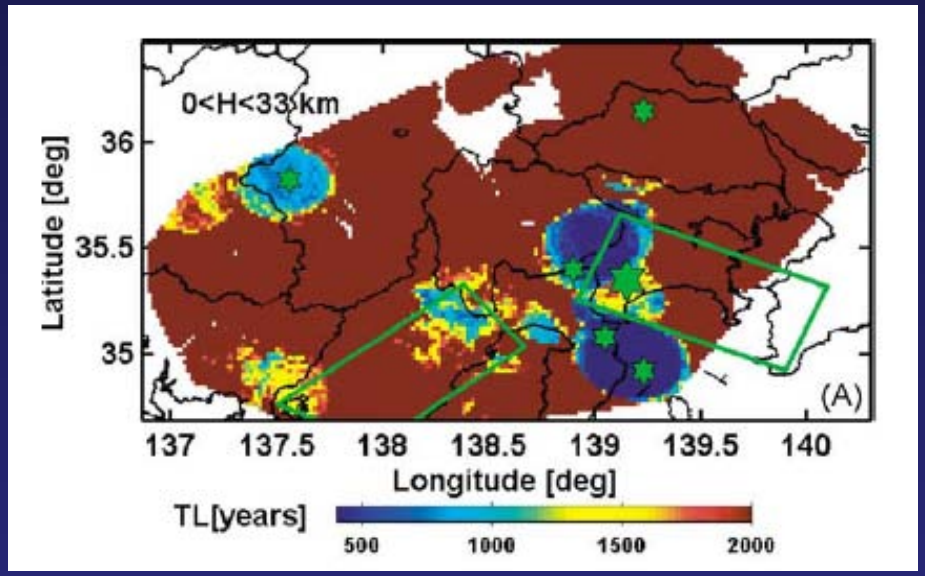
Modern catalogue 1.2<=M<=5.0 (1981-1998)
6 historic mainshocks M>=5.6
5 of historic events ruptured substantial parts of the 4 mapped asperities

Anomalies in b-value and local recurrence times correlate with mainshock locations and known asperities

Much stronger, more clearly separated anomalies in local recurrence times than b-values

Kanto-Tokai

Wyss & Matsumura, Tectonophysics, 2005

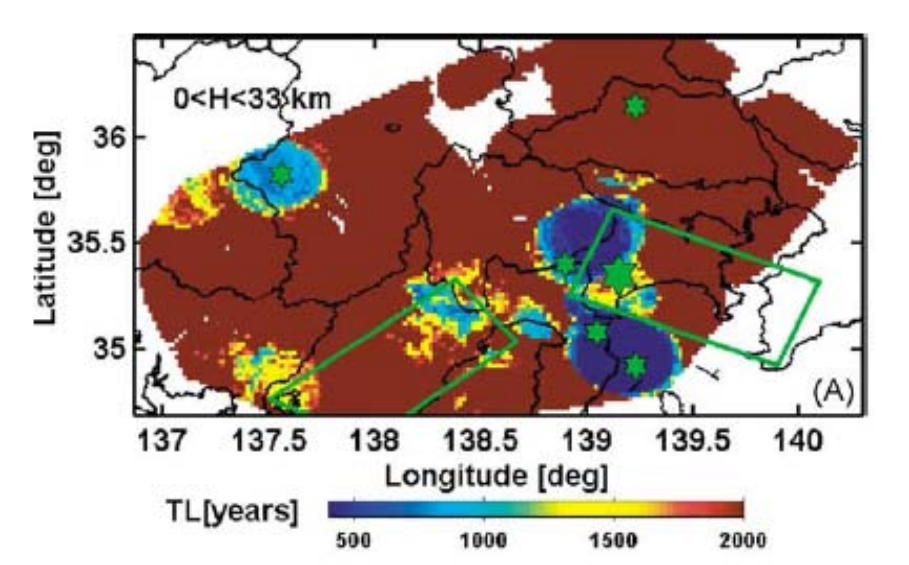


2002:
Calculation of b-value and local recurrence time (TL) anomalies using declustered data M>=1.5, 1980-1999

TL of less than 1000 years includes 5 of 6 historic mainshock locations, covering 12% of the study area

Kanto-Tokai

Wyss & Matsumura, Tectonophysics, 2005



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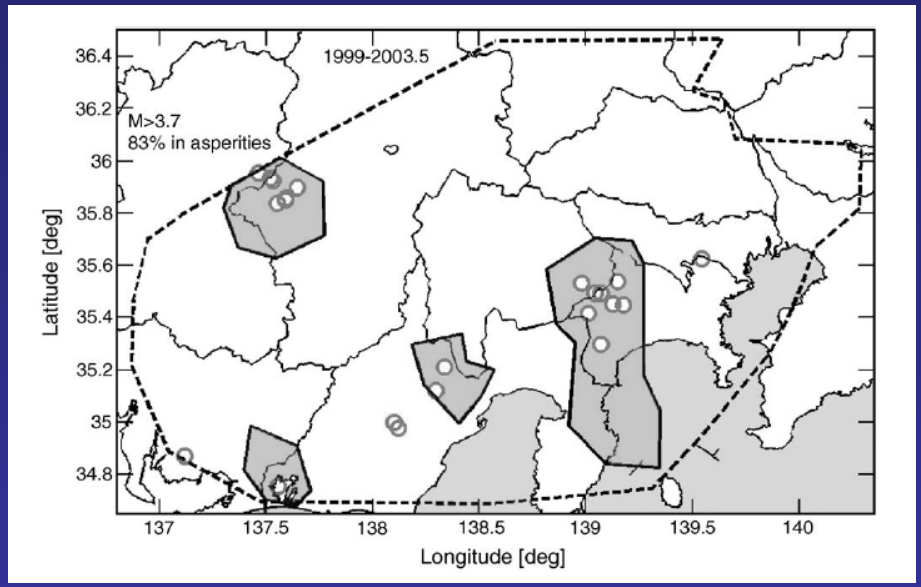
2005:
Correlation of local recurrence time anomalies (2002) with seismicity 1999-2003.5

→ 13% of all and ≈75% of M3.5+ seismicity fall into the 12% TL anomaly areas (max: 83% of M3.8+)

→ $P_{rand}=2*10^{-14}$



Calaveras

Parsons, JGR, 2007

Do temporal and spatial b-value variations portend M>=4.0 events?

Calaveras

Parsons, JGR, 2007

Do temporal and spatial b-value variations portend M>=4.0 events?

- temporal variations do not correlate with mainshock times
- spatial analysis:
  - catalogue from 1968-2005, Mc=2.0
  - boxes of 5x5 km, overlapping by 2.5 km
  - define M>=4.0 events as test events → cut catalogue at M<4.0
  - calculate b-value distribution for each of the 20 test events
  - compare local b-value with mean b-value → significant deviation?

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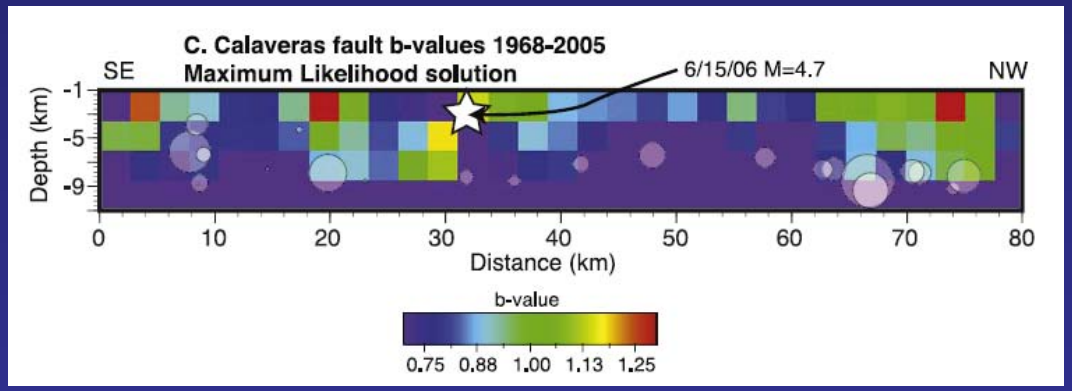

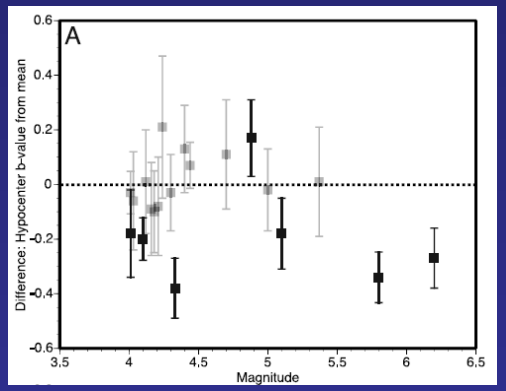

Results:	consistent (90%)	inconsistent (90%)	inconclusive
20:	6	1	13

Calaveras

Parsons, JGR, 2007

Is the forecast experiment a conclusive test?

- DATA QUALITY since 1968 (e.g. magnitude shifts)
- ML MATHEMATICS correction for upper limit on magnitude range, deviations from uncorrected formula will be significant?
- BIAS: large events have been taken out, aftershocks not, not comparable to San Jacinto
- TARGET MAGNITUDE: M4 too small to test asperities: rupture lengths of 1-2km → test is not sensitive to such small scale heteorogeneity (different radii, binning in cylinders?)

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Parsons, JGR, 2007

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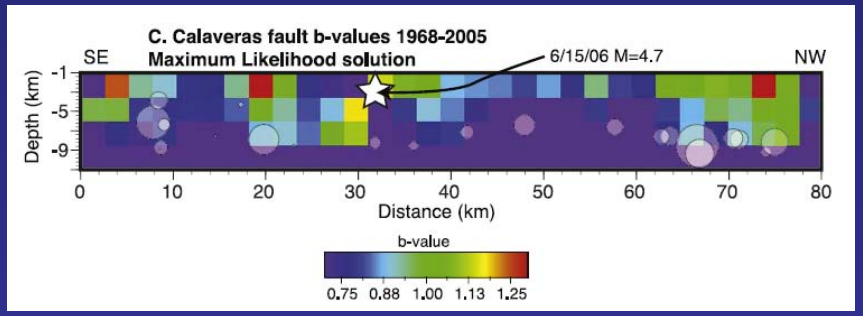
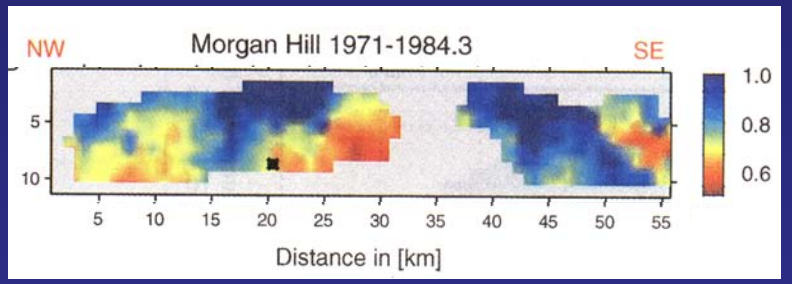
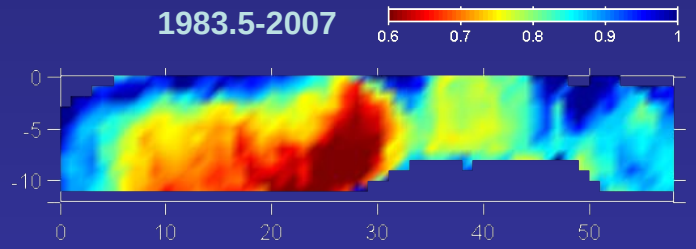
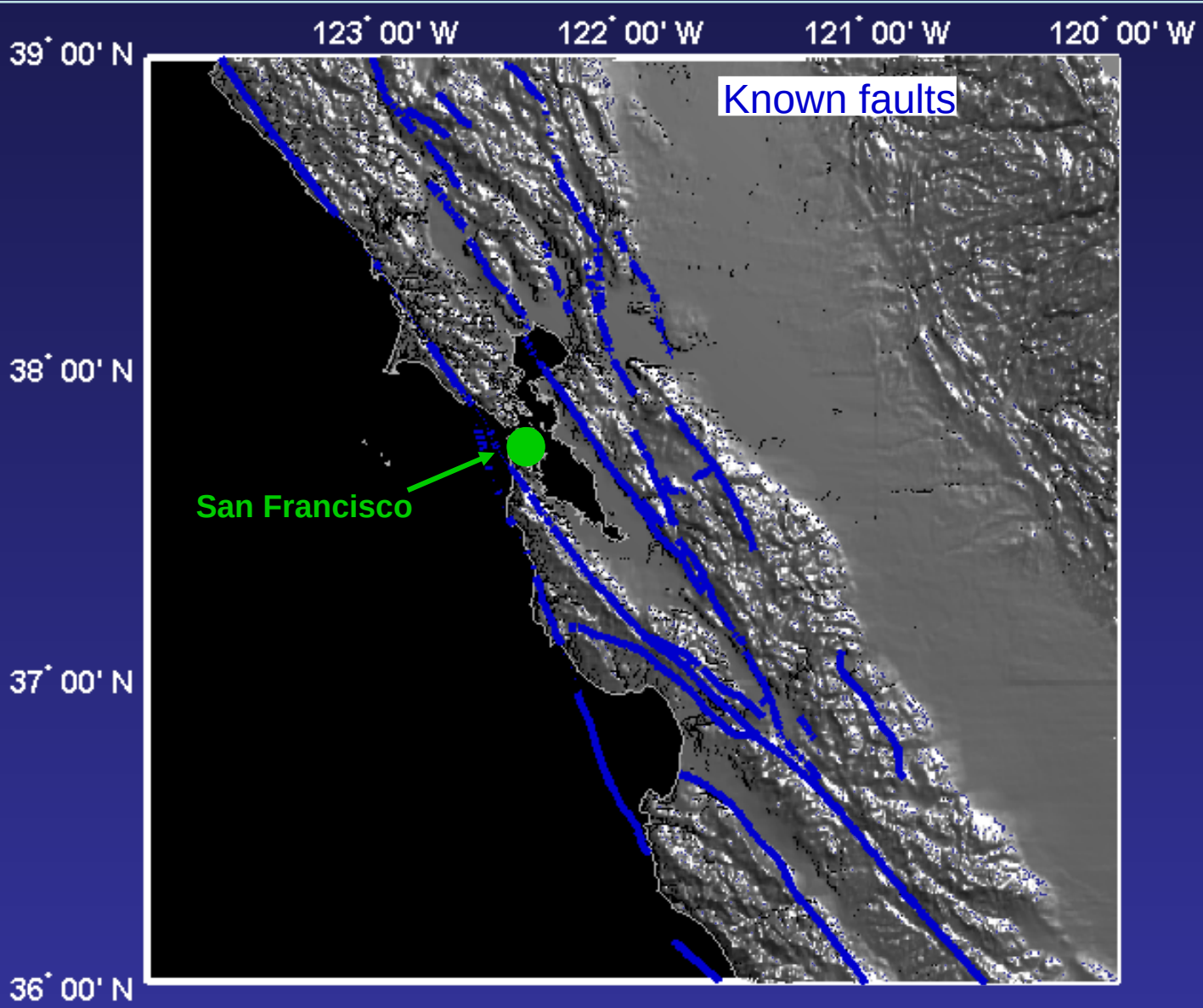






San Francisco Bay Area



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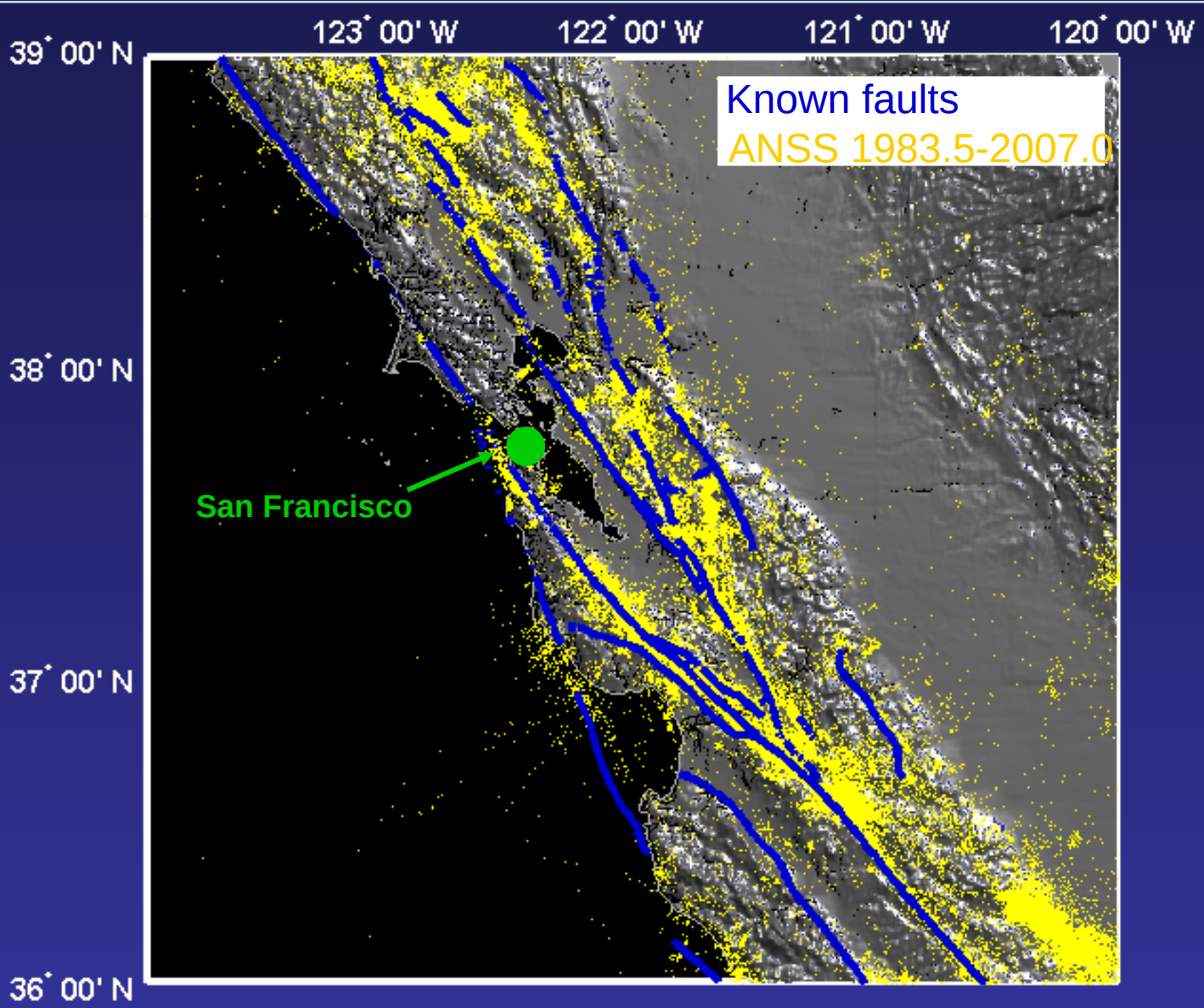

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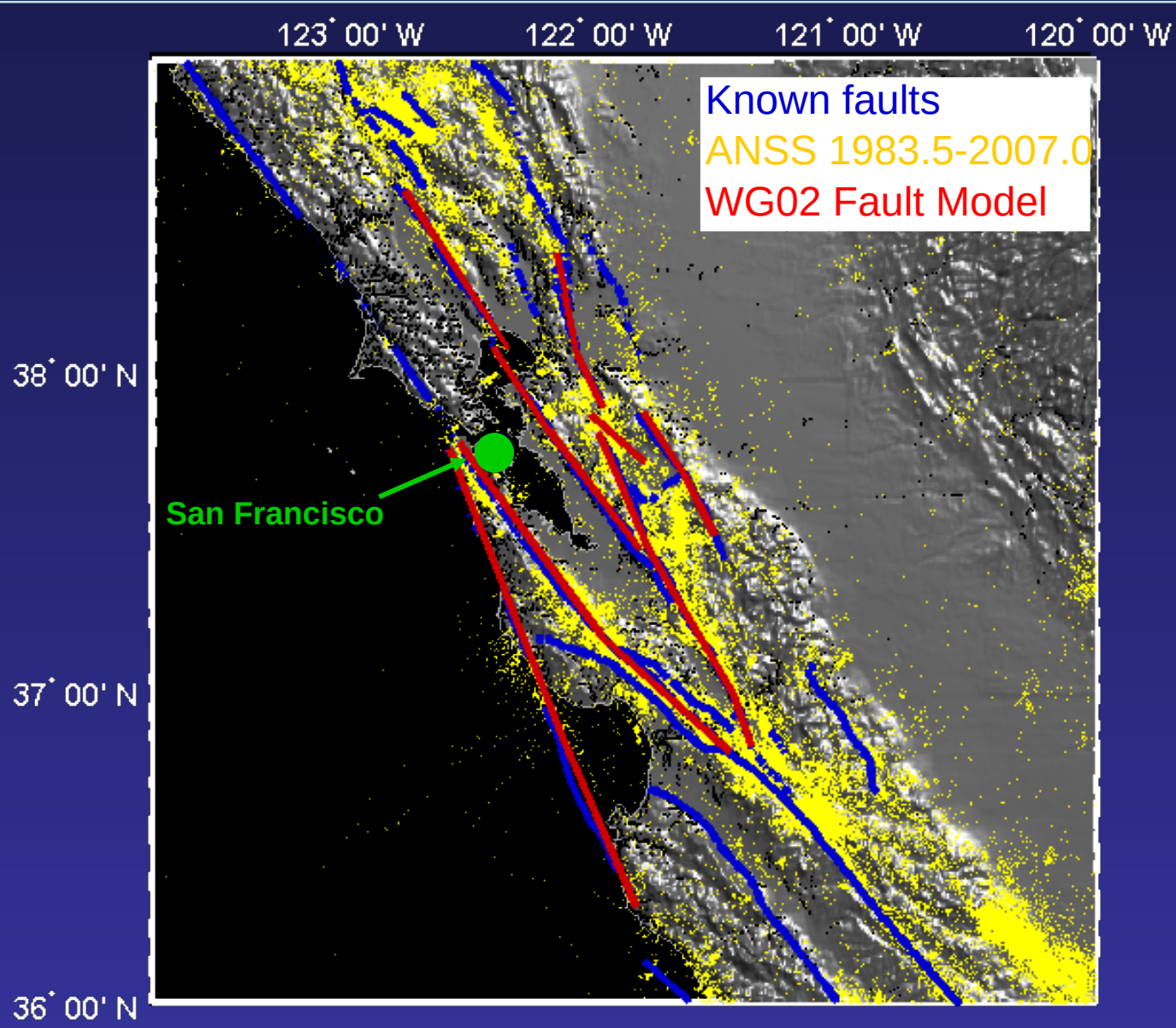
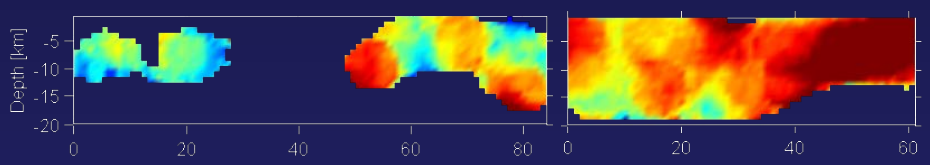
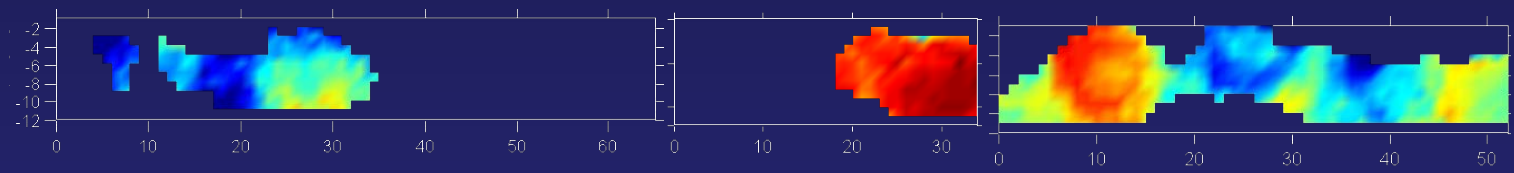


San Francisco Bay Area

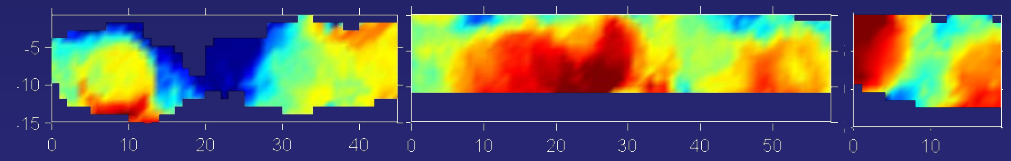
All segments b-value 0.6-1.2



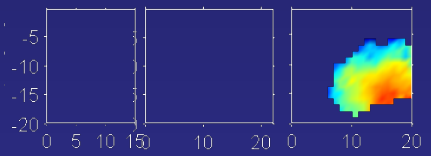
San Andreas



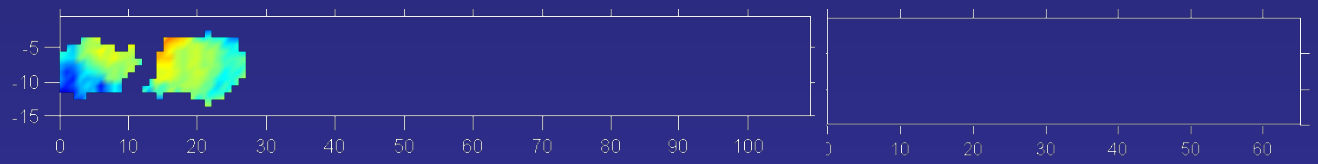
Hayward



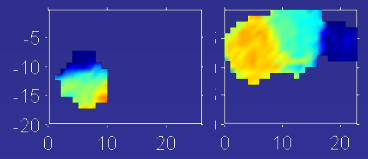
Calaveras



Concord

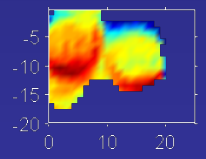


San Gregorio

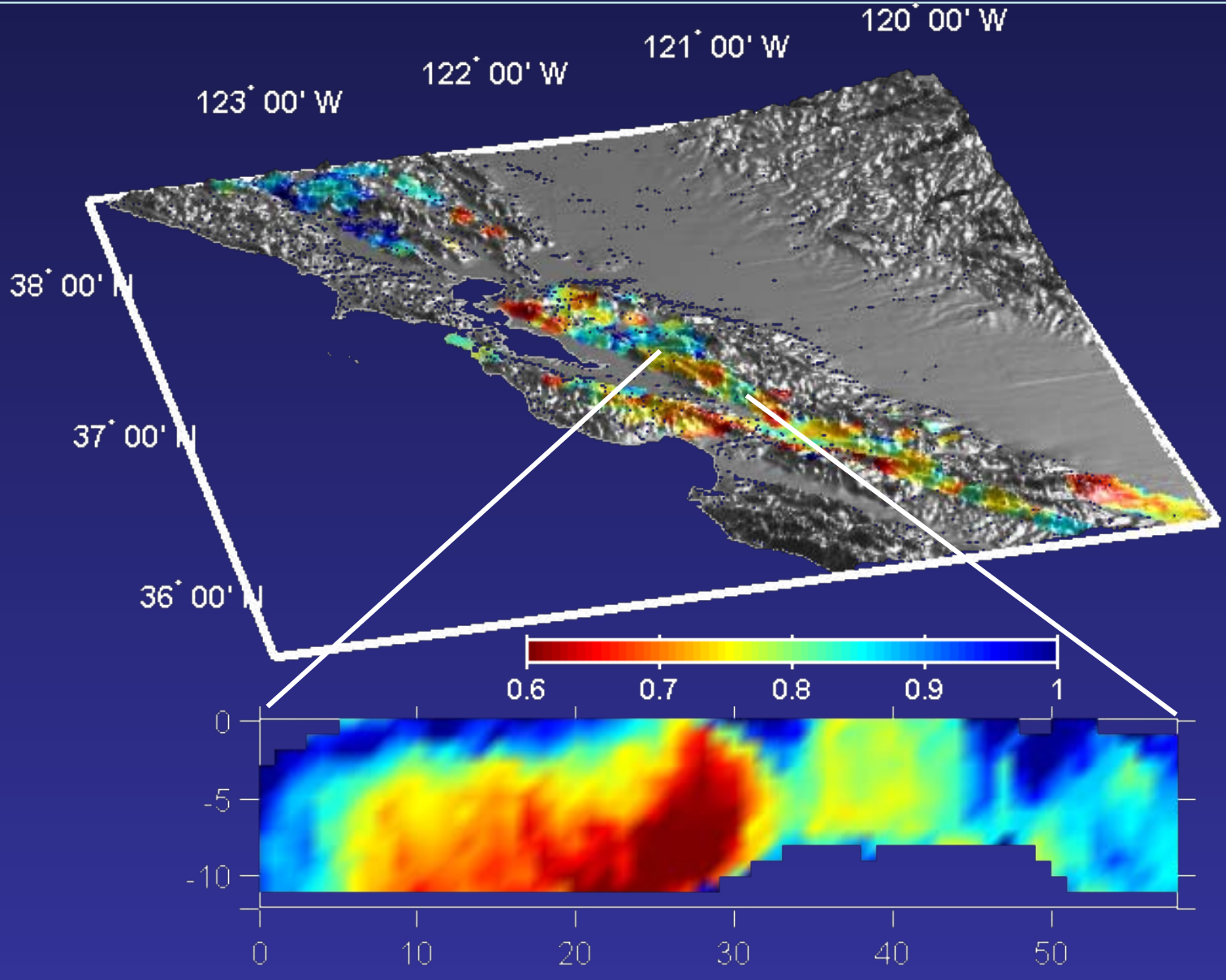


Greenville

Mt Diabolo

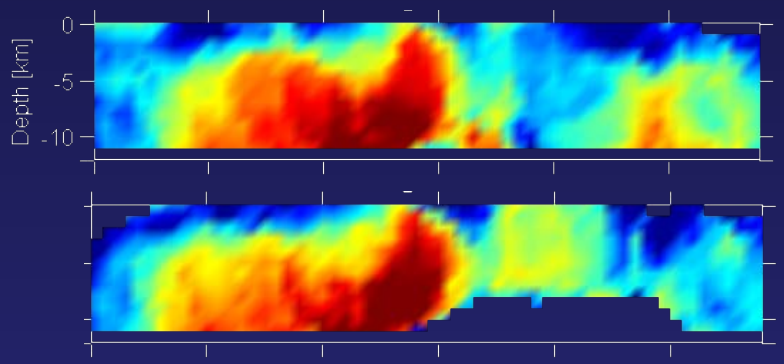


SFBA: Central Calaveras



SFBA: Central Calaveras

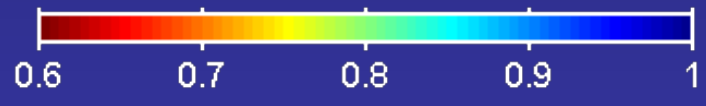
Data Selection



WG02
(+-5.5km)

Wiemer/Wyss
(+-2km)

Constant width



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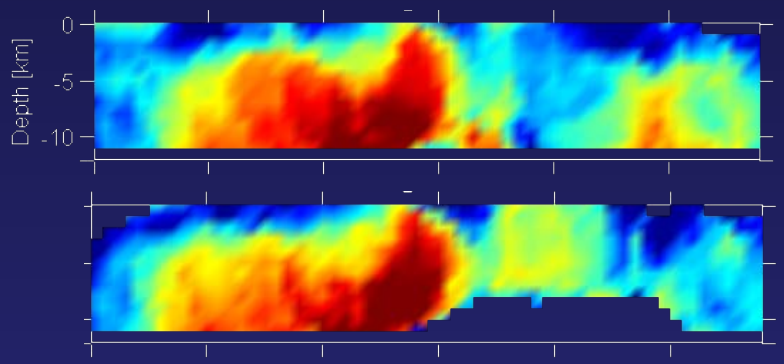
Data Selection



WG02
(+-5.5km)

Wiemer/Wyss
(+-2km)

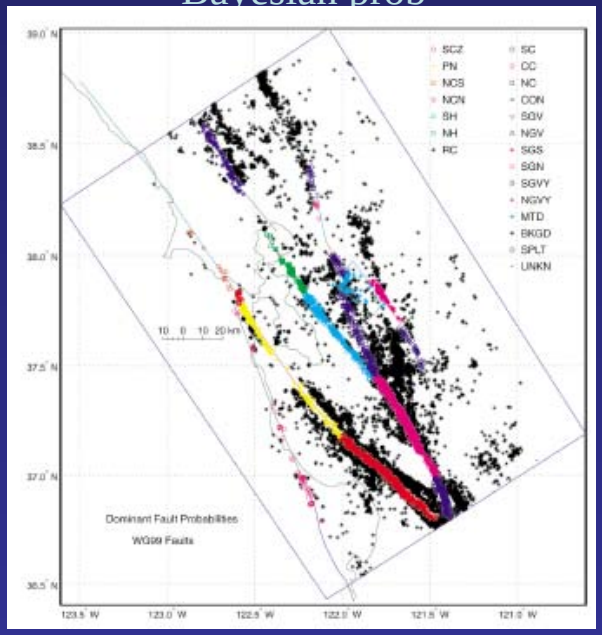
Constant width

More physical based approach for associating faults and events:

Bayesian statistics

- equal prior → pure distance-based association
- slip rate weighted prior → faster faults are more likely to produce earthquakes

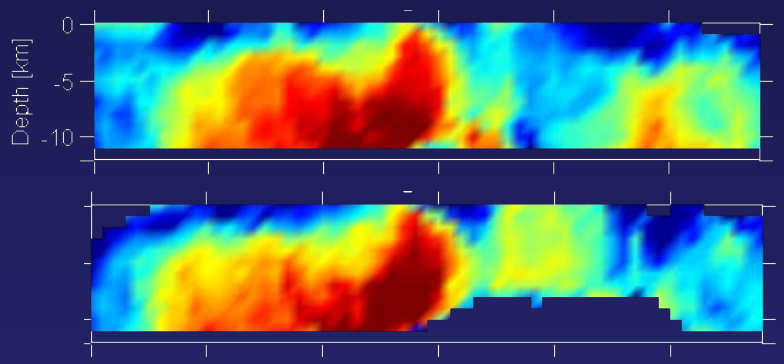
Bayesian prob



Wesson, 2003, BSSA

SFBA: Central Calaveras

Data Selection



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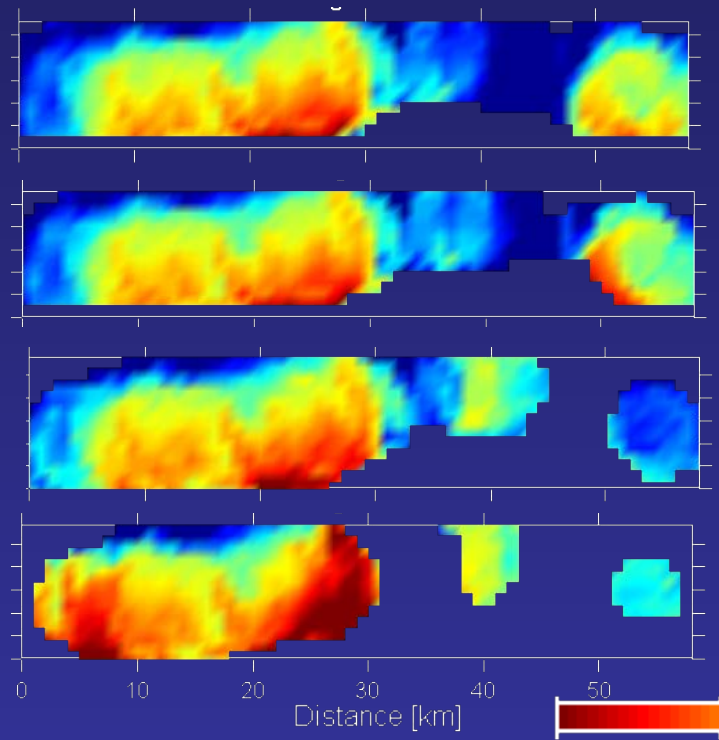


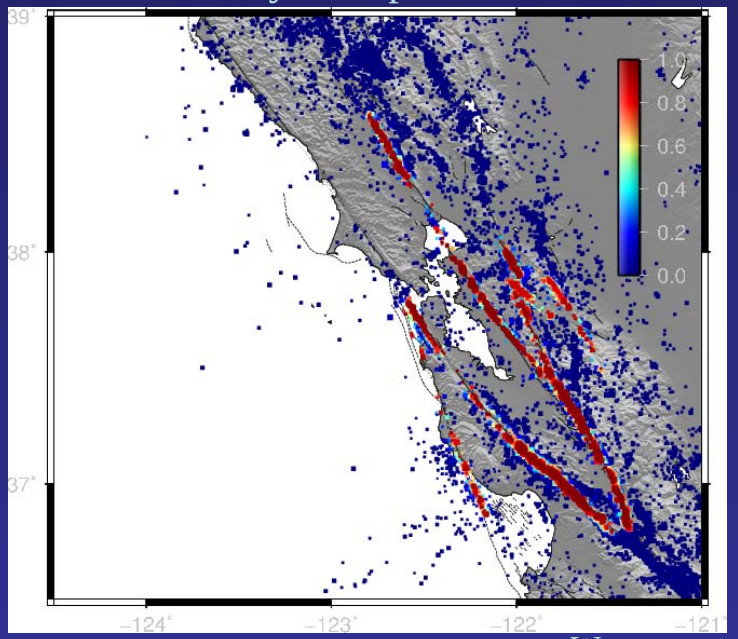
>= 20%

>= 50%

>= 80%

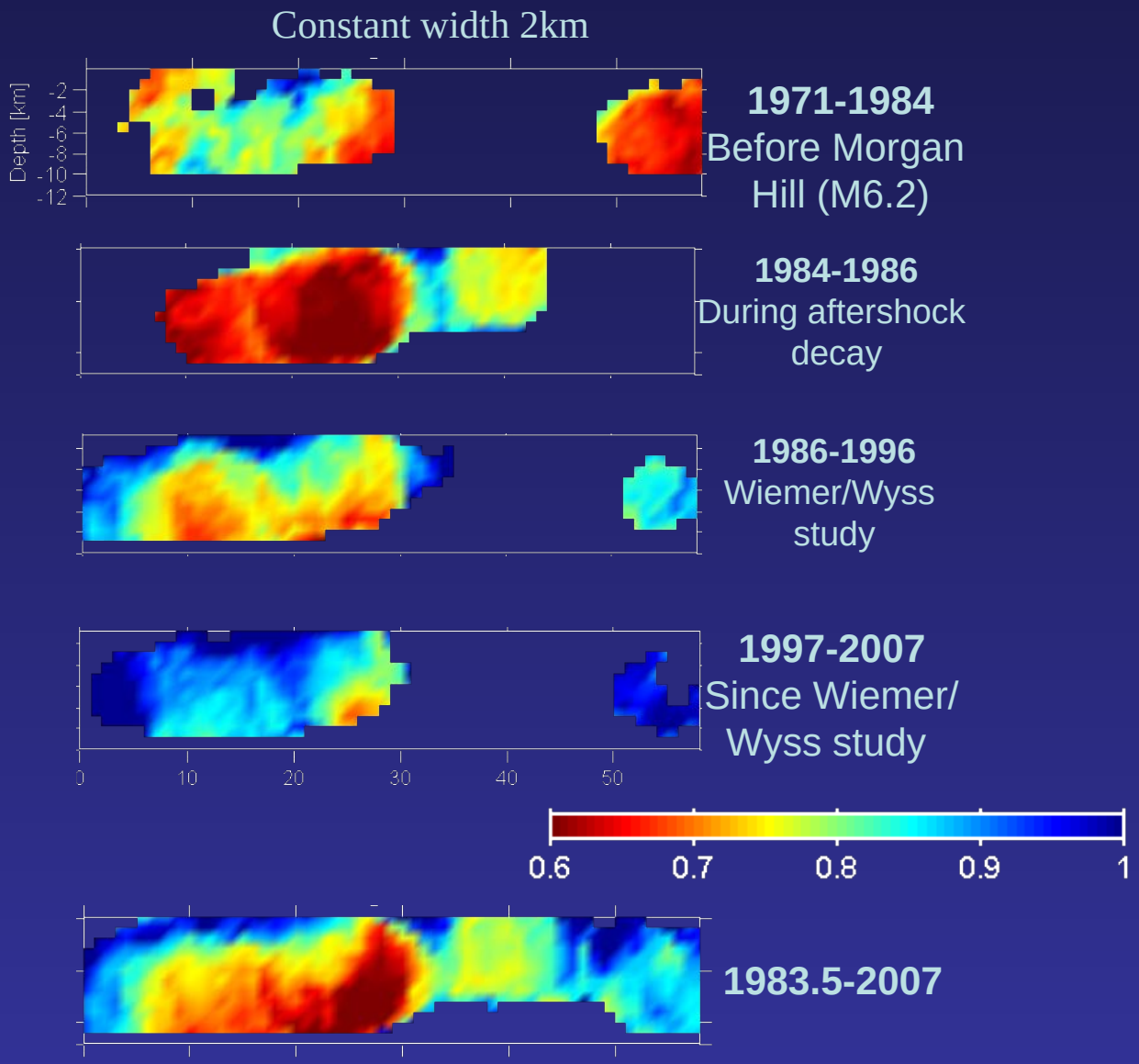
>= 95%

Bayesian prob



Woessner

SFBA: Central Calaveras
→ Re-investigation



1971-1984
Before Morgan Hill (M6.2)

1984-1986
During aftershock decay

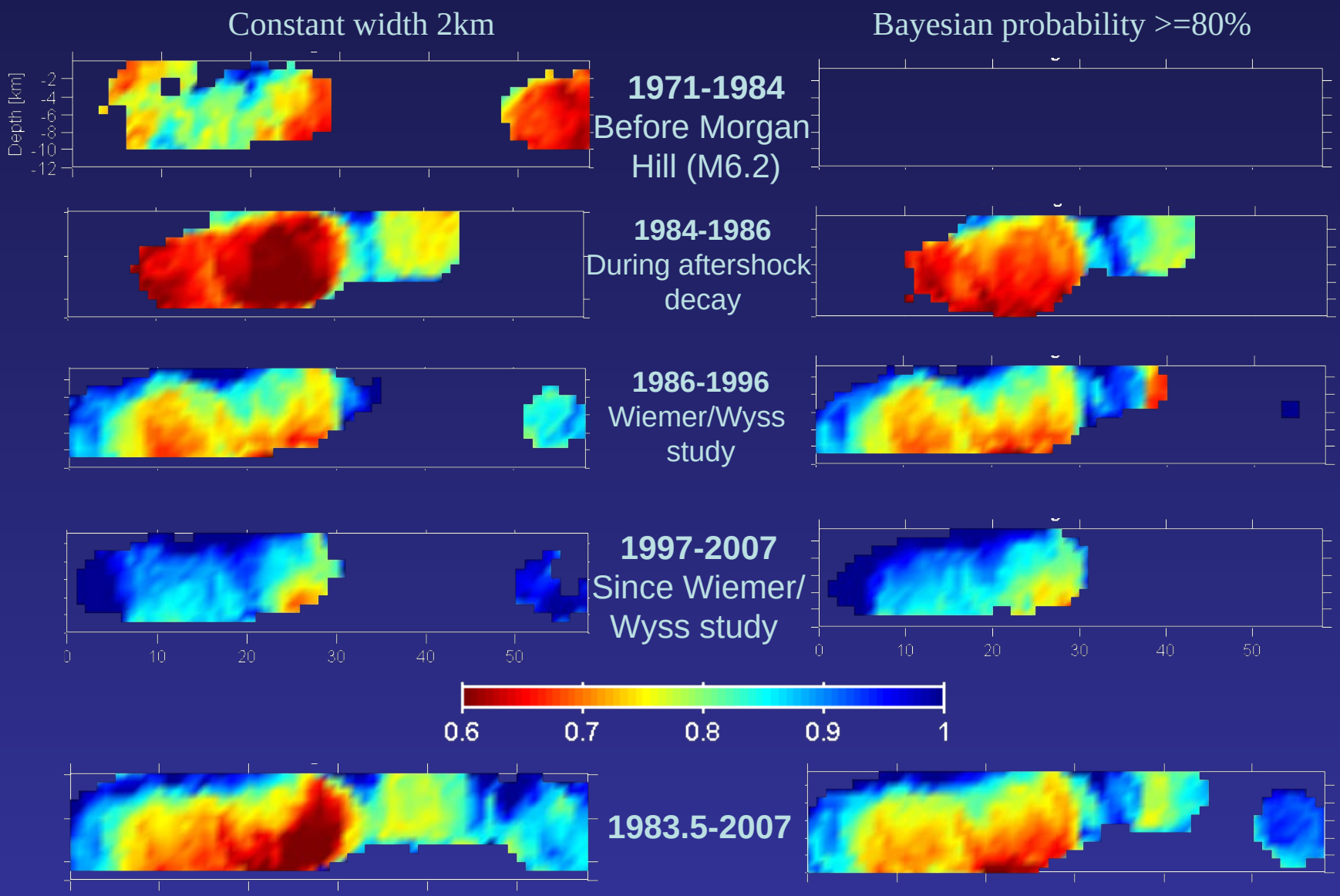
1986-1996
Wiemer/Wyss study

1997-2007
Since Wiemer/ Wyss study

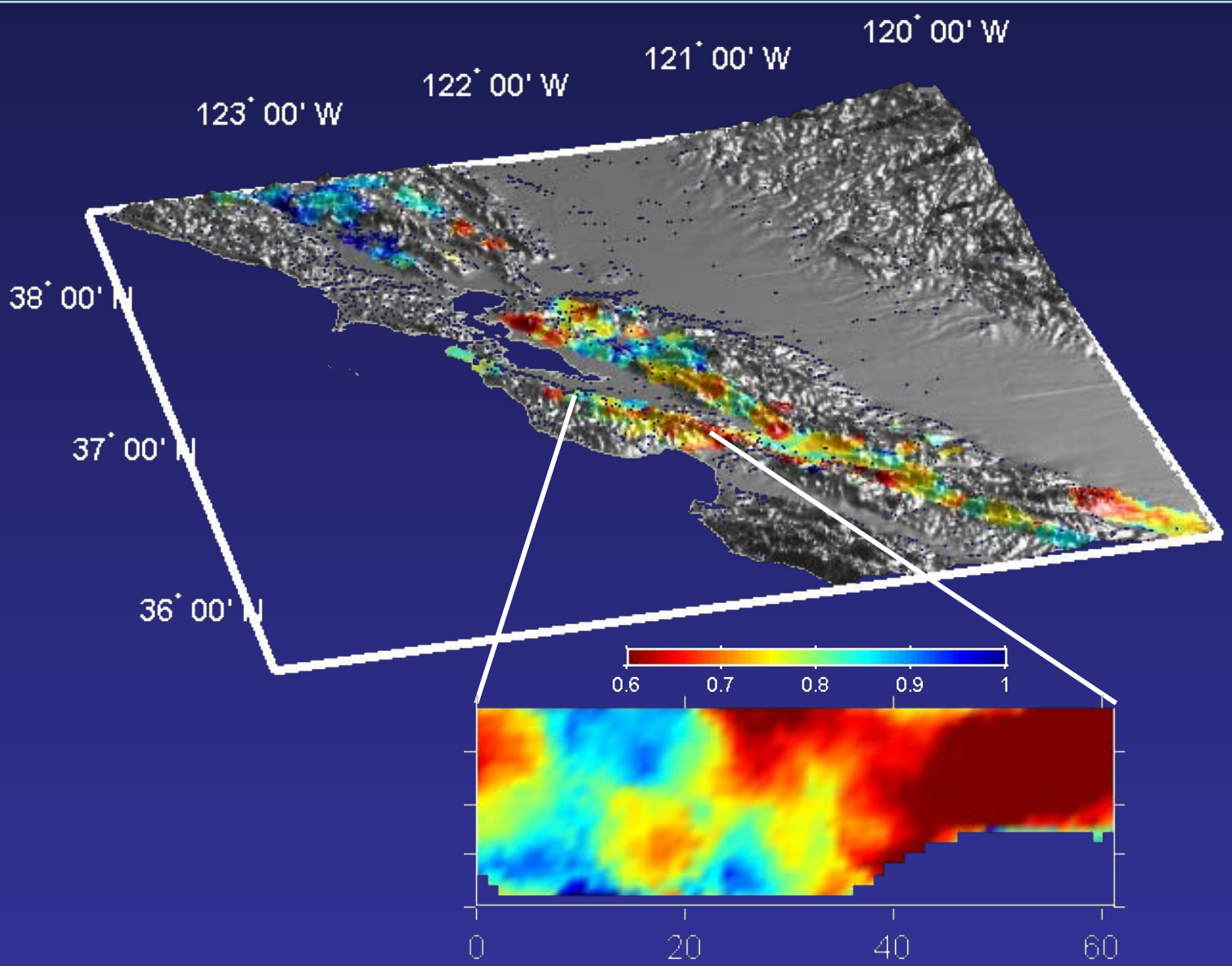
1983.5-2007

SFBA: Central Calaveras

→ Re-investigation

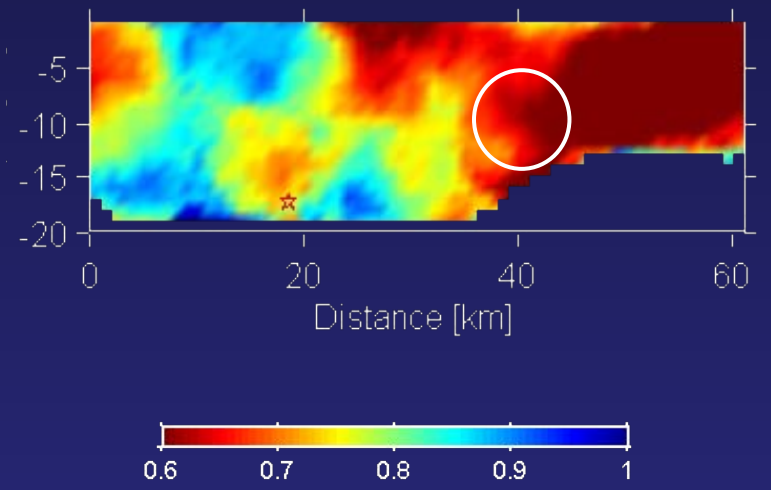


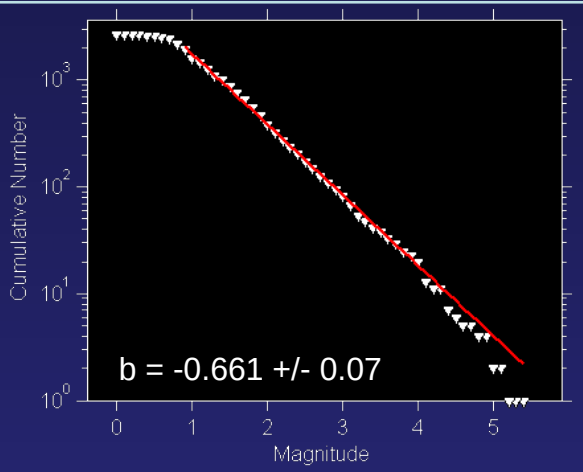
SFBA: San Andreas – Santa Cruz



SFBA: Santa Cruz

→ Non-linear FMDs



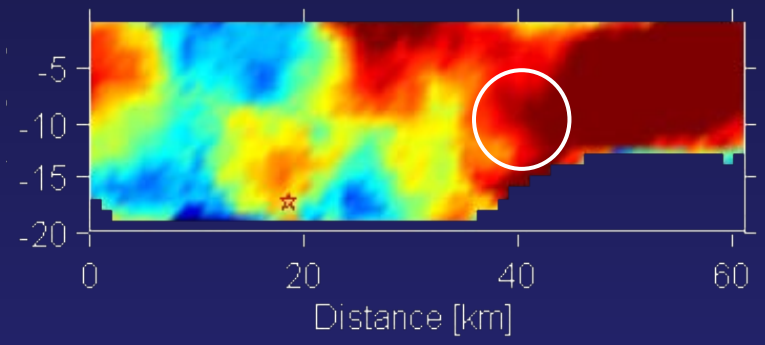


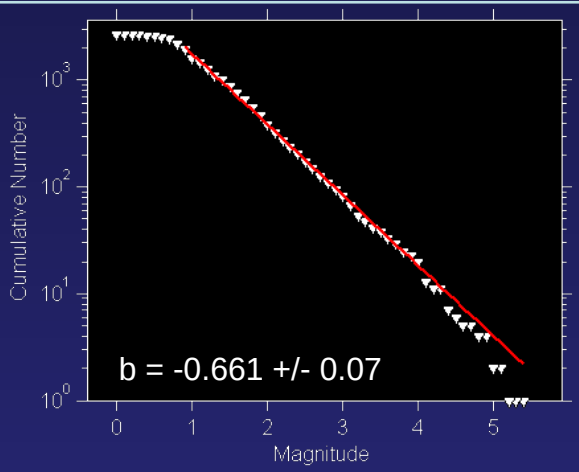
Nicely linear

Frequency
Magnitude
Distribution

SFBA: Santa Cruz

→ Non-linear FMDs





Nicely linear

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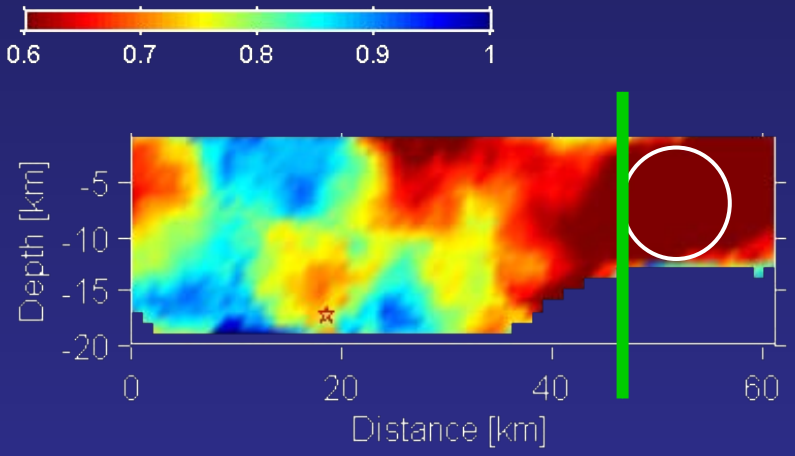
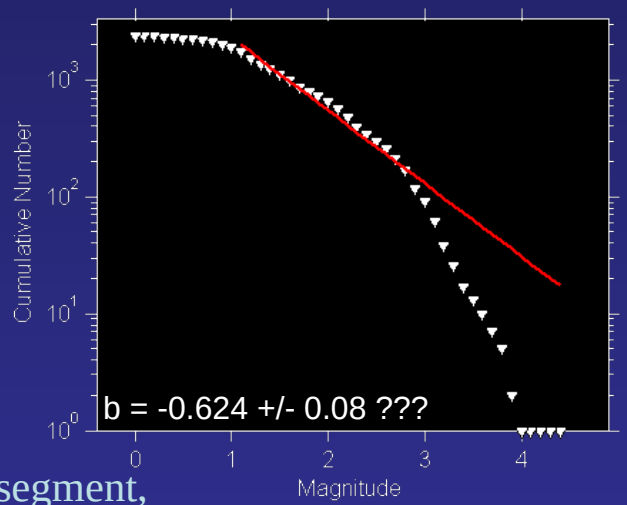




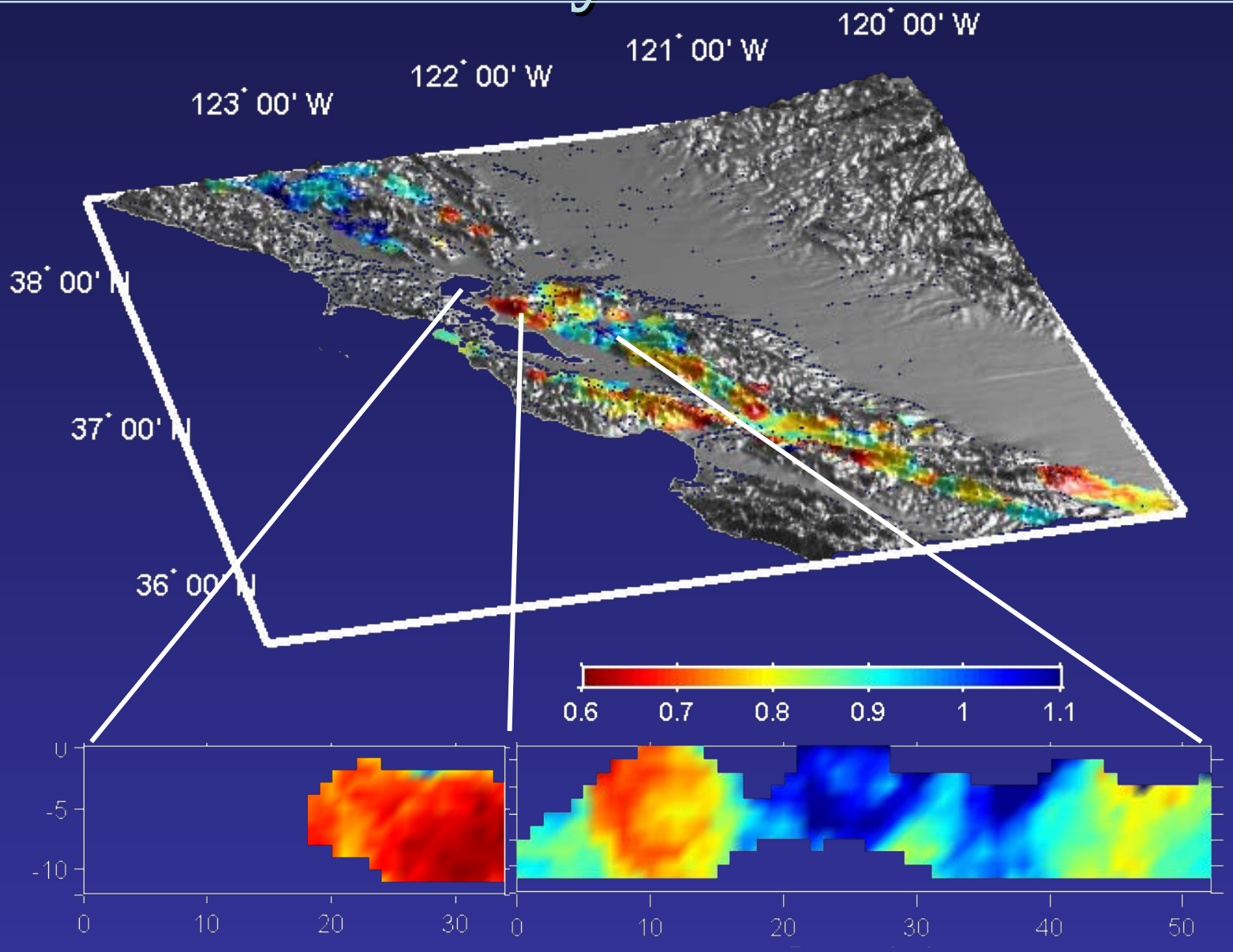
Transition zone between locked and creeping segment, Slow earthquakes (San Juan Bautista)

→ Non-linear frequency-magnitude distributions

→ No sensible b-value calculation

→ Ignore data to the right of green line

SFBA: Northern & Southern Hayward



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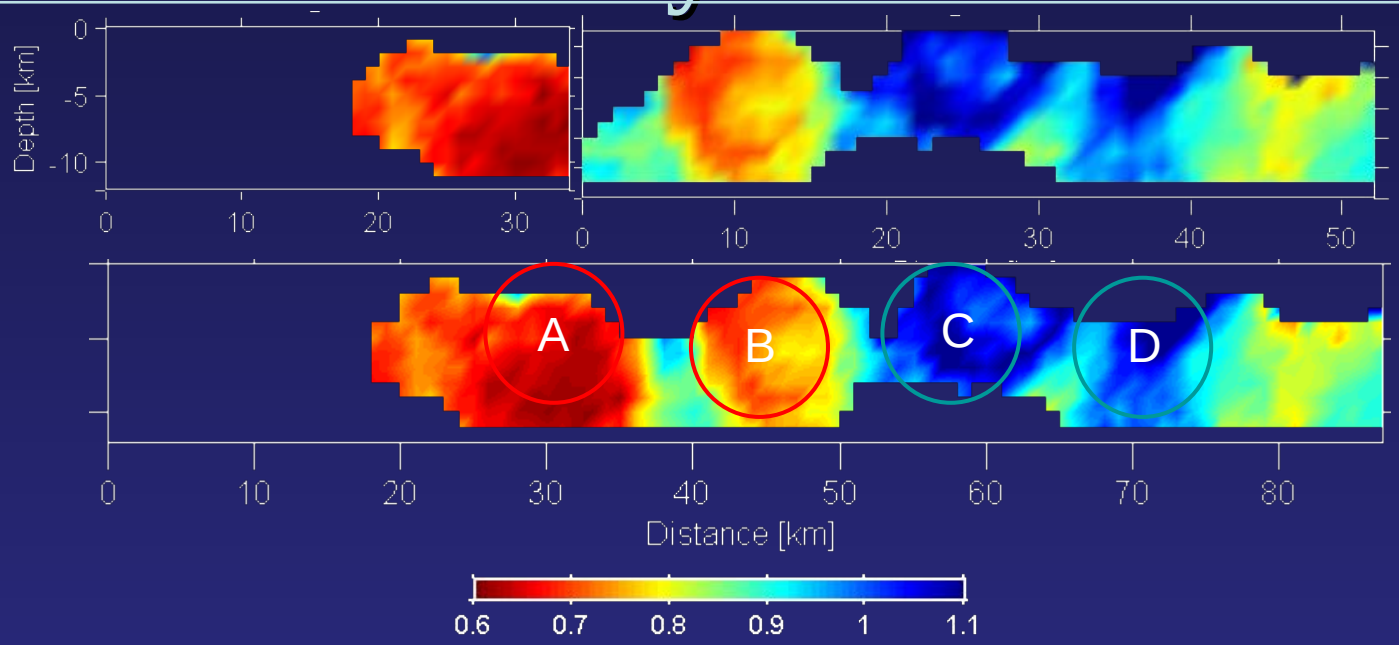
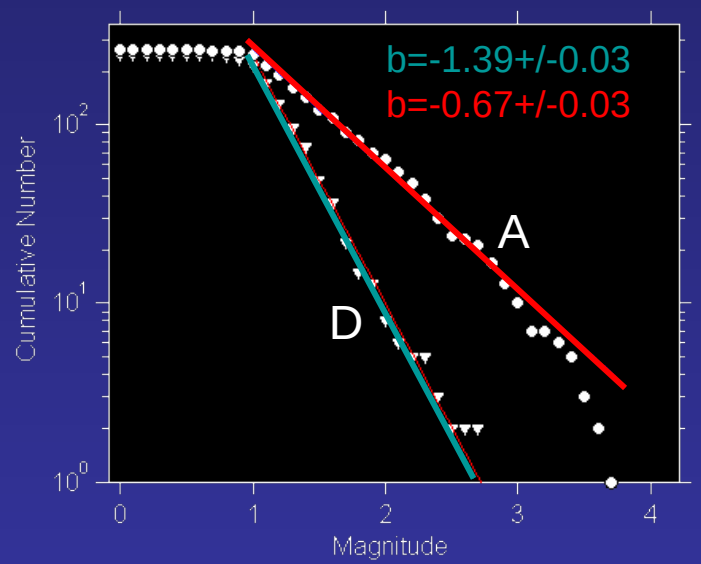
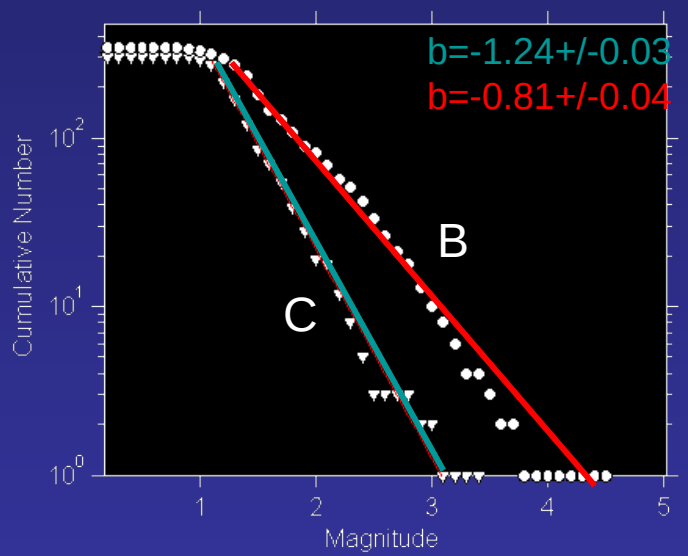






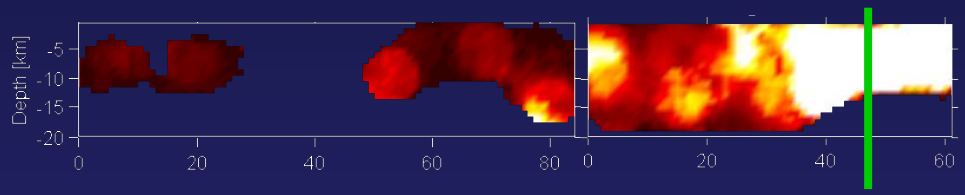
SFBA: From b-values to probabilities

- Calculate b-value for each point
- Calculate a-value for each point
- Choose target magnitude
- Calculate annual probability of occurrence of an earthquake equal to or larger Mtarg:

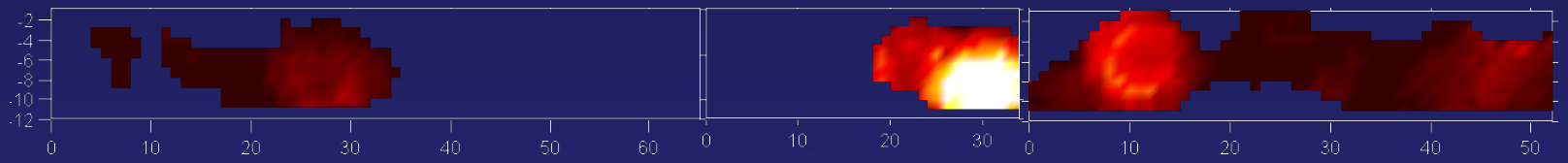
$$P = 1 - e^{-\frac{10^{a - bM_{targ}}}{\Delta T}}$$

SFBA: All segments

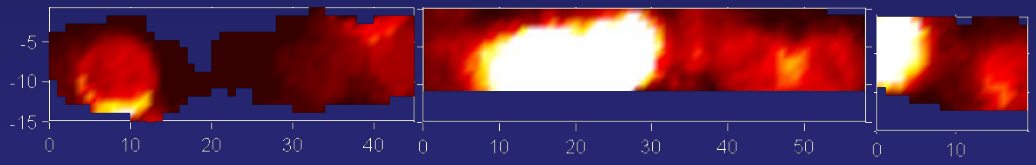
Annual Probabilities M6+



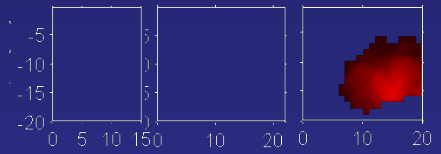
San Andreas



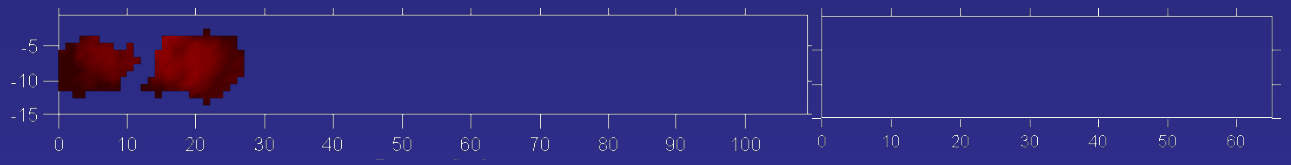
Hayward



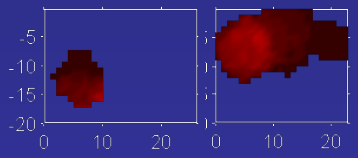
Calaveras



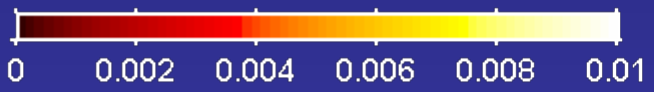
Concord



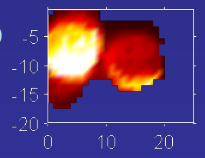
San Gregorio



Greenville

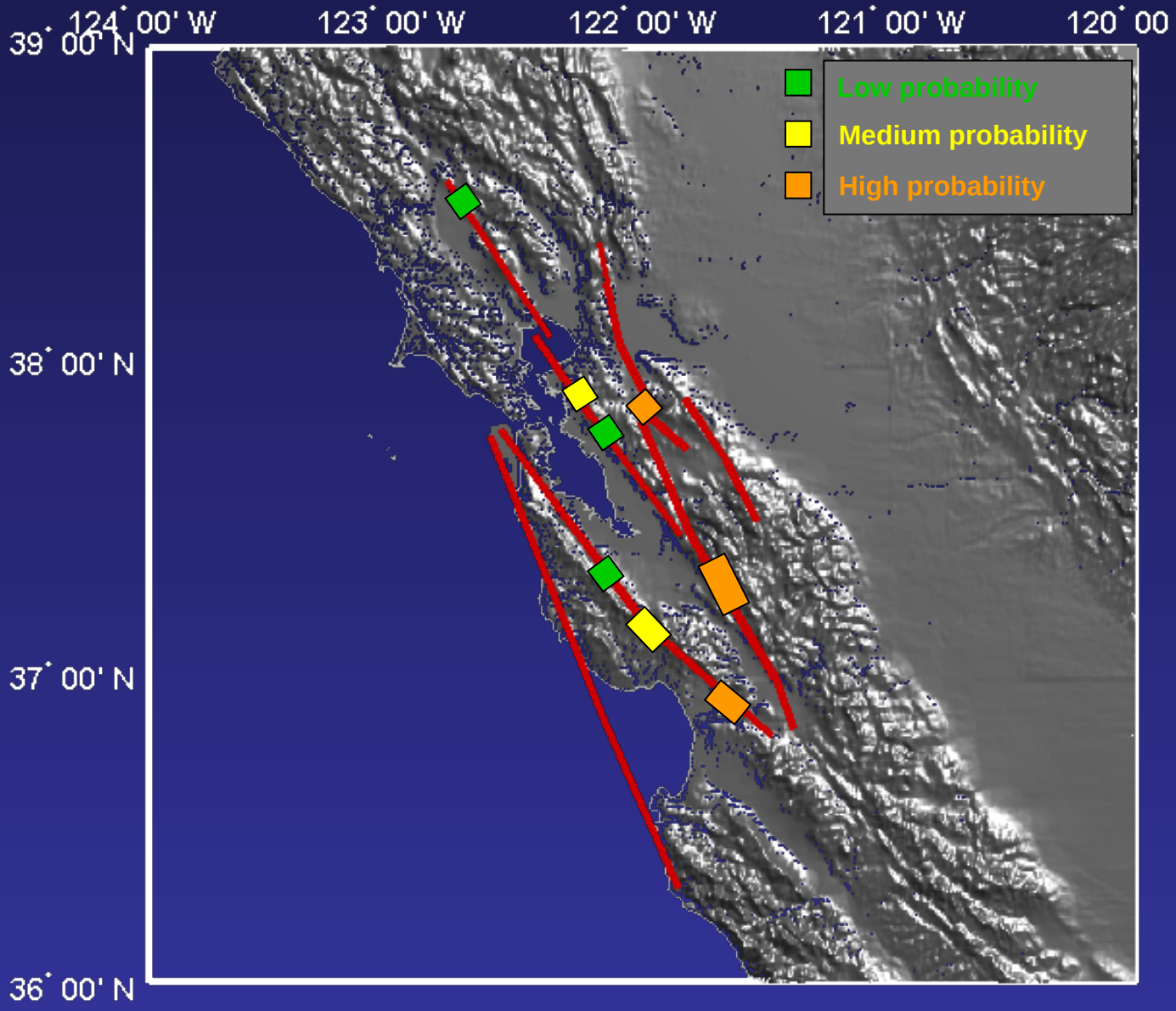


Mt Diabolo



San Francisco Bay Area

Preliminary asperity map



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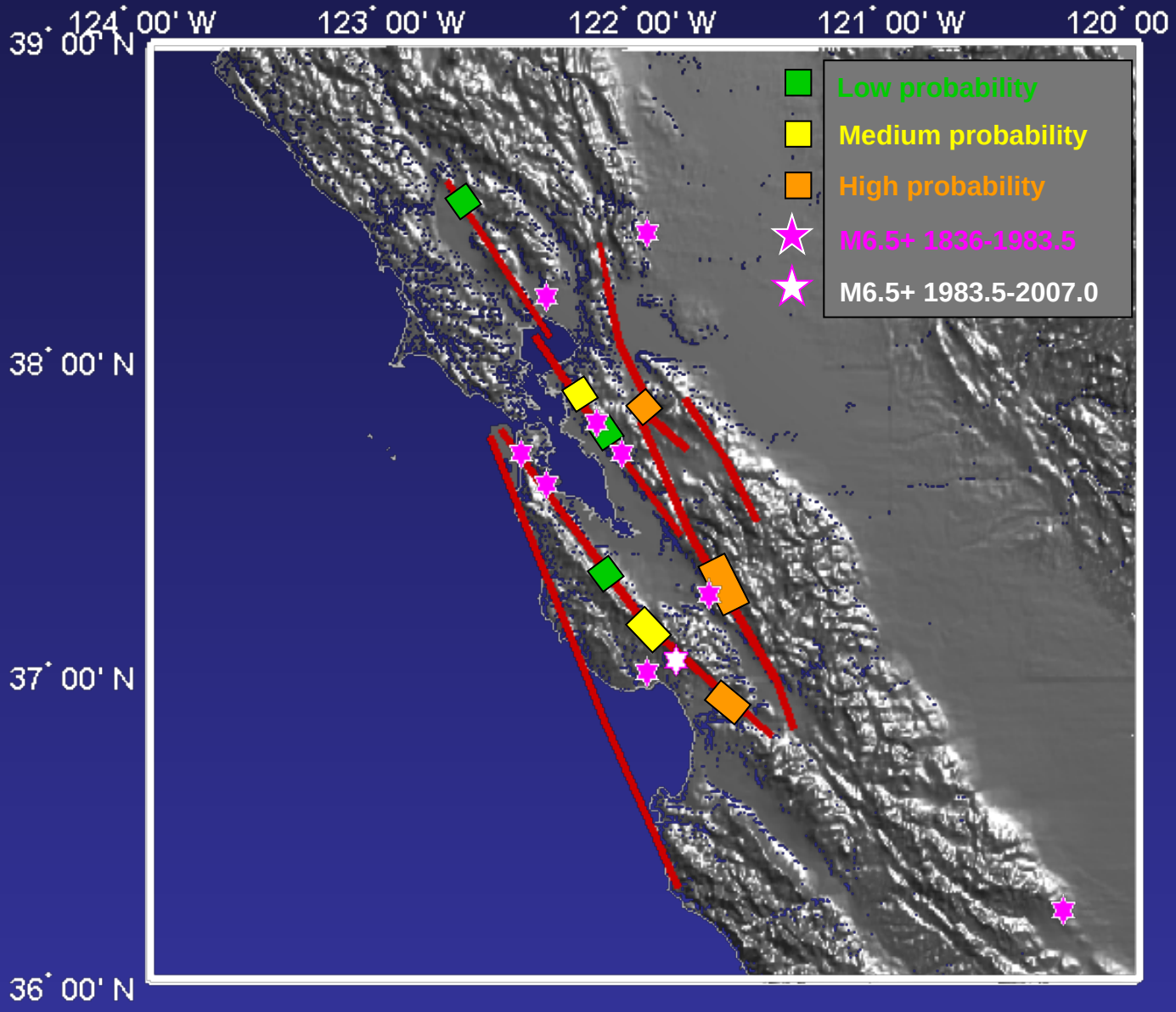

Model Summary

Three categories of studies:

1. Pure case study:
   correlation with mainshocks/known asperities
2. Consisitency test
   does medium scale seismicity continue to concentrate in low b-value areas?
3. Retro/Prospective test:
   does microseismicity forecast large events‘ locations?

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Hayward (2001)	Calaveras (2007)	Parkfield (2004)
Turkey (2001)		
Mexico (2001)		
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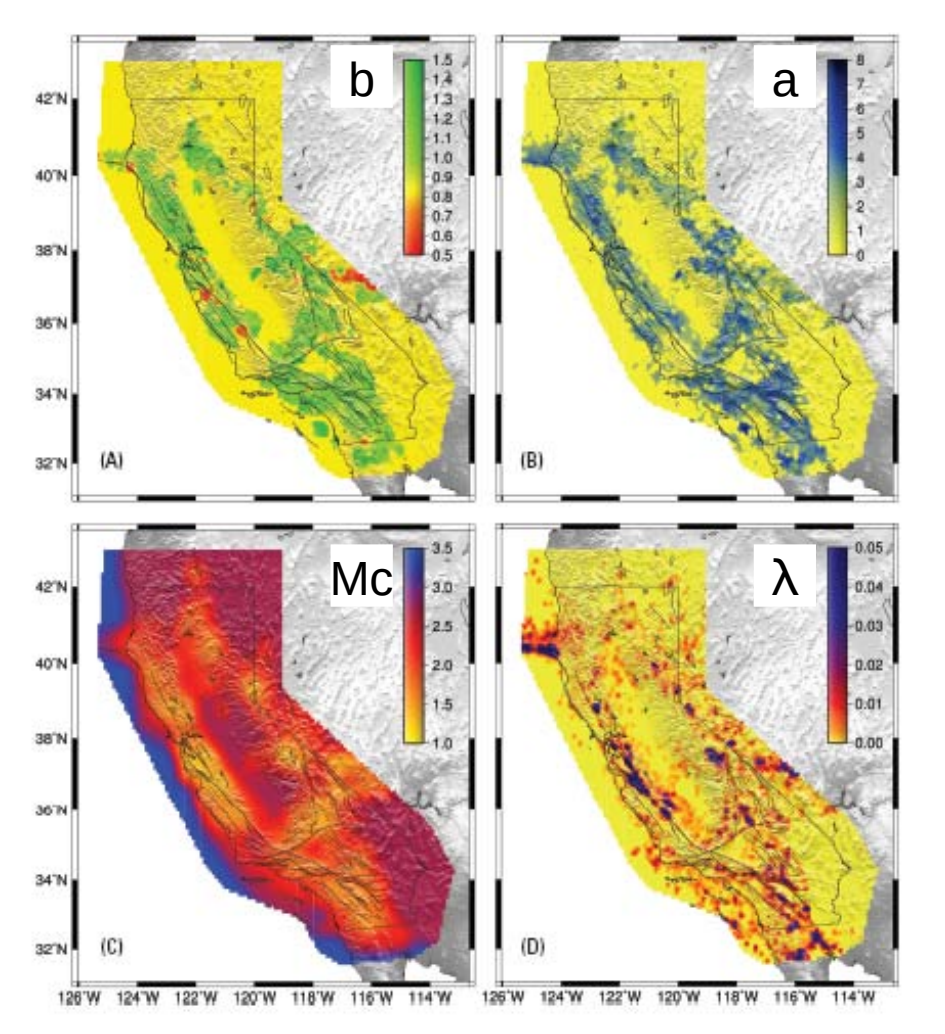
This is where we need more and systematic effort

ALM

Wiemer & Schorlemmer, SRL, Special Issue on RELM, 2007

Asperity-based Likelihood Model for California



Achievements

- First testable model forecasting future seismicity on the basis of spatially varying b-values
- Submitted for prospective testing within RELM

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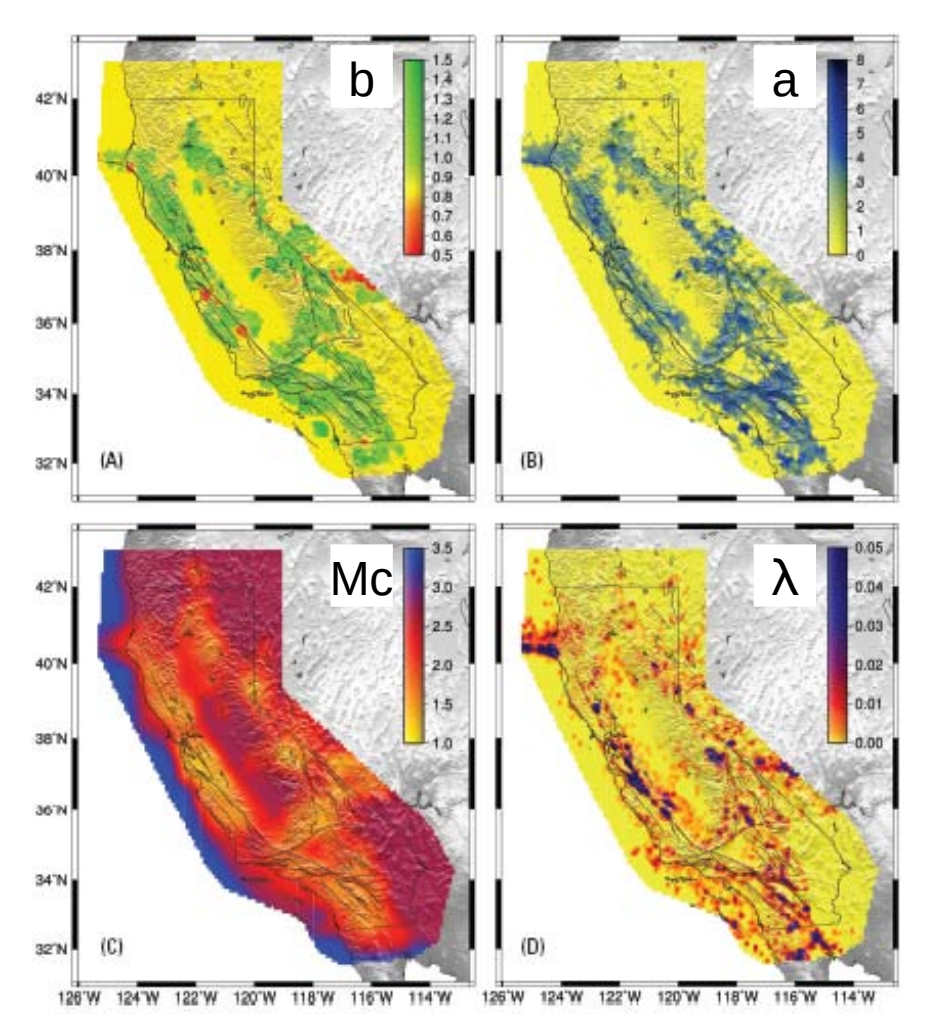

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Shortcomings

- No treatment of depth
- Oversimplifying low resolution mapview approach

CALM

Cross-sectional Asperity Likelihood Model for California

- Testable hybrid model: advanced ALM plus fault information
- Pseudo fault based testing grid: fine grid near fault, coarse grid off fault
  → to be developed by and for CSEP
- Near fault: real forecasts → EMR completeness, b-value and a-value mapping
- Off fault: background → PMC, a-value mapping and constant b-value
- Proper treatment of depth

→ To be submitted as possible prototype for pseudo-fault-based testing in CSEP

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→ **Start with pseudo-fault based testing as envisioned in CSEP:**

rate and focal mechanism forecasts on fault based grid